

Technology of Bottled Water

Technology of Bottled Water

Third Edition

Edited by

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Preface

Following the positive reception in 1998 of the first edition of *Technology of Bottled Water*, the second edition, published in 2004, met with equal success, being sold in the English language version across a broad range of markets, and also translated into Chinese and Russian. It was originally written from a global perspective to shed some light on the complexities of the industry, prompted by the realization that there was much confusion in the minds of consumers and regulators alike regarding quality, safety and identity of bottled waters, and that there was an increasing number of new entrants to the industry who, in many cases, lacked the practical knowledge of the inherent difficulties in such an enterprise. The process of bottling water might, at first sight, seem to the uninitiated to be simple and risk-free, especially, for example, when compared with those more complex ones required for producing soft drinks. In practice however, because water is so sensitive to chemical, physical and microbiological contamination, it is one of the more difficult products to package to a consistently high standard. The book's principal aim therefore was to provide much needed guidance to producers, regulators, beverage and packaging technologists, microbiologists and specialists in hygiene and food safety.

The continuing perceived value of the book in many markets reflects the fact that, more than ever, bottled water is a commodity of increasing significance worldwide. Growth in the large developed European and North American markets has slowed, but growth has, if anything, accelerated in the developing markets. This has partially resulted from the way in which the larger companies have extended their operations into the newer markets, but along with this has been the appearance of countless smaller bottlers, encouraged by the success of others and the relatively low cost of entry.

The second edition covered the bottled water market, legislative requirements and hydrogeology, with specific guidance on water treatments, filling technology, cleaning and disinfection, methods and materials, watercoolers, quality management, auditing and microbiology.

For this edition, most of the original authors have brought their chapters up to date, although in some cases, new and additional material has been provided by new authors. Thus, Chapter 4 on hydrogeology has been updated by Peter Ravenscroft, and Chapter 5 on water treatment has been updated by Sébastien Saby. Chapter 7 on filling equipment has been entirely rewritten by Manfred Faltermeier to include a new section on PET manufacturing, and Chapter 13 on the microbiology of treated bottled water has been updated by Manuel Chaidez.

As an addition, following product developments within the industry, a new chapter has been authored by Fred Jones to cover the formulation and production of flavoured and functional waters.

Furthermore, in recognition of the increasing emphasis on the importance (both within the industry and beyond) of environmental stewardship, a new chapter on the environment has been added by Tod Christenson and John Stier.

Once again, many thanks to the authors, all of whom are busy people. Their contributions make this book a diverse, comprehensive and unique volume, which has proven through the previous two editions to have been of value. It is hoped that this third edition will prove of equal value to those both within and having an interest in the bottled water industry.

Finally, I would like to extend my thanks to Dorothy Senior, who through her editorship was instrumental in making this book a success in the first and second editions. Although, since her departure from the industry, she chose not to edit the third edition, her updated chapters still have value and relevance; more importantly, the work she did in making this book possible remains a valuable legacy for those of us still involved in this fascinating business.

Nicholas Dege

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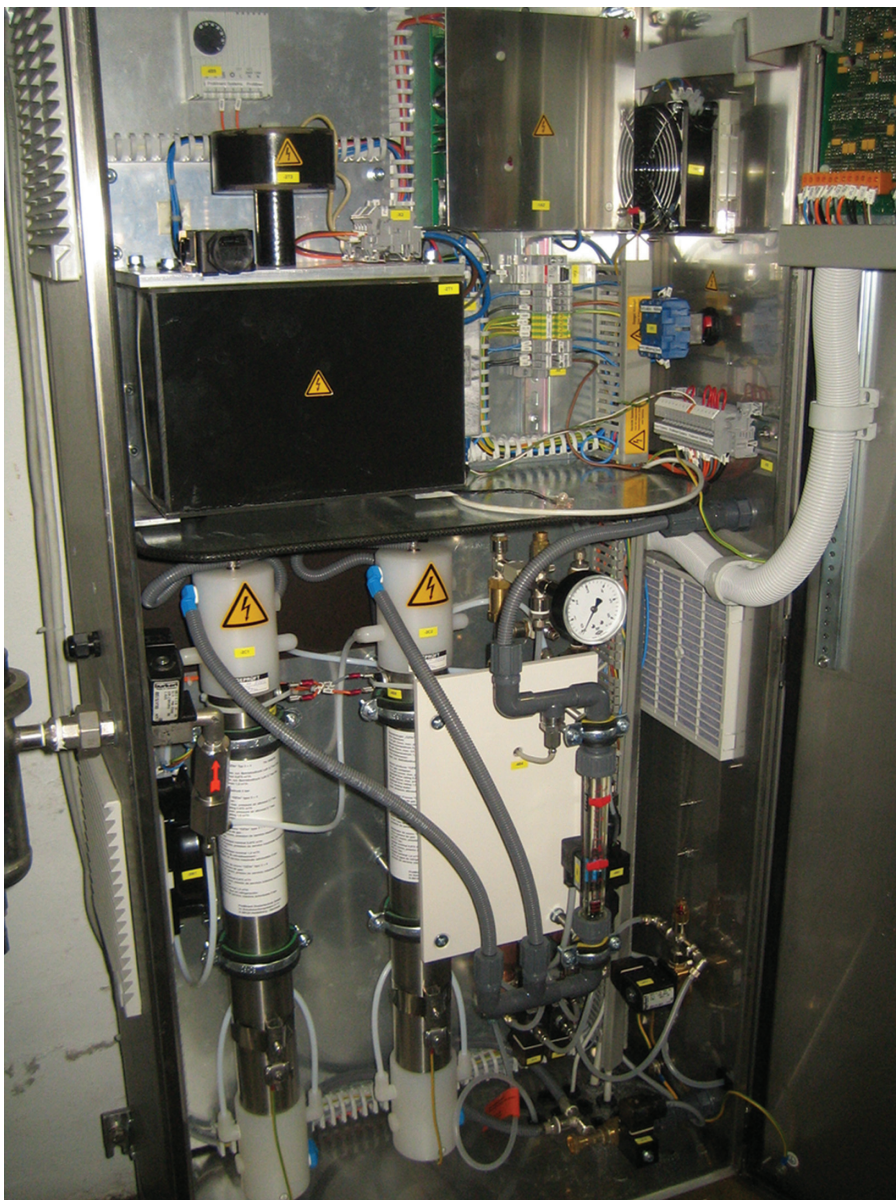


Plate 1 Example of an ozone generator (Prominent).

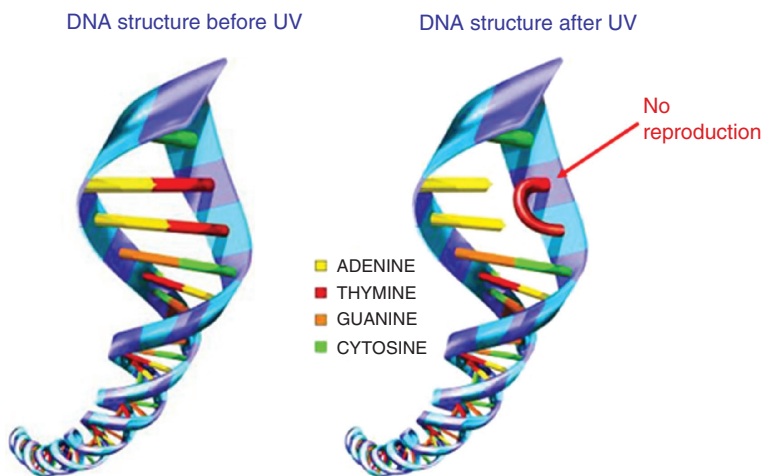


Plate 2 Inactivation of micro-organisms by UV radiation (From Hanovia Ltd., 2008).

1 Introduction

Nicholas Dege

1.1 BACKGROUND

Every living thing has a fundamental requirement for water, and as humankind developed, focus was always on access to reliable supplies of clean water from springs, wells and rivers. As populations grew and civilisation and technology evolved, there was inevitably an increase in the demand for water for domestic and industrial purposes; delivery systems were developed, as were the methods for treating water supplies effectively to ensure that they were safe for consumption, and to prevent the spread of diseases that could be carried by water to the general population.

However, although in most of the developed world there is a reliable supply of water, even with the benefits of modern water supply systems, some types of chemical treatment and the deterioration of pipes can cause organoleptic changes to municipal water, giving it an unpleasant taste. There are also concerns in many countries about potential (and in some cases, real) contamination of municipal supplies, and for these reasons amongst others, consumption of bottled water has steadily increased in both the developed and developing worlds. Furthermore, with the arrival of the unbreakable, resealable, lightweight polyethylene terephthalate (PET) bottle, providing the convenience of being able to consume a wholesome and refreshing drink at will, the consumer in many parts of the world has seized the opportunity to migrate from other beverages to bottled water.

In the light of this growing demand, the first and second editions of *Technology of Bottled Water* had as the principal objective to provide guidance on the legal and technical aspects to those requiring it (technical managers, packaging technologists, microbiologists). It was also deemed appropriate to give guidance to anyone wanting to understand the industry, and particularly those who were charged with the responsibility of regulation, whose own understanding of the industry was not always as complete as might be expected.

Finally, and perhaps most importantly, a key reason for the publication of the book was a general lack of practical information on what was then a relatively young industry in many parts of the world; it was seen as essential that new entrants to the industry were provided with at least a basic introduction to the complexities and potential challenges that they were likely to face. This was and remains particularly important at a time when many people with access to springs or groundwater supplies were avid to enter the industry, seeing it as an easy route to wealth. There was real concern that such new entrants might, in the absence of strong guidance, underestimate the real quality and food safety risks inherent in such a step, with consequential damage not only to themselves and their consumers, but also potentially

to the reputation of the industry as a whole. It was therefore seen as essential to present in one volume some practical and technical advice for those involved in (and those considering entry to) the bottled water industry.

This, the third edition, is being published at a time when the industry is at a decisive point in its development. As predicted at the time of the publication of the second edition, the bottled water market continued to grow, and the new markets (particularly in the Indian sub-continent, the Middle East and Far East) are still gaining momentum. However, in the developed markets, this growth has since slowed (to some degree as a direct result of the global recession), and the value of bottled water is also being challenged by activists who question its relevance and environmental acceptability. Nonetheless, bottled water continues to provide a convenient, healthy source of refreshment and hydration to those not wishing to consume other beverages. Indeed, it is also frequently called upon to be the sole source of potable water in times of emergency, whether simply as a substitute for municipal supplies undergoing periodic deviations from legal or safety standards, or as the only water available when a natural disaster strikes. Furthermore, bottled water companies the world over have long been conscious of the need to protect their sources, thus ensuring that they had a sustainable resource of high quality. Such environmental stewardship is in direct contrast to the claims sometimes made by critics, that bottled water companies are irresponsibly wasting natural resources.

Against this background, this book has been updated and continues to be a source of guidance for anyone wanting to bottle water safely. The third edition also contains two new chapters, of which the first covers the basic requirements for anyone considering developing or producing products in the category of flavoured or functional waters, and the second provides an overview of the work being done by the industry to address the environmental concerns, and to put into context the (actually very limited) impact of the industry.

1.2 THE THIRD EDITION

Although there have been some changes since the publication of the second edition, a major objective for the industry continues to be to find, protect and abstract good supplies of water, followed by filling and distribution to the ultimate consumer of a packaged product that meets all quality, safety and legal requirements. Increasingly also, some bottlers take waters of inconsistent and even of dubious quality (sometimes from private sources and sometimes from municipal supplies) and subject them to various treatments, often with the aim of producing water with a known and consistent composition.

By way of an introduction to the rest of the book, these developments and those of the product sector are covered in Chapter 2, which examines the development of the maturing bottled water market, taking into account historical and regional influences. Changes in packaging formats, reflecting lifestyle changes, and pressure from consumer groups are also shown to influence trends.

Different regions of the world continue to have a wide range of requirements and specifications for bottled water. This is examined in Chapter 3, primarily from the European and North American perspective, though the requirements for bottled waters in other markets are also covered. A part of this chapter also discusses the work done by the WHO/FAO Codex Alimentarius Commission in establishing worldwide standards for bottled waters.

The activities of man can be responsible for pollution of water, for example through agriculture, industry, road and rail construction, and special awareness and control is needed

to protect vulnerable groundwater from undesirable changes in quality when there is a requirement to bottle it without treatment. Chapter 4 describes the evaluation of groundwater sources, discussing varying geological influences. Development and protection of boreholes, and management of catchment zones and water yields, are also covered.

Water may come from various sources or supplies so, in many instances, treatments are used either for safety or legal reasons or to change the compositional quality of the water. Chapter 5 looks at the many options and possible reasons for choosing one or a combination of several treatment processes, although the choice available is always subject to local regulations.

The susceptibility of water to change, chemically, microbiologically or organoleptically, brings challenge to the bottling process. The inherent properties of water, the raw and packaging materials available and the equipment used all have profound implications for the safety and quality of the finished product that reaches the consumer. Chapter 6 looks at the potential impact of the choice of materials and the design and construction of equipment, and provides practical advice concerning the factors to be considered in order to protect the integrity of water throughout the process.

The ultimate objective for the bottler is to package the water in bottles, and although there are several different materials customarily used for bottled water, increasingly it is the ubiquitous PET bottle that dominates. Chapter 7, which covers product preparation and filling, also has a new section describing PET bottle manufacture and handling.

In view of the need for rigorous standards in good manufacturing practices, and more specifically for hygiene when dealing with bottled water, Chapter 8 deals with cleaning and disinfection, describing why and when this is needed. Cleaning-in-place methods and schedules, employee training and safe use of chemicals are also discussed.

Chapter 9 on quality management covers the principal programmes necessary for consistent high quality; areas of process control, in which operators undertake monitoring of quality parameters, as well as the more technical work performed in the quality assurance laboratory, are described. This section also covers food safety, in terms both of the action to be taken on the factory floor and also in evaluating risks throughout the entire supply chain. Hazard analysis critical control point (HACCP) remains central, but with the steady pressure from customers to establish more formalised systems for food safety, the use of standards such as ISO 22000 is also discussed.

Many offices and public places (and, increasingly in some markets, many homes) in densely populated areas, where the quality of municipal water is more affected chemically and organoleptically, have water dispensers, supplied through the 'Home and Office' channel. These dispensers, commonly called watercoolers, can incorporate facilities for chilled and hot water and in some cases, sparkling water. Although in some respects there are similar considerations to those for the retail sector, there are some additional priorities associated with their distribution, as well as the design of the dispensing equipment, all of which are discussed in Chapter 10.

Although companies producing bottled waters may adopt best practices for the industry, it is often the independent audit of the bottling process and systems used that give it credibility with customers and regulatory authorities. Chapter 11 sets out to detail the philosophy behind (and the steps taken during) the process of third-party auditing.

All bottled waters must be safe to drink and are required to be free from any pathogenic (disease-causing) micro-organisms. Some, such as natural mineral waters and spring waters, are required to be free from pathogens without treatment, and compliance with this requirement is monitored by testing for the absence of indicator organisms, as specified by

applicable legislation. On the other hand, some bottled waters, especially those originating from surface or municipal supplies, may be treated to kill any harmful bacteria and make them safe to drink; indicator organisms are again the means of monitoring this.

In the case of groundwater, there is also a natural population of indigenous harmless bacteria. In some markets, these naturally present bacteria are simply monitored to ensure that the normal condition of the water is not compromised; in others, it is a requirement that they remain within specified limits, both in the source and at the time of bottling. Thereafter, even though in still (non-carbonated) water, the number of these organisms grows logarithmically within days of bottling and can remain high for many months; these benign bacteria are not detrimental to the keeping quality of the water or to the well-being of the healthy consumer.

The difference in microbiological status between municipal or mains water and bottled waters is often used in alarmist articles in the media, where the two products are compared. Such a comparison is perfectly understandable and justifiable, but the assumption that the same qualitative standards apply to both products is not. All waters for consumption must be safe to drink. Municipal water achieves and maintains this status through chemical treatments and the presence of residual chlorine disinfection at the point of use. In the case of bottled water, such chemical residues are not only undesirable, as they impart an unpleasant taste and odour, but are also prohibited by legislation, as they contravene the 'standard of identity' of the product. The fact that bottled waters are usually governed by legislation different from that applied to municipal water demonstrates recognition by governments that these products are different. It is therefore no accident that both Chapters 12 and 13 discuss the subject of microbiology, one dealing with water bottled without treatment and the other for which treatment is used. Chapter 14, the first of the new chapters, entitled 'Formulation and Production of Flavoured and Functional Waters' – addresses the technology behind the growing range of products built upon the more traditional water base, and often used to extend brand recognition.

For very good reasons, there is an increasing awareness of environmental issues, and reputable companies include an environmental programme in their corporate agenda. Although the drivers towards this action can be legislation and consumer groups, it also makes good business sense to have sound environmental practice. As the industry continues to develop, much has been achieved in recent years to minimise the impact on the environment by improved manufacturing methods, rationalised distribution and reduction in packaging materials, for example by the light-weighting of containers. Chapter 15, on the 'Environment', is a considered examination of the factors of increasing concern for any modern producer, including raw material and energy use, waste and recycling, and provides some insight into the way these concerns are being addressed.

In publishing the third edition of *Technology of Bottled Water*, it is certain that the industry (which has matured significantly since the publication of the first edition) will continue to evolve and to play a major part in ensuring that consumers across the world have access to a convenient and safe supply of water, wherever they live, and regardless of the water type. Whatever the preference of the individual for style of consumption, bottled water will provide much needed nutriment and refreshment, and add to the pleasure and enjoyment of life.

2 Market Development of Bottled Waters

Duncan Finlayson

2.1 INTRODUCTION

In the second edition of this book, I wrote of how the perspective of bottled water had changed between 1997 and 2003. Now in 2009 perspectives have changed yet again in ways both predictable and surprising. The world economy suffered a major recession in 2008/09. Stronger growth rates in China and other Asian countries have hastened the supremacy of Asia/Australasia, which is now by far the biggest regional market, although the USA remains the largest national market. Here growth is still strong whilst in Western Europe and North America, the next largest markets, it has stalled. Up until 2003, the four major companies Nestlé, Danone, Coca-Cola and PepsiCo rapidly gained a share of the global bottled water market, but have now begun to fall back slightly. Bottled watercooler volume in Europe peaked shortly after the market consolidations of 2002/03, and has since fallen, a victim of plumbed-in watercoolers that are sold on the claim that they purify public municipal water.

During 1997–2008, the world bottled water market grew from 90 to 218 billion litres. The Asian/Australasian market multiplied by more than four. Even geriatric Western Europe managed a 50% increase, whilst dynamic North America added 144%. Healthy growth indeed. However, the same regions show a quite different pattern for 2007/08. The Asian/Australasian market grew by 11%, Western Europe had zero growth, whilst North America fell back by 1%. The world market grew by 5%.

The world recession is affecting current conditions, no doubt, but as an overlay on a number of factors, which contribute to growth differently in different segments of the market. Moreover, parts of the world have diverse traditions of water consumption, which means that they respond to market pressures in distinct ways. Overlaying them all are modern global factors such as the environment and health and well-being. Important questions in a market analysis include: What is the recent history? Where is the market today? Which are the important market drivers? What will the future be? Providing answers requires knowledge of these factors and traditions.

This chapter starts by giving a historical perspective, which touches also on the relationship between bottled waters and other soft drinks. Section 2.3 discusses product and market attributes to make the following sections intelligible. These definitions are dealt with more fully in Chapters 3 and 10. Section 2.4 introduces the big four global bottled water companies. A brief global review that puts bottled water into the context of other beverages is then

followed by three sections looking at different countries by way of example – USA, Europe and China. Section 2.9 considers the effect of environmental pressures, whilst Section 2.10 gives some characteristics of the market for flavoured and functional waters. The final section looks at future trends.

2.2 THE HISTORICAL BACKGROUND

You could say that bottled water once had an Old World and a New World. The Old World is Europe, West and East, extending into Russia. The New World has its older markets – in the USA – and the very youngest such as China. The New World does not have the same traditions, and is driven by modern concerns. Today the Old World, although still exerting a strong influence on the industry and home to Nestlé and Danone (the two largest global bottled water companies), is giving way to the New.

Let us first consider the Old World. Every pupil knows that water is essential for life. Throughout history we have taken in water to survive, but have added to this use, at every opportunity, its role as the base of something more convivial such as wine and beer. Nevertheless, it is possible to discern an early trend for drinking water on its own, of two kinds. The first is a highly mineralised water, prized for its health-giving attributes and possibly for its medicinal properties. This water would often be naturally carbonated from an effervescent spring, and might well be hot on emergence. The second is a cool, fresh water, drunk for its purity and cleansing properties. Here these are named *Mineral Waters* and *Spring Waters*, respectively – terms that should not be confused with modern legal definitions such as Natural Mineral Water and Spring Water, which are referred to later.

The doyenne of the Old World would be a place such as Vichy in France. The history of Vichy reads as a history of Europe: first exploited by the Gallo-Romans during the first two centuries AD, the town and spa became part of the Bourbon estates of Louis II. The cures became famous during the Renaissance, but were really first developed for leisure during the Second Republic when the Parc des Sources was created by order of Napoleon. A second great period of construction followed during the Belle Époque (1890–1930). The two bottled waters of Vichy are Vichy St-Yorre and Vichy Celestins, both highly mineralised. Commercialisation on a major scale started in the 1860s. Both are now in the stable of Groupe Alma, the number one bottled water company in France.

We now turn to the UK, where, as in many markets, the development of bottled water consumption has been closely linked with that of soft drinks. The following brief review is adapted from a publication in the Shire series by Colin Emmins (1991).

The Romans developed various spas including Bath (Aquae Sulis) and Buxton (Aquae Arnemetiae), but more for bathing than drinking. By the eighteenth century, spa resorts were once again flourishing. The properties of various mineral waters became well known including those of the Epsom Spa (from which Epsom salts were extracted). Even the Bath water was drunk in the elegant Pump Room. Spring waters had been bottled from Tudor times, and by the year 1700, flasks of spring water were being taken from Hampstead Wells for sale in Fleet Street.

The technique of carbonation (adding carbon dioxide gas to water) was discovered by Dr Joseph Priestly in the late 1760s, a technique which turned out to be the spur to the creation of commercially manufactured soft drinks. Interestingly, much of the development was in artificial or manufactured mineral waters. Soda waters as well as artificial Seltzer, Spa and Pymont waters were on sale by 1800. Schweppes was set up in 1792. By the early 1800s,

Table 2.1 European patterns of consumption for 1980.

Country	Annual bottled water sales (million litres)	Annual bottled water sales (litres/person)	Annual soft drinks sales (million litres)	Bottled water as percentage of soft drinks
UK	30	0.5	4840	0.6
Spain	800	21	3050	26
Germany	2550	41	8450	30
Italy	2350	42	4100	57
France	3125	68	5715	55

Source: Zenith International © Zenith International 2009.

carbonated spring waters were being offered for sale. However, the tone was still overwhelmingly medicinal and the market still small.

During the nineteenth century, the market changed to one of much wider consumption, developing as much if not more in lemonade, ginger beer and other flavour-based soft drinks than in soda and Seltzer waters. This trend towards an increasing share for non-bottled water soft drink consumption accelerated in the UK because of the giant leaps made in the safety and palatability of the public water supply: progress not reflected on the Continent. Mineral waters, such as Apollinaris from Germany, were still fashionable mixers in the 1890s, but did not have a mass market. By 1902, arguments about naturalness had arisen. Apollinaris was taken to court for claiming that it was a 'natural mineral water' (*Davenport v. Apollinaris Co Ltd*), when the composition in the bottle did not exactly match that in the spring (a case rejected, see Chapter 3 for more details on modern natural mineral waters).

Nevertheless, the trends in the twentieth century, especially in the UK as opposed to Continental Europe, remained inexorably of rising consumption of non-water soft drinks. Fruit squashes as dilutables were introduced just before World War I. Coca-Cola was introduced in the 1930s, remaining a modest item until the arrival of American troops for World War II, when consumption became firmly established.

Thus the UK did not go the way of the Old World, because of the good quality of tap water. By 1980, a distinctive European pattern of consumption had been established, with the UK as an atypical Anglo-Saxon outlier, strongly influenced by the USA (Table 2.1).

And what of the New World? Here bottled water has developed as a safe, reliable, consistent, refreshing and convenient alternative, both to traditional soft drinks and to tap water. As consumers have become more health conscious, bottled water provides a calorie-free alternative to sweetened soft drinks. In large parts of the world, where tap water is not universally available, or may be unsafe, bottled water is not a luxury.

2.3 MARKET SEGMENTATION

An analysis of trends in the bottled water market requires market segmentation. In addition, bottled water is itself a segment of the overall soft drinks market. Segmentation is needed because different product/market combinations react in different ways in different countries. Various approaches have been used. Here the main segments, with some element of hierarchy, have been taken as follows:

For bottled water	
packaged	vs. watercoolers
high mineralisation	vs. low mineralisation
still	vs. carbonated
Natural Mineral Water	vs. Spring Water
purified/remineralised	vs. Natural Mineral Water and Spring Water
brands	vs. own label
international brands	vs. others
global brands	vs. international brands
mainstream	vs. flavoured and lightly sparkling
glass	vs. plastic
PET	vs. other plastics
nonreturnable (NR)	vs. returnable (R)
supermarkets	vs. other outlets
multi-sources	vs. unique source
national brands	vs. regional brands

Some of the complexity behind this selection is indicated in Table 2.2. Each of these attributes is worth considering more fully. However, as many are interrelated, the following segmentation is necessarily simplified.

- *Product type*: Packaged water is sold in containers of not usually more than 5–10 litres capacity, directly for consumption. Watercoolers are refrigerating units which dispense water from a large bottle into a cup. The watercooler market worldwide has developed from the US market, where polycarbonate returnable bottles, originally of 3, 5 or 6 US gallon capacity (11.4, 18.9 or 22.7 litres), are supplied to rented cooler units. Nowadays, the larger container hardly exists. The US market is established both in offices and the home. Transfer to the European and other markets is mainly post-1985, and in Europe is so far confined to offices. Bulk water, such as in tankers, is progressively being taken over by the 19-litre container, in some cases through specialist water shops known as water stores or water stations. Mexico, for example, is the third largest bottled water market in the world, with relatively few coolers but widespread sales in 19-litre bottles. Water is drawn from the bottle through valves or ceramic pots. In poorer markets, PET is often used for the large bottles, although shrinkage and a lower washing temperature make it a more challenging material to use.
- *Water type*: The still/carbonated split dates back to the original mineral water/spring water differentiation. However, artificial carbonation, widely available from the nineteenth century, ‘muddled the waters’ as it removed the correspondence between naturally carbonated waters which were mostly highly mineralised and still waters which were generally low in mineral content. The water that bridged the two, and proved to be the outstanding success of the twentieth century, was Perrier. Nevertheless, post-1990, the trend has been towards still waters for home consumption.
- *Mineralisation*: It is a truism in the European context that, as you travel eastward, the traditional palate for water becomes stronger. Generally speaking, US consumers are interested in the absence of microbes, minerals and certainly contaminants, and a typical water would have a dry residue of 200 mg/litre. (Dry residue is the solids left after heating to 180°. It is a measure of dissolved minerals, which is usually less than total dissolved solids. It is used because it is directly measurable in a single test.) In France, on the other hand, highly mineralised waters such as Contrex and Vichy Celestins have

Table 2.2 Elements contributing to market segmentation.

Attribute	Categories	Subcategories
Product type	Packaged water Watercooler Bulk water	
Water type	Still Carbonated (sparkling)	Naturally carbonated Lightly/highly carbonated
Mineralisation	Range high to low	
Flavourings	Natural low calorie Sweet/artificial	Becomes a soft drink 'clear flavoured drink'
Functionality	Many, also known as near waters	Becomes a soft drink
Legal status	Natural Mineral Water Spring Water Other waters	Purified municipal water Treated well water Remineralised water
Container	Glass Plastic	R NR PET (R & NR) PET multilayer PVC (now rarely seen) Polycarbonate (R) Polyethylene
Positioning	Premium Lifestyle Mainstream Ethical Budget Staple	
Branding	Global International National Regional Retailer own label	
Distribution	Supermarkets HORECA ^a Convenience stores Offices Independents Door-to-door Vending machines Others	

^a Hotels, restaurants and catering.

Source: Zenith International © Zenith International 2009.

long had a special role. These are in the range 1700–3000 mg/litre. Even mainstream Vittel (Grande Source) has a dry residue of 850 mg/litre. However, Evian and Volvic are the big international brands from France, and these are both lower mineralisation. The German market has long been based on relatively highly mineralised waters. In the

former Soviet Union, waters were categorised into medicinal/mineral, mineral and fresh. The major brand was Borjomi, from Georgia, a sodium bicarbonate water with dry residue in the range 5000–6500 mg/litre. However, tradition is being eroded and more lightly mineralised water is now the future in Russia and elsewhere. In parts of the world without a bottled water tradition the product is very often water stripped of its minerals through Reverse Osmosis (RO) then remineralised to about the 200 mg/l level. Even in the US, although Nestlé is mostly on a natural water platform, the leading brands of Coca-Cola and PepsiCo, and actually Nestlé Pure Life are waters treated by RO.

- *Flavourings*: Perrier with a twist (of orange, lemon, lime or berry) was introduced to Europe in the 1980s, following its successful launch in America. These are natural flavourings with negligible calorie content, and though legally classified as soft drinks, can be legitimately presented as modified waters. However, the majority of the market is for waters which contain added sweetness, whether natural or artificial. Volvic Touch of Fruit is the most successful example.
- *Functionality*: Functional offerings are relatively new but increasingly numerous. They are one of the fastest developing categories of soft drink at the time of writing, and attaining a significant volume around the world. Some of these are on a water platform, otherwise known as near waters. Examples include calcium fortified water, sports waters and calming waters. See Section 2.10 and Chapter 14 for more details.
- *Legal status*: Obviously legal status depends on which part of the world a water originates from and (less and less) is marketed in. Full details are given in Chapter 3. The categories in Table 2.2 correspond to the European regulations.
- *Container*: Glass has always been the choice for premium products. In some countries, such as Germany and Austria, a tradition exists for returnable glass of a standard format. This has been promoted as environmentally friendly, and even used as an excuse for excluding non-returnable products. However, it is not clear cut that the life-cycle cost of returnable glass really is lower, because of the weight of the glass container, the energy required for washing and the chemicals used. Returnable PET is well established. In the non-returnable field, PVC has disappeared in favour of PET. Difficult applications, such as the new Perrier bottle, require multilayer technologies. Polyethylenes are used for larger containers of budget products, and polycarbonates have captured the watercooler bottle market. PET is used in large numbers for the lower-priced bulk market in essentially the same format as that used for watercoolers (and does also appear on coolers). Bottled waters are also marketed in cans for the airline trade and vending machines, and cups, again for airlines and in fast food outlets. In the United States in particular, there is also still a thriving business for water bottled in one-gallon HDPE containers of the type typically used for milk.
- *Positioning*: Generally speaking, there is a relationship between price and total market size. Premium products in high-quality, individually designed glass bottles aim at profitable, small-volume niche markets. The mainstream is aimed at the wider market. Lifestyle/convenience positioning has been adopted by Nestlé, Coca-Cola and PepsiCo with great success in the USA. Budget brands are a feature of supermarkets in western countries and also of 19-litre distribution elsewhere. Staple products are a direct tap water replacement. A new development for the new millennium has been ethical brands, which devote a proportion or all of profits to charitable causes, typically providing water in Africa.
- *Branding*: Branded products cost more for consumers, a differential they are willing to pay provided they perceive added value, either in product quality or product values or both. Even own-label products have become bound up with the branding of the supermarkets

themselves. In the third millennium, branding has a new dimension, which we categorise as international vs. global. It used to be said that water is a local business because it is tied to a source. Then the big international brands were created – Perrier, Vittel, Evian, San Pellegrino, Volvic. These are tied to a source but sold all round the world. Then Nestlé created the first global brand Pure Life, a staple water produced mostly by RO and remineralisation at locations all round the world. This provides arguably the best platform, being globally recognised but locally produced.

- *Distribution:* Distribution patterns have been quite different across countries, although the trend is towards supermarkets, mass merchandisers and club stores being the dominant outlets for volume consumption of a variety of package sizes. Nevertheless, in Western markets, HORECA is disproportionately important to market value because of the loading on premium brands and smaller sizes. In Asia, for example, direct delivery of the 19-litre package can be very important, whether delivered by truck or two-by-two on the back of a bicycle.

2.4 GLOBAL GIANTS AND LOCAL LEADERS

In the late 1990s, it became clear that the historical position of the two giant soft drinks companies and their ambition meant the world had four global bottled water companies: Nestlé Waters, Danone, Coca-Cola and PepsiCo. In 2004, the bottled water volumes of these four peaked at just over 30% of the global market and has since fallen back slightly (Fig. 2.1). In the case of Coca-Cola and PepsiCo, their share includes water brands owned by bottler partners or franchisees.

However, underlying this is a more startling picture of the ambitions of The Coca-Cola Company. The traditional foundation to both Coca-Cola and PepsiCo has been a relationship between brand owner (the Company) and bottler, which allowed the company to concentrate on marketing and the bottler on production and distribution. The Company

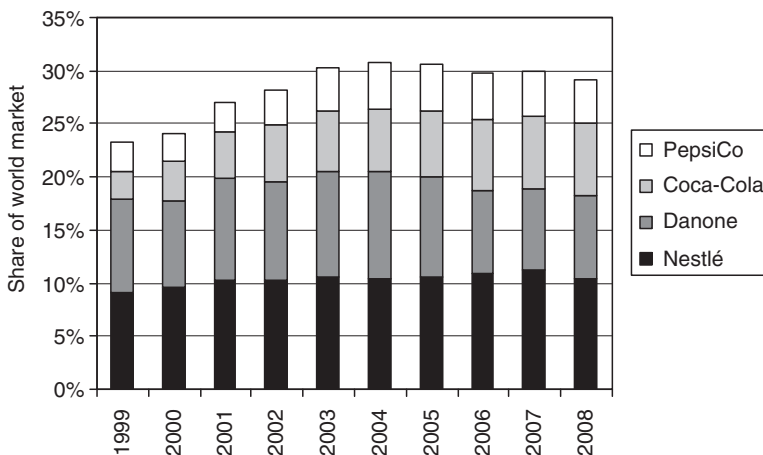


Fig. 2.1 The global companies' share of the bottled water market.

Source: Zenith International © Zenith International 2009.

maintained control and income by providing the proprietary syrup formulation on which the product is based. Bottled waters were an incidental activity of the bottler, with the brand not owned by the Company at all. Two trends have overtaken this. The first is the consolidation of bottling into regional anchor bottlers in which the Company has a substantial or majority stake – deals that in places have included the transfer of water brands to the Company. The second is the launch and expansion of the Company's own brands: for example, in the case of Coca-Cola, Dasani and Ciel and for PepsiCo, Aquafina and Aqua Minerale. The result is a marked switch into own water brands as opposed to bottler-owned products (Fig. 2.2). Note how different Coca-Cola is to PepsiCo in this respect. In 1999, both companies had around 40% of volume in owned brands, a position that PepsiCo has stuck with, whilst Coca-Cola has grown the proportion to more than 70%.

There is no doubt that Coca-Cola has a strategy of expanding its mainstream business into still drinks in general and bottled water in particular. In May 2007, the company stunned the beverage world by announcing a \$4.1 billion acquisition of Glaceau, producer of Vitaminwater and other water plus products. However, how successful it will be in plain bottled water against the bottled water specialists is an open question. In the USA, Nestlé Waters North America is more than holding its ground (see Section 2.6).

A small cadre of international brands sells round the world on a large scale: Perrier, Vittel, San Pellegrino, Evian, Volvic. Other than these, bottled water is a local business, because it is not economic to transport product over long distances. In the Old World (see Section 2.2), this meant also local brands, because the brand is tied to the source. In the New World, such restraint is missing. A link still exists for natural waters, although it is tenuous. For example, the two giant natural spring water brands in America – Arrowhead and Poland Spring – both come from multiple sources. Poland Spring sources are all in Maine, but Arrowhead now has sources in Canada and California. No such link exists for manufactured water products. Coca-Cola and PepsiCo major waters are typically treated and then remineralised, and can therefore be produced, in principle, at any soft drinks plant (although quality problems can arise if water is not bottled on a dedicated line).

So the Europeans can only develop regional brands, whilst Coca-Cola and PepsiCo are free to create global brands – but is that the picture? Not really – for several reasons. First, it is the Europeans who hold all the international brands mentioned above, which can be

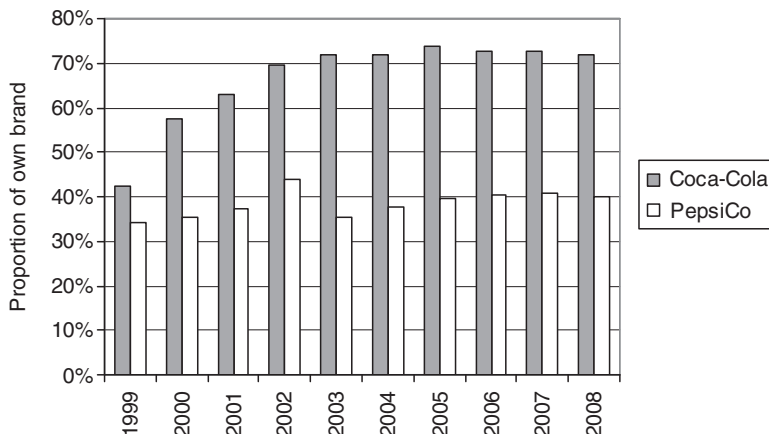


Fig. 2.2 Share of Coca-Cola and PepsiCo water as Company brand.

Source: Zenith International © Zenith International 2009.

thought of as global, although they can never be produced around the world. Second, Nestlé is determined to exploit its eponymous brands, Nestlé Pure Life and Nestlé Aquarel. Pure Life is the first truly global brand. Aquarel perhaps has only regional ambitions in Europe. Third, Coca-Cola has several brands in different countries for its treated water, and in the first decade of the millennium has bought many natural waters in Western and Eastern Europe as well as in farther flung places such as Turkey and Kazakhstan.

What is clear is that Danone and Nestlé Waters have changed from being French companies at heart with a natural water ethos to global entities on multiple platforms – a transition certainly encouraged if not dictated by the activities of Coca-Cola and PepsiCo.

2.5 GLOBAL REVIEW

When examining trends for bottled water, it is useful to create a context that includes other beverages. The normal classification of the global sectors is as follows: hot drinks, milk drinks, soft drinks and alcohol. Globally, hot drinks dominate world consumption, with an estimated 597 billion litres drunk in 2008 (globaldrinks.com). Soft drinks come second at 571 billion litres. Bottled water is a segment of soft drinks. Figure 2.3 compares bottled water with the rest of the soft drinks segment and with alcoholic drinks over the historic period from 1997 to 2008 and projected from 2009 to 2013.

Bottled water is poised to overtake alcohol in 2011, and exceeds 50% of the volume of other soft drinks. What factors are driving this high growth rate compared to other beverages? The mix will vary according to the part of the world, but the following influences probably come into play everywhere to some degree:

- *Wealth*: Increasing prosperity allows the Chinese to buy bottled water as a staple, and the Americans to buy water on the go for its image and active lifestyle choice.

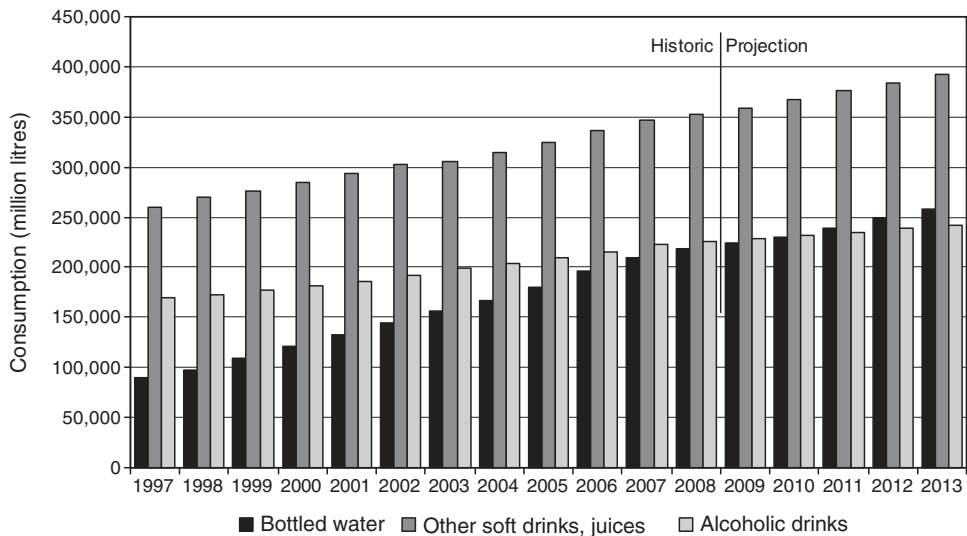


Fig. 2.3 Global bottled water growth in context, 1997–2013.

Source: globaldrinks.com © Zenith International 2009.

- *Health*: Greater affluence has combined with more attention to healthy living and bottled water has the attraction of no calories, additives or alcohol. In the USA especially, obesity has become a major issue, which will drive both consumers and producers away from sugar-based soft drinks – the latter because of questions of liability.
- *Lifestyles*: Bottled water's image has also been developed to fit contemporary lifestyles, with emphasis on nature and purity.
- *Marketing*: Effective marketing and packaging have enhanced this appeal and so enabled premium prices for certain brands.
- *Quality*: Even in the West there are many incidents of tap water pollution, which receive extensive media coverage, each giving bottled water a powerful boost. In many countries, the public water supply is unsafe or of variable quality.
- *Availability*: Some countries are unable to extend the public water supply to their populations. In others, water infrastructure development cannot keep up with the pace at which cities are expanding.
- *Occasion*: Bottled water is the only all-day beverage.
- *Taste*: People are becoming more sensitive to discolouring or off-tastes in tap water.
- *Habit*: Once the change has been made, people are unlikely to move back unless their confidence in bottled water is shattered or their economic circumstances decline – the new habit gains its own momentum.

In fact, the fastest growing markets are those in Asia, which come from a low base of consumption, have experienced rapid economic growth and where the public supply infrastructure is either poor or struggling to keep pace (Fig. 2.4). China is the engine for growth in this region, but Indonesia and India are also substantial and important. Moreover, it is striking how low that base really is in terms of per capita consumption (Fig. 2.5), given that North America and West Europe are at more than 100 litres per capita per year, whilst the Asia/Australasia region has still not reached 20 litres.

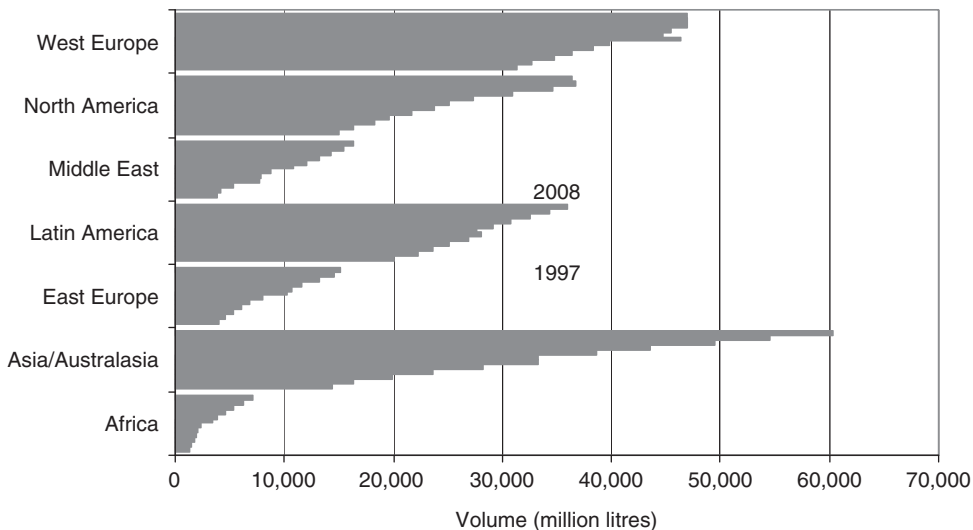


Fig. 2.4 Regional bottled water growth, 1997–2008.
Source: globaldrinks.com © Zenith International 2009.

Figure 2.4 also shows that growth has stuttered in the two most developed regions, North America and West Europe. For the former, it was only in 2008 that a drop in volume occurred. In West Europe, a heat-wave summer in 2003 was followed by bleak weather in 2004. Extraordinary growth in 2003 led to a correction in 2004; the market dropped as a consequence. Growth resumed but then the market fell again in 2007 and 2008.

The year 2008 will have been affected by the global recession, most acute in North America and West Europe. However, there are also long-term opposing forces to balance the picture of inexorable and natural development. Some markets are close to saturation. Moreover, as the industry grows and particularly as the major companies become more visible, bottled water has become a target for vested interests who seek to hinder its development or feel they can attack the industry to promote their own agenda. In some of the developed countries, the water utilities are one such vested interest who see the public's confidence in bottled water as undermining their status and image. Bottled water developments based on natural waters can provoke vociferous opposition. Such waters best come from unspoiled environments, so there can be a tension between preserving the landscape and constructing a factory. On the other hand, bottling plants often provide employment in rural areas where opportunities are scarce, and depopulation is threatening the environment in a different way. They also have low environmental impact and use a renewable resource. Communities have to resolve these legitimate issues through their planning and permitting procedures. Whatever the merits of a particular situation, the industry's visibility and the large size of the major companies encourage both campaigners and lawyers.

The use of water resources can also be the cause of dispute. In a locality this may well be a legitimate concern, again dealt with through the permitting system. However, claims of impact on a regional or national scale can hardly be justified, because even highly developed bottled water markets represent only a fraction of total water consumption. It is estimated that bottled water in total amounts to less than 0.01% of fresh water use globally.

To enlarge this perspective, the sections that follow pick three markets to look at in more detail: the USA, West Europe and China. Since concerns about environmental impact are shaping the way both soft drinks and bottled water companies act, this topic is also explored in Section 2.9.

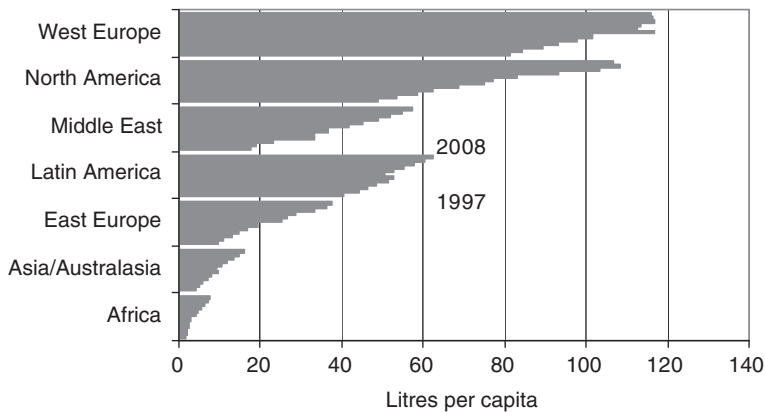


Fig. 2.5 Regional bottled water per capita growth, 1997–2008.

Source: globaldrinks.com © Zenith International 2009.

2.6 USA

At over 32 billion litres in 2008, the USA has the largest bottled water market in the world, ahead of China (21 billion litres), Mexico (16 billion litres) and Indonesia (12 billion litres). Besides being the largest, it is in many ways also the most developed. How so, cry the Europeans, whose consumption per capita is nearly 30% higher, and whose brands are the best known on the planet? Because the USA has a much more integrated market than Europe, because the watercooler market is mature with a high penetration into homes and because the Americans have gone further in the adoption of modern technology. It has also been a key battleground between the two global water companies Nestlé and Danone on the one hand, and the soft drinks giants Coca-Cola and PepsiCo on the other. Figure 2.6 gives the trend in the market since 2000, showing startling development at 14% CAGR (compound average growth rate) from 2000 to 2007, coming to a crash stop in 2008 when the market fell by 0.9%.

The growth is by no means evenly spread. ‘Greater than 10 litres’, which is almost exclusively Home and Office Delivery (HOD), managed a geriatric 1% CAGR to 2007, then fell by 2.5% in 2008; whilst the separate line for ‘still to 1 litre’ shows that this segment is providing nearly all of the growth in packaged water. Thus, the US market is very focused on lifestyle and convenience, i.e. on the small packs that can be bought at outlets everywhere and consumed on the go.

This condition has been influenced partly by the entry of Aquafina (PepsiCo) into national distribution in 1997 and Dasani (Coca-Cola) in 1999. Both corporations have applied their marketing talents to exploit this convenience orientation and an already existing distribution infrastructure. So how did their entry affect the other bottled water companies? Figure 2.7 indicates that the smaller companies suffered first – losing market shares to the big four. Second, Danone has been squeezed and eventually fell out of the market. In 2002, the company announced a partnership with Coca-Cola for the production, marketing and distribution of Groupe Danone’s retail bottled water throughout the USA. Danone contributed the assets of its US businesses, licences for the Dannon and Sparkletts brands and ownership of several value brands. Coca-Cola contributed cash and ran the new company

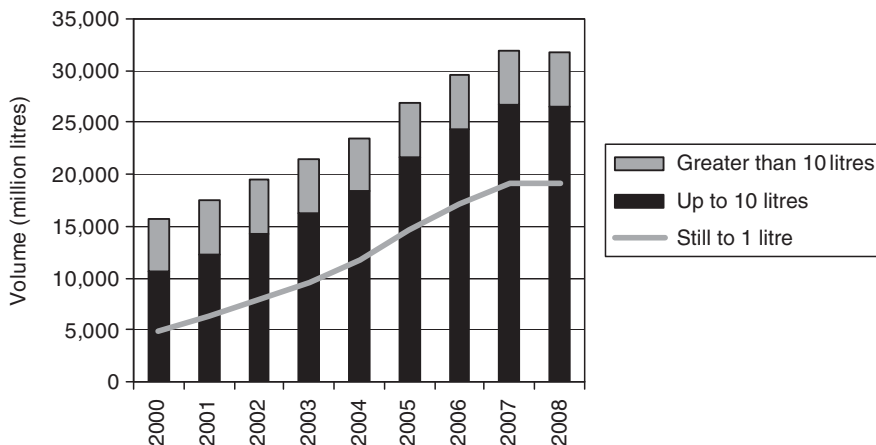


Fig. 2.6 United States bottled water market, 2000–2008.

Source: Zenith International © Zenith International 2009.

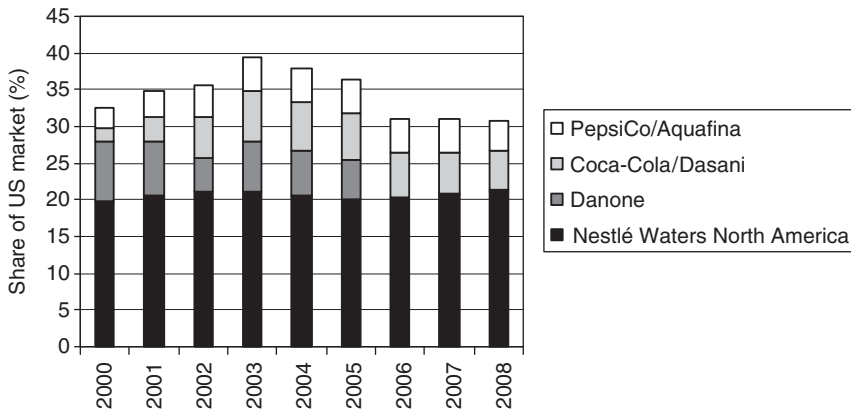


Fig. 2.7 United States market shares, 2000–2008.
Source: Zenith International © Zenith International 2009.

Danone Waters of North America with a 51% share. Danone and Coca-Cola also signed a master distribution agreement under which Coca-Cola managed marketing execution, sales and distribution for the Evian brand in North America. Figure 2.7 allows for the shift in activity from Danone to Coca-Cola. Moreover, in 2003, Danone put its HOD operations into a joint venture with Suntory of Japan, called DS Waters. Neither initiative succeeded. In 2005, Coca-Cola bought Danone's share of the joint venture, and DS Waters was sold to US investment fund Kelso.

The third trend in Fig. 2.7 is that over the period Nestlé Waters North America has managed to increase its market share. Formerly Perrier Group of America, the Connecticut-based company has been the leading bottled water company in the USA since the late 1980s with a stable of important sources, including the giant brands Poland Spring in Maine and Arrowhead in California. Most of the company's products are regionally distributed natural spring water and the local water brand is the primary platform, rather than the Nestlé name. However, a recent development has been the rapid growth of Nestlé Pure Life as an important part of the portfolio, to become the number one bottled water brand in 2008.

2.7 WEST EUROPE INTO THE NEW MILLENNIUM

In Table 2.1, European patterns of consumption as they existed in 1980 are illustrated for sample countries. It is interesting to see how these have changed in the 15 years up to 1995 and then on to 2002 and 2008, a comparison which is made in Table 2.3.

The German figures are distorted by unification. The 1980 figure is for West Germany, the 1995 for unified Germany. The per person consumption dropped from 86 to 72 litres in 1990, the year of unification, because of the low consumption of the former East Germany.

Table 2.3 presents a remarkable picture of growth, which has continued from 1995 into the new millennium. From 1980 to 1995, Italy experienced a CAGR of 8.5%; France 5.2%; the UK 24%. From 1980 to 2008, the growth has been 5.9%, 3.3% and 16.7%, respectively, a startling record over such a long period. Per capita consumption has now reached 199 litres/year in Italy, but is still only 34 in the UK.

Table 2.3 Changes in West European consumption between 1980 and 2008.

Country	Annual bottled water sales (million litres)				Annual bottled water sales (litres per person)			
	1980	1995	2002	2008	1980	1995	2002	2008
UK	30	800	1770	2055	0.5	13	29	34
Spain	800	3100	4801	6347	21	79	121	142
Germany	2550	7935	9289	12 865	41	97	111	146
Italy	2350	7950	9917	11 736	42	139	171	199
France	3125	6670	8813	7788	68	115	147	126

Source: Zenith International © Zenith International 2009.

However, Table 2.3 hides some woes in the recent past. France per capita consumption peaked in 2003 and has dropped from 157 to 126 litres per year. Growth over West Europe as a whole has been flat since 2006. In 2008, the UK and French markets dropped by 5.5% and 6.2%, respectively.

In fact, the picture is one of some fragility. Table 2.4 highlights those countries that suffered negative growth in the period since 2001. There was a slowdown in 2002 during economic uncertainty following the terrorist attacks of 9/11. However, only the Baltic states contracted. A year of growth in 2003, driven by a summer heat wave, was followed by a correction back to trend growth or below in the indifferent weather of 2004. Low growth resumed in 2005 and 2006, but then 2007 and 2008 were zero growth years.

The question is, what are the relative influences of market saturation, poor summers, recession and environmental pressures? There seems little doubt that 2008 has been affected by the recession. However, France has been a poor performer since 2003, the market dropping by more than 17% since then. It seems likely that environment is a factor. France has seen a very public clash between a bottled water producer (Cristaline) and the tap-water companies, as a result of the tension brought about by publicity from tap-water companies that urges consumers not to drink bottled water (Section 2.9). However, other factors also come to bear. Stylish water filter jugs are becoming more and more popular within homes, sitting alongside microwaves and toasters, the main motivation supposedly being to save money. Also consumers have lost their respect for the leading brands and are going for best promotions. Recent legislative changes from the European Union mean that the premier rank of 'Natural mineral water' status is now no longer issued by the Ministry of Health but from the local prefecture. Spring water bottlers have taken advantage of a less onerous bureaucracy to rebrand their waters, leading to a glut of discount priced mineral waters.

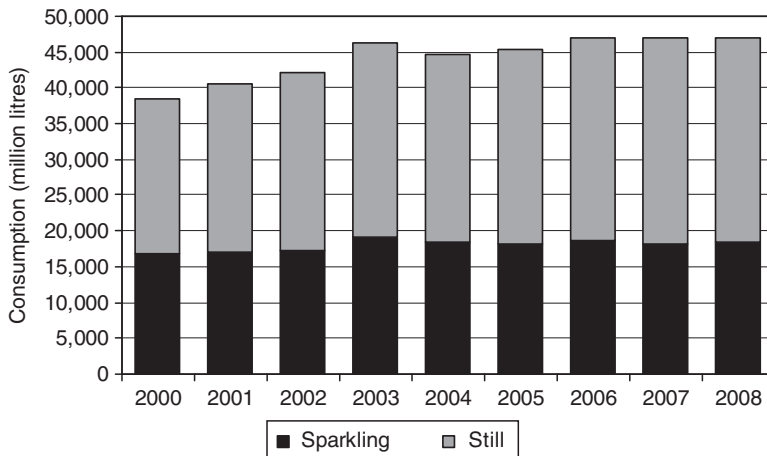
For now the jury is out on whether Western Europe as a whole will go the way of France. The picture will be clearer once economies have recovered a measure of vitality. In the interim, how has the overall market been changing in other ways?

- After losing market share in the 1990s, sparkling water is holding its own and enjoying a slight resurgence (Fig. 2.8).
- Germany and Austria have held onto their sparkling tradition (Fig. 2.9).
- Bottled watercoolers grew rapidly to just over 3% of the market and have now started to lose ground (Fig. 2.10).
- PVC packaging has disappeared in favour of PET. Glass has reduced substantially. Polycarbonate packaging is at 3% of the market because of watercoolers (Fig. 2.11).

Table 2.4 Growth in West European consumption 2001 to 2008.

	2001	2002	2003	2004	2005	2006	2007	2008
Austria	7.9%	4.8%	8.9%	-8.8%	-2.9%	-0.4%	3.5%	2.9%
Belgium	5.5%	3.5%	5.5%	-4.9%	0.9%	5.6%	-2.1%	-3.5%
Denmark	8.8%	25.7%	20.1%	-4.5%	8.2%	7.9%	2.5%	2.4%
Finland	2.4%	7.5%	-2.8%	-3.3%	0.8%	8.0%	-0.4%	-5.0%
France	4.7%	2.0%	7.3%	-6.7%	-0.9%	-1.1%	-3.8%	-6.2%
Germany	3.8%	4.1%	13.6%	-1.5%	1.5%	4.2%	-0.9%	4.9%
Greece	9.1%	6.1%	7.5%	8.1%	6.5%	7.4%	15.6%	11.4%
Ireland	7.7%	7.7%	10.1%	3.4%	12.2%	8.5%	14.1%	-5.1%
Italy	3.1%	1.6%	9.0%	-6.8%	-1.7%	2.9%	1.2%	-0.2%
Netherlands	4.4%	6.0%	5.7%	1.0%	1.9%	3.0%	0.9%	-3.9%
Norway	6.1%	-7.9%	4.5%	0.2%	5.6%	5.6%	1.7%	-1.9%
Portugal	6.9%	8.4%	8.8%	4.8%	7.8%	8.0%	1.2%	-4.3%
Spain	10.0%	8.3%	8.7%	2.0%	9.0%	6.7%	1.4%	1.1%
Sweden	0.9%	-1.7%	8.5%	-2.5%	5.7%	12.4%	0.6%	-15.2%
Switzerland	9.4%	5.6%	18.1%	-5.3%	0.3%	2.5%	2.1%	-1.0%
UK	12.4%	10.7%	17.6%	-0.5%	4.4%	5.8%	-4.4%	-5.5%
Others	9.6%	10.7%	15.8%	7.6%	5.6%	6.8%	2.6%	-2.7%

Source: Zenith International © Zenith International 2009.

**Fig. 2.8** West European still/sparkling split, 2000–2008.

Source: Zenith International © Zenith International 2009.

The West European watercooler market makes a good tale, illustrating the maxim that what goes up can easily come down. It was developed through the 1990s firstly by small-scale entrepreneurs and then by some companies who saw the opportunity to consolidate. Starting in 2001, Nestlé Waters and Danone acquired extensively so that by early 2003 they had changed from small or non-existent positions to the number one and two spots, respectively, with 25% and 20% of the market.

The events (by announcement date) were as follows:

- *December 2001*: Ionics sells the US and European Aqua Cool business to Nestlé Waters – 80 000 coolers in Europe for €247m. (exchange rate on the day).

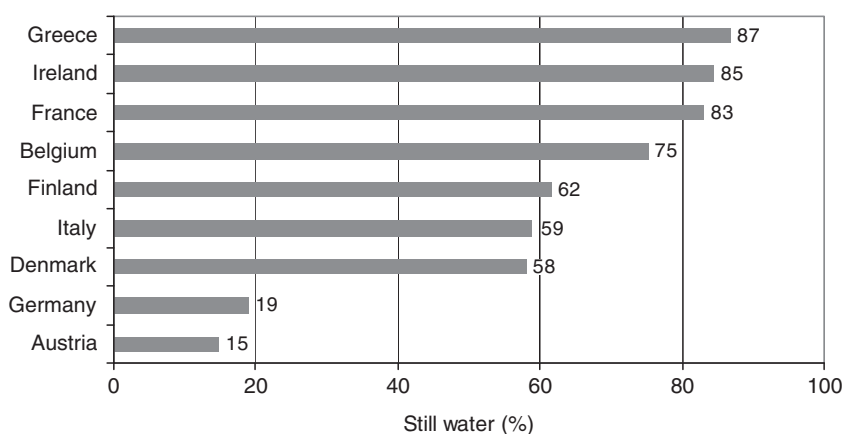


Fig. 2.9 West European percentage of still water, 2002.

Source: Zenith International © Zenith International 2009.

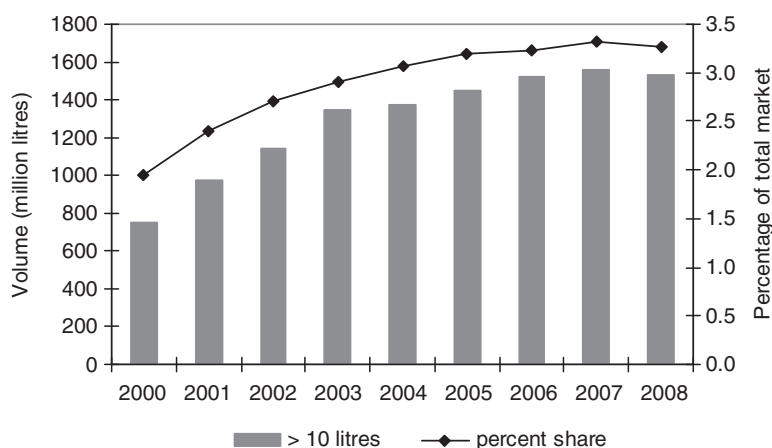


Fig. 2.10 Growth in the West European watercooler market, 2000–2008.

Source: Zenith International © Zenith International 2009.

- *October 2002*: Ondeo (the water division of Suez) sells Chateau d'eau to Danone for an undisclosed sum, totalling 130 000 coolers in Europe.
- *November 2002*: Danone buys Sparkling Spring of Canada, including a European portfolio of 55 000 coolers.
- *March 2003*: Nestlé acquires Powwow from Hutchison Wampoa for €560 m., thus gaining 230 000 coolers.
- Danone announces a joint venture (JV) with Eden Springs, to put Eden's 155 000 West European coolers with Danone's 210 000, the JV to be run by Eden.

Neither company sustained their position. In July 2007, Danone withdrew from the Eden Springs joint venture, having been bought out by their partner. Nestlé Waters Powwow Ltd, the UK business and Nestlé Waters' largest operating unit, was sold to a new entrant, Lomond Hills Mineral Water, in February 2009. Both companies had struggled with issues

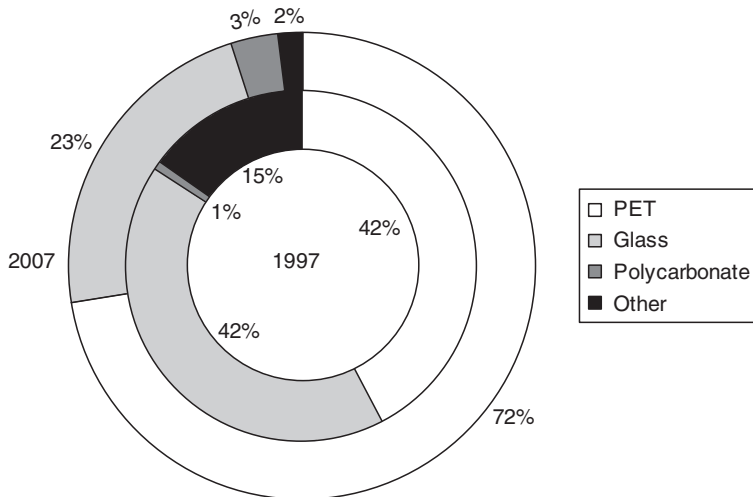


Fig. 2.11 West European packaging split, 1997–2007.

Source: Zenith International © Zenith International 2009.

of integration arising from the rapid consolidation, whilst plumbed-in (Point of Use) water-coolers have ridden the environmental debate and captured all the growth in the market.

2.8 CHINA

China is vast but information is becoming more reliable. All indicators and industry sources point towards a bottled water market in China that has really developed its potential in recent years. Chinese consumers have embraced the bottled water concept. Some consumers have taken to using bottled water for cooking as well as regular consumption. In urban areas, households have embraced watercooler bottles simply because there is often no infrastructure in place for reliable municipal water. This is particularly so in outlying areas of rapidly growing cities. Here water for cooler delivery has assisted the rapid commercial expansion of cities such as Shanghai, and to a lesser extent Beijing. However, per capita consumption, and therefore penetration, is still low at 15.5 litres in 2008, and consumption is polarised towards the cities.

The market was pioneered in the Guangdong region in 1986, at a time when the area was spearheading growth for the country as a whole – assisted by close political and economic links with Hong Kong. In recent years, Beijing and Shanghai in particular have become increasingly important for growth across the cooler and retail pack size segments. Beijing, Guangdong, Hebei, Jiangsu, Shanghai and Zhejiang are the highest yielding soft drinks areas, and consequentially pivotal for bottled water activity. China's policy of reform and the opening up of markets greatly benefited bottled water. As a result of corporate restructuring, asset reorganisation and a strong brand strategy, the market saw an influx of major bottled water players in the late 1990s. Coupled with consolidation amongst existing local players, this changed the shape of China's bottled water industry.

As a consequence, China's share of the world bottled water market nearly doubled from 5.5% in 1995 to 9.4% in 2008 (Fig. 2.12). Figure 2.13 shows the characteristics of the market and demonstrates how in the early years the large watercooler size bottle predominated.

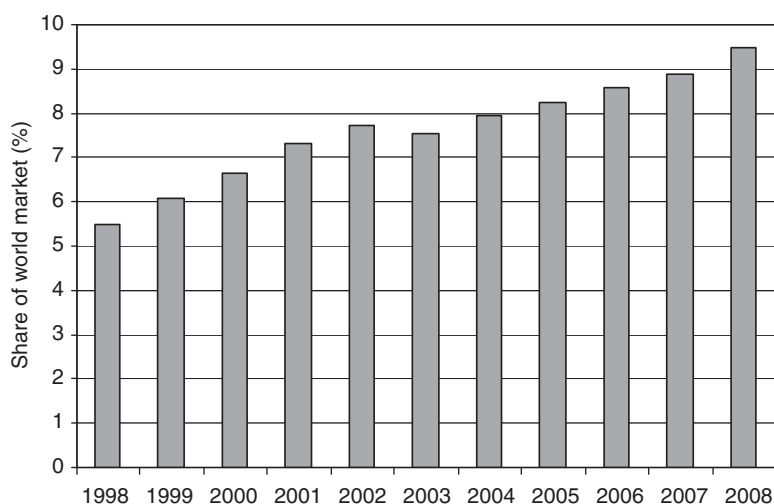


Fig. 2.12 Growth in China's share of the world bottled water market.

Source: Zenith International © Zenith International 2009.

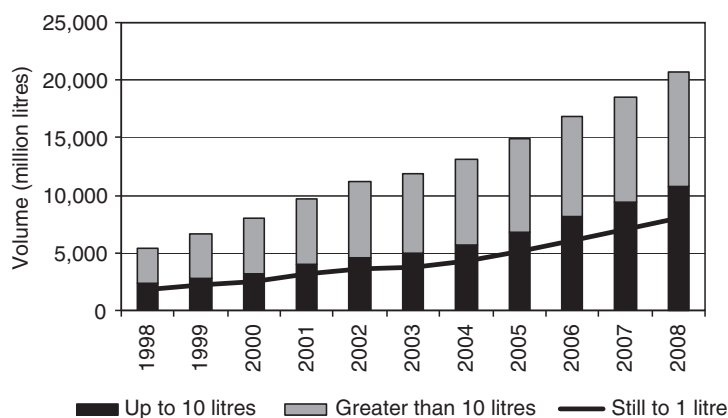


Fig. 2.13 China bottled water market, 1998–2008.

Source: Zenith International © Zenith International 2009.

However, since 2003, smaller formats have consistently grown more than the bulk pack, a reflection of increasing diversity in distribution and more sophisticated consumers, so that this segment is now in the majority.

The market is fragmented. In 2008, the top seven companies in descending order were Wahaha, Danone, Tingyi, Nong Fu Shan Quan, Coca-Cola, AS Watson, and Nestlé. Together these represent 40% of volume. However, the remaining 60% could be shared by as many as 1500 companies. Nobody knows. New entrants are joining all the time and companies falling out because of the competitive pressures on sales pricing, although this has eased since 2005, with some price increases working through. The degree of regional diversity within China means that the typical producer focuses sales and distribution activity on one region or locality. Informal and formal trade barriers between different regions also contribute. National

distribution is becoming established. Nevertheless, the larger 'national brands' are usually only present in the cities. Indeed, the rural market remains very much untapped at present. Launching a bottled water product does not therefore mean immediate access to 1.3 billion potential consumers. Purified water represents approximately 80% of the market; the balance is natural or source water.

Many companies have grown up through joint venture or acquisition. For example, Danone first entered the Chinese market in 1996 when it became majority shareholder in a joint venture set up with market leader Wahaha. Danone also acquired number four, Shenzhen Health, in 1998. By March 2000, the company had added market number two, Guangdong Robust, and in December 2000 agreed to acquire 50% of another important bottled watercooler player, Shanghai Aquarius. But these relationships can also run into trouble. In 2007, the Danone Wahaha joint venture turned sour when Wahaha said that Danone were laying claim to assets to which they did not have a right. Twenty-one legal hearings later, in October 2009, Danone exited the joint venture after a bitter legal and political battle. However, this has not deterred others. In May 2008, Californian investment company Heckmann Corporation acquired 100% of the capital of China Water and Drinks Incorporated in a US\$ 625 million transaction.

Standards are an issue both as a market driver and for consumer safety. Despite a growing economy, the quality of tap water in China still falls far behind western standards. Although the government recently reviewed some of the regulation relating to how water can be treated and how it can be described depending on that treatment, the quality of tap water – especially in the northern region – has so far failed to improve greatly. In fact, some believe the situation will only get worse due to the pollution resulting from industrialisation. However, the quality of bottled water can also be an issue. In April 2008, source water contamination led to an outbreak of Hepatitis A in Guiyang City; 330 people were infected. On a more subtle note, the Chinese consumer has started to become more sophisticated when it comes to making decisions about consuming water, with growing awareness of the differences between source and purified waters. This has been helped by the local media paying more attention to any water quality scandals, as was the case in 2008 with the Master Kong brand, produced by Tingyi Holdings.

In its advertisements, the company described its bottled water as having a high mineral content, though it emerged that the water was in fact purified municipal water. The company later issued an apology to the public for any misunderstanding caused, and the product's packaging has since been redesigned. It is scandals such as this that have helped drive increased awareness in the origins of bottled water on sale in China. Other elements helping to boost the bottled water market include increasing consumer affluence and a growing middle class, as well as the increase in tourism, largely thanks to the 2008 Beijing Olympics. As consumers see their disposable income rise, the public debate with regards to tap water has turned bottled water into an essential purchase item for many Chinese consumers.

The future looks bright, with a CAGR of 7% predicted for the period 2009 to 2013, despite the world financial crisis.

2.9 BOTTLED WATER AND THE ENVIRONMENT

Soft drinks in general and bottled water in particular have been subject to criticism because of their environmental impact. The focus is on four issues:

- (i) Damage to the environment from discarded PET packaging, which does not degrade.
- (ii) The additional burden on disposal caused by bottles going to landfill.

- (iii) The carbon footprint along the supply chain but particularly arising from the manufacture of PET bottles and the transportation of product.
- (iv) The use of water resources.

Bottled water is particularly vulnerable to these arguments because under many circumstances consumers can drink tap water instead, which has a much lower environmental impact.

Chapter 15 deals with the true environmental impact of bottled water and how it is improving. This section is concerned with the history of environmental opposition, how companies are responding to it and the possible effects on market growth.

Water utility companies in the UK have long seen the development of bottled water as reflecting a lack of public confidence in tap water quality. Since they were privatised, they have viewed this lack of confidence as a disadvantage in their periodic negotiations with the water regulator about investment plans, consumer bills and return on capital. So since the early 1990s they have promoted stories in the media about how much more bottled water costs than tap water and how tap water is more stringently controlled.

In the United States, the National Resources Defence Council (NRDC) published a 1999 report entitled *Bottled Water – Pure Drink or Pure Hype?*, which they used to support a petition to the FDA in support of tighter regulation. Their overall conclusion reads as follows:

While we reasonably may choose to use bottled water for convenience, taste, or as a temporary alternative to contaminated tap water, it is no long-term national solution to this problem [of poor quality tap water]. Bottled water sometimes is contaminated, and we don't use it to bathe, shower, etc. – major routes of exposure for some tap water contaminants. A major shift to bottled water could undermine funding for tap water protection, raising serious equity issues for the poor. Manufacture and shipping of billions of bottles causes unnecessary energy and petroleum consumption, leads to landfilling or incineration of bottles, and can release environmental toxins. The long-term solution to our water woes is to fix our tap water so it is safe for everyone, and tastes and smells good.

This concern that over-reliance on bottled water could lead to a lack of investment in tap water was picked up by the World Wide Fund for Nature (WWF) in 2001, when they declared that, in the light of a new independent study, the conservation organisation was urging people to drink tap water – which is often as good as bottled water – for the benefit of the environment and their wallets. The study was in fact a WWF commissioned review by the University of Geneva, which in itself was uncontroversial. It seemed that the WWF also thought that the availability of bottled water is easing the pressure on governments to provide potable water supplies, especially in the developing world.

By 2005, US environmental interest groups including NRDC, the Sierra Club, Greenpeace, Friends of the Earth and Earth Policy Institute had started to criticise the environmental impact of bottled water. FIJI Water had come under attack for its long transportation distances. Nestlé Waters North America was encountering vociferous opposition to development of new water resources, leading in 2008 to a special interest website stopnestlewaters.org. By 2006, the UK's *Independent* newspaper felt able to report that drinking bottled water was 'environmental insanity'. Politicians followed suit. Phil Woolas, the UK environment minister famously said that the amount of money spent on mineral water 'borders on being morally unacceptable'. Tap water companies have devoted PR resources to exploiting this sentiment. Thames Water set up an organisation 'Water for London', whose well funded

brief is to encourage restaurants to put tap water on tables, and preferably not offer bottled water. A few prominent New York restaurants have introduced a (filtered) 'tap water only' policy. On both sides of the Atlantic, some central and local government bodies have voted to ban bottled water from government premises.

Nor has France been immune from the tension. In 2007 Cristaline, the country's most popular spring water, angered the Government, the Paris council and Green groups with a poster campaign implying that the capital's tap water is undrinkable and polluted. Pierre Papillaud, President of Cristaline was unrepentant, claiming he was responding to a campaign by the Paris water authority promoting its 'eau du robinet' as superior to bottled water.

There are many campaigning websites such as thewaterproject.org, which asks people to donate money saved on bottled water to developing water supplies in Africa. However, the motivation of some sites is difficult to discern. allaboutwater.org has a platform that leads one to suspect it is funded by the water filtration industry. tapping.com was founded by two PR/product branding professionals. It campaigns against bottled water, urging consumers to send a message in an empty plastic bottle, which they will deliver to Coca-Cola once a million have been collected. It is also linked to startalie.com (strapline: 'Start a Lie' about the bottled water industry – if they can lie, so can you), which uses social networking to spread comments about bottled water. However, the site sells reusable water bottles, so is it a commercial venture?

Thus the bottled water industry is facing genuine environmental concern as well as its exploitation by vested interest. The questions are, what effect is this having on sales, and what can the industry do about it?

Concerning the effect on sales, it is very difficult to say because as the intensity of opposition in the public domain has increased, so the world has fallen into recession. Nestlé Waters announced a 1.8% decline in global sales for the first 9 months of 2009, but the company put that down to not reacting quickly enough to price cuts by competitors. However, it is likely that at a minimum, the US and UK markets have been or will be affected, because this is where the debate is concentrated. Europe may well follow suit, depending on how successful the industry is in making its case.

How can the industry do this? By demonstrating that companies are stewards of the environment, that bottled water serves a role in society, that it does have genuine benefits; by pointing out (despite unfounded claims to the contrary) that it is subject to regulatory oversight; and by championing consumer choice. Nestlé Waters North America is the leader in this activity, being the largest bottled water producer in the US where the sustainability debate is at its most ferocious. The company has set out six commitments in its Corporate Citizenship programme:

- (i) promoting health and hydration;
- (ii) responding to disasters;
- (iii) managing water resources for long term sustainability;
- (iv) supporting sustainable packaging;
- (v) reducing supply chain footprint;
- (vi) being a good neighbour.

Leading beverage companies have been in the forefront of global sustainability initiatives – Nestlé, PepsiCo and Coca-Cola are all founding signatories of the CEO Water Mandate, a UN Global Compact Initiative. The CEO Water Mandate engages with the need to improve access to water and sanitation around the world. It commits business leaders to take action in a number of areas – including Direct Operations; Supply Chain

and Watershed Management; Collective Action; Public Policy; Community Engagement; and Transparency.

In the UK, a number of ethical brands have sprung up including Belu, Thirsty Planet, One and Frank Water; likewise Ethos, NIKA and several others in the US. Although on a small scale, they either donate a proportion of profits to charities that develop water and sanitation in poor countries (e.g. Belu) or have a more direct relationship with a partner organisation (e.g. One, which is linked to PlayPumps International). Also in the UK, Danone's Volvic has a 1 for 10 programme, where it pays for 10 litres of water in Africa for every 1 litre sold. Volvic has similar programmes in other countries.

It is clear that for the future, bottled water companies must demonstrate their engagement with sustainability in the wider sense, be transparent and continually make the case that bottled water is a healthy substitute for high calorie drinks. The battle is not only to maintain the loyalty of consumers but also to be seen as having a function in society and avoid being successfully portrayed as a social pariah.

2.10 FLAVOURED AND FUNCTIONAL WATERS

The first flavoured waters were launched by Perrier in 1985. Unsweetened aromas were added to the naturally sparkling water; the initial line being Perrier Zeste on the French market in lemon, lime and orange. The next year saw the establishment of Clearly Canadian, marketing sweetened fruit flavours, again in a sparkling water. Then 1990 saw the launch by Volvic of the first still flavoured range in lemon-lime and orange. These are sweet natural flavours. Thus, in the first three years of development, three of the main platforms for flavours were established – sparkling unsweetened, sparkling sweetened and still sweetened.

A departure of a different kind took place in the US in 1996. A New York entrepreneurial start-up called Energy Brands launched Glacéau Smartwater. This product was a step change from the then current 'water with flavours' concept, introducing functionality in a water base. Smartwater is a vapour distilled water with added electrolytes; it was followed by Fruitwater in 1998 and Vitaminwater in 2000. Coincidentally, South Beach Beverages, a new company in Connecticut, was transforming its products from standard New Age beverages on a hydration platform to real functionality with added herbs and vitamins. It also transformed its brand into SoBe, complete with 'attitude' and guerrilla marketing. Those initial products were teas and fruit drinks, so do not qualify as functional waters. But eventually SoBe Life Water was launched in 2006. By then the company was owned by PepsiCo, who ran straight into a lawsuit by Energy Brands for copying its colours, flavours and ingredients. The suite was settled but Life Water's 'brand dressing' was changed.

Over the period since the mid-1990s, thousands of different products have been created – leading market analysts to ponder how to reasonably classify such a diverse offering. A starting point therefore, is definitions:

- *Plain bottled water*: mineral, spring or purified bottled water with nothing added (except possibly carbon dioxide).
- *Plain naturally functional bottled water*: plain water with inherent health promoting properties, such as natural sources of magnesium and calcium, which can increase the body's metabolism and improve weight loss – e.g. Contrex (plain variant).
- *Plain added functional bottled water*: plain water with added vitamins, minerals or other health promoting ingredients, but no flavourings or added sweeteners.

- *Flavoured water*: plain water with added flavourings. Typically clear and with less than 10% fruit juice. Flavourings can be either natural (i.e. derived from fruit, tea, herbs, etc.) or manufactured synthetically:
 - with sugar and/or sweetener – e.g. Volvic Touch of Fruit;
 - unsweetened – e.g. flavoured Perrier.
- *Flavoured functional water*: mineral, spring or purified bottled water with added botanicals, vitamins, minerals, oxygen or other functional ingredients. The functional ingredients (e.g. herbs such as mallow) may also serve as flavourings. Typically clear and with less than 10% fruit juice – e.g. Nestlé Wellness.

How these categories interrelate is indicated in Fig. 2.14. The market figures that follow relate to flavoured water and flavoured functional water, collectively known as ‘water plus’. Water plus itself sits within the ‘healthy refreshment’ zone of soft drinks, as indicated by Fig. 2.15. This zone is an area of migration for both the soft drinks and bottled water giants.

Since functionality is the area of most complexity, it is also useful to segment the different kinds, be they herbal, sports, energy and so on, relating each segment to the attributes offered and the composition. Table 2.5 does this across all drinks, bracketed by medicines on the one hand and pure drinks on the other, together with some product examples. However, any segment can apply to products on a water platform. There are even probiotic waters!

From small beginnings in the late 1980s, the category has grown to a near US\$ 16 billion market in 2008. Now more than 6% of small pack world volume (excluding sizes above 10 litres), its value is disproportionately high at over 14% (Table 2.6).

In 2008, volume growth slowed from 13% (2007) to 1% for flavoured waters and from 20% to 8% for flavoured functional waters. However, value growth was much stronger at 23% slowing to 9% and 28%, slowing to 17%, respectively. This reflects the continual launch of more ‘added value’ and therefore higher cost products.

Although many functional brands especially were started by entrepreneurs, it would not be surprising if the major companies were very active in such a high value market, where they have the technological and production expertise, and also the financial strength to acquire

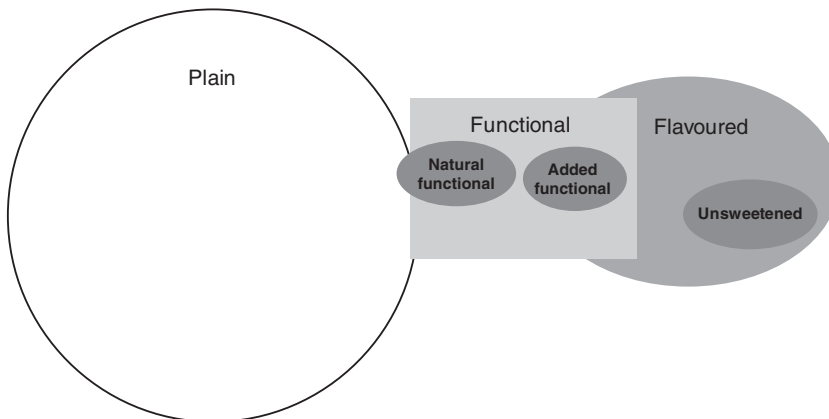


Fig. 2.14 Overlapping water categories.

Source: Zenith International © Zenith International 2009.

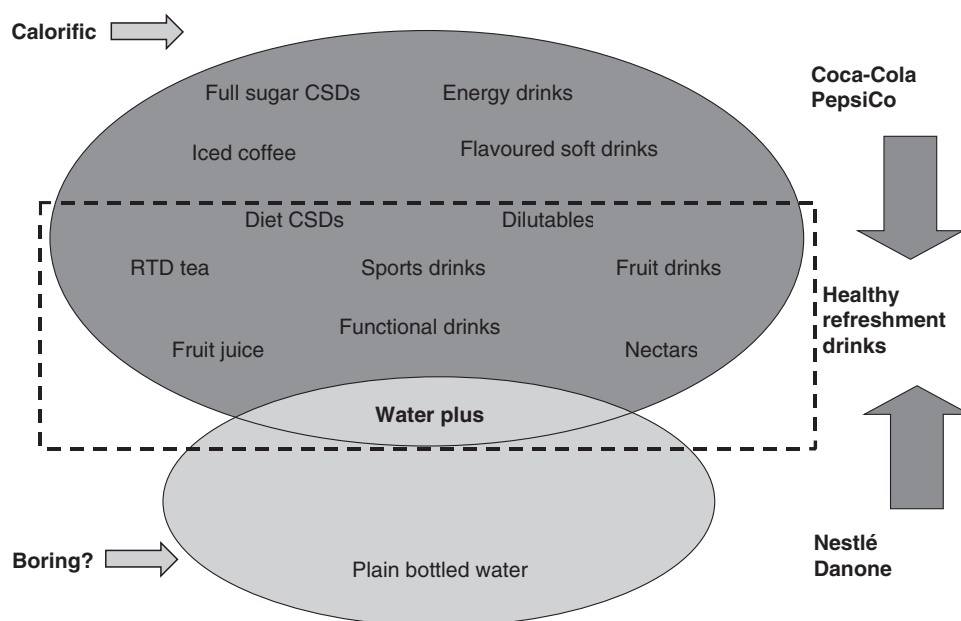


Fig. 2.15 Water plus within the 'healthy refreshment' zone.
Source: Zenith International © Zenith International 2009.

when entrepreneurs want to move on. This is confirmed by Fig. 2.16. The top three companies' brands include: Coca-Cola: Apollinaris, Bonaqua, Dasani, Glacéau; Danone: Bonafont, Mizone, Ser, Volvic Touch of Fruit; PepsiCo: Aquafina, Propel, SoBe. These top ten accounted for 52% of world volume in 2008. How this volume is distributed is shown in Fig. 2.17. It is no surprise that the US is number one. That the Czech Republic is number three reflects an old tradition of flavoured water, which has survived the transition from the Soviet bloc, hence the presence of Karlovarske and Podebradka in the top ten companies list.

The distinction between soft drinks and flavoured bottled water categories continues to blur. While flavoured and functional water brands provide bottled water consumers with an alternative to plain variants, they are also increasingly attracting customers from the traditional soft drinks market.

Many established mineral and spring water bottlers, confident of their heritage, have extended their ranges to include water-based products that have been positioned as sodas, lemonades and soft drinks. Packaging is increasingly adapting to tie in with lifestyle/on-the-go consumption/sports market (e.g. sports bottles, sports caps, sports grips) – and to attract increasing attention through the HORECA distribution channels. Product innovation as well as (re)positioning, (re)launching and rebranding efforts, have been accompanied by huge marketing drives – and here the parallels are often stronger with soft drinks than with bottled water. A notable characteristic is the high degree of consumer segmentation. Flavoured and functional water promotion is also beginning to draw more parallels with the soft drinks industry – especially those designed for younger audiences. In a further move away from marketing push to marketing pull, an increasing number of flavoured water products are being promoted via viral marketing campaigns and YouTube, which is proving a particularly significant tool for the energy drinks industry. For a more detailed examination of flavoured and functional waters, see Chapter 14.

Table 2.5 Growth in flavoured and flavoured functional water since 2003.

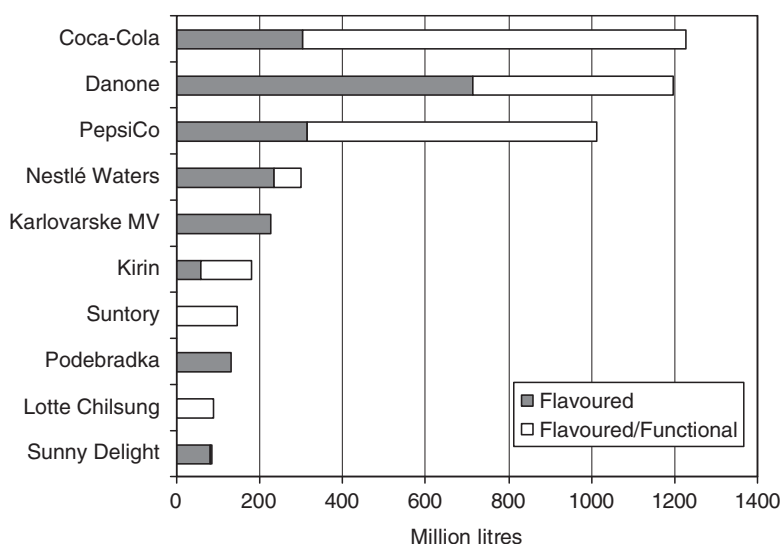
	Primary segments	Goal/attribute	Composition	Company/brand
Pure/simple ↑	Bottled water	Hydration, well being	Water, minerals	Danone/Evian/ Nestlé Waters
	Tea	Stimulation	Tea leaves	Twinings/various
	Juice	Well being	100% juice, 25–99% juice	Tropicana/various
Functional drinks ↓	Herbal	Relaxation, well being	Herbs, spices, fruits	Nestlé/Nestlé Wellness Relax
	Enriched	Well being, nutrient boost	Vitamins, minerals, herbs, protein, fibre, algae, tea extracts	Procter & Gamble/ Sunny D
	Sports	Energy, recovery, performance	Electrolytes (sodium and potassium), simple and complex carbohydrates	Coca-Cola/ Powerade
	Oxygenated water	Energy, recovery, performance	Water, oxygen	Adelholzener/ ActiveO2
	Energy	Energy, alertness	Caffeine, taurine, guarana, B vitamins	Red Bull
	Mind nutraceuticals	Mental alertness, anti-anxiety, relaxation, positive mood	Vitamins, minerals, herbs and fruits	Yagua/Yagua Brain Juicer
	Body nutraceuticals	Slimming, detox, metabolic enhancer/ cholesterol lowering, anti- hypertension, heart health/ immunity boost, anti-allergy, hormone balance, hangover, eye health/ aphrodisiac, anti-ageing, beauty enhancing, nicotine craving relief, PMS symptom relief	Herbs, spices, vitamins, minerals, amino acids, fibres, bacteria, vegetables, vinegars, tea extracts, fatty acids	Jacoby/Be Beautiful
	Probiotics	Gut health	Active bacteria	Yakult Honsha/ Yakult
	Vitamins, supplements	Specific purpose according to vitamin type		
← Complex/ medicinal	Prescribed medicine	Prescribed purpose		

Table 2.6 Growth in flavoured and flavoured functional water since 2003.

	2003			2008		
	Flavoured	Flavoured/ functional	Total	Flavoured	Flavoured/ functional	Total
Volume million litres	1500	1200	3700	5400	3400	8800
Value US\$ million	2800	2700	5500	7100	8800	15 900
Of world ^a volume	2.4%	1.0%	3.4%	3.7%	2.4%	6.1%
Of world ^a value	4.4%	4.1%	8.5%	6.5%	7.9%	14.4%

^a world volume is volume of water plus and plain waters but excluding bulk (sizes above 10 litres).

Source: Zenith International © Zenith International 2009.

**Fig. 2.16** Top ten global water plus producers in 2008.

Source: Zenith International © Zenith International 2009.

2.11 TRENDS FOR THE FUTURE

This section in the Second Edition pointed towards two new developments for the future: that the industry would come under environmental pressure, and that flavoured and functional waters would become an important extension of the bottled water category. Now, six years later, these two topics merit a section in their own right. The ferocity of the environmental debate and the way that vested interests have tried to cast bottled water as a social pariah have nevertheless been a surprise. Likewise, the range and pace of development in flavoured and functional waters has been remarkable.

The major influence on the future is going to be the impact of the environmental debate, coupled with how well the industry makes its case: that companies are conscientious stewards of the environment; that bottled water is not socially undesirable; that it does have genuine benefits, and that it remains a worthwhile consumer choice. Bottled water markets have

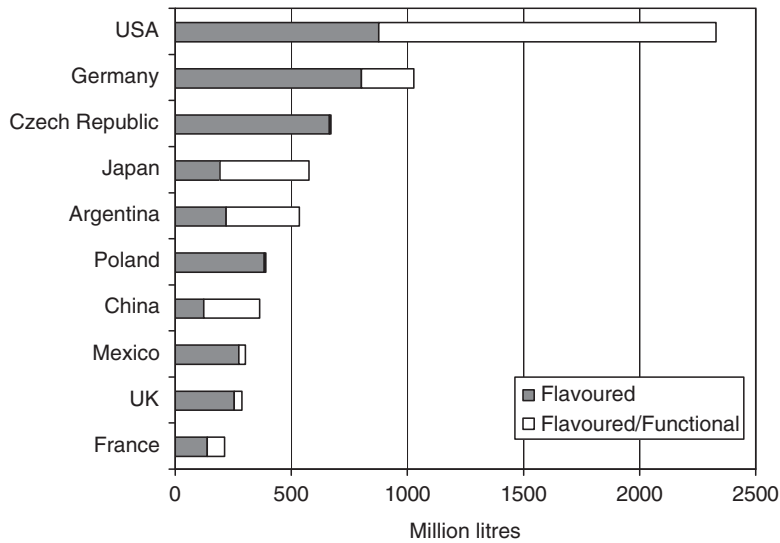


Fig. 2.17 Top ten water plus consuming countries in 2008.

Source: Zenith International © Zenith International 2009.

fallen in 2009, and in some places such as France for some years previous. It is impossible in 2009 to disentangle the effects of global recession and changes in consumer sentiment. So it is also very difficult to predict the outcome. What is clear is that the US and West Europe will be affected first, but given the pace of global change, whatever happens there will translate probably sooner than we think into the most important market for the future, China.

However, the terminal conclusion of the Second Edition remains the same. There will be opportunities for all including small, entrepreneurial concerns. Whatever the developments, it should be an exciting time for those in the industry – small, medium and large.

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FURTHER READING

- Zenith International Ltd (2008) *Zenith Report on West Europe Flavoured and Functional Water – October 2008*. Zenith International, Bath, UK.

3 Categories of Bottled Water

Nicholas Dege

3.1 INTRODUCTION

When the first edition of this book was published, the main purpose was to provide clarification and guidance to all those either having a stake in or merely an interest in the bottled water industry. It was the objective of this chapter to bring the same clarity to what was then a particularly confusing area – namely the nature of bottled water itself; where the water came from, how it was treated and regulated, and what distinguished one type from another. As the market has matured, legislators in many countries have worked to establish greater consistency in their approach, and as the industry has developed, trade associations have to some degree also evolved common standards. For consumers, the choice between one bottled water and another will be influenced by availability, habit and, to an increasing extent, their knowledge of the product, but nonetheless, the difference between water types of various origins, some having undergone treatments and others untreated, may not be obvious.

What, for example, is the difference between a natural mineral water sold within the European Union (EU) and a mineral water sold in the USA? How do these waters compare qualitatively with the tap water available from municipal suppliers within the same community? Furthermore, the distinction between, and relative merits of, Natural Mineral Water, mineral water, spring water, ‘natural’ water, table water, flavoured water, purified/demineralised/remineralised waters and so on can be difficult to determine.

This chapter is an attempt to clarify these differences and to explain why bottled water, an increasingly universal product, is marketed under such a wide variety of names. It is not possible here to carry out a complete country-by-country study of water worldwide, so the focus is on principles, with examples where appropriate. The springboard for this is Europe, as it was here that the market for bottled water first developed. By way of comparison, the approach in the USA is also examined, as is the position in principle of other important markets, which have tended to follow one of two distinct philosophies.

Some waters, especially those originating as groundwater from a protected source, may require little or no treatment to guarantee fitness for consumption. Such supplies will always be valued, whether abstraction is through a naturally flowing spring, a sunken well or a borehole. In Europe, many of these sources underwent development, not only to provide for local consumption but also to supply bottled waters for distribution further afield.

To guarantee consistency of quality, the emphasis lay not on treatment, but on protection of the original unpolluted state of the water and prevention of pollution, even up to the point of consumption at a place and time far removed from the original source.

In other areas, particularly where the supply is principally from the surface, the wholesomeness of water can only be guaranteed by treatment to modify its chemical and microbiological condition. The extent of such treatment will vary according to the nature of the supply, the technology available and the quality required. Hence, systems have developed to ensure that all waters for public supply, regardless of origin, comply with given standards at the point of consumption.

Although specific standards for different parameters have varied, technological development in the nineteenth and twentieth centuries enabled operators and regulators to compile a comprehensive list of standards (a parametric list) to cover microbiological condition, major, minor and trace elements and indicators of pollution. The content and extent of the list varied in accordance with local requirements and the acquisition of knowledge, while the pertinent regulatory framework also differed markedly. This meant that in some areas, the quality of water was and is heavily controlled and dictated by the regulators and enforcement agencies through national regulations, and in other countries, fewer quality standards have existed. To some extent and particularly in markets that are heavily regulated, this philosophy of control is equally applicable both to water supplied through the tap and to bottled water.

Thus, there have evolved two distinct regimes for ensuring water quality. On the one hand, naturally wholesome water from a protected source is supplied without treatment other than precautionary measures during abstraction and bottling to ensure that it is not polluted chemically or microbiologically. On the other, water from a range of sources and often of dubious quality is taken and treated to comply with a list of chemical and microbiological standards at the point of consumption.

This is illustrated by the publication of two standards by the Codex Alimentarius Commission (see Section 3.4). These standards were written in recognition of the growing significance of bottled water worldwide, both as a commodity and as an alternative (frequently necessary) to tap water. Of these, the second – the *Code of Hygienic Practice for Bottled/Packaged Drinking Waters* (other than Natural Mineral Waters), contains an introduction that explicitly recognises the reasons why such a standard is required, namely the rapid increase in the international trade in bottled water. This has been driven not only by the growing traditional bottled water market but also by the need for reliable supplies of potable water in geographical areas of risk and, with improved transport capacity, the increasing ease with which such supplies can now be made available. Even in those areas where the public supply is normally of good quality, the role played by bottled water has been increasingly significant in times when, due to natural or man-made disaster, public supplies have been disrupted.

In recent years, there has also been continued development in the range of other products, which are somewhat related to the bottled water category, but which are not in most markets regulated as such, since legally, they fall under the heading of beverages. Some of these are simple flavoured waters (natural mineral waters, spring waters or others with added essence) and others, containing artificial sweeteners, acids and preservatives, are effectively soft drinks. Some bottlers are also working hard to develop a market for ‘functional’ beverages, which bring added value to the consumer in the form of vitamins, added minerals and herbal extracts. By using aseptic technology, non-preserved versions (often also non-sweetened or only naturally sweetened with fruit juice) are also being made available. Since this chapter is intended to focus only on the specific

legislative and regulatory requirements for bottled water, these beverages will not be covered here; however, the technology associated with their production is explored in Chapter 14 of this book.

3.2 EUROPE

Although many of the European waters have been exploited since classical times, the present European bottled water market stems from a tradition originating in the late Middle Ages. During this time the great 'spa' towns developed, patronised by visitors from far and wide, who were attracted by the various therapeutic claims made about the different waters.

There is no doubt that one of the key reasons for their popularity was the dubious quality of the surface water supplies available at the time, so that any source of good, clean water would have been particularly valued. In addition, the mineral content of many of the waters was regarded as a positive aid to health. In the absence of modern medicine, different waters became recognised for their own particular health benefits: cures for kidney, urinary and digestive disorders were claimed of highly mineralised waters, while total hydrotherapy treatments, including immersion combined with dosed drinking of the water, were used to alleviate arthritis, rheumatism and respiratory problems.

By the eighteenth and nineteenth centuries, many of the 'spa' towns, including the original Spa in Belgium, Baden-Baden in Germany, Vittel and Vichy in France and Bath, Malvern and Buxton in England, had grown prosperous and fashionable through the influx of wealthy visitors in search of good health. With the development of improved water supplies and with it the advances in modern medicine, many of the great spas declined, most notably in Britain. In other parts of Continental Europe, however, particularly in France, Belgium, Germany and Italy, the custom of drinking waters for their health benefits was so deep-rooted that the practice of bottling water for distribution, both in the country of origin and abroad continued, eventually resulting in a large international bottled water market. It is not surprising, therefore, that the methodology for exploitation and the criteria for 'recognition' of waters should be rooted in the European, and particularly the French, tradition.

In 1856, the French government drew up a law decreeing that a water source could be declared *d'intérêt public*; this was the first procedure by which the health benefits of waters could be officially recognised by the authorities and was equally applicable to the water at source and in the bottle. Many further developments took place, but these original principles played a key part in the evolution of the EEC Directives governing natural mineral water (NMWs) and (subsequently) spring waters (SWs).

The dual evolution outlined in Section 3.1 is well illustrated in Continental Europe, where the two philosophies have developed side by side, undergoing many changes and adaptations, but eventually resulting in the publication of two Directives, both of which have undergone amendment:

- (i) Council Directive of 5 July 1980 relating to the quality of water intended for human consumption (80/778/EEC) (known as the Drinking Water Directive), replaced on 3 November 1998 by an updated Directive (98/83/EC) with the same title.
- (ii) Council Directive of 15 July 1980 relating to the exploitation and marketing of NMWs (80/777/EEC) (known as the Natural Mineral Water Directive). This Directive served the community for many years, but developments in scientific methods, the need to

clarify the criteria for certain treatments and, most importantly, the need to bring into the same legislation a prescription specifically for spring waters, led to the publication in 1996 of an amendment (Directive 96/70/EC). In May 2003, a further Commission Directive (2003/40/EC) was adopted, 'establishing the list, concentration limits and labelling requirements for the constituents of natural mineral waters, and the conditions for using ozone-enriched air for the treatment of natural mineral waters and spring waters'. Finally, in order to consolidate the legislation, Directives 80/777/EEC and 96/70/EC were repealed and recast on 18 June 2009 as Directive 2009/54/EC on the exploitation and marketing of natural mineral waters.

This Directive consists of 18 Articles, covering definitions, conditions for exploitation, permitted treatments, microbiological standards and methods. The text details the requirements for packaging and labelling and explains the process for incorporation of the Directive into national regulations. The Directive also has five annexes, which contain the detailed requirements for recognition, exploitation and marketing. This directive also contains the requirements for exploitation of spring water, although spring waters are additionally required to comply with the provisions of the Drinking Water Directive 98/83/EC.

3.2.1 Natural mineral waters (NMWs)

Annex I, Section I of 2009/54/EC defines NMW as follows:

1. 'Natural mineral water' means microbiologically wholesome water, within the meaning of Article 5 [which deals with microbiological standards], originating in an underground water table or deposit and emerging from a spring tapped at one or more natural or bore exits.

Natural mineral water can be clearly distinguished from ordinary drinking water:

- (a) by its nature, which is characterised by its mineral content, trace elements or other constituents and, where appropriate, by certain effects;
 - (b) by its original state, both characteristics having been preserved intact because of the underground origin of such water, which has been protected from all risk of pollution.
2. These characteristics, which may give natural mineral water properties favourable to health, must have been assessed:
 - (a) from the following points of view:
 1. geological and hydrological,
 2. physical, chemical and physico-chemical,
 3. microbiological,
 4. if necessary, pharmacological, physiological and clinical;
 - (b) according to the criteria listed in Section II; [see below].
 - (c) according to scientific methods approved by the responsible authority.

SECTION II REQUIREMENTS AND CRITERIA FOR APPLYING THE DEFINITION [OF NMWS]

1.1 Requirements for geological and hydrogeological surveys

There must be a requirement to supply the following particulars:

- 1.1.1 the exact site of the catchment with indication of its altitude, on a map with a scale of not more than 1:1000;

- 1.1.2 a detailed geological report on the origin and nature of the terrain;
- 1.1.3 the stratigraphy of the hydrological layer;
- 1.1.4 a description of the catchment operations;
- 1.1.5 the demarcation of the area or details of other measures protecting the spring against pollution.
- 1.2 Requirements for physical, chemical and physico-chemical surveys

These surveys shall establish:

 - 1.2.1 the rate of flow of the spring;
 - 1.2.2 the temperature of the water at the source and the ambient temperature;
 - 1.2.3 the relationship between the nature of the terrain and the nature of the type of minerals in the water;
 - 1.2.4 the dry residues at 180°C and 260°C;
 - 1.2.5 the electrical conductivity or resistivity, with the measurement temperature having to be specified;
 - 1.2.6 the hydrogen ion concentration (pH);
 - 1.2.7 the anions and cations;
 - 1.2.8 the non-ionised elements;
 - 1.2.9 the trace elements;
 - 1.2.10 the radio-actinological properties at source;
 - 1.2.11 where appropriate, the relative isotope levels of the constituent elements of water, oxygen (^{16}O – ^{18}O) and hydrogen (protium, deuterium, tritium);
 - 1.2.12 the toxicity of certain constituent elements of water, taking account of the limits laid down for each of them.
- 1.3 Criteria for microbiological analyses at source

These analyses must include:

 - 1.3.1 demonstration of the absence of parasites and pathogenic micro-organisms;
 - 1.3.2 quantitative determination of the revivable colony count indicative of faecal contamination:
 - (a) absence of *Escherichia coli* and other coliforms in 250 ml at 37°C and 44.5°C;
 - (b) absence of faecal streptococci in 250 ml;
 - (c) absence of sporulated sulphite-reducing anaerobes in 50 ml;
 - (d) absence of *Pseudomonas aeruginosa* in 250 ml.
 - 1.3.3 determination of the revivable total colony count per ml of water:
 - (a) at 20°C to 22°C in 72 hours on agar-agar or on agar-gelatine mixture,
 - (b) at 37°C in 24 hours on agar-agar.
- 1.4 Requirements for clinical and pharmacological analyses
 - 1.4.1 The analyses, which must be carried out in accordance with scientifically recognised methods, should be suited to the particular characteristics of the natural mineral water and its effects on the human organism, such as diuresis, gastric and intestinal functions, compensation for mineral deficiencies.
 - 1.4.2 The establishment of the consistency and concordance of a substantial number of clinical observations may, if appropriate, take the place of the analyses referred to in Section 1.4.1. Clinical analyses may, in appropriate cases, take the place of the analyses referred to in 1.4.1 provided that the consistency and concordance of a substantial number of observations enable the same results to be obtained.

Thus, the fundamental principles are that the water should be taken from a single protected source, be naturally wholesome and of consistent mineral character, and must be bottled in its unaltered state.

3.2.1.1 *Recognition of natural mineral waters*

Source recognition is the responsibility of the member states, and is normally performed by the relevant health or trading standards authorities. To enable this recognition, particulars must be established in the following areas:

- source protection (hydrogeological description/abstraction method);
- physical and chemical characteristics of the water (proof of stability);
- microbiological analyses (to confirm that the water is wholesome in its natural state);
- freedom from pollution (absence of toxic substances);
- limits on certain constituents;
- chemical and pharmacological analyses (where required);
- derecognition of NMWs.

Source protection

It is a requirement of the Directive that the hydrogeology of the source be established and appropriate measures implemented to prevent pollution. As a minimum this means that:

- the catchment area must be identified, the level of risk to the aquifer evaluated, and appropriate controls put in place to eliminate the risk;
- the aquifer and subterranean route for the water must be established;
- the source or point of emergence must be protected against pollution, such as surface water or chemical contaminants.

In practice, different sources require different kinds of management, because conditions such as size and characteristics of catchment, type of aquifer and travel time vary significantly.

Physical and chemical characteristics

The chemistry of the water will depend on several factors, including the types of soil and rock through which it passes, the depth of the aquifer and the travel time. The composition of waters can vary significantly, from the very heavily mineralised ones beloved in Germany, to the lighter ones generally preferred in the UK. Some also contain naturally occurring carbon dioxide, which originates in rocks with relatively recent volcanic activity, or perhaps due to alteration of limestone. Note, however, that (unlike in other markets) there is no 'minimum mineral requirement' for a NMW in Europe; the key requirement here is consistency of composition. Annex I, Section I states:

3. The composition, temperature and other essential characteristics of natural mineral water must remain stable within the limits of natural fluctuation; in particular, they must not be affected by possible variations in the rate of flow.

In most cases, the recognition process for a 'new' NMW requires a minimum of two years' evidence of stability; once established, however, the consistency must be demonstrated on an ongoing basis. As a minimum, this requires a regular (at least annual) analysis against a scheduled list within the Directive. In practice, it is recommended that newly established sources are subject to a much more rigorous regime to ensure that minor seasonal variations are understood, and that more radical changes indicative of major alterations are recognised at the earliest opportunity.

In the case of 'back-up' boreholes sunk in order to increase the yield from a NMW aquifer, the process can be shorter (a matter of months), but contiguity with existing boreholes must be demonstrated. Continuous monitoring at the source of temperature, pH, conductivity, flow rate and water level provides an 'early warning' system of any potential changes in the source. In addition, regular full chemical analyses provide comprehensive evidence of continuing consistency.

Microbiological analyses

Paragraphs 1 and 2 of Article 5 and Section II of Annex I give details of the microbiological requirements for NMW; key to the recognition procedure and also essential during marketing is the need to demonstrate the following:

- 1) The water is free from specified parasites and pathogenic micro-organisms (see 1.3 under Section II above).
- 2) The number of naturally occurring benign bacteria, though present, is at low levels; this is done by determination of the revivable total colony count – often referred to as the total viable colony count (TVC) per millilitre of water after incubation on agar media, thus:

At source, these values should not normally exceed 20 per millilitre at 20–22°C in 72 hours and 5 per millilitre at 37°C in 24 hours respectively, on the understanding that they are to be considered as guide figures and not as maximum permitted concentrations.

It is important to note that the revivable total colony count – often referred to as the total viable colony count (TVC) – will develop and change with time, because sterilisation or disinfection of the water is prohibited. In recognition of this, the Directive specifies limits on counts, but only within 12 hours of bottling, the water being maintained at 3–4°C during this time. Thereafter, according to paragraph 3 of Article 5:

- the revivable total colony count of a natural mineral water may only be that resulting from the normal increase in the bacteria content which it had at source,
- the natural mineral water may not contain any organoleptic defects.

Consequently, counts in still waters, which will be very low at source and at the time of bottling, can rise exponentially throughout the shelf-life of the product to 10^5 and even 10^6 organisms per ml within days of bottling before ultimately declining several months later.

The constituents of the natural flora, sometimes known as autochthonous (indigenous) bacteria, are important, because their presence in the source provides evidence that chemical pollution is *absent*. In addition, it is commonly accepted that the original natural flora stabilises the water microbiologically and renders it less susceptible to the growth of undesirable organisms.

Freedom from pollution

Although it is an inherent requirement that freedom from pollution should be established, the Directive specifies only microbiological standards; no standards for indicators of chemical pollution are included. It has therefore been left to Member States to compile appropriate standards for such substances and to determine whether a water complies. In practice, most states have adopted a list of volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs) and pesticides, to act as indicator parameters. Other states have taken this further; in Italy, for example, it has been proposed to de-recognise any NMW in which

any pollution was detected *at any level*. However, with the continuing development of analytical methods, enabling detection of constituents at lower and lower trace levels, it is difficult to see this as realistic. The Commission has for several years been considering a definition of 'freedom of pollution', perhaps along the lines of the French proposal for a maximum limit of 0.1 microgram/litre for total pesticides in NMW.

Limits on certain constituents

Article 12 of the Directive states that there should be limits on certain naturally occurring constituents, and makes reference to the conditions of use of ozone-enriched air for the removal of unstable substances (iron, manganese, sulphur and arsenic compounds). This is expanded further in Commission Directive 2003/40/EC, Annex I of which specifies maximum limits for the levels of some naturally occurring constituents:

ANNEX I

Constituents naturally present in natural mineral waters and maximum limits, which, if exceeded, may pose a risk to public health.

Constituents	Maximum limits (mg/l)
Antimony	0.005
Arsenic	0.010 (as total)
Barium	1.000
Boron	For the record*
Cadmium	0.003
Chromium	0.050
Copper	1.000
Cyanide	0.070
Fluorides	5.000
Lead	0.010
Manganese	0.500
Mercury	0.001
Nickel	0.020
Nitrates	50.000
Nitrites	0.100
Selenium	0.010

* The maximum limit for boron will be fixed, where necessary, following an opinion of the European Food Safety Authority and on a proposal from the Commission by January 2006.

The deadline for compliance is stated in the Directive as being 1 January 2006 (with the exception of fluoride and nickel, for which the deadline was extended until 1 January 2008). However, in acknowledgement of the fact that many NMWs have naturally occurring fluoride at levels exceeding the limit, the Commission has drafted a Directive and guidelines (still undergoing review) on the conditions for using activated alumina for the removal of fluoride from NMWs and spring waters.

Clinical and pharmacological analyses

According to paragraph 1 of Article 9 of Directive 2009/54/EC:

2. All indications attributing to a natural mineral water properties relating to the prevention, treatment or cure of a human illness shall be prohibited.

However, the indications listed in Annex III [reproduced in Section 3.2.1.3 of this chapter] to this Directive shall be authorised if they meet the relevant criteria laid down in that Annex or, in the absence thereof, criteria laid down in national provisions, and provided that they have been drawn up on the basis of physico-chemical analyses and, where necessary, pharmacological, physiological and clinical examinations carried out according to recognised scientific methods, in accordance with Annex I, Section 1, point 2.

Article 9 also goes on to state:

Member States may authorise the indications ‘stimulates digestion’, ‘may facilitate the hepato-biliary functions’ or similar indications. They may also authorise the inclusion of other indications, provided that the latter do not conflict with the principles provided for in the first paragraph and are compatible with those provided for in the second subparagraph.

Thus, while the Directive rules out claims that may be of a curative or medicinal nature, it does implicitly suggest that characteristics beneficial to health *may* be demonstrated by appropriate scientific methods; the requirements for these analyses are outlined in paragraph 1.4 of Annex I, Section II.

There was considerable debate over this aspect of the Directive, in that some states originally interpreted it as a *requirement* that NMW should have some properties favourable to health. However, few European nations in implementing the Directive have tried to enforce such a requirement; where such physiological and medical studies are performed, the objective has traditionally been to establish by trials the effects of mineral intake on health and the particular benefits to be derived from specific waters. Such trials have been performed since the origin of spa treatments in the eighteenth century and continue, with the aid of modern medical methods. There is good and increasing evidence that waters rich in calcium, magnesium and sulphates can have measurable benefits and in continental Europe, consumers purchase waters with these particular characteristics in mind.

In addition to the requirements for clinical and pharmacological analyses, Section II of Annex I prescribes the requirements for geological, hydrogeological, physical, chemical and physicochemical surveys and the criteria for microbiological analyses at source.

Derecognition of NMWs

If, for some reason, following the recognition process, a NMW is found to have fundamentally changed its character, its status as a NMW may be jeopardised, since stability and safety are prerequisites for recognition. In order to provide guidance on this, Article 11 states:

1. Where a Member State has detailed grounds for considering that a natural mineral water does not comply with the provisions laid down in this Directive, or endangers public health, ... that Member State may temporarily restrict or suspend trade in that product within its territory. It shall immediately inform the Commission and other Member States thereof and give reasons for its decision.

There have been some instances in which waters that had originally been recognised as NMWs were subsequently found to have become polluted following extreme climatic changes or local contamination of the aquifer, and have been forced to cease operations pending remedial work. In more extreme cases, the NMW registration has been removed altogether. In addition, the exploiter of the source has the right voluntarily to request

derecognition of a source; this has been done in several instances by bottlers wishing to exploit a source for multiple purposes, including other non-NMWs.

3.2.1.2 *Exploitation of natural mineral waters*

Having gained recognition for a NMW, it is imperative that it is abstracted and packaged in a way that does not pose a threat to its quality or change its natural characteristics. Maintenance of the absence of pollution can only be assured during exploitation by adherence to several strict principles.

In paragraph 2 of Annex II, the Directive makes a general prescription for the methods of abstraction, suitability of materials used for product contact and the actions to be taken for a NMW source proved to be polluted:

2. Equipment for exploiting the water must be so installed as to avoid any possibility of contamination and to preserve the properties, corresponding to those ascribed to it, which the water possesses at source.

To that end, in particular:

- (a) the spring or outlet must be protected against the risks of pollution;
- (b) the catchment, pipes and reservoirs must be of materials suitable for water and so built as to prevent any chemical, physico-chemical or microbiological alteration of the water;
- (c) the conditions of exploitation, particularly the washing and bottling plant, shall meet hygiene requirements. In particular, the containers must be so treated or manufactured as to avoid adverse effects on the microbiological and chemical characteristics of the natural mineral water;
- (d) the transport of natural mineral water in containers other than those authorised for distribution to the ultimate consumer shall be prohibited.

However, point (d) need not be applied to mineral waters exploited and marketed in the territory of a Member State if, in that Member State on 17 July 1980, transport of the natural mineral water in tanks from the spring to the bottling plant was authorised.

3. Where it is found during exploitation that the natural mineral water is polluted and no longer presents the microbiological characteristics laid down in Article 5, the person exploiting the spring shall forthwith suspend all exploitation, particularly the bottling process, until the cause of pollution is eradicated and the water complies with the provisions of Article 5.
4. The responsible authority in the country of origin shall carry out periodic checks to see whether:
 - (a) the natural mineral water in respect of which exploitation of the spring has been authorised complies with the provisions of Annex I, Section I;
 - (b) the provisions of paragraphs 2 and 3 are being applied by the person exploiting the spring.

Point 2(d) is a specific reference to the tankering of waters for bottling. The final comment on 17 July 1980, that this restriction need not be applied to waters already being tankered, was written to prevent a constraint on trade for those waters; however, it is not applicable to NMW whose exploitation commenced after that date. Hence, in those Member

States where this allowance was incorporated into national regulations, there are still some NMWs that legitimately can be tankered and others that cannot.

The principle behind these general requirements is one of good manufacturing practice, bearing in mind the prohibition on any treatment calculated to improve or alter the quality of the water, as specified in Article 4:

Article 4

1. Natural mineral water, in its state at source, may not be the subject of any treatment other than:
 - (a) the separation of its unstable elements, such as iron and sulphur compounds, by filtration or decanting, possibly preceded by oxygenation, in so far as this treatment does not alter the composition of the water as regards the essential constituents which give it its properties;
 - (b) the separation of iron, manganese and sulphur compounds and arsenic from certain natural mineral waters by treatment with ozone-enriched air in so far as such treatment does not alter the composition of the water as regards the essential constituents which give it its properties, and provided that:
 - the treatment complies with the conditions of use to be laid down in accordance with the procedure laid down in Article 12 and following consultation of the Scientific Committee for Food ... [whose role is to advise on matters likely to have an effect on public health];
 - the treatment is notified to, and specifically controlled by, the competent authorities;
 - (c) the separation of undesirable constituents other than those specified in (a) or (b), in so far as such treatment does not alter the composition of the water as regards the essential constituents which give it its properties, and provided that:
 - the treatment complies with the conditions of use ... [as in (b) above];
 - (d) the total or partial elimination of free carbon dioxide by exclusively physical methods.
2. Natural mineral water, in its state at source, may not be the subject of any addition other than the introduction or the reintroduction of carbon dioxide under the conditions laid down in Annex I, Section III.
3. Any disinfection treatment by whatever means and, subject to paragraph 2, the addition of bacteriostatic elements or any other treatment likely to change the viable colony count of the natural mineral water, shall be prohibited.

Thus, a water can be subject to physical or mechanical filtration to remove 'unstable' elements, such as iron, manganese or sulphur compounds, which might otherwise precipitate in the bottle. The Directive also allows pre-oxygenation and the use of ozone-enriched air to reduce the solubility of such compounds (also including arsenic) to aid removal. The use of ozone-enriched air, though employed in some Member States, has been the cause of much discussion, as ozone is known to have bactericidal properties and hence its use seems to contravene the prohibition of disinfection treatments in paragraph 3 of Article 4. However, ozonation is permitted only if the exploiter can demonstrate the need for it and only when its use is approved by the enforcing authorities. In addition, details of its use must appear on the label (see Section 3.2.1.3).

With regard to the removal of the other undesirable constituents, as specified in 2003/40/EC, any methods other than the use of ozone have not yet been identified except (as stated above) the possible use of activated alumina for removal of fluoride.

3.2.1.3 Labelling of natural mineral waters

There are six key requirements for the labelling:

- 1) The *Commercial Designation* must include the name of the source or the place of exploitation in letters at least one and a half times larger than any other part of the commercial designation.
- 2) The *Description* must be one of 'natural mineral water', or as defined in Annex I, Section III, in the case of *effervescent (carbonated)* natural mineral waters:

SECTION III SUPPLEMENTARY QUALIFICATIONS RELATING TO EFFERVESCENT NATURAL MINERAL WATERS

At source or after bottling, effervescent natural mineral waters give off carbon dioxide spontaneously and in a clearly visible manner under normal conditions of temperature and pressure. They fall into three categories to which the following descriptions respectively shall apply:

- (a) 'naturally carbonated natural mineral water' means water whose content of carbon dioxide from the spring after decanting, if any, and bottling is the same as at source, taking into account where appropriate the reintroduction of a quantity of carbon dioxide from the same water table or deposit equivalent to that released in the course of those operations and subject to the usual technical tolerances;
- (b) 'natural mineral water fortified with gas from the spring' means water whose content of carbon dioxide from the water table or deposit after decanting, if any, and bottling is greater than that established at source;
- (c) 'carbonated natural mineral water' means water to which has been added carbon dioxide of an origin other than the water table or deposit from which the water comes.

Part (a) simply means that the water contains only naturally produced carbon dioxide from the original source and at the original 'natural' concentration. Part (b) means that the carbon dioxide originates at the source, but may have been tapped off and recombined with the water at a higher concentration than that naturally occurring. Part (c) refers to a still water to which artificially manufactured carbon dioxide has been added.

- 1) *Composition* must be indicated by means of a list of the major components in accordance with the officially recognised analysis, expressing their concentration in mg/l. This list will normally include the major anions and cations, together with the 'dry residue' – sometimes also referred to as the total dissolved solids (TDS).
- 2) *Information on any treatments* using ozone-enriched air for removal of iron, manganese, sulphur or arsenic, or any other treatments designed to remove undesirable constituents.
- 3) It is not permitted to sell a NMW which is not marked or labelled in accordance with the regulations. No water other than a NMW can be labelled in such a way as to cause confusion with a NMW.
- 4) No therapeutic claims attributing properties relating to the prevention, treatment or cure of human disease can be made.

However, Annex III does permit the use of 'indications' on the label, provided that they are based on '...physico-chemical analyses and, where necessary, pharmacological, physiological and clinical examinations carried out according to recognised scientific methods' in accordance with Section I, paragraph 2 of Annex I (reproduced in Section 3.2.1 above).

ANNEX III**INDICATIONS AND CRITERIA LAID DOWN IN ARTICLE 9(2)**

Indications	Criteria
Low mineral content	Mineral salt content, calculated as a fixed residue, not greater than 500 mg/l
Very low mineral content	Mineral salt content, calculated as a fixed residue, not greater than 50 mg/l
Rich in mineral salts	Mineral salt content, calculated as a fixed residue, greater than 1500 mg/l
Contains bicarbonate	Bicarbonate content greater than 600 mg/l
Contains sulphate	Sulphate content greater than 200 mg/l
Contains chloride	Chloride content greater than 200 mg/l
Contains calcium	Calcium content greater than 150 mg/l
Contains magnesium	Magnesium content greater than 50 mg/l
Contains fluoride	Fluoride content greater than 1 mg/l
Contains iron	Bivalent iron content greater than 1 mg/l
Acidic	Free carbon dioxide content greater than 250 mg/l
Contains sodium	Sodium content greater than 200 mg/l
Suitable for the preparation of infant food	–
Suitable for a low-sodium diet	Sodium content less than 20 mg/l
May be laxative	–
May be diuretic	–

3.2.2 Spring water (SW)

Spring water, although also covered by Directive 2009/54/EC and Commission Directive 2003/40/EC, is also (unlike NMW) subject to the Drinking Water Directive 98/83/EC. This state of affairs came about because for many years, SWs (and other bottled non-NMWs) were not subject to their own regulation, had no official definition and were thus required simply to meet food safety standards; in practice, this meant that they had only to comply with parametric standards laid down in the Drinking Water Directive, which was written primarily to prescribe the standards for tap waters. When the term ‘spring’ water was for the first time incorporated in the modifying Directive 96/70/EC and ultimately recast in Directive 2009/54/EC, many of the strictures that previously only applied to NMWs were also applied to SWs. However, the expectation that SWs should comply with the parametric standards in the Drinking Water Directive was not revoked.

In summary, the main requirements for SW are:

- (i) a single name for a single source;
- (ii) unlike a NMW, no ‘source recognition’ procedure is required. This is one of the most important differences between NMW and SW;
- (iii) unlike a NMW, SW is not required to have a stable composition;
- (iv) naturally wholesome, no treatments permitted other than those for a NMW. However, according to paragraph 5 of Article 9, in the absence of Community provisions on the treatment of SWs, Member States may maintain national provisions for treatments. In practice, this means that in some countries, other treatments, such as ion exchange for removal of nitrates, are still permitted;

- (v) must meet the conditions of exploitation laid down in paragraphs 2 and 3 of Annex II of the NMW Directive, (see above); in particular, source protection, suitable materials, methods and hygienic practices so as to prevent any alteration of the water;
- (vi) must be bottled at source (although see notes following Table 3.2);
- (vii) SW may not be labelled as having any health benefits;
- (viii) as a minimum, must meet the microbiological standards applicable to NMWs and the chemical standards for drinking waters as specified in the three Annexes to Directive 98/83/EC. Annex I details the parameters to be monitored, divided between (A) microbiological parameters, including those specific to bottled waters; (B) chemical parameters, based on health risks; and (C) indicator parameters, which are not necessarily health-related but give warning of a deteriorating condition. These lists include additional notes explaining the bases for the values and any developments pending. A simplified version of the tables in Directive 98/83/EC is reproduced in Table 3.1. Annexes II and III deal with monitoring and analytical methods, respectively.

3.2.3 Other bottled waters in Europe

For other non-NMWs and non-SWs there is range of different descriptions. For these waters, variously labelled as purified, drinking, table and, in a couple of cases, ‘English Water’ and ‘Pure Irish Water’, there are no requirements for source recognition, but they cannot be labelled in any way that allows confusion with NMWs or SWs. A fixed composition is not mandatory and they can be taken from any source and transported by tanker prior to bottling. Any treatment is permissible that ensures compliance with Directive 98/83/EC on the quality of water intended for human consumption (see Table 3.1). Labelling of such waters is regulated at national level – no harmonisation between Member States currently exists.

3.2.4 Implementation of the Directives in Europe

The previous sections examined the overall European position, with specific reference to the Directives that are binding in principle for all Member States, but which are left to the individual States to implement within their own regulations. Note that a ‘Directive’ is an instruction to Member States to incorporate the agreed legislation into their own national regulations, in order to harmonise legislation within the community. However, there are different types of Directives. Sometimes they just define the goal the Member States have to reach, and Member States remain free to decide how to reach the targets fixed by the EU. In other cases they give very prescriptive instructions and it is virtually impossible for Member States to deviate from the European document. Directive 2009/54/EC belongs to the latter category, meaning that the freedom of Member States is limited and that they are expected to respect the letter and spirit of all articles.

Sometimes, however, Member States do not respect harmonisation directives (and the European Commission is at liberty to launch an infringement procedure against such a country), but such infringements are usually applicable only to those that do not export to other countries. In addition, the translation and interpretation process sometimes leads to minor variation between the different versions, influenced also by historical practice, cultural differences and the state of the market. Table 3.2 summarises the key requirements for NMW, SW and drinking water, and the text that follows highlights some differences in application within Europe.

With regard to implementation in the Member States, Table 3.3 shows examples illustrating some of the remaining differences in interpretation by different members of the European Union.

Table 3.1 Simplified list of parameters from Annex I of Directive 98/83/EC relating to the quality of water intended for human consumption (official Journal No L 330/32).

Part A: Microbiological parameters			
Parameter		Parametric value	
Escherichia coli (E. coli)		0/100 ml	
Enterococci		0/100 ml	
The following applies to water offered for sale in bottles or containers:			
Escherichia coli (E. coli)		0/250 ml	
Enterococci		0/250 ml	
Pseudomonas aeruginosa		0/250 ml	
Colony count 22°C		100/ml	
Colony count 37°C		20/ml	
Part B: Chemical parameters		Part C: Indicator parameters	
Parameter	Parametric value (µg/l)	Parameter	Parametric value
Acrylamide	0.1	Aluminium	200µg/l
Antimony	5	Ammonium	0.5 mg/l
Arsenic	10	Chloride	250 mg/l
Benzene	1	Clostridium perfringens	0/100 ml
Benzo(a)pyrene	0.01	(including spores)	
Boron	1	Colour	Acceptable to consumers and no abnormal change
Bromate	10		
Cadmium	5	Conductivity at 20°C	2500µS cm ⁻¹
Chromium	50	Hydrogen ion concentration	≥ 6.5 and ≤ 9.5 pH units
Copper	2	Iron	200µg/l
Cyanide	50	Manganese	50µg/l
1,2-dichloroethane	3	Odour	Acceptable to consumers and no abnormal change
Epichlorhydrin	0.1		
Fluoride	1.5	Oxidisability	5 mg/IO ₂
Lead	10	Sulphate	250 mg/l
Mercury	1	Taste	Acceptable to consumers and no abnormal change
Nickel	20		
Nitrate	50*	Colony count at 22°C	No abnormal change
Nitrite	0.5*	Coliforms	0/100 ml
Pesticides	0.1	Total organic carbon (TOC)	No abnormal change
Pesticides – total	0.5	Turbidity	Acceptable to consumers and no abnormal change
Polycyclic aromatic hydrocarbons	0.1		
Selenium	10		
Tetrachlorethene and Trichlorethene	10		
Trihalomethanes – total	100		
Vinyl chloride	0.5		
RADIOACTIVITY			
Parameter		Parametric value	
Tritium		100Bq/l	
Total indicative dose		0.10 mSv/year	

* mg/l

Table 3.2 Comparing NMWs, SWs and other drinking waters in the European Union.

	NMWs	SWs	Other drinking waters, including tap water
Must demonstrate source protection	Yes	No	No
Source recognition	Yes	No	No
Must be bottled at source	Yes	Yes ^a	No
Source must be specified on the label	Yes	No	No
One brand-named water comes only from a single source	Yes	Yes	No
Must have a constant composition	Yes	No	No
Must specify mineral content	Yes	No ^b	No
Must be wholesome in its untreated state	Yes	Yes	No
Treatment permitted for removal of unstable constituents	Yes	Yes	Yes
Treatment permitted for removal of undesirable substances	Yes	Yes	Yes
Treatment permitted for removal of pathogenic micro-organisms	No	No	Yes
Safe to drink	Yes	Yes	Yes

^a Does not apply to spring waters authorised to be tankered from the spring to the bottling plant on or before 13 December 1996.

^b Although, as there is no prohibition for SWs, a 'typical' composition is sometimes included.

Source: Based on a table supplied by British Bottled Water Producers Ltd.

Table 3.3 Showing the interpretation of Directive 2009/54/EC in European member states.

Austria

- (1) *NMW*: Regulated according to the *NMW Directives*. No tankering allowed. Non-effervescent waters meeting some additional criteria may also use the words 'Suitable for the preparation of infant food'. Maximum values specified as follows:
Sodium 20 mg/l, Potassium 10 mg/l, Calcium 175 mg/l, Magnesium 50 mg/l, (1*) Fluoride 1.5 mg/l, Chloride 50 mg/l, Iodide 0.1 mg/l, Nitrate 10 mg/l, Nitrite 0.02 mg/l, Sulphate 240 mg/l (2*) Bicarbonate 550 mg/l:
1*) 50–70 mg/l allowed, if the ionic equivalent of Ca is at least 20% higher than that for Mg;
2*) 240–300 mg/l allowed, if there are at least as many sulphate ions as Ca ions (in ionic equivalents)
If the water contains more than 1.5 mg/l of Fluoride the following must appear on the label; 'contains more than 1.5 mg Fluoride/l. Not suitable for regular consumption for infants and children below 7 years'. The Fluoride content must also be stated on the label.
- (2) *Quellwasser* (SW): This is naturally wholesome without treatment other than those permitted for *NMW*. Its composition may vary. Limits for substances are based upon Directive 98/83/EC. No tankering allowed. Use of ozone must be reported to the health ministry.
- (3) *Trinkwasser* (drinking water): This may be treated and must meet the quality requirements in Directive 98/83/EC. No tankering allowed.

France

- (1) *Eaux Minérales Naturelles* (NMW): Arrêté du 14 mars 2007 relatif aux critères de qualité des eaux conditionnées, aux traitements et mentions d'étiquetage particuliers des eaux minérales naturelles et de source conditionnées ainsi que de l'eau minérale naturelle distribuée en buvette publique.

In addition to general compliance with the Directives, it is also required that the compatibility of the container material with the water is confirmed by the Ministry of Health. A draft proposal is under review to establish a limit for pesticides of 0.1 micrograms /litre. The indications 'stimulates digestion', 'may be diuretic', 'may facilitate the hepato-biliary functions' may be permitted, on authorisation from the relevant local Prefecture. No treatment permitted. Non-effervescent waters meeting some additional criteria may also use the words 'Suitable for the preparation of infant food'.

- (2) *Eaux de Source* (SW or source waters): CIRCULAIRE DU 7 MAI 1990 relative aux produits et procédés de traitement des eaux destinées à la consommation humaine. Arrêté du 11 janvier 2007 relatif aux limites et références de qualité des eaux brutes et des eaux destinées à la consommation humaine mentionnées aux articles R. 1321-2, R. 1321-3, R. 1321-7 et R. 1321-38 du code de la santé publique. These must comply with the same basic requirements (naturally wholesome, bottled at source, etc.). Treatment with ozone-enriched air for the removal of undesirable compounds may be permitted.
- (3) *Eaux rendues potable par traitement* (waters made potable by treatment): CIRCULAIRE DU 7 MAI 1990 relative aux produits et procédés de traitement des eaux destinées à la consommation humaine. Arrêté du 11 janvier 2007 relatif aux limites et références de qualité des eaux brutes et des eaux destinées à la consommation humaine mentionnées aux articles R. 1321-2, R. 1321-3, R. 1321-7 et R. 1321-38 du code de la santé publique. Here, any treatment is permitted, provided that the final product complies with 98/83/EC. The treatment received must be indicated on the label. Tankering is permitted.

Germany

- (1) *NMW*: Regulated according to the NMW Directives. Mineral- und Tafelwasser-Verordnung vom 01 August 1984 (BGBl. I, S.1036), i.d.F. v. 01. Dezember 2006.
Non-effervescent waters meeting some additional criteria may also use the words 'Suitable for the preparation of infant food'.
- (2) *Quellwasser* (SW). This is naturally wholesome without treatment other than those permitted for NMW. Its composition may vary. Limits for substances are based upon Directive 98/83/EC.
- (3) *Tafelwasser* (table water). This is a manufactured water, made with NMW or drinking water and authorised added minerals. Tankering is permitted
- (4) *Trinkwasser* (drinking water). This may be treated and must meet the quality requirements in Directive 98/83/EC.

Italy

- (1) *NMW*: Decreto Legislativo 25.1.92 n. 105 Attuazione della Dir. 80/777/CEE relativa alla utilizzazione e alla commercializzazione delle acque naturali Così modificato da avviso di rettifica in G.U. 51, 2.3.92, da D. L.vo 4.8.99 n. 339 e da L. 1.3.02, n. 39.

Decreto 29 dicembre 2003

Ministero della Salute - Attuazione della direttiva n. 2003/40/CE della Commissione nella parte relativa ai criteri di valutazione delle caratteristiche delle acque minerali naturali di cui al decreto ministeriale 12 novembre 1992, n. 542, e successive modificazioni, nonché alle condizioni di utilizzazione dei trattamenti delle acque minerali naturali e delle acque di sorgente.

The indications 'stimulates digestion', 'may be diuretic', 'may facilitate the hepato-biliary functions', 'suitable for the preparation of infant food' may be permitted, on the basis of clinical studies. Tankering is not permitted for any bottled water category.

Poland

- (1) *NMW and Spring waters*: Regulated according to the DECREE OF THE MINISTER OF HEALTH on April 29th 2004 - natural mineral waters, natural spring waters and table waters + Law about food safety (25 August 2006).
- (2) *Drinking water*: Regulated according to the DECREE OF THE MINISTER OF HEALTH on 29 March 2007.

Portugal

NMW and SW covered by Decreto Lei 156/98. Drinking water covered by Decreto Lei 306/2007

- (2) NMW: must be labelled with the following indications where relevant; 'Low mineral content' (minerals not greater than 500 mg/l), 'Very low mineral content' (minerals not greater than 50 mg/l), 'Rich in mineral salts' (minerals higher than 500 mg/l), 'Contains bicarbonate' (Bicarbonate content higher than 600 mg/l), 'Contains sulphate' (Sulphates higher than 200 mg/l), 'Contains chloride' (Chloride content higher than 200 mg/l), 'Contains calcium' (calcium content higher than 150 mg/l), 'Contains magnesium' (magnesium content higher than 50 mg/l), 'Fluoridated or Contains fluoride' (Fluoride content higher than 1 mg/l), 'Contains iron' (iron content greater than 1 mg/l), 'Contain carbonic gas' (free carbonic gas content greater than 250 mg/l), 'Contains sodium' (sodium content greater than 200 mg/l), 'Suitable for a low-sodium diet' (sodium content less than 20 mg/l)

Spain

All bottled waters covered by Real Decreto 1074/2002, de 18 de octubre, por el que se regula el proceso de elaboración, circulación y comercio de aguas de bebida envasadas.

Use of ozonation must appear on the label for NMW and SW. Not required for Drinking water. Maximum limits specified for pesticides, VOCs, trihalomethanes, Epiclorhydrine, Acrylamide, polycyclic aromatic hydrocarbons (PAHs), vinyl chloride. No claims permitted on labels.

The United Kingdom

All bottled waters covered by Statutory Instruments; The Natural Mineral Water, Spring Water and Bottled Drinking Water (England), Regulations No. 2785 (2007) and the Natural Mineral Water, Spring Water and Bottled Drinking Water (England), (Amendment) Regulations No. 1598 (2009).

- (1) NMW.

There is at present no formal mechanism for establishing or recognising pharmacological benefits.

The UK has adopted the derogation permitting the tankering of NMWs that were being tankered for bottling prior to the date of the publication of the NMW 1985 regulations. It is not permitted to use the claim 'suitable for the reconstitution of infant preparation'.

- (2) SWs.

Certain disinfection treatments – UV or microfiltration are permitted, provided that no residues remain which may render the water unfit for human consumption. The derogation applicable to NMWs tankered prior to the publication of the 1985 regulations has also been applied to SWs tankered before the publication of 96/70/EC.

- (3) Other bottled drinking waters

Any treatment is permitted; tankering is also permitted. May not be labelled in such a way as to be confused with NMW or SW.

3.3 NORTH AMERICA

3.3.1 United States

From the middle of the nineteenth century, spas developed in many areas of the USA, where good supplies of wholesome groundwater (often in the form of spectacular hot springs) were available. Unlike in mainland Europe, however, the spas declined during the first half of the twentieth century and, though some of the more famous brands continued to be bottled, the market became polarised between the rare exotic imported waters from

Europe and the ubiquitous larger glass (later polycarbonate) bottles used to supply water-coolers for domestic and business premises – the so-called ‘home and office’ market.

In the last quarter of the twentieth century, a move to a healthier life-style made bottled waters more popular, and the market, prompted by the success of imported waters, grew steadily, encouraging the exploitation of the many local or regional springs that dominate the market today. In parallel with the ongoing growth of Spring Water, other bottled waters have also found a market. In the latter case, emphasis has generally been on the compliance of the water to parametric standards, rather than on the traditional European ‘non-treated’ approach. Consequently, a wide variety of different bottled water types developed, with different methods and levels of treatment and to some extent different nomenclature.

The regulation of water for human consumption in the USA falls under the jurisdiction of two agencies:

- (i) Water supplied through private and public treatment and distribution systems (tap water) is regulated by the Environmental Protection Agency (EPA), which is also responsible for establishing minimum standards of quality.
- (ii) Bottled water is regulated at the Federal level, but the individual states and the industry itself also have a role to play.

3.3.1.1 *Federal regulation*

The US Food and Drug Administration (FDA), through the Federal Food, Drug and Cosmetic Act, has overall responsibility for setting quality criteria, establishing labelling standards (‘standards of identity’) and specifying good manufacturing practices (GMPs) for all bottled waters (which are legally considered a food). Since the early 1970s, the FDA, in cooperation with the American Bottled Water Association (later to become the International Bottled Water Association, IBWA), has promulgated operating codes and quality standards for bottled waters. This culminated in a ‘Final Rule on a Standard of Identity for Bottled Waters’, published in the Federal Register, Vol. 60, No. 218 on 13 November 1995, which not only provided definitions for many different types of bottled waters, but also finalised standards of quality. The FDA’s standards of identity are contained in Part 165.110(B) of Title 21 Code of Federal Regulations 2002 (CFR 21) and the requirements for processing and bottling are specified in Part 129. The FDA Final Rule also confirms the principle of pre-emption. This ensures that the FDA’s rules take precedence in the case of interstate trade, in that any bottled water crossing state boundaries for sale must comply with Federal requirements as a minimum. On the other hand, in states where the standards of quality are higher than the Federal regulation, the state requirements also apply to imported waters.

3.3.1.2 *State regulation*

The individual states have responsibility for sampling, analysis, source permitting and (where appropriate) certification of factory laboratories. They are also responsible for inspecting sources and bottling premises to monitor compliance. In addition, anyone wishing to import bottled water from another state must obtain a permit to do so, based on analyses for compliance. States can also write regulations that are more rigorous than those of the FDA, and these in effect become applicable to any bottled water sold within that state. States are also at liberty to impose additional requirements on those wishing to bottle water within the state; for example, in Texas, it is a requirement that all water transported for

bottling (whether by tanker or even through a pipeline directly to the bottling plant) must be chlorinated during distribution, and the chlorine removed prior to bottling.

3.3.1.3 Industry regulation

At the Industry level, the IBWA has worked with the FDA in developing a Model Bottled Water Regulation (also known as the Model Code). This provides specific guidance to bottlers on legal requirements, GMPs, quality standards, monitoring procedures and labelling requirements. All members of the IBWA are expected to abide by the Code, and membership is contingent upon bottlers submitting to unannounced third-party auditing of sources and bottling premises, for which a passing score must be achieved.

The definitions that appear in CFR Part 165.110 (B) are summarised below:

Natural spring water

- water derived from an underground formation from which water flows naturally to the surface of the earth;
- ... collected only at the spring or through a borehole tapping the underground formation feeding the spring;
- spring must naturally flow to the surface (even if tapped via a borehole);
- there must be a measurable hydraulic connection between any borehole and the natural outlet or spring, and the quality and composition of the water from the borehole must be the same as that from the spring;
- water must continue to flow at the spring during exploitation;
- location of the spring must be identified (though not necessarily on the label);
- water must be naturally wholesome; at source and after bottling it must meet the compositional and quality standards laid down in CFR 21 (see below). Treatments are limited to those that control the hygienic condition of the water during distribution and packaging. Thus, microfiltration, UV treatment and ozonation are permitted, but other treatments that may alter the mineral composition are not;
- sources (springs, and if used, boreholes) must be approved and licensed by State.

Natural spring water has long been the major category of bottled water in the USA. For many years, uncertainty about the quality of public water supplies and a rigorous control of the integrity of sources used for SW has ensured a high level of consumer loyalty, even in the face of competition from processed waters from other sources.

Artesian water

- water from a well, tapping a confined aquifer in which the water level stands at some height above the top of the aquifer;
- ... may be collected with the assistance of external force to enhance the natural underground pressure. [The external force may not draw the level down below the level of the top of the aquifer, or change its natural state.]

Mineral water

- water containing not less than 250 mg/litre total dissolved solids; [Consumer expectation is that minerals will be present.]

- ... from one or more boreholes or springs originating from a geologically and physically protected underground water source;
- constant level and relative proportions of minerals and trace elements at the point of emergence, within natural fluctuations.
- Labelling must include the following: in the case of a water with a TDS of <500 mg/litre – ‘low mineral content’; in the case of a water with a TDS of >1500 mg/litre – ‘high mineral content’. No minerals may be added to this water.

Mineral waters are also exempt from the allowable levels for colour, odour, TDS, chlorine, iron, manganese, sulphate and zinc.

Sparkling bottled water

- ... water that, after treatment and possible replacement with carbon dioxide, contains the same amount of carbon dioxide that it had at emergence from source. [This definition is equivalent to that for a naturally carbonated NMW; however, waters containing artificial carbon dioxide, which were described previously as ‘sparkling’, can continue to be so described.]

Purified water

- Water that has been produced by distillation, de-ionisation, reverse osmosis, or other suitable processes. [This meets the definition of the term ‘purified water’ in the most recent edition of the United States Pharmacopoeia, 23rd revision, 1 January, 1995. The terms ‘demineralised’, ‘distilled’ and ‘reverse osmosis water’ may also be used.]

This category of bottled water has grown significantly in recent years, resulting from the relative ease with which municipal waters can be taken and treated in any number of ways to achieve a consistent finished product. In addition to those above, microfiltration, UV treatment and ozonation are also used. Unlike the case of Spring Water, the only criterion is that the water must be wholesome at the point of consumption; no ‘source identity’ (as in the case of spring water) is required. However, the treatment methods may also be detailed on the label, so the descriptions, ‘purified drinking water’ (often with added minerals), ‘reverse osmosis drinking water’, etc. may be used.

Water for infant use

- Some waters, even ones not guaranteed to be sterile, are supplied for infant use. In this case, the label should read ‘Not sterile. Use as directed by physician or by labelling directions for use of infant formula’.

3.3.1.4 *Quality standards*

With the exception of the particular requirements for mineral water, compositional and quality standards for bottled water in the USA are also unified through CFR 21 (which was amended on 1 December 2009 to include a prohibition on the use of a (non-public water supply) source demonstrated to contain *E. coli* bacteria). In all cases, the parameters in question are to be analysed using the methods described in the most recent edition of the

Standard Methods for the Examination of Water and Wastewater (published jointly by the American Public Health Association, the American Water Works Association and the Water Environment Federation), as follows:

Microbiological quality of the source; according to Part 129.35 (a) (3):

- (i) ...source water obtained from other than a public water system is to be sampled and analysed for total coliform at least once each week. If any coliform organisms are detected, follow up testing must be conducted to determine whether any of the coliform organisms are *Escherichia coli*. Source water found to contain *E. coli* is not considered water of a safe, sanitary quality as required by...this section.

This regulation goes on to say that once a source has tested positive for *E. coli*, it cannot be used for the production of bottled water – regardless of any further treatments to which it may be subjected. Only once effective remedial steps are taken to eliminate the cause of the contamination (as demonstrated by negative *E. coli* results on 5 samples taken from the source during a 24-hour period) may the source again be used for the production of bottled water:

Microbiological quality of the finished product; according to Part 165.110 (b) (2):

- (i) Bottled water shall...meet the following standards of microbiological quality:
 - (A) *Total coliform*
 - (1) *Multiple-tube fermentation (MTF) method*: Not more than one of the analytical units in the sample shall have a most probable number (MPN) of 2.2 or more coliform organisms per 100 ml and no analytical unit shall have an MPN of 9.2 or more coliform organisms per 100 ml; or
 - (2) *Membrane filter (MF) method*: Not more than one of the analytical units in the sample shall have 4.0 or more coliform organisms per 100 ml and the arithmetic mean of the coliform density of the sample shall not exceed one coliform per 100 ml.
 - (B) *E. coli*: No *E. coli* shall be detected. If *E. coli* is present, then the bottled water will be deemed adulterated

Physical quality; Part 165.110 (b) (3):

- (i) The turbidity shall not exceed 5 units.
- (ii) The color shall not exceed 15 units.
- (iii) The odor shall not exceed threshold odor No .3.

Chemical quality; Part 165.110 (b) (4) (reproduced in simplified form in Table 3.4) provides allowable levels for (A) inorganic substances, (B) volatile organic compounds (VOCs), (C) pesticides and other synthetic organic chemicals (SOCs), and (D) certain chemicals for which EPA has established secondary maximum contaminant levels in its drinking water regulations.

There are also maximum levels at which fluoride can be added to bottled water, and an additional table specifies the allowable levels for residual disinfectants and disinfection by-products. In particular, the latter refers to those substances (organochlorines and related substances) potentially resulting from chlorination, and those formed as a consequence of ozonation which, if not properly controlled, oxidises naturally occurring bromide to bromate in some types of water.

Table 3.4 Code of Federal Regulations, Title 21 – Standard of Identity for Bottled Waters – simplified list of maximum allowable levels. 'Bottled water shall...meet standards of chemical quality and shall not contain chemical substances in excess of the following concentrations.'

Substance	Concentration (mg/l)
Arsenic	0.05
Chloride ¹	250.0
Iron ¹	0.3
Manganese ¹	0.05
Phenols	0.001
Total dissolved solids ¹	500.0
Zinc ¹	5.0

¹ Mineral water is exempt from allowable level. The exemptions are aesthetically based allowable levels and do not relate to a health concern.

Source: From the Code of Federal Regulations, Title 21; US Government Printing Office: Washington, DC, 2002.

(ii) (A) Bottled water packaged in the USA to which no fluoride is added shall not contain fluoride in excess of the levels in Table 1 and these levels shall be based on the annual average of maximum daily air temperatures at the location where the bottled water is sold at retail.

Table 1

Annual average of maximum daily air temperatures (°F)	Fluoride concentration (mg/l)
53.7 and below	2.4
53.8–58.3	2.2
58.4–63.8	2.0
63.9–70.6	1.8
70.7–79.2	1.6
79.3–90.5	1.4

(B) Imported bottled water to which no fluoride is added shall not contain fluoride in excess of 1.4 mg/l.

Source: From the Code of Federal Regulations, Title 21; US Government Printing Office: Washington DC, 2002.

(C) Bottled water packaged in the USA to which fluoride is added shall not contain fluoride in excess of levels in Table 2.

Table 2

Annual average of maximum daily air temperatures (°F)	Fluoride concentration (mg/l)
53.7 and below	1.7
53.8–58.3	1.5
58.4–63.8	1.3
63.9–70.6	1.2
70.7–79.2	1.0
79.3–90.5	0.8

(D) Imported bottled water to which fluoride is added shall not contain fluoride in excess of 0.8 mg/l.

Source: From the Code of Federal Regulations, Title 21; US Government Printing Office: Washington DC, 2002.

(A) The allowable levels for inorganic substances are as follows:

Contaminant	Concentration (mg/l or as specified)
Antimony	0.006
Barium	2.0
Beryllium	0.004
Cadmium	0.005
Chromium	0.1
Copper	1.0
Cyanide	0.2
Lead	0.005
Mercury	0.002
Nickel	0.1
Nitrate	10 (as nitrogen)
Nitrite	1 (as nitrogen)
Total nitrate and nitrite	10 (as nitrogen)
Selenium	0.05
Thallium	0.002

Source: From the Code of Federal Regulations, Title 21; US Government Printing Office: Washington DC, 2002.

(B) The allowable levels for volatile organic chemicals (VOCs) are as follows:

Contaminant	Concentration (mg/l)
Benzene	0.005
Carbon tetrachloride	0.005
<i>o</i> -Dichlorobenzene	0.6
<i>p</i> -Dichlorobenzene	0.075
1,2-Dichloroethane	0.005
1,1-Dichloroethylene	0.007
<i>cis</i> -1,2-Dichloroethylene	0.07
<i>trans</i> -1,2-Dichloroethylene	0.1
Dichloromethane	0.005
1,2-Dichloropropane	0.005
Ethylbenzene	0.7
Monochlorobenzene	0.1
Styrene	0.1
Tetrachloroethylene	0.005
Toluene	1.0
1,2,4-Trichlorobenzene	0.07
1,1,1-Trichloroethane	0.2
1,1,2-Trichloroethane	0.005
Trichloroethylene	0.005
Vinyl chloride	0.002
Xylenes	10

Source: From the Code of Federal Regulations, Title 21; US Government Printing Office: Washington DC, 2002.

(C) The allowable levels for pesticides and other synthetic organic chemicals (SOCs) are as follows:

Contaminant	Concentration (mg/l)
Alachlor	0.002
Atrazine	0.003
Benzo(a)pyrene	0.0002
Carbofuran	0.04
Chlordane	0.002
Dalapon	0.2
1,2-Dibromo-3-chloropropane	0.0002
2,4-D	0.07
Di-(2-ethylhexyl)adipate	0.4
Dinoseb	0.007
Diquat	0.02
Endothall	0.1
Endrin	0.002
Ethylene dibromide	0.00005
Glyphosate	0.7
Heptachlor	0.0004
Heptachlor epoxide	0.0002
Hexachlorobenzene	0.001
Hexachlorocyclopentadiene	0.05
Lindane	0.0002
Methoxychlor	0.04
Oxamyl	0.2
Pentachlorophenol	0.001
PCBs (as decachlorobiphenyl)	0.0005
Picloram	0.5
Simazine	0.004
2,3,7,8-TCDD (Dioxin)	3×10^{-8}
Toxaphene	0.003
2,4,5-TP (Silvex)	0.05

Source: From the Code of Federal Regulations, Title 21; US Government Printing Office: Washington, DC, 2002.

(D) The allowable levels for certain chemicals for which EPA has established secondary maximum contaminant levels in its drinking water regulations: (40CFR part 143) are as follows:

Contaminant	Concentration (mg/l)
Aluminum	0.2
Silver	0.1
Sulfate ¹	250

¹Mineral water is exempt from allowable level. The exemptions are aesthetically based allowable levels and do not relate to a health concern.

Source: From the Code of Federal Regulations, Title 21; US Government Printing Office: Washington DC, 2002.

(H) The allowable levels for residual disinfectants and disinfection byproducts are as follows:

Substance	Concentration (mg/l)
Disinfection byproducts:	
Bromate	0.010
Chlorite	1.0
Haloaceticacids (five) (HAA5)	0.060
Total trihalomethanes (TTHM)	0.080
Residual disinfectants:	
Chloramine	4.0 (as Cl ₂)
Chlorine	4.0 (as Cl ₂)
Chlorine dioxide	0.8 (as ClO ₂)

Source: From the Code of Federal Regulations, Title 21; U.S. Government Printing Office: Washington DC, 2002.

Mineralisation, though not regulated (with the exception of mineral waters), is often given consideration by the consumer when choosing which waters to buy. In general, the market preference in the USA is for relatively low mineralisation, unlike in Europe, where typical mineral levels range from 250–1500 mg/l (see Chapter 2). The more favoured brands in the USA are those in the range of 75–250 mg/l.

3.3.2 Canada

In Canada, the responsibility for the regulation of bottled water is shared between two bodies: Health Canada (responsible for establishing health and safety standards and policies related to health and nutrition) and the Canadian Food Inspection Agency (CFIA), which is charged with inspection and monitoring of products and premises and enforcement of standards. In addition, the Canadian Bottled Waters Association (CBWA) has drafted a Model Bottled Water Code somewhat similar in structure and content to that used by its sister organisation in the USA.

Bottled water is regulated under the Food and Drugs Act and the Food and Drug Regulations Part B, Division 12, governing 'Prepackaged Water and Ice', according to which bottled water is in one of two main categories:

- (i) mineral water and spring water;
- (ii) bottled waters, not represented as mineral water or spring water (other waters).

These two categories fall into the broad definitions established by Codex Alimentarius (see Section 3.4) in which a distinction is drawn between 'Waters Defined by Origin' (whether from an underground source or from the surface) and 'Prepared Waters', which may come from any water supply. Indeed, Health Canada is presently proposing that these designations are adopted.

3.3.2.1 Mineral water and spring water

Under the current regulations, there is no difference in the definition between mineral water and spring water, and therefore the terms may be used interchangeably. Both must comply with the guidelines for chemical and physical parameters in the Guidelines for Canadian Drinking Water Quality.

According to the Food and Drug Regulations Part B, Division 12, mineral water and spring water:

- (i) shall be potable water obtained from an underground source but not obtained from a public community water supply;
- (ii) shall not contain any coliform, as determined by official method MFO-9, Microbiological Examination of Mineral Water, Nov 30, 1981.

The microbiological requirements for Canadian bottled water specify absence of *E. coli* and coliform organisms. Absence of *Pseudomonas aeruginosa*, though not explicitly required in the regulations, is stated as a Health Canada guideline:

- (iii) shall not have its composition modified through the use of any chemicals; and
- (iv) notwithstanding paragraph (c), may contain:
 1. added carbon dioxide;
 2. added fluoride, if the total fluoride content thereof does not exceed one part per million;
 3. added ozone.

Labelling

The following information must appear on the label:

- a statement of the geographical location of the underground source;
- the total dissolved mineral salt content expressed in parts per million;
- the total fluoride content expressed in parts per million;
- a statement concerning any addition of fluoride or ozone.

In addition, if its composition has not been modified through the use of chemicals, it may be labelled 'natural mineral water' or 'natural spring water'. It may also be labelled 'naturally carbonated', provided that the added carbon dioxide originated from the decarbonation of the water upon its emergence from the source, and the carbon dioxide is not added at a level greater than the naturally occurring level in the source.

If the carbon dioxide comes from a different origin, or is present at a greater level than naturally found at the point of emergence, it must be labelled 'carbonated'.

3.3.2.2 *Bottled waters, not represented as mineral water or spring water (other waters)*

In this case, according to the Food and Drug Regulations Part B, Division 12, there are no specific requirements for the quality of the water at source, and any treatments are permitted. For the finished product, however, the following standards are specified:

- absence of coliform bacteria, as determined by official method MFO-15, Microbiological Examination of Water in Sealed Containers (Excluding Mineral and Spring Water) and of Prepackaged Ice, Nov 30, 1981;
- no more than 100 total aerobic bacteria per millimeter, as determined by official method MFO-15;
- naturally occurring fluoride may not exceed its naturally occurring amount;
- total of naturally occurring and added fluoride may not exceed 1 part per million.

Labelling

In addition to the common designation 'water', the product may be labelled 'distilled', 'demineralised' (if the mineral content is reduced, by means other than distillation) or 'carbonated' when carbon dioxide is added.

If fluoride is added, the fluoride must be stated in parts per million on the principal display panel.

Any treatment must also be declared, with the exception of the addition of an ingredient declared on the label, chlorination and subsequent de-chlorination, decantation or filtration. Guidelines for chemical and physical parameters are given in Table 3.5.

3.3.2.3 *Canadian Bottled Waters Association*

The CBWA has also drafted a Model Bottled Water Code, with the following additional voluntary requirements:

Glacial or Glacier water:

- shall be water collected from glacial melt water, and shall maintain the same consistent composition of the major minerals and characteristics as that of the proglacial stream at the point of emergence.

Spring water:

- The TDS content may not exceed $500 \text{ mg/l} \pm 10\%$.

Mineral water:

- shall have a TDS content above $500 \text{ mg/l} \pm 10\%$.

(Note that the TDS requirements for Spring and Mineral water were introduced by the CBWA, and have not yet been adopted by Health Canada. Also note also that the TDS value of 500 mg/l is twice that for a mineral water in the United States.)

Both of the above may also be labelled 'natural', provided that they are obtained from an underground or approved natural source or sources; they may also be subject to treatments as follows:

- use of ozone or other 'acceptable and suitable' disinfection processes (provided that this does not result in a change in its general composition and characteristics);
- treatment to remove or reduce the concentration of dissolved gases or undissolved solids;
- treatment to remove or reduce the concentration of unstable and undesirable substances.
- The model code also requires that the water should have a stable composition at the point of emergence.

According to the model code, bottled waters other than mineral waters or SWs may come from any approved source, including a municipal supply. They can be treated to make them fit for consumption (must also in their packaged state comply with the *Guidelines for Canadian Drinking Water Quality*), but any significant modifying treatments must be detailed on the label.

In addition to the requirements for source water and finished product monitoring, the Model Code also provides guidance on the management, cleaning and monitoring of bulk water tankers (tankering is permitted for all categories) and lays down requirements for cleaning and disinfection of water processing and filling equipment.

Table 3.5 Guidelines for chemical and physical parameters, extracted from the Guidelines for Canadian Drinking Water Quality.

Guidelines for health-based standards are given as maximum acceptable concentrations (MAC); those based on aesthetic considerations are aesthetic objectives (AO), and those based on operational considerations are operational guidance values (OG).

Parameter	MAC (unless stated otherwise) All values in mg/l	Parameter	MAC (unless stated otherwise) All values in mg/l
Aldicarb	0.009	Fluoride	1.5
Aldrin and dieldrin	0.0007	Glyphosate	0.28
Aluminum	0./0.2 (OG)	Iron	≤0.3
Antimony	0.006	Lead	0.01
Arsenic	0.010	Malathion	0.19
Atrazine & metabolites	0.005	Manganese	≤0.05
Azinphos-methyl	0.02	Mercury	0.001
Barium	1	Methoxychlor	0.9
Bendiocarb	0.04	Methyl tertiary-butyl ether (MTBE)	0.015 (OG)
Benzene	0.005	Metolachlor	0.05
Benzo[a]pyrene	0.00001	Metribuzin	0.08
Boron	5	Monochlorobenzene	0.08
Bromate	0.01	Nitrate	45
Bromodichloromethane	0.016	Nitritotriacetic acid	0.4
Bromoxynil	0.005	Odour	Inoffensive
Cadmium	0.005	Paraquat (as dichloride)	0.01
Carbaryl	0.09	Parathion	0.05
Carbofuran	0.09	Pentachlorophenol	0.06 ≤0.030 (OG)
Carbon tetrachloride	0.005	pH	6.5 – 8.5 (AO)
Chloramines – total	3	Phorate	0.002
Chloride	≤250 (AO)	Picloram	0.19
Chlorpyrifos	0.09	Selenium	0.01
Chromium	0.05	Simazine	0.01
Colour	≤15 TCU	Sodium	≤200
Copper	≤1.0	Sulphate	≤500
Cyanazine	0.01	Sulphide (as H ₂ S)	≤0.05
Cyanide	0.2	Taste	Inoffensive
Cyanobacterial toxins	0.0015	Temperature	≤15°C
Diazinon	0.02	Terbufos	0.001
Dicamba	0.12	Tetrachloroethylene	0.03
1,2-Dichlorobenzene	0.2	2,3,4,6-Tetrachlorophenol	0.01
1,4-Dichlorobenzene	0.005	Toluene	≤0.024
1,2-Dichloroethane	0.005	Total dissolved solids	≤500
1,1-Dichloroethylene	0.014	Trichloroethylene	0.005
Dichloromethane	0.05	2,4,6-Trichlorophenol	0.005
2,4-Dichlorophenol	0.9	Trifluralin	0.045
2,4-Dichlorophenoxy acetic acid (2,4-D)	0.1	Trihalomethanes – total THMs)	0.100
Diclofop-methyl	0.009	Turbidity	
Dimethoate	0.02	Uranium	0.02
Dinoseb	0.01	Vinyl chloride	0.002
Diquat	0.07	Xylenes – total	≤0.3 (AO)
Diuron	0.15	Zinc	≤5.0 (AO)
Ethylbenzene	≤0.0024 (AO)		

Source: Guidelines for Canadian Drinking Water Quality summary table – March 2007.

3.4 CODEX ALIMENTARIUS

There is as yet no universal standard for any category of bottled waters, and even the meaning of some of the words used to describe different waters can differ from country to country. For example, in Europe, a Natural Mineral Water is not expected to contain any particular level of minerals, whereas in other parts of the world, a specific minimum level of minerals is a prerequisite.

However, during the 1980s and 1990s, significant work was done to establish some universal standards, the most significant of which was through the Codex Alimentarius Commission. Codex Alimentarius, in Latin, means ‘food code’ and the Codex Alimentarius Commission, which was set up in 1962 through collaboration between the Food and Agriculture Organization (FAO) of the United Nations and the World Health Organization (WHO), has as its aim ‘to guide and promote the elaboration and establishment of definitions and requirements for food, to assist in their harmonisation and, in doing so, to facilitate international trade’.

Codex has a membership exceeding 150 countries and has produced numerous sets of standards and guidelines aimed at ensuring the wholesomeness of food. Codex standards, which may be regional or national, but which can also be international, have no legal force as such, and usually have the status of codes of practice when adopted. However, in developing countries where no food laws currently exist, Codex standards are increasingly seen as quasi-legal and do form the basis of legislation as it evolves. These standards have also been acknowledged in the more developed markets as they fine tuned their legislation.

The original *Codex Standard for Natural Mineral Waters* was written in the early 1980s as a European Regional Standard. It mirrored the principles laid down in Directive 80/777/EEC, in that it required exploitation of water from a protected source, bottled without treatment. During the 1990s, conscious of the need to provide standards not only for NMWs but also for all bottled waters, the Codex commission published two pairs of standards in parallel, one for NMWs and one for bottled/package waters other than NMWs.

3.4.1 Codex and Natural Mineral Waters

The standard for NMWs (but not including non NMWs) (Codex Stan 108 Rev 1) was adopted in mid-1997 by the Codex Commission as a worldwide standard, and amended in 2008. Like the European Directive, the Codex standard contains a definition, a recognition requirement and specifications for treatment and handling. In another Codex document – *International Code of Hygiene Practice for the Collecting, Processing and Marketing of Natural Mineral Waters* (CAC/RCP 33-1985) – hygiene rules are outlined, packaging and labelling requirements are covered, and reference is also made to the methods of analysis and sampling appropriate to NMW (published in other Codex documents). Principal differences from the Directive are as follows:

- *Product* recognition, but no requirement for geological/hydrogeological surveys to permit *source* recognition.
- The removal of unstable compounds containing iron, manganese, sulphur or arsenic is permitted using ‘decantation, and/or filtration, if necessary, accelerated by previous aeration.’ The specific use of ozone is not mentioned, although it is explicitly stated that any treatment must not alter the natural composition of the water.

- Unlike in the Directive, which requires details of the *treatment*, if any such treatments are applied, the *results* of that treatment must be declared on the label – hence ‘arsenic removed’, etc.
- Products must be packaged at source (no tankering).
- The product is to be labelled as one of the following:
 - naturally carbonated natural mineral water;
 - non-carbonated natural mineral water;
 - decarbonated natural mineral water;
 - natural mineral water fortified with carbon dioxide from the source;
 - carbonated natural mineral water.
- No claims concerning medicinal (preventative, alleviative or curative) effect can be made on the label, but ‘claims of other beneficial effects related to the health of the consumer shall not be made unless true and not misleading’. However, the method of establishing such benefits is not touched upon.
- The label must bear the indications ‘contains fluoride’ in the case of a water containing more than 1 mg/l of fluoride, and the words: ‘The product is not suitable for infants and children under the age of seven years’, in the case of a water containing more than 1.5 mg/l of fluoride.

Like the NMW Directive, the Codex contains health-related limits for some substances. These are similar to those in 2003/40/EC, and Sections 3 and 4, concerning composition and quality factors and microbiological standards, are shown in Table 3.6 and Table 3.7. Note, however, that the Codex standard has a maximum limit for Manganese set at 0.4 mg/l, as opposed to 0.5 mg/l in the Directive).

3.4.2 Codex and non-Natural Mineral Waters

For waters other than NMWs, Codex has drafted a second pair of standards: The general *Standard for Bottled/Packaged Drinking Waters (other than Natural Mineral Waters)* Codex Stan 227-2001, and *Code of Hygienic Practice for Bottled/Packaged Drinking Waters (other than Natural Mineral Waters)* CAC/RCP 48-2001.

Under the General Standard, a distinction is drawn between ‘Waters Defined by Origin’ (whether from an underground source or from the surface) and ‘Prepared Waters’, which may come from any water supply. For Waters Defined by Origin, the Standard requires that precautions are taken at source to prevent contamination by any means, that the conditions of collection are controlled in order to maintain the original microbiological purity and essential composition, and that they are fit for consumption at source. Inspection and monitoring of the source of Waters Defined by Origin is also specified, though no source recognition process of the type applicable to NMWs is required. Furthermore, they can only receive treatment (as in the case of NMWs) for the elimination or reduction of unstable elements and the removal of undesirable elements present in excess of maximum concentrations or (in this case) maximum levels of radioactivity. Antimicrobial treatments may only be used ‘to conserve the original microbiological fitness for human consumption, original purity and safety of Waters Defined by Origin’. On the other hand, Prepared Waters, which need not meet any specific standards at origin, can be treated in any manner deemed necessary to make them microbiologically and chemically wholesome.

Table 3.6 Section 3 of Codex Standard 108 for Natural Mineral Waters. 3.2 Health-related limits for certain substances. Natural Mineral Water in its packaged state shall contain not more than the following amounts of the substances indicated hereunder.

Parameter number	Substance	Amount (mg/l)
3.2.1	Antimony	0.005
3.2.2	Arsenic	0.01, calculated as total As
3.2.3	Barium ¹	0.7
3.2.4	Borate	5.0, calculated as B
3.2.5	Cadmium	0.003
3.2.6	Chromium	0.05, calculated as total Cr
3.2.7	Copper	1.0
3.2.8	Cyanide	0.07
3.2.9	Fluoride	[See labelling indications above]
3.2.10	Lead	0.01
3.2.11	Manganese	0.4
3.2.12	Mercury	0.001
3.2.13	Nickel	0.02
3.2.14	Nitrate	50, calculated as nitrate
3.2.15	Nitrite	0.1, as nitrite
3.2.16	Selenium	0.01

The following substances shall be below the limit of quantification² when tested, in accordance with the methods prescribed in Section 6 [ISO methods]:

- 3.2.17 Surface active agents³
- 3.2.18 Pesticides and PCBs³
- 3.2.19 Mineral oil³
- 3.2.20 Polynuclear aromatic hydrocarbons³

¹ Pending further review of new scientific evidence by an appropriate scientific body to be determined by FAO/WHO

² As stated in the relevant ISO methods.

³ Temporarily endorsed pending elaboration of appropriate method(s) of analysis.

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Table 3.7 Section 4 of Codex Standard 108 for Natural Mineral Waters – Microbiological Requirements for Natural Mineral Waters, 4.4 Microbiological requirements.

During marketing, natural mineral water:

- shall be of such a quality that it will not present a risk to the health of the consumer (absence of pathogenic micro-organisms); and
- furthermore, it shall be in conformity with the following microbiological quality specifications.

First examination				Decision
<i>E. coli</i> or thermotolerant coliforms	1 × 250 ml	}	if ≥ 1 or ≤ 2	Must not be detectable in any sample Second examination is carried out
Total coliform bacteria	1 × 250 ml	}		
		}	if > 2	Rejected
Faecal streptococci	1 × 250 ml	}		
<i>Pseudomonas aeruginosa</i>	1 × 250 ml	}		
Sulphite-reducing anaerobes	1 × 50 ml	}		

Source: Reproduced by permission of the Food and Agriculture Organization of the United Nations.

The microbiological, chemical and radiological quality of packaged waters is not included in the Codex standards, but is defined in the *Guidelines for Drinking Water Quality* published by the WHO. These standards are not reproduced in their original form here, but are included in Table 3.11.

The Code of Hygienic Practice, which also states that it is to be read in combination with the *Recommended International Code of Practice – General Principles of Food Hygiene*, gives general guidance on precautions in selecting a resource site, protection of groundwater and surface water supplies, hygienic extraction or collection of water and storage and transport of water. It also gives basic advice on design of facilities, processes and packaging, with further sections dealing with maintenance and sanitation, personal hygiene, training, product information and consumer awareness.

Having published standards for both NMWs and other packaged waters, Codex Alimentarius continues to promote them, particularly in those areas where local standards or regulatory requirements do not exist; sometimes they are fully adopted, while in other cases, only the health-based limits required for food safety are applied.

3.5 RUSSIA

Russia is a growing market for bottled water with, in effect, five different categories, regulated by three sets of standards and directives. Here, a strong contrast can be seen between the basic drinking waters, which can be produced using any treatments and modified to taste, and the very highly mineralised waters being consumed in small quantities for their reported health benefits. The three sets of standards are:

- (i) *SanPiN*: Government approved Sanitary Rules and Norms, covering hygiene and safety, prepared by the Sanitary Administration.
- (ii) *MUK*: Health Ministry directives, covering application of Russian standards.
- (iii) *GOST*: State Standards, covering labelling, packaging and general process conditions.

The word GOST (Russian: ГОСТ) is an acronym for **gosudarstvennyy Standart** (Russian: **государственный стандарт**), which means state standard. GOST standards were originally developed by the government of the Soviet Union and they now have the status of regional standards, and are administered by the Euro-Asian Council for Standardization, Metrology and Certification (EASC), a standards organisation chartered by the Commonwealth of Independent States. The following countries have adopted GOST standards in addition to their own, nationally developed standards: Russia, Belarus, Ukraine, Moldova, Kazakhstan, Azerbaijan, Armenia, Kyrgyzstan, Uzbekistan, Tajikistan, Georgia and Turkmenistan.

The five different categories in Russia are as follows:

- Bottled mineral water, with three sub-categories:
 - (i) natural mineral table water;
 - (ii) mineral medicinal table water;
 - (iii) mineral medicinal water.
- Bottled drinking water, with two sub-categories:
 - (iv) First standard;
 - (v) Superior standard.

These are discussed in more detail below.

3.5.1 Bottled mineral water

This is the natural water category, complying with the general food standard SanPiN 2.3.2.1078-01. All three sub-categories must meet the following as a minimum:

- (i) Microbiological standards:
TPC – <100/ml at 37°C;
total coliform, faecal coliform and *Pseudomonas aeruginosa* – all absent per 100 ml.
- (ii) Chemical composition:
Lead < 0.1 mg/l; Cadmium < 0.01 mg/l; Mercury < 0.005 mg/l.
- (iii) Radiological standards; Alpha and Beta radioactivity.
- (iv) Origin and process requirements.

According to GOST and MUK requirements, the water must be from an underground source with demonstrated mineral stability (taking into account natural seasonal fluctuations). In addition:

- no treatment changing the natural mineral composition is permitted;
- it must be evaluated every 5 years by State Balneology Institutes;
- possible yearly check of mineral stability (still under consideration).

3.5.1.1 *Natural mineral table water – additional requirements:*

- Mineralisation below 1 g/l.
- Must be approved by State Balneology Institute.
- Must be evaluated upon technical documentation only.
- Must be suitable for daily usage.

3.5.1.2 *Mineral medicinal table water – additional requirements:*

- Highly mineralised; mineralisation above 1–10 g/l (although some waters with mineralisation below 1 g/l may also be treated as mineral medicinal table water if some minerals with therapeutic effects are present in appropriate concentrations) (as recognised by SanPiN 2.3.2.1078-01).
- Must be approved by State Balneology Institute.
- Must be evaluated by clinical experiments.
- Must have a confirmed therapeutic effect.
- Must be suitable for medium term usage (a few months).

3.5.1.3 *Mineral medicinal water – additional requirements:*

- Very highly mineralised; mineralisation above 10–15 g/l.
- Must be approved by State Balneology Institute.
- Must be evaluated by clinical experiments.

- Must have a confirmed therapeutic effect of great value.
- Suitable for short-term usage only (a few weeks).

3.5.2 Bottled drinking water

This is processed water, complying with the special bottled drinking water standard SanPiN 2.1.4.1116-02. Both sub-categories must meet the following as a minimum:

- (i) Microbiological standards:
TPC - <100 cfu /ml at 22°C, and <20 cfu /ml at 37°C;
viruses (phages), coliforms, spores and *Lamblia*: 0 cfu /20 ml in a 50 litre sample.
- (ii) Chemical composition:
~50 chemicals regulated.
The First standard has lower requirements in terms of chemical composition, and there is no written recommendation for minimum mineralisation, although water with mineralisation above 100 mg/l is regarded as physiologically valuable.
The Superior standard has some more specific chemical requirements, among them:
 - TDS @ 105 between 200 and 500 mg/l;
 - hardness between 1.5 and 7 mg-eqv/L;
 - calcium between 25 and 80 mg/l;
 - magnesium between 5 and 50 mg/l;
 - fluoride between 0.6 and 1.2 mg/l;
 - iodine between 40 and 60 µg/l.
- (iii) Treatments
According to GOST R52109-2003; any water treatment process is authorised, including addition of chemicals.

3.6 LATIN AMERICA

The Latin American market, which includes South and Central America and also Mexico, shows a diversity of approach, in that some countries have adopted the European approach and others are closer to the US model. Some consistency has developed in those countries (particularly in Central America) in which bottlers have become members of the Latin American Bottled Water Association (LABWA), itself a member of the independent International Council of Bottled Water Associations (ICBWA). However, there remain some significant differences across the region.

3.6.1 Argentina

Applicable legislation is included in the Argentine Food Code, Chapter 12, some of which covers Water-based Beverages, Drinking Water and Carbonated Water. Article 985 (Resolution No. 209 of 7 March 1994) of the Code contains specifications for NMW and Article 983 deals separately with carbonated water. Here, the definition is almost identical to that in the Codex standard for NMW, including source protection, controls during exploitation and limits on allowable treatments. The microbiological requirements are similar, in that the Code requires the absence of parasites, *E. coli*, faecal streptococci,

sulphite-reducing anaerobes and *P. aeruginosa* in 250 ml of water. However, the limits for health-related substances differ in some instances, and there is a maximum limit of 2 litres on pack size. A variety of descriptions can be used, including 'natural spring mineral table water' or 'natural mineral spring water', or 'natural mineral table water' or 'natural mineral water'.

3.6.2 Brazil

In Brazil, Resolution RDC No 54 of 15 June 2000 of the Directorate of the National Agency for Sanitary Enforcement contains a Standard of Identity and Quality for Natural Mineral Water and Natural Water. This standard refers both to the compositional requirements of the Codex for NMWs and to the GMPs and hygiene requirements laid out in the draft International Code of Hygiene Practice for the Manufacture and Marketing of Bottled Waters (other than NMWs). In the case of both NMWs and natural waters, they must be of subterranean origin, collected under conditions that guarantee maintenance of original composition and absence of pollution, with the only difference between them being mineral content. Further permitted treatments include decanting and filtration, but again, no alteration of mineral content is permitted.

3.6.3 Mexico

All water for human consumption in Mexico is regulated by the Ministry of Health, through the 'Regulation of the General Law of Health in the matter of Sanitary Control of Activities, Establishments, Products and Services'. The sanitary authorities are responsible for monitoring public and private suppliers and for granting certificates of Sanitary Condition of Water. This principally applies to waters provided through public supply, but also encompasses packaged waters, regardless of denomination. In chapter 1 of the third part of the Regulations, entitled 'Water and Ice for Human Consumption and for Refrigeration', as defined by Article 209, water is considered fit for human consumption if it does not cause injurious effects to health and is free of pathogenic germs and toxic substances. The standards by which this is measured are specified in subsequent articles: Article 210 specifies the microbiological standard as ≤ 2 coliform organisms per 100 ml, and absence of faecal organisms. This is the same standard for coliform required by Codex. Articles 211 and 212 deal with the aesthetic characteristics of pH, flavour, scent, colour and turbidity, while Article 213 provides maximum concentrations for health-related and other chemical substances (see Table 3.8).

The definitions for packaged potable water within Article 788 include purified water, NMW and artificially mineralised (carbonated or uncarbonated) water. As a minimum, the microbiological quality and the physical and chemical specifications laid out in Articles 789–792 correspond to those for potable water, the only difference being that NMW and mineralised water must contain from 500–1000 mg/l of sodium bicarbonate or sulphate, or an innocuous mixture of salts. Article 793 contains a detailed specification for the carbon dioxide used for artificial carbonation of prepared water.

Table 3.8 provides a comparison between the health-related limits for Latin American countries.

Table 3.8 Health-related physical and chemical limits for some Latin American waters.

	Mexico: all bottled waters	Brazil: Mineral water and Natural water	Argentina: Mineral water
Physical characteristics			
pH	6.9–8.5		4.0–9.0
Flavour	Characteristic	Characteristic	Characteristic
Odour			Characteristic
Colour	<20 units on Pt Co scale	5 hazen units	5 units on Pt Co scale
Turbidity	<10 units of the silica scale	<3 units Jackson	<3 units Jackson
Chemical parameters	(mg/l)	(mg/l)	(mg/l)
Total alkalinity as CaCO ₃	400		600
Aluminum	0.20		
Antimony		0.005	
Arsenic	0.05	0.05	0.2
Barium	1.0	1.0	1.0
Boron		5	30 (as HBO ₃)
Cadmium	0.005	0.003	
Chloride			900
Chromium		0.05	
Cyanide as CN	0.05	0.07	0.01
Copper	1.50	1.0	1.0
Free chlorine	0.20		Absent
Chlorine in chlorinated water	1.0		
Hexavalente chromium	0.05		0.05
Chromium total		0.05	
Calcium hardness as CaCO ₃	300		
Phenolic compounds	0.001		Absent
Iodide			8.5
Iron	0.30		5.0
Fluoride as F	1.50		2.0
Magnesium	125		
Manganese	0.15	2.0	2.0
Mercury	0.001	0.001	0.001
Nitrate as N	5.0	50 as nitrate	45
Nitrite as N	0.05	0.02 as nitrite	0.1
Ammoniacal nitrogen	0.10		0.2
Permanganate oxidisability	3.0		3.0
Lead	0.05	0.01	0.05
Selenium	0.05	0.05	0.01
Sulphate as SO ₄	250		600
Zinc	5.0		5.0
Active substances on methylene blue	0.5		
Substances extractable in chloroform	0.3		
Substances extractable in alcohol	1.5		
Hydrocarbons			
Dry residue at 180°C			50–2000
Products of contamination			Absent
Pesticide residues			Absent

Table 3.9 Principal health-related limits for packaged water from the Australia New Zealand Food Standard 2.6.2 and from the ABWI Model Code 2005.

Substance	FSANZ limit	ABWI limit
Antimony	0.15	0.006
Arsenic	0.05	0.05
Barium	1.0	1.0
Borate	30 (calculated as H_3BO_3)	30 (calculated as H_3BO_3)
Bromate	N/A	0.02
Cadmium	0.01	0.005
Chlorine (free)	–	<0.1
Chromium	0.05	0.05
Copper	1.0	1.0
Cyanide	0.01 (calculated as CN^-)	0.1
Fluoride	2.0 (calculated as F^-)	1.5
Lead	0.05	0.05
Manganese	2.0	0.05
Mercury	0.001	0.001
Nickel	–	0.1
Nitrate	45 (calculated as NO_3^-)	10.0 (as N)
Nitrite	0.005 (calculated as NO_2^-)	1.0 (as N)
Organic matter	3.0 ($KMnO_3$ digested as O_2)	3.0 ($KMnO_3$ digested as O_2)
Selenium	0.01	0.01
Sulphide	0.05 (calculated as H_2S)	0.05 (calculated as H_2S)
Thallium	–	0.002
Zinc	5.0	5.0

3.7 AUSTRALIA AND NEW ZEALAND

Legislation governing bottled water in Australia and New Zealand is set out in the Australia New Zealand Food Standards Code. Various parts of this Code, which is written by Food Standards Australia New Zealand Food Authority (FSANZ), deal with labelling requirements, substances added, contaminants and residues, and microbiological limits, but the principal requirements for bottled waters are laid out in Standard 2.6.2 – ‘Non-Alcoholic Beverages and Brewed Soft Drinks’. In addition, there are further standards covering food safety requirements, which are applicable to Australia only. As in other markets, the industry is also self-regulating – in this case by the Australasian Bottled Water Institute (ABWI), who have drafted a Model Code against which bottlers can be certificated, based upon mandatory third-party inspections and audits. There are no limits on the treatments permitted, including micro-filtration, UV treatment, reverse osmosis, distillation and ozonation. Table 3.9 shows a comparison between the maximum contaminant levels for packaged water from the Australia New Zealand Food Standard 2.6.2 and from the ABWI Model Code 2005.

3.8 ASIA

The Asian bottled water market, which extends from Jordan to Japan, includes several thousand bottlers in at least 40 countries. Of these, many operate in a relatively unregulated framework, but a growing number are becoming members of the Asia Bottled Water Association (ABWA), which was formerly the ‘Far East Chapter’ of the IBWA, but which

became a founder member of the independent International Council of Bottled Water Associations (ICBWA). In addition, there are more than a hundred other members, comprising suppliers, distributors, affiliates, as well as new candidates for membership. The ABWA has developed a Model Code, based on the Codex Standard for Bottled/Packaged Drinking Waters other than NMWs, enhanced by the ICBWA model. All members are subject to mandatory inspections and annual unannounced third-party audits to confirm compliance with the Code, and thus enabling use of the Association logo and certification on the label.

All bottled water offered for sale must be safe for consumption. Bottled water originating from natural sources can be labelled 'spring' or 'mineral' water on the same basis as in the USA. Mineral water is SW with a larger amount of dissolved mineral solids, usually above 500 mg/l, and neither SW nor mineral water may have its composition modified through the use of chemicals. The terms 'well water' and 'artesian water' are also commonly used. These must all originate from sources that are well protected and monitored by both the exploiter and the State, but may all be subject to treatments including reverse osmosis, UV, microfiltration, distillation and ozone for the purpose of disinfection. Mineral water or SW must not contain any coliform bacteria or harmful substances at the source. Other bottled waters may undergo a variety of treatments and should meet the regulatory requirements for coliform and aerobic bacteria. Where the national standards are more stringent, the standard of identity is enhanced to meet the national requirement. Pre-packaged ice is also expected to comply with the regulations.

However, the market for purified water from various original sources, including municipal, well water and even sea water, is growing tremendously, and for these there are no limits on the types of treatment available, the only aim being to manufacture bottled water fit for consumption. These waters must not be labelled in such a way as to be confused with SW or mineral water and the label on these water containers must show how they have been treated, for example, 'carbonated', 'demineralised', 'distilled', 'de-ionised', 'desalinated'.

When the source for bottled water comes from a community water system and does not undergo any treatment, the product label must state that the bottled water is 'from a community water system' or 'from a municipal source'. However, if the water is subject to distillation, de-ionisation or reverse osmosis, the bottled water product can be legally defined as purified water, demineralised water, de-ionised water, distilled water or reverse osmosis drinking water, and does not have to state the above phrases on its label.

Not all bottlers are members of the ABWA however, and legislation obviously varies from country to country. Table 3.10 shows a broad comparison between the legislative requirements in some Middle Eastern and Asian countries, and Table 3.11 shows a comparison of ABWA Guidelines with WHO drinking water standards, also showing standards for individual Asian countries.

3.9 SOUTH AFRICA

The African market for bottled waters has generally been confined to those countries connected geographically to Europe and to the European tradition. Hence Egypt, Algeria and Morocco, through their Mediterranean link, have a strong and growing market based upon watercoolers, most commonly using processed and purified waters. In the Republic of South Africa, as in other parts of the world, bottled water has been regulated according to the general safety and quality criteria governing the production of food, but the government had published no specific legislation for bottled water. Thus it was left to the industry to set the

Table 3.10 Comparison of Legislative requirements in some Middle Eastern and Asian Countries.

Country / Product name	Legislation	Origin of water, and protection requirements	Water treatment required or permitted	Label requirements
China				
Drinking Natural Mineral Water	1. GB8537-2008 Drinking Natural Mineral Water Permits required: Mine Extraction Permit (The Ministry of Land and Resources PRC/ Provincial) Water Obtaining Permit (Municipal Water Conservancy Dept) Prospecting Permit (Provincial Ministry of Land and Resources) Natural Mineral Water Prospecting and Environment Evaluation Report (submitted by Metallurgical & Geological Institute or related organisations) Technical Certification Approval Document (approved by Provincial / Municipal Committee on Mineral Reserves) 2. GB 16330-1996 Hygienic standards for factories packaging natural mineral water 3. GB 7718-2004 General standard for labelling of food 4. GB/T 13727-92 Geological exploration specification for natural mineral water GB 16330-1996 Hygienic specifications for factories packaging Natural Mineral Water	Underground source (artesian well, spring). Characteristic content must comply with GB8537-2008 Drinking Natural Mineral Water, and be free of contamination. Must comply with GB/T 13727 and GB 16330: protection of source and surrounding area, with regular monitoring.	Sand filtration Selective removal of iron or manganese Ozonation UV light Micro filtration Active carbon filtration Fibre filtration and membrane filtration (provided that there is no change in the level of characteristic and major elements of natural mineral water) Addition or removal of CO ₂ permitted Addition of disinfectants or antiseptic is not permitted Details of treatment not required on label Tankering not permitted	Labelling must comply with GB 7718-2004: Product name Ingredients list Net content Name and address of producer / importer / distributor Production and best before date Storage directions Country of origin Quality rating

Other Packaged Drinking Water	1. GB 19298-2003 Hygienic Standard for Bottled Drinking Water 2. GB 19304-2003 Hygienic specifications for factory packaging drinking water 3. GB 7718-2004 General standard for labelling of food Mine Extraction Permit (Municipal Water Supply Planning Office) for water originating from Deep Well Water Acquiring Permit (Municipal Water Supply Planning Office)	Any source water which complies with GB 5749-2006 Standards for Drinking Water Quality: Includes underground sources, naturally flowing streams, municipal water systems Must comply with GB19298-2003 – Hygienic standard of water for drinking. Also, GB 19304-2003 ('Hygiene Standard for factories for packaging of Drinking Water') : Requirement to protect the source and surrounding area, with regular monitoring	
Purified Drinking Water (including Distilled Water)	1. GB 17323-1998 Bottled Purified Water for Drinking 2. GB 19304-2003 Hygienic specifications for factory packaging drinking water 3. GB 7718-2004 General standard for labelling of food		As above – but water subject to distillation must be labelled as Distilled Water
Drinking Natural Spring Water	1. GB 19298-2003 Hygienic Standard of Bottled Water for Drinking 2. GB 19304-2003 Hygienic specifications for factories packaging drinking water 3. GB 7718-2004 General standard for labelling of food	Underground source (artesian well, spring), uncontaminated and not connected to a municipal system	Not specified
Other Natural Drinking Water	1. GB 19298-2003 Hygienic Standard of Bottled Water for Drinking 2. GB 19304-2003 Hygienic specifications for factory packaging drinking water 3. GB 7718-2004 General standard for labelling of food	Sourced from surface water (well, water reservoir, lake or mountain glacier, etc.). Uncontaminated and not connected to a municipal system	Not specified

Table 3.10 (cont'd)

Country / Product name	Legislation	Origin of water, and protection requirements	Water treatment required or permitted	Label requirements
China (cont'd)				
Mineralised Drinking Water	1. GB19298-2003 Hygienic Standard of Bottled Water for Drinking 2. GB 19304-2003 Hygienic specifications for factory packaging drinking water 3. GB 7718-2004 General standard for labelling of food	Any source water which complies with GB 5749-2006 Standards for Drinking Water Quality (Reference 1). Ex: underground source, naturally flowing stream, municipal water system	Not specified	
Egypt				
Drinking Water	Standard # 1589/2007 1. Permit for the bottled product and the well renewable every 5 years issued by the ministry of health 2. Permit for the well exploitation issued by the ministry of irrigation and water resources every 3 years	Deep well – 50-m radius around the source to be maintained clear of all construction	If mineral elements are removed or added, it has to be mentioned on the label. Tankering not permitted	
India				
Packaged Drinking Water (other than packaged Natural Mineral Water)	IS 14543:2004	Any source of potable water According to IS 14543:2004, Annex B, B-3, protective measures; All possible precautions should be taken within the protected perimeter to avoid any pollution of, or external influence on, the quality of the ground or surface water	Decantation, filtration, combination of filtration, aeration, filtration with membrane filter, depth filter, cartridge filter, activated carbon filter, demineralisation, remineralisation, reverse osmosis or any other (disinfection with chemical agents and/or physical methods) Treatment for disinfection must be detailed on the label Tankering permitted	1. Name of the product 2. Supplementary designations (if any) 3. Name and address of the processor 4. Brand name 5. Batch or Code number 6. Date of processing/ Packing 7. Best before date 8. Net volume 9. Location and name of the source of natural mineral water 10. Directions for storage 11. ISI mark, standard number and license number 12. Any other markings required under the Standards of Weights and Meas- ures (Packaged Commodities) Rules, 1977; and the Prevention of Food Adulteration Acts, 1954, and the Rules framed thereunder

Packaged Natural Mineral Water	IS 13428:2005	Obtained directly from natural or drilled sources from underground water-bearing strata All possible precautions should be taken within the protected perimeter to avoid any pollution of, or external influence on, the quality of the ground or surface water	Separation of unsuitable constituents, such as compounds containing iron, manganese, sulphur or arsenic Carbonation from same/ external source, decantation and/or filtration Tankering not permitted	PFA; Rule 32: 1. Brand name 2. PFA Category of water 3. Name and address of the processor 4. Batch or Lot number 5. Date of processing/ packing 6. Best before date 7. Net volume 8. Directions for storage
Packaged Drinking Water	PFA; Appendix B; Standard A. 33 PFA rule 32	Any source of potable water	Decantation, filtration, combination of filtration, aeration, filtration with membrane filter, depth filter, cartridge filter, activated carbon filter, demineralisation, remineralisation, and reverse osmosis (disinfection with chemical agents and/or physical methods) Sea water: desalination and related processes before any of the above-mentioned processes Tankering permitted	
Mineral water	PFA; Appendix B; Standard A. 32-1 PFA rule 33	PFA; Appendix B; Standard A. 32-1 Obtained directly from natural or drilled sources from underground water bearing strata All possible precautions should be taken within the protected perimeter to avoid any pollution of, or external influence on, the quality of the ground or surface water	Separation of unsuitable constituents such as compounds containing iron, manganese, sulphur or arsenic Carbonation from same/ external source, decantation and/or filtration Tankering not permitted	

Table 3.10 (cont'd)

Country / Product name	Legislation	Origin of water, and protection requirements	Water treatment required or permitted	Label requirements
Indonesia				
Bottled Drinking Water	SNI 01-3553-2006	Municipal spring water KepMen 705/MPP/Kep/II/2003 p. 7, pasal 6 point 2: Source water location should be located at a minimum radius distance from potential sources of pollution: Min 15 m from impermeable waste water canal or line – Min 30 m from permeable waste water or septic tank – Min 60 m from well hole, animal farm and waste accumulation site Agreement with municipality for maximum discharge/flow rate	Mandatory minimum treatment as follows: 1. Prefilter 2. Carbon filter 3. Micro filter max 10 micron 4. Disinfection treatment using ozone or UV lamp or other equipment with the same capability for disinfection Tankering permitted	Label requirement as per KepMen 705/ MPP/Kep/II/2003 page 9 BAB VII, pasal 10 Label should contain minimum information: 1. Name of product: Bottled drinking water 2. Brand name 3. Manufacturer or importer name 4. Manufacturer or importer address 5. Net content 6. Registration number from National Agency of Drug and Food Control 7. Month and year of expiry or best before 8. Production code in label or packaging 9. SNI code
Iran				
Natural Mineral Water	ISIRI NO. 2441, Section 1–4 Any plan for exploiting ground water sources should be examined and approved by the Ministry of Health and Ministry of Power (Standard 2441, article 8–3 Note)	Underground source, naturally flowing stream (Standard No 2441, article 4–1B) Action should be taken to prevent any contamination and or external effects on quality (Standard 2606, article 3). Precautionary measures must be taken adjacent to the spring or well so that no	Separation of unstable particles such as iron, manganese, sulfur and arsenic compounds by decantation and /or filtering, and if needed accelerated by aeration are allowed provided that no fundamental changes occur in the amount of mineral composition	1. Name and type of product 2. Name and location of the source 3. Name and complete address of manufacturer 4. Trade mark 5. Quantified chemical composition

Drinking water	Standard 6694 Ministry of health, Ministry of power and water organization (Stan 6694, article 8-5)	contaminants infiltrate to the point of extraction. Protected area is usually considered to be a 60-m circle; environmental and geological elements also to be taken into account. The production unit must be as close to the place of extraction as possible (Standard 2606, article 3-7)	Tankering not permitted	6. Volume in metric units 7. Product licence No. 8. Batch number 9. Shelf-life or Production and expiry date 10. Storage condition. (standard No 2441, article 10) If the product contains > 1 mg/l fluoride, the phrase 'Contains fluoride' must appear on the label. If >2 mg/l, 'Not suitable for infants & children age below 7' and >10mg/l, 'Not suitable for infants' should be declared on the label
		Underground source, naturally flowing stream, glacial water, municipal water system (Standard 6694, article 2-4) Conditions of collection of water must be such as to prevent any change of physical specification and quality of water before purification (Standard 6694, article 5-1-1)	No restrictions, but details must appear on the label Tankering permitted	1. Name & type of product (Water naturally containing CO₂ should be named as 'naturally carbonated' or 'naturally sparkling'. Packaged water with added CO₂ should be named as 'Carbonated') 2. Minerals, total dissolved solid and chemical compounds 3. Location of source (if the water is supplied by public or private distribution system the phrase 'From public or private distribution system' should be declared on the label) 4. Product licence number 5. Name and complete address of manufacturer 6. Volume in metric units 7. Batch number 8. Production and Expiry date 9. Storage condition (Standard 6694, article 7)

Table 3.10 (cont'd)

Country / Product name	Legislation	Origin of water, and protection requirements	Water treatment required or permitted	Label requirements
Iran (cont'd)				
				The waters with the name 'Fluoride water' should contain at least 0.8 mg/l fluoride. If water > 1 mg/l fluoride, the phrase 'contains fluoride' should be declared. For water with > 2 mg/l fluoride, the phrase 'Not suitable for infants and children under 7' must be declared on the label
Iraq				
Natural Mineral Water	1351/1988	From natural sources such as springs or underground-excavated wells Spring should be protected from potential pollution	Physical separation of unstable content / Addition/removal of carbon dioxide Must be labelled as such Tankering not permitted	
Japan				
Natural water	The Japanese Law concerning Standardisation and Proper Labelling of Agricultural and Forest Products - has two parts: The Japanese Agricultural Standard (JAS) system The Standardised Quality Labelling System Under these standards, authorisation is needed for	From an underground source	Precipitation, filtration and heat treatment is allowed If the product is not sterilised or disinfected, it should be so labelled Tankering permitted for products that undergo sterilisation/disinfection	[the Quality Labelling Guideline for mineral water under the Japanese Agricultural Standard Law (JAS law)]
Natural mineral water		Mineralised natural water from a spring or an underground source		
Mineral water		Mineralised natural water from a spring or an underground source	Mineral adjustment, aeration, mixture of natural water taken from multiple sources	

	exploitation (each local government unit) and for manufacturing of soft drinks including bottled drinking water (each local government unit)		If the product undergoes treatment such as mineral adjustment, aeration, blending of natural water taken from multiple sources, it should be so labelled Tankering permitted	
Drinking water other than natural water, natural mineral water, mineral water		NA	No restrictions If the product undergoes treatment such as mineral adjustment, aeration, blending of natural water taken from multiple sources, it should be so labelled Tankering permitted	

Jordan

Natural Mineral water	JS200:2009	From natural sources through springs or underground excavated wells The distance between two wells must be at least 1 km. For any new well, the extraction quantity for a specific period must be determined	Physical separation of unstable content Treatment with ozone or UV rays Addition/removal of carbon dioxide Any other approved physical treatment such as precipitation It is not permitted to use chlorine compounds in sterilizing mineral waters Tankering not permitted	Mandatory requirements: Category: natural mineral water or drinking water Name and location of the source, net content, name and location of the company and brand name if any, country of origin, production date. In case of a mineral water containing $>600 \text{ mg/l SO}_4$, the label should state 'may be laxative' Any mineral addition should be stated on the label 'Acidic' if $>250 \text{ mg/l CO}_2$ 'Basic' if $>600 \text{ mg/l HCO}_3$ 'Salty' if $>1000 \text{ mg/l NaCl}$ 'Contains Iron' if $>5 \text{ mg/l}$ 'Contains Iodide' if $>1 \text{ mg/l}$ 'Contains fluoride' if $>1 \text{ mg/l}$ and $<1.5 \text{ mg/l}$

Table 3.10 (cont'd)

Country / Product name	Legislation	Origin of water, and protection requirements	Water treatment required or permitted	Label requirements
Jordan (cont'd)				
Drinking water	JS1214:2009 Ministry of water	Municipal water system JS286:1999 The distance between two wells must be at least 1 km. For any new well, the extraction quantity for a specific period must be determined	Permitted treatments include: microfiltration, RO, distillation, ozone, UV and any other approved method Tankering permitted	'May be diuretic' if > 1000mg/l or > 600mg/l Bicarbonate Water composition Licence number No claims may be made concerning medical or therapeutic use (natural Mineral water JS200:2009 and drinking water JS1214:2009)
South Korea				
Spring Water Natural Mineral Water	The legal denomination of source water for bottling is spring water The legal denomination of treated water from source water is 'Drinkable spring water' But the law allows to display 'Natural Mineral Water' on the label of final product. Latest revision date of the law was October 2008 Licencing process is as follows: 1. Provisional license from the province 2. Develop wells 3. Environment impact study for 6 months 4. Submit study report to the province 5. Field inspection by the ministry of environment 6. Inspection reports including daily allowance of quantity from the ministry to the province 7. Issue license by the province	Underground source – defined as follows: 1. Underground water taken from under rock bed 2. Spring water from underground 3. Stable and sustainable quality water from nature The developer of the source must predict and analyse the impact to/ from the surrounding environment and submit a report to the province, including countermeasures to minimise the impact	Only minimum physical treatments such as precipitation, filtration, aeration, UV and ozonation. Reverse osmosis is not permitted, but the product must meet legal standards; changes in Ca, Na, K, Mg, after evaporation and pH should be <20%. Activated carbon may be used. Carbonation is permitted, but the CO ₂ must be natural and originate in the source water. Final products treated by ozonation, heating and adsorption to remove health risky materials CANNOT use 'Natural' mineral water on the label Tankering not permitted	Category of water Brand name Location of water source Manufacturer Shelf-life Code of Business Licence or Import & Sale Business Registration Net content Storage advice Customer service centre (phone number) Treatments method to water (if it necessary- ozone, heating, etc.) Major minerals: Calcium, Sodium, Potassium, Magnesium, Fluorine

Lebanon				
Bottled mineral natural water	Libnor 162:1999, 2.2	Drinkable ground water, naturally emerging at the surface or extracted from wells Exploitation licence and bottling authorisation	Treatment not allowed	
Bottled Natural Water	Libnor 162:1999, 2.1	Drinkable ground water, naturally emerging at the surface or extracted from wells Exploitation licence and bottling authorisation	Treatment not allowed	
Bottled Drinking Water	Libnor 162:1999	Drinkable ground water, naturally emerging at the surface or extracted from wells Exploitation licence and bottling authorisation	Treatment allowed For bottled drinking water that is treated to be drinkable, the method of treatment must appear on the label	
Pakistan				
Bottled Drinking water	PS 4639-2004 (R)	Bottled Drinking water, PS 4639-2004 (R)	No restrictions Tankering permitted	
Philippines				
Mineral Water, Purified water with added minerals	BFAD AO18-A s. 1993/ PNSDW 2007 Licence required to operate as Food Distributor and as Bottled Drinking Water Processor	Approved source – means any spring, drilled well, public or community water system or any other source that has been inspected and the water sampled, analysed and found safe sanitary, with or without treatment. BFAD AO18-A s.1993: Section V/2	All treatment of product water by distillation, exchanging, filtration, UV treatment, reverse osmosis, carbonation, mineral addition or any other process shall be done in a manner so as to be effective in accomplishing its intended purpose	BFAD AO18-A s. 1993 Sect. IX Labelling Requirements 1. Name and address of manufacturer 2. Type of water either 'spring, mineral', etc. 3. Brand name shall conform with BFAD 4. Geographical location

Table 3.10 (cont'd)

Country / Product name	Legislation	Origin of water, and protection requirements	Water treatment required or permitted	Label requirements
Philippines (cont'd)				
		All possible precautions should be taken within a 60 m radius perimeter of the source to avoid pollution		5. Composition; TDS in ppm, Bicarbonate, Calcium, Magnesium, Chloride, Sulphate, Sodium*, Potassium*, Fluoride** * optional ** optional except for fluoridated water
Saudi Arabia /Lower Gulf				
Bottled Drinking Water	SASO 409 (GS1025/2000) Permits/licence for exploitation has to be obtained from Ministry of Commerce and Ministry of Water	Any source of water suitable for human consumption; includes Artesian well, drilled well, a spring, public or private water distribution system. SASO 409 (GS1025/2000) Section 3.4 A Royal Decree in 1979 approved enacted a 'Water Sources Protection System'	No restrictions Tankering permitted	The following information shall be declared on the label: 1. Name of product as (Bottled Drinking Water) 2. Water content of different anions and cations, TH and TDS expressed in p.p.m. 3. pH 4. Net volume in metric units
Syria				
Natural Mineral water	SNS 191:1980	From sources as springs or underground-excavated wells Spring should be protected from potential pollution	Physical separation of unstable content/Addition/removal of carbon dioxide Must be labelled as such Tankering not permitted	
Uzbekistan				
Drinking Water	TSh 10-130:2005 (Technical Conditions) Standard for Drinking Bottled Water, # 1.1 1.1. Characteristics:	TSh 10-130:2005 Technical Conditions. Standard for Drinking Water # 1.2 Origin of the water used for filling:	The following are permitted: Ozonation, UV light, microfiltration, reverse-osmosis	TSh 10-130:2005 Technical Conditions. Standard for Drinking Water 1.4. Requirements for labelling:

	1.1.1 Drinking Bottled Water must be produced in accordance with the requirements of present Technical Conditions, observing approved sanitary norms and rules Licence for exploitation from the Government Committee for Geology and Mineral Resources #9 Government control of usage and protection of water fulfilled by: – State Committee of Nature Protection of the Republic of Uzbekistan – Inspection Agency of Safety Works in Industrial and Mountain Control – Ministry of Health of the Republic of Uzbekistan – Ministry of Agriculture and Water Resources of the Republic of Uzbekistan according to order regulated by legislation Law # 837-XII, 'Law on water and water usage', 'Law on usage of natural resources'	– spring water – artesian water – municipal water – well water	– Name of Water – Name of the manufacturer – Brand – Type (still or sparkling) – Mineral concentration – Applicability (Drinking Water) – Storage conditions (from 5 until 20, protect from direct sunlight) – Date of manufacturing – Shelf-life – Capacity or technical specifications – Bar code – National mark of conformity according to GOST 1.19 – Claim 'Made in Uzbekistan' 1.4.2. Transportation Marking according to GOST 14192. Drinking Water, TSh 10-130:2005 (Technical Conditions) Standard for Drinking Bottled Water, #1.1

Vietnam

Mineral Water	TCVN 6213 : 2004, Second edition No.: 1232/GP-DCKS (Licence of Mineral Water Exploitation)	Underground water	Treatments permitted include separation of unstable constituents, i.e. compounds containing iron, manganese, sulphur or arsenic, by decantation and/or filtration, if necessary, accelerated by previous aeration	* DECREE 86/2006/ND-CP for Directions for Labelling * TCVN 6213 : 2004 6.2.1 Labelling for bottled/package natural mineral water in accordance with TCVN 7087:2002 [CODEX STAN 1-1985 (Rev. 1-1991, Amd. 1999 & 2001)] Labelling of prepackaged foods

Table 3.10 (cont'd)

Country / Product name	Legislation	Origin of water, and protection requirements	Water treatment required or permitted	Label requirements
Vietnam (cont'd)			The treatments above may only be carried out on condition that the mineral content of the water is not modified in its essential constituents, which give the water its properties Treatments must appear on the label Tankering not permitted	The following provisions shall apply: 6.2.2.1 The name of the product shall be 'Natural mineral water' with the trade name or name of locality. In addition, based on the nature of natural mineral water ... the following designations shall be noted: – Naturally carbonated natural mineral water – Non-carbonated natural mineral water – Decarbonated natural mineral water; – Natural mineral water fortified with carbon dioxide from the source – Carbonated natural mineral water 6.2.2.2 The analytical composition giving characteristics to the product shall be declared on the label: – Total dissolved solids (TDS), Sodium, Calcium, Potassium, Magnesium, Iodine, Fluoride, HCO₃ contents 6.2.2.3 If > 1 mg/l fluoride, the label shall state 'contains fluoride'. If >2.0 mg/l fluoride, the label shall state 'The product is not suitable for infants and children under the age of seven years' 6.2.2.4 The treatments used shall be declared on the label 6.2.5 No claims concerning medicinal effects shall be made

standards; in 1997 the principal producers took the lead by forming the South African Natural Bottled Water Association (SANBWA – now renamed as the South African National Bottled Waters Association) and, in 1999, they published their *Standards and Guidelines for Bottling Lines*. These were updated in 2007, and in the same year SANBWA was instrumental in assisting the Department of Health in finally publishing legislation for bottled water, No R.718 – ‘Regulations Relating to All Bottled Waters’ – under the Foodstuffs, Cosmetics and Disinfectant Act 1972. This legislation, based upon the Codex Alimentarius standards, recognises three classes of water.

3.9.1 Natural waters

These waters (which will normally be designated Natural Mineral Waters or Natural Spring Waters) must originate in an underground aquifer, be of constant composition and have a stable discharge rate and temperature; they must be collected under conditions that ensure protection from pollution, and be bottled at source (no tankering is allowed).

The only treatments permitted are separation of unstable elements by decantation or filtration, which can be accelerated by previous aeration; they can have carbon dioxide added or (if initially present) removed.

Labelling must include the name of the product, the physical address and name of the source, and the analytical composition in mg/litre.

3.9.2 Waters defined by origin

This class of waters can originate from rainwater, streams, glaciers, springs, snow melt and even from the sea. Nonetheless, they must be extracted in such a way as to avoid any contamination, pollution or external influence on the chemical, microbiological and physical quality of water at the origin;

A variety of treatments is allowed ‘provided that these modifications or treatments and the processes used to achieve them do not compromise the chemical, radiological and microbiological safety of these waters’. These include:

- Reduction or elimination of dissolved gases and unstable constituents such as iron, manganese, sulphur and excess carbonates. Addition of carbon dioxide is also permitted, or re-incorporation of original carbon dioxide present at the emergence.
- Addition of air, oxygen or ozone, on condition that the by-products due to ozone treatment do not affect the maximum levels for elements stipulated in the general requirements for bottled waters as set out in a list in an Annex to the regulations (reproduced below).
- Decrease or increase in temperature, and reduction or separation of elements originally present in excess of acceptable levels as stipulated in the general requirements for bottled waters in the Annex.

The regulations also state that:

Antimicrobial treatments shall be used in order to conserve the microbiological fitness for human consumption, original purity and safety of these waters.

For waters defined by origin, labelling must include the name of the product, the physical address and name of the source, and the analytical composition in mg/litre, and the method

Table 3.11 Comparing the WHO Drinking Water Standards, ABWA Guidelines and some standards from the regulations applicable in some Asian countries.

Parameter	WHO (drinking® water)	ABWA	Pakistan (drinking water)	Indonesia	Singapore	SASO	Oman (NMW)	Malaysia (NMW)	Malaysia (drinking water)	Vietnam (NMW)	Japan All waters	India (NMW)	India (drinking water)	PRC (NMW)	PRC (drinking water)
Inorganic constituents	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Aluminum	0.2***	0.2***							0.2				0.03		
Ammonia	1.5***	1.5***		0.15					0.5	1.5					
Antimony	0.005P	0.005P	0.005				0.005					0.005		0.005	
Arsenic	0.01P	0.01P	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.05	0.05	0.05	0.01	0.01
Barium	0.7	0.7	0.7	1.0	1.0	1.0	1.0			0.1	1.0	1.0	1.0	0.7	
Beryllium	NAD														
Boron (as borate)	0.5P	0.5P	0.5				5.0	30			30 ⁽¹⁾	5.0		5.0	
Cadmium	0.003	0.003	0.003	0.005	0.01	0.01	0.003	0.01	0.005	0.003	0.01	0.003	0.01	0.003	
Chloride	250***	250***	250		250	250	250	250	250	250		200			
Chromium	0.05P	0.05P	0.05		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Copper	2P1***	2P1***	1.0	0.5		1.0	1.0	1.0	1.0	2.0	1.0	1.0	0.05	1.0	1.0
Cyanide	0.07	0.07	0.07	0.05	0.01	0.05	0.07	0.01	0.1	0.07	0.01	0.07	0.05	0.01	0.002
Fluoride	1.5	1.5	0.7	1.0	2.0	0.01	> 1 and > 2	2.0	1.5	1.5	2.0	2.0	1.0	1.5	
Hydrogen sulphide	0.05***	0.05***						0.05		0.05		0.05			
Iron	0.3***	0.3***	0.3	0.3		0.3			0.3	0.03			0.1		
Lead	0.01	0.01	0.01	0.005	0.05	0.05	0.01	0.05	0.05	0.01	0.05	0.01	0.01	0.01	0.01
Manganese	0.5P0.1***	0.5P0.1***	0.05	0.05	2.0	0.05	2.0	2.0	0.1	0.5	2.0	2.0	0.1	0.4	
Mercury (total)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.0005	0.001	0.001	0.001	
Molybdenum	0.07	0.07													
Nickel	0.02P	0.02P	0.02				0.02					0.02	0.02	0.02	
Nitrate	50 (as NO ₃)		10 (as N)								10 (as N)			45	
Nitrite (as NO ₂)	3PAcute	3PAcute	1 (as N)	0.005	0.005		0.02	0.005	0.02		10 (as N)	0.02	0.02	0.1	0.1
Nitrate/Nitrite	0.2P Chronic Sum of (conc: GV) ≤ 1	0.2P Chronic Sum of (conc: GV) ≤ 1				Sum of (conc: GV) ≤ 10									
Selenium	0.01	0.01	0.01		0.01	0.01	0.05	0.01	0.01	0.01	0.01	0.05	0.01	0.05	
Silver	U	U	0.1			0.05			0.05	0.01		0.01	0.01	0.05	
Sodium	200***	200***	50						200			150	200		
Sulphate	250***	250***	250	200		250			400	250		200	200		
Zinc	3***	3***	3.0			5.0		5.0	5.0	3.0	5.0	5.0	5.0	0.2	

[illegible]

Table 3.11 (cont'd)

Table 3.11 (cont'd)

Cyanogen chloride (as CN)	70	70
Dichloramine	NAD	
Formaldehyde	900	
Trichloramine	NAD	
<i>Chlorophenols</i>		
2-Chlorophenol	0.1–10***	0.1–10***
2,4-Dichlorophenol	0.3–40***	0.3–40***
2,4,6-Trichlorophenol	200; 2–300***	200; 2–300***
<i>Halogenated Acetic Acids</i>		
Monochloroacetic acid	NAD	
Dichloroacetic acid	50P	50P
Trichloroacetic acid	100P	100P
<i>Haloacetic Acids</i> (HAA-s); includes mono-, di-, and trichloroacetic acid and mono- and dibromoacetic acid)		
<i>Halogenated Acetonitriles</i>		
Bromochloroacetonitrile	NAD	
Dibromoacetonitrile	100P	100P
Dichloroacetonitrile	90P	90P
Trichloroacetonitrile	1P	1P
<i>Trihalomethanes</i>		
Bromodichloromethane	60	60
Bromoform	100	100
Chloroform	200	200
Dibromochloromethane	100	100
Total THMs	Sum of (conc: GV) ≤ 1	Sum of (conc: GV) ≤ 1
Other chemical/physical parameters		
Colour	15 TCU***	15 TCU***
Odour	Acceptable***	Acceptable
	5 TCU	5 TCU
	No smell	No smell
	15 TCU	15 TCU
	Unobjectionable	Unobjectionable
	2	2
	Agreeable	Agreeable
	2	2
	Agreeable	Agreeable
	15	15
	Unobjectionable	Unobjectionable
	5	5
	None	None
	0.02	0.02
	30	30

Table 3.11 (cont'd)

Parameter	WHO (drinking® water)	ABWA	Pakistan (drinking water)	Indonesia	Singapore	SASO	Oman (NMW)	Malaysia (NMW)	Malaysia (drinking water)	Vietnam (NMW)	Japan All waters	India (NMW)	India (drinking water)	PRC (NMW)	PRC (drinking water)
pH	< 8 for effective disinfection w/ chlorine***	6 - 8 for effective disinfection w/ chlorine***	6.5–8.5	6.5–8.5		6.5–8.5	4.5–6.5 for carbonated		6.5–8.5			6.5–8.5			5.0–7.0
Taste	Acceptable***	Accept-able***				Unobjec- tionable						Agree-able	Agreeable		
Total dissolved solids (TDS)	1000 mg/l***	1000mg/l***	500	500		100–700				1000		150–700	500	1000	
Turbidity	5 NTU***	5 NTU***		5 NTU		5 NTU		3.0		5 NTU		2.0	2.0	5.0	1.0
Oxidisability				1.0											
Total organic carbon (TOC)					3.0						12 mg/l				
Radiological constituents															
Alpha activity, gross	0.1Bq/l	0.1Bq/l			1.0 pCi/l	10 pCi/l		0.1 Bq/l	0.1Bq/l	0.1Bq/l		0.1Bq/l	0.1Bq/l	1.5Bq/l	
Beta activity, gross	1Bq/l	1Bq/l			30pCi/l	1000 pCi/l		1 Bq/l	1Bq/l	1Bq/l		1Bq/l	1Bq/l	1.1Bq/l	
Combined radium-226 and radium-228						3 pCi/l									for 226
Tritium and man-made radionuclides															
Uranium	0.002Pmg/l						10Bq/l for cesium 134 and 137								
Strontium 90															
Microbiological constituents															
E. coli or thermotolerant coliform bacteria	0/100 ml	0/100 ml	0/250 ml	0/100 ml	0/250 ml	0/100 ml	0/100 ml	Nil	Nil	Nil	Nil	Nil in any 250 ml sample	Nil in any 250 ml sample		3 MPN
Total coliform bacteria			0/250 ml	0/100 ml		4/100 ml and arithmetic mean	1/100 ml	10 MPN/4 MF	10 MPN/4 MF	Nil	Nil	Nil in any 250 ml sample	Nil in any 100 ml sample	Nil in any 100 ml sample	

<i>Clostridium perfringens</i> Colony count at 22°C (72 h)	100 CFU/ ml tested	1/100 ml	0/50 ml	100 CFU/ml tested within 3 days of production	100 ml for second examination	100/ml	100/ml	100/ml	50/ml
Colony count at 37°C (24 h) Enterococci Streptococci	20/ml 0/250 ml 0/250 ml	10/ml	10/ml				20/ml	20/ml	50/ml
<i>Staphylococcus Aureus</i>			0/250 ml	2/250 ml fecal streptococci	Nil	Nil	Nil in any 250 ml sample Nil in any 250 ml sample	Nil in any 250 ml sample	Nil
Sulphite-reducing anaerobes			0/50 ml			Nil	Nil in any 250 ml sample		
<i>Pseudomonas aeruginosa</i>	0/250 ml		0/250 ml	0/250 ml			Nil in any 250 ml sample	0/250 ml	0/250 ml
Yeast and mold								Nil in any 250 ml sample	<10/ml
<i>Salmonella</i> and <i>Shigella</i>			0/250 ml				Nil in any 250 ml sample		Absent
<i>Vibrio cholera</i> and <i>V. parahaemolyticus</i>							Nil in any 250 ml sample		Absent

Key P = Provisional value.
Values shown as (for example) 5000; 600–1000*** are to be interpreted as follows: 5000 = health risk limit, 600–1000 = range for aesthetic unacceptability threshold.
*** = acceptability aspect (not a health related limit) ⁽¹⁾As boric acid
(conc:GV) ≤ 1 = Gross value must be ≤ 1 SASO = Saudi Arabian Standards Organization
NAD = No available data PRC = Peoples' Republic of China.
Adapted from the Asia Bottled Water Association (ABWA) – excerpt modified from ABWA's Technical Manual.

Table 3.12 Comparison of maximum limits specified in Annexure to No R.718 – ‘Regulations Relating to All Bottled Waters’ and the limits for toxic substances in the South African National Bottled Water Association Guidelines and Standards.

I Substance	Maximum limit (mg/l) (from Annexure to No R.718)	Maximum limit (from SANBWA Guidelines & Standards). Where not specified, SANBWA follows No R.718
Antimony	0.005	–
Arsenic	0.01 (as total arsenic)	0.01
Barium	0.7	–
Borate	5.0 (as total boron)	–
Bromate	0.01	–
Cadmium	0.003	0.003
Chromium	0.05 (as total chromium)	0.05
Copper	0.5	1.0
Cyanide	0.07	0.05 calculated as CN
Fluoride	See note* below	1 calculated as F
Lead	0.01	0.01
Manganese	0.5	–
Mercury	0.001	0.001
Nickel	0.02	–
Nitrate	50 (calculated as nitrate)	10 calculated as N
Organophosphate pesticides	Below the limit of quantification	–
Organochlorine pesticides and polychlorinated biphenyls	Below the limit of quantification	–
Selenium	0.01	0.01
Surface active agents	Below the limit of quantification	–

Note: * Bottled water containing more than one mg/litre of fluoride must be prominently labelled ‘contains fluoride’. If it contains more than 2 mg/litre of fluoride, it must be labelled ‘this product is not suitable for infants and children under the age of seven years’.

of sanitisation. In addition, the terms ‘naturally carbonated’ or ‘naturally sparkling’, or ‘with added carbon dioxide’ or ‘non-carbonated’ or ‘non-sparkling’ or ‘still’.

3.9.3 Prepared waters

These waters can be taken from any supply, including surface water and municipal water. Any treatments are allowed (chemical modification or disinfection), provided that the finished product meets the standards laid down in the Annexure.

Labelling must include the words ‘prepared water’, and a description of the treatments – for example, ozonated, demineralised, remineralised, reverse osmosis, etc. If taken from a public or private distribution system, this must also be indicated on the label. Finally, the chemical composition also needs to be included.

Table 3.12 compares the maximum limits from the Annexure to No R.718 – ‘Regulations Relating to All Bottled Waters’ with the limits for toxic substances in the South African National Bottled Water Association Guidelines and Standards.

The microbiological criteria are laid down in the Schedule to the Regulations Governing Microbiological Standards for Foodstuffs and related matters – Government Notice No. R.692 (1997) amended by R.1588 (December 2002):

In the case of natural mineral water or bottled water which is sold as a foodstuff:

- (a) it shall be free from:
 - (i) parasites and pathogenic organisms which may render such product unfit for human consumption;
 - (ii) *Escherichia coli* and other coliforms and faecal streptococci in a sample of 250 ml;
 - (iii) *Clostridium* species in a sample of 250 ml; and
 - (iv) *Pseudomonas aeruginosa* in a sample of 250 ml.
- (b) when tested in accordance with SABS method 221, the total viable colony count shall not exceed 100 organisms per 1 ml. The TVC shall be measured within 24 hours after bottling, the water sample being maintained at $4^{\circ}\text{C} \pm 3^{\circ}\text{C}$ during the period. Thereafter, up to and including the point of sale, the TVC shall be no more than that which results from the normal increase in the bacterial content which the water had at source.

3.10 CONCLUSIONS

At the time this chapter was first written in 1998, and in both the second and this third edition, an attempt has been made to examine the similarities and differences between the ways in which bottled waters are sourced, exploited and regulated in different countries around the world. The two principal approaches have been explored; the first founded upon source selection, protection and minimum treatment, the second based upon the assumption that a source of indeterminate quality, if appropriately treated, can still result in bottled water of consistent and potable quality. In many cases, of course, we have seen that the philosophy has fallen somewhere between these two approaches, in that regulators have as a matter of prudence recognised the value both in the exploitation of well protected sources, and also in permitting (and in some instances enforcing) certain treatments in the interests of quality and public safety.

In the older markets nonetheless, though there have been some refinements to some of the standards since the original publication of this book (most particularly with the consolidation of the legislation governing Natural Mineral Waters and Spring Waters in Europe), the approach has been well established. Similarly, the model in North America has undergone little change since 1998, although the legislators in Canada have at times shown signs of a more 'European' approach. Meanwhile, the newer markets have continued to develop, often founded on the success of products imported from the major European producers, and the way that they regulate their products often has much to do with the prevailing views, not only of their own regulators, but also of the countries from which their imports originate. In many of the 'old' economies outside Europe but where the European influence has been prevalent, the traditional concept of natural, untreated waters has survived. On the other hand, the parallel adoption by the newer markets, such as Australasia and Asia, of the principles laid down in the IBWA Model Code has continued the trend set in the USA. In addition, the work of the Codex Alimentarius Commission has provided guidance for all in establishing safety-related standards for all bottled waters, regardless of origin and increasingly, the newer markets look to these for guidance.

In many parts of the world, the consumption of bottled water has become the norm, and consumers quite rightly have the expectation that the product will always meet the highest standards. At the same time, as technology improves, lower and more precise detection limits for analysis become possible, while higher and higher standards are demanded. This will continue to place a premium, not only on water that undergoes extensive treatment in order to ensure compliance but perhaps more importantly on water which, by a combination

of natural protection and good environmental and resource management, can continue to prove to be of the highest quality.

ACKNOWLEDGEMENTS

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Asia Bottled Water Association (ABWA): www.asiabwa.org
Australasian Bottled Water Institute Inc. (ABWI): abwi@bottledwater.org.au
British Soft Drinks Association: www.britishsoftdrinks.com
Canadian Bottled Water Association (CBWA): www.cbwa-bottledwater.org
European Bottled Water Cooler Association (EBWA): www.ebwa.org
Health Canada, Ottawa, Ontario K1A 0K9 <http://www.healthcanada.gc.ca>
International Bottled Waters Association (IBWA): www.bottledwater.org
International Council of Bottled Waters Associations (ICBWA): www.icbwa.org
Latin American Bottled Water Association (LABWA): www.labwa.org
South African National Bottled Water Association (SANBWA): www.sanbwa.org.za

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4 Hydrogeology of Bottled Waters

Mike Streetly, Rod Mitchell, Melanie Walters
and Peter Ravenscroft

4.1 INTRODUCTION

There has been substantial growth in the market for bottled waters over the last few decades. Accompanying this growth have come significant changes in both the legislation and regulations that govern production of bottled waters, and in public opinion that drives the market. Guidelines have also been developed to ensure that the product maintains the highest possible standards required by the consumer.

Arising from this change is the increasing need for the water bottler to understand more about the nature of the water resource – the factors that govern the occurrence and hydrochemical characteristics of underground water. And yet not only are the processes that create their product natural and largely out of their control, but they also occur below ground, at depths of tens or even hundreds of metres, and so are out of sight, and sometimes, unfortunately, out of mind.

Although the processes may not be directly controllable, they can be influenced for good or ill. Careful development and management of a groundwater source can ensure a steady and reliable supply of the highest quality water. Hasty or ill-judged development can damage the crucial raw source on which bottled waters ultimately rely. In some cases irreversible damage can be done.

This chapter provides a concise description of the hydrogeological principles that govern the quality and quantity of the bottled water source. We first explain the science of the flow and chemical evolution of underground water. Those already familiar with the basic science may still find Sections 4.2 and 4.3 useful for occasional reference. With this background, the measures needed to develop and manage a source in a sustainable manner are described in Sections 4.4, 4.5 and 4.6. Building on the second edition of this book, more detail is presented on catchment protection, in line with the greater awareness of the need to rigorously protect water sources and the availability of tools to assess risks.

Once the science is appreciated, it may seem quite straightforward, but what is less straightforward is the large combination of factors involved, the degree of interaction between them, and the distribution of all of these over large volumes of space and, more worryingly, over time (by the time a change in water quality is detected at a source, the reason for it may have been happening for years). What is needed is a person whose broad hydrogeological experience enables them to diagnose and predict with confidence. The principles discussed in this chapter form the basis for source management, but cannot consider all geological and

hydrochemical conditions. Many water bottlers will also access help from a qualified hydrogeologist to ensure that they use the guidance of an appropriate expert.

4.2 UNDERSTANDING UNDERGROUND WATER – HYDROGEOLOGY

4.2.1 Underground water – a key part of the water cycle

The concept of a global water cycle has been appreciated for over 300 years. The cycle is driven by solar energy that evaporates sea water to form clouds, which in turn fall as rain, supplying the rivers with water that flows back to the sea. Only part of this cycle – that proportion of water which, after falling as rain, percolates (recharges) into the ground before emerging sometime later from springs and boreholes – is of direct relevance to those interested in the development of bottled water sources.

Unlike rainfall, which directly affects our daily lives, underground water is largely invisible and thus is rarely appreciated or understood. This is despite the fact that at any one time, worldwide, there is over 30 times as much fresh water stored underground as in rivers and streams, and that much of our public water supply is sourced from underground water rather than from much more conspicuous surface water reservoirs.

The few places in which groundwater flow may be visible, for instance in large caves, are often dramatic and this fact gives rise to the common misconception that underground water, like surface water, flows in rivers and streams. In fact, such occurrences are largely atypical.

The following account of hydrogeology draws on the standard texts listed at the end of this chapter.

4.2.2 Recharge to underground water

In this section we outline how water enters, flows through and is stored underground, and how it may flow to wells, boreholes, rivers and streams. At present, the average precipitation over the whole of the Earth is estimated to be around 900 mm/year. In the UK, the long-term average rainfall varies from 500 to 4300 mm. (Precipitation usually falls as rain, but other forms such as snow and dew, are included in these figures.) As a result of a number of processes, not all precipitation infiltrates into the ground and recharges the body of underground water that supplies streams and boreholes (Fig. 4.1). Recharge is the volume of rainfall that remains after all these processes have occurred. Thus:

$$\text{Recharge} = \text{rainfall} - \text{interception} - \text{runoff} - \text{evapotranspiration} - \text{interflow}$$

Recharge is the primary resource for all supplies sourced from underground water. All the water that is recharged to underground water eventually emerges in springs, streams and rivers. This component of flow to rivers is referred to as baseflow, and, because there may be a long period between recharge of the water table and emergence in springs and rivers, baseflow is vital to the support of river flows during dry periods. Human intervention now means that some of this baseflow may be intercepted by wells or boreholes.

The porous nature of most soils enables them to hold a certain volume of water against the force of gravity. This volume is referred to as the *field capacity*. If the soil has less moisture than this (i.e. has a *soil moisture deficit*) owing to the effects of plants, no water will

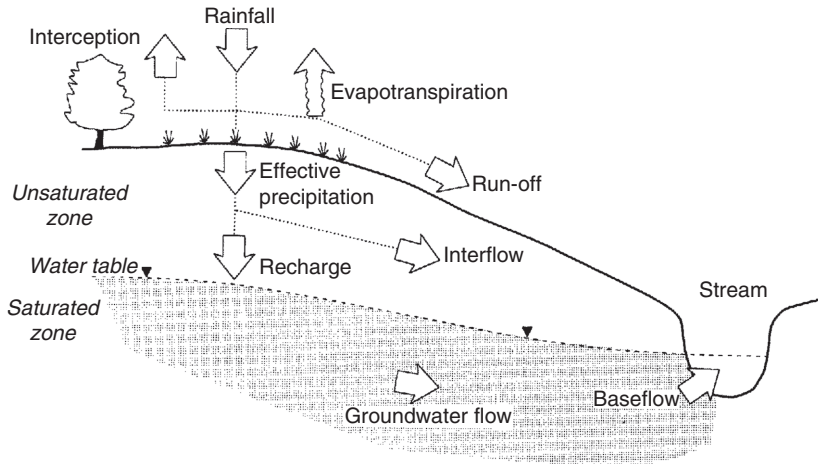


Fig. 4.1 Groundwater flow in the hydrological cycle.

percolate downwards. Thus, summer rainfall does not usually result in any recharge to groundwater. Consequently a hot, dry summer (an *agricultural drought*) may have little effect on groundwater sources. Most groundwater recharge occurs during winter months and a dry winter may lead to a *hydrological drought*. Soil moisture deficits cannot increase indefinitely, as at some point the process of evapotranspiration will cease to function and plants will wilt.

4.2.3 Groundwater occurrence

Almost all rocks occurring in the surface layers of the Earth's crust contain some void space that may be filled with fluids or gases. Below a depth of about 10km the stress caused by the overlying rocks usually causes these to close. Voids of fairly uniform shape (such as the spaces between sand grains) are referred to as *pores*, whereas voids that are predominantly linear are referred to as *fractures* or *fissures*. The ratio of void space in the total rock volume is referred to as porosity. The porosity of clean sands or gravels may be from 25% to 50%, whereas for granite and other fractured rocks, it is usually less than 10%. Different types of porosity are illustrated in Fig. 4.2.

Water occurs in two distinct zones underground; in the upper, *unsaturated zone* the voids are only partially filled with water (held in the necks of the pores by capillary forces), and the remainder is filled with air: below this, in the *saturated zone*, the voids are entirely filled with water. The boundary between these two zones is referred to as the *water table* and can be observed as the level of water in wells and boreholes where these penetrate through the unsaturated zone to the saturated zone.

Porosity is not a measure of the ability of a rock to transmit water; a rock may be very porous but if the voids are not connected it will not transmit water easily. *Permeability* (measured in m/day) is the usual measure of the ability of a rock to transmit water. Typical values of permeability for different rock types are shown in Fig. 4.3. A related parameter is *transmissivity* (m^2/day), which is a measure of the ability of a formation to transmit water (i.e. $\text{transmissivity} = \text{permeability} \times \text{thickness of formation}$).

A formation that can store groundwater and that is sufficiently permeable to transmit to wells and springs is referred to as an *aquifer*. A formation that is effectively impermeable to water is referred to as an *aquiclude*. Even the most impermeable materials that occur in nature are, in

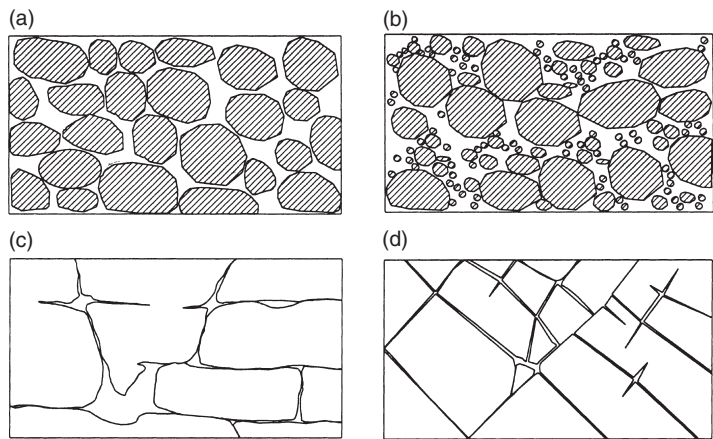


Fig. 4.2 Different types of porosity in rocks.

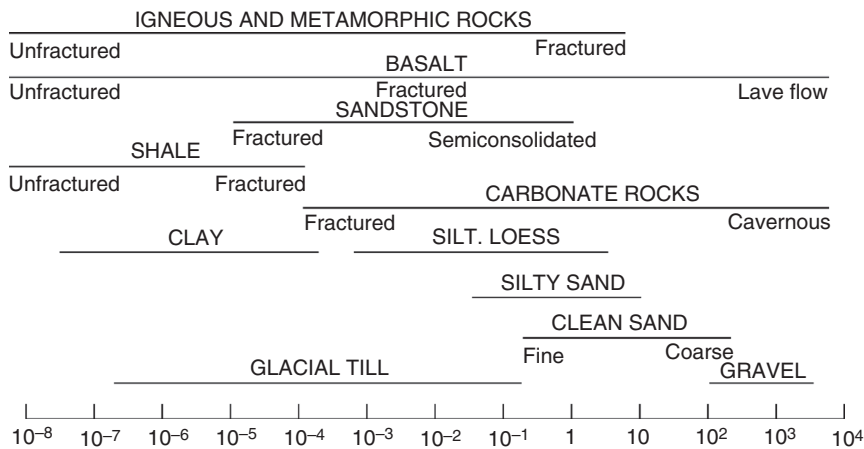


Fig. 4.3 Permeability of selected rocks (from Ralph C. Heath, Basic Ground Water Hydrology, US Geological Survey Water Supply Paper 2220, United States Department of the Interior, 1984).

fact slightly permeable to water, particularly on a long timescale. Where these minor flows are of relevance, these formations may be referred to as *aquitards* rather than aquicludes.

An *unconfined aquifer* (see Fig. 4.4) is one which contains an unsaturated zone and a water table (one in which the position of the water level in wells and boreholes lies within the aquifer). If an unconfined aquifer is filled up to the top by recharge, it will start to overflow when the water table intercepts ground level (i.e. at a spring). However, often aquifers are partially overlain by aquitards or aquicludes (confining layers). If water fills up to the top of the aquifer, it cannot overflow (is confined) and the water is stored under pressure. This is referred to as a *confined aquifer*. If a borehole penetrates through the confining layers into a confining aquifer, the water level will rise up the borehole above the top of the aquifer. The amount of rise depends on the pressure at which the water is stored. The water level may rise above ground level, whereupon the borehole will overflow naturally. This is

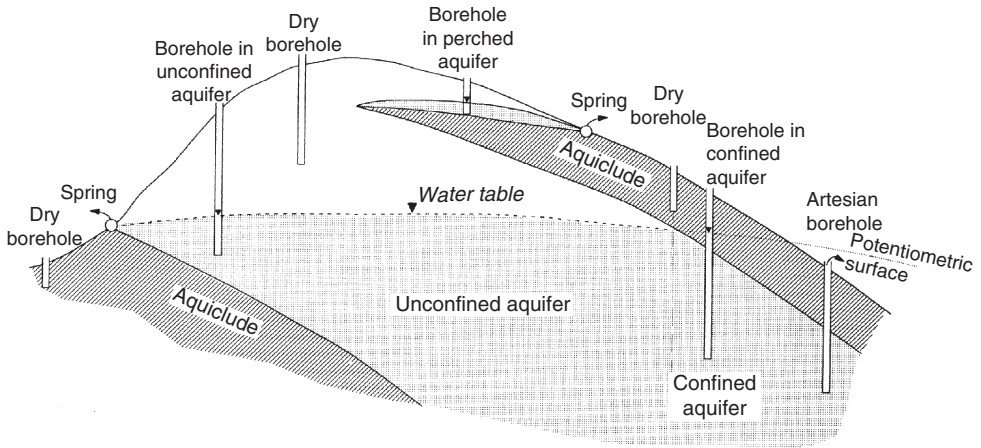


Fig. 4.4 Types of aquifer.

referred to as an *artesian borehole*. Where a thin confining layer occurs within the unsaturated zone of an unconfined aquifer, recharge may accumulate on this layer forming a *perched aquifer*.

Aquifers in which the pores are relatively evenly distributed and interconnected (e.g. sand and gravels) are referred to as *intergranular aquifers*. Flow in such aquifers is usually evenly distributed throughout, and the water is slowly filtered through the pores. In *fractured aquifers* flow is concentrated in the fractures or fissures, and water often flows more rapidly than in intergranular aquifers. As a result, contamination can travel through fissured aquifers much more rapidly and with less retardation than in intergranular aquifers.

4.2.4 Water levels and groundwater flow

Groundwater flows from areas with high water levels to those with low levels. The potential energy that drives groundwater flow may be measured by the water level (or *groundwater head*) in wells and boreholes, measured as height above a standard datum (such as sea level).

The direction of such flows can be determined by constructing a contour map of groundwater levels; groundwater flow will be perpendicular to the contours of groundwater levels (just as flow of water along the ground will be perpendicular to ground level contours). Determining an accurate flow direction requires a minimum of three wells. The surface defined by the water level in wells and boreholes is referred to as the *potentiometric* or *piezometric surface*. In unconfined aquifers this is the same as the water table. In confined aquifers the potentiometric surface lies within the confining layer or above ground level.

The slope of the potentiometric surface is called the *hydraulic gradient* and this, together with permeability, controls the rate at which groundwater flows. Groundwater head differences may also occur vertically, and hence groundwater may flow vertically as well as horizontally, for example through an aquitard separating an upper and lower aquifer.

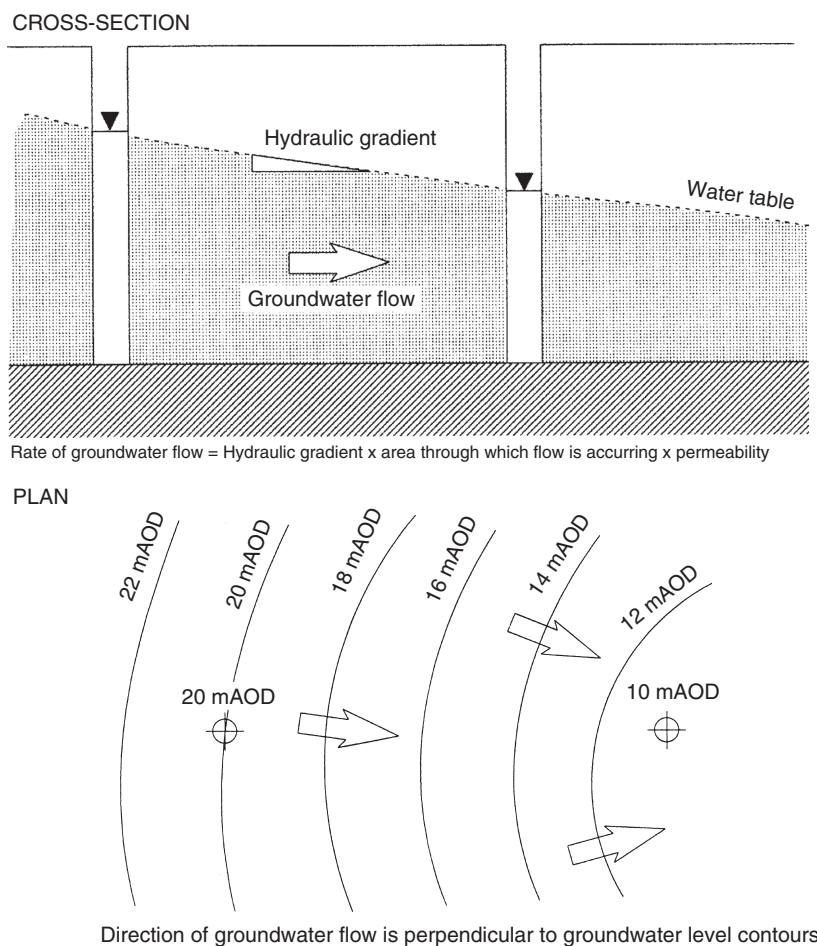


Fig. 4.5 Groundwater flow and Darcy's law. (m AOD = metres above Ordnance Datum.)

Groundwater flow, particularly at depth, can also be driven by thermal energy, density differences, or in some cases by geochemical factors. The rate of groundwater flow is dependent on both the hydraulic gradient and permeability. Darcy's law describes this quantitatively:

$$Q = KiA$$

where (see Fig. 4.5): Q = the flow of groundwater (m^3/day); K = permeability (m/day); i = hydraulic gradient (difference in water levels divided by separating distance); and A = area of rock through which groundwater is flowing (m^2).

This law is directly analogous to Ohm's law that describes the flow of electricity through a conductor. Darcy's law is valid only for laminar (non-turbulent) flow. As most groundwater flows very slowly, the flow is almost always laminar. However, in fissured aquifers and near boreholes, flows are much faster and may become turbulent, in which case a steeper hydraulic gradient is required to force the same rate of flow through the rock.

4.2.5 Storage of water in aquifers

4.2.5.1 Storage in unconfined aquifers

When water flows out of an unconfined aquifer, the level of the water table falls. The volume of water that flows out is equal to the volume of water that has drained out of the zone where the water table has fallen.

A preliminary assessment might suggest that this volume is the volume of rock that has drained multiplied by the porosity. However, this is not the case as not all the water in the voids drains freely under gravity – some is held back by capillary effects. The actual volume of water that drains by gravity out of a given volume of rock is referred to as the *specific yield* (see Fig. 4.6). Thus:

$$\text{Volume of water released from storage} = \text{volume of rock drained} \times \text{specific yield}$$

The specific yield is always less than the porosity, sometimes significantly; the Chalk aquifer in the United Kingdom has a porosity of 40% but a specific yield of only 1–2% (also written as a ratio 0.01–0.02). This is because the very small necks of the voids in the Chalk matrix restrict water from being drained from them.

4.2.5.2 Storage in confined aquifers

This concept of storage can best be illustrated by an analogy; when air is let out of a bicycle tyre, the volume of air released is much greater than the volume of the tyre when fully inflated. This is because the air in the tyre has been compressed and expands as it is released. The tyre also contracts a little as the air is let out, contributing a small amount to the volume released. Water is much less compressible than air, but the effect is the same and slight compression of the aquifer acts in the same way as the contraction of a bicycle tyre. Both of these effects are very small but are still sufficient for confined aquifers to release significant quantities of water from storage when they are pumped.

The coefficient that describes the volume of water released from a confined aquifer by this pressure release mechanism is called the *storativity* (or confined storage coefficient, see Fig. 4.6). Thus:

$$\text{Volume of water released from confined storage} = \text{area over which water levels} \\ \text{have fallen} \times \text{fall in water levels} \times \text{storativity}$$

The value of storativity is much smaller than specific yield (typically 10^{-4} but may vary from 10^{-3} to 10^{-5} , depending on the type of aquifer). Once the confined storage has been used up, the aquifer will become unconfined and water will come from the specific yield.

4.2.5.3 Natural fluctuations in water levels

Water levels in boreholes are rarely static. Natural fluctuations may occur due to several causes:

- *Seasonal variations in recharge:* Recharge to groundwater occurs mostly during winter, leading to a rise in groundwater levels. During summer months, groundwater levels gradually fall as water is discharged without being replenished. Longer-term

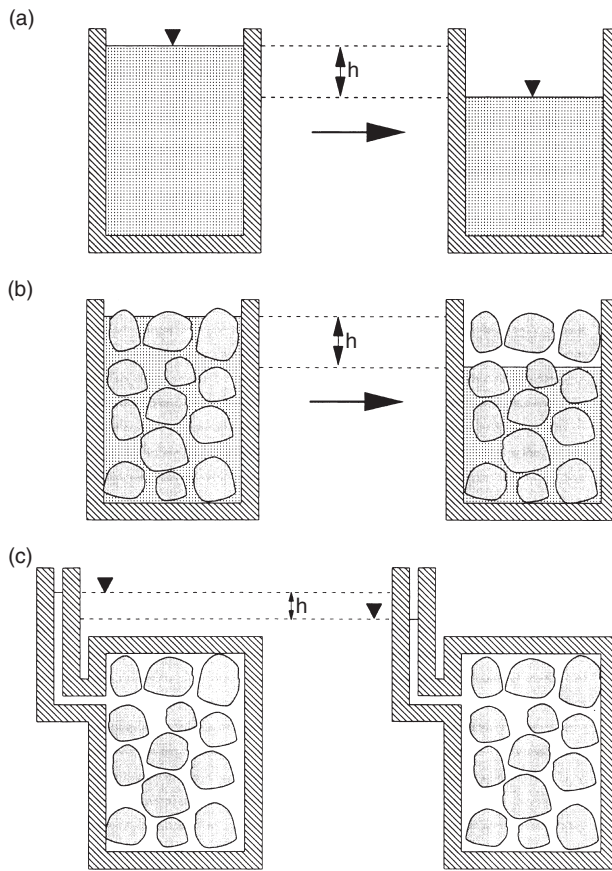


Fig. 4.6 Types of storage in aquifers. (a) Volume released from storage = $h \times \text{area}$. Volume released from storage per unit area = h . (b) Volume released from storage = $h \times \text{drained porosity}$. Drained porosity is called specific yield or unconfined storage coefficient. (c) Most of the storage has been released by water expanding as the pressure falls. The pores in the aquifer will also compress slightly as the pressure falls.

fluctuations in groundwater levels may be caused by a succession of dry or wet years.

- *Short term variations:* These are often observed in boreholes on a timescale of hours to several days. These fluctuations occur most often in deep, confined aquifers and may be linked to variations in atmospheric pressure or to gravitational influence of the moon (earth tides). In aquifers near to the coast, ocean tides may also cause water level fluctuations.

4.2.6 Wells, springs and boreholes

Groundwater flows naturally either to static water (ponds, marshes and wetlands) or to flowing water (streams and rivers). In either case, groundwater is often essential for maintaining the surface hydrological system, particularly during dry periods. Groundwater may discharge either over a broad zone (*seepage*) or at a distinct point (*spring*). Springs are more commonly associated with fractured aquifers, which tend to concentrate flows

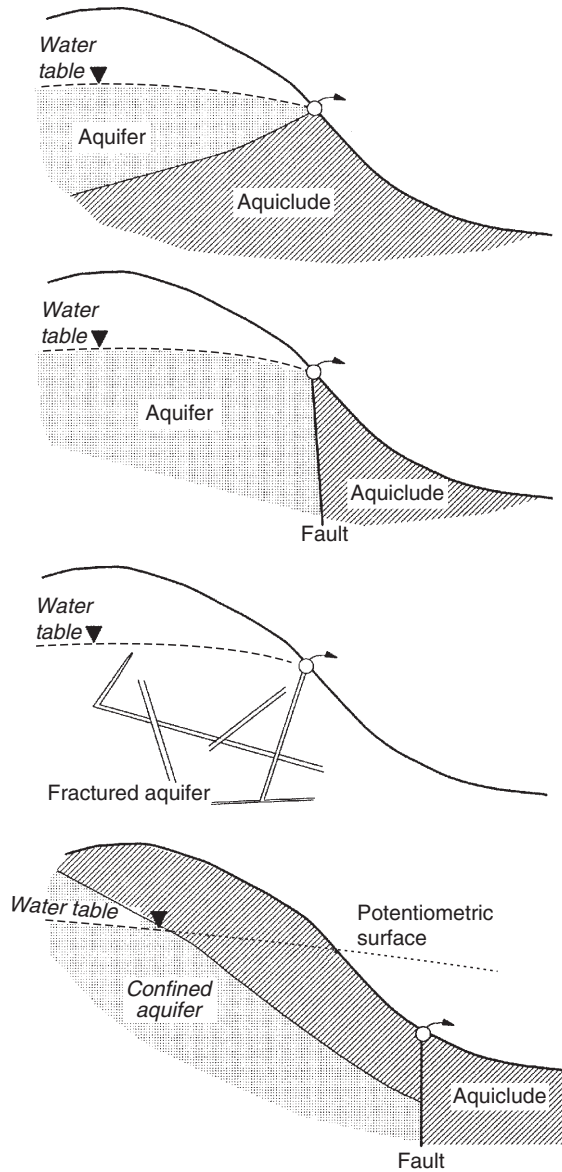


Fig. 4.7 Types of springs.

in discrete zones, but springs can also occur in intergranular aquifers, depending on how the aquifer intersects the ground. A variety of possible spring configurations is illustrated in Fig. 4.7.

A well is essentially a man-made static source of groundwater, in contrast to a spring, which is a naturally flowing feature. However, many famous ‘wells’ are in fact springs that have had protective structures built over them. Wells are usually subdivided into two groups according to their method of construction: *hand-dug wells* or *shafts*, and machine-drilled wells or *boreholes*. Hand-dug wells are rarely constructed in developed countries now

as they are slow, labour intensive and often dangerous to dig. As hand-dug wells usually only penetrate the aquifers nearest to the surface, they are particularly prone to both contamination and the effects of drought. A common feature in deep hand-dug wells that have been constructed in competent (i.e. firm) rock is the construction of horizontal collecting galleries referred to as *adits*. A variation on this, the Ranney well, involves the drilling of horizontal boreholes in which small diameter well screens are installed. These structures are very effective at increasing the yield of wells, particularly in less permeable aquifers. Drilling techniques are discussed in Section 4.4.4.

4.2.7 Flow to wells and boreholes

When we start to pump a borehole, water is first removed from storage in the borehole. This creates a hydraulic gradient across the sides of the borehole and water starts to flow from the aquifer into the borehole (Fig. 4.8a). Water is now being taken from storage in the aquifer and the piezometric surface starts to fall (Fig. 4.8b). This creates a *cone of depression* around the borehole. The radius of this cone is called the *radius of influence* (r_0). Eventually water levels stop falling, which is called *steady state*. Until this point is reached, the situation is transient (*unsteady state*), with water being taken from storage, causing the levels to fall.

There are three different ways of describing the yield of a borehole, depending on the timescale over which the yield is being assessed:

- *Borehole yield*: This is a short-term measure of how much can be pumped from a particular borehole. This yield is often measured by the specific capacity. The specific capacity is defined as:

$$\text{Specific capacity} = \frac{\text{pumping rate}}{\text{steady-state drawdown at that pumping rate}}$$

- *Specific capacity*: This is usually the same order of magnitude as the transmissivity of the aquifer, and can be used to approximate transmissivity where proper pumping test interpretations are not available.
- *Aquifer yield*: This is a more general medium-term measurement of the ability of the aquifer to yield water to springs, wells and boreholes. Unlike low borehole yield, which can be compensated for by drilling more wells, aquifer yield is determined by the resource and is a fundamental constraint.
- *Sustainable (or safe) yield*: The term sustainable yield is somewhat subjective, but describes the achievable yield that does not involve excessive economic cost or unacceptable cost to the surface environment or other abstractors. It is often said that if the sustainable yield of an aquifer is exceeded, water levels will fall year on year as water is drawn from groundwater storage. This is sometimes called groundwater mining. While this concept is useful, it may be simplistic, because unlike surface water catchments, groundwater catchments are generally not tightly bounded, and so it may be possible to mine groundwater storage for a number of years until a new equilibrium condition, with a larger catchment, is established.

It is also useful to distinguish the *potential yield* of a borehole (the maximum theoretically available) from the *deployable output*, which takes into account practical considerations such

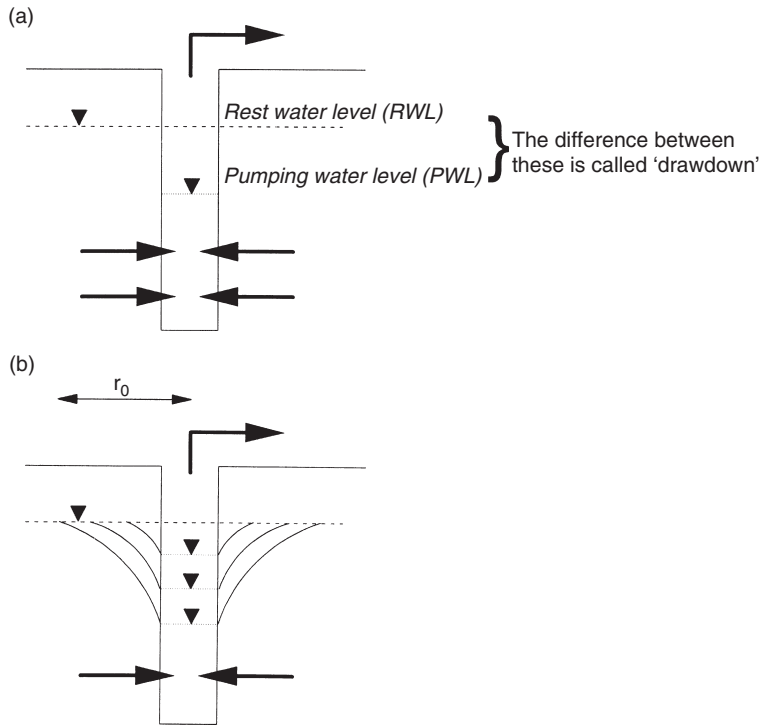


Fig. 4.8 Flow to a borehole. (a) Flow to a borehole. (b) Unsteady state pumping, showing increases in water level and radius of influence as water is taken from storage.

as pump level, processing capacity and licensed capacity. The yields listed above can be determined by testing the borehole in the following ways.

4.2.7.1 Step test

As water flows towards a borehole it converges and, as the same volume has to flow through a smaller and smaller area, the velocity increases. If the velocity increases beyond a certain value (0.03 m/s is often quoted, but the real value is proportional to permeability), turbulent flows may occur and this requires greater hydraulic gradients to drive the same flow of water through the aquifer. Consequently, where turbulent flows occur, drawdown in a pumping borehole will be greater. The extra drawdown is referred to as *well loss* in contrast to *aquifer loss*, which is the inevitable drawdown in a borehole for an aquifer with those properties. Well efficiency is a useful guide to the condition of a borehole and is defined as:

$$\text{Well efficiency} = \frac{\text{aquifer loss}}{\text{total drawdown}}$$

Well efficiencies are typically in the range 60–70% but may be as low as 10–30%. They usually fall at higher pumping rates and may change with time. Well efficiencies are a useful guide to the condition of a borehole.

Step tests are used for determining both borehole yield and well efficiency. In a step test, drawdowns are monitored while the borehole is pumped for steps of sequentially increasing

pumping rate (e.g. 100 min at 50 m³/day followed by 100 min at 100 m³/day followed by 100 min at 150 m³/day). At least three, and preferably five, steps are performed to define the yield-drawdown curve. Step tests are used to distinguish aquifer losses (which increase in proportion to the pumping rate) and well losses (which increase in proportion to the square of the pumping rate). This is usually expressed as:

$$\text{Total drawdown} = BQ + CQ^2$$

where B = aquifer loss coefficient (BQ = aquifer loss), C = well loss coefficient (CQ^2 = well loss) and Q = pumping rate.

Step tests are also useful for identifying critical pumping levels at which borehole yield declines drastically, or the water quality changes. These effects are particularly important in fractured rock aquifers.

4.2.7.2 Constant rate test

This test is used for defining the aquifer yield and aquifer parameters. Pumping water levels are monitored while a borehole is pumped at a constant rate. Drawdowns change with time (and with distance if water levels are measured in surrounding boreholes) and can be used to calculate aquifer parameters such as transmissivity and storativity and may also indicate the presence of aquifer boundaries and interconnection between layered aquifers. Constant rate tests may also be used to determine whether pumping a borehole will have any impact on surrounding water features (lakes, ponds, streams) or other water users.

4.2.7.3 Recovery test

This test is routinely and easily carried out at the end of the constant rate test by measuring the rise in water levels after the pump is switched off. This test has two main benefits. First, it can be interpreted to provide a cross-check on the aquifer parameters derived from the pumping test and second, it is crucially important to determine whether there has been a significant permanent lowering of water levels in the aquifer as a result of pumping. For the latter purpose, it is essential that water level readings are made for several days before and after the pumping test, so that the effect of any long term trend can be accounted.

4.2.7.4 Long-duration pumping

Preliminary estimates of sustainable yield can be made by studying aquifer geometry, recharge rates and constant rate pumping test results, but the long-term sustainable yield can only be determined by a long period of pumping. It is therefore very important that records of operational pumping rates and water levels are continuously maintained.

4.3 GROUNDWATER QUALITY

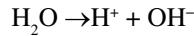
4.3.1 Hydrochemistry – the history of a groundwater

Hydrochemistry is the most distinguishing signature of any groundwater source. While there is relatively little variation in the chemical composition of water falling as rain or snow, the hydrochemistry of groundwater varies enormously from very lightly mineralised

waters that are essentially filtered rainwater to highly mineralised brines. The precise composition of a groundwater source is a record of its history since falling as rain and in particular a record of the strata through which it has passed and the temperature and pressures to which it has been subjected.

4.3.2 Terms, definitions and concepts

Water is very effective at dissolving salts and some types of organic matter owing to the electrically polarised nature of the water molecule and its tendency to dissociate into constituent ions:



These positively and negatively charged ions are extremely effective at binding with oppositely charged mineral ions to form hydrated ions, thus taking them into solution. This makes water one of the most effective solvents in nature.

The total amount of dissolved material in a sample of water is referred to as the *total dissolved solids* (TDS). The TDS is measured by heating the sample to 180°C so that all the water evaporates, leaving a dry residue that can be weighed. As these dissolved constituents are mostly in ionic form, water solutions are good conductors of electricity (measured as *electrical conductivity* (EC) in micro-siemens per centimetre, $\mu\text{S}/\text{cm}$). As the EC of water increases with increasing ionic content, EC is approximately proportional to TDS. EC is a useful field measure of how ‘mineralised’ a water is.

The constituents of groundwater can be classified first as organic (carbon based) or inorganic. Inorganic constituents are positively charged (*cations*), negatively charged (*anions*) or non-ionic. They have been classified as *major ions*, *minor ions* and *trace elements* according to the frequency with which they occur in groundwater (See Table 4.1). Major ions normally comprise at least 90% of the TDS. As virtually all elements are soluble in water to some degree, only the most common trace elements are shown in Table 4.1. Dissolved organic matter is ubiquitous in natural groundwater. The *total organic carbon* (TOC) concentration in groundwater is typically in the range 0.1–3 mg/l. Table 4.1 includes the inorganic parameters prescribed under typical bottled water regulations.

Dissolved gases are commonly present in groundwater and may contribute significantly to the character of a bottled water. Nitrogen and oxygen are the most common constituents of the Earth’s atmosphere and are present in most recharge waters. Carbon dioxide occurs in equilibrium with carbonate and bicarbonate ions common in most groundwaters. Methane, hydrogen sulphide and nitrous oxide are products of biologically related processes that can occur in confined aquifers. A variety of units is used in the water industry to express the concentration of dissolved constituents.

4.3.2.1 Mass concentration (mg/l or $\mu\text{g}/\text{l}$)

This is the most commonly used unit of concentration and is an expression of the actual mass of that constituent dissolved in a litre of water. This is straightforward when the ion consists of a single element (e.g. Na, Cl, etc.), but confusion can arise where the ion consists of a multi-element species (e.g. HCO_3^- , NO_3^-). The concentrations of these are sometimes reported as the mass of the species in solution (e.g. nitrate as NO_3^-) and sometimes as the mass of the key element in solution (e.g. nitrate as N). It is therefore essential to be clear

Table 4.1 Classification of dissolved inorganic constituents of groundwater.

Cationic			Anionic	
Major ions	Minor / trace elements		Major ions	Minor / trace elements
Calcium (Ca)	Aluminium (Al)	Lithium (Li)	Carbonate (CO ₃)	Arsenic (As)
Magnesium (Mg)	Ammonium (NH ₄)	Manganese (Mn)	Bicarbonate (HCO ₃)	Boron (B)
Sodium (Na)	Antimony (Sb)	Mercury (Hg)	Chloride (Cl)	Bromide (Br)
Potassium (K)	Barium (Ba)	Molybdenum (Mo)	Sulphate (SO ₄)	Bromate (BrO ₄)
	Beryllium (Be)	Nickel (Ni)	Nitrate (NO ₃)	Cyanide (CN)
	Cadmium (Cd)	Strontium (Sr)	Silicate (SiO ₄)	Fluoride (F)
	Chromium (Cr)	Uranium (U)		Iodide (I)
	Cobalt (Co)	Zinc (Zn)		Nitrite (NO ₂)
	Copper (Cu)			Phosphate (PO ₄)
	Iron (Fe)			Selenium (Se)
	Lead (Pb)			Sulphide (S)

Table 4.2 Conversion of mass concentration units.

Original units	Multiply by	To give required units
mg/l nitrate as N	4.43	mg/l nitrate as NO ₃ ⁻
mg/l ammonia as N	1.29	mg/l ammonia as NH ₄ ⁺
mg/l bicarbonate as CaCO ₃	1.22	mg/l bicarbonate as HCO ₃ ⁻
mg/l carbonate as CO ₃	2.03	mg/l bicarbonate as HCO ₃ ⁻

about the system that has been used for reporting concentrations. Conversion factors for concentration units commonly reported are listed in Table 4.2.

4.3.2.2 Measure of the number of molecules per litre (mol/l or meq/l)

Molarity (mmol/l) is the most fundamental measure of the actual number of molecules in a litre, as opposed to the mass of those molecules in a litre (mg/l):

$$\text{Molarity (mmol / l)} = \frac{\text{mg / l}}{\text{molecular mass}}$$

A more common notation is milli-equivalents per litre (meq/l), which takes into account the valency of the ion (Na⁺ valency one, Ca²⁺ valency two) so that:

$$\text{meq / l} = \text{molarity (mmol / l)} \times \text{valency} = \frac{(\text{mg / l}) \times \text{valency}}{\text{molecular mass}}$$

This is useful because a groundwater sample must have a balanced charge. Thus the sum of cations (positively charged) in milli-equivalents is equal to the sum of anions (negatively charged). This provides a useful check for results from laboratory analyses. Groundwater sampling and analysis should include duplicates and blanks as agreed with the laboratory or chemist.

4.3.2.3 Parts per million (ppm) or parts per billion (ppb)

This is another measure of mass concentration similar to mg/l and $\mu\text{g/l}$. However, instead of being the mass of an ion dissolved in a litre of water, it is the mass of an ion dissolved in a kilogram of solution (water plus ions). For non-saline waters, ppm is practically equivalent to mg/l, and ppb equivalent to $\mu\text{g/l}$.

4.3.3 Hardness and alkalinity

Hardness is the property of water that causes it to form scum rather than lather when mixed with soap. Many hard waters also precipitate scale in equipment that heats water, such as kettles and boilers. Hardness is caused by polyvalent cations, mainly calcium and magnesium, which form insoluble carbonates on heating. Iron and manganese also contribute to hardness. Hardness that disappears on boiling is *temporary hardness* (sometimes called carbonate hardness); that which remains is *permanent hardness*.

Total hardness can be measured directly or, more commonly nowadays, the individual ions are measured and the hardness calculated. For concentrations in mg/l, total hardness in mg/l CaCO_3 is:

$$\text{Total hardness} = [(\text{Ca}/20.04) + (\text{Mg}/12.16)] \times 50.04$$

Alkalinity is a measure of the capacity of a solution to neutralise an acid. As such it does not reflect the concentration of a single parameter. However, in most natural waters, alkalinity is produced largely by bicarbonate ions and, to a lesser extent, carbonate ions. The concentration of bicarbonate (and hence the alkalinity) may change rapidly on being exposed to air, as the bicarbonate breaks down to precipitate carbonate and release carbon dioxide. Alkalinity is best measured in the field, because laboratory determinations are affected by processes occurring during transit. Alkalinity is usually reported as an equivalent amount of calcium carbonate (Table 4.2).

In most groundwaters, if the total hardness is greater than the alkalinity (in equivalent units), then the temporary hardness is the alkalinity, and the permanent hardness is the difference. If sulphate concentrations are low, alkalinity should be similar to hardness.

4.3.4 Evolution of groundwaters

As water flows through the ground, it will gradually acquire a chemical signature from the rocks. Many of the dissolution processes involved are very slow and a groundwater may still be evolving chemically after many thousands of years underground. However, as groundwater flow is also a very slow process (typically a few metres to a few hundreds of metres a year) it is possible to track many of the evolutionary sequences by testing the quality of water at various points in the aquifer between the recharge areas and the discharge area. Increasing the rate of flow through an aquifer (by pumping) may disturb the equilibrium of such a system and lead to discernible changes in groundwater quality.

The chemical evolution of groundwater starts with rainwater. There is a common perception that this is pure H_2O , but in coastal areas rainfall may have a TDS of several tens of mg/l (mainly Na^+ , Cl^- and SO_4^{2-} derived from seawater). Even in inland areas, rainwater may have a TDS of several mg/l, due to the dissolution of carbon dioxide (CO_2) to form bicarbonate (HCO_3^-). This process releases hydrogen ions (H^+), making rainwater slightly

acidic (pH 5–6). In industrial areas, the pH of rainwater may be even lower than this owing to the dissolution of sulphur dioxide/trioxide to form sulphuric acid and nitrous/nitric oxide to form nitric acid. This effect is called *acid rain*. Rainwater also contains dissolved nitrogen and oxygen. The combination of oxygen and salt gives rainwater a corrosive effect familiar to most car owners living near the sea.

Almost all water that recharges to aquifers passes through a soil zone and the nature of the processes occurring in this zone exerts a strong influence on the character of the resultant recharge water. These processes may be chemical or biological and are influenced by human activity.

Most soils have a capacity to generate acids and to consume most of the oxygen dissolved in the percolating rainwater. The most important acid generated in the soil is carbonic acid, formed by the dissolution of carbon dioxide in water. The main source of carbon dioxide is the decay of organic material in the soil, a process that consumes oxygen. Some organic acids are also generated in the soil zone (particularly in peaty soils) and these may contribute significantly to the TOC of the resultant groundwater. Because this process is linked to biological activity, there may be seasonal variations in the composition of recharge waters.

Water infiltrating through the unsaturated zone commonly encounters minerals that are slightly soluble under the influence of carbonic acid to produce recharge water that is often of the calcium bicarbonate type. The following are the main processes that drive the hydrochemical evolution of groundwaters in the saturated zone.

4.3.4.1 Mineral dissolution/precipitation

Water is a very effective solvent and, given enough time, will dissolve most naturally occurring minerals. Mineral availability is thus the primary control on whether a particular ion is present in groundwater. However, the maximum concentration of the ion that can be held in solution (the solubility) varies with temperature and pressure, which may change as the groundwater flows deeper into the aquifer. Thus, a mineral may be being dissolved at one point in an aquifer while being precipitated at another.

4.3.4.2 Oxidation/reduction

Recharge water is usually oxidising but, as the groundwater evolves, this oxygen is consumed by oxidation of organic material so that in confined aquifers (and deep unconfined aquifers) reducing conditions develop. (The oxidising zone is often referred to as the *aerobic zone* and the reducing zone as the *anaerobic zone*.) This transition from aerobic to anaerobic can appreciably effect the composition of groundwater. A common series of reactions that may occur in the anaerobic zone includes:

- reduction of nitrate to nitrogen gas;
- reduction of solid ferric (Fe^{3+}) iron oxides to soluble ferrous (Fe^{2+}) iron;
- reduction of sulphate, possibly accompanied by generation of hydrogen sulphide gas;
- bacterial fermentation of organic material to produce methane.

Where iron oxides are reduced, this may be accompanied by release of adsorbed metals or metalloids such as arsenic.

4.3.4.3 *Ion exchange*

This is the process used in commercial water softening systems, where calcium in solution is exchanged for sodium bound to the surface of minerals called zeolites. These minerals occur naturally in basalts, and the same processes can occur on clays and in glauconitic sands, and can cause the commonly occurring calcium bicarbonate-type recharge waters to evolve to sodium bicarbonate-type waters. The processes are reversible, and can also occur during the early stages of saline intrusion.

4.3.4.4 *Adsorption/desorption*

These processes have similarities with ion-exchange. Adsorption involves the attraction of charged particles in solution to the charged edges of small mineral grains such as clays and iron and manganese oxides and hydroxides. The process is pH dependent, with a critical pH above and below which they adsorb positive or negative ions. Adsorption is a major mechanism for attenuating pollutants such as trace metals and metalloids.

4.3.4.5 *Processes on discharge to the surface*

As a groundwater is discharged at the surface, either at a spring or from a borehole, rapid changes in temperature and pressure may affect the solubility of minerals dissolved in the water. Bicarbonate may dissociate as it depressurises on discharge to precipitate insoluble carbonates and release carbon dioxide. Fe^{2+} may be oxidised to Fe^{3+} , precipitating a rusty-red, insoluble hydroxide. Dissolved gases are often released on discharge and may be potential hazards: methane can accumulate in buildings, creating a risk of explosion; hydrogen sulphide has an unpleasant smell and at concentrations over 1 mg/l renders water unfit for human consumption. Radon is a common constituent of groundwater in areas underlain by certain rock types, particularly granite, and the by-products of its radioactive decay are harmful to health.

These processes may combine in different ways to produce groundwaters of markedly different qualities.

4.3.4.6 *Naturally occurring minor and trace elements*

As noted in Table 4.1, a wide range of minor and trace elements may be present in groundwater. Normally, most are present at insignificantly low concentrations, but occasionally elements such as arsenic, barium, beryllium, manganese, selenium and uranium may exceed drinking water standards. Because natural mineral water is not governed by the same regulations as drinking water, some natural mineral waters can exceed drinking water standards. Some elements, such as lithium, are thought to be harmful even though no threshold concentrations have been specified. Therefore, when evaluating a source, the developer should be conscious of all relevant regulations and guidance both in the domestic and any possible export markets, and ensure that all potentially significant parameters are tested for.

4.3.4.7 *Anionic evolution*

A common sequence of evolution of a groundwater's anionic composition is:

- *Recharge zone*: Active groundwater flushing through well leached rocks. Low TDS with bicarbonate (HCO_3^-) as the dominant anion.
- *Intermediate zone*: Less active groundwater circulation. Higher TDS with sulphate dominant.
- *Deep zone*: Very slow groundwater flow with high TDS and highly soluble minerals present in the groundwater (e.g. chloride).

This sequence can be explained in terms of two factors: mineral availability and mineral solubility. In the recharge zone the most soluble minerals, such as halite (rock salt, NaCl), will have been flushed out long ago so that the groundwater now consists of rainwater modified by dissolution of calcium carbonate. Further into the sequence there has been less flushing and minerals such as gypsum and anhydrite (forms of CaSO_4) may still be present and contribute sulphate to the groundwater. Evolution to chloride-rich brines can occur if the water penetrates into deep sedimentary basins. Chloride-rich groundwaters also occur in coastal aquifers, which may contain slightly modified sea water.

4.3.4.8 Groundwater evolution in carbonate rocks

Carbonate-based rocks (limestone and dolomite) are particularly soluble with respect to slightly acidic recharge waters. This explains how caves commonly develop in this type of rock. A consequence is that groundwaters in such aquifers evolve relatively rapidly to calcium or calcium/magnesium bicarbonate type. Such groundwaters may contain subsidiary quantities of other ions such as sulphate and iron, depending on which other minerals are present in the aquifer. The pH of most of these waters lies between 7 and 8.

4.3.4.9 Groundwater evolution in crystalline rocks

Most crystalline rocks (e.g. basalt and granite) contain a high proportion of quartz (SiO_2) and aluminosilicate minerals, such as feldspars and mica. Dissolution of these minerals by slightly acidic recharge water usually releases silica and cations (e.g. sodium, magnesium, calcium and, to a lesser extent, potassium) to groundwater and leads to a rise in pH and bicarbonate concentration. Because this process is slow, whereas flow in fractured rocks tends to be rapid, young groundwaters in crystalline aquifers tend to be dominated by soil zone processes and to have relatively low TDS and pH (<7). Silica concentrations are typically in the range 10–30 mg/l. Chloride and sulphate, when present, can usually be attributed to atmospheric sources but can be due to the presence of saline groundwater.

4.3.4.10 Groundwater evolution in alluvial and fluvio-glacial sediments

Young sediments, laid down by rivers or glaciers, are the most important source of groundwater worldwide, albeit they are probably relatively less important as sources of bottled water. The evolution of groundwater in these aquifers is affected by how much the sediments have been weathered before deposition and by the amount of interbedded organic matter that can create reducing conditions leading to elevated concentrations of iron, manganese, ammonium, arsenic and methane gas.

4.3.4.11 Groundwater evolution in mixed sequences

Where groundwater flows through a number of different strata, it may follow a complex evolutionary sequence, as minerals are first dissolved and may be then precipitated later in the sequence. Ion exchange is often an important mechanism in this process.

4.3.5 Human influences on groundwater

Up to the twentieth century, groundwater resources had been developed slowly, and generally on a quite localised basis, so that the effects were able to be absorbed by natural processes. Within the last 100 years, and particularly in the last few decades, human activities have progressively modified natural conditions, resulting in significant impacts on groundwater composition in many parts of the world.

4.3.5.1 Agricultural practices

The widespread agricultural application of NPK (nitrogen, phosphorus, potassium) fertilisers since the 1940s has had probably the greatest impact on shallow groundwater quality. Almost all of the phosphate in fertiliser is consumed in the soil zone, but significant concentrations of nitrate and potassium are released to groundwater.

Nitrate concentrations in excess of a few milligrams per litre usually indicate waters derived from shallow aquifers that are polluted, for example by septic tanks or from nitrate residues from farming. Boreholes in many intensively farmed catchments have experienced rising nitrate levels over decades and now exceed drinking water standards. The presence of elevated nitrate concentrations can have significant implications for development of bottled water sources. Since elevated nitrate concentrations can be taken as an indicator of surface pollution, and therefore that the aquifer is not being fully protected from contamination, the recognition of certain categories of bottled waters, such as Natural Mineral Water and Spring Water in many markets, may be compromised.

Much less information is available on the concentration and behaviour of pesticides in groundwater, owing to their much lower levels of occurrence. However, with more accurate analytical techniques available, this is rapidly becoming recognised as a significant issue and maximum concentrations are prescribed for Spring Waters and Drinking Waters.

4.3.5.2 Livestock and wildlife

The faeces of animals are major sources of bacteria, viruses and parasites, such as *Cryptosporidium* and *Giardia*. Normally, most bacteria and parasites are filtered out in the soil and unsaturated zone, and so the risk to groundwater is normally small, except where soils and the unsaturated zone are thin or discontinuous or where recharge to groundwater by-passes this near surface filtration zone.

4.3.5.3 Sewage

Leakage from sewers, septic tanks and cess pits may contaminate groundwater with nitrate, organic compounds and bacteria. The characteristic contaminants, faecal coliforms, are easy to test for and provide evidence of pathways for more dangerous pathogens. Under oxidising conditions, faecal bacteria die quickly but under reducing conditions may survive

for up to a hundred days or so. *Cryptosporidium*, if present, may survive significantly longer. Recent analytical developments use the presence of compounds such as surfactants and caffeine to prove the effect of human sewage effluent on groundwater.

4.3.5.4 Landfills

All forms of waste disposal to land or below the ground endanger groundwater, and can be a major source of contaminants. While most modern active landfills are well understood and monitored, abandoned landfills continue to pose a less clear risk.

4.3.5.5 Acid rain

Burning of sulphur-rich fossil fuels has led to the generation of significant concentrations of sulphur dioxide in the atmosphere in many industrial areas. This forms sulphuric acid in rainwater. The main effect has been on surface ecosystems, but there has also been a discernible effect on some shallow groundwaters.

4.3.5.6 Solvents

Many industrial processes use a variety of chlorinated organic compounds, such as trichloroethene (TCE), tetrachloroethene (PCE) and other volatile organic compounds (VOCs) as solvents. These compounds are very resistant to biodegradation, except under very strongly reducing conditions, and once released into aquifers can be remarkably persistent.

4.3.5.7 Hydrocarbons

Leakage from underground tanks at petrol stations and depots is recognised as a major source of groundwater pollution by benzene, toluene, xylenes and some polyaromatic hydrocarbons (PAHs). Oils and greases are less mobile but may still cause an appreciable problem.

4.3.5.8 Pharmaceuticals

Medicines, through their casual disposal, are an emerging class of groundwater pollutant, and chemicals such as antibiotics can be effective in suppressing natural attenuation of contaminants.

4.3.5.9 Tritium

Atmospheric hydrogen bomb tests in the 1960s led to significant increases in the concentration of tritium (a stable and harmless radioisotope of hydrogen) in rainwater. In many places this can still be detected working its way through the groundwater system. The presence of elevated tritium concentrations is often used as an indicator of relatively young groundwaters, along with other anthropogenic tracers such as ^{85}Kr and SF_6 .

4.3.5.10 Climate change

The issue of climate change, although there is some dispute as to its anthropogenic cause, has evolved to such a degree of certainty that it cannot be ignored by water bottlers. The impacts of climate change will vary geographically, and while predictions of their magnitude and rate

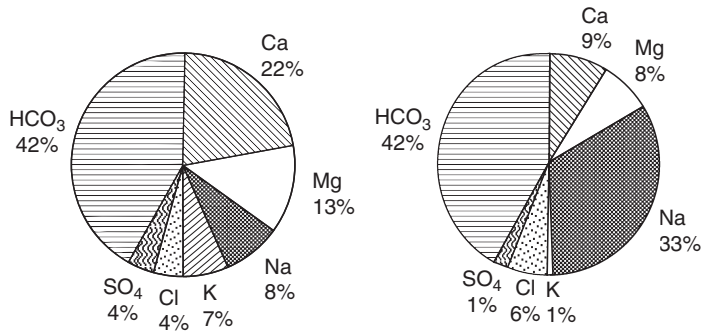


Fig. 4.9 Pie charts to illustrate different groundwater qualities.

of change may be unreliable, the direction of change can be deduced with a fair degree of confidence, and on this basis can be planned for. In northwest Europe, the general predictions are of warmer and drier summers but wetter winters, with an overall increase in short-term variability under all conditions. The first implication of this variability is that groundwater resources will acquire greater value because of their storage capacity. On the other hand, some aspects may have negative impacts, such as reduced availability during drought, and alteration in water quality due to changes in the recharge process resulting from changes in land cover. Changes will not occur suddenly, and the fundamental requirement for the operator is to improve monitoring and more rigorously evaluate changes in groundwater levels, flows and quality.

4.3.6 Hydrochemical classification of bottled waters

As groundwater contains a large number of constituents, classification can quickly become complex. A useful initial approach is to present the information simply and visually. In doing so it is important to use meq/l rather than mg/l, as the latter is biased towards heavier ionic species. Figure 4.9 shows two pie charts that have been used to compare the concentrations of the major elements of two different waters. A variety of other plots has been developed to illustrate composition and evolution of groundwaters, the most common being the Piper diagram and the Durov plot (see Fig. 4.10).

The simplest classification of bottled waters is in terms of their TDS; very lightly mineralised (0–50 mg/l), lightly mineralised (50–500 mg/l), medium mineralisation (500–1500 mg/l) and high mineralisation (150–10 000 mg/l); the exact boundaries between these categories could be selected slightly differently. Most other classifications are based on the dominant cation and anion in terms of meq/l (e.g. calcium bicarbonate type waters). A classification of some well-known brands based on these two approaches is given in Table 4.3.

4.4 GROUNDWATER SOURCE DEVELOPMENT

4.4.1 Stages of development

This section sets out the stages involved in developing a protected groundwater source that is both chemically and bacteriologically safe.

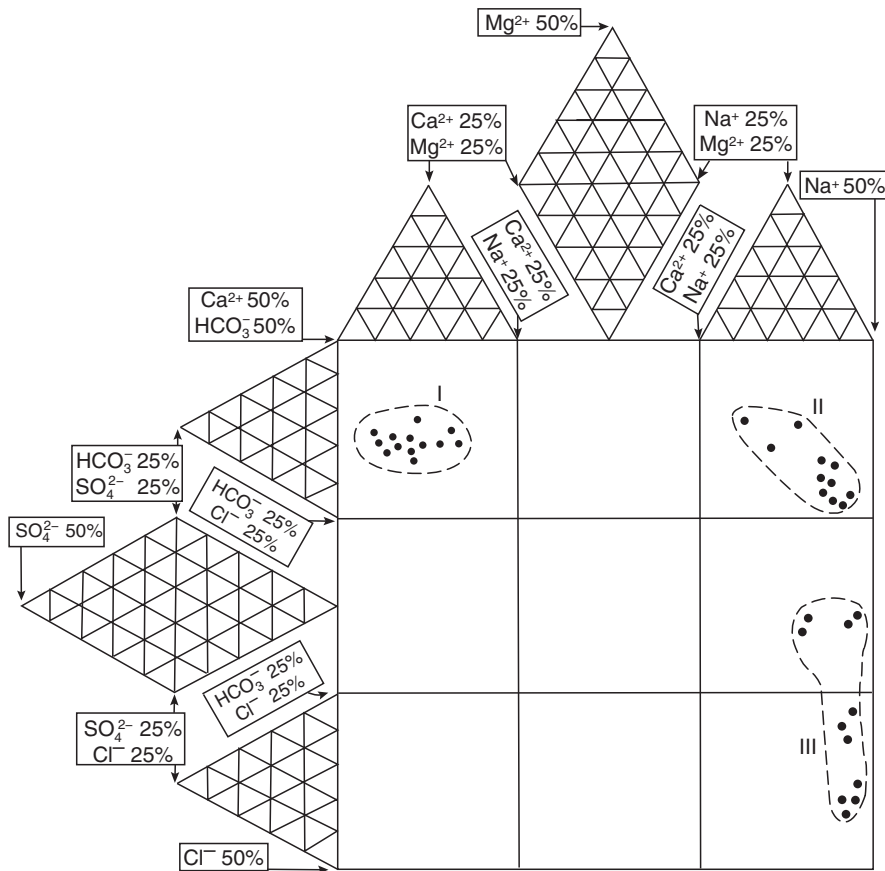


Fig. 4.10 Water types grouped using a Durov diagram. I, fresh recharge water; II, ion-exchanged water; III, old, brackish water (after J. Lloyd and J. Heathcote, *Natural Inorganic Hydrochemistry in Relation to Groundwater*, Clarendon Press, 1985).

Groundwater is naturally better protected from contamination than surface water but is susceptible to mismanagement: it can become chemically or microbiologically contaminated either via inadequate borehole construction or via contamination in the source zone. It can be affected by over-abstraction, and can have unacceptable effects on other local hydrological features (streams and wetlands). The bottled water manufacturer needs to know how to avoid problems that result from the activities of others and of their own exploitation of groundwater. The main stages of developing a resource are as follows:

- **Resource evaluation:** identification of the physical characteristics of the source that govern the quantity and quality of water delivered to it. This should include assessment of the catchment area and the hydrogeology.
- **Source definition:** measurement of the physicochemical and microbiological characteristics of the water. Also defining the variability of the source in terms of flow and composition.
- **Source construction:** borehole drilling and testing or spring works construction.
- **Source management:** continuous monitoring to identify any changes and to provide information for managing the source. This must include designing a strategy for

Table 4.3 Classification of bottled waters.

	Very lightly mineralised (TDS < 50 mg/l)	Lightly mineralised (TDS 50–500 mg/l)	Medium mineralisation (TDS 500–1500 mg/l)	High mineralisation (TDS > 1500 mg/l)
Calcium bicarbonate	San Bernardo Poland Spring	Buxton Evian Font Vella Levissima Panna Perrier Arrowhead	Boario Ferrarelle	Gerolsteiner Sprudel St Gero
Calcium/magnesium bicarbonate	Spa Reine	Highland Spring San Benedetto Volvic	Badoit Vittel Grande Source	
Calcium sulphate			San Pellegrino	Contrex
Sodium bicarbonate				Appolinaris Hassia Sprudel Überkinger

protecting against any factors in the catchment, source or associated works that represent risks to the source water quality.

4.4.2 Resource evaluation

The (surface) *catchment area* of a source is the area within which any rainfall falling on the ground finds its way to the source. The boundary of a surface water catchment is defined by ridges – surface water divides – shown on topographic contour maps. Defining the ground-water catchment area is less straightforward. Ideally it is defined from a water table contour map (see Fig. 4.11). However, the position of the water table is not always known accurately enough to allow this, and indeed may not be fixed in time. Instead, the groundwater catchment must be defined indirectly, using information such as the extent of the aquifer, the position of the water table at boreholes and springs, and the assumption that the water table mirrors the topography. If the recharge to the aquifer is known, the area of a groundwater catchment can be estimated from the relationship:

$$\text{Groundwater catchment area} = \frac{\text{average flow}}{\text{average recharge}}$$

Where the source taps a confined aquifer, the catchment area may be a considerable distance away. For example the recharge area for the Great Artesian basin in Australia is hundreds of kilometres away from the centre of the basin. In reality, estimating recharge rates and sometimes the catchment area can be difficult, but evolves to greater certainty over time as monitoring data are collected and evaluated.

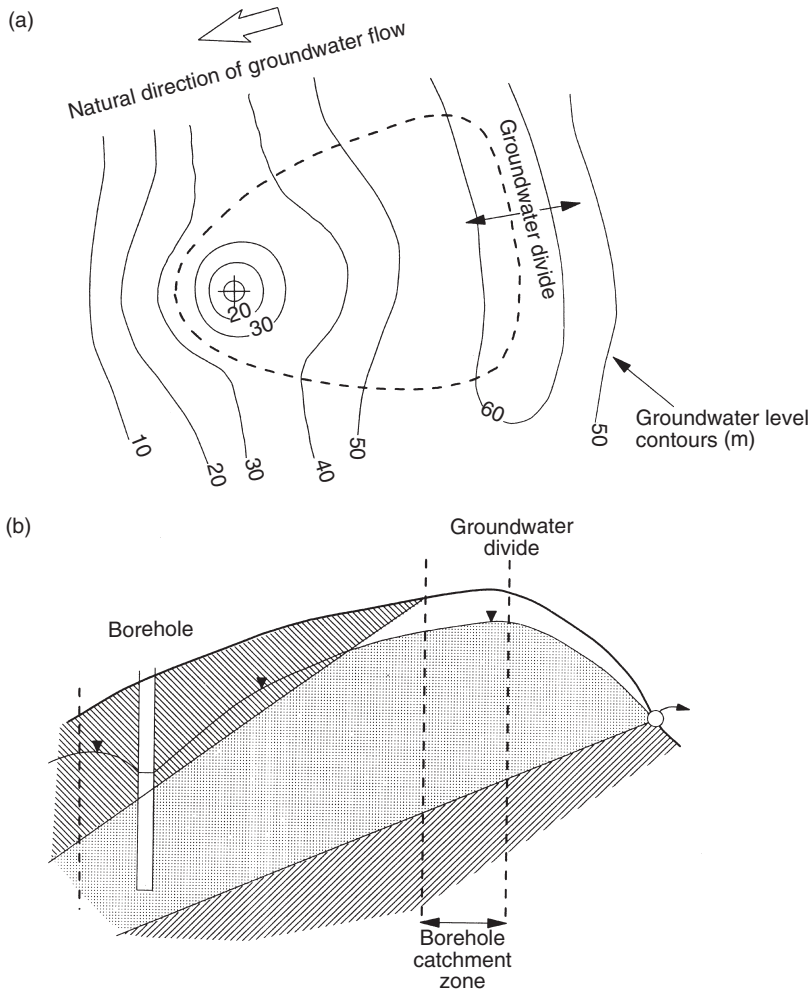


Fig. 4.11 Borehole catchment zones. Top: unconfined aquifer. Bottom: confined aquifer. (After Lloyd, J. and Heathcote, J. (1985) *Natural Inorganic Hydrochemistry in Relation to Groundwater*. Clarendon Press, Oxford.)

Once the catchment area has been defined, the next stage is to develop a *hydrogeological conceptual model* of the processes occurring between the catchment boundary and the source. The aim of this model is to provide a qualitative understanding of how the aquifer system behaves. The conceptual model should define all inputs to the system (usually recharge plus any surface water inflows) and outflows (which may include spring flows, river baseflow and borehole abstraction). The initial conceptual model may identify areas where insufficient information is available and requires further investigation.

A *water balance calculation* is a useful first step in moving from a qualitative to a semi-quantitative understanding. The water balance works on the principle that:

$$\text{Inputs} - \text{outputs} = \text{change in storage}$$

Estimating the volume of storage in the system is important in assessing the vulnerability of the system to drought; a source with large storage will be less vulnerable. Quantification

of the resource can be improved by constructing a computer groundwater model of the aquifer. However, this is a major undertaking, requiring a large amount of data, and should only be attempted if it is judged that the additional assessment will provide a sufficiently improved understanding of the aquifer system.

Developing a source should include an assessment of the hydrogeological impacts on existing water features. In many cases, the environmental effects may be insignificant, but sometimes even a small increase in abstraction can have a large environmental impact. A formal impact assessment may be required by the planning/licensing authorities before permission is granted.

4.4.3 Source definition

There is always some variability in the quality and quantity of groundwater sources. As a consequence it is necessary to monitor the source for a reasonable period in order to define the quality and the reliable yield. For more stable sources, a period of a year may be sufficient, but shallow sources may show greater variability from year to year and will need several years of monitoring. There is a variety of different systems operating worldwide for registering mineral waters and spring waters and the appropriate details should be ascertained for the target market(s).

Before completing the resource evaluation and source definition stage, the potential developer should also make a preliminary assessment of the risks of anthropogenic pollution. Although these are largely operational issues, as described in Section 4.6, any business critical hazards and risks should be identified.

4.4.4 Source construction

4.4.4.1 Springs

Protection

As springs discharge at ground level, there is often significant potential for contamination from the surrounding soil. The first step in developing a spring is therefore to secure the spring head against contamination. As each spring is different, there are no standard construction specifications and great care should be taken to: (i) avoid accidentally blocking or diverting the spring; and (ii) separate the spring flow from any potentially contaminated sources of water such as shallow soil water.

In some cases it may be impossible to prevent all shallow waters from joining the spring flow and hence necessary to cordon off the area from which shallow flows may contribute to flow and strictly control potentially contaminating activities in this area. To avoid turbidity, a filter pack of washed and graded gravel and sand is often included in the spring box together with a settlement tank and washout pipe. A typical spring box construction is illustrated in Fig. 4.12. Water should be piped directly from the spring head to the point of use to prevent contamination; however, a sampling point for water quality testing should be included together with drainage and access points for future use.

Yield

Because springs are natural phenomena, it is difficult to significantly increase their yield without drilling a borehole. In cases where several springs occur in the same vicinity, it may be possible to collect all these flows into one chamber by channelling or cutting the spring back

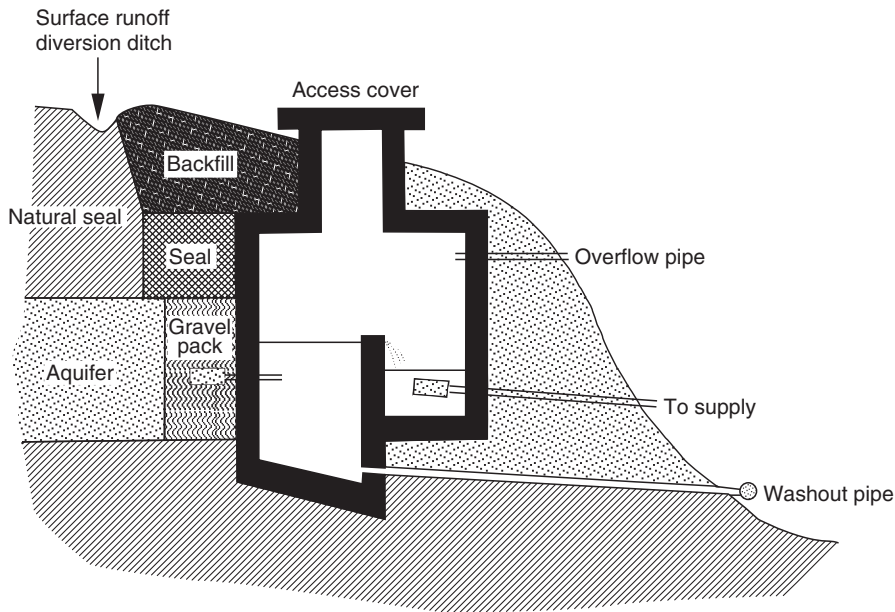


Fig. 4.12 Typical spring chamber construction.

into the water table. As flows cannot normally be increased, it is important to measure the natural flows accurately to determine the available yield and its variability through the year.

Variability

Deep-sourced springs can have remarkably constant yields and quality. The Bath Hot Springs in England appear not to have changed significantly in quality or quantity for several hundred years. However, shallow-sourced springs are more likely to have variable quality and quantity, which may make them less suitable as natural mineral water sources.

4.4.4.2 Boreholes

The drilling of boreholes should be carried out by a specialist drilling contractor under the supervision of an experienced hydrogeologist or engineer. The steps in drilling and testing a borehole are discussed here.

Site selection

In some cases the flow of water through an aquifer is fairly evenly distributed. This does not mean that all boreholes in an aquifer will yield the same amount of water, and the precise yield cannot be predicted accurately. There is always an element of risk in drilling boreholes. The precise siting of boreholes is a compromise between geological factors and practical considerations, such as finding a level spot with sufficient room for a drilling rig near to the point at which the water will be required.

In fractured rock aquifers, where borehole yields are particularly variable, the chances of success may be enhanced by drilling near to faults (which may be indicated on geological maps, detected by aerial photography or in some cases by spring lines). Surface geophysical surveys may also be of assistance in locating suitable sites.

Drilling techniques

Percussion drilling is the simplest but usually the slowest form of drilling. A heavy chisel is continually raised and dropped, breaking up the formation below. The chisel is then withdrawn and a bailer with a flap bottom is dropped down the hole to pick up the debris. As the drilling progresses, temporary steel casing is driven or allowed to drop down, thus sealing the sides of the hole against collapse.

In *rotary drilling* a rugged drill bit is attached to the end of one or more lengths of drill pipe. The top of the drill pipe is rotated by the drilling rig while downward pressure is applied. This causes the drill bit to grind against the rock formation. The drilling fluid is continuously pumped down the drill pipe and returns up the borehole, carrying the drilling cuttings to the surface. The drilling fluid may consist of air, foam, water or a mixture of water and clay referred to as 'mud'. The choice of drilling fluid depends on the depth of hole and type of strata encountered. A variant on rotary drilling is *reverse circulation drilling* in which the drilling fluid passes down the hole between casing and drill pipe and then comes up the drill pipe. Rotary drilling is usually quick and is applicable in most formations.

Rotary drilling rigs may be equipped with a *downhole hammer* (similar to a pneumatic drill), which uses compressed air to fire a rotating percussive drill head, and is particularly useful in hard formations. However, the depth of drilling below the water table is limited by the size of the compressor.

Borehole drilling can contaminate an aquifer. It is therefore essential to ensure that the drilling rig is cleaned before starting to drill and that great care is taken to prevent spillage of oil or diesel during drilling and testing. Fuel bowsers should be double-bunded and kept away from the borehole location when not in use. Specification of biodegradable greases and drilling fluids is also recommended. Drip trays and absorbent matting should be placed beneath the drilling rig and other machinery.

Borehole logging

Where the geology of an area is known, the required depth of a borehole can be predicted. Where drilling is more investigative or the aquifer is more variable, it is often useful to make actual measurements of the rock properties down a borehole. To make these measurements, a specialist contractor will run a suite of *geophysical tools* down the borehole. A wide range of properties can be measured by borehole geophysics, but it is most often used to detect the presence of clay-rich layers, fissures and inflow zones (where the temperature and EC of the inflowing water may change). Closed-circuit television (CCTV) surveys may also be run to examine the nature and extent of fissures.

Borehole completion

Where a borehole has been drilled in a competent (firm) formation, the borehole sides may stand up without any support. However, it will always be necessary to install *casing* (pipes) in the top section of the borehole and to fill (grout) the annular space between the casing and the geological formation with (sulphate resistant) cement to prevent near surface contamination entering the borehole. Ensuring a sanitary seal around the wellhead, and preventing any short circuiting by pollutants through the shallow soil zone, is a vital aspect of protecting a water source. Casing should extend for at least 6 m and possibly more, depending upon the nature of the near surface geology, down to the maximum depth of any unstable materials and probably into the top of the exploited aquifer. Pressure grouting, where grout is pumped upwards from the base of the borehole, though not always possible, will always be preferred to pouring grout from above.

Below the solid casing, the borehole may be completed as either open-hole or with a slotted casing or *screen* to prevent the formation collapsing or the well pumping sand. Even in an apparently competent aquifer it is prudent to install, often just suspend, a slotted casing to protect the pump from collapsing blocks of rock. Where the formation is less competent and shows signs of collapse, it is essential to install slotted casing or screen against the water-yielding sections of the aquifer. The size of slots or screen is determined by the size of grains in the aquifer formation. Where the aquifer is fine grained it may be necessary to install a *filter pack* (gravel pack) of graded sand or gravel in the annulus between screen and aquifer face to prevent the aquifer grains from passing through the screen slots. All materials used in borehole construction should be resistant to corrosion. Stainless steel (grade 316) casing and screen are normally used for natural mineral water boreholes.

Borehole development

The process of drilling a borehole creates much fine material that can clog the water-yielding horizons in an aquifer. After the casing and screen have been installed, the borehole should be developed, without delay, to flush out this loose material. There is a variety of techniques including *airlift pumping*, *over pumping* and *surge pumping*. Boreholes in limestone aquifers may be developed by *acidisation* (the introduction of concentrated hydrochloric or sulfamic acid into the borehole). The acid reacts with the limestone, generating carbon dioxide, and enlarges the fissures around the borehole by dissolution. The acid is consumed in a few hours and the borehole is then flushed again to remove loose debris and the residual chloride from the acid-limestone reaction.

Test pumping

After drilling and development, a step test and constant rate test should be carried out to determine the borehole yield (see Section 4.2.7 for more details on pumping tests).

Water quality testing

Water quality should be monitored during development and testing as the quality may have been affected by construction and only equilibrates after a prolonged period of pumping. Values of pH, EC, temperature and alkalinity should be measured at least daily at the well-head. Samples for analysis of major ions should also be collected daily with samples for minor ions perhaps every two or three days during testing. At the end of the test, samples should be collected for analysis of a comprehensive suite of determinants. Hydrochemical analysis and classification are discussed in Section 4.3.

Borehole redevelopment

The condition of a borehole may deteriorate over time (often indicated by a drop in well efficiency) and it may become necessary to redevelop it. A CCTV survey should be run to examine the condition of casing and screen and to investigate the presence of clogging caused by chemical precipitation or by biofouling (e.g. by iron bacteria). Boreholes can be redeveloped by a combination of brushing, airlift pumping, jetting and acidisation to remove encrustation. Boreholes can be sometimes relined if the existing casing is damaged or leaking.

Pumps

Pumps are selected on the basis of borehole diameter, required yield, pumping water level and water quality. Where the pumping water level is within 7 m of the surface, it is possible to use a surface-mounted suction pump, although the yields of such pumps decline rapidly

as suction limits are approached. Where the pumping water level is deeper than this, it is necessary to use either a submersible pump and motor or a line-shaft pump with a surface surface-mounted motor. Other types of lifting devices exist, but will not normally be used for bottled water applications.

Several other factors should be considered when specifying borehole pumps. Where declining yield, as a result of falling water levels is anticipated, provision should be made for controlling the flow by varying the motor speed or throttling the discharge. The well head should allow for inclusion of monitoring or sampling points, and consider access for geophysical logging if possible. Stainless steel will normally be the preferred material for pumps, rising main and fittings. Electrical power is normally preferred because of low noise, higher efficiency and minimising the handling of hydrocarbons.

4.4.5 Variation of aquifer properties with depth

Where groundwater is abstracted through boreholes, especially those with long intake sections, it is possible for hydraulic and chemical properties of the aquifers to vary with depth. Sometimes this occurs gradually and sometimes as step changes; and occurs at times when the water table falls to unusually low levels, i.e. during droughts. The practical effects of this can be a rapid decline in borehole yield and/or a change in water quality. In severe cases, this can result in having to take boreholes temporarily out of operation. Where only yield is lost, this may be partly compensated for by having stand-by boreholes where all boreholes are operated at lower pumping rates. In the case of deteriorating water quality, this may restrict the source's designation (e.g. as a Natural Mineral Water). It is important therefore, to try to predict whether such situations will develop. First, the operator should always monitor the water table in the catchment, and possibly also natural groundwater flows such as springs. Second, direct indications of critical flow horizons can be identified from a number of the measurements referred to in Section 4.4.4: the geological log; changes in flow when drilling with air; geophysical logging; step testing; and long-term monitoring of water quality and levels.

4.5 MANAGEMENT OF GROUNDWATER SOURCES

4.5.1 Record keeping

Like all manufacturing processes, production of spring water and natural mineral water requires constant vigilance to ensure quality and to provide advance warning of the onset of problems. The collection and preservation of records on construction, operation, maintenance and abandonment is an essential activity. If neglected, it may not be possible to identify and correct problems economically, possibly leading to declining yield or deterioration in water quality.

Every groundwater source should have a routine monitoring scheme. A file should be established at the time when initial development plans are formulated and it should be maintained right through to the time when the borehole is finally abandoned or otherwise disused. The data collected should include:

- details of the design of individual boreholes and of the wellfield, if multiple boreholes are used;
- borehole or spring construction records;

- natural discharges of flowing wells or springs;
- pumping test data, including tests conducted at the time of construction and subsequent step tests to monitor borehole yield characteristics;
- records of the type and capacity of the pump and the depth to which it is installed;
- operating records, which should include pumping rates and static and pumping water levels;
- water quality testing;
- records of any maintenance that is carried out on the borehole or spring;
- record of abandonment.

The format of the data collected is not critical. What matters is that the records are collected on a *routine* basis and are *regularly* reviewed. If the data show any signs that parameters (e.g. water levels, yield or water quality) are moving away from their long-term values, a period of more intense monitoring and assessment should be implemented.

Consideration should be given to installing dataloggers that can automatically collect water level and quality (e.g. EC) data at preset frequencies, ranging anywhere from seconds to days.

4.5.2 Monitoring, maintenance and rehabilitation

In Europe at least, the spring and natural mineral water manufacturer is affected by one factor that distinguishes him from the rest of the water industry – that he is tied to a single, named source. There is usually no option to obtain water from another location should something go wrong with the borehole or spring. Proper care and maintenance of the source, coupled with a detailed knowledge of its history and operational use, are therefore essential to the long-term viability of the business.

Often the borehole or spring are the least well known of the bottled water manufacturer's assets, and yet they are the most important. While large amounts may be spent in marketing or upgrading the bottling plant, comparatively minor sums are often spent on the water source itself. This partly stems from the assumption that there is relatively little that can go wrong with a borehole other than the pump, and also from an approach that is 'out of sight, out of mind'. However, the results of a breakdown can be catastrophic and may potentially result in major disruption to production. Moreover, this is most likely to occur at times of peak production when the aquifer and borehole are under greatest stress.

Awareness and understanding of a problem are usually the key to its cure, and diagnosis requires a range of hydrogeological and operational information that are all too often not available because appropriate monitoring has not taken place. Maintenance and rehabilitation lack glamour and are sometimes tainted with the perception of something having gone wrong. However, economic advantages can be gained from provision of adequate and proper management of the source. The three functions of monitoring, maintenance and rehabilitation should be regarded as integral to the business because:

- (i) monitoring identifies the need for maintenance;
- (ii) maintenance, of the pump and the borehole or spring structure, involves routine actions to maintain performance and to prevent deterioration;
- (iii) rehabilitation is the repair of a borehole or pump that has failed to meet its required or expected performance, possibly due to inadequate monitoring and maintenance.

The maintenance regime will depend on the local aquifer conditions. Both the frequency of maintenance and the action needed to maintain borehole performance vary, but in all cases should be based on data from the monitoring programme.

4.5.3 Sampling and water quality analysis

The chief distinguishing feature of most bottled water is its chemical quality, particularly for natural mineral waters that are required by legislation to have the stable chemical composition displayed on the label of the bottle. It is therefore vital to have accurate measurements over time of the constituents that contribute to that unique character.

Because of their nature, some measurements should be made in the field and others in the laboratory. The two main reasons for measuring parameters in the field: (i) it allows rapid assessment of changes in the sampled water; and (ii) because some parameters are unstable when removed from the aquifer and will change before they can be measured in the laboratory. Key determinants that should be measured in the field include EC, temperature, pH, dissolved oxygen and alkalinity. Most are determined using hand-held meters or probes that can be linked to dataloggers. Alkalinity is measured using a field titration kit.

The key consideration when collecting a water sample for laboratory analysis is to ensure that it is representative of conditions in the aquifer. Water that has been standing in a borehole or spring tank will have changed in composition and should be flushed out before sampling. Samples should be collected in clean bottles and immediately sealed with no air space remaining in the bottle. Samples should be refrigerated and then transferred to the laboratory in a cool box. For determinants that may change during transit, the laboratory may supply bottles containing preservatives. For instance, when analysing for dissolved iron, the sample should first be filtered to remove any solid particles and then preserved by adding concentrated nitric acid to prevent iron from precipitating.

A variety of analytical techniques are available for most determinants. The laboratory will suggest the most appropriate technique, taking into account the accuracy and limit of resolution required.

The frequency of sampling and analysis will depend on the size of the source, and the particular requirements of the regulatory body that implements the relevant legislation. For a moderate sized source (e.g. 10–30 Ml/year), the following frequencies for sampling at source may be appropriate:

Water levels, pumping rates	Daily (hourly during operation)
pH, EC, temperature	Daily
Taste, odour, visual check	Daily
Major and minor ions, metals	Monthly or quarterly
Microbiology	Daily
Full analytical suite	Annually

4.5.4 Monitoring borehole yield

The yield of a borehole depends on three main factors: the aquifer, the borehole and the pump, and a decline in yield can be related to a change in any one of these factors. Routine monitoring of water levels and pumping rates is fundamental to the initial identification of problems through the water level – discharge rate relationship. Measurements of specific capacity and available drawdown are neither difficult nor time consuming, and are based on the following:

- *Static (non-pumping) water level*: this should be measured at least weekly, and preferably daily, at the end of the longest non-pumping period (often the end of the weekend).
- *Maximum pumping level*: as with static water level, this should be measured at least weekly and preferably daily, at the end of the longest pumping period. Many bottlers will choose to automatically measure pumping rate and water level hourly.
- *Pumping rate* should be measured at the same time as the maximum pumping level, and total abstraction should be recorded daily at a fixed time.

Water level and pumping rate data should be collected and reviewed on a continuous basis. The onset of problems can then be easily identified and then usually halted or reversed through timely maintenance. There are many possible actions, and some examples include:

- If the discharge rate is maintained at a fairly constant level, a slight but continuous fall in water level may indicate a depletion of resources within the aquifer.
- If there is clogging of the well screen, there will be a more marked fall in water level in the pumping well than in nearby observation boreholes.

A more rigorous assessment of borehole behaviour can be obtained by carrying out planned step drawdown tests (ref. Section 4.2.7), typically on an annual basis. The timing of the test should take into account natural seasonal changes in the aquifer, so that, for example, invalid comparisons are not made between high and low water level conditions.

Although the condition of a borehole can be monitored through changes in the pumped borehole, conditions within the aquifer are best determined through monitoring water levels in observation wells that are not greatly affected by pumping. The monitoring of water levels in both production and observation boreholes should be integral to the monitoring programme.

Some common reasons, and possible solutions, for declining yield are summarised below:

4.5.4.1 *The aquifer*

Where the observed decline in yield is accompanied in a fall in water level, but with no change in the specific capacity, the cause of the problem is probably a change in conditions within the aquifer.

A decline in yield may occur as a result of falling water levels, possibly caused by a decline in recharge (drought) or excessive abstraction leading to partial dewatering of the aquifer.

The most immediate solution to the problem would be to reduce the rate of abstraction, although this may be practical only if the problem relates to a short-term occurrence, such as a summer drought. Longer-term solutions may be to spread the abstraction over a larger area of the aquifer (more boreholes each pumping less water) or even implement measures to artificially enhance recharge to the aquifer.

4.5.4.2 *The borehole*

A fall in yield that is due to problems within the borehole is manifest by a reduction in specific capacity, but no change in water level. In particular, a marked fall in the pumping water level that is not seen in nearby observation boreholes is most likely due to deterioration in the borehole structure. This often results from blockage of the well screen by rock

particles, deposition of carbonate or iron compounds, build up of biofilm inside the borehole or through reduction in the length of open hole by movement of sediment into the borehole.

The solution is usually to re-develop the borehole through physical (airlift pumping and surging, scrubbing) and/or chemical (acid to dissolve encrustations, disinfectant to remove biofilm) means.

4.5.4.3 *The pump*

Where the cause is attributable to the pump, no change is usually seen in water level or specific capacity. The cause may be due to wear of pump impellers, other moving parts or to loss of power from the motor. The solution almost always requires that the pump is removed from the borehole and is either reconditioned or replaced.

4.5.5 **Changes in water quality**

Changes in water quality can fundamentally impact the viability of a bottled water source and so water quality monitoring is perhaps the most important aspect of source management.

Regulations governing bottled water production almost always require that water quality is assessed on a regular basis to ensure that the water continues to meet set standards. However, analyses done for regulatory purposes will generally not be frequent enough to determine whether changes are occurring, so that timely corrective action can be undertaken. Routine monitoring should focus on parameters that are indicative of changing conditions.

A change in water quality can occur as a result of changes in the aquifer or in the borehole and can affect the biological, chemical or physical quality of the water.

Variations in pumped water quality result from changes occurring in the aquifer, may involve almost any substance soluble or mobile in water, and may occur in a variety of ways:

- Natural changes in hydrochemistry in response to seasonal fluctuations in rainfall and recharge will generally raise few concerns for the bottled water producer, but must be recognised. Some regulations, such as those governing natural mineral water, require that the composition of the water is stable. This requirement must take into account the limits of natural fluctuations, which can vary from virtually no change in confined aquifers in hard rock areas to substantial changes in shallow, unconfined aquifers. What matters is that the source water is monitored sufficiently regularly that deviations from the ‘norm’ can be identified.
- Changes in water quality can be induced by pumping and can occur in several ways. As the pumping rate increases, water is drawn from areas increasingly further away from the borehole. This can draw in water from different geological strata or different fracture systems. Close to the sea, brackish water can enter the bottom of the borehole through upconing of the saline interface. The solution to such changes usually involves limiting the pumping rate so that water is always obtained from the same catchment area or does not otherwise draw in water of undesirable quality.
- Accidental or intentional release of pollutants within the catchment area of the source. Of particular concern to bottled water producers are persistent substances that may travel unchanged over long distances, such as herbicides, pesticides and other complex hydrocarbons, petroleum products and some trace metals.

Deterioration in the biological quality involves the occurrence in the water of bacteria, viruses and/or parasites associated with human or animal wastes. Such deterioration indicates, in nearly all cases, a connection between ground surface and the open section of the borehole, either through the ground or via the borehole itself.

Changes in physical quality involve the appearance, taste and temperature of the water. Taste and temperature changes are likely to be associated with changes in water quality, and will occur for similar reasons. A gradual change in appearance or colour may result from the presence of rock particles in the water, indicating that the strata adjacent to the borehole contain fine-grained material that was not adequately removed during borehole development (see Section 4.4.4). Several solutions are possible, depending on the nature of the problem, including:

- removing the pump and re-developing the borehole;
- decreasing the pumping rate to reduce inflow velocities and prevent mobilisation of fine particles;
- installing a coarse filter at the wellhead to remove particles before they enter the distribution system. However, allowing the problem to continue could lead to excessive wear and damage to the pump and possibly to the borehole itself.

The sudden appearance of suspended solids in the water is more likely to indicate the failure of the well screen or casing, perhaps as a result of corrosion. The solution in this case may involve removal and replacement of the old casing and screen or the installation of a smaller diameter screen inside the original casing. The former is often not possible, while the latter will restrict the size of the pump that can be installed and hence the maximum yield that can be obtained. Through careful monitoring, the onset of problems can be identified and catastrophic failure avoided.

When developing a new source, determining the scope and frequency of water quality monitoring must take account not only of natural changes in the aquifer but also artificial changes induced by pumping, and the risks arising from historic and future pollution incidents. Lack of regular and thorough monitoring may result in the failure to detect indications of problems that could occur at a time when a reliable source is most needed.

4.5.6 Control of resource exploitation

An essential aspect of source management is to ensure that the abstraction is sustainable, and does not cause detrimental impacts upon the aquifer or other abstractors. This requires that:

- abstraction is maintained at a rate commensurate with the amount of water required for the production process, ensuring that the long-term abstraction does not exceed the available resource (i.e. avoids over-abstraction);
- the source is adequately protected so as to exclude, or reduce the risk of, pollution;
- the quantity and quality of the abstraction are continuously monitored and that any variations are promptly identified and rectified;
- routine analyses are undertaken as required by local or national regulations.

Increasingly, bottled waters are drawn from groundwater resources that are subject to competing demands from other abstractors and for environmental support. It is good practice to be aware of pressures on the resource from other abstractors, and to be in regular contact with the water resources regulator and evolving regulations.

4.6 PROTECTING GROUNDWATER QUALITY

4.6.1 Changing policies and perspectives

Since the second edition of this book was published, there has been a shift in policy towards a more holistic consideration of groundwater quantity and quality issues and their relation to the surface environment. In Europe, this is reflected in the Water Framework and the Groundwater Directives, and in particular a move away from end-of-pipe (treatment) solutions for public water supply towards preventing pollution. During the same period, the World Health Organization (WHO) has been promoting Water Safety Plans as a means of improving health through better water quality management from the catchment boundary to the point of use, an approach that is being widely adopted by water supply utilities, and could be usefully applied by water bottlers. The consequences of contamination of a bottled water source can be even greater than for a public water supply source, particularly for natural mineral waters and spring waters, which may not be treated to remove contaminants.

To protect water quality, the water bottler should understand the catchment to their source and be able to conduct a risk assessment of potentially polluting activities within that catchment. Then he should seek to remove or mitigate potentially polluting activities, depending on the risk to the source.

The catchment risk assessment may be qualitative or quantitative, and is described in terms of the hazard-pathway-receptor (HPR) conceptual model. For the water bottler, the 'receptor' is simply the point of abstraction; the 'hazard' is an inventory of all pollution hazards within the catchment; and the 'pathway' refers to any means by which a pollutant might reach the point of abstraction. For groundwater pollution risk to be real, all three elements of the HPR linkage must be present. The overall procedure can be broken down into four phases of risk management:

- (i) defining the area to be protected;
- (ii) hazard identification and mapping;
- (iii) pathway analysis and risk assessment (in *sensu stricto*);
- (iv) mitigation and control measures.

4.6.2 Source protection zones

The starting point for the catchment risk assessment is to define the catchment area, including both the surface and groundwater catchments and within this, the source protection zones (SPZs), which are concentric zones around the source within which pollution prevention or response measures can be planned. All bottled water sources should have SPZs defined, where possible with an appropriate legal status. In most countries, the approach is standard for public water supplies, other important potable supplies and supplies used for food and drink processing, which are sourced from groundwater. In the UK, three zones are defined:

- (i) *Zone 1 or (SPZ1)*: Inner Source Protection, based on a 50-day travel time from any point at on the water table to the source. The 50-day criterion is based on the survival of typical pathogenic micro-organisms that can cause outbreaks of even fatal disease. In SPZ1, which has a minimum 50 m radius, the strictest controls are applied.

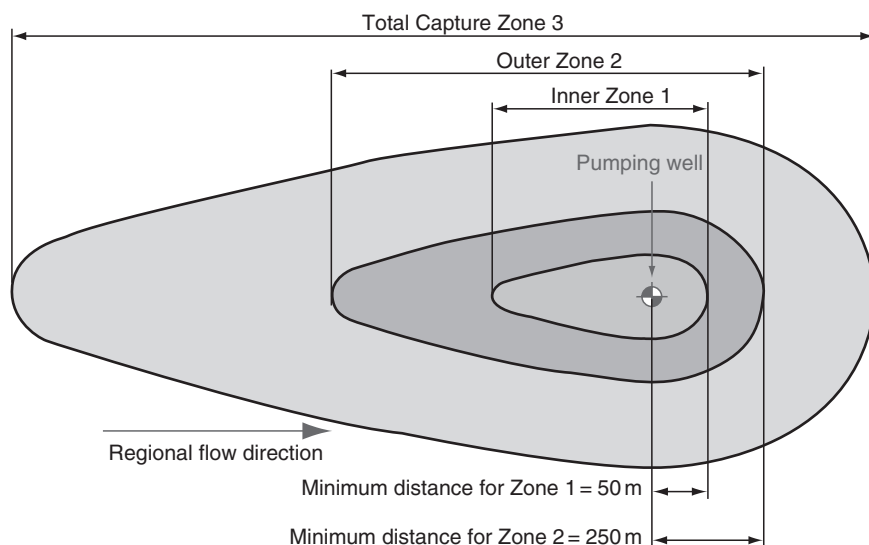


Fig. 4.13 Schematic representation of the UK Source Protection Zones.

- (ii) *Zone II (or SPZ2):* Outer Source Protection, based on a 400-day travel time from any point on the water table to the source. The 400-day criterion is based on the attenuation of many common chemicals. SPZ2 has a minimum radius of 250 m, or 500 m if the yield exceeds 2 MI/d. Some activities are controlled in SPZ2.
- (iii) *Zone III (or SPZ3):* Total Catchment Protection, is the complete catchment of the groundwater source. Management policies such as reduction of fertiliser inputs may be appropriate for this area, and some activities may be legally controlled.

A schematic diagram of these zones is given on Fig. 4.13. In the case of confined aquifers, where the aquifer is naturally protected from contamination by the impermeable confining layer, SPZs are normally defined (in UK practice) as circles of minimum radius. Nevertheless, it is worth estimating the travel time from the edge of the unconfined aquifer to check that there is sufficient natural protection. This can be done by calculating the groundwater velocity (Section 4.2.4) or isotopic dating of the water. It is also important to appreciate that confined aquifers can be contaminated along artificial pathways such as abandoned boreholes.

Source protection zones may be delineated by a variety of methods with increasing degrees of sophistication. The simplest methods involve drawing circles around the source or variations thereon. This is not sufficient for a bottled water source unless water is drawn from a strongly confined aquifer. There are two basic approaches to better delineating SPZs, either using expert hydrogeological judgement or using computer models. The former may be preferred in areas of particularly complex geology, and especially for karst aquifers. Various bespoke computer models have been developed for, or adapted to, SPZ delineation, although existing regional water resource models may also be used. Whichever modelling approach is adopted, hydrogeological guidance will be required.

The process of approving statutory SPZs lies with the regulator, and it is in the interest of the abstractor to actively participate in the definition process so that the maximum legal protection is ensured.

4.6.3 Hazard identification and mapping

An inventory of all hazardous substances and activities within the catchment should be prepared and mapped. The complete range of potential hazards is enormous, and cannot all be listed here and, in no particular order, could include:

- dry deposition of atmospheric contaminants;
- surface water bodies that may drain into groundwater;
- regional application of fertilisers and pesticides;
- access by humans or animals, either farmed or wild, and including birds;
- all houses, commercial building and factories;
- storage of chemicals;
- transport of chemicals through pipelines or on vehicles or trains;
- all motorised vehicles and roads;
- waste disposal, on-site sanitation, sewerage and sewage treatment;
- historical activities such as old landfills;
- changes in land use, for example ploughing up grassland or pasture;
- all underground structures and excavations, including borehole drilling.

Identifying and locating these hazards could be carried out by examining maps, aerial photographs and by consultation with local councils, environmental agencies and sewerage undertakers. Having compiled an inventory, the hazards should be scored on the basis of their quantity and toxicity and persistence in the environment.

4.6.4 Groundwater vulnerability and natural attenuation

The potential for a pathway to exist between each contamination hazard and the source needs to be examined. Even where a contaminant is present at the ground surface, there is no certainty that it will reach the water table, let alone survive transport through the aquifer. The soil and the unsaturated zone of the aquifer often provide the most effective barrier to pollution, except where they have been bypassed by man's activities.

The ability of soils and aquifer to attenuate pollutants will vary depending on their chemical nature. The protective capacity of soils is greatest where the soils are thick and continuous, with high organic matter and a year-round vegetation cover. High clay content will also protect groundwater through its low permeability and ability to adsorb metals. Because of its biological activity, the shallow soil zone is effective in retarding microbes and general organic waste. Where the unsaturated zone of the aquifer comprises certain types of fractured rock, such as sandstones and some limestones, pollutants may be further retarded by diffusion into the rock matrix. Conversely, the greatest natural vulnerability occurs where rock outcrops at the surface, or where there are (karstic) features, such as swallow or sink holes.

There are many artificial means by which contaminants may by-pass the soil and unsaturated zone to reach aquifers, and these include boreholes, cellars, tunnels and shafts, water and sewerage pipes, trenches for power and communication lines, mining and quarrying, any temporary excavations or clearing of vegetation.

The ability of aquifers to attenuate pollutants will vary greatly according to their lithology (Section 4.3.4) and the nature of the pollutants. Alluvial aquifers will tend to have a high attenuation capacity compared, for instance, to fractured rock aquifers. The movement of chemicals through fractured rock aquifers may be retarded by their

diffusion into the matrix of the adjoining blocks of rock. There will be many combinations of geology and contaminants that will lead to different vulnerabilities. For example, aquifers containing oxygenated water may be effective in attenuating both bacteria and petroleum hydrocarbons, but not chlorinated solvents or nitrates. Aquifers with intergranular flow will tend to prevent migration of *Cryptosporidium*, which may be mobile in fractured rock.

4.6.5 Wellhead protection

The simplest means of polluting a groundwater supply is through the well itself or its immediate environs. This is also the simplest risk to control, and can be achieved through good housekeeping and at little cost. The measures described here overlap with controls that may apply to inner source protection zones (see below), but what is addressed here are factors that are both of the very highest priority and under the direct control of the operator. Wellhead protection can be discussed in terms of two factors: first the borehole itself and second the pump house and surrounds.

The procedure for preventing the accidental ingress of surface waters into new wells by grouting of the surface casing was described in Section 4.4.4. In the case of existing boreholes that were not installed to such standards, it may be possible to improve sanitary protection by excavating around the casing and placing cement by hand. In extreme cases, however, eliminating near-surface pathways to the intake section of the borehole may require relining or even replacement of the well. Furthermore, the integrity of casing may deteriorate over time and should be guarded against by periodic CCTV surveys.

The operator should define a protected area around each abstraction point within which an over-riding requirement should be that all workers and contractors have received training in good hygiene, and there should be no unsupervised access by others. Within this protected area, the following risks should be assessed, documented, and control measures applied:

- *Drainage*: The slope of the ground and any drainage features must lead away from the wellhead and to an appropriate drain. The wellhead itself should be protected from rain and secure from intruders. It will usually be in a building that facilitates sampling, monitoring and good hygiene.
- The well casing should be raised and/or bunding installed to prevent floodwater ever entering the borehole.
- The top of the well casing should be physically protected to prevent the entry of small mammals or insects.
- Storage of chemicals, such as fuels, lubricants and cleaners, or any material that could attract vermin, should be prohibited.
- Non-essential underground pipes and utility trenches should be re-routed to eliminate sources of, or pathways, for pollution.

Any equipment that is lowered into the well or borehole, and tools used to handle this equipment at the surface, should be disinfected with a strong chlorine solution. This should include using a chlorine spray to disinfect drill rods during borehole construction. It may also be necessary to sanitise the whole borehole from time to time, particularly if the borehole has been unused for a period of time. This can be achieved by surcharging the borehole with disinfectant and then pumping the disinfected water to waste.

Table 4.4 Hypothetical risk assessment for spring water.

Consequence		Deviation in water quality from background levels but within statistical range and of acceptable quality	Water quality outside background range for an individual abstraction point, but acceptable after blending	The bulk composition of the source outside specified water quality limits
		Insignificant	Moderate	Major
Likelihood		1	2	4
<once in 10 years	1	1	2	4
Once in 10 years	2	2	4	8
Annually	4	4	8	16
Monthly	8	8	16	32

Risk levels: White = insignificant; light grey = low risk; dark grey = medium risk; black = high risk.

4.6.6 Risk assessment and catchment management

4.6.6.1 Risk assessment

Each hazard – pathway – receptor linkage should be assessed. The conventional risk assessment scheme assigns integer scores to the likelihood and consequence of the pathway being active. Likelihood is scored on a scale from continuous to very rare, and the consequence is scored on a scale from insignificant to major (source temporarily/permanently inoperable). The likelihood and consequence are then multiplied to generate a measure of risk to the abstraction. The results can be expressed in matrix, such as shown in Table 4.4 for a hypothetical spring water source, where a change in water quality is considered. The table is indicative and should be adjusted and enhanced to suit individual circumstances.

The numerical values do not have precise significance, but allow a ranking to prioritise action to reduce the risk. This may be investigations to reduce uncertainty (usually as to the existence of an active pathway) or mitigation and control measures. The scores are not fixed forever, but represent an agenda for a continuous programme of risk reduction.

4.6.6.2 Mitigation and control measures

The level of control that can be exerted over land use and potentially contaminating activities will depend on land ownership within the catchment area. Ideally the abstractor would have complete control over land use, but in reality direct control is usually limited to an area close to the abstraction points, beyond which the abstractor must rely on influence, awareness-raising and financial inducements.

The nature of control measures can be extremely diverse, and can be classified in several ways. First, following the hazard-pathway-receptor concept, measures can address:

- Action at the source of the hazard, such as removing or relocating stored chemicals or animals in the catchment, particularly in the inner and outer protection zones. This could also include awareness raising or changing land management practices.
- Modifying or breaking pathways, such as by installing bund, linings or improved surface drainage to prevent contaminants reaching the abstraction.
- Modifying the receptor, such as by re-drilling a borehole to change the depth of intake, providing a better sanitary seal or installing on-line monitoring at the well-head.
- Contingency planning to deal with pollution incidents after they happen but before they cause actual harm to the supply.

In addition to the physical interventions described above, a wide range of soft measures may be appropriate, such as training and awareness raising among employed staff and contractors. This awareness, supported by public education and visits, can be used to persuade local landowners and businesses to modify their practices. This strategy can also be pursued by lobbying with local government and regulators to promote enforcement of pollution prevention legislation.

The risk of a pollution incident can never be entirely eliminated, and so it is very important that the operators maintain, and staff are kept aware of, contingency plans. Through rapid and appropriate response to spills or leaks, pollution of the groundwater resource can be prevented, or at least constrained. Through delay or misguided action, the viability of the business may be endangered. These responses need not be restricted to accidents on the operator's land, but anywhere in the catchment, which could endanger the groundwater resource.

A particularly relevant aspect of contingency planning is the installation of observation wells in the catchment area to provide advance warning of problems, and to initiate timely corrective action. There are two common situations where observation wells, installed in between the hazard and the receptor, could be appropriate. The first is where it is thought that an ongoing activity, such as farming, might result in a rising trend in nitrate concentrations at the source, and hence a rising trend at an observation well would provide support or justification for a change in land management. The second situation would apply to storage of hazardous liquids, especially in underground storage tanks where a slow leak might otherwise go undetected until a large volume of the aquifer has been contaminated.

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5 Water Treatments

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5.1 WHY AND WHEN WATER MUST BE TREATED

Just as there is a wide variety of different bottled water types, waters used for bottling in different geographical locations can also come from a wide range of sources, including naturally flowing springs, ground water, brackish water and even (in some parts of the world) coastal water and seawater. Increasingly, previously treated municipal water supplies are also being used. Water may be bottled for human consumption or may be used for some other essential part of the process, such as cleaning or for other industrial purposes, but regardless of its origin or ultimate purpose, it may be necessary or desirable to treat it further before use. Depending on the incoming quality, there is now a wide range of treatments available, and this chapter attempts to provide some basic information to assist bottlers in choosing which methods to use. Water treatment may be used for various reasons, some of which are discussed below.

5.1.1 Compliance with local regulations

Local regulations may impose limitations on the quantities of some microbiological and chemical elements in the bottled product. Most of the time, these regulations are based on international legislation or recommendations or guidelines, such as those provided by the WHO and Codex (see Chapter 3). Depending on the nature and objective of the treatment, the treated water might be bottled under a different status (Mineral Water, Spring water, Natural Water, Prepared Water, Drinking Water, Purified Water, etc.) according to local definitions. The main constituents are the microbiological indicators of contamination (coliform, *Pseudomonas aeruginosa*, etc.) and chemical elements of 'health significance' (inorganic and organic elements).

5.1.2 Quality reasons

For some specific quality reasons, it is necessary to remove some elements from the water before bottling, even if their quantities are below the local regulation limits. A very practical example is in the case of unstable elements such as dissolved iron, which may give brown deposits of oxidised iron in the bottled product after a few weeks of storage. Such treatments

can be applied to any water, and are usually accepted by local regulations for natural waters, as they do not modify the composition in terms of the characteristic constituents.

5.1.3 Marketing reasons

For marketing reasons, some modifications may be made to the original composition of the water, such as removal of minerals or addition of valuable constituents (salts, vitamins, fibres, etc.), to be adjusted to market needs and preferences, and the target product. In the case of a treatment that strongly modifies the original composition of the water, the product can no longer be classified as a 'natural' water.

5.2 WATER TREATMENT OBJECTIVES

5.2.1 Removal of undissolved elements

Undissolved elements found in water can be in particulate or colloidal form, and may originate from the aquifer, or from one of the process steps themselves, such as a bed media filter. Removal is generally done using a retention process, which is preceded by oxidation and/or coagulation, if necessary. The main retention processes include bed media filters, bag and depth filters.

5.2.2 Removal/inactivation of undesirable biological elements

Undesirable biological elements found in water may originate from the source (in the case of surface, sea or superficial water), or from contamination during the water process, and must be removed or inactivated before bottling. They include (ranked in size from larger to the smaller) protozoa, mould and algae, bacteria and finally viruses. Removal of these elements can be achieved by physical retention (adsorption/screen effect). Inactivation is generally obtained by destruction of the cell structure and genetic material using chemical oxidation (chlorine, ozone, peroxide, etc.) or irradiation (ultraviolet (UV)). In many cases, such microbiological treatments are used as safety barriers just before bottling to prevent any potential accidental contamination.

5.2.3 Removal of undesirable and/or unstable chemical elements

Undesirable chemical elements, in stable or unstable form, are of natural origin, due to the geological characteristics of the aquifer, water origin (sea), or from contamination linked to human activities (industry, urban and agricultural). Specific removal of these elements can usually be achieved by one (or a combination) of the standard water treatments based on oxidation, filtration, adsorption, ion exchange or bioelimination.

5.2.3.1 Ammonium

Ammonium is not identified as a 'chemical of health significance' by WHO; however, it has to be strictly controlled in non-sterile water, considering its ability to be biologically oxidised into nitrite, which is recognised to be toxic. Removal of ammonium can be done by

chemical oxidation with sodium hypochlorite or by bio-oxidation. Due to the risk of by-product formation, bio-oxidation is the recommended process in bottled water.

5.2.3.2 *Arsenic*

Arsenic is identified as a 'chemical of health significance' by WHO; it is widely distributed throughout the Earth's crust and very often found in underground water originating from volcanic strata. Removal of arsenic can be done by co-precipitation with ferric hydroxide, or adsorption onto activated alumina, granular ferric hydroxide or manganese dioxide sand. Depending on the speciation (oxidation state) of the arsenic, reverse osmosis can also significantly reduce the level of arsenic.

5.2.3.3 *Boron*

Boron is identified as a 'chemical of health significance' by WHO. Naturally occurring boron is present in groundwater primarily as a result of leaching from rocks and soils containing borates and borosilicates; but its presence in surface water is frequently a consequence of the discharge of treated sewage effluent containing used detergents. Removal of boron can be achieved by the use of reverse osmosis or specific ion exchange resins.

5.2.3.4 *Bromide*

Bromide is not identified as a 'chemical of health significance' by WHO; however, it has to be strictly controlled in ozonated water, because of its ability to be oxidised into bromate, which is recognised to be toxic. Removal of bromide can be achieved by the use of reverse osmosis or specific ion exchange resins.

5.2.3.5 *Fluoride*

Fluoride is identified as a 'chemical of health significance' by WHO; it is a fairly common element found in a number of minerals. Very often, fluoride is associated with highly mineralised and naturally carbonated water. Removal of fluoride can be achieved by adsorption onto activated alumina.

5.2.3.6 *Iron and manganese*

Iron and manganese are dissolved in their stable form in the water whilst it is underground, but as soon as they contact the outside air, they may begin to oxidise and precipitate out naturally (though manganese oxidation with air takes somewhat longer). Removal of iron and manganese consists of a forced oxidation with an oxidant (principally air or ozone in the bottled water business), followed by bed media filtration (sand, anthracite, etc.).

5.2.3.7 *Nitrate*

Nitrate is identified as a 'chemical of health significance' by WHO; it is a naturally occurring ion that is part of the nitrogen cycle, but it is also used in inorganic fertilizers. Its concentration in groundwater and surface water is normally low, but can reach high levels as a result of leaching or runoff from agricultural land or contamination from human or animal

wastes as a consequence of the oxidation of ammonia and similar sources. Removal of nitrate can be achieved by the use of specific ion exchange resins.

5.2.3.8 *Organic matter*

Although not considered as a toxic element, organic matter may have to be removed from water to limit the risk of uncontrollable biological growth in the process that may lead to biomass accumulation and off-odour/taste issues. Organic matter may also develop toxic by-products when oxidised with chlorine or ozone. Removal of organic matter can be done by adsorption onto activated carbon or biological degradation on media filter. Membrane filter processes, such as nanofiltration (NF) and ultrafiltration (UF), can also significantly reduce the level of organic matter.

5.2.3.9 *Volatile organic compounds and pesticides*

Volatile organic compounds (VOCs) and pesticides are identified as 'chemicals of health significance' by WHO; they usually result from contamination by human activities, though some VOCs are of natural origin, particularly in the case of ancient sedimentary and volcanic reservoirs bearing naturally carbonated water. Removal of VOCs and pesticides can be done by adsorption onto activated carbon.

5.2.4 **Addition of 'valuable' elements**

A wide range of constituents are added to water for commercial reasons. The different categories of water or beverage available in the market are:

- flavoured (flavours, flavour enhancers, etc.);
- nutritional (mineral salts, vitamins, etc.);
- functional (plant extract, fibres, etc.).

Addition of these elements can be done by traditional batch preparation, or by in-line dosing of a concentrate. Specific chemical and microbiological treatment may be necessary to stabilise such products. Carbon dioxide addition is also a very common water treatment; it can be done by dosing natural or industrial carbon dioxide directly into the water flow (in-line injection or tank saturator).

5.3 **WATER TREATMENT PROCESSES**

5.3.1 **Filtration**

Filtration is a physical process widely used in water treatment to remove different types of particles, such as suspended solids (turbidity), colloidal compounds, metalloid complexes, biological species and dissolved salts. Typically, the size of particulate and dissolved material ranges from approximately 0.0001 μm to 100 μm in highly variable shapes (see Fig. 5.1).

The various filtration technologies currently available can be categorised on the basis of the size of particles removed from a feed stream. Conventional macrofiltration of suspended

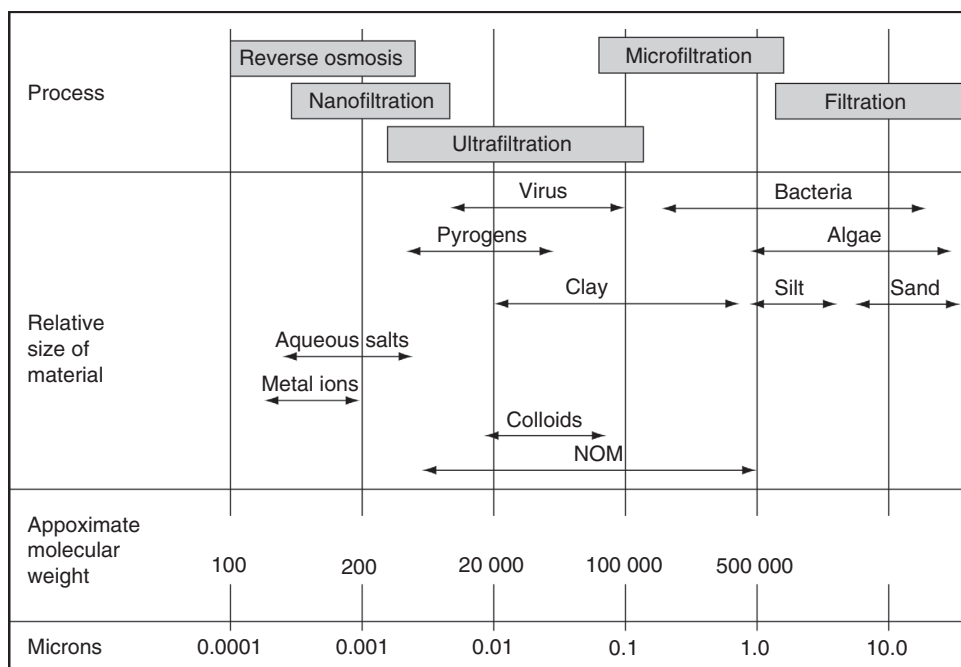


Fig. 5.1 Size ranges of membrane and bed media-type processes and contaminants.

solids is accomplished by passing the feed stream through the filter media in a direction perpendicular to the media. The entire solution passes through the media, creating only one exit stream. Depending on the application, the filtering component is granular material, depth cartridge filter or multilayer cartridge filter. Macrofiltration separation capabilities are generally limited to undissolved particles greater than $1\text{ }\mu\text{m}$.

To remove smaller particles in the range of approximately 0.1 to $1\text{ }\mu\text{m}$, membrane cartridge filters can be used; in general, suspended particles and large colloids are rejected, while macromolecules and dissolved solids pass through the membrane.

For the removal of small particles and dissolved salts, crossflow membrane filtration is used. In this case, a pressurised feed stream flows parallel to the membrane surface, and a portion of this stream passes through the membrane, leaving behind the rejected particles in the concentrated remainder of the stream. Since there is a continuous flow across the membrane surface, the rejected particles do not accumulate, but instead are swept away by the concentrate stream.

5.3.1.1 Bed media filters

Bed media filters are common in water treatment processes. The most frequently used are pressure or gravity filters, which are used for removal of particles down to $20\text{--}30\text{ }\mu\text{m}$. Depending on the filtration media material used, they have very high retention capacities, and are therefore well adapted to the treatment of water with a heavy particle load.

Pressure filters, which are very common in the rapid sand filter category, are widely used in the bottled water business. The vessel is normally cylindrical, made from coated steel,

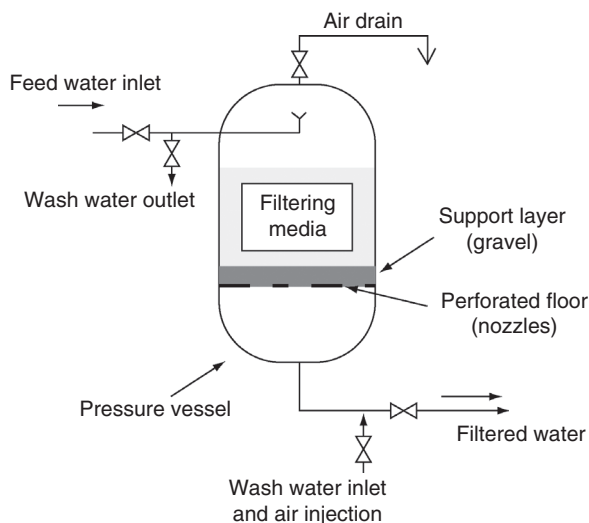


Fig. 5.2 Pressure filter.

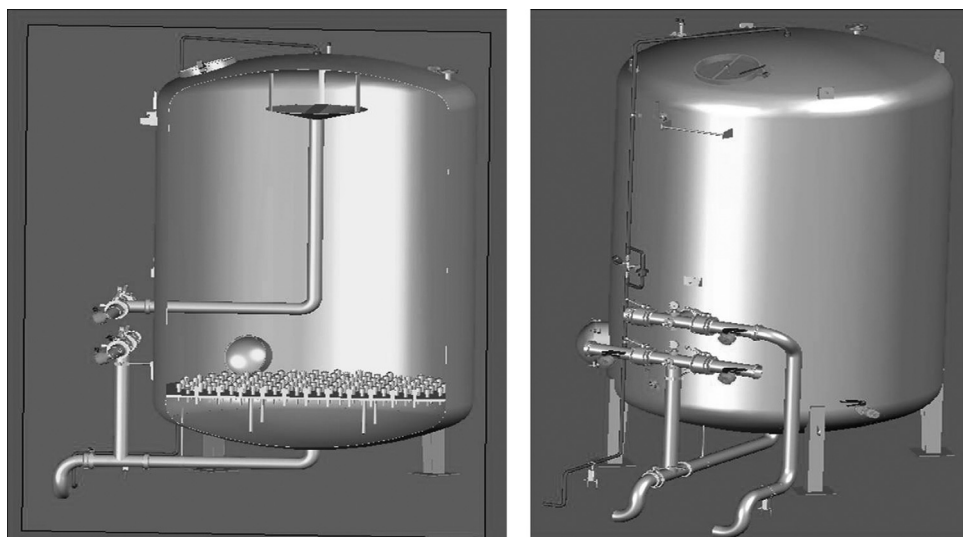


Fig. 5.3 Pressure filter details.

stainless steel or plastic materials, with a diameter of up to 4 m. The majority are downflow forward, with upflow backwash (for the cleaning step), as this is the simplest arrangement in terms of hydraulics and protection of filtered water quality. In these running conditions, the upper part of the filter is the effective section involved in the filtration process, as the continuous 'cake' formation (accumulation of the deposit) contributes to the filter efficiency. The main components of a pressure filter are represented in Fig. 5.2 and Fig. 5.3.

The minimal equipment installed for such filters comprises:

- pipes and valves required for the production mode and the backwash mode;
- vessel itself with a floor usually fitted with nozzles;
- media.

The vessel is also fitted with an upper air vent system. The sizing is mainly established based on the flow rate calculated on:

- A filtration rate, defined as the ratio between flow rate and cross-section (expressed in $\text{m}^3/\text{m}^2\text{h}$ or m/h). In the bottled water treatment, the normal range for a rapid sand filter is from 8–15 m/h , according to the scope.
- An empty bed contact time (EBCT), defined as the ratio between the height of material and the filtration rate (expressed in minutes). Depending on the application, EBCT range is between 5 and 15 min.

The most commonly used media materials are silica sand and anthracite. In many filters, only a single grade of sand (supported on coarser sand and gravel) is used but dual- and multi-media beds are sometimes employed. For iron removal applications, a standard configuration would be a sand filter with one filtration layer of the following characteristics:

Sand layer	Height (mm)	Grain size distribution (mm)
Quartz (minimum: 98% silica)	800–1000	0.8–1.2 mm – sand (Effective Size (ES): 0.95 mm*)

*If an effective size of 0.95 mm is not sufficient to achieve the treatment targets, sand with an effective size of 0.55 mm can be used.

According to the filter design support layers (gravel and/or sand) can be added to cover the nozzles.

Efficient filtration during the production mode is achieved through:

- controlling the filtration flow to within design limits;
- limiting the flow and pressure variations;
- monitoring the filtrate quality and pressure drop;
- maintaining the correct frequency and conditions for the backwash of the filter.

Simple instruments, such as flowmeters and pressure gauges, allow continuous monitoring of the process and can be complemented by specific instruments such as turbidity-meters, sensors, etc.

Filtration process control is also achieved through efficient backwashes. The backwash process consists in pumping filtered water in reverse flow (in this case upwards) through the filter bed. It fluidises the filter media and removes particles that have been trapped within the media. Backwashing should provide a minimum bed expansion of 10–20% to ensure a partial fluidisation and adequate cleaning of the media. The required backwash flow is governed by media size, type and water temperature. Dual- and

multi-media beds need slightly greater bed expansion than single-media beds to maintain a good stratification. Higher backwash flow may be needed at the start of the washing to overcome the initial resistance of the bed. To prevent this, air injection is often used before backwash to create pathways for better distribution of backwash flow through the bed. Air injection rates are normally between 20 and 40 m/h and backwash is done with a flow rate equivalent to 2–3 times the nominal flow rate. The duration of air injection and backwash varies, but typically would be less than 5 min for air injection and 10–20 min for the backwash. The final step is a rinse to recover the standard quality of the treated water.

5.3.1.2 *Depth filters*

Depth filters are characterised by a fibrous or metallic matrix, which provides a random pore size distribution; the more commonly used materials are polypropylene, cellulose acetate, glass fibre and sintered metal. Spaces between the particles or fibres serve as the filter pores, and pore size distribution can be made progressive (from larger to smaller) by steadily increased density of packing of the media. In depth filters, particles are trapped mainly within the thickness of the filter matrix. These filters are cheaper than surface filters and have high retention capacities; they are often characterised by a ‘nominal’ pore size, indicating the ability of the filter to retain the majority of particulates (60–98%) at or above the rated pore size. Particles smaller than the nominal size may also be trapped in the matrix through adsorption (see definition in Section 5.3.2). Filter cartridges (10, 20, 30 and 40 ins) with a diameter of approximately 70 mm are widely used. To increase the filtering surface, several cartridges can be installed in the same housing. These filters are installed at the beginning of the filtration chain protecting down stream layers and membrane cartridge filters.

Larger size depth cartridges, such as the coreless type (Fig. 5.4) are capable of treating at higher flow rates (80 m³/h for a 40 in. cartridge.) at a lower cost, due mainly to the fact that the depth media is fixed on a stainless steel support mounted in the housing. The coreless cartridge diameter is around 150 mm for heights up to 40 ins.

The bag filter system can be the right solution to protect downstream depth media from problems arising from variations in water quality (entrained sand from the source, etc.). It is a low-cost device that enables treatment at a high flow rate (60 m³/h for a 40 in. cartridge), but with a low capacity (Fig. 5.5). Depending on the materials used to produce the bags (polyamide, viscose, polyester, polypropylene, PTFE, etc.), particle size between 1 and 1000 µm can be removed with variable efficiency.

5.3.1.3 *Layer cartridge filters*

Layer cartridge filters are composite filters with several layers of filtration materials made of glass microfibres or polymers. Particles larger than the pores inside the filter matrix are in this case trapped mainly at the surface of the filter, while smaller particles are often trapped inside the matrix. These types of filters have both membrane and depth filter properties. The number of pleated layers gives to these filters a high retention capacity, and their ‘controlled’ pore structure leads to a better efficiency compared with depth filters. Layer filter cartridges can have the same standardised height (10, 20, 30 and 40 ins) and diameter as depth and membrane cartridges. To increase the filtering

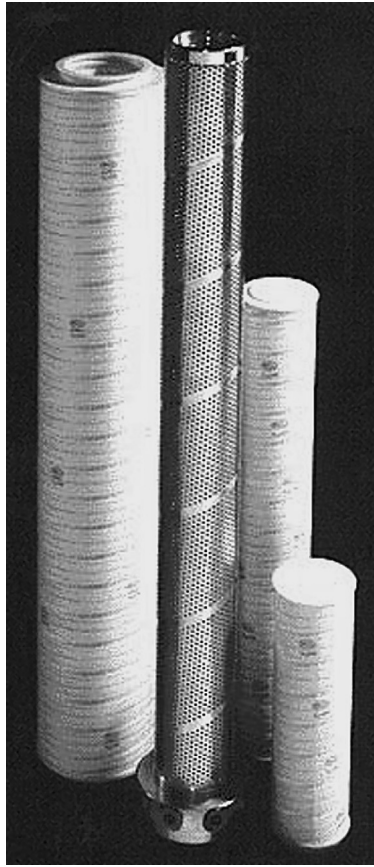


Fig. 5.4 Coreless cartridge. (Photo courtesy of Pall Corporation.)

surface, several cartridges can be installed in the same housing. Layer cartridge filters are cheaper than membrane filters, and so they are frequently used upstream in order to protect them.

5.3.1.4 *Membrane cartridge filters*

Membrane filters can be described as a porous matrix with a controlled pore size. Particles are stopped at the surface, or in the upper part of the membrane thickness. All particles larger than the pores are trapped (nominal cut-off). They are characterised by an absolute pore size, indicating the pore size at which a challenge organism of a particular size will be retained with 100% efficiency under strictly defined test conditions. The challenge using micro-organisms is described in the standard test method (ASTM F 838-05) for determining bacterial retention of membrane filters utilised for liquid filtration. Filter cartridges (10, 20, 30 and 40 ins) with a diameter around 70 mm are widely used. The most common cartridge connection is the double 'O'ring with bayonet lock (Code 226) with fin at the top. Compared to depth or layer cartridge, membranes are more expensive and have a lower

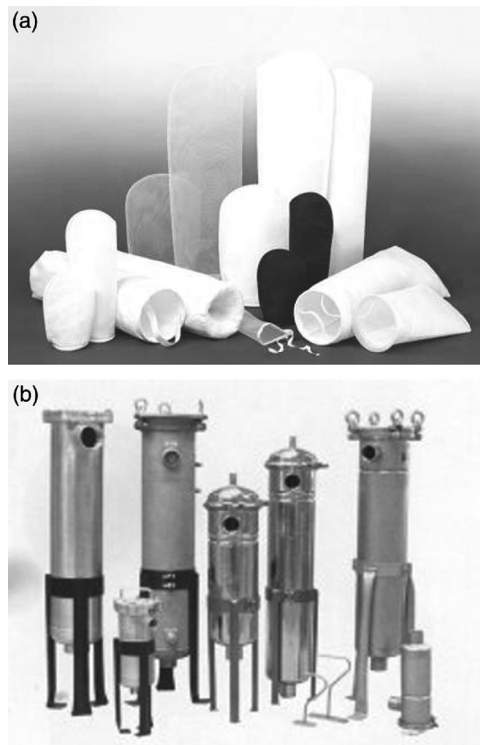


Fig. 5.5 Bags, filters and housings: (a) bags; (b) filters and housings. (Photo courtesy of Pall Corporation.)

capacity but higher efficiency. They are characterised by an ‘absolute’ pore size, indicating the ability of the filter to retain 98 to 99.9999 % particulates at the rated pore size. They can be used for particle removal and microbiological filtration with an absolute cut-off size between 0.1 and 100 μm . According to the application (i.e. the cut-off size), the flow rate will be between 0.25 and 1 m^3/h for a 10 in. cartridge. Generally, there are three elements in this type of cartridge:

- (i) filtering material, made of nylon, polypropylene, PVDF or PES;
- (ii) support layers, mainly in polyester or polypropylene;
- (iii) polypropylene core.

Membrane thickness is around 300 μm , depending on the filtering material used and manufacturer. Membranes can have symmetric or asymmetric shape, allowing retention of particles in the media and an absolute retention of particles. Membrane filter cartridge construction can be with one to two membranes with the same or different absolute cut-off size. When two membranes with different cut-off size are assembled in a filter, the first membrane plays the role of a pre-filter, protecting the second membrane (e.g. 0.8–0.2 μm).

To increase the filtering surface, the membrane is pleated (see Fig. 5.6), and several cartridges can be installed in the same housing.

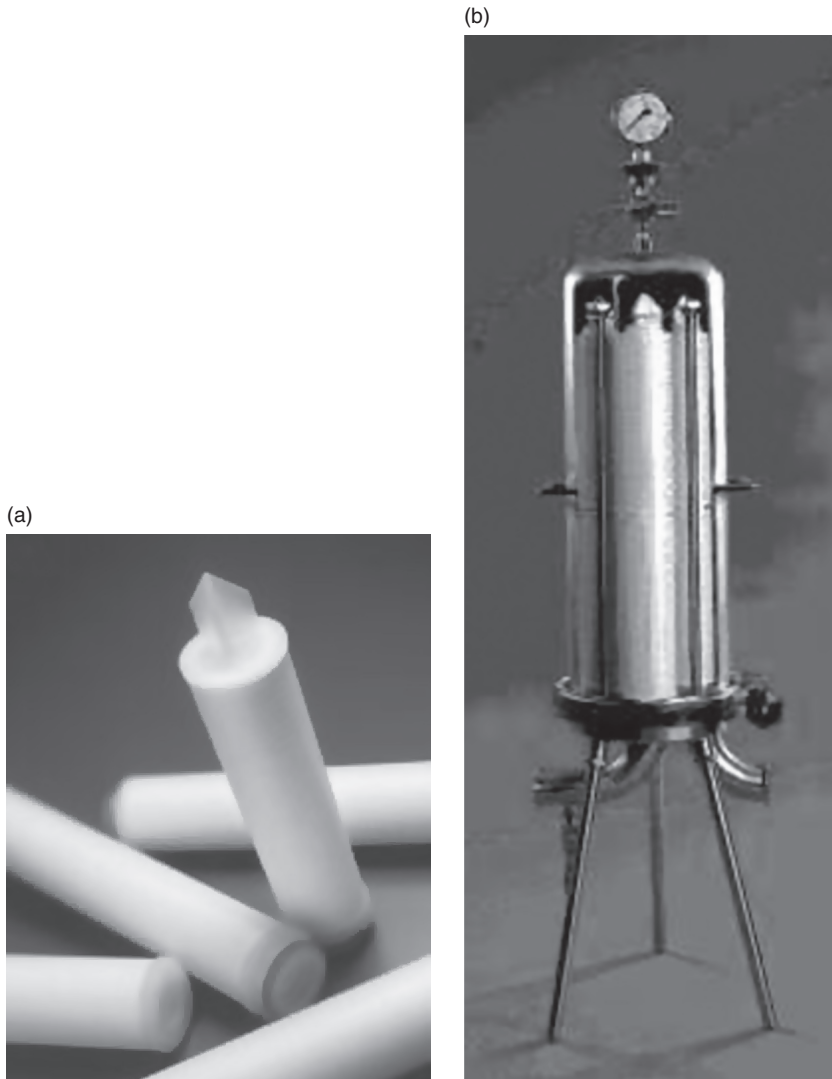


Fig. 5.6 Structure of a filter cartridge and housing: (a) cartridge; (b) cartridge housing;

Some suppliers also propose metallic filters (stainless steel) with cutoff size between 1 and $30\mu\text{m}$. The choice of filtration systems is dependent on:

- treatment flow rate;
- the objective of the treatment (particles, microbiology);
- cost of maintenance.

Monitoring of the process is mainly achieved by observing the pressure drop, checking the outlet water quality and doing integrity tests to detect any possible defects in the reliability of the system. A pressure decay or diffusion flow test is the most common test

(c)

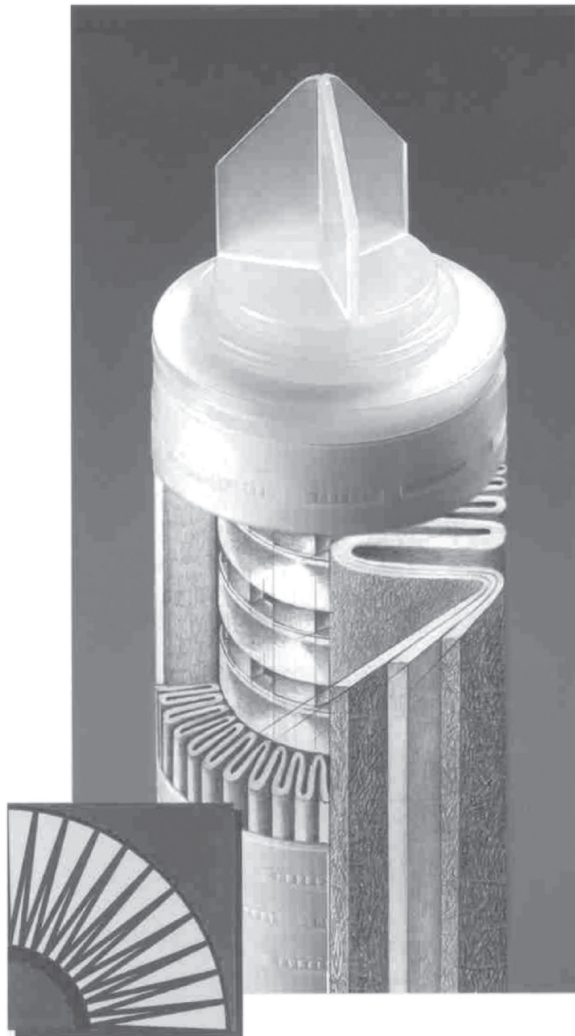


Fig. 5.6 (cont'd) (c) fluted cartridge. (Photo courtesy of Pall Corporation.)

used for membrane cartridge filters. The test can be done automatically by pressurisation from the top filtration system with sterile air, while an automatic integrity test device measures the pressure decay on the system due to air diffusion through the membranes (see Fig. 5.7).

Cartridge filtration processes need to be strictly controlled and accurately monitored to check that the filter runs continuously and that it is full of water. Otherwise, biomass build-up often develops at the surface of the filter and this can lead to quality issues. Sanitation must also, therefore, be done periodically.

In order to increase efficiency and running cost of filtration stages, depth filters (high capacity, low cost) are used prior to and in conjunction with layer filters and membrane filters (high selectivity, low capacity, high cost).

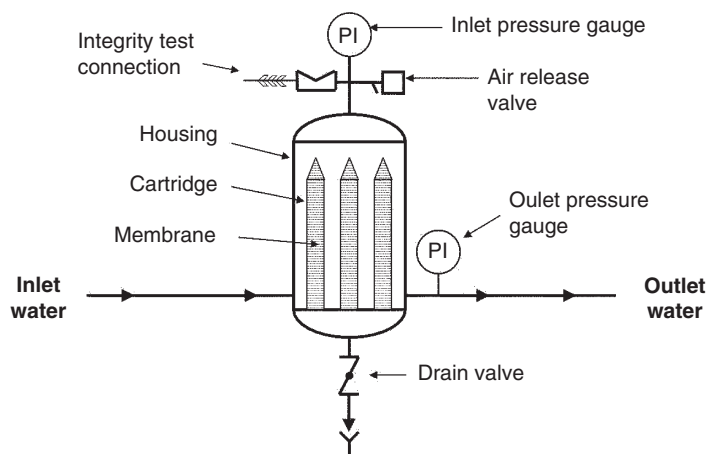


Fig. 5.7 Schematic view of a sterilising grade filter.

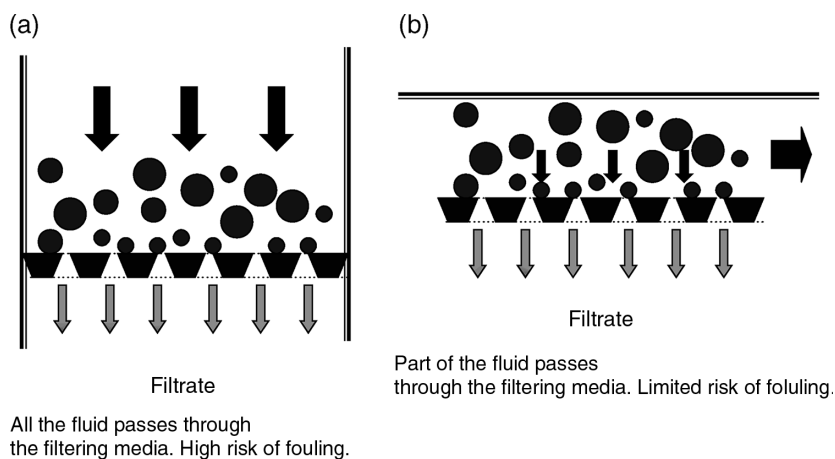


Fig. 5.8 Filtration modes: (a) dead-end filtration; (b) cross-flow filtration.

5.3.1.5 Membrane processes

Membranes represent an important set of methods for drinking water treatment. These processes are: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), which are filtration-controlled membrane processes; and reverse osmosis (RO), which is a diffusion-controlled membrane process. Electrodialysis (ED) is also sometimes classified in the category of ion exchange processes, as it uses an ion exchange membrane. Filtration processes are used in two possible running conditions:

- (i) Dead-end filtration, in which all the flow goes through the filter. The main advantage of this mode is that it treats all the water without any loss, but the pressure drop increases with the fouling over time, and it is therefore necessary to increase the working pressure progressively to maintain the process efficiency (Fig. 5.8a). In this case,

the lifetime of the filter depends very much on the inlet water quality. This configuration is used in many MF processes.

- (ii) Cross-flow filtration, in which only a part of the inlet flow (up to 98%, depending on the application) goes through the membrane, the other part remaining untreated. In this configuration, the fouling on the membrane is continuously removed by the 'shear-force' engendered by the flow velocity at the membrane surface. This configuration is mainly used in UF, NF and RO processes (Fig. 5.8b).

RO has been primarily used to remove salts from brackish water or seawater, although it is also capable of very high rejection of organic compounds. ED is mainly used to demineralise brackish water and seawater and to soften freshwater. NF is the most recently developed membrane process, used to soften freshwaters and remove disinfection by-product (DBP) precursors. Finally, UF and MF are used to remove turbidity, microbiological elements and particles from fresh waters. Figure 5.1 gives the size range of membrane processes and contaminants.

Membranes, the key components of the process, are manufactured as flat sheets, hollow fibres or coated tubes. They must be configured into elements to manage the flow streams in the membrane machines and support the membrane under the required hydraulic pressures.

Flat sheet configurations include the plate-and-frame and spiral-wound design; the latter predominates all forms including hollow fibre and tubular. The plate-and-frame design allows a variety of feed- and permeate-channel designs, but is a high-cost approach (see Fig. 5.9a). The spiral-wound design affords the best 'all-around' characteristics, of high packing density, low cost and rugged high-pressure operation (see Figs 5.9b and 5.9c). With the recent advent of specialised feed-channel spacer materials, a wider range of applications, such as RO and NF, now employs the spiral design.

Hollow fibres (0.5–2 mm diameter) are mainly used in UF processes (Fig. 5.9d). They can handle high solid loading without plugging and can be back-flushed to remove fouling layers. Since they are self-supporting homogeneous fibres, they are limited by the tensile, compressive and flexural strengths of the membrane material, which is porous. This limits the operating pressure and flow rates to less than those of spiral wounds.

Coated tubes are large-scale versions of hollow fibres (0.6–2.5 cm), with the membrane coated on the inside wall of a support porous material. This support material gives the tube its strength so that higher operating pressures are possible (Fig. 5.9e).

Principal materials used in membrane manufacturing are: cellulose acetate (CA), polyamide (PA), polysulfone (PS), polyvinylidene fluoride (PVDF) and acrylonitrile (AN). All these are suitable for organic membranes, whereas metallic oxides (AlO_2 , TiO_2 , ZrO_2) or carbon-based coatings are best for inorganic membranes. In addition to the shape and the material used for membrane production, pore size and 'cutoff' – expressed in Daltons (the unit for molecular weight) – are, of course, key parameters for the choice of membrane processes. The membranes are installed in pressure-bearing housings, often with several membranes in the same housing.

A typical membrane process design for RO, NF and UF includes a pump to provide the necessary pressure and cross-flow velocity, the filter elements and housings, connecting parts, control valves and instruments (pressure gauges, flow-meters, conductivity-meter, etc.). The applied pressures are between 2 and 4 bar for UF, 4 and 8 bar for NF and above 8 bar for RO application (depending on the initial salt level). Prefilter cartridges or other pretreatments (e.g. MF or UF prior to RO) are usually included to protect the expensive

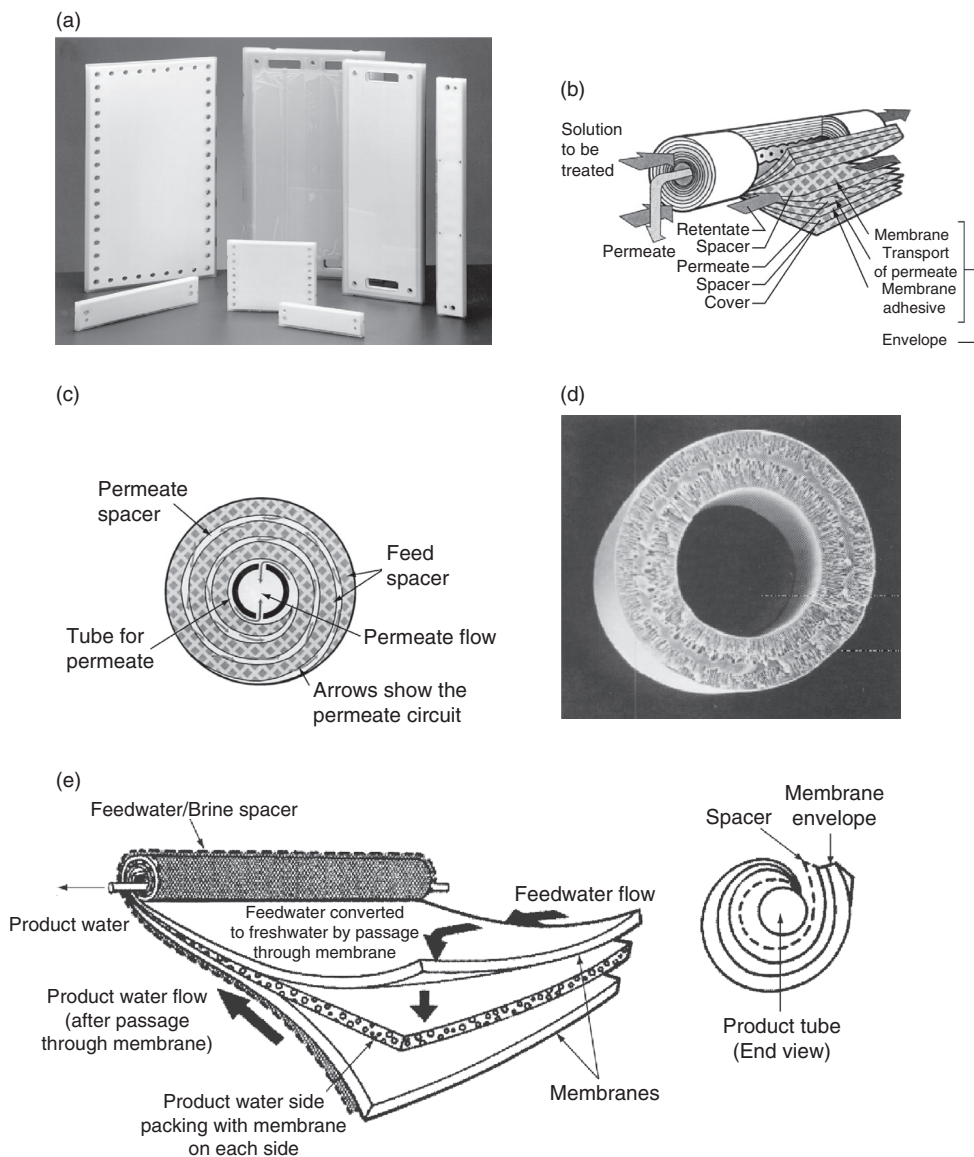


Fig. 5.9 Some examples of membrane configurations: (a) plate-and-frame membrane (photo courtesy of Pall Corporation); (b and c) spiral-wound membrane; (d) hollow fibre membrane (photo courtesy of Pall Corporation); (e) tubular membrane (American Water Works Association/Letterman, R.D. (1999) *Water Quality and Treatment – A Handbook of Community Water Supplies*, 5th edn. © McGraw-Hill, Inc.).

membrane against physical, chemical or biological fouling. In some cases, mainly for RO, chemical injection (antiscaling agents) is used. Figure 5.10 gives a schematic view of a membrane process, which is generally assembled on a skid.

The key indicators for the efficiency of the process are:

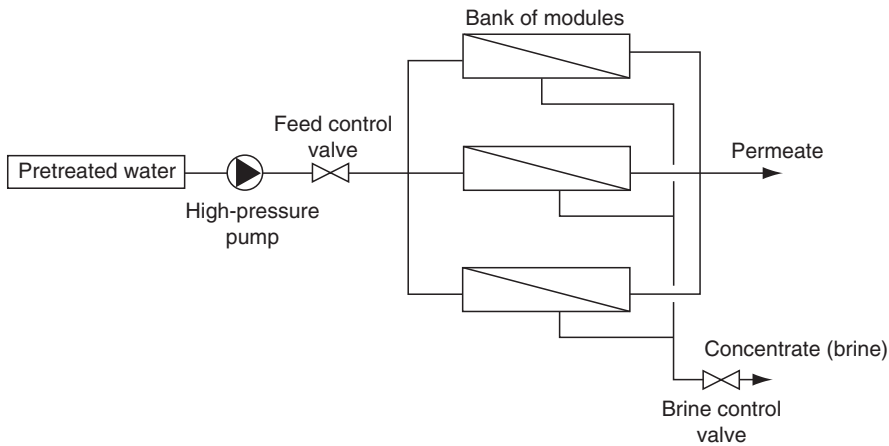


Fig. 5.10 Schematic view of a membrane process.

- pressure drop from the upstream to the downstream side;
- recovery, defined as the ratio of permeate to feed volume;
- outlet water quality;
- rejection rate, defined as the percentage of elimination for a component.

NF and RO applications usually have a 75–85% recovery, and UF and MF can reach up to 98%. Efficiency is directly proportional to effective pressure, water temperature and characteristics of the water (e.g. fouling index).

To maintain high efficiency for RO, it is sometimes necessary to include a pretreatment, such as UF and iron removal. Biofouling is a major issue for RO membranes, because of the difficulty in cleaning and sanitising them efficiently. This is due to the spiral-wound configuration of the membrane and the nature of the membrane itself; only a few newly developed membranes are compatible with hot water and strong chemical sanitation.

5.3.2 Adsorption

Adsorption is the physical and/or chemical process in which a substance is accumulated at an interface between two phases (e.g. solid/liquid). The adsorbate is the substance being removed from the liquid phase, and the adsorbent is the solid phase onto which the accumulation occurs. Adsorption of substances onto adsorbents takes place because there are forces at the molecular level that attract the adsorbate from solution to the solid surface. Two operating modes (physical or chemical) can be used in adsorption:

- One-way operation:* When maximum capacity is reached, the adsorbent is changed. This happens when the adsorbate is trapped deep inside the porous structure and is very difficult or impossible to extract, or if capacity and cost of the adsorbent are such that regeneration is not economical.
- Regeneration operation:* When maximum capacity is reached, adsorbent is regenerated. Such regeneration includes a desorption step (removal of the adsorbate trapped on the adsorbent) using a chemical reagent such as soda or acid followed by a neutralisation step. The adsorbent then recovers its full capacity for adsorption.

Adsorption plays an important role in the improvement of water quality. Adsorption from solution occurs when impurities in the water accumulate at the solid/liquid interface. The ideal case, of a single adsorbate being selectively removed onto an adsorbent, occurs very seldom in practice; the objective in most real systems is to remove several adsorbates simultaneously. The heterogeneous mixture of compounds in natural waters reduces the number of sites available for the trace compounds, because of direct ‘competition’ for adsorption sites or because of pore blockage.

The adsorption equipment is similar in design to pressure filters used for filtration applications. Sizing is also mainly established from the filtration rate and EBCT (up to 20 min). The ‘breakthrough curve’, and hence the adsorbent capacity, must be assessed beforehand through small-scale column tests (SSCTs) to size the unit. Depending on the application and the adsorptive material, regeneration and/or backwash operations can be adapted in terms of flow rate and duration. For all types of media, the principle of the support layers with gravel and sand is maintained but has to be adapted according to the adsorptive material.

In all cases, process efficiency is determined by monitoring the constituent being removed. Other parameters, such as pressure drop, should also be checked to control the process.

5.3.2.1 *Activated carbon*

Of all water treatments based on adsorption, activated carbon is by far the most widely used. The raw materials are lignite, coal, bone charcoal, coconut shells and wood charcoal. Pores are developed during activation, partly by burning away carbon layers, the thickness of which depends on the structure of the starting material. The activation step, which produces the pore structure, influences the adsorptive properties. It is accomplished either by heating to 200–1000°C in the presence of steam, carbon dioxide or air, or by wet chemical treatment at lower temperatures with exposure to agents such as phosphoric acid, potassium hydroxide or zinc chloride. The method and temperature of activation strongly influence pore size distribution and chemical properties. Hence, depending on the production method of the activated carbon, the initial conditioning before treating water for bottling becomes very important (because of the risk of pH modification or chemical compound release). In most cases, the activated carbon is a single-use material because regeneration (steam or thermal reconditioning) is not possible on-site. The main ‘target constituents’ to be removed by activated carbon for drinking water are:

- specific organic molecules that cause taste and odour, mutagenicity and toxicity;
- natural organic matter (NOM) that causes colours;
- disinfection by-products (DBPs);
- volatile organic compounds (VOCs) and synthetic organic chemicals (SOCs);
- chlorine or ozone.

Activated carbon is available in powdered form (in mixed reactors) or in granular form (using a ‘bed’ configuration): granular activated carbon (GAC) is the type most commonly used in the bottled water business. Backwashing of GAC filter adsorbers is essential for removal of solids, to maintain the desired hydraulic properties of the bed and to control biological growth. To limit bacterial growth on the media, the activated carbon filter may also require regular sanitation using hot water and steam.

5.3.2.2 *Manganese dioxide*

Manganese dioxides (either from natural sand or synthetic origins) are being increasingly used for water treatment, with the objective of removing manganese and arsenic. Several products are available in the market with different efficiencies, but in each case, the material is placed in a conventional 'sand-type' filter vessel, sized according to the standard parameters (filtration rate, EBCT) and based on previous capacity tests. Backwashing conditions need to be adapted to the materials as some of them are very crumbly and can produce a lot of fine particles during this operation.

For manganese removal, a chemical regeneration can be done when the material is saturated or when the breakthrough point is reached. This regeneration, which is a reoxidation of the media, is done using potassium permanganate or chlorine. For maximum efficiency, a backwash is required before chemical regeneration.

For arsenic removal, manganese dioxide is an effective adsorbent, and high performance can be easily achieved (release of arsenic is <2 ppb) with high reliability. In this case, adsorption is reversible, which means that regeneration of the material is possible. This chemical regeneration includes caustic soda for desorption, acid neutralisation and a final water rinse step. Regeneration is a constraint of this process, and the management of wastewater should also be taken into consideration.

Manganese dioxide has a strong affinity for iron; thus, when a manganese dioxide filter is used for the removal of manganese or arsenic, it is essential that iron be removed first. Iron is a 'competitor' to manganese, and is preferentially trapped on the material, and in this case, adsorption sites become less or not at all accessible for other compounds, and so the efficiency decreases for manganese removal.

5.3.2.3 *Activated alumina*

Activated alumina is mainly used for the removal of arsenic, fluoride and, occasionally, selenium. As with other adsorbents, preliminary tests (pilot tests) are essential before any industrial design to assess the performance of the process (capacity) and the impact on water characteristics. Efficiency depends on the activated alumina used, the running conditions and the water characteristics. For fluoride or arsenic removal, adsorption is reversible and so chemical regeneration can be applied when the material is saturated or when a fixed breakthrough point is reached.

5.3.2.4 *Granular ferric hydroxide (GEH)*

GEH is mainly used for the removal of arsenic. It is a very high capacity material, which is used as a one way material (no regeneration). Depending on the initial arsenic level, the material can be continuously used between 1 and 2 years (up to 5 years). However, the effectiveness of this material is significantly reduced when treating waters high in phosphate and silica.

5.3.3 Ion exchange

Ion exchange is also used in water treatment. The process has been primarily used for the removal of hardness and for demineralisation, but is now being implemented for other applications. As its name implies, ion exchange describes the physicochemical

process by which ions are transferred from a solid to a liquid, and vice versa. All ion exchangers, whether natural or synthetic, have fixed ionic groups that are balanced by counter-ions (anions or cations, which exchange with ions in solution) of opposite charge to maintain electroneutrality. Figure 5.11 gives a schematic diagram of this exchange.

As the resin initially containing counter-cation A^+ is placed in a solution containing B^+ , diffusion is established due to the concentration difference between counter-ions A and B in the resin and in solution. Exchange occurs until equilibrium is reached between the solution within the matrix of the resin and the bulk solution.

Nowadays, most resins used in water treatment processes are synthetic ion exchange resins. Due to their higher capacity, synthetic resins are preferred to natural materials such as greensand, clay, peat, bauxite, charred bone or zeolites. The majority of ion exchange resins are made by the copolymerisation of styrene and divinylbenzene (DVB). Styrene molecules provide the basic matrix of the resin, while DVB is used to cross-link the polymers

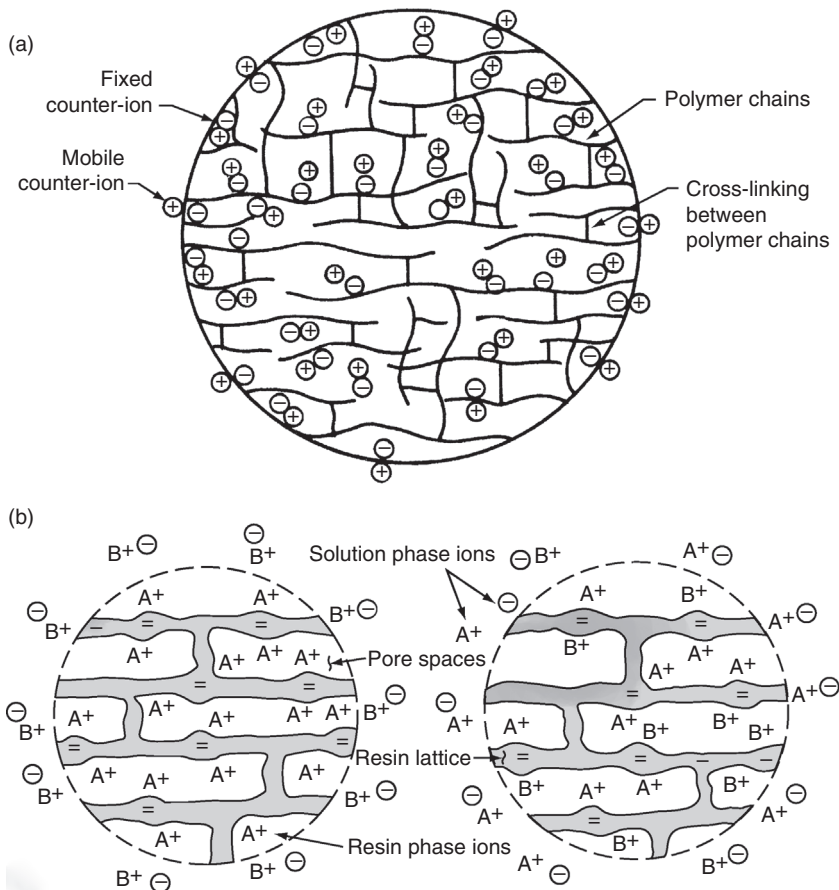
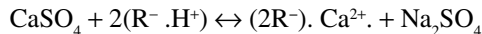


Fig. 5.11 Schematic diagram of a cation exchange resin. (a) Structure of organic cation-exchanger bead (American Water Works Association/Letterman, R.D. (1999) *Water Quality and Treatment – A Handbook of Community Water Supplies*, 5th edn. © McGraw-Hill, Inc.). (b) Initial and steady state of a cation-exchange resin (Montgomery, J.M. (1985) *Water Treatment Principles and Design* © John Wiley & Sons, Inc. Reproduced with permission).

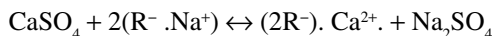
to allow for the general insolubility and toughness of the resin. They are generally available in spherical shapes with particle diameter size between 0.04 and 1.0 mm. Particle size is a key parameter for the rate of exchange (proportional to either the inverse of the particle diameter or the inverse of the square of the particle diameter) and also for the hydraulic design of the column (pressure drop). To produce the various types of cationic and anionic resins, the plastic structure is reacted with either acids or bases. The ionisable group attached to the resin structure determines the functional capability of the exchanger. There are four general types of ion exchange resins based on their functional groups, which are used in water treatment:

- (i) strong-acid cation exchangers;
- (ii) weak-acid cation exchangers;
- (iii) strong-base anion exchangers;
- (iv) weak-base anion exchangers.

Each category of resins must be implemented with adapted running conditions and regeneration procedures. Strong-acid exchangers can convert neutral salts into their corresponding acids if operated in the hydrogen cycle (e.g. $\text{NaCl} + \text{R-H} \leftrightarrow \text{HCl} + \text{R-Na}$). In this case, the functional groups can be derived from sulfonic (HSO_3^-), phosphonic (H_2PO_3^-) or phenolic groups. For this type of resin, the chemical regeneration is usually done with HCl or H_2SO_4 , or during a sodium cycle where the resin is regenerated with NaCl. The hydrogen cycle removes nearly all major raw water cations and is usually the first step in demineralising a water. It can be represented by the following reaction:



The sodium cycle is used for softening waters and also for the removal of soluble iron and manganese in the following form:



Weak-acid exchangers differ from strong-acid exchangers in that weak-acid resins require the presence of some alkaline species to react with the more tightly held hydrogen ions of the resin. The exchange is a neutralisation with the alkalinity (HCO_3^-), neutralising the H of the resin. So weak-acid resins will split alkaline salts but not monoalkaline salts (e.g. NaHCO_3 , but not NaCl). In contrast with strong-acid resin regeneration, where a large excess of regenerant is required to create the concentration driving force, weak-acid resins use up to 90% of the acid (HCl or H_2SO_4) regenerant, even with low acid concentrations. Weak-acid resins are favoured when the untreated water is high in carbonate hardness and low in dissolved carbon dioxide; they are primarily used for achieving simultaneous softening and dealkalisation.

Strong-base exchangers split neutral salts into their corresponding bases if operated on the hydroxide cycle (e.g. $\text{NaCl} + \text{R-OH} \leftrightarrow \text{NaOH} + \text{R-Cl}$). They are typically used after cation exchangers to remove all anions for complete demineralisation, but weakly substances such as silica and carbon dioxide can also be removed. In the chloride cycle (e.g. $\text{SO}_4^{2-} + 2(\text{R}^+ \cdot \text{Cl}^-) \leftrightarrow 2(\text{R}^+) \cdot \text{SO}_4^{2-} + 2\text{Cl}^-$), strong resins have been used for nitrate and sulfate removal. The functional sites are derived from quaternary ammonium groups. There are two types of strong-base resins: type I, with three methyl groups as the functional group; and

type II, with an ethanol group that replaces one of the methyl groups. Type I has greater chemical stability, while type II has a slightly greater regeneration efficiency and capacity. Depending on the use, the strong-base resins are regenerated with NaOH or NaCl.

Weak-base exchangers remove free mineral activity (FMA), such as HCl or H_2SO_4 . They are sometimes used in conjunction with strong-base resins in demineralising systems to reduce regenerant costs and to attract organics that might otherwise foul the strong-base resins. They are regenerated with NaOH, NH_4OH or Na_2CO_3 .

Resins are mainly used in fixed-bed columns, which are steel pressure vessels constructed to provide a good feed and regenerant distribution system and appropriate bed support, including provision for distribution of backwash water and enough free space above the resin to allow for the bed expansion that is expected during backwash. Again, the key parameters in designing the process are EBCT, rate and capacity. This is why, before any sizing, SSCTs must be performed to check the capacity of the resins, in order to monitor the possible release of chemical compounds. These tests also give data about the selectivity of the resin, the competitiveness with other elements and the impact on the main characteristic components of the water.

The stability of an ion exchange resin under certain physical, chemical and/or radioactive conditions plays a major role in many applications. Physical stress may change the structure of the resin, the most common example being excessive osmotic swelling and shrinking, which may break the bed. Mechanical compression, abrasion and excessive temperature can also rapidly degrade the characteristics of a resin. Chemical degradation can occur, with the breaking of the polymer network, modification of the functional groups or fouling of the resin by the species in solution. Possible release of by-products is also a high risk for the resins.

Bacterial growth can be a major problem with anion resins because the positively charged resins tend to 'adsorb' the negatively charged bacteria that metabolise the adsorbed organic material – negatively charged humate and fulvate anions. The use of chemical disinfectants or hot water is not recommended. To correct this issue, special resins have been developed, which contain bacteriostatic long-chain quaternary amine functional groups on the resin surface.

5.3.4 Chemical oxidation

Chemical oxidation processes play several important roles in the treatment of drinking water. Chemical oxidants are used mainly for the oxidation of reduced inorganic species to destroy taste- and odour-causing compounds and to eliminate colour. Because many oxidants also have biocide properties, they can be used to control biological growth. The most common chemical oxidants used in water treatment are:

- air;
- chlorine;
- chlorine dioxide;
- ozone;
- potassium permanganate.

5.3.4.1 Chlorine

Chlorine is the most widely used oxidant in water treatment. Molecular chlorine is typically provided in pressurised cylinders so that it exists as a liquid under pressure. It is then added to the water by reducing the pressure in the tank and releasing it as a gas. Because of the

risks involved in transport and handling of hazardous chemicals, liquid sodium hypochlorite (NaOCl), supplied as a concentrated bulk solution, is increasingly used despite its higher cost. The main problem with hypochlorite is the stability of the product, which tends to degrade over time, particularly when it is stored at high temperatures and/or exposed to sunlight. Chlorine oxidation is mainly used for:

- oxidation of iron and manganese;
- taste and odour control;
- colour removal;
- ammonium removal (using NaOCl).

The main disadvantage of chlorine is the production of a variety of chlorine-substituted halogenated compounds, for example chloramines are produced when chlorine oxidation is used for ammonium removal.

5.3.4.2 Chlorine dioxide

Chlorine dioxide (ClO_2) is a greenish-yellow gas at room temperature, unstable at high concentrations and potentially explosive upon exposure to heat, light, electrical sparks or shocks. It does not hydrolyse in water like chlorine, remains in its molecular form as ClO_2 and results from the reaction of sodium chlorite (NaClO_2) with either gaseous chlorine (Cl_2) or hypochloric acid (HOCl). Its first application in the past was for taste and odour control, although it is also an effective oxidant for reduced iron and manganese. One of its principal advantages is that it does not react with ammonia; also, it does not enter into substitution reactions with NOM to the same degree as chlorine. So it does not produce trihalomethanes (THMs), haloacetic acids (HAAs) or most of the other oxidation by-products that result from chlorination. Chlorite (ClO_2^-) is considered to be the principal oxidation by-product of chlorine dioxide.

5.3.4.3 Potassium permanganate

Potassium permanganate (KMnO_4) has been used as a water treatment oxidant for decades. It is commercially available in crystalline form and is prepared on-site. As an oxidant, KMnO_4 is more expensive than chlorine and ozone, but it has been reported to be as efficient for iron and manganese removal and may require less equipment and thus less capital investment. Potassium permanganate solution is injected in the water to be treated; contact time after oxidant addition is typically 5 min at 20°C , followed by bed media filtration. The process is more efficient at pH values above 7.5. It is also used for the chemical regeneration of manganese dioxide in manganese removal filters.

5.3.4.4 Ozone

Ozone gas is formed by passing dry air or oxygen through a high-voltage electric field (see Plate 1 in the colour plate section). The resultant ozone-enriched air is added directly into the water by means of porous diffusers or venturi systems. The injection point is generally at the base of a contact tank (in the case of diffusers), or on the infeed supply (in the case of a venturi injector). Subsequent mixing and diffusion in the contact tank over a period of 10–15 min allows dissolution of the gaseous ozone. The most common

Table 5.1 Standard potentials for chemical oxidants used in water treatment.

Oxidants	OH•	O ₃	H ₂ O ₂	KMnO ₄	ClO ⁻	HOCl	O ₂	ClO ₂
E• (V)	2.85	2.08	1.78	1.68	1.64	1.48	1.23	0.95

use of ozone in Europe is for manganese removal, while in the USA, it is used widely as a final disinfection step prior to bottling. Ozone is also sometimes used to transform nitrites to nitrates during a nitrification process. Because of its high oxidising power, ozone reacts with many constituents of the water. In particular, it can lead to the formation of brominated by-products when applied to waters with moderate to high bromide levels. Some of this oxidised bromine will continue to react to form the bromate ion (BrO₃⁻). Other by-products attributed to ozone include hydroxyacids, aromatic acids and hydroxyaromatics. When ozone reacts with organic contaminants in water, including NOM, it partially oxidises them to lower molecular weight with higher polarity. These biodegradable by-products can contribute to biofouling problems in the water process if not properly controlled. Ozonation is therefore often followed by a biological activated carbon (BAC) process, to remove such biodegradable organic matter (BOM). Of all the previous oxidation processes, ozone is the most widely used in the bottled water business to oxidise dissolved iron or manganese. Ozone is sometimes used in conjunction with hydrogen peroxide or UV irradiation to produce hydroxyl radicals (OH•), which have powerful oxidative properties.

5.3.4.5 Air

Air oxidation is the simplest oxidising process and is most widely used in the bottled water industry for iron removal. However, air oxidation is not effective for manganese removal when the pH of water is below 9.5, due to its very slow kinetic reaction; hence, a more powerful oxidant such as ozone is required for this application. Several devices are used to inject the air (venturi, porous diffuser, direct injection in a mixing pot), and an oxidation tower is set up to increase the required contact time between water and air for oxidation reactions. The airflow rate must be properly adapted to the water flow rate and to the initial level of iron. Table 5.1 gives the oxidation potential for the main oxidants.

5.3.5 Biological processes

Biological processes are commonly used in the treatment of tap water. The main benefits from these processes are iron and manganese removal, ammonium and nitrate removal (nitrification and denitrification) and the elimination of BOM. In many cases, biological processes are oxidising processes in which the oxidation is done by different types of micro-organisms. These micro-organisms are fixed on a support material, such as sand, anthracite, manganese dioxide or activated carbon, within a conventional filter vessel, and they use the element to be removed as a nutrient for their growth. In general, the efficiency of biological processes is dependent on the running conditions, and more accurately, the possible variations of the running conditions, such as flow rate, temperature, dissolved oxygen level, change in the water characteristics, due to which the process control can be critical, particularly during the starting phase.

In the bottled water business, the use of a full biological process is generally limited to ammonium removal (biological nitrification) and in some cases to organic matter removal. However, it is known that many physicochemical-based iron and manganese removal processes become in effect 'hybrid' processes (physicochemical biological) with time, due to the fixing of micro-organisms on the support.

Biological nitrification is an oxidation process done in two stages: first, the conversion of ammonium (NH_4^+) to nitrite (NO_2^-) and second, conversion of nitrite to nitrate (NO_3^-). *Nitrosomonas* and *Nitrobacter* are species of bacteria that can be involved, under aerobic conditions, in ammonium removal. Natural nitrifying flora becomes established over time and the biological process starts; the first phase leads to nitrite production, and after a short nitrite build-up, the second part of the reaction starts with the production of nitrates. During this phase, it is necessary to control as well as possible the key parameters involved in the biological reaction:

- temperature ($>17^\circ\text{C}$);
- flow rate (as constant as possible);
- dissolved oxygen ($>2\text{ mg/l}$);
- pH (optimum range 7.2–7.8).

The typical time to reach a fully efficient nitrification is between 3 and 5 weeks, depending on the running conditions and the water characteristics. Some adjustments (e.g. increasing the temperature by adding a heat exchanger) can be considered during this key step. Of course, parameters such as filtration rate (8–10 m/h) and EBCT (10–12 min) have to be optimum for the process design itself. Concerning the process control, flow rate variations must be avoided and dissolved oxygen must be checked. Periodic backwashes have to be done (based upon pressure drop) maintaining 'gentle' conditions to limit the biomass loss due to abrasion.

In addition to being an efficient adsorbent, activated carbon is also a useful support for bacterial growth. Many BAC beds are used in order to achieve some biodegradation of organics in the water. The total organic carbon (TOC) is not significantly reduced by ozone alone, but the biodegradable proportion of TOC is increased (up to a factor of 10 depending on running conditions). Removal of this assimilable organic carbon (AOC) with BAC may be sufficient to give a significant reduction in TOC.

Biological processes require very strict hygienic conditions. Any uncontrolled microbiological growth or contamination in the biological filter may dramatically affect the efficiency of the treatment and can be source of contamination downstream of the process. Specific microbiological pretreatment might be necessary to protect the biological process, and regular backwashing of the biological filter is recommended to eliminate any accumulated excess of biomass.

5.3.6 Remineralisation

The objective of remineralisation is to add specific minerals to water that is free of minerals (e.g. reverse osmosis permeate) or to water in which it is considered desirable for the concentration of certain minerals to be artificially enhanced.

By means of a dosing pump, the selected minerals are dosed into the water from different mineral tanks, each of which contains the concentrated solution of one specific mineral salt. To monitor the mineral dosing on-line, there is a static mixer followed by a conductivity meter

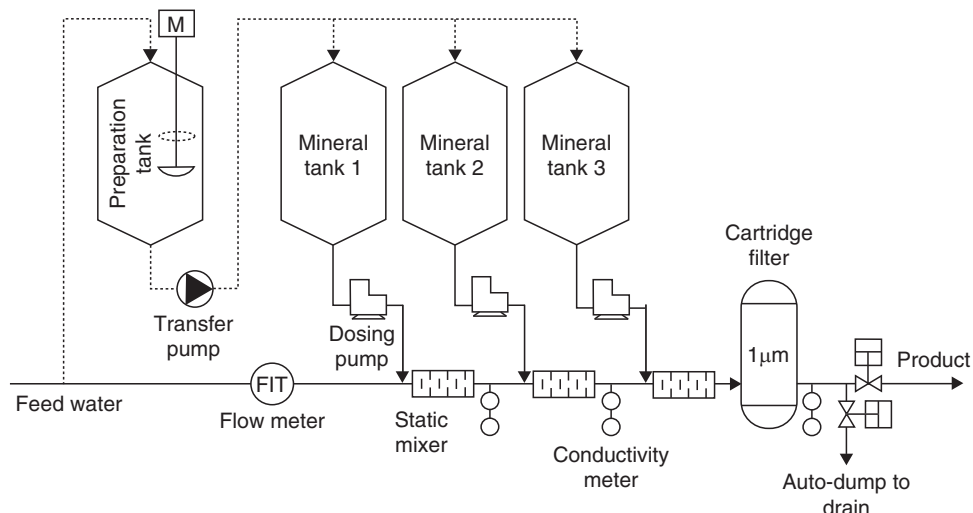


Fig. 5.12 Schematic diagram of a standard remineralisation unit.

downstream of each injection point. To avoid the risk of non-dissolved mineral particles reaching downstream processes, the water is filtered with a $1.0\mu\text{m}$ cartridge filter after mineral dosing. At the outlet of the remineralisation, an auto-dump valve allows draining of water that is out of specification. To assure uninterrupted operation (e.g. when mineral tanks are empty), a preparation tank is available to prepare the required mineral solution and transfer it to the respective mineral tank before the respective tank is completely empty (see Fig. 5.12).

5.3.7 Microbiological treatments

Microbiological treatments are designed for a partial or full inactivation or removal of micro-organisms. Inactivation is a process by which a micro-organism is rendered unable to reproduce, thereby making it incapable of infecting a host. Processing experts evaluate treatments intended to inactivate food pathogens in terms of 'logs of inactivation' (the term log is a shorthand expression of the mathematical term logarithm). Each log of inactivation is capable of causing a ten-fold reduction in the number of organisms of the target pathogen.

Initial number of micro-organisms per ml	Log inactivation	Decrease in micro-organism bacteria levels	Percent of change	Final number of micro-organisms per ml
100 000 (10^5)	1	10-fold	90	10 000 (10^4)
100 000 (10^5)	2	$10 \times 10 = 100$ -fold	99	1000 (10^3)
100 000 (10^5)	3	$10 \times 10 \times 10 =$ 1000-fold	99.9	100 (10^2)

It is important to check if microbiological treatments are permitted by local regulations. The microbiological quality of a source water, or the efficacy of a treatment system for inactivation of micro-organisms, can be assessed by direct monitoring of pathogens or by use of an indicator

system. Because pathogens are a highly diverse group, generally requiring a highly specialised analytical technique for each pathogen, the use of indicator micro-organisms is a more popular method. The main processes used for the control of water microbial quality are:

- physical treatment, such as MF or UF (removal);
- chemical treatment, i.e. ozone, chlorine, chlorine dioxide (inactivation);
- photochemical treatment with UV irradiation (inactivation).

Combinations of some of these treatments are also sometimes used, for example MF and UV, UV and ozone.

5.3.7.1 *Sterilising grade filtration (commonly known as microfiltration)*

The principle of MF is described in Sections 5.3.1.2 and 5.3.2. It successfully removes the vast majority of micro-organisms present in a water, with a high removal efficiency (up to 5 log reduction) for cysts and bacteria, where the filter cartridges typically have 0.45 and 0.22 µm pore size. These cartridges are set up in a stainless steel housing (see Fig. 5.6 and Fig. 5.7). Micro-organisms are trapped on the upstream side of cartridges, which allows high efficiency for their removal. In normal running conditions, the cartridges have to be changed regularly every 3–6 months, or more frequently if pressure drop increases. Process control is mainly done through the monitoring of the pressure drop and the outlet water quality. Integrity tests can also be done to check the nondegradation of the cartridge.

For better physical removal of micro-organisms, UF is also sometimes used; in this case, all the micro-organisms, including viruses, are stopped by the membrane barrier. This solution is more complex and costlier than MF because of the equipment required for implementing it (see Section 5.3.2 for more details). The bottled water industry generally uses MF rather than UF.

5.3.7.2 *Chemical disinfection*

Chemical treatments used for bottled water, in particular chlorine and ozone, vary. For example, some countries impose requirements for the maintenance of high hygienic conditions during water transportation from the spring (in the case of tankering) or during water storage, and in this case, chlorine is sometimes added to the water to guarantee water quality. The dose has to be adapted according to the water composition (i.e. NOM, iron, manganese and ammonium levels). The CT factor is a relevant parameter to determine or predict the germicidal efficiency of a disinfectant. It results after integration of the residual disinfectant concentration with respect to time. If the disinfectant concentration is stable, the CT value is defined as the product of the residual disinfectant concentration, C, and the exposure time, T, during which the residual disinfectant is in contact with water:

$$CT [mg \times min/L] = C [mg/L] \times T[min]$$

5.3.7.3 *Chlorination*

Chlorination is widely used in some countries as a pre-disinfection step for transportation of the raw water through tankers or underground pipes. The chemical most frequently used for chlorination is usually sodium hypochlorite (NaHClO – commonly called bleach). In some cases, calcium hypochlorite or chlorine gas can be used.

Due to the impact on the taste of the water, chlorine is always removed before bottling. The most common de-chlorination step is a Granulated Activated Carbon filter (GAC). Moreover, due to its oxidation power, chlorine must be removed before any reverse osmosis treatment, to prevent damage to the RO membrane.

Level of chlorination must be controlled so as to limit the reaction with organic matter that might lead to the conversion to chlorination by-products such as trihalomethanes (THMs).

Chlorine dioxide is seldom used in the bottled water business, except (very rarely) for the water used to rinse bottles prior to filling.

5.3.7.4 Ozonation

Due to its high oxidising power, ozone is also used in some markets to inactivate micro-organisms by destruction of the cellular membrane (See Fig. 5.13). Due to its high reactivity with many water constituents, ozone is not stable in aqueous solution. Its stability strongly depends on the water matrix (pH, dissolved organic carbon (DOC), alkalinity and temperature).

Once dissolved in water, ozone partly decomposes into hydroxyl radicals ($\text{OH}\bullet$), a very powerful oxidant (See Fig. 5.14). Ozone has two modes of reaction, and can react in one or both modes in aqueous solution:

- (i) direct oxidation of compounds by molecular ozone ($\text{O}_3(\text{aq})$);
- (ii) oxidation of compounds by hydroxyl free radicals ($\text{OH}\bullet$) produced during the decomposition of ozone.

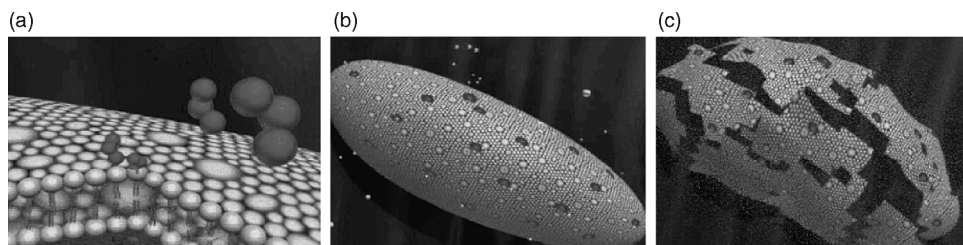


Fig. 5.13 Schematic view of the action of ozone on micro-organisms: (a) attack of the ozone molecules onto the micro-organisms; (b) first impact of ozone producing 'holes' in the cell membranes; and (c) full destruction of the cell membrane by ozone.

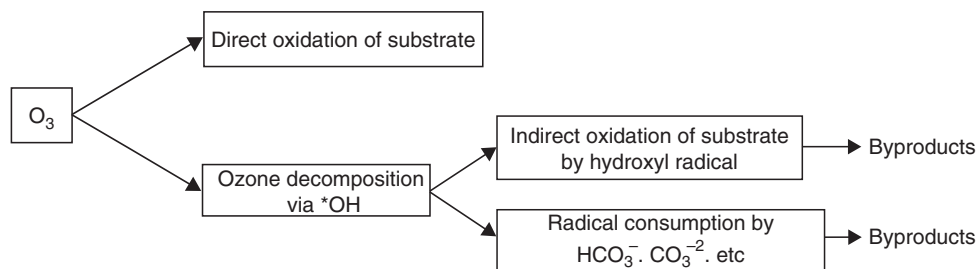


Fig. 5.14 Ozone decomposition mechanisms (from USEPA 1999).

Molecular ozone or its decomposition products (i.e. hydroxyl radical) inactivate micro-organisms rapidly by reacting with intracellular enzymes, nucleic material and components of their cell envelope, spore coats or viral capsids.

Two major configurations using ozone are:

- (i) A standard microbiological treatment, in which running conditions are calculated to reach what is referred to as a CT value (ozone concentration multiplied by contact time), allowing a total inactivation of micro-organisms. A standard CT value is 1.2 (0.3 mg/l $\pm$ 0.1 mg/l for 4 min).
- (ii) 'Germ free' bottling, in which water is bottled with an ozone residual to prevent any microbiological growth in the final product, the ozone residual having the effect of sanitising the packaging (cap and bottle) at the time of bottling. Note, however that considering the time needed for total natural elimination of the residual ozone, a high CT can be reached, and therefore bromate formation might be an issue.

5.3.7.5 Design of ozonation unit

There are two principal layouts for ozone disinfection units. The main components of each layout are described below:

Layout	Description
1st layout	The ozone gas is directly injected into the contact tank.
2nd layout	The ozone gas is injected into the water stream and passed to the contact tank for a correct dissolution.

1st design – Main components (See Fig. 5.15)

In the first design, the main components of the ozonation unit are:

Part	Function
Gas feed system	Feeds the ozone generator with air, oxygen or oxygen-enriched air.
Generator	Produces ozone from a feed gas. Also called ozonation unit or ozonator.
Diffusion device	Dissolves gaseous ozone in water (e.g. porous diffuser, injector...).
Oxidation tower	Provides the required contact time so that dissolved ozone reacts with constituents in the water. Also called contact tank or contactor.
Aqueous ozone analyser	Measures the ozone residual concentration in the outlet water. It should be positioned as close as possible to the filler.
Off-gas discharge system	The minimum is to have an exhaust pipe to the outside of the building to evacuate any excess ozone gas in excess. According to the legislation and/or safety issues, an off-gas destruction system could also be put in place.

Second design – Main components (see Fig. 5.16)

In the second design, the ozonation unit is composed of the parts as shown in Fig. 5.16.

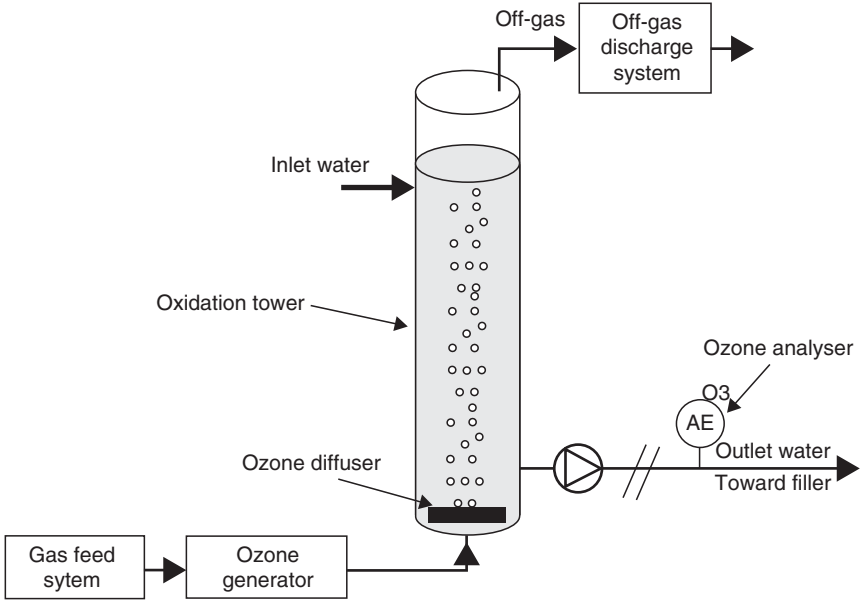


Fig. 5.15 Schematic view of a water ozonation process with porous ozone injector.

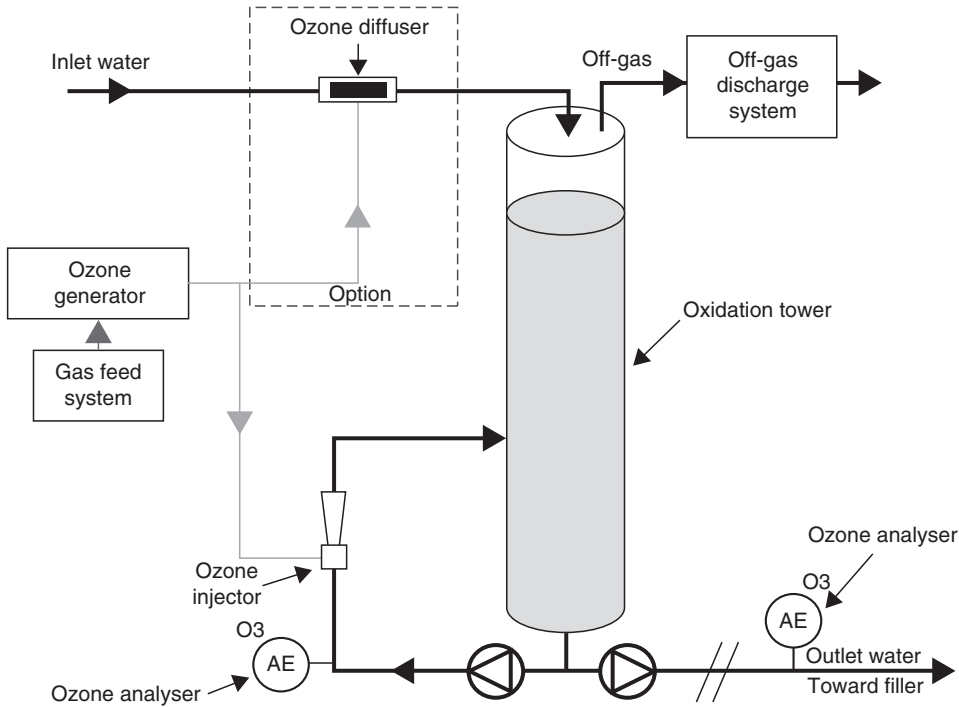


Fig. 5.16 Schematic view of a water ozonation process with in-line ozone injector.

The use of ozone disinfection for water may lead to the formation of potential by-products, such as aldehydes (e.g. formaldehyde, acetaldehyde), organic acids (e.g. acetic acid), brominated by-products (e.g. bromate ion, bromoform) and other by-products.

In the case of bottled water, the main concern is the formation of bromate (BrO_3^-) through oxidation of naturally occurring bromide (Br^-) present in the incoming water. The EU and the US EPA (United States Environmental Protection Agency) have set a maximum contaminant level for bromate of 10 ppb. Bromate formation is the result of a complicated multi-step reaction, and for water with bromide concentrations higher than 6 ppb, there is a risk of exceeding this standard.

Different options are available to minimise the risk of bromate formation:

- reduction of ozone exposure;
- pH reduction;
- NH_4 addition;
- Cl_2 - NH_4 addition.

However, in the context of bottled water treatment, two main methods can be applied:

- (i) reduction of ozone exposure;
- (ii) pH reduction.

5.3.7.6 Ultraviolet light

Antimicrobial treatment based on UV irradiation is well-known and widely used. Disinfection is achieved through the degradation of the nucleic acids (mainly adenine and thymine) within the bacterial cell (see Plate 2 in the colour plate section). The maximum effect is obtained at a wavelength of around 260 nm. Although all micro-organisms are sensitive to UV radiation, the sensitivity of the organisms varies, depending on their resistance to penetration by UV energy. Certain literature mentions a phenomenon of photoreactivation of UV-disinfected micro-organisms; however, the operation of these repair processes in micro-organisms is not very clear.

UV radiation is obtained from mercury discharge lamps, which can be of two types, low pressure and medium pressure. This depends on the partial pressure of the mercury vapour in the lamp. Low-pressure lamps are more efficient at converting electricity to UV energy, giving an output within a narrower wavelength band than medium-pressure lamps. However, the latter give a much higher output of UV radiation for the same size unit; they are generally more compact and the capital costs are lower. Generally, the life of a low-pressure lamp is estimated at 8000 hours. A new generation of low pressure lamps (amalgam lamps) has been developed. Instead of using elemental mercury, amalgam lamps use mercury combined with other metals to form an amalgam, which makes the lamp less sensitive to the effect of temperature. They offer up to three times the UV-C light output compared with conventional low pressure lamps and the lifetime of this kind of lamp is usually estimated at 12 000 h. Most UV disinfection units are tubular in design, with water flowing parallel to the long axis of a centrally positioned lamp or a bank of lamps, which are housed in quartz tubes to protect them. The inlet and outlet of the UV housing are perpendicular to the lamp; the same UV housing can hold several lamps installed around the diameter of the housing. Figure 5.17 shows a general view of a UV device. Specific sensors are set up to monitor the

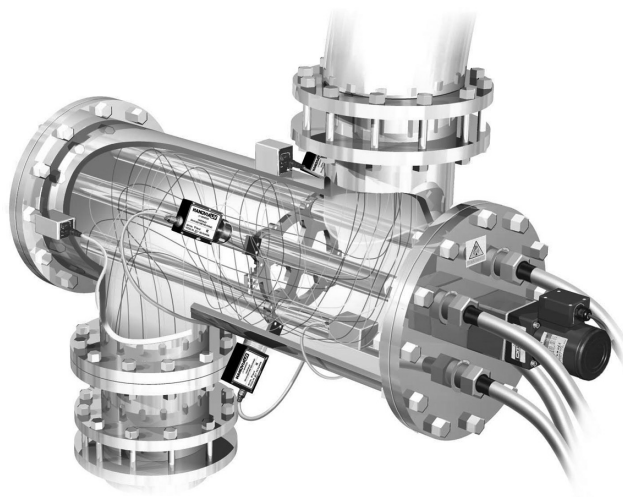


Fig. 5.17 Schematic view of a UV system. (Reproduced with permission of Hanovia Ltd.)

UV intensity and allow detection of any defects in the running conditions, for example if a lamp is off. An ‘hours run’ meter also gives an indication of the remaining lamp lifetime.

A key parameter in designing a UV reactor is the UV dose, which is defined as the amount of energy of UV light per unit area incident on a surface. The applied dose, which is expressed in mJ/cm^2 , depends on the application. The standard dose for drinking water disinfection is $40 \text{ mJ}/\text{cm}^2$, which is effective for the majority of micro-organisms, except for some viruses and for moulds and amoeba that may need a higher dose (up to $200\text{--}250 \text{ mJ}/\text{cm}^2$). The dose distribution a UV reactor delivers can be estimated using mathematical models based on computational fluid dynamics (CFD) or the light intensity distribution (LID). However, a validation test called ‘biodosimetry’ is often used to verify these modelling results (Fig. 5.18). Indeed, the UV dose received by a waterborne micro-organism in a UV reactor depends on several parameters, including:

- hydraulic effects of the UV installation (flow rate, UV reactor design);
- the effects on UV irradiance of the water UV transmittance, absorbance of quartz sleeves, reflection and refraction of light from the water surface and reactor walls.

For that reason, the UV dose delivered by a reactor is determined through a biodosimetry validation test which compares two things:

- (i) the log inactivation of a challenge micro-organism obtained with the UV reactor – under specific operating conditions of flow rate, UV transmittance and UV irradiance;
- (ii) the UV dose response curve of the challenge micro-organism established with a perfect reactor.

To reach its full efficiency, a UV device requires a few minutes (lamp heating) when water is not flowing through the UV chamber. UV lamps best operate in a continuous mode, as one ‘on/off’ operation is equivalent to 1 hour of operating time for the lamp. A key requirement to maintain a high efficiency level for a UV device is to clean the quartz tube periodically to prevent fouling. The UV transmittance of water decreases with increasing

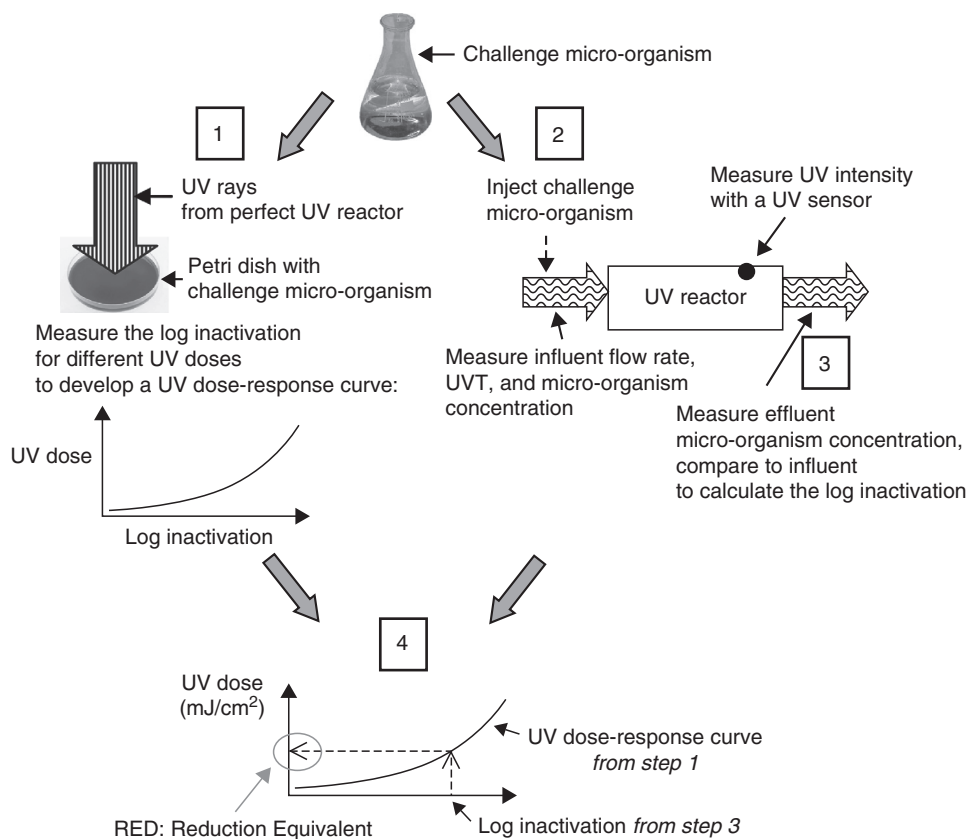


Fig. 5.18 Different steps of a biosimetry validation test.

colour, turbidity, iron and manganese; so these elements have to be removed before the UV step, if the irradiation is to maintain a high efficiency.

In addition, UV can be used to destroy residual ozone in the water, and when used for this purpose, $180 \text{ mJ}/\text{cm}^2$ is required.

Table 5.2 provides a summary of the general water treatment processes.

5.4 CONCLUSIONS

The objective of this chapter is to give a brief overview of the treatments available for use in the bottled water business. Though the range of such treatments is very wide, the following factors must be taken into account when considering which treatments to use:

- It is an expensive affair in terms of investment and operation.
- It may generate liquid/solid wastes.
- It may generate undesirable by-products in the treated water.
- It may itself be at the origin of quality issues (failure of treatment/contamination).

Table 5.2 Water treatment processes.

General processes	Type	Main applications	Efficiency	Advantages	Disadvantages
Filtration	Bed media filter	Particle and iron removal	Moderate to high	Backwashable	Size
	Bag filter	Particle removal	Variable	High flowrate/low cost	Low capacity
	Coreless filter	Upstream particle filtration	High	High capacity and flow	Low range of cut-off size
Membrane	Cartridge	Particle removal/microbiology	High	Low cutoff size	Operation cost/oneway
	Microfiltration	Particle removal/microbiology	High	Absolute cut-off	Clogging
	Ultrafiltration	Particle removal/microbiology	High	Some large organic molecules/viruses	Investment cost
	Nanofiltration	Partial demineralisation	Moderate to high	Removal of some dissolved molecules	Investment cost
	Reverse osmosis	Total demineralisation	High	High quality of water	Bacterial growth (biofouling)
Adsorption	Activated carbon	NOM, VOCs, DBPs, chlorine, ozone removal	Variable	Wide range of 'pollutants' removal	Bacterial growth/no possible regeneration
	Manganese dioxide	Manganese and arsenic removal	High	Selectivity/capacity/ regeneration	Wastewater from the regeneration
	Activated alumina	Arsenic and fluoride removal	Variable	Selectivity/regeneration	Low capacity/wastewater for the regeneration
Ion exchange	Resin	Softened water/manganese removal/demineralisation	Variable	Wide range of products	Possible release of chemical compounds/bacterial growth/low selectivity
Chemical oxidation	Chlorine	Iron and ammonium removal/microbiology control	High	Inexpensive/strong oxidant/persistent residual	Halogenated by-products may contribute to taste and odour issues
	Chlorine dioxide	Taste and odour control/iron and manganese removal/microbiology control	High	No HAA and THM by-products/no reaction with ammonia	Chlorite and chlorate formation/may produce undesirable odours
Biological irradiation	Potassium permanganate	Regeneration of manganese dioxide/iron and manganese removal	Variable	No halogenated by-products/easy to feed	Process control (pink water)
	Ozone	Manganese oxidation/microbiology control	High	Very strong oxidant	By-products/process control/impact on NOM
	Air	Iron oxidation	High	Very simple	Weak oxidant
	Pressure filter	Ammonium removal	High	No by-products	Process control
	UV	Microbiology control	High	No by-products	Impact of turbidity on transmissivity

Implementation of any water treatment must be absolutely justified, and the method and sizing must be correctly adapted to the need. Many constituents in the composition of the water may affect not only the elements to be treated but also the performance of the water treatment itself.

It is vital to have a thorough knowledge of the raw water composition, over a period long enough to understand the natural fluctuation in composition (e.g. during low and high flow periods). This will make it possible to limit as much as possible any inadequacies in definition and rating, which may otherwise lead to extra costs in investment and operation, loss of performance and quality issues.

Water treatment processes should be subjected to a thorough hazard identification process (HACCP) and the results incorporated in the quality management system. Finally, most important is that any treatment used must be authorised by local regulations for the specific status of the water, whether it is ultimately being bottled or used simply as part of the bottling process.

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6 Bottling Water – Maintaining Safety and Integrity through the Process

Dorothy Senior and Nicholas Dege

6.1 THE NATURE OF WATER

Over the years, we have repeatedly encountered professionals who have extensive experience in the bottling industry, but not necessarily in the field of bottling water. At first glance, their expectation (and that of others entering the industry for the first time) is often that it must be the easiest thing in the world; what could be simpler than using modern technology to just put water (the ‘simplest’ of substances) into bottles? Experience tells us however, that the reality is somewhat different; water is actually a much more complex and sensitive substance than the uninitiated may realise, and there are many real challenges inherent in bottling water successfully. It is important therefore that anyone wishing to embark on the business of bottling water should make it their business to have at least a basic understanding of the properties of water and of the potential difficulties they are likely to encounter, as dictated by the character of water itself, the materials used and the processes through which water passes on the way to the consumer.

6.1.1 Physical properties

In many ways, water is an amazing substance, with unique properties that are worthy of examination, as they influence the ways in which it is appropriate to collect, store, treat and bottle this very special product. One of the characteristics of water is that it can exist in all three states of matter – solid (ice), liquid (water) and gas (water vapour) – in normal climatic conditions. Evaporation can take place from water or ice at any temperature. Liquid water is at its maximum density at 3.94°C. In ice, at 0°C and below, the existence of a very open molecular structure causes the solid state to be less dense than its liquid counterpart, and as ice melts, the molecular lattice breaks up and the molecules can pack more closely together, resulting in a denser substance. This unusual characteristic has enormous biological and environmental consequences, ensuring survival of underwater life. This is because (unlike most other substances) when water changes from the liquid to the solid state, it becomes *less* dense, and as a result, ice floats on the surface and acts as an insulating layer for the liquid below. If it were otherwise, the oceans would have frozen from the bottom up, and would have remained solid for the duration of the planet, and thus life would have been unlikely to have gained a foothold on Earth.

In its liquid form, water tends to form a sphere (as in droplets) and it is drawn by gravity to eventually seek a level with the whole. Given energy, water creates rhythm that can be

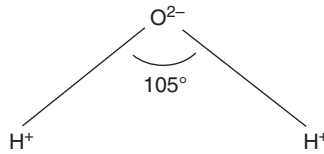


Fig. 6.1 Molecular structure of water.

observed in the pattern of waves or in meandering watercourses. Water moves in layers that pass each other at varying speeds, and vortices create the pattern of changing activities in water. Because water has a high heat capacity, it requires a large increase or decrease in the surrounding temperature to affect the temperature of the water, which will only equilibrate with the environment over time. Its high boiling point of 100°C ensures its continued existence as liquid on the Earth.

6.1.2 Chemical properties

The molecular structure of water is asymmetrical, with the bonds to the hydrogen atoms at an angle of 105° (Fig. 6.1). A partial separation of electric charge (as shown in Fig. 6.1) produces a bipolar molecule, with the highly electronegative element oxygen forming 'hydrogen bonds', with the hydrogen atoms in adjacent water molecules to produce strong intermolecular forces. The strength of this bonding accounts for the large latent and specific heat capacities of water, its cohesive nature and for the inward-acting forces at the surface that enable water to have the highest surface tension of all liquids. This facilitates capillary action and the ability of water to wet surfaces.

The bonding within other substances is weakened in the presence of water, resulting in the separation of electrostatically charged cations and anions which, when surrounded by water molecules, become dissolved, forming a solution. This powerful solvent action of water is vital for plant and animal life, as it enables transport of chemicals and nutrients and facilitates life processes. However, this same characteristic can also work to transport harmful pollutants and toxic substances. It is almost impossible to produce or store pure water (H₂O), since virtually all substances are soluble to some extent in water and almost all chemical changes are dependent on water.

6.1.3 Biological properties

Water provides the medium for all biochemical reactions through four of its characteristics:

- (i) solvent property;
- (ii) heat capacity;
- (iii) surface tension; and
- (iv) properties on freezing.

Most biological processes take place within a narrow temperature range; consequently most organisms cannot tolerate wide variations in temperature. The maintenance of a narrow range of temperature as a result of water's very high heat capacity thus makes it ideal for supporting animal and human life. Water is needed to transport food around the body, eliminate waste, regulate body temperature and to control organ functions. It sustains all the

processes of life, carrying dissolved elements vital for every form of life, from the tiniest bacterial cells to the most complex human organism.

6.2 INFLUENCING FACTORS

It follows from the foregoing brief outline of the nature of water that it is highly susceptible to chemical and organoleptic change as well as being easily contaminated by allochthonous (those not indigenous) microflora. In order to maintain its active balance and integrity, it is necessary to develop a 'water consciousness' – a means of recognising and preserving the qualities of wholesome water. To achieve this, it is important to give careful consideration to all the materials that will come into contact with the water and also to the procedures for handling the water as 'product' and to appropriate hygiene practices.

The following section of this chapter provides guidance on the factors to be considered when selecting equipment, materials and processes, with a view to minimum product degradation and maximum product safety. They will also be an essential part of the prerequisite programme to support a Hazard Analysis Critical Control Point (HACCP) system, as described in Chapter 9.

6.2.1 Materials in contact with water

Consideration of materials in contact with water throughout the bottling process is likely to include:

- plant equipment (lining of boreholes, pipelines and tanks, etc.) (see Section 6.2.2);
- bottle-filling equipment (see Chapter 7);
- filters or treatment equipment (see Section 6.2.3 and Chapter 5)
- carbon dioxide (see Section 6.2.4);
- process air (see Section 6.2.5);
- packaging materials (see Section 6.2.6).

6.2.2 Plant equipment

Whenever feasible, it is advisable (and, in some markets, legally required) to have plant equipment that is dedicated to the bottling of water. Residues of sugar, fruit cells and flavours associated with soft drinks are extremely difficult to eradicate and can lead to organoleptic and microbiological problems with water. Even given the transient status of water within the bottling plant, it is worth choosing materials that have as little reaction with water as possible and by design are capable of being maintained to a high standard of hygiene. All materials used in contact with water must be approved for food use.

Stainless steel is the most widely used material, since it meets these requirements. Where plastics are selected on economic grounds, it is important to be satisfied that these not only have approval for food contact but that they specifically do not affect the water in any way. Contact surfaces should be smooth to facilitate product flow and also to enable them to be cleaned easily and effectively. Where permanent joints are needed in stainless steel, they should be smooth and continuous, polished to the same standard as the surrounding material and able to augment the mechanical strength of the material. Integrated stainless steel (ISS) fittings should be used on pipework designed for use with cleaning-in-place (CIP) systems.

Hygienic, good-quality tungsten inert gas (TIG) welds are needed to avoid areas for build-up of contamination and localised corrosion, and to facilitate cleaning and disinfection. Orbital welding ensures reproducible quality and a high grade of stainless steel is recommended, for example 316 with a low carbon content.

Any pipework should be self-draining to avoid residual liquid that could lead to contamination of product, either through cleaning substances or through build-up of bacteria. Equally, 'deadlegs' and air spaces should be avoided while installing the plant. (A deadleg is defined as a section of pipe tee-ing off the main pipe run, which is not susceptible to cleaning and does not experience the normal turbulence or water flow prevalent in the main section of the pipe. This area is therefore more likely to permit the development of biofilm and consequent unhygienic conditions, which may well have an adverse effect on the microbial and/or organoleptic quality of the finished product. Generally, a deadleg is created when the length of the tee exceeds $2 \times$ the diameter of the main pipe section.) (See also Chapter 8 on 'Cleaning and Disinfection'.)

Where valves are used, similar grade stainless steel combined with hygienic design will maximise product safety. Typically, these will be diaphragm valves with a straight-through flow path to minimise turbulence. Servicing of valves should be possible in-line. This standard of stainless steel material is appropriate for use in any equipment, starting with lining of boreholes through transporting pipework, tanks, fillers, etc. Although 304 stainless steel is appropriate for general use, 316 is better for salty environments. The grade selected would also be based on the action of cleaning and disinfecting chemicals, as well as suitability for product water contact.

Consideration needs to be given to gaskets in pipework joints and valves. Materials are continually developing and improving. The material used in bottled water equipment needs to be approved for food use by local regulations and compatible with cleaning methods and chemicals used.

Elastomers, such as silicone, which are synthetic, rubber-like materials with compressible, springy properties, can be misaligned. Because of this, protrusion of the gasket into pipework can cause difficulties in fully draining the system, providing sites for cleaning products to remain or build up of organic matter, and thus lead to potential contamination. To avoid this, the pipework needs to be designed in such a way that it cannot be misaligned, and can be effectively cleaned and drained.

Polytetrafluoroethylene (PTFE), which is not an elastomer, is an extremely stable material with lubricious properties. The downside of PTFE is its low compressibility and tendency to 'creep', which can lead to a permanent change in shape. Again, the design of the pipework and the gasket material needs to be compatible, and in some gasket designs, spring arms to self-centre the seal to the pipework build in a mechanical stop. Ethylene propylene diene monomer (EPDM) gaskets are also suitable for pipework carrying water for bottling. In any case, specialised technical advice (taking into account the product type and CIP chemicals to be used) on the selection of suitable joints is recommended, together with a schedule for their inspection and servicing.

6.2.2.1 Tankers

Under ideal conditions, water for bottling is supplied from the source directly to the factory through a pipeline. Sometimes, however, environmental or local planning considerations make it impossible to build a factory close enough to the source to make this possible and, in this case, tankering becomes the alternative procedure. Indeed, there are some factories that operate entirely through the use of tankers, with dedicated fleets delivering tens (sometimes

hundreds) of loads each day. Whether operating such a fleet or only a single tanker, the following factors must be controlled:

- The tanker loading station, including valves, hoses, joints and fittings, must be kept secure, as the source is often in a remote location.
- The loading equipment must be properly designed to ensure maximum integrity; this means at best that the hose is permanently fitted to a 'swivel' joint at the loading pump, thus eliminating the need to connect and disconnect with every delivery.
- The delivery end of the hose must be capped at all times when not in use, and great care taken not to contaminate it when connecting it to the tanker. The loading pump and hose should be regularly cleaned and disinfected, with full records being maintained of all cleaning, disinfection and loading activities.

The tankers themselves should be designed to minimise the number of internal surfaces and to maximise cleanability. They should also be dedicated to use for water; many water bottlers have in the past suffered serious organoleptic and other quality defects as a direct result of using tankers that were previously used for other purposes such as milk or fruit juice. Tankers should be maintained clean (not just sanitised) and to this end they should be fitted with appropriate spray ball fittings. The frequency of cleaning will depend to some extent on the frequency of use. Perhaps, paradoxically, those used continuously are in effect 'cleaner' than those used only on an occasional basis: for the former, a monthly CIP may be sufficient; for the latter, cleaning and disinfection may need to be performed before every load. In either case, periodic microbiological analysis will help in deciding the appropriate regime. Tanker unloading stations at the factory require the same design features as the loading stations and must be managed with the same degree of diligence.

6.2.3 Filters

Various applications for filtration involve contact with product water – either directly for the water or indirectly in providing protection for carbon dioxide, process air or the bottling environment (see also Chapter 5 on 'Water Treatments').

Direct filtration of product water may be used for a variety of reasons, depending on the category of water: for example, natural mineral water (NMW), spring water (SW) or other bottled drinking water. In the case of NMW, mechanical filtration is permitted by European Legislation to remove particulates such as sand and unstable elements, but must be carefully selected to avoid any compositional change and to allow any autochthonous (indigenous) organisms to remain in the downstream filtrate. In other markets, the use of finer filters – down to 0.2 µm (0.2 microns) – may not only be permitted, but may also be encouraged by local legislation. Depending on the amount and size of particulates, such as sand from groundwater supplies, it may be found beneficial to use two or three grades of filter in series. The first 'coarse' filter should be as near to the source as possible to prevent aggressive action of sand in moving water through pipework. The final 'fine' filter would then be prior to bottle filling. Another reason for filtering in series is to prolong the life of the final filter, which is the most costly.

One important factor to be borne in mind is that the effectiveness (and, by definition, any failure) of such a filter is not detectable by eye, and may only become apparent through deteriorating microbiological results. In order to monitor filter performance and detect failures early, some filter manufacturers have developed non-destructive technology to enable testing the integrity of the filters. Such 'integrity tests' are performed by applying a pressure

differential using sterile air across the filter and by measuring the rate of pressure decay. With the appropriate equipment (obtainable from the filter manufacturer) this is a simple exercise that should be performed regularly (recommended weekly) and always following filter installation, cleaning and disinfection.

Several factors need to be considered in filter selection, such as the nature of the water to be filtered, the flow rate, temperature, pressure drop, surface area, the degree of filtration required and whether pre-filtration is taking place. The choice of micron rating of a final filter for NMW will need to take into account the diminutive size of autochthonous (naturally present) organisms, permitting these into the filtrate, but at the same time retaining allochthonous species (i.e. those 'non-native' micro-organisms that may have been introduced during transport of the water), which are much larger. This fulfils a requirement to exercise due diligence in protecting consumer safety. Each water will be different, but typically a nylon medium of 0.2 µm rating will satisfy these requirements.

Carbon dioxide and process air need to be filtered to remove any particulates and to provide microbiological safety. Hydrophobic cartridges, typically of 0.01 µm rating, are employed for this purpose. Compressed process air, however, should pass through several stages of prefiltration, such as a coalescing filter, desiccant dryer and carbon adsorption. Activated carbon filters are sometimes used to remove taints and odours from carbon dioxide and processed air. In this application, carbon may also adsorb volatile organic compounds (VOCs). Where carbon filtration is used, care must be taken that it does not introduce microbiological contamination. For this reason, the carbon filter should be upstream from the final filtration. To reduce the risk of air contamination to product water around the filling operation, the air supplied to an enclosed environment can be filtered and maintained under a positive pressure.

It is advisable to use reputable suppliers of filters, to advise in the first instance on suitable filtration options and to provide supportive technical services in the event of any enquiries. It is important to realise that any filtration is a process and as such it can go wrong, resulting sometimes in a greater problem than would have occurred if the filter had not been there in the first place. It is therefore necessary to monitor results of filtration regularly. In addition, a schedule for changing filtration cartridges at appropriate frequencies is imperative. It is prudent to maintain records of such replacements and of filter efficiency.

6.2.4 Carbon dioxide

Some groundwaters have a natural carbonation, but where a water is still (noncarbonated), carbon dioxide gas may be added to achieve a sparkling, effervescent product. Carbon dioxide is a colourless, odourless and nonpoisonous gas readily soluble in water. It can be produced as either a by-product of a fermentation process or chemically as a by-product of fertiliser manufacturing. Carbon dioxide has on occasions been found to impart taste and/or odour taints to bottled waters. There have also been concerns, notably in 1998, regarding levels of benzene in supplies of carbon dioxide to the beverage industry. Purification of the gas is required to ensure its suitability as an additive for bottled waters and other beverages.

In 1999, the International Society of Beverage Technologists (ISBT) produced *Quality and Purity Guidelines for Carbon Dioxide*. These provide valuable technical information on parametric limits and other relevant data for producers of the gas and its users in the beverage industries. The guide was revised in 2001 and entitled *Quality Guidelines & Analytical Procedure Bibliography for 'Bottlers' Carbon Dioxide*.

The British Soft Drinks Association (BSDA) convened a working group in 1998 to address the issue of carbon dioxide safety and suitability and, as well as supporting the

ISBT Guidelines, also identified approved laboratories within the UK for undertaking analysis of carbon dioxide through ring testing.

Water bottlers are advised to give high priority to the safety and purity of carbon dioxide used as an ingredient for their products. Supplier audits and an effective HACCP programme can ensure that all routes liable to cause contamination are covered. Deliveries of carbon dioxide can be analysed through an approved laboratory, and organoleptic evaluation of the gas carried out, using an adapted mini carbonator, similar to the one often used at home to make single-serve carbonated drinks, before offloading from the tanker.

6.2.5 Process air

Compressed air is used at virtually all stages of the water bottling process, depending on the type of equipment installed. It may be used for bottle cleaning prior to filling; however, in instances where polyethylene terephthalate (PET) bottles are blown direct to line, neither water nor air rinsing may be necessary. It is also sometimes used in the fillers themselves and for assistance in moving caps or in cap vibratory bowls. If bottle blow-moulding equipment is used on-site, compressed air is used there also.

In any of these functions, the microbiological and organoleptic quality of the process air must be of a very high standard; this can be achieved by appropriate filtration to 0.01 µm rating. For machinery after capping of bottles, i.e. labelling, packing, palletising, etc., the quality of compressed air is important but less critical. It is sometimes feasible to provide these two qualities of process air from two different generating supplies.

6.2.6 Packaging formats

While water is only briefly in contact with plant equipment during the bottling process, it may be in contact with the primary packaging for many months, and even years. For this reason it is even more important to consider packaging formats to maintain the integrity of the water and maximise shelf-life for the product.

Fundamentally, the functions of packaging are to contain the product and to protect it from possible hazards and contamination during transportation and distribution, and throughout its shelf-life. Packaging also serves to inform the distributor, retailer and consumer about the product, its identity, volume and characteristics and any other legislative requirements. In addition, it acts as a silent salesperson and marketing tool to present the product and identify the brand.

Various packaging formats and sizes may be used to provide consumer choice in different retail outlets. Sizes range typically from 20 cl to 2 litres, though 3-litre and 5-litre containers are also available. Larger containers, typically 11.5 litres or 19 litres (3 and 5 US gallons, respectively), are used for watercoolers (see Chapter 10). Although the bottle or any other container is the main part of the packaging, the closure must also be considered carefully as an integral component.

6.2.6.1 Glass

Of all packaging materials, glass is the most suitable for containing water for a variety of reasons:

- It is chemically inert and does not affect the quality, odour or taste of the water.
- It is usually a clear material and therefore enhances the clarity of the water itself.

- It is hygienic – a major consideration.
- It is rigid, which gives it strength and enables it to be run efficiently on high-speed bottling lines.
- It is impermeable and has the best ability of all bottle materials to retain carbonation, enabling maximum shelf-life to be prescribed.
- It is suitable for still and sparkling water.
- It is resealable, recyclable and is perceived as high quality.

To be set against the above advantages, glass is the heaviest packaging material for bottles. Great care is needed in its handling, both during the filling and distribution process and in consumer use, owing to its breakability. Although it is an inherently strong material, it can be weakened by impact, and this can lead to spontaneous explosion at a later time if the water in it is carbonated. For obvious reasons, it is also not suitable for the increasingly popular larger capacity bottles, and is normally limited to a maximum volume of 1.0 litre.

Glass has been used for making bottles for hundreds of years. It is made from readily available natural ingredients: sand (silica, SiO_2), soda ash (Na_2CO_3) obtained by chemically treating common salt and limestone (CaCO_3). These are the main components, but small amounts of other elements may be added to achieve particular qualities or colours. Glass bottle production is schematised in Fig. 6.2.

Glass is recyclable and large percentages of cullet (recycled glass), typically 85%, are used to advantage in the manufacture of bottles, reducing the process's energy consumption. Furnaces vary but 25% energy savings are an accepted industry standard. The average energy consumption of a furnace is 1380 kWh/t of glass melted, so each tonne of cullet used saves 345 kWh of (gas) energy. The incorporation of cullet also reduces carbon dioxide emission resulting from the process.

Both single-trip and multi-trip bottles are available in glass. Multi-trip bottles need to be more robust, use more glass and can become very scuffed through many journeys, detracting from the presentation of the product. Other considerations related to multi-trip bottles are the logistics of returning bottles to the production unit, the use of hot caustic soda solutions, and large volumes of water and energy use. These are serious environmental issues and, at the same time, returned bottles also need vigilance to ensure their continued fitness for purpose.

Single-trip bottles are often the preferred choice for bottled water. They provide fitness for purpose, bringing least risk of compromise to product safety and integrity. Single-trip glass bottles eliminate the need for bottle washing, since all that is required prior to filling is rinsing with water or air. They present the product in premium condition. Advances in design and the manufacturing process have also enabled light-weighting of single-trip containers.

6.2.6.2 *Polyethylene terephthalate*

PET is now by far the most important material used for the packaging of bottled waters, being suitable for the full range of sizes up to 19 litres (5 US gallons). Sourced from crude oil, it is a synthetic thermoplastic polyester made when terephthalic acid, derived from xylene, is reacted with ethylene glycol to produce the esterified monomer. This is polymerised and the material supplied to bottle manufacturers as granules. The production process is schematised in Fig. 6.3.

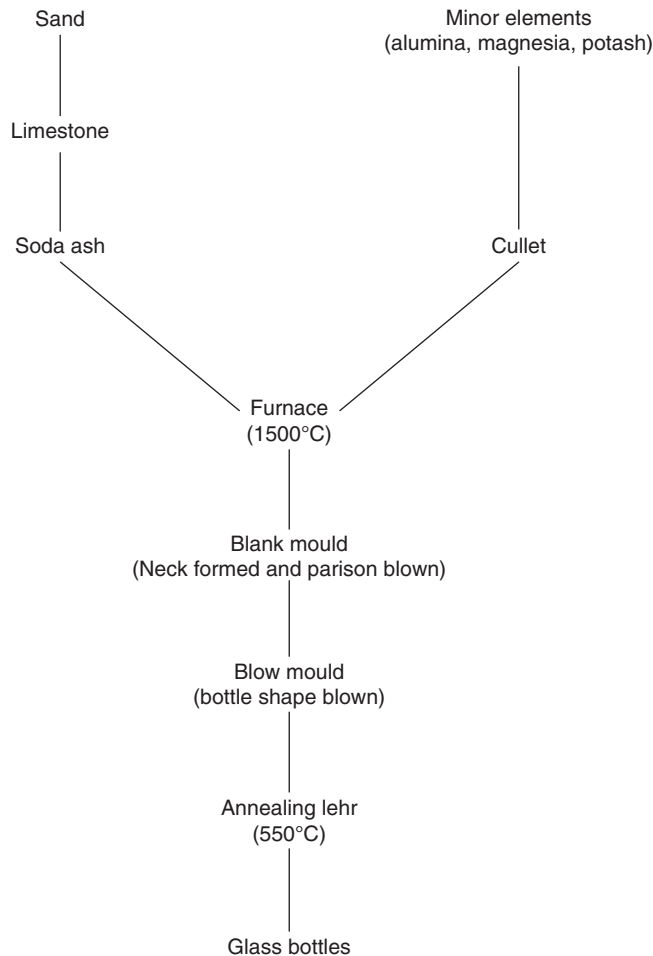


Fig. 6.2 Glass bottle production.

PET is a very lightweight material with good clarity. It can be used for still and sparkling products, though it does lose carbonation through the wall of the bottle, which restricts the shelf-life that can be prescribed. There is also a risk of organoleptic effects when acetaldehyde content in the bottle is greater than 4 ppm. PET bottles are resealable, unbreakable and recyclable.

When empty, PET bottles lack rigidity which, together with their lightweight, makes them unstable unless (as is now increasingly the case) they are transferred in ‘airveyors’; in which they can be conveyed at high speed suspended by the neck ring. Few water-bottling companies produce their own glass bottles, but many have plastic bottle manufacturing facilities, which have distinct advantages in saving transport and storage costs. The bottles are usually made in a two-stage process: first, the injection-moulding of preforms, during which the neck finish is completed. In the second stage, which may take place at the bottling facility, the test tube-shaped preforms are stretch blow-moulded to their final shape and size, which may take place at the bottling facility. In recent years, blow-moulding PET bottles from preforms directly to the water bottling line has become virtually the norm, though

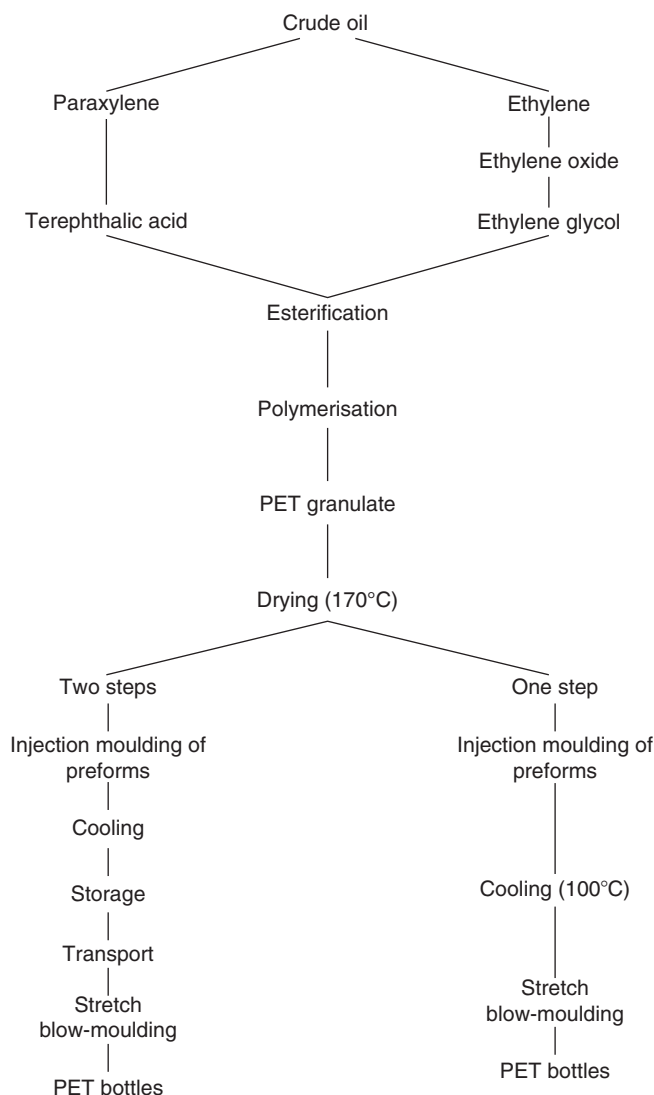


Fig. 6.3 PET bottle production.

sometimes bottle storage silos are used to provide greater capacity and to ‘even out’ any supply interruptions caused by stoppages at either the blow-moulder or the filler. The manufacture of the preforms themselves is also increasingly being done by bottlers, with consequent improvements in control over the process and significant cost savings. Lightweighting of PET bottles, without loss of performance and with better environmental impact, is now attainable with recent advances in design and manufacture. There are now PET bottles in use for still water with half the weight of material being used for the same sized container ten years ago.

For a more detailed description of the manufacture of PET bottles, see Chapter 7.

PET is recyclable, although plastics reprocessing is still very much in developmental stages; the largest stumbling block is the lack of collection facilities. At present, most reprocessed material

is utilised as fibre for clothing, sleeping bags, carpets, etc; however, there are several recyclers who now have the technology to ‘clean up’ post-consumer PET sufficiently well that the use of recycled PET for the manufacture of new bottles has now become a reality in some markets.

6.2.6.3 *Polyvinyl chloride*

Over several decades, PVC served the industry well, being light in weight and relatively low cost for the packaging of still waters. However, the preference for, and versatility of, PET, together with concerns about the propensity of PVC to generate phthalates, led to the decline and, ultimately, the demise of PVC in the bottled water industry.

6.2.6.4 *Cans*

Cans are used for only a very small percentage of the packaged water market. They have the advantage of being lightweight, easily handled and recyclable. They hold carbonation very well and can be used in vending machines. A disadvantage is that the product is not visible. Cans are ideal for single servings but have the disadvantage of not being resealable. Very expensive plant equipment is required to fill this relatively small percentage of product.

Aluminium is preferred to steel, as it gives better organoleptic and corrosion test results. Both steel and aluminium cans are internally coated with an epoxy-based lacquer that protects the product from direct contact with the metal. The sealing mechanism between the can body and the end is critical to this packaging format, and precise specifications and monitoring of this are essential throughout the filling process.

6.2.6.5 *Cartons*

Cartons are used for an even smaller percentage of packaged waters than cans. Cartons, where used, are usually of a multilayer laminate material. A layer of paper provides rigidity to the pack, an aluminium layer forms a barrier to gases and polyethylene (PE) layers top and bottom ensure that the pack is watertight. The resultant packs are lightweight and easily handled. This method of packaging is very space-efficient. Cartons can only be used for still product and, although major advances have been made in laminate, there may be an effect on the taste of the water that limits its optimum shelf-life. In reality, this makes cartons a more practical package for flavoured waters and beverages, where they have been used with great success.

6.2.6.6 *Polycarbonate*

Polycarbonate has for many years been the material of choice for large bottles – 11, 19 and 22 litres – for use with watercoolers. Considering the size of the bottles, they are lightweight, and when empty, they are robust, but susceptible to cracking if dropped when full. A collection system is needed to facilitate reuse and a very thorough bottle washing process is required (see Chapter 10 for further information).

6.2.6.7 *High-density polyethylene*

In some countries, most notably the USA, high-density polyethylene (HDPE) is used for packaging water. It is lightweight, low cost, robust and recyclable. Disadvantages are that it is not a clear material, it cannot be used for carbonated water and it may (if the process is

not well controlled) affect the organoleptic properties of the water. However, there is a successful market in larger-sized packages, particularly 1.0 and 2.5 US gallons. The use of HDPE was actually an offshoot from the dairy industry, for whom (prior to the development of PET technology) it was the only source of larger containers. In a development somewhat similar to that in the dairies, many US bottlers have developed 'through the wall' arrangements with the HDPE bottle manufacturers, who produce their bottles on the same site as the bottling facility.

Considerations in the choice of container materials for bottled water are summarised in Table 6.1.

6.2.6.8 Closures

The efficacy of any packaging format in fulfilling all its functions relies heavily on an efficient and suitable sealing system. There must be compatibility between the bottle or container and the closure. Both must be designed to work together.

Just as with the bottles, the materials used for closures must not in any way affect the product water – organoleptically, physically or chemically. Equally, the water and closure must be compatible so that the materials of the closure and its performance are not impaired. Overall and specific migration testing as well as organoleptic evaluation will provide evidence of a closure's suitability for the task.

The size of the closure is significant: the smaller the closure diameter, the less contact there will be between closure and product, and this is particularly important for smaller-volume bottles.

In carrying out suitability trials with prospective packaging formats, it cannot be assumed that what is compatible with still water will also be suitable for carbonated water.

Closures require both strength and rigidity for application on high-speed bottling lines and to withstand substantial internal pressures during service. Products carbonated to 3–4 volumes of carbon dioxide can result in an internal pressure within the headspace of up to 10 bar, especially at elevated temperatures, since the solubility of carbon dioxide in water decreases as the temperature increases. Both at the design stage and while filling the bottle, it is important to be aware of the optimum percentage vacuum to minimise internal headspace pressure. This internal pressure must be capable of release prior to complete removal of the closure. In the case of glass bottles, this is usually achieved through irregularities in the finish (the mouth of the bottle). However, in PET bottles, where more precision is achieved in the finish, a venting system has been designed into the thread for this purpose. Such prior venting minimises the risk of closures 'missiling' (blowing off the bottle and becoming a missile), which can cause possible injury.

As well as withstanding internal pressure, closures need to be able to sustain external pressure in stacking, storage and transport.

Much emphasis is now being placed on the ease of opening without mechanical aids, especially since the elderly are becoming a more significant percentage of the population. Plastics closure manufacturers sometimes incorporate a chemical 'slipping agent' into the polymer, which is intended to assist in application at the time of capping, and also to reduce the torque required for removal. However, some of these agents are known to impart off-tastes to sensitive products such as water, so it is advisable to work with the closure supplier to know exactly what materials are used, and what their impact will be. Generally speaking, the less colouring material and slipping agent used, the more likely that the closures will be organoleptically compatible with the product.

Table 6.1 Factors influencing choice of containers for bottled water.

Type of bottle/ container	Advantages	Disadvantages
Glass	Chemically inert – will not affect quality/odour/taste Clear Strength in rigidity – can be run efficiently on high-speed bottling lines Hygienic Retains carbonation well Can give maximum shelf-life to product Suitable for still or sparkling product Resealable Recyclable Impermeable High quality	Heavy Care needed in handling, both in filling and consumer use Breakable Impact damage can result in spontaneous explosion with possibility of injury to consumers Could be subject to foreign body contamination from broken glass
PET	Lightweight Clear Suitable for still or sparkling product Resealable Unbreakable Recyclable	Nonrigidity can cause: (1) spillage on opening (2) instability of pallet with still product Loss of carbonation Limited shelf-life for sparkling products
Cans	Lightweight Holds carbonation well Use in vending machines Easily handled Recyclable	Not resealable Expensive plant required for relatively small percentage of business Product not visible
Cartons	Lightweight Easily handled Space-efficient	Only suitable for still product May affect taste Limited shelf-life
Polycarbonate (water coolers)	Lightweight Returnable Reusable	Requires collection system Requires thorough bottle-washing facilities
HDPE	Lightweight Low cost Robust Recyclable Suitable for large containers	Not clear Cannot be used for sparkling product May affect taste/smell

Tamper evidence is an essential feature in the light of increasing incidence of malicious tampering, and is in most major markets a legal requirement to ensure safety and integrity. As far as cap materials are concerned, they may be metal, for example aluminium or aluminium alloys and tin plate, or plastics, for example polypropylene (PP), low-density polyethylene (LDPE) and high-density polyethylene (HDPE).

The closure may be one-piece (plastics only) or two-piece. Plastic closures, introduced in the 1980s, are mainly injection-moulded and any printing or design work is applied after this process. Metal closures usually have a flowed-in plastic liner, and two-piece plastic

closures have a resilient and compressible liner usually based on PVC or PE. Metal closures are stamped and drawn out of sheet that has been suitably decorated and lacquered. Crown closures are usually made of tin plate as this has the attributes of high strength and rigidity, whereas rolled-on closures need to be softer and here aluminium is more suitable. Although crown closures are used on some single-use bottles, most bottled waters are fitted with screw caps. In the case of metal closures, the thread is formed at the point of application to fit the individual bottle, and this type of closure is especially suitable for glass bottles. Plastic closures have their thread moulded in the injection-moulding process.

The chosen closure should be applied immediately after filling the bottle to maximise the integrity and safety of the water. Recommended application and removal torques are provided by the closure manufacturer, and these should be closely adhered to and monitored throughout the bottling process.

For sports bottles, introduced in the 1990s (see Fig. 6.4), there are several variants, but the general design is similar, in that the main shell of the closure has installed within it a valve mechanism that is activated either by twisting or pulling the spout, thus adding to the convenience for the consumer 'on the go'. In the early days of its development, however, there were a few unfortunate incidents in which the small components of sports closures became detached, and in response to this, a *Code of Practice for Sports Closures*, developed by the British Soft Drinks Association (BSDA), was developed to give advice on assessing the risks of choking hazards, test procedures and labelling recommendations.

Water bottles discussed in this chapter are essentially for single usage. Once empty, they should be discarded appropriately, to facilitate their recycling. It is recommended that bottles should not be refilled or reused by consumers. Contamination can result from this. In addition, other components of the packaging format, for example the sports closure, are not designed for repeated use.

6.3 LABELLING

Labelling performs several functions as part of a packaging format: labels identify the product and proclaim the brand; they act as silent salespeople. The average consumer can scan approximately 1.3 m of supermarket shelf space per second, so the label has about 0.1 s to make an impact, thus providing a challenge to both marketing executives and designers.

There are various requirements of legislation to be incorporated into the label design – for example, within the European Community these include the product description, volume declaration, name and address of the bottler and their country of origin, and indication of Best-Before-End (BBE) duration. Although not a legal requirement in all territories, important element of information declared on the label is a Typical Analysis panel. This provides levels of composition for several parameters, enabling the consumer to make a choice relating to taste preferences or dietary needs. Composition is usually given in mg/l. The bottler may wish to include other consumer use advice on the label, such as serving suggestions and storage recommendations. Nutrition facts are often given. With increasing awareness of environmental issues, as well as requirements of legislation, identification of bottle material and recyclability may also be displayed. As well as the name and address of the bottler, it can be helpful to the consumer to give a toll-free number and a website address through which they can direct any enquiries they may have in relation to the product.

On single-unit bottles, a bar code is printed on the label; however, in the case of multi-packs, the bar coding is usually on the outer sleeve or other means of collating the bottles in



Fig. 6.4 Generic sportsbottle. (Photography courtesy by James Roddicks Gleneagles Spring.)

the pack. In designing new or revised labels, it is advantageous to liaise with enforcing authorities to ensure that the requirements of legislation have been met.

6.4 SHELF-LIFE, BATCH CODING AND TRACEABILITY

In some markets, the shelf-life or expiration date is dictated by law; in others, it is left to bottlers to evaluate and recommend the shelf-life of the product. In this case, it will be necessary to perform chemical migration and organoleptic monitoring throughout a proposed period, to ensure that the product is still largely of the same quality at the end of its shelf-life as it was at the time of bottling. The duration of shelf-life that can be prescribed for a bottled water will be influenced by the bottle and closure materials and by the size of the container. Generally, the smaller the container, the shorter the shelf-life. The shelf-life may be different for still and sparkling products, depending on the nature of the packaging.

Water bottled in glass, either still or sparkling, remains in good condition for several years. Considerations in this case focus on the effects of the closure mechanism and on the

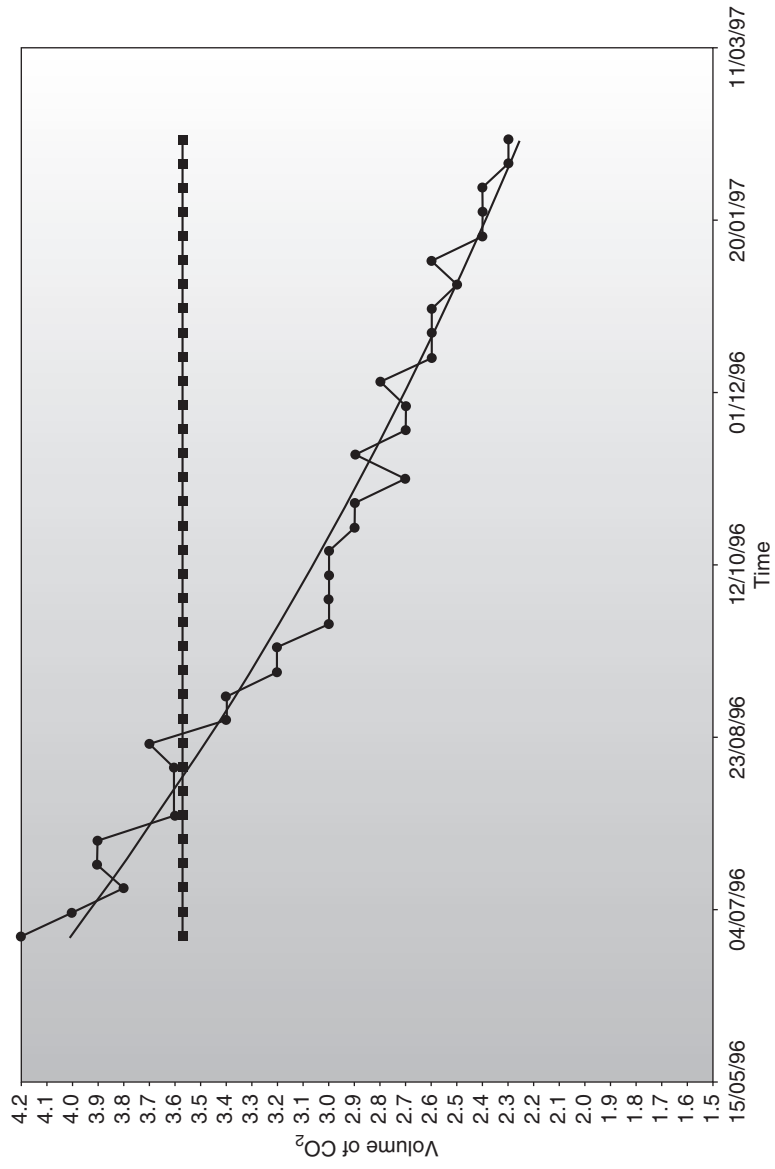


Fig. 6.5 Typical carbonation loss from a generic 2 litre Euro bottle (15% loss).
Source: Constar International.

outer presentation remaining in pristine condition. Still water in PET bottles remains in good condition for many months, perhaps years. However, sparkling products in PET lose carbonation through the wall of the bottle, showing greater loss from smaller bottles through the relationship of volume of water to surface area of the bottle. This restricts shelf-life to about 12 months for bottles of 1 litre or more capacity and considerably less for smaller sizes. Figure 6.5 illustrates typical carbonation loss from 21 PET bottles.

Still and sparkling water in cans may be given a shelf-life of at least 12 months, but it is advisable to be satisfied that there is no increase in aluminium content beyond that period.

Individual waters may behave differently over time, depending on their characteristics and composition in relation to the packaging used, and it is wise to monitor performance chemically, microbiologically and organoleptically during and beyond prescribed shelf-life, which can then be reviewed accordingly.

Inclusion of a 'best before end' (BBE) or 'best by' (BB) date is a legislative requirement in most, though not all markets. In any case, it does have the real benefit of facilitating stock rotation within the distribution and retail systems and also provides guidance for the consumer. It must be understood that the dates given refer to the bottle in its unopened state.

Batch coding may be positioned on the bottle, label or on the closure (although the third option is not recommended, in case the closure is mislaid or exchanged once the bottle has been opened). Coding may be 'ink jetted', or with increasing frequency 'laser jetted' (in effect, etched onto the bottle). In addition to giving the BBE date, the code usually shows a lot number, which may refer to the date and time, and also the line or shift of bottling. To facilitate traceability still further in the event of any recall, the bottles themselves may be coded with the date and time of manufacture. This can be located in the area where the label covers it so that it does not confuse the consumer. Where PET bottles are blown direct to line, this marking is not required, though it may be advisable to retain records of preform manufacturing dates relevant to the bottling dates on which they were used.

6.5 HYGIENE AND GOOD MANUFACTURING PRACTICES

Bottled waters are classed as food and in many instances receive little or no treatment prior to bottling. Good hygiene practices are therefore an essential prerequisite of a successful operation. These prerequisites, together with HACCP (described in Chapter 9), form the basis of good practice for the industry.

The starting point for protection is the source of water itself (see Chapter 4). Because this is a highly specialised area, it is recommended to have input on developing a ground-water source for bottling from a reputable hydrogeologist. Wherever possible, it is good to have control of activities in the catchment area through specific practices to protect the groundwater from all kinds of pollution. A protocol for the entry of visitors to the bottling plant or its water source will ensure maximum protection to staff, premises, equipment and products.

6.5.1 Buildings and facilities

Many bottled waters, especially Natural Mineral Waters, are bottled at source, and the location of the source and/or the bottling facility is important, which should be selected on a criterion of minimum risk of pollution from the external environment such as factory fumes and industrial and agricultural odours. The buildings need to be sound and well maintained

with well-fitted external doors and windows to prevent ingress of pests and insects. A reputable pest control contract is advisable.

6.5.1.1 *Internal building surfaces*

Floors should be sealed and easily cleanable. In filling rooms, the floor should be coved at junctions with the walls. Walls and ceilings should be light in colour to reflect as much light as possible, as well as to make any soiling visible. The surfaces should be smooth and impervious to facilitate effective cleaning. Junctions between walls and ceilings in filling rooms should be coved. Light fittings should, where possible, be flush with the ceilings and should be shatterproof. External windows should not open into filling rooms. Windows should be close fitting and any sills sloped to discourage their use as shelves. External windows can be fitted with appropriate mesh to prevent insect ingress. The mesh itself must be capable of being effectively cleaned.

6.5.2 **Maintenance activities**

A high standard of maintenance within the plant not only maximises efficiency, but also contributes towards achieving good hygiene. Consideration needs to be given to when such maintenance will be undertaken so as to minimise any risk to the product. A planned maintenance schedule is the ideal, and activities should be performed with care (and in the case of major maintenance) behind suitable partitioning to avoid contamination of product or lines still in operation. It is also essential that maintenance activities are properly planned with the involvement of a multi-disciplinary team, to ensure that all aspects of the work are understood, and that there are no unforeseen consequences. There have been incidences in the past when engineering work or even simple maintenance performed without the knowledge of other departments has resulted in catastrophic contamination of equipment and product. In all such cases, a simple discussion beforehand could have ensured that the issue was avoided. Similarly, the use of a post-maintenance, pre-production inspection by the same multi-disciplinary team should be documented and signed-off by all parties. When extensive structural repairs or developments are undertaken, these are best tackled during a planned shutdown period.

Selection of substances used, for example lubricants, needs care and these should always be approved for use in food production environments. Where it is necessary for equipment mechanical reasons to use non-food grade lubricants, careful labelling and segregation should be exercised to minimise the risk of inadvertent use or contamination. The choice of paint and when it is used is also important, since some paints are very odorous and can taint water.

6.5.3 **Layout and process flow**

A design enabling continuous process flow – with materials receipt and storage at one end, finished goods and despatch at the other and the processing stages in sequence in between – will optimise good hygiene practice and minimise any cross-contamination (see Fig. 6.6).

Within this design, it is desirable to allocate a particular area for the vulnerable open bottle stages of rinsing, filling and capping. With provision of an enclosure for these stages, it is feasible to control this environment by treating the air inside and imposing a positive

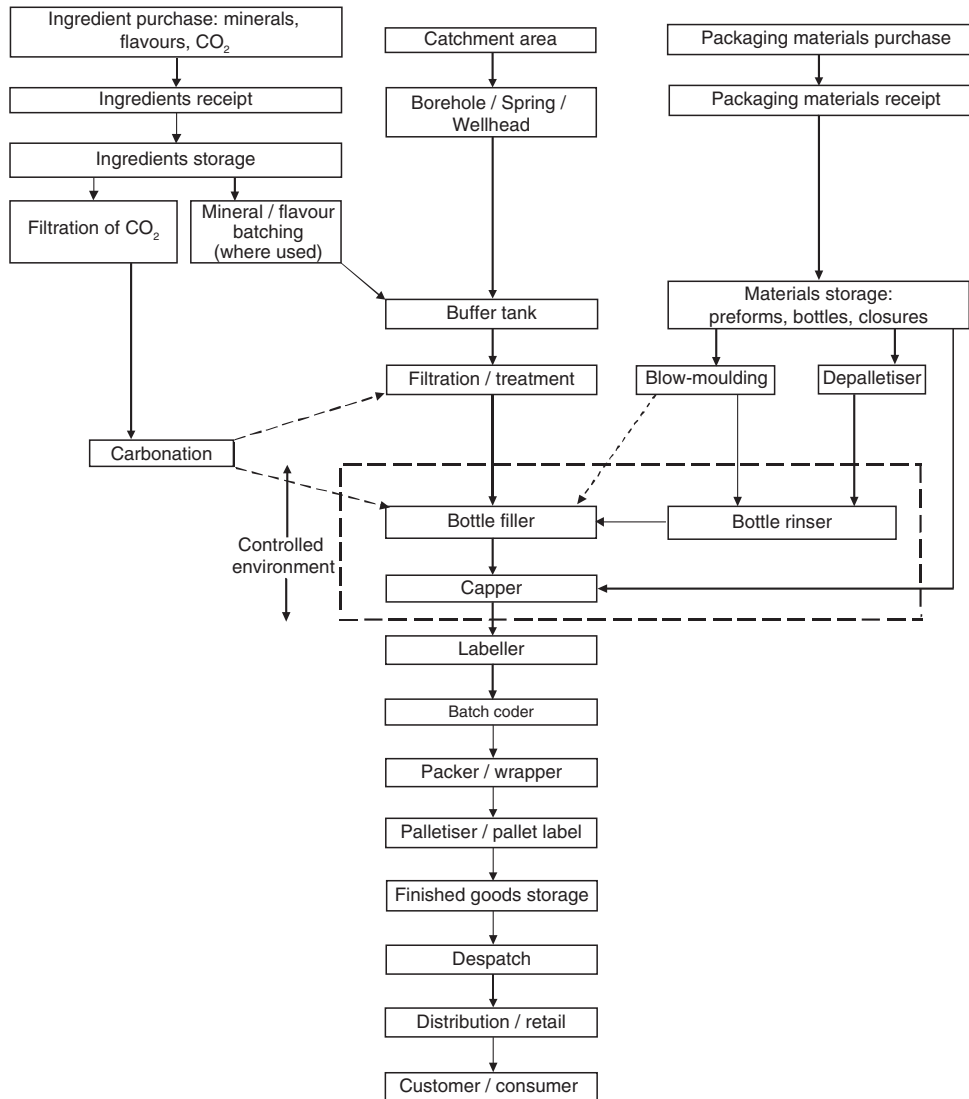


Fig. 6.6 Typical process flow for bottled water.

pressure. Such an enclosure also makes it possible to exclude other activities and to minimise the impact of people. Such an approach can also be integrated into a larger policy in which all areas of the factory are allocated a hygienic ‘status’, with rules governing what activities may be performed in each.

6.5.4 Ancillary facilities

Facilities provided for staff, laboratories, maintenance workshops and chemical storage should be separated from the main production area and be capable of being maintained to the same hygienic standard as the rest of the plant. In addition to washbasins, which

must be provided in toilets and canteens, it is recommended to provide further hand-washing facilities at entry points to filling rooms. In all locations, hand washbasins (not to be confused with sinks) must be maintained immaculately and should not be used for other purposes.

6.5.5 Cleaning and disinfection

Routine, scheduled cleaning and disinfection is an essential part of running a water bottling plant. This not only protects the safety of the product but also provides a good working environment for employees. It removes extraneous matter that could be conducive to microbial activity and provide a risk of foreign body contamination.

Schedules will define what is to be cleaned, who will undertake the task, the frequency of cleaning and disinfection and how it will be done. They also prescribe chemicals, their use and precautions and means of monitoring the efficacy of the procedures. Like other potable liquid installations, a water bottling plant is often designed for CIP, i.e. the process is carried out with bottling equipment in its assembled state.

The choice of the cleaning chemical or disinfectant must be made taking into consideration whether the plant is dedicated to water or whether it is also used for soft drinks, the level of soil/biofilm expected, frequency of cleaning, compatibility with equipment and filter materials and its rinsability and removal to leave no trace of odour or taste.

For dedicated water equipment, cold/ambient cleaning and disinfection may be appropriate and effective, although experience indicates that in general, more rigorous routines with high temperatures are required to achieve satisfactory results. In the case of equipment shared with soft drinks (where permitted), a very thorough CIP regime must be used prior to switching the line back to the bottling of water.

Each plant will be different, so the cleaning programme and its frequency will be planned accordingly to maximise product integrity and safety (see also Chapter 8).

6.5.6 Personnel

It is important that the staff involved in the production process or its ancillary functions are appropriately trained in the awareness of the vulnerability of product water and how to protect its cleanliness and safety, as well as to be experts in procedures to carry out their particular roles. A company hygiene policy will outline expected standards of personal hygiene and fitness, specifying any medical screening the company may adopt, and good practices. Such a policy will also instruct on the use of protective clothing and on where this is applicable. The policy will include requirements on reporting sickness or infections and on the suitable covering of cuts and open wounds.

Personal hygiene aspects include the need for clean, short fingernails, clean, covered hair, and a requirement for not using perfumes and aftershaves. A lack of jewellery will also appear as a requirement. The good practices include when and where to wash hands, housekeeping, handling and use of primary packaging components, filling room protocol, locker usage and eating/drinking locations. An endorsement by the company chief executive can be included in the food safety and hygiene policy, which lends credence to top management commitment.

Importantly, as well as being given training, staff need to be appropriately supervised or managed to ensure that the training and the company policy are fully implemented. In this way, each and every employee contributes to the product's safety and integrity.

Good practices incorporated within personnel training specify that product containers are never used for anything other than product. All too easily they can be viewed as handy containers for a whole range of things – lubricants, cleaners, nuts and bolts, flowers, etc. – and this could pose a serious risk to the product.

The principles of good hygiene practice, which apply not only to plant personnel but also to all visitors and contractors, will be incorporated within an overall quality management system (see Chapter 9) and as such should be subject to audit and review (see Chapter 11) to ensure that such practices are effectively implemented.

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7 Bottle Manufacture and Filling Equipment

Manfred Faltermeier

7.1 INTRODUCTION

Since the publication of the second edition of this book, continuing developments in the range of pack types (especially small packs) and in the bottling of water have kept the market and the production equipment in a constant state of evolution. The triumphal march of the PET bottle continued to dictate the filling strategies of water companies worldwide, for several key reasons:

- Marketing departments benefit from the opportunities in designing new forms and shapes to distinguish their product from those of competitors.
- Due to the opportunity for manufacturing PET bottles on site, filling capacities can be planned exactly and there is no longer a need for storage of bottles before filling.
- As a consequence of the ability to link directly the bottle manufacturing machine with the filler, the handling of empty bottles in the production area is no longer necessary.

Consequently, in this updated chapter, the growing significance of the PET bottle is recognised with the inclusion of new information concerning PET bottle manufacture and the requirements when running PET on bottling lines.

Furthermore, a noticeable trend towards bottling lines running with fewer and fewer people is continuing to force changes in procedures in bottling halls, leading to more automation and control systems throughout the line. It is true that this aspect might be less important in countries where labour costs are lower, but even in these countries, automation may be seen as beneficial and necessary to ensure a high quality process.

When considering the key factors in packaging water, perfect raw water product quality, the best possible hygiene conditions and an optimum process for handling the container type chosen are fundamental for cost-efficient production. For example, by using fit-for-purpose systems for product treatment prior to filling, such as flexible, high-performance de-aerating and carbonating systems fitted with buffer tanks, water can be stored temporarily during brief line stoppages and processed in variable product quantities. A high product quality is assured by using stainless steel for all parts that come into contact with the beverage. And finally, the filling technology involved has to be flexible and able to handle different container variants at high speeds.

One of the crucial factors involved when it comes to planning the filling technology is the characteristics of the product concerned: still water products can be bottled using simpler



Fig. 7.1 Neck guidance enables complete control of PET bottles throughout the complete cycle of bottle infeed, filling and discharge.

technology than is the case for their carbonated counterparts. The second, equally important factor is the type of container. Glass bottles, PET, HDPE or PEN bottles are the most widely chosen packaging variants for the different water products and in some cases, aluminium cans are also used. Bottle sizes ranging from 0.2 to 2.0 litres for example, necessitate a different design of the filling system for each product. Depending on the range of bottles being handled, container guides will be needed, which can be matched to the disparate bottle circumferences for spacing and feeding the bottles into the line. Options for quick changes at the container infeed (Fig 7.1) and discharge give the opportunity to introduce new bottle diameters into the system. Considering also the longevity of filling equipment, upgrades for older machines are often offered to bring the equipment to an improved level of operation. In particular, changes in the bottle infeed and discharge components can bring high efficiency to equipment that has already been running for many years.

Hygiene considerations within the filling system are gaining progressively in perceived importance. When filling valves are being designed, for instance, special care is taken to ensure optimised flow routing, so that dead spaces or areas not amenable to easy cleaning are avoided. When using closed-circuit cleaning (cleaning-in-place or CIP) processes, which are now becoming standard, it must be possible for the cleaning solution to reliably reach all areas coming into contact with the product. For more sensitive products, there are systems available that offer optimised hygiene conditions or even aseptic production conditions.

The production outputs of modern-day filling systems range up to 72 000 containers an hour for a bottle volume of 0.5 litres. By combining individual machines into so-called 'monobloc' configurations, comprising a rinser, a filler and a capper (Fig. 7.2) (an increasingly common arrangement for bottling lines) and by linking up a stretch blow-moulding machine or a labeller, compactly dimensioned, synergised units with maximised automation can be created.

In addition to the filling technology proper, monitoring procedures and documentation tasks are gaining steadily in perceived importance for production facilities. This relates to the trackability of production operations and the production conditions under which the beverage is produced and bottled. Statutory regulations, such as Directive 178/2002 of the European Union regarding procedures to guarantee food safety, lay down that the production

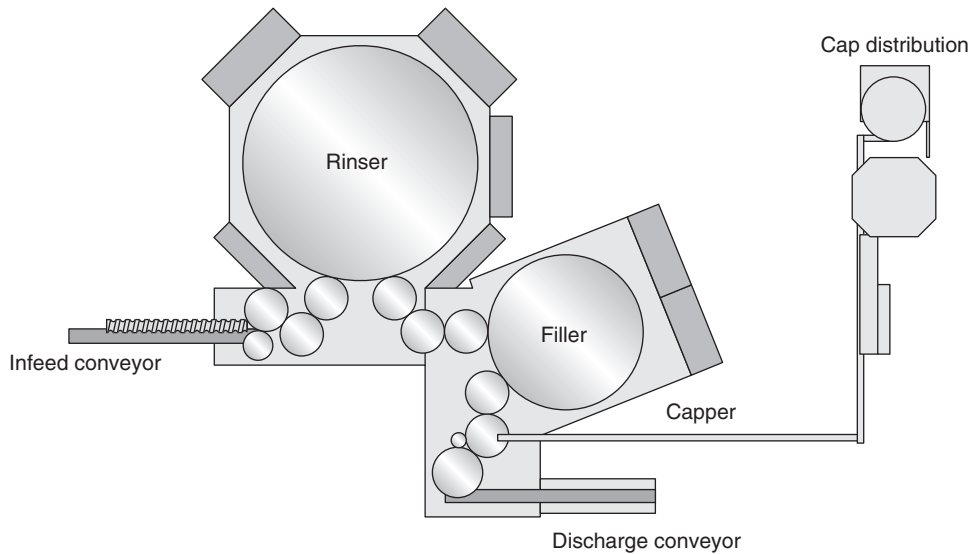


Fig. 7.2 A compact blocked unit, comprising rinser, filler and capper.

conditions be rendered precisely trackable for each individual batch. Integrated production data monitoring systems enable the bottles produced to be accurately identified and any sources of malfunctions inside the production sequence to be reliably located. Thus the facility can have full-coverage tracking of which product batch was handled by the filling line on a particular date. An additional option now being adopted by many beverage producers is the integration of production planning systems, designed to ensure that production runs are efficiently scheduled on the line, with concomitant gains in its cost-efficiency.

7.2 PET BOTTLES – ONE OF THE MOST IMPORTANT PACKAGES FOR WATER

PET bottles are gaining market share worldwide as a packaging option for still and carbonated water products.

One major plus of the PET container for the beverage bottler is indubitably the option for producing the bottles in-house. This means that PET bottle production can be matched to the demand of the bottling lines, without the need to transport or store large amounts of empty containers. There is also a broad scope for creative PET container design, enabling bottlers to position their own water products in the market to optimum effect and thus to gain high recognition among consumers.

PET bottles are made from a preform (Fig. 7.3), which is manufactured in an injection moulding process, sometimes in-house, but often produced by a third-party supplier and delivered to the beverage bottler. Among the preform's key features is the neck-ring, which is required for transporting the preform during the container production process and for transporting the container in the bottling line. The neck finish geometry and type of thread are already predetermined in this bottle blank, laying the foundations for future processability in the production operation for the PET bottle.

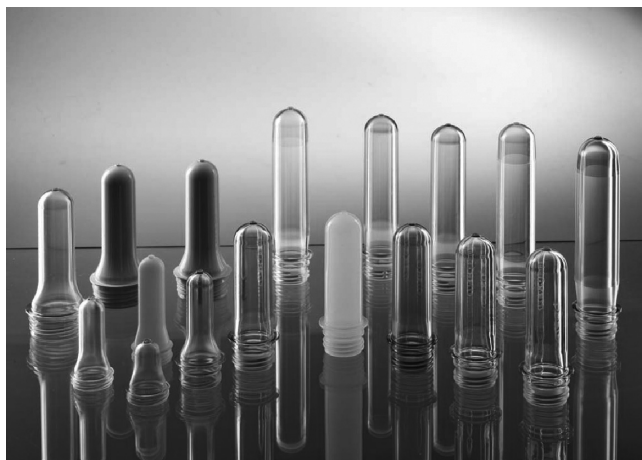


Fig. 7.3 Different types of preforms for PET bottles.

One important criterion for designing the PET bottle is the preform weight. In addition, the ratio between the preform's and the bottle's geometries determines the material's axial and radial stretchability during the bottle production process, and thus the wall thicknesses in the various areas of the final bottle.

7.2.1 PET bottle manufacture – process technology

The process engineering steps for producing a PET bottle from a preform are divided into a heating process and a blow-moulding process (stretching).

For manufacturing PET bottles, it is customary to use rotary high-performance stretch blow-moulding machines (Fig. 7.4), which produce large quantities of PET bottles at high speed. The typical production output of a stretch blow-moulding machine is determined by the number of blow-moulding stations involved and the output per station, and is usually expressed in bottles per hour. Depending on the size of the PET bottle and the desired bottling speed, these stretch blow-moulding machines can be fitted with between 8 and 30 stations. Nowadays, station outputs of up to 2000 containers an hour are possible, although for smaller production outputs, linear stretch blow-moulding machines can also be used. To enable higher line output speeds to be reached, for example, for producing still-water bottles, small-cavity machines are used, which possess up to 40 particularly small blow-moulding stations arranged on the blowing wheel, and are suitable for producing container sizes of up to approximately 0.7 litres.

The stretch blow-moulding machine basically comprises an oven and a blowing wheel accommodating the individual blow-moulding stations. In addition, modules are required for feeding the preforms into the oven and for passing the heated preforms into the blow-moulding machine.

In the oven, the preforms are placed on mandrels, which transport them on a guide chain. The linear oven features integrated heating panels, the number of which will depend on the size and output of the machine concerned. The heating panels are fitted with 6 or 9 infra-red lamps, each rated at 2500 to 3000 watts. While the preforms are passing through the oven, they are continuously rotated around their own axes, so that they are evenly heated from all

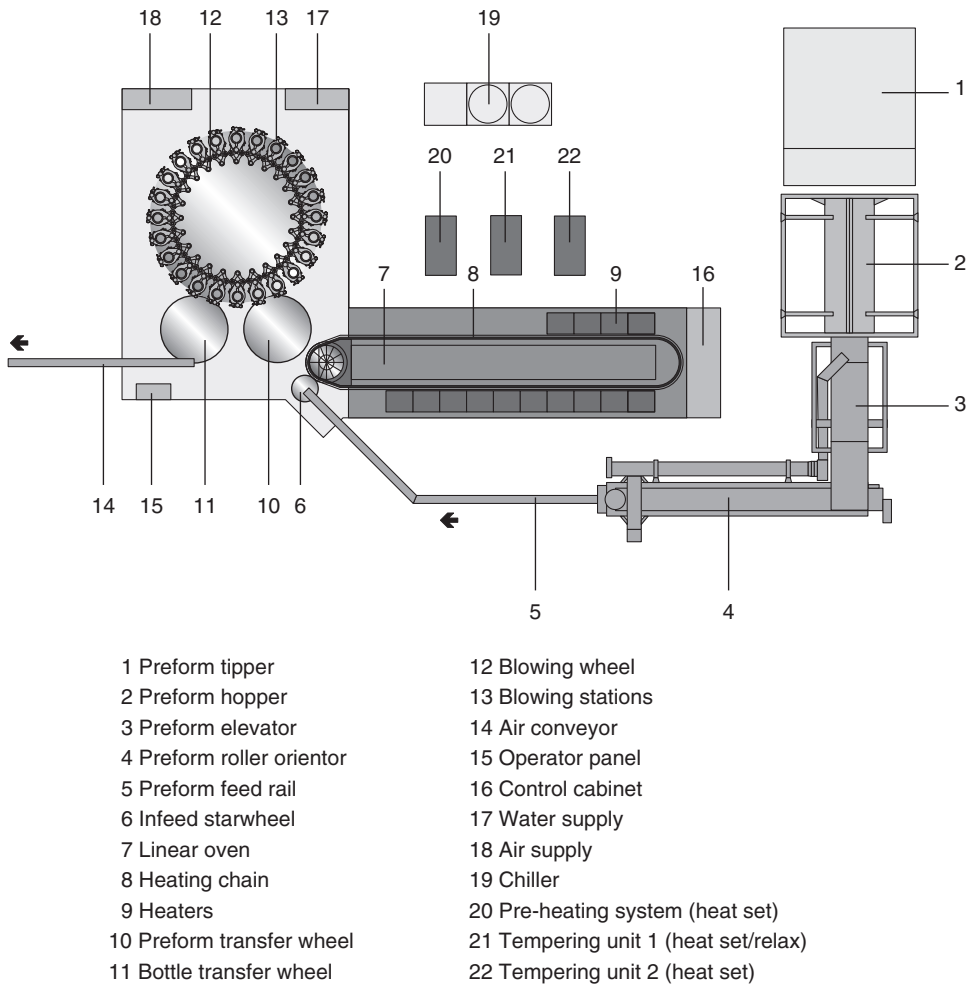


Fig. 7.4 Layout of stretch blow-moulding machine.

sides. Reflectors at the side walls help to ensure even heat distribution. During the time it is passing through the oven, the neck finish of the preform is mechanically shielded from the heating channel, and is thus protected against deformation and overheating.

In the heating process, the preform is warmed up to between 100 and 115°C, so that the bottle moulding process proper can proceed in the mould. Preforms have a wall thickness in the range of 2.0–3.8 mm, and during heating, equalisation times are required in order to even out the temperature profile in the preform over the entire surface, and with the radiant heat absorbed being passed from the outer to the inner preform wall. These equalisation times are provided at least once during the heat-up time and once following it. The heating function accounts for approximately 65% of the total process time involved in stretch blow-moulding, while the equalisation times take up another 25%, which means that about 9% of the entire process time, totalling approximately 30 seconds, is consumed by temperature adjustment in the preform.

The most important process parameters during heat-up are the temperature profile along the preform axis and over the wall thickness, the temperature profile in the circumferential direction, and the crystallinity. The design of the heat-up function enables different viscosities to be created in the preform structure, with colder areas exhibiting a higher viscosity and warmer zones a lower viscosity. In accordance with the viscosity distribution, the cross-sections of the preform are then, in the subsequent stretch blow-moulding process, stretched to differing degrees, so that different wall thicknesses are achieved in different areas of the bottle wall. The temperature distribution is important, because the preform's inner wall is more extensively stretched than the outer wall. The crystallinity is a crucial quality feature in the stretch blow-moulding process, as it has a bearing on the PET bottle's mechanical strength.

After being heated, the preforms are placed on the blowing wheel at the correct pitch via a transfer starwheel, and enter the blow-moulding station, which closes and is mechanically locked. The blow nozzle then moves to a position above the preform's mouthpiece, and is sealed against the neck-ring. The thread area is protected during the entire blow-moulding operation, thus precluding any deformation of the thread. Directly above the blow nozzle is the valve block incorporating the valves required in the blow-moulding operation, for pre-blowing, final blow-moulding and pressure relief. In addition, many machines feature another air recycling valve, which after the blow-moulding operation returns the unneeded final blow-moulding air to the circuit for pre-blowing, thus making a substantial contribution towards energy saving. An additional dynamic mould locking feature, known as a pressure cushion, prevents the parting plane of the two mould halves being visible on the blow-moulded bottles.

The preforms are stretched by a pneumatically driven stretching rod, guided by a roller along a cam. All movements of the blow-moulding station, such as opening and closing, are performed under positive mechanical cam control, which means that all functions can be reproduced for all stations, ensuring a high level of process stability and repeatability for bottle production.

The actual stretch blow-moulding process – axial stretching of the preform using a stretching rod and radial moulding using high pressure – takes up only about 1.5% of the total process time after the heat-up function. The remaining time components, accounting for 8.5% of the total process time, are required for cooling the bottle in the mould, for pressure relief, and for the discharge operation.

Stretching causes the molecular chains of the PET to be elongated and aligned, and thus expanded to the size and shape dictated by the mould. The stretching process ensures maximised mechanical strength and minimised gas-permeability of the finished PET bottles. The preheated preform is passed into the mould, and once positioned and the mould locked, the actual stretching process begins. For moulding the bottle into its final shape, the following key process parameters must be controlled:

- stretching velocity;
- pre-blowing pressure;
- start of blowing;
- blowing pressure;
- equalisation and cooling times.

Axial stretching of the preform, the elongation function, is effected by the mechanical action of the stretching rod and the inflowing pre-blowing air, while radial moulding of the bottle is accomplished solely by the action of pressure inside the mould.



Fig. 7.5 The air conveyor system for the transport of PET bottles between blow-moulding machine and filler.

Following a time-delay after the stretching operation commences, the preform's circumference is altered using the pre-blowing pressure of approximately 7–15 bar. When the stretching rod has axially stretched the preform completely to the bottle length desired, the full blow-moulding pressure of 25–40 bar is applied. This high pressure ensures that the warm material, with its internal stresses, is pressed against the cooled wall of the mould, so given good heat transmission, it will quickly be cooled down to create a stable bottle. If the final pressure selected is too low, the internal stresses in the material may cause the bottle to shrink at some points, and thus lead to poor mould contact and inadequate heat transmission. The equalisation and cooling time required will depend on the blowing and mould temperature and on the greatest wall thickness of the moulded bottle. This is in almost all cases the centre of the bottle's base, which is stretched only slightly.

Once completed, the bottles are transferred from the blowing wheel to what is in most cases a container air conveyor (Fig. 7.5), which transports the bottles to the filler and the downstream labeller. With increasing frequency nowadays, the machines for producing PET bottles, the filler/capper, and sometimes also the labeller, are directly monobloc-synchronised with each other (Fig. 7.6), a configuration that offers advantages in reduced capital investment and operating costs, a smaller footprint and reduced consumption.

7.3 FILLING TECHNOLOGY

For filling water products, there are two basic process variants to consider: filling carbonated water and still water. These variants are covered by differing filling processes, though the filler's basic construction is largely identical in both cases.

7.3.1 The construction of a filler

All fillers share the same basic construction, with a machine frame and drive units, plus a front table that links all the filler's feed elements, such as the infeed worm and the infeed and discharge starwheels (Fig. 7.7). Sloping roof constructions are often provided for the filler's front



Fig. 7.6 Preforms are delivered on the right to the heating oven. The blow-moulding process can be observed via the windows in the blow-moulding machine. The filling system is also directly blocked (from the middle to the left) with a hygienic housing and a fully automated filling procedure.

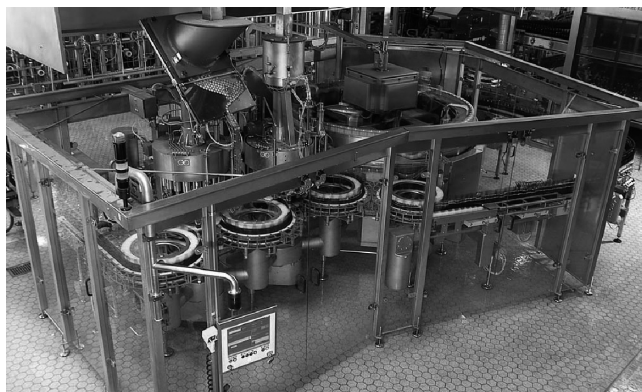


Fig. 7.7 A typical filling unit.

table, enabling product or cleaning agents to drain off automatically downwards. This hygienic filler environment is designed to significantly discourage the formation of micro-organisms.

The upper part of the filler accommodates what is called the rotary media manifold (for feeding in product and media), and a compressed-air and power distributor in the upper section of the machine for the electro-pneumatic control system. Other modules are the ring bowl and the filler valves, plus the container guides, including the lifting units. The ring bowl is supplied with product via the rotary media manifold through radially arranged feed pipes. Alternatively, a central tank can be used in conjunction with smaller machine diameters or tubular ring bowls. Depending on the filler design, filling valves are affixed directly to the filler, or linked to it by a pipe connection with associated flow meter equipment (Fig. 7.8). The design of the filling valve area will depend on the characteristics of the product and the resultant nature of the filling operation. In addition to a control valve for opening and closing the filling valve, other control valves can also be integrated at the filling valve.

During operation, product is fed to the machine ring bowl via a feed pump or directly from an in-line carbonation system. Product level within the ring bowl is maintained by

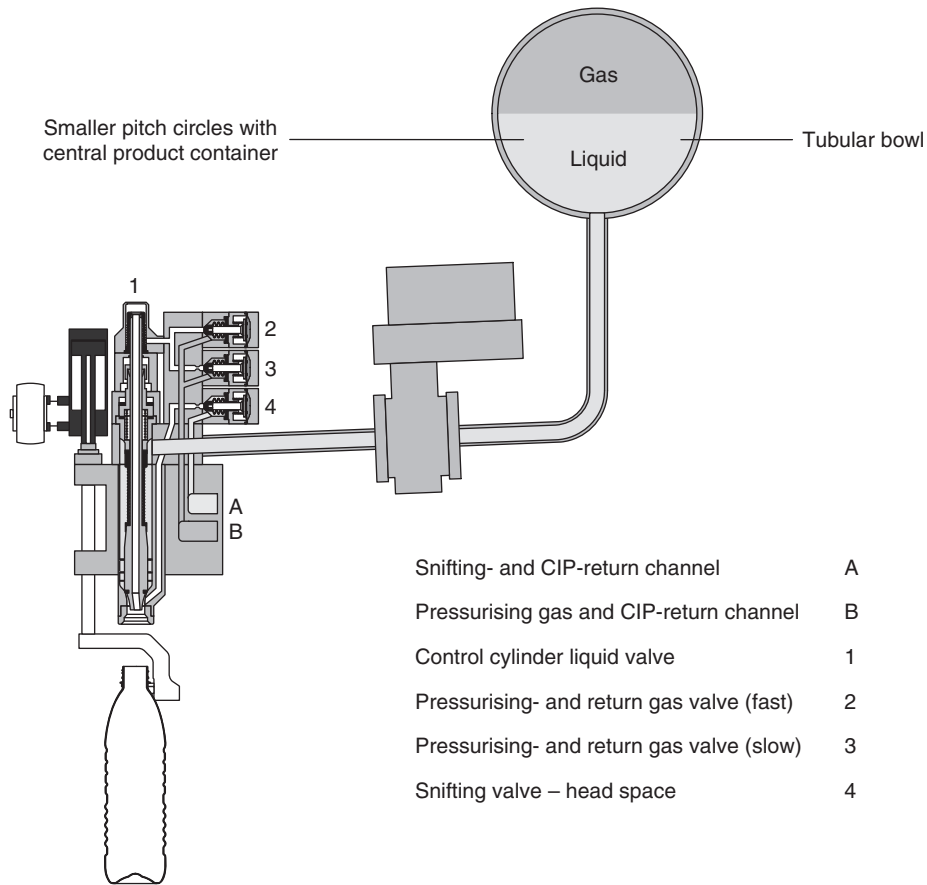


Fig. 7.8 Cut out view of the filler with central tubular ring bowl and integrated valves for filling.

means of control floats, or more usually nowadays by a series of level probes positioned within the ring bowl.

The filler and the infeed units are driven by a three-phase motor and a V-belt powering a worm gear. The drive power is transmitted from the central gear unit to the individual guide starwheels via universal-joint shafts and gearwheels. In large fillers, the power from the motor in the filler carousel is transmitted to the gearwheel-driven elements of the front table by cardan shafts. Modern-day drive designs are based on servo-drive technology with decentralised servomotors for the various components of the filler, so that the drive functions can be designed without any mechanical wear-susceptible gear units and shafts, in lubrication-free construction.

7.3.2 Filling principles

There is a wide range of filling systems available and it is impossible to provide here a complete description of all types of machines. However, for filling water products, depending on the type of bottle involved and the control concept desired, level-controlled filling systems or volumetric filling systems can be used. For non-conductive products, a weight filling system may be required in some cases.

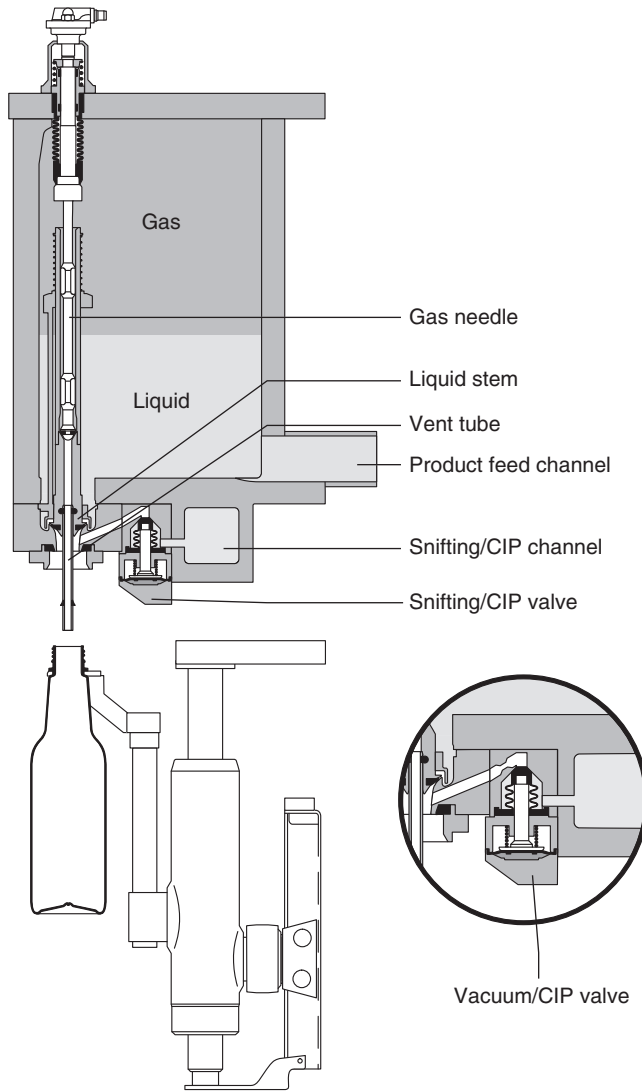


Fig. 7.9 Level controlled electro-pneumatic filling system; lifting the bottle actuates the filling process and opens the liquid stem.

In level-controlled filling systems, the filling operation begins with the electro-pneumatic actuation and opening of the filling valve (Fig. 7.9). The air inside the bottle is displaced by the inflowing liquid, and flows through the vent tube either back into the ring bowl or (in what are called multi-chamber systems) is drained off separately. As soon as the liquid level inside the bottle being filled has reached the bottom edge of the vent tube, the inflow of product is interrupted, since it is now impossible for the air to exit. The filling valve is closed mechanically with the aid of an actuator at the filler carousel. Different fill levels, which have to be provided for when different bottle sizes are being run, can be assured by changing the vent tube when changing over to a different bottle.

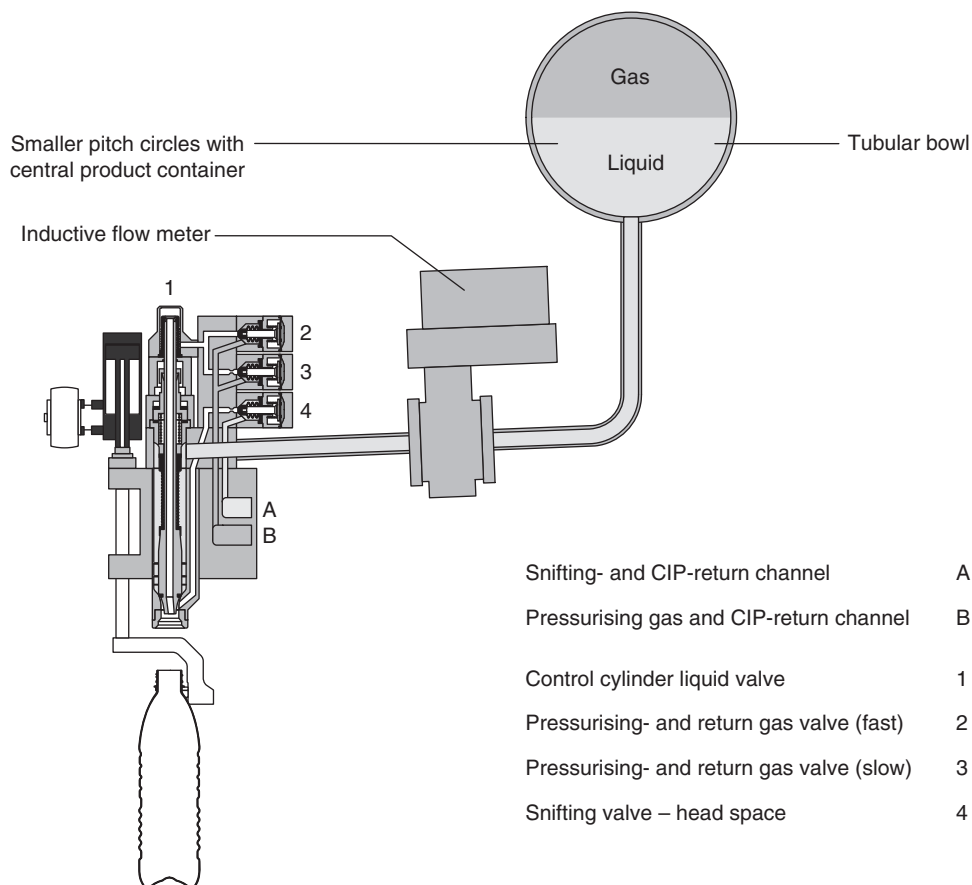


Fig. 7.10 Volumetric filling system; the flow meter integrated in the product supply from the bowl to the filling valve opens and closes the filling valve based upon the measured volume delivered.

A different variant of the level-controlled filling systems uses electronic signals to terminate the filling operation. A probe at the filling tube signals that the preprogrammed fill level has been reached. This signal triggers another signal in the control system for closing the filling valve. In order to transmit the signal, the probe area at the filling tube is constructed from conductive material. Using an electronic filling system of this kind is conditional on the conductivity of the product concerned, which has to be less than $40 \mu\text{S}/\text{cm}$. This system enables the fill level to be changed automatically by adjusting the time-delay between signal transmission and closing of the filling valve.

A volumetric filling system measures the product flow while it is being passed from the ring bowl to the filling valve (Fig. 7.10). An inductive flow meter integrated at the feed line tracks the amount of product flowing through, and under sensor control transmits the signal to close the filling valve. Changes in the fill quantity can in this volumetric filling system be simply accomplished by appropriate programming. The advantage of a volumetric filling process is that the bottles can always be filled with precisely reproducible quantities. This means the process is particularly well suited for



Fig. 7.11 Full-jet filling for still water ensures high flow velocity.

handling PET bottles, which in comparison to their glass counterparts exhibit a high level of dimensional accuracy, thus assuring an identical level of beverage in all the containers filled.

A weight filling system integrates a weighing unit at each container's lifting unit for determining the fill quantity. This system is required when bottling water products such as demineralised waters or distilled water, since the product's conductivity does not permit a different electronic system to be used. On fillers equipped with this system the empty bottles are weighed directly after entering the filler carousel. The amount of filled product is measured by the increasing weight of the bottle during the filling process. Here the final fill level does not depend on the filled volume but on the measured weight difference of the bottle.

The filling valve geometry will be designed to suit the particular variant of filler involved. When a filling system with a vent tube is being used, integration of a swirl insert in the filling valve's outlet generates a rotational movement in the product flow, which guides the product to the inside wall of the bottle, enabling a high flow velocity and a high filling speed to be achieved, while ensuring that the product flows into the bottle without foaming. Alternatively, spreaders can be fitted to the vent tube, producing precisely the same effect. In the case of short-tube filling systems or filling-tube-less bottling, with the return gas being vented into the atmosphere, the filling valve geometry can also be designed for full-jet filling, which for still products, in particular, is an attractive option without any tendency to foaming (Fig. 7.11).

7.3.3 Filling technology for carbonated products

For filling carbonated water, it is absolutely essential to create a situation before the bottles are filled that will prevent the CO_2 from coming out of solution in the beverage. These filling systems are referred to as counter-pressure filling systems, since before filling, identical pressure conditions are established between the ring bowl, which is under overpressure, and the bottle to be filled. This is accomplished using ring bowl gas to pressurise the bottle in a

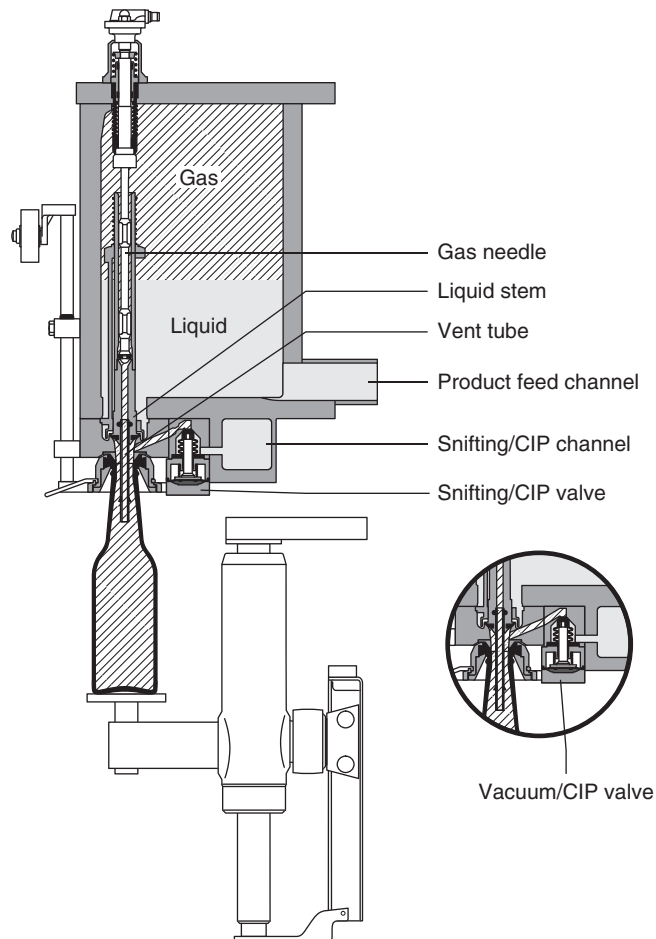
Pressurisation

Fig. 7.12 When filling carbonated products, the bottle is pre-pressurised with ring bowl gas to ensure the same pressure conditions in bottle and ring bowl.

gastight seal with the filling valve. Depending on the filling system involved, this is done either via the gas needle in the case of electro-pneumatically controlled mechanical filling systems (Fig. 7.12), or in the case of electronic filling systems, through a pressurisation valve that is connected to the ring bowl's gas phase. This routing produces pressure equalisation between the ring bowl and the bottle.

It may also be necessary to limit oxygen pick-up in the product during the filling operation. This is accomplished by running a double pre-evacuation step before pressurising the bottles. By subjecting the glass bottles to a vacuum from an additionally provided vacuum channel (Fig. 7.13), the residual air content in the bottles can be reduced to 1–1.5% given a vacuum of 100 mbar.

When running PET bottles, which are not suitable for pre-evacuation, a pre-flushing step, using ring bowl gas or pure gas, is integrated before pressurisation, performed via the pressurisation or pre-flushing valve in order to displace the air located inside the bottle (Fig. 7.14).

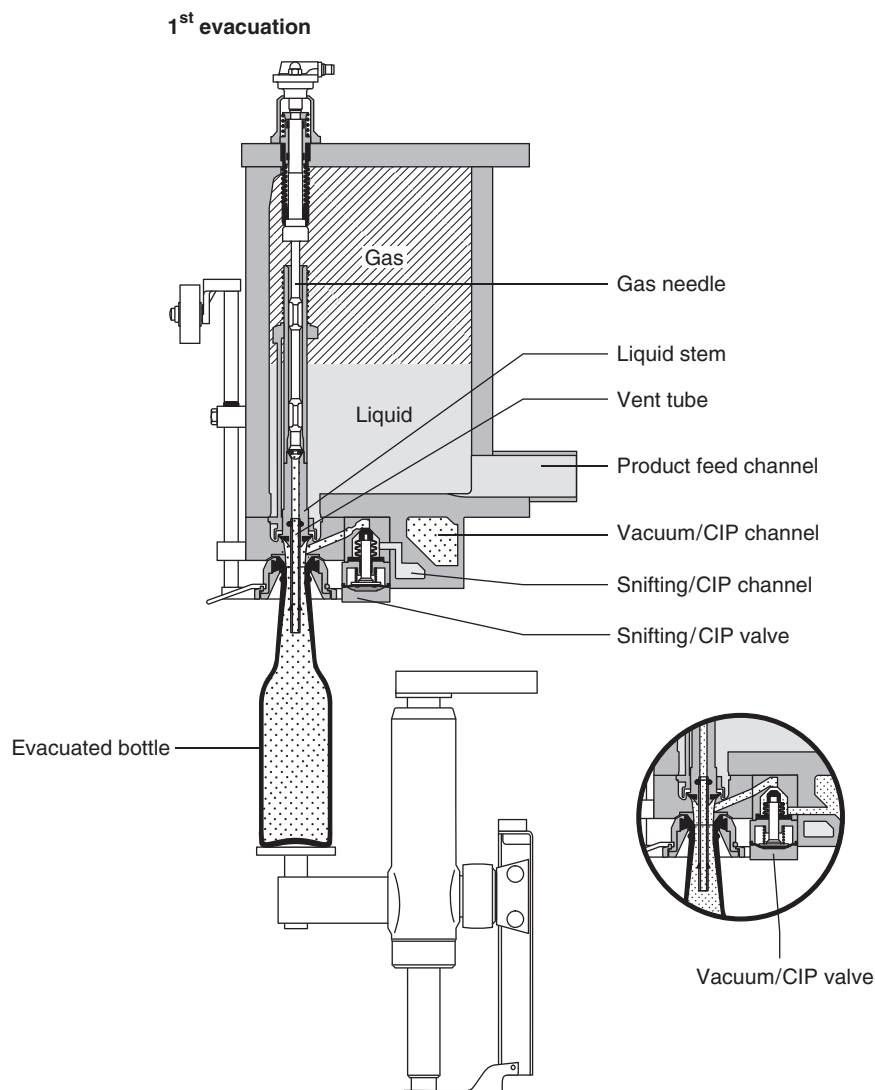


Fig. 7.13 Pre-evacuation step in preparation for filling glass bottles.

These systems were developed for products that are extremely sensitive to oxygen contamination. Today, with the increasing demand for improved product quality in the bottling of carbonated water products, fillers with pre-evacuation or pre-flushing are becoming more desirable.

When filling carbonated water, after completing the filling process, the overpressure in the bottle must be reduced in a controlled manner to equal that of the surrounding environment, otherwise, when the bottle is removed from the filling valve, the larger internal pressure in the bottle would cause the contents to spontaneously gush from the bottle. This reduction in pressure is achieved via a special 'snifting' valve, which opens after filling and allows the pressure in the headspace to be lowered slowly until it is equalised with atmospheric pressure without foaming of the beverage.

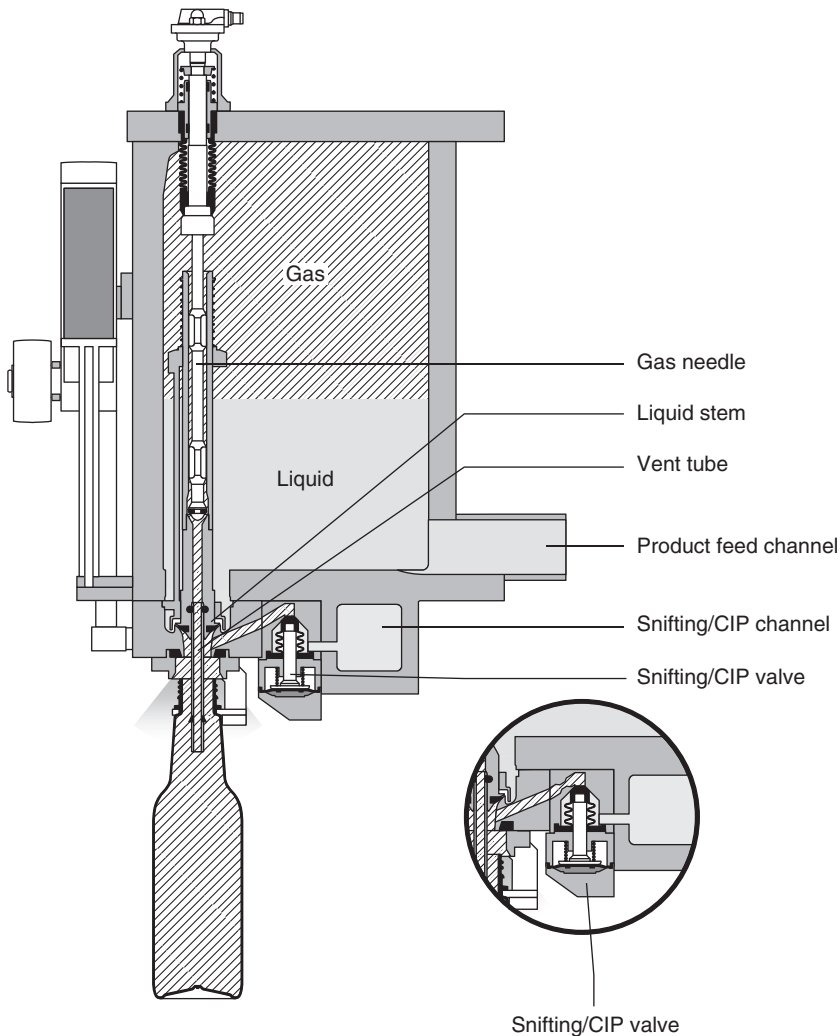
CO₂ flushing

Fig. 7.14 CO₂ flushing, by flushing the PET bottle with ring bowl gas or pure gas the air content in the bottle can be displaced prior to filling.

Figure 7.15 illustrates a filling sequence showing an additional double vacuum/gas flushing sequence:

7.3.4 Filling technology for non-carbonated products

Still water can be bottled using simpler systems, as it is not necessary to pressurise the bottles in order to create the same situation in the bottle as in the ring bowl. Filling systems for still water are referred to as gravimetric fillers, as the product is passed from the ring bowl into the bottle without pressure, simply by the force of gravity. These filling systems may also operate without any physical contact to press the bottle against the filling valve, and are in particular used for PET bottles, which are passed through the machine in a neck-handling configuration. After the bottle has arrived under the filling valve, the filling operation begins,

Procedural steps

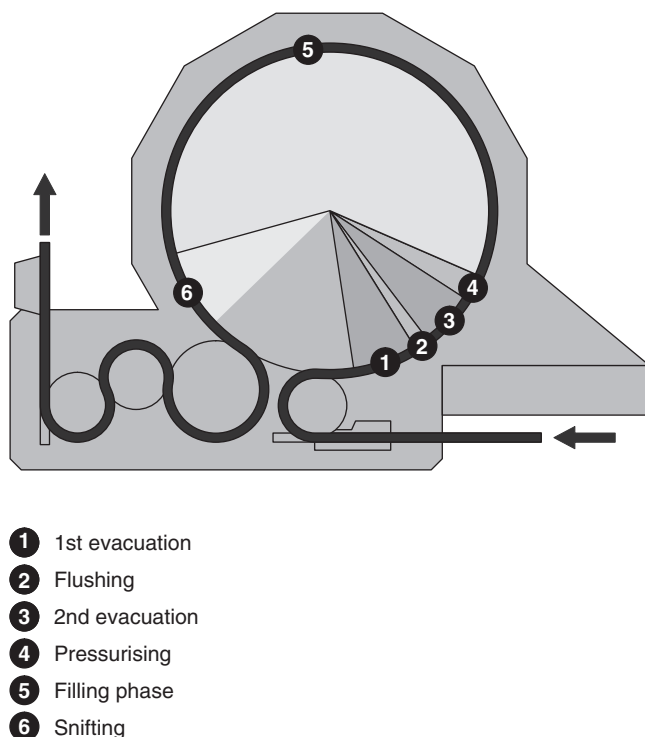


Fig. 7.15 A filling cycle showing additional double vacuum/gas flushing sequence.

and the water flows into the bottle in full-jet mode (Fig. 7.11). Volumetric filling systems with a flow meter are the design of choice here, since by reason of the non-contact filling mode there is no physical contact with a probe or the vent tube.

As the lift movements involved are small, and a pressurisation step is not required, these systems can be fitted with fewer filling valves for the same output, since the amount of time required for sealing the bottle against the filling valve and pressurising it can be entirely eliminated.

7.3.5 The filling operation

The sequence involved is independent of the filling process chosen: the containers are spaced in the bottle infeed to match the filler's pitch. In the case of glass bottles, which are brought to the filler on conventional conveyors, transfer worms precisely matched to the bottle geometry are used (Fig. 7.16). After the bottles have been spaced, the infeed starwheel accepts the glass bottles and transports them by means of a body guide to the filler's transfer position.

PET bottles are usually fed through an air conveyor to the filler, where with the aid of a bottle infeed starwheel with controlled clamps, they are passed into the machine. The bottles in this case are guided by their neck rings, which has the advantage that no handling parts have to be replaced for running different bottle sizes. Only when changing over from one neck finish size to another does the transfer starwheel need to be exchanged.



Fig. 7.16 Infeed worm separating the bottles to match them to the pitch of the filler.

At the transition point between the transfer starwheel and the filler, glass bottles are placed on a lift plate underneath the filling valve, while PET bottles are held by a clamp underneath the neck-ring. As soon as the bottles have been fixed in this position, they start to be raised towards the filling valve. When running carbonated water, the bottles are pressed against the centring unit under the filling valve in a gastight seal, while for still water they are merely raised. Modern-day filling systems for PET bottles designed for bottling still water even manage to do without an integrated lifting unit entirely, since the bottles are passed from the transfer starwheel to the filler at the same level.

Now begins the filling operation proper, which as the bottles travel around the carousel subsumes the steps of pre-evacuation/pre-flushing, pressurisation, filling, settling and sniffing, depending on the actual filling process selected. The lifting unit then lowers the bottles and passes them to a transfer starwheel in the bottle discharge, from where they are fed to a usually monobloc closer.

7.3.6 Filler configuration

Depending on the filling concept involved, a rinser may also be integrated into the machinery design when bottling water. Its primary purpose is to remove any dust and foreign-body particles from new bottles, both glass and PET (if a stretch blow-moulding machine is not integrated into the line concerned), by blowing or flushing them out. This is accomplished using cold or warm water, air, sterile air, ionised air, ozonated water, disinfectants or saturated steam. Mostly featuring either one or two channels, the rinser sprays the upside-down bottles with up to three media from the above-listed options. The rinser concept is finalised to suit the line layout involved and the bottles' exposure to sources of contamination.

After being filled, the bottles have to be capped: directly synchronised cappers for plastic screw caps on PET bottles or for aluminium roll-on closures and crowns for glass bottles, are usually integrated into the filler unit.

Via the sorter, the screw caps (which are mostly the closure of choice for water) are spaced, aligned and fed into the capper from above and retained inside the capping heads by a holding feature. Bottles are simultaneously fed to the machine; glass bottles are secured against turning by a central starwheel, and PET bottles by spikes (called anti-rotation knives)

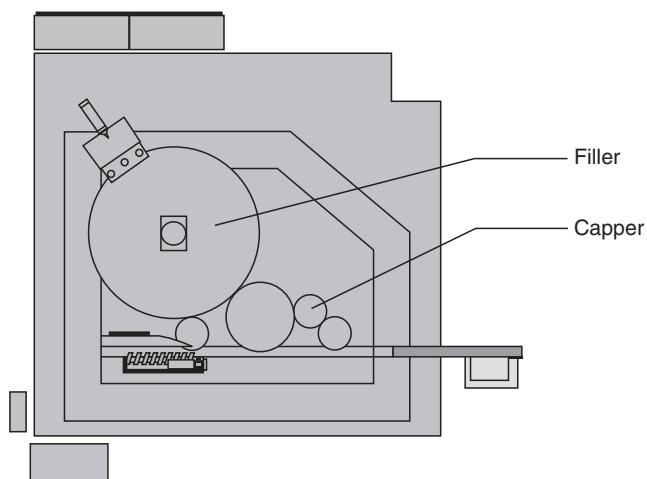


Fig. 7.17 Filler and capper concept for high speed operation.

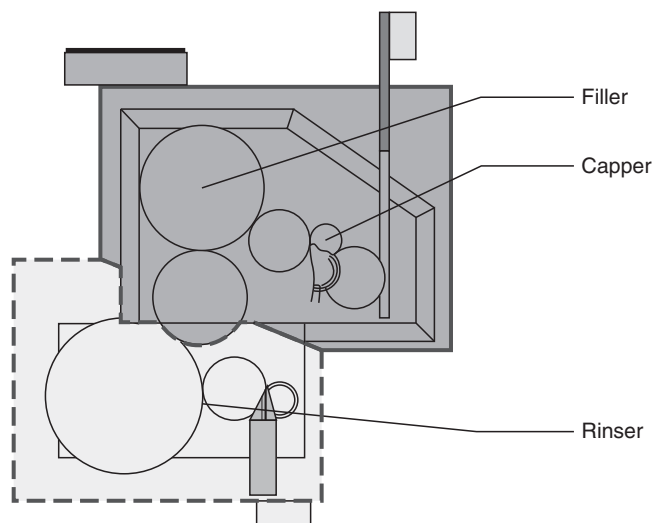


Fig. 7.18 Monobloc set-up with rinser, filler and capper.

at the neck starwheel. The capping head then places the closure on the bottle, whereupon the closure is pressed onto the bottle by spring pressure and simultaneously screwed onto the thread of the neck finish.

Traditional machine configurations use free-standing rinser/filler/capping machines with an interconnecting conveyor system and controls. As line speeds have increased however, monobloc systems have become more commonplace. The introduction of the filler/capper monobloc has been followed by the development of a rinser/filler/capper monobloc system. Figure 7.17 shows a typical arrangement of filler/capper suitable for high speed operation, and Fig. 7.18 shows a typical rinser/filler/capper monobloc system.



Fig. 7.19 In an aseptic filling concept, the filler and its systems are completely separated from their surroundings.

When handling and producing PET bottles with an in-house stretch blow-moulding machine, bottlers can choose between an air conveyor to transport the bottles to the filler, or BLOC-synchronising the blow-moulder directly with the filler. This is an extremely space-saving machine configuration, with the further advantage that a high level of system hygiene can be achieved, since the freshly blow-moulded PET bottles are passed directly to the filler via an enclosed transfer starwheel system, without coming into contact with the outside environment. In order to stabilise the bottles during the filling process for carbonated beverages, this transfer section can also feature an integrated base cooling system using water flushing. The water used here can be recirculated for resource economy. A rinser is not required in this machine configuration.

When PET bottles are being handled, nowadays a labeller can also be included in the monobloc configuration. The sequence here begins with production of the PET bottles in the stretch blow-moulding machine, followed by the monobloc labeller, which applies the desired dress to the empty plastic bottles, after which the empty PET bottles are passed directly to the monobloc filler. Suitable rejection systems inside the monobloc configuration at the various positions ensure that bottles tagged as defective do not disturb the smooth functioning of the monobloc unit.

7.3.7 Aseptic line concepts

The development of volumetric filling systems has also made it possible to run filling processes that are entirely isolated from their surroundings (Fig. 7.19). Since here the filling and control valves are actuated fully automatically, changes in the filling parameters can thus be made directly at the system, without any manual interventions from the operator.

Machines of this generation – as well as machines integrating a weigh-cell system – can also be equipped to handle the filling processes under sterile conditions. In particular, when handling sensitive still products, they can fill without the bottles touching the filling valves (Fig. 7.20). This minimises the risk of contamination from bottle contact with the valve. To gain a proper decontamination of the packaging material and the isolator surfaces liquid peracetic acid (PAA) or gaseous hydrogen peroxide (H_2O_2) are the chemicals in use. This



Fig. 7.20 In the hygienic filling design, the bottle is filled without any contact with the filling valve.

design of filler, installed in conjunction with an isolator and bottle/closure disinfection systems, represents the optimum combination for aseptic filling of sensitive products.

A clean environment around the filling process is just as important as a clean filler. Traditionally, the filling process has been separated from the rest of the filling line in a 'clean' area or room. Developments in this area have introduced cleanrooms which, integrally with the new style of clean guard systems, fully surround the filling process. The complete process, through rinsing, filling and capping, is housed in a cleanroom incorporating fans with microbial filters (HEPA). The fans create a positive airflow inside the filling area, which is ventilated to atmosphere at a low level. By creating this environment around the filling process, the cleanroom size is minimised and it is more effective. A filler cleanroom can be seen in Fig. 7.21. The variant shown constitutes a stage of development between traditional fillers (open design, no shielding against their surroundings) and an aseptic model, which is protected from its surroundings by an isolator construction. Products typically bottled on lines with this large cleanroom include non-ozonated water, weakly carbonated spritzers or sensitive milk-based products for the cold chain. How bottle and closure handling is implemented in these solutions will depend on the characteristics and desired shelf-lives of the products involved. The more sensitive the product,

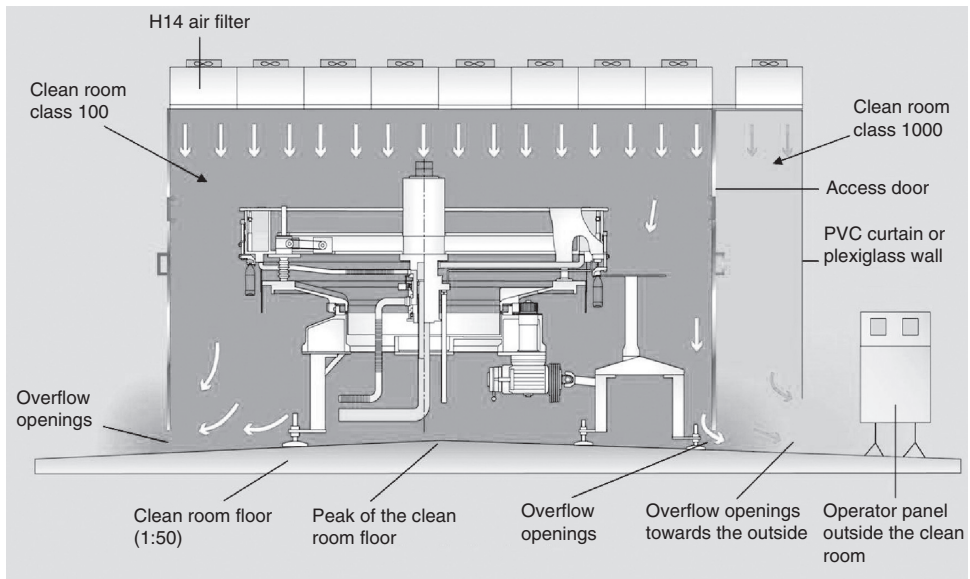


Fig. 7.21 A cleanroom design for the filler integrates the laminar flow of filtered air around the filler to avoid intake of microbiological contaminants.

the more priority must be attached to the line's hygienic design and to appropriate handling of the packaging materials concerned.

In particularly sensitive areas, especially where bottles and caps have to be stored prior to filling, system design has also been extended to cater for bottle and cap sterilisation. Whilst, traditionally, PET bottles are rinsed internally before filling, systems are now available to internally and externally rinse bottles. In extremely sensitive areas, bottles can be treated by the above-mentioned disinfectants PAA (liquid) or H_2O_2 (gaseous). Cap feed systems deliver caps to the capping machine from an external source of storage. In order to complete the cleaning of the total package, cap feed systems can be fitted with ultra-violet lamps. Spraying systems for flushing out the caps with ozonated water, and also rinsing systems with ionised air, are getting more and more popular. For sterilising the caps, however, systems are available that transport the caps through a sterilant disinfecting bath or a treatment chamber with an H_2O_2 -enriched atmosphere. From these cap disinfection units placed on a platform above the filler, the sterilised caps are transferred via a completely enclosed chute to the capper where they are applied to the bottle.

7.3.8 Monitoring and inspection technology

Maximised reliability is essential for any filling operation. This is why at various positions within the filling system, monitoring or inspection units are installed, for verifying that all functions are operating properly. From the extensive range of inspection units available, only a few examples will be selected, as essential for monitoring product quality. If returnable glass bottles are being run, it is advisable to provide a foreign-body inspector before they are fed into the filling system, and a detection system for residual cleaning chemicals after returnable bottles have been discharged from the washer.



Fig. 7.22 Filler in a cleanroom with hygienic guarding.

After the filling and closing operations, the fill level and the closure should be inspected: this enables the fill levels in the bottles (which consumers rightly expect to be always identical) and a secure fit of the closure on the bottles to be verified. Skewed closures may be responsible for CO₂ escaping or for contaminants entering the bottle during storage and distribution.

7.3.9 CIP cleaning of filling systems

Internal cleaning (Cleaning-in-Place or CIP) of the filler is now, in most cases, fully automated, and can be carried out effectively and to a very high standard with minimum operator intervention.

In order to provide an overall 'Clean' filling system however, the external parts of the filling system must be designed to be easily, quickly and effectively cleaned. Developments in electro-pneumatic technology have allowed the elimination of external cams, levers and operating cylinders from the external surfaces of the filler bowl. This has led to the creation of smooth surfaces without crevices and protrusions, which would otherwise be difficult to clean.

Further changes in design have been made to other areas of the filler, to incorporate sloping surfaces, which allow product and cleaning agents to run off the inclined surfaces to the floor, where they can readily be flushed away. Guarding systems with large doors, and crevice-free surfaces, have also provided an even more cleanable surface. An example of a typical 'Clean' guarding system can be seen in Fig. 7.22.

By creating smooth surfaces in all parts of the filling area, automatic external CIP systems can be utilised to maximum effect with minimum operator intervention. Systems can be selected to provide spraying nozzles for the application of contact detergents and sanitisers for effective external cleaning. With an optimum choice of cleaning systems, both internal and external CIP can be carried out simultaneously, thus making more time available for production.

In the CIP process, CIP liquor flow is supplied, controlled and monitored by a separate free-standing supply system (Fig. 7.23). Often this is part of an overall CIP cleaning process



Fig. 7.23 A compact CIP module integrates the tanks for cleaning chemicals, hot and cold water. The system is automated and directly connected to the filler.

supplied to all areas of the bottling hall. Control of the CIP process within the filler provides a necessary link with this external CIP supply. The valves and controls are provided for the pre-determined CIP programme to suit the cleaning requirements of a particular filling system. The filler would normally incorporate the necessary valves and interconnecting pipe-work to ensure the cleaning of all its internal components. These valves and cleaning routes can be controlled by either manual or automated operation.

A manual CIP system applied to a filler is entirely operator-dependent but incorporates the most important features required to carry out the CIP functions. However, a system of this kind offers a less-than-easy operator environment: for all operations; for example, opening/closing of the correct valves and the valve sequence to suit the CIP programme – are totally dependent upon the operator's intervention. Compared with an automated system, the scope of manual functions available within the CIP process is very limited and is subject to operator error.

The fully automated programme built into the filler control system provides a guaranteed completion of any pre-determined CIP cleaning programme, and the process is completed without any operator intervention. By the use of programmable logic control (PLC), all preset criteria for the CIP process are monitored by this automated system. This ensures the completion of each pre-programmed sequence within the cleaning process. Several cleaning programmes can be stored for various applications.

A typical automated cleaning process within a filler unit would include integration of each cleaning flow programme, confirmation that each function within the pre-set programme has been completed; and the timed phase of opening and closing of each of the valves within the filler that control flow to each of the product routes within the filler.

The CIP process requires flooded and pressurised ring bowl (CIP supply from external source at approx. 3 bar), and a high volume flow of CIP liquor through the system (depends on performance and type of filler: usually in the region of 30 000 litres per hour). To provide a closed pressurised system for CIP flow, it is necessary to fit a special CIP cup (Fig. 7.24) to each filling valve to create a seal. This CIP cup provides the 'closed loop system' and the necessary flow path for liquid return to the CIP supply set, by a special CIP return channel within the machine.



Fig. 7.24 Automated CIP cups close the filling valves to create a cleaning loop.

CIP systems are available as small modularised installations, which depending on the line layout concerned can be assigned to the filler in a decentralised configuration. A variable number of batch tanks for the various cleaning media, such as batch water, caustic, acid, hot water, disinfectant solution and fresh water, create a cleaning programme responsively matched to the particular application. Cleaning agent concentrates can be dosed in from concentrate packs or from a central chemicals store. With the aid of fully automated valve racks and operator control using touch-screens, and preprogrammed sequences, a standardised but individualised cleaning programme can be created for the fillers.

7.4 CARBONATION AND FLAVOUR ADDITION PRIOR TO FILLING

If the intention is to produce carbonated water beverages, it is necessary to dissolve gaseous CO_2 in the product. This operation is executed prior to filling, in a carbonator. The degree of carbonation of bottled water is expressed as the ratio of absorbed carbon dioxide (CO_2) to water by volume. Thus, 4 litres of carbon dioxide absorbed into 1 litre of water represents a carbonation level of 4 volumes.

The maximum amount of carbon dioxide that can be absorbed is dependent upon pressure and temperature, such that the higher the pressure and the lower the temperature, the more gas can be absorbed. The basic principle behind all process variants is that first of all, in a de-aeration step, all the constituents of oxygen and nitrogen dissolved in the water are reduced. This is accomplished alternatively in a pressure or vacuum de-aeration step or in a combined pressure/vacuum de-aeration process. The principle of pressure de-aeration is based on adding CO_2 in a de-aeration tank, so that air is displaced by CO_2 .

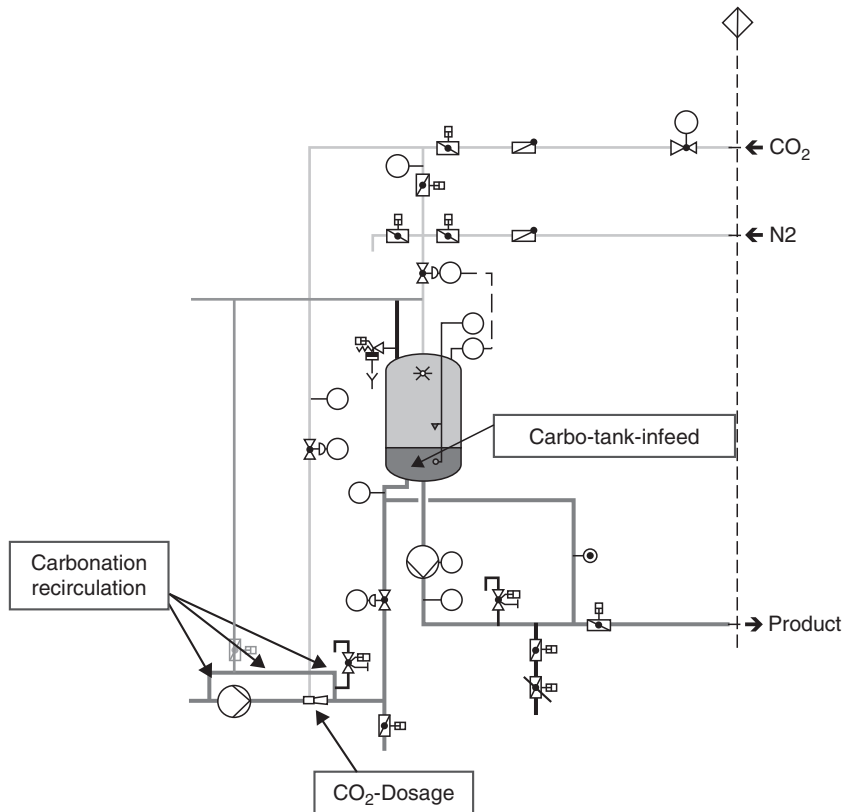


Fig. 7.25 Compact units integrate all functions for de-aeration and carbonation of water products.

Vacuum de-aeration utilises a vacuum atmosphere in the de-aeration tank. Oxygen and nitrogen molecules in the water being de-aerated are removed in this underpressure situation, and extracted from the tank. This is followed by carbonation, using an injector integrated into the pipe, which inserts CO_2 into the inflowing water before it passes into the saturation tank at an overpressure of 8–10 bar. A circulation line enables the water product to be homogenised, with the CO_2 bubbles being reliably dissolved. Now carbonated, the water flows into a pressurised carbonation tank, from where the filler receives the requisite amount of product to suit the operating speed. Figure 7.25 shows a typical arrangement of a carbonator. This unit is a carbonating system suitable for outputs of between 8000 and 90 000 litres per hour. A two-tank system incorporates a water de-aeration tank and provides stable product quality that will assist in the filling process. Incoming product is atomised by means of vacuum or pressure inside the de-aeration tank. A carbonator pump draws off the de-aerated water and passes it through an injector into the tank, where it is saturated with CO_2 . Following a settling phase, a pump feeds the finished product to the filler.

By linking up a dosing function for aromas or flavours, the bottler acquires an option for expanding the carbonator to create a mixer, and this offers for the means to make flavoured water products. Concentrates or aromas can be added to the product directly from the drum supplied by the manufacturer, and avoidance of any preparatory dilution assures microbiological safety up to the moment of dosage. The aromas are added using a special dosing

system that adds the desired taste component to the product water in the right proportion. The concentrate is dosed in using a piston-type dosing pump and a flow meter, after which it is diluted and homogenised in several stages on its way to the carbonation tank. The dosing system is designed for minimised volume, and at the start of production is put into its hydraulically filled state under programme control, thus assuring exceptionally accurate and economical utilisation of the concentrate until the concentrate supply has been entirely used up.

FURTHER READING

Blüml, S. and Fischer, S. (2004) *Manual of Filling Technology*, ed. Kronseder, V. Behr's, Hamburg.

8 Cleaning and Disinfection in the Bottled Water Industry

Winnie Louie and David Reuschlein

8.1 INTRODUCTION

With the increase in terrorist attacks in the past years, the importance of protecting the food supply against further terrorist threats became a top priority for governments across the world. The result in many markets has been a strong emphasis on security programs and procedures by companies to continually improve and enhance the strength and effectiveness of their food security programs. Those involved with sanitation must be knowledgeable about food contaminants, including allergens, physical, microbiological, and chemical hazards. In addition, companies must increasingly be aware of the threats to food safety through contamination of product, tampering during processing and preparation, and the potential for extortion. Increased food safety and environmental stewardship has created additional challenges for the bottled water industry. In addition, with the increased financial pressures of a new world economy, cleaning and disinfection become even more important. With ever tightening profit margins, the bottled water industry cannot overlook the importance of maximum utilization of assets and hence faster cleaning and disinfection, but without compromising quality.

As before, this chapter deals with the science and technology of cleaning and disinfection methods used within the bottled water industry. The choice of methods, combinations, and frequencies will depend on equipment design, process layout, factory location, and the quality of the incoming water. It will also be influenced by the normal operating pattern of the factory, whether it is running 24 hours a day, 7 days a week, or on an intermittent basis. No bottling plant can operate continuously without a well-considered and correctly implemented cleaning and disinfection regime. It will require the allocation of time to maintain product safety and quality standards. The amount of time required will also depend on the nature of the facility and the technology available; for example, a dedicated water bottling line will require a significantly different program from a soft drink factory with lines that also produce bottled waters. In deciding the amount of time required, methods and frequency of cleaning and disinfection, advice should be sought from the manufacturers of cleaning products and equipment suppliers.

The role of cleaning and disinfection in the bottled water industry is more than that of only cleaning the filler and filling room. In considering an effective program for a water bottling facility, it is important to take into account the whole operation, from the parking lot to the point of dispatch. The principal concern in this chapter however, is to discuss the methods for sanitation of the primary product contact areas – pipework, storage vessels, and filling equipment.

Firstly, some definitions: depending on which dictionary or other reference source is used, the terminology associated with sanitation can be ambiguous in its definitions. Though cleaning and disinfection (in some countries referred to as cleaning and sanitizing) are two separate procedures, potential for confusion exists because in different parts of the world the words used to describe the various products employed are also different. For example, in the United States, a sanitizer (see definition below) has only biocidal properties and is not recommended for the purpose of cleaning:

- Cleaning is the process that removes soil and prevents accumulation of residues, which may decompose to support the growth of disease or nuisance causing organisms. It must be accomplished with water, mechanical action, and detergents.
- A cleaner (detergent) is a substance that breaks the bond between the soil and the surface being cleaned. Not only must it remove the soil, it must also hold it in suspension and allow it to be flushed away. It does not kill bacteria.
- Disinfection is the killing or inactivation of micro-organisms, except for some spore forms. The efficacy of disinfection is affected by a number of factors, including the type and level of microbial contamination, the activity of the sanitizer, and the contact time. Organic material and soil can block sanitizer contact and may inhibit activity. Therefore, cleaning must precede all disinfection processes. There are three different levels of disinfection:
 - (i) High level disinfection refers to sterilization activities in which all microbial life, including spores and viruses, are destroyed. High level disinfection is reserved for special applications, such as disinfection of surgical equipment and medical devices.
 - (ii) Medium level disinfection usually refers to elimination of micro-organisms as well as the destruction of the more resistant types of viruses.
 - (iii) Low level disinfection refers to the destruction of bacteria and is not effective against spores and viruses.
- A disinfectant is a chemical agent that is capable of destroying disease causing bacteria or pathogens, but not spores and not all viruses. In a technical and legal sense, a disinfectant must be capable of reducing the level of pathogenic bacteria by 99.999 % during a time frame of more than 5 but less than 10 minutes, as tested by the Association of Analytical Communities (AOAC) method.

The main difference between a sanitizer and a disinfectant is that at a specified use dilution, the disinfectant must have a higher kill capability for pathogenic bacteria than that of a sanitizer:

- To sanitize means to reduce the number of micro-organisms to a safe level.
- A sanitizer, according to the AOAC test method, should be capable of killing 99.999 % (5 log reduction) of a specific bacterial test population, (*staphylococcus aureus* and *Escherichia coli*) within 30 seconds at 25°C (77°F). A sanitizer may or may not necessarily destroy pathogenic or disease-causing bacteria, as is a criterion for a disinfectant.
- Sanitation is the term used to describe the complete plant cleaning and disinfection program to ensure public health.

Although this chapter deals with cleaning and disinfection, as used here, the word “disinfection” refers to low level disinfection, and this is in practice achieved without the use of disinfectants as defined above, but rather through the use of cleaners and sanitizers.

Today, with larger processing facilities and worldwide distribution, the importance of sanitation is greater than ever before, and a well-managed sanitation program must encompass the employee, the customer, and the environment. An effective sanitation program is important for many reasons:

- to protect the company's reputation;
- to reduce the potential for financial losses;
- to remove and prevent bacterial buildup;
- to reduce the chance of off flavors developing;
- to maximize the shelf life of the product;
- to ensure compliance with Government regulations.

However, the main reason that the bottled water industry needs well-managed sanitation programs is to ensure customer satisfaction and safety standards. A complete bottled water food safety program should include both cleaning and disinfection and the use of methods of microbiological testing as a means of monitoring the performance of the sanitation program.

8.1.1 Why clean?

In order to control cleanliness and minimize the spread of bacteria, it is important to know proper sanitation procedures, to determine application frequencies, and to be vigilant in following the procedures. It is also useful to be able to understand and distinguish between micro-organisms such as pathogens (disease causing organisms, such as *Escherichia coli* – Fig. 8.1b), and spoilage organisms. There are thousands of different kinds of bacteria, yeasts, molds, and viruses, which are categorized by their shapes and the way in which they grow. Bacterial cells exist in many different shapes, but there are three basic forms: round or cocci, rod shaped, and spiral (see Fig. 8.1a).

Identification of different types of bacteria can provide some insight into their source and control. The major causes of food contamination are pathogenic micro-organisms that live in soil, water, air, and organic matter and on the bodies of animals and humans. Put simply, they are to be found everywhere.

Most bacteria do not have the ability to travel on their own, at least not very far. Those that can move independently – motile bacteria – use appendages called flagella. All bacteria have the ability to travel widely by “hitching rides” on air, water, bottles, caps, people, and anything else that goes from place to place.

Not only are bacteria plentiful and easily spread from surface to surface, they can also reproduce quickly. One bacterium becomes two, two become four, four become eight, and so on and on by a process of cell division called binary fission, which can occur as frequently as every 20 to 30 minutes.

In a short time, one bacterium can produce millions of bacteria. This build-up of bacteria on surfaces is often referred to as biofilm (see Fig. 8.2).

Under ideal conditions, bacteria will grow in phases and in a short time can get out of control. The first phase, called the lag phase, typically lasts 3–4 hours, and during this time, binary fission occurs relatively slowly as bacteria adapt to their surroundings. After that however, they reproduce faster and faster – this is called the logarithmic phase – and contamination becomes much more difficult to control. Eventually they will reach a stationary

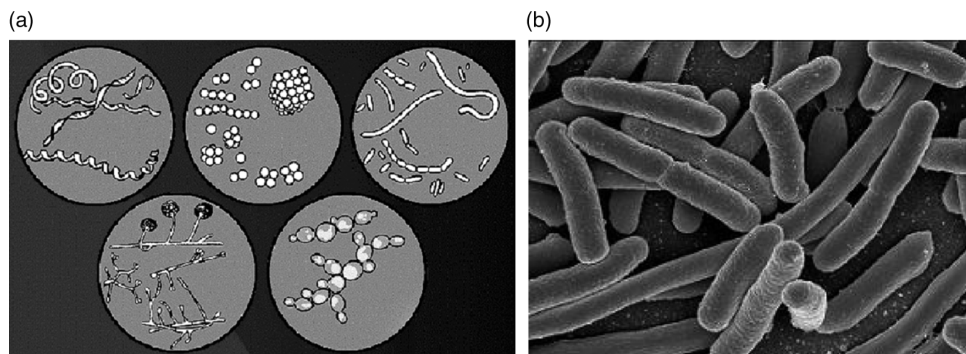


Fig. 8.1 (a) Top row (from left to right): Spiral bacteria, cocci, and rod-shaped bacteria; (b) *Escherichia coli* bacteria.

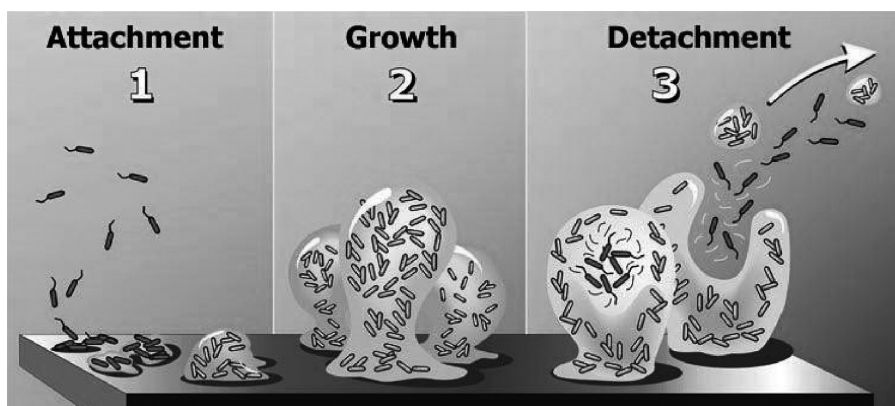


Fig. 8.2 The biofilm life-cycle: individual cells populate the surface, attachment becomes irreversible as biofilm develops and matures and finally single cells are released from the biofilm.

phase where they can maintain a very high population, and finally, in the death phase, they begin to die off due to lack of food, water, and other nutrients.

A good food handling, processing, and sanitation program will take advantage of the lag phase, in which very little growth occurs. A quick, thorough response to control bacteria is therefore a critical factor in sanitation. The sooner bacteria can be destroyed, the greater the chances of eliminating contamination and biofilm build-up, thus reducing the potential for sickness and disease. Equipment that has already been sanitized but that might harbor bacteria surviving beyond the three-to-four hour lag phase should always be sanitized again before use.

8.2 CLEANERS (DETERGENTS)

In the sanitation process, Time, Temperature, Concentration, and Mechanical Action are the four cleaning variables. Choosing the right systems is a necessary part of the process, but they cannot work without the right cleaners and sanitizers. In most parts of the world

cleaners and sanitizers are two distinct categories and sometimes governed by different agencies. To choose the right cleaner, consideration should first be given to the water, the surface to be cleaned, and the method used (application method) and the environment.

Selection of cleaning compounds, methods, and frequency of use depends upon the following factors:

- the type and amount of “soiling” on the surface;
- nature of the surface to be cleaned;
- physical nature of the cleaning compound;
- method of cleaning (foaming, CIP, soaking, manual cleaning, etc.);
- quality of water available;
- time available;
- temperature allowance.

Heat breaks up fat and grease and assists in its removal and an increase in temperature by 32.4°C (18°F) will double the activity of the chemical. However, excessive temperature can also cause cleaning problems. For example, temperature above the “denaturation” point will increase the adhesion of protein to the surface.

An effective cleaner must have the following properties:

- rapid penetrating and wetting power;
- ability to control water hardness;
- high detergent power to remove soil;
- suspending power to keep the removed soil from redepositing on the surface;
- easy rinsability;
- non-corrosiveness to surfaces being cleaned and to cleaning equipment.

In practice, these functions are not performed independently, but tend all to occur together. No simple chemical – alkali, acid, wetting agent, etc. can supply all the properties, but by combining selected chemicals, cleaners can be prepared that are effective on given applications. Different cleaning compounds are required for different cleaning tasks; one group of cleaners that works satisfactorily in one plant may not be effective in another, because of differences in composition of the water supply. However, chemicals should never be mixed at the point of use; any combination of chemicals must be performed by the manufacturers.

8.2.1 Chemistry of cleaning

Bacteria are living organisms that have the same basic needs as man to sustain life and to multiply. That is, they need food, moisture, sometimes oxygen or air, a place to live, and time; cleaning chemistry will remove one of those basics, namely food, and by scheduling cleaning, the time required for multiplication of organisms is addressed.

There are no magic wands in the area of cleaning chemistry; but the selection of cleaning chemicals can either make the job a lot easier or turn it into a nightmare. Even a properly designed cleaning product, if handled incorrectly, can become a dangerous liability.

One tool used in selecting the proper cleaning chemistry is the pH scale, which gives some general information on how alkaline or acidic is the type of cleaning product being used. Different organic challenges require different pH levels in cleaning chemicals.

In general, fats, oils, greases, proteins, and carbohydrates require a cleaner with a pH of above 12, which is highly alkaline. Low pH products are commonly used for removing mineral deposits such as calcium carbonate, which is sometimes known as “stone”. The most efficient method for removing this build-up is by using a phosphoric acid or a blend of acids such as phosphoric, nitric, sulfuric, etc.

Cleaners act in two ways: they either interact with soils on a physical basis by changing their solubility characteristics or they interact with soils chemically to form a modified substance with desirable solubility characteristics in water. Cleaner components are generally classified in the following manner:

- (i) *Surface active agents (surfactants)*: are organic materials generally composed of two parts, one part that is water loving (hydrophilic) and one part that is water hating (hydrophobic), or oil loving (lipophilic). Consequently they have one part of their structure that wants to dissolve in water and one part that is insoluble in water; they provide three types of action: wetting/penetration, emulsification, and suspension.
- (ii) *Builders*: a category that includes:
 - alkaline builders;
 - acid builders;
 - enzymes;
 - water conditioners; and
 - oxidizing agents:
 - Alkaline builders are generally used to provide a source of alkali-negative ions in cleaners. Alkaline builders are a rich source or donor of electrons, or negative ions. These electrons congregate at the surfaces of many soils and in much the same way as emulsification by surfactants; they disrupt the structure, swell the soil, and break it free. The highly negatively charged particles are repulsed from each other and dispersed in the cleaning solution. Strong alkalis such as sodium hydroxide are used in heavy-duty alkaline cleaners for bottle washing or various CIP applications. Highly alkaline materials at high temperatures react with fats and oil to form soaps which are soluble in water.
 - Acid builders include phosphoric acid, nitric acid, and sulfuric acid. In the food and water industries, phosphoric acid is commonly used to remove and help prevent mineral stone on processing equipment.
 - Enzymes are specialized protein catalysts or molecules, which speed up a chemical reaction. An enzyme reacts with a specific organic substance, a protein, a fat, or carbohydrate. Enzymes are very specific in their action; they will only interact with the particular substance they are designed to work on. This generally is not used in the bottled water industry, as protein is not found in our normal process.
 - Water conditioners can be an important component in treating impurities in the water source. Minerals such as calcium and magnesium salts in the water may react with ingredients in the cleaning compound to form insoluble salts. These salts then form a film that builds up on equipment. To prevent this, materials are added to alkaline cleaners to interact with the calcium and magnesium.
 - Oxidizing agents are used as a cleaning booster in many alkaline detergents. Sodium hypochlorite is sometimes used as an aid in protein removal at concentrations in the

range of 50–100 ppm as available chlorine. Sodium hypochlorite is also often used as an effective sanitizer. However, when it is used in a high pH environment, it loses its sanitizer properties but remains very effective in solubilizing and removing protein soils or protein films from equipment surfaces.

There is a great deal of flexibility in the selection of cleaners to match specific cleaning requirements and conditions. To make the right choice, it is necessary to select the detergent system that adequately conditions the water and neutralizes its effects on the cleaning system, provides wetting or contact with the soil, dissolves the soil, and holds it in suspension so that it can be flushed away.

8.2.2 The five factors

Before finally selecting a cleaner, the interaction of five key factors needs to be understood:

- (i) *The nature of the soil*: an understanding of the soil to be cleaned is essential in determining the right choice for cleaning. This is further complicated by other factors; the solubility varies depending on the soil's condition, the quantity of heat and how long it was applied, and the age and moisture content of the deposit. Here are some examples of soils and methods of cleaning them:
 - *Light soil*: in this case, an oxidizing agent such as sodium hypochlorite in the presence of an alkaline cleaner will be effective. This will hydrolyse, meaning that it attacks the large molecule and breaks it up into smaller, more easily dissolved particles. Typical chlorine concentrations should be somewhere between 50 and 100 parts per million in the alkaline cleaner solution.
 - *Mineral salt*: calcium and magnesium in their insoluble form are responsible for most mineral salt deposits. However, iron and manganese are also objectionable because of their intense color. These deposits not only create sanitation problems, but if they are allowed to accumulate, they may contribute to corrosion and poor heat transfer. Acid is the most economical material for removing mineral deposits; Inorganic acids such as phosphoric acid are preferred because of their effectiveness, low cost, and generally non-corrosive nature to stainless steel food processing equipment. Organic acids, such as citric acid, may have special applications but are not widely used because of their cost.
 - *Grease and oil*, including those approved for use in the bottled water industry, are not solubilized by either acids or alkali. Surfactants allow the detergent solution to wet these soils so that they can be suspended in water or so they can be flushed from the surface to be cleaned.
- (ii) *The role of water*: more than 99% of the cleaning solution is water and it is necessary to know about the specific attributes and impurities in the water being used, including the following:
 - *Water hardness*: the most important chemical property of water because it has a direct effect on cleaning and disinfection. It is responsible for excessive detergent consumption; it also encourages scale deposits, so that undesirable films and precipitates can be left on equipment following improper cleaning procedures. Hardness forms scale or leaves film. When calcium and magnesium are present in

water as bicarbonates, it is referred to as “temporary” hardness. Both of these salts are quite soluble in water, and consequently, they can both exist in water at very high concentrations. However, when water containing these salts is heated, they convert to calcium and magnesium carbonates, which are insoluble in water, and will precipitate in the form of scale. “Permanent” water hardness (which cannot be forcibly precipitated by heating) exists when calcium, magnesium, or both are present as chloride or sulfate salts.

- *Micro-organisms*: water can harbor significant numbers of micro-organisms, which can exist in water for extended periods, even if nutrient levels are low. Groundwater may contain significant amounts of organic matter that can provide the nutrient source, either in dissolved or dispersed form.
 - The pH of water also varies considerably. The normal range is from 6.5–8.5, (with a pH of 7 being neutral) and a pH outside these limits is considered unusually alkaline or acid. It may be necessary to treat water in these extreme ranges in order to achieve effective results. Acid and alkaline cleaners are generally not affected by water pH; their acidity or alkalinity far outweighs the effect of the water itself. In sanitizer solutions however, the pH of the water supply and the resulting pH of the sanitizer solution can greatly affect its effectiveness as an antimicrobial agent.
- (iii) *The surface or material to be cleaned*: it is essential to consider the composition of the surface being cleaned whether it is stainless steel, aluminum, brass, copper, iron, tile, or plastic. Different materials interact with soil and with the cleaner in different ways. In the bottled water industry, stainless steel is the best material for product contact surfaces, and 304 or 316 stainless is often preferred, because it presents a smooth, cleanable surface, as well as protecting the organoleptic integrity of the water. Rough, cracked, pitted surfaces are much harder to clean because of the difficulty of removing the soil from crevices or holes.
- (iv) *The method of application*: there is a number of different ways to apply cleaners to the area being cleaned and each presents a different level of exposure to the employee:
- *Hand or manual cleaning*: because the employee has the greatest potential for physical contact, with manual or hand cleaning the pH of the solution must remain between 4 and 10.5.
 - *Spray or high-pressure cleaning*: because of misting and atomization there is likely to be some exposure of the employee to cleaning products. Products should not be used that are highly alkaline or acid, unless employees are provided with suitable personal protective equipment.
 - *Cleaners applied as foam or gel*: have less potential for employee contact.
 - Where mechanical cleaning or CIP is used, no direct employee contact would be expected. This provides the least risk to the employee, since the solution is contained within a vessel or lines.
- (v) *Environmental concerns*: all cleaning solutions and soils eventually become part of the waste stream and need to be properly treated prior to disposal or discharge. This effluent may be treated at a public or privately owned treatment plant; in either case, there are certain restrictions on the quality or characteristics of that waste stream. Major considerations are pH, phosphorus, biological oxygen demand (BOD), fats, oils and greases, the volume of water discharged, dissolved solids, conductivity, and the presence of heavy metals.

8.2.3 Types of cleaner (detergents)

There are four basic categories of cleaning chemistry: alkaline, acid, neutral pH, and solvents. Prior to using any cleaner, it is first necessary to consider the organic challenge and the technology of the equipment and surfaces being cleaned:

- (i) *Alkaline cleaners*: these cleaners have a pH of 11–13.5:
 - *Heavy-duty alkaline cleaners*: usually caustic cleaners such as sodium or potassium hydroxide. Chelators have been added to tie up minerals and wetting agents added to allow free rinsing. Because of their caustic nature, they should not be used on soft metals and should have very little or no human contact.
 - *Medium alkaline cleaners*: in most cases these are excellent products to remove fats, oils, and greases and are commonly applied by using foam.
 - *Chlorinated alkaline cleaners*: may be either heavy or medium alkaline. Hypochlorite is added to the alkali to peptize the proteins for easier removal. Excellent on fats, oils, grease, proteins, and carbohydrates, they are also used for CIP cleaning of pipes, tanks, etc.
- (ii) *Acid cleaners*: are at the other end of the pH spectrum; these include:
 - *Phosphoric acid*: effective on most light mineral salts and relatively safe for hand scrubbing. It is often used at a concentration between 2 and 3% for cleaning.
 - *Sulfamic acid*: excellent for use in enclosed vessels because it is lower in pH than phosphoric acid. Concentration used at 1–3% for cleaning.
 - *Acid blends*: there are various products that combine acids such as phosphoric, nitric, sulfuric, and sulfamic. These products are very effective on mineral build-up.
- (iii) *Neutral pH cleaners*: these are designed specifically for use where an acid or alkaline cleaner can do damage to a specialized piece of material or equipment, such as packaging systems, scales, or other sensitive equipment.
- (iv) *Solvents*: water based solvents are used where light oil, light grease, and other soft organics are deposited. These products can contain a foaming agent to aid in the application and cleaning. Unlike high alkaline cleaners that digest the organics, solvents break down the organics.

In general, Table 8.1 should assist in choosing cleaning chemicals.

8.3 SANITIZERS

Cleaning removes soils, but after the cleaning operations, equipment surfaces and the environment can still be contaminated with micro-organisms. If these micro-organisms are not destroyed, the bottled water being produced may be contaminated. Disinfection is therefore the most critical step in a sanitation program. To ensure a high degree of sanitizer efficacy:

- Analyze and determine the best sanitizer for the application. The supplier should have a high degree of expertise in this area.
- Ensure that all cleaning chemical residues have been rinsed thoroughly before disinfection.

Table 8.1 Properties of detergents.

Acid detergents		Comparative ability									
Ingredients		Mineral/Scale removal	Emulsification	Penetration	Suspension	Rinseability	Foam	Noncorrosive stainless steel	Noncorrosive soft metals	Nonirritating	Passivation
Mineral acids	Muriatic hydrochloric	A	C	B	C	C	D	D	C	D	DD
	Sulfuric	B	B	C	C	B	D	D	C	B	D
	Sulfamic	C	C	C	C	C	D	C	C	C	C
	Nitric	C	B	C	C	C	C	C	C	C	D
	Phosphoric	C	B	C	C	B	A	A	C	A	A
Organic acids	Citric	C	A	C	C	A	AA	A	C	A	A
	Hydroxyacetic	C	A	C	C	A	AAA	A	C	A	A
	Gluconic	C	C	C	C	C	B	C	C	A	A
	Wetting agents	C	C	C	C	C	AA	C	C	A	A
Alkaline detergents		Comparative ability									
Ingredients		Saponification	Emulsification	Protein control	Penetration	Suspension	Water conditioning	Rinseability	Foam	Noncorrosive	Nonirritating
Basic alkalis	Caustic	A	C	B	C	C	D	D	C	D	DD
	Silicates	B	B	C	C	B	D	D	C	B	D
	Carbonates	C	C	C	C	C	D	C	C	C	C
	Trisodium phosphate	C	B	C	C	C	C	C	C	C	D
Complex phosphates	Tetrasodium pyrophosphate	C	B	C	C	B	A	A	C	A	A
	Sodium tripoly phosphate	C	A	C	C	A	AA	A	C	A	A
	Sodium polyphosphate	C	A	C	C	A	AAA	A	C	A	A
	Gluconates	C	C	C	C	C	B	C	C	A	A
Organic materials	EDTA	C	C	C	C	C	AA	C	C	A	A
	Phosphonates	C	C	C	C	C	AA	A	C	A	A
	Ploymers	C	B	C	C	A	A	B	C	A	A
	Wetting agents	C	AA	C	AA	A	C	AA	A	A	A
	Chlorine source	C	C	A	C	C	C	C	C	B	B

A, excellent; B, good; C, no ability; D, negative performance.

- Dilute all sanitizers according to label directions, and follow all labels and instructions to the letter.
- Confirm approval by regulatory/environmental authorities.
- Ensure that the sanitizer application methods provide coverage for all food contact surfaces.
- Train staff in proper use and handling of sanitizers, and also in using them to best advantage given the particular plant conditions and circumstances.
- Use automatic dilution systems to ensure the correct dilution rate.

Sanitizers can be sprayed on or circulated through equipment. They can also be foamed on a surface or fogged (under very extreme and exceptional circumstances) into the air to help reduce airborne contamination. The key to effectiveness of any application method is intimate contact of the proper sanitizer concentration with the microbial cell. The sanitizer needs to thoroughly cover the surface for the proper recommended contact time.

Ideally, disinfection on equipment should be performed just prior to start up. However, there are times when equipment is left idle before production re-starts. In this case, it is recommended that the sanitizer be applied to the equipment immediately after cleaning in order to leave the surface with minimal microbial contamination. This will minimize any regrowth that could occur during downtime. Following extended downtime, sanitizer should be applied again, and the equipment finally rinsed with product or treated water at start up.

8.3.1 Regulatory considerations

The sanitizer used must always comply with the regulations applicable in the geographical location. For example, sanitizers in the USA are regulated by the Environmental Protection Agency (EPA) and are of two types: no-rinse food contact surface sanitizers and non-food contact surface sanitizers. The second are generally referred to as environmental sanitizers. The Food and Drug Administration (FDA) is charged with approving anything used on food contact surfaces that could potentially contact food items. Ingredients used in sanitizers must comply with FDA requirements as safe and effective. The active ingredients for approved no-rinse food contact sanitizer formulations and their usage concentrations are listed in *the US Code of Federal Regulations*, 21 CFR 178.1010.

In the USA, the official challenge test demands that they must reduce microbial activity of two standard test organisms (*staphylococcus aureus* and *Escherichia coli*) from a designated microbial load by as much as 99.999% or 5 logs in 30 seconds at 25°C (77°F).

Regulations for usage instructions are very specific for each product and label instruction must be followed precisely. In fact, the EPA requires a warning statement on the label that says, "It is a violation of federal law to use this product in a manner inconsistent with its labeling." Sanitizers are treated differently worldwide and it is important to consult local regulations to ensure that they are used accordingly.

Sanitizer solutions can only be prepared using potable water and concentrations must be accurate. If the concentration is below the recommended level, the result may be inadequate microbial control. A concentration that is too high is also undesirable. "No-rinse" food contact sanitizers are considered indirect food additives, so concentrations above recommended levels are not allowed. However, in the bottled water industry, the use of no-rinse sanitizers without a final rinse is ill-advised, as it can potentially leave residues, which affect product quality and jeopardize its inherent properties, thus altering the nature of the product.

8.3.2 Types of sanitizers and their uses (Table 8.2)

- (i) *Chlorine products*: these are the most commonly used. Typical chlorine sanitizers include various forms; of which the most popular is sodium hypochlorite.
- Advantages:
 - Chlorine is effective against a wide variety of bacteria, fungi, and viruses, including bacteriophage. All chlorine products, regardless of their type (elemental chlorine, hypochlorites, or organochlorines) form hypochlorous acid (HOCl) in solution. HOCl is the most germicidal species of chlorine. The amount of HOCl is dependent on the pH of the solution. As the pH is lowered, more HOCl is formed. However, as the pH is decreased below 4.0, increasing amounts of toxic and corrosive chlorine gas (Cl_2) are formed. Chlorine is much more stable at higher pH, but is less effective. Hard water salts do not affect chlorine unless they cause an upward drift in the pH of the use solution. Chlorine is effective at fairly low temperatures and is not as temperature sensitive as other common sanitizers. It has the advantage of being relatively inexpensive and is often preferred because it does not foam.
 - Disadvantages:
 - Residual chlorine at low levels imparts a taste and odor to the water and obviously alters its nature.
 - The potential for toxic gas formation: care must be taken, as deadly chlorine gas (Cl_2) will be formed if the pH drops below 4. Chlorine is also corrosive to many metals; inorganic forms are more corrosive than organic forms and may adversely affect plastics and rubber. A concern for those who work with chlorine is that it is irritating to the skin and mucous membranes.
 - Chlorine is unstable and dissipates rapidly from solution. It loses activity rapidly in the presence of organic materials, light, air, and metals. Liquid chlorine deteriorates during storage and stability decreases with increasing temperature. Because chlorine products degrade with age, solutions need to be prepared more frequently than some other sanitizers with concentration level tested and adjusted to obtain the required level of available chlorine.
 - There is also controversy over its environmental impact, because of the formation of potentially toxic organochlorine by-products. This concern is based on findings that chlorine reacts with naturally occurring organic materials, primary humic acid, naturally present in some waters, which results in the formation of suspected carcinogenic trihalomethane (THM) compounds.
- (ii) *Iodophors*: these are compounds that contain iodine dissolved in a surfactant carrier and an acid. The surfactant carrier provides a soluble, stable medium for the iodine and in the diluted form controls the release of iodine. On a parts per million basis, iodophors are one of the most effective sanitizers available, and are especially effective against most yeasts and molds.
- Advantages:
 - Iodophors provide a weak acid rinse for mineral control, and are less irritating to the skin than chlorine. They offer less toxicity, and have a broader effective pH range than chlorine. Generally more effective at pH 2–5, iodophors offer acceptable disinfection efficacy at slightly alkaline pH, depending on the formulation and conditions.

- They are less corrosive than chlorine when used below 48.9°C (120°F), and the activity is not lost as rapidly as chlorine in the presence of organic matter. This is especially true at low pH. Concentrated iodophors also have a long shelf-life – another advantage over chlorine. Working with iodophors offers a number of other advantages: the concentration is easily determined by common field methods, and the amber color is an obvious visual indicator of the presence of active iodine, which makes this type of sanitizer good for hand disinfection.
- Disadvantages:
 - Iodophors can cause staining problems and discolor equipment. Depending on the formulation, iodophors may be more adversely affected by water hardness than chlorine and they have poor activity against bacteriophage.
 - The efficacy of iodophors is adversely affected by low temperatures; this effect can be overcome by using higher concentrations or longer contact times. In addition, they cannot be used at temperatures above 48.9°C (120°F) or on hot equipment. At that temperature, iodine begins to vaporize and the vapor is very corrosive to equipment, including stainless steel. In addition, some people find the odor of iodophors offensive. Iodophors are more expensive than hypochlorite.
- (iii) *Quaternary ammonium compounds*: these are sometimes referred to as Quat sanitizers, or QACs. They are often the right choice when the situation calls for an effective environmental sanitizer. The maximum concentration allowed by FDA for use in a no-rinse food contact sanitizer is 200 ppm of the active QAC.
 - Advantages:
 - QACs at normal use concentrations are non-toxic, relatively odorless, colorless, and non-corrosive. They are stable to heat and relatively stable in the presence of organic matter. Most QAC sanitizers have a neutral pH, but are effective over a fairly broad pH range. In most cases, the maximum efficacy is exhibited in the alkaline pH range. However, research has indicated that the effect of pH may vary with bacterial species, with gram negatives being more susceptible to Quats in the acid pH range, pH 7 and below, and gram positives in the alkaline pH range, pH 7 and above.
 - These compounds possess some detergency because of their surfactant activity. They are active against a wide variety of micro-organisms, including yeasts and molds.
 - Disadvantages:
 - QACs are generally considered less effective against gram-negative bacteria than against gram-positive bacteria. This drawback can be overcome by using higher concentrations, or by providing longer contact time.
 - QACs are less effective against bacteriophage and because they are cationic molecules, they are incompatible with soaps and anionic detergents (most general cleaners are anionic). Therefore, surfaces must be rinsed thoroughly between the cleaning and disinfection steps to prevent inactivation of the sanitizer. They also have low hard water tolerance, although it can be improved by the addition of chelating agents such as Ethylenediaminetetra-acetic acid (EDTA). QACs are not as effective at low temperature as the oxidizing sanitizers such as chlorine and peroxyacetic acid. When used in mechanical operations they can cause a foaming problem, which is why they are not recommended for use as CIP sanitizers.

Table 8.2 Advantages and disadvantages of sanitizer types.

Chemical	Advantages	Disadvantages
Chlorine	• Broad spectrum of activity • Hard water tolerant • Low temperature. Efficacy • Relatively inexpensive • No residual activity • Non film forming	• Potential for toxic gas formation • Corrosive • Irritation • Unstable, short shelf-life • Potential for toxic by-products
Chlorine dioxide	• Strong oxidizing chemical • More tolerant of organic matter than chlorine • Less corrosive to stainless steel • Less pH sensitive	• Safety • Toxicity • Sensitive to light & temperature • Cost
Iodophors	• Broad spectrum of activity • Less irritating than chlorine • Low toxicity • Effective pH range • Broader than chlorine • Less corrosive than chlorine • Stable, long shelf-life • Color of use solution provides visual control	• Staining porous and plastic materials • Poor activity against bacteriophage • Poor low temperature efficacy • Corrosive at high temperatures. • DO NOT USE ABOVE 120°F (48.9°C) • May produce excessive foam on CIP application • More expensive than chlorine • Odor may be offensive
Quaternary ammonium	• Non toxic, odorless, colorless • Non-corrosive • Temperature stable • Relative stability in presence of organic soil • Broad spectrum of activity • Residual antimicrobial film • Some detergency and soil penetrating ability • Stable, long shelf-life • Mold and odor control	• Incompatible with anionic wetting agents • Low hard water tolerance • Limited low temperature activity • Excessive foaming in mechanical applications • Antimicrobial activity may vary depending on formulation
Acid anionic sanitizers – older technology for CIP application	• Stable – long shelf-life • Generally non-corrosive • Non-staining • Low odor	• Incompatible with anionic wetting agents • Low hard water tolerance • Limited low temperature activity • Excessive foaming in mechanical applications

Carboxylic acid sanitizer	• Not affected by hard water • Removes and controls mineral films • Good bacteriophage activity • Low foaming CIP application • Broad spectrum of bacterial activity • Stable, good shelf life • Not affected by hard water salts • Remove and control mineral films • Non-staining	• Antimicrobial activity may vary depending on formulations • Limited and varied activity against fungi • pH sensitivity – optimum activity pH < 3.5 • Inactivated by cationic surfactants • Temperature sensitivity, use at > 55°F (12.7°C) • Corrosion potential & equipment compatibility issues
Peroxy acid compounds – newer formulations combine carboxylic acid for better mold and fungi control	• Low foam • Broad temperature range of activity • Combine disinfection and acid rinse • No residue • Generally non-corrosive to stainless steel • Relative tolerance to organic soil • Phosphate free • Environmentally responsible • Broad spectrum of bactericidal activity • Active over broad pH range up to pH 7.5	• Metal ion sensitivity • Corrosive to soft metals • Odor of concentrate • Varied activity against fungi
Hot water - Min. of 185°F for 15 minutes	• Inexpensive • Easily available • Broad spectrum efficacy • Non-corrosive • Penetration	• Slow • Film formation • Equipment damage • Condensation formation • Safety • Cost
Ozone	• Powerful oxidizing gas • Broad spectrum germicidal activity	• Unstable • pH sensitive • Temperature sensitive • Safety issues • Toxicity • Cost

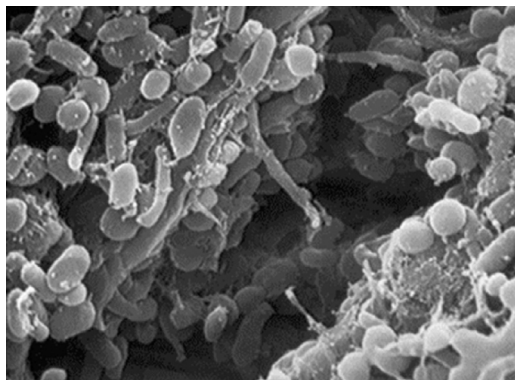


Fig. 8.3 Biofilm (see also Fig. 8.2).

(iv) *Acid anionic sanitizers*: these are fast-acting compounds.

- Advantages:
 - Acid anionic sanitizers work well on yeasts and viruses. Bacteria do not survive well in an acid environment and an acid sanitizer can work best when the pH range is below 3. Antimicrobial activity is drastically reduced or stops when pH levels climb to neutral. Acid anionic sanitizers not only rapidly kill bacteria but they also provide a method to acid rinse equipment, which leaves stainless steel bright and shiny. They have very good wetting properties and are usually non-corrosive, which means they can be left on equipment overnight, and do not stain. Hard water and organic challenge do not have a major effect on the ability of acid anionic sanitizers to kill micro-organisms, and they can be applied by CIP or spray, or can be foamed on if a foam additive is used.
- Disadvantages:
 - Acid sanitizers can lose all their effectiveness in the presence of any alkaline residuals or cationic surfactants. It is important to thoroughly rinse all cleaning agents from surfaces before application of the sanitizers.

(v) *Peroxy acid compounds*: hydrogen peroxide products represent the newest class of sanitizers, although they have been used extensively in Europe since the 1970s. Peroxyacetic acid is a strong, fast acting sanitizer that (like chlorine-based sanitizers) works on the basis of oxidation. FDA regulation allows peroxyacetic acid to be used as a no-rinse food contact surface sanitizer at the dilution specified on the label, but it is advised that within the bottled water industry, it is thoroughly rinsed from all production equipment prior to production.

Peroxyacetic acid is one of the most effective sanitizers against biofilms, which are composed of a collection of bacteria that have attached to surfaces and have excreted an extracellular polysaccharide, or slime layer (Fig. 8.3). This slime layer protects the cells from adverse environmental conditions. In fact, research shows that bacteria within a biofilm are up to 1000 times more resistant to some sanitizers than those cells freely-dispersed in solution.

- Advantages:
 - The low foam characteristics of these compounds, like chlorine, make them suitable for CIP applications. They offer a broad range of temperature activity, even down to 4.4°C (40°F). As acid-type sanitizers, they combine the

sanitizer and acid rinse in one step. They leave no residues and they are generally non-corrosive to stainless steel and aluminum in normal surface application. They are relatively tolerant of organic soil, which probably accounts for their superior activity against bacteria harbored in biofilms.

- Peroxyacetic acid sanitizers are generally formulated with phosphate-free compounds, which are environmentally friendly. They are readily biodegradable and break down into water, oxygen, and acetic acid, and this lack of environmental impact is a major positive benefit. They provide a broad spectrum of bactericidal activity, and they can be used in a broader pH range than other acid-type sanitizers, with activity up to pH 7.5.
- Disadvantages:
 - Peroxyacetic acid sanitizers lose their effectiveness in the presence of some metals and organic materials, for example, when make-up water contains more than 0.2 ppm iron. They are corrosive to some metals, such as brass, copper, mild steel, and galvanized steel. This corrosiveness is accelerated by the presence of high chlorides in the water (>75 ppm). High temperatures will also accelerate the corrosion rate. Although “use” solutions are virtually odorless, full strength peroxyacetic acid sanitizers have a strong, pungent smell. As with all chemicals, proper, safe-handling techniques must be followed.
- (vi) *Hot water*: another disinfection method providing a viable alternative to chemical sanitizer is also one of the oldest and simplest: heat. It is critical that a proper time and temperature combination is used, i.e. 85°C (185°F) for 15 minutes.
 - Advantages:
 - Hot water has the advantages of being relatively inexpensive, easily available, and effective on a broad spectrum of micro-organisms. It is non-corrosive, and provides excellent heat penetration into “difficult to reach” areas such as behind gaskets, and in threads, pores, and cracks.
 - Disadvantages:
 - It is comparatively slow compared to chemical sanitation, requiring a lengthy process involving heat, hold, and cool down. It can lead to film formation or “heat fixing” of any remaining soils, making future clean-up much more difficult. Hot water can shorten equipment life. Thermal expansion and contraction stresses equipment and can lead to premature failure. Equipment, including gasket materials, must be specially designed to withstand temperatures in excess of 82.2°C (180°F). Hot water in the system also creates potential condensation problems within the plant production environment.
 - Water heated in excess of 76.6°C (170°F) is hot enough to cause serious burns; as with chemical sanitizers, proper safe handling procedures must be followed. Energy costs can be high to sustain high temperatures and there are others costs, including that of the water, heating equipment, and maintenance. In addition, water conditions are important, as high temperatures will increase the formation of hard water film and scale.
- (vii) *Ozone*: an allotrope of oxygen, ozone is a powerful and naturally unstable oxidizing gas. It is a more powerful oxidizer than chlorine with an excellent broad spectrum of germicidal activity. Because of its instability, it cannot be stored, but must be produced on site at the location where it is to be used. Like chlorine, ozone is affected by pH, temperature, organics, and inorganics. It is most effective at a pH of 6–8.5. As the temperature increases, the half-life of ozone is reduced. It is not tolerant of organic

soil. There are safety issues with the use of ozone, as it is a powerful irritant to the respiratory tract. There is also a high capital cost associated with the use of ozone.

Disinfection is the most critical step in a sanitation program. To ensure a high degree of sanitizer efficacy:

- It is necessary to determine the best sanitizer for the application. The supplier should have a high degree of expertise in this area.
- Ensure that all cleaning-chemical residues have been rinsed thoroughly before disinfection.
- Cleaning agent surfactants need to be compatible with sanitizer surfactants.
- All sanitizers must be diluted according to label directions.
- Staff must be educated not only on the proper use and handling of sanitizers, but in how to use them to best advantage given the particular plant conditions and circumstances.

Generally in selecting a sanitizer, it is important to consider the method of application, and spray, circulate, and foam are the normal choices. A sanitizer can only reduce the number of bacteria; it must therefore be applied to as clean a surface as possible. Corrosion is one of the largest concerns, as it damages lines and filling equipment and acts as a harbor-age for microbes. All sanitizers should be used at the proper temperature within the recommended concentration guidelines.

8.3.3 Maximizing effectiveness

Whichever sanitizer is chosen, a number of additional factors contribute to the effectiveness of disinfection:

- *Cleanliness of the surface:* soil can chemically inactivate the sanitizer as well as physically protect the microbial cell from direct contact with the sanitizer. The surface must be cleaned and thoroughly rinsed, so that it is free of soil and residual detergent that can chemically inactivate the sanitizer.
- *Intimate contact:* in order for a sanitizer to be effective, it must come into contact with the cell wall of the organism. Harborage, such as pits, crevices, and cracks, as well as soil residue can prevent this intimate contact from occurring.
- *Suitable product temperature and concentration:* chemical reactions are accelerated by a rise in temperature, so the efficacy increases as temperature and concentration is increased. An exception to the rule is in the case of iodophors, which vaporize at temperatures above 49 °C (120°F), so their use is somewhat limited.
- *Contact time:* the longer the contact time, the greater the kill.
- *Proper pH is crucial:* this is especially true with acid sanitizers and with chlorine, since chlorine has greater activity as the pH is lowered.
- *Composition of the water:* this can make the sanitizer chemically inactive, or buffer the pH and diminish the sanitizer's effectiveness.
- *Types of micro-organism:* not all sanitizers are equally effective against all micro-organisms, or the various forms of the micro-organisms. For example, cells in the spore state or in a biofilm are much more resistant than cells in the vegetative and freely suspended state.
- *Numbers of organisms present:* a sanitizer is only capable of reducing the number of bacteria, which means the higher the initial number present, the higher the number of possible survivors. High numbers can overwhelm the sanitizer.

All of these factors are interrelated and can normally be compensated for by adjusting another. If the sanitizer can only be prepared in cold water, it may be necessary to increase the contact time or the concentration to obtain the effectiveness comparable to that at a higher temperature with a shorter contact time or lower concentration. Also, to ensure maximum effectiveness, sanitizer solutions should be prepared fresh for each use.

In the past it was standard practice to spray or flood disinfectants on the surface of the filler. Today suppliers are offering sanitizers built on the latest chemistry that are self foaming and approved for no rinse applications when used in accordance with label directions. They offer the advantage of visual monitoring and longer cling time to vertical surfaces. Acid-based foaming sanitizers are available to aid in controlling mineral deposits on stainless steel surfaces. For walls, floors, and conveyors made of plastic polymers, self foaming quaternary ammonium based sanitizers using long chain technology have also been developed. In order to save time, and to increase efficacy, these new products are worth a practical test in the bottling facility.

8.3.4 New chemical technology for water and energy saving

Just as in every other part of the food industry (and perhaps more so), the bottled waters industry is responding to the increased emphasis on environmental stewardship, coupled with growing food safety concerns, and this is a key driving force affecting the choice of chemicals used for cleaning in the modern bottled water plant. Whether imposed by choice or by regulation, this has led to the development of cleaners that are effective at lower temperatures, which clean faster, and also save water.

Low temperature, one-step CIP cleaners are more commonly used in Europe, where they are often classified or recognized as germicidal cleaners, but are expected increasingly to come into use elsewhere. One such cleaner, tested for cleaning efficiency and efficacy, is a two-part product:

- (i) Part A – Heavily wetted caustic solution.
- (ii) Part B – PAA (Peroxyacetic acid).

The caustic solution and wetting agent penetrate the attached micro-organisms and/or soils. When the PAA combines with caustic, it releases free oxygen radicals that further break the attachment, freeing the soil and/or micro-organisms from the surface.

The example below illustrates how this new formulation compares favorably with more conventional methods.

Wash comparison example:

Conventional wash	Low temp wash
1. Pre-rinse/establish circulation	1. Pre-rinse/establish circulation
2. Caustic wash 71°C (160°F) 20 min at 3900 ppm	2. Low temp wash 105°F 15 min
3. Post-rinse	a. 1.5% active caustic
	b. POAA 8 min injection during final portion of caustic wash 1% to 1.5% must have active residual in return line.
4. Acid wash 60°C (140°F) 20 min at 4000 to 10000 ppm	3. Treated water rinse to release.
5. Post-rinse	
6. Hot water sanitize 85°C (185°F) 15 min)	
7. Treated water rinse to release.	
Total time 311 min.	Total time 116 min.

Savings: Temperature = Energy
 Total Water = Incoming + sewer
 Time = Opportunity time for production, less down time

The advantages can easily be illustrated by putting financial values to the numbers. The following example is in USD:

Energy cost per million BTU (British thermal unit)
 – \$ 14.80 Water – plant source cost to pump only
 Sewer – city municipality \$6.00/1000 gal
 Line Speed 1100 BPM
 Efficiency 85%
 Opportunity time value \$1000 per hour

	Energy	Chemical	Time	Water	Total
Current	\$18.03	\$13.88	\$10,366.67	\$192.60	\$10,591.18
Low temp	\$6.10	\$28.80	\$1,933.33	\$73.80	\$2,042.04
Savings	\$11.93	(\$14.92)	\$8,433.33	\$118.80	\$8,549.14

With only a small investment in chemistry, thousands of dollars worth of added time can be realized for production. This is accomplished without any compromise in disinfection efficacy.

8.4 TYPES OF CLEANING AND BASICS

Depending on the facility and the situation, there are several types of cleaning that make up a well-managed sanitation program, including dry cleaning, wet cleaning, manual and automatic, Clean in Place (CIP), Clean out of Place (COP), and Hi-Pressure.

In order for these to be effective, there are basic rules that employees and management must follow, generally referred to as the “6 × 4” process, comprising 6 steps necessary for cleaning and the 4 variables that we control in the process. The 6 steps are preparation, pre-rinse, washing, post-rinse, inspection, and disinfection. The 4 variables are time, temperature, concentration, and mechanical action.

Many sanitation articles refer to the “4 × 4” process, often without reference to the 2 steps of preparation and inspection. However, good preparation prevents cross-contamination during cleaning and ensures that the employee has necessary training and equipment to do the job. Inspection ensures that the cleaning process is done properly, with no short cuts. In modern line CIP applications, inspection may be facilitated by observing swing elbows or hook-up stations. Emphasizing inspection as part of the process will gain valuable data that will ensure control of the process and consequently clean lines and vessels.

8.4.1 Cleaning dynamics

Installing the proper sanitation equipment will accomplish two basic things. First, it will increase labor efficiency by reducing costs; second, it will provide a consistently effective sanitation program. Whether manual or mechanical soil removal is selected, the

four variables, sometimes referred to, in automated cleaning, as the 4 Ts – Time, Temperature, Titration, and Turbulence, apply to every cleaning operation. All four are equally important, and effective sanitation cannot take place without the use of all variables in one degree or another. There are two basic ways to remove soils: manually or by mechanical methods. Each is effective in particular situations and for particular types of equipment.

8.4.1.1 *Manual method*

There is no doubt that the best-known and oldest method of cleaning is using just a bucket and brush. Hand cleaning is good for small areas or small pieces of equipment that must be disassembled and manually scrubbed. With manual methods, one is restricted to small areas and mild detergents, and if the person cleaning does not expend enough manual energy, poor cleaning will result. The detergent must be mild enough so that splashing will not cause skin burns. The contact time will vary with the size of the equipment but must be sufficient to ensure soil removal. Chemical usage can be high if an automatic dispensing system is not used, and manual cleaning is time-consuming with higher labor costs. In addition, cleaning aids, such as sponges or rags, should never be used in a bottled water plant; they entrap soils, providing breeding conditions for microbes, are hard to clean, and can contaminate surfaces. Color coded equipment for different areas or tasks are recommended and all equipment should be maintained in clean condition, fit for the purpose.

8.4.1.2 *Mechanical methods*

These offer advantages in controlling the temperature and concentration; however, it takes more engineering design to achieve proper mechanical action.

Depending on the concentration, temperature, and mechanical action, it is possible to adjust the contact time to maximize the cleaning cycle. One can increase one or the other of these variables, but they must all be in balance. However, the law of diminishing returns comes into play; just because good cleaning is achieved with a 0.5% solution at 71°C (160°F) for 30 minutes contact time, it does not necessarily mean that a change to 5% solution at 71°C (160°F) for 3 minutes will achieve the same results. In most situations, minimal contact time at a given temperature and proper mechanical action is needed to get consistent results. In addition, it would take extra rinsing to remove the 5% solution. When optimizing cleaning, it is necessary to establish base-line data and monitor the results of the changes. Changes in cleaning parameters should be made only with the assistance of the chemical supplier and plant management. The effects on the effluent system, water, and sewer cost also come into play when determining the best cleaning parameters.

Production time may be the most costly part of the sanitation process. Generally, cleaning and disinfection takes place at the expense of operations, and often it is viewed as a necessary evil. This is not a suitable or sustainable approach, as cleaning and disinfection is an essential function of the process. It is up to the plant management to learn how to optimize cleaning time and performance. The ultimate cost, in addition to lost product and product recalls, may well be “your brand”, and in optimizing mechanical cleaning, investment must be weighed against the return. Several methods of cleaning need to be analyzed against the expense of time and utilities, energy, water, and sewer cost.

Some examples of mechanical systems are:

- *Foam systems*: foam application systems are widely used and are very effective for a range of applications. Foam cleaners can be applied directly to the surface of the soiled equipment, where the foam remains for three to five minutes, providing extended contact time. A brush is then used to scrub down all surfaces and properly rinse equipment with clean soft water to remove the cleaner and loosened soil. Foam in itself does not contribute to cleaning other than helping the chemistry to work more effectively. Care must be taken when using any high foaming product and it is important to be sure that the product in question has a specified content of cleaning product, so that the factory is not just buying “suds”. It is also important to read the Material Safety Data Sheet and to review the chemical breakdown of the cleaning product by comparing cleaning compound content and dilution rates. Both foam and thin film will allow the employee to clean more surface area faster than bucket and brush; however, they are only ways to dispense the cleaning chemical. The real-time savings come by combining them with a properly designed rinse system.
- *Foam tank*: this is a 5, 15, or 30 gallon tank, which must meet regulatory requirements as a pressure vessel. Water and an appropriate amount of cleaner are added to the tank, the lid is secured; with an air hose attached, the pressure is brought from 40 to 60 psi to provide thick foam.
- *Wall mounted foamer*: this unit works off a central system in which the chemical is brought up into the foamer from the one-gallon container. Air and water are supplied to the unit and the chemical is automatically diluted. A wall-mounted unit can be configured to include cleaner and sanitizer dispensing systems with a rinse feature, enabling foam, rinse, and sanitizer from a single unit.
- *Central system*: in this application, the chemicals and the pumping system are located in a central room. One pump brings prediluted cleaning product to foam or sanitation stations throughout the plant. Sanitizer is also pumped out to these stations through a separate line. Pump and line size are important, and the type of pump is also critical; it should be made of sanitary plastic tubing or stainless steel, so it will have the highest resistance to chemical corrosion. This is an excellent method of cleaning and allows total control.
- *High pressure spray*: this is not best suited for use inside a processing environment because a spray unit creates aerosols, meaning that pathogens can be carried on the airborne spray to other areas throughout the plant. The spray can also have the disadvantage that instead of ridding the processing area of organics, it may only be blowing them from one side to another. One other concern with high pressure is possible damage to process equipment by blowing the grease out of bearings or forcing water into crevices and electrical outlets. Care and instruction need to be provided to personnel, as high pressure air can be dangerous.

A good sanitation program may also use COP (Clean out of Place) and CIP (Clean in Place) systems, both of which allow the employee efficient use of time. COP washer tanks (Fig. 8.4) are designed for parts that are otherwise manually washed, the parts being placed in baskets that are loaded into the COP tank. Each COP System uses a variety of different high velocity water jets to clean the parts as they are submerged in a cleaning solution. This allows parts to be cleaned while the operator does additional tasks; higher temperature and concentrations are also possible than with manual methods. Ultrasonic baths can also be used for cleaning intricate small parts.



Fig. 8.4 A COP tank.

The above methods can save time and increase sanitation efficiency; again, the only factors controlled are time, temperature, concentration, and mechanical action. Nevertheless, a well-trained, well-motivated employee is the most important part of good sanitation. However, as bottling plants grow, high volume production equipment and lines require stand-alone CIP equipment, and this is covered in Section 8.5.

8.4.2 Brush Program – guidelines on the proper use of brushes in bottling plants

Brushes used in different parts of the plant and for different purposes should be segregated. Brushes should be maintained in good repair, properly stored when not in use, and sanitized in between uses. Brushes and the maintenance of brushes are important parts of a complete sanitation program:

- (i) Why should you color-code?
 - Help prevent cross-contamination between food contact areas and non-food contact areas.
 - Easy reference on proper use of color-coded tools.
 - Reduce cleaning tools migrating from one dept to another.
 - Better credibility with current and potential customers, a well-designed color-coding system is an important part of GMPs, HACCP plan and overall food safety programs.
 - Ship safer product.
- (ii) Color-coding in practice:
 - The first step is planning. Involve both employees and management. Management should explain the reasons for color-coding to all employees. The best ideas for color-coding often come from production, sanitation, and/or maintenance workers. Also, employees are more likely to be enthusiastic about color-coding if they have been involved in the planning stages.

- Walk through the plant and try to divide areas into zones with different hygiene requirements. Assign a different color to each zone. This process can take some time, with several modifications along the way. Make sure everyone agrees to the scheme before implementation. Keep in mind there are no standardized plans. Choose the colors that work best for your plant.
- The plan should be visual, and as simple as possible. Overly complicated plans will be difficult for employees to understand and for supervisors to implement.
- Cleaning tools with the same color should be cleaned and stored separately. Once cleaned, they should not come in contact with other brushes.
- All key areas should be marked with signs or posters, in multiple languages if necessary.
- Training is crucial. Behind every successful color-coding plan is a company management that has provided training and motivation to improve hygiene.
- Material of construction – brushes need to be of a synthetic composition (no wood or natural bristle). Polypropylene bristles should be used with acids.
- Wash, rinse, and sanitize food contact brushes between every use. Hang similar color brushes together when not in use. Check condition of brushes regularly. Replace worn and matted brushes as needed.
- Color coding – brushes should be identified and utilized only in specific production areas.
- The following color usage profiles are suggested:

WHITE	Food contact surfaces
BLUE	Non-food contact surfaces
RED	Sanitation
ORANGE	Allergen line
YELLOW	Restrooms
GREEN	Maintenance
GREY	Waste or trash
BLACK	Floor drains

8.4.3 Master sanitation schedule

For effective cleaning and sanitation, it is necessary to define a plan, known as a “master sanitation schedule” or, as some call it, a “task manager”. The master sanitation schedule can range from a simple form to a computer driven database linked to scheduling, man-hour projections, and Sanitation Standard Operating Procedures (SSOPs). In any case, it must cover the whole plant, from parking lot to roof maintenance, to filling room.

This tool ensures that the whole plant is cleaned and sanitized on a regular basis. To acquire information, data will be needed from many sources to determine the frequencies

for cleaning and disinfection. Equipment manufacturers will provide general guidelines; laboratory data such as microbiological swabs will also give guidance on appropriate frequencies. Employee feedback, sanitation inspections, and audits will also be a useful source of monitoring to provide information. The key is that this is a living document, and by keeping the schedule updated it is possible to have a cleaner and better running plant, reliably producing safe and wholesome product.

8.4.4 Sanitation Standard Operating Procedures (SSOPs)

Sanitation Standard Operating Procedures (SSOPs) should be in place for every task that is on the Master Sanitation Schedule and should contain the following information:

- *Equipment*: name or reference.
- *Revision date*: everyone needs to know it is current.
- *Supplies needed*: chemical, brushes, wrenches. etc.
- *Safety equipment*: Personal Protective Equipment (PPE) needed for the job – Lock out/ Tag out instructions if needed.
- *Cleaning procedure*: this can be as detailed as needed on complex equipment and pictures can be attached. Abstracts from the equipment manuals may be helpful.
- The employee should be involved in describing the job and cleaning.
- This document should be at the job site and updated if changes in procedures are made.
- Sign off and audit by management and employee.

An inspection and equipment release form should accompany the SSOP, enabling all parties to know that the job has been completed properly. The inspection should have an objective non-biased test if possible to ensure satisfactory results have been achieved. Many inspections include quick testing methods to give employee feedback.

The employee is the key to any sanitation program; he or she must be well trained on Good Sanitation Practices (GSP) and follow them and SSOPs zealously. GSPs involve employee hygiene, equipment, and cleaning aids maintenance.

8.5 CLEANING IN PLACE (CIP)

CIP is the process of bringing the cleaning solution to the equipment and piping. It can be manual or automated, and as bottling plants grow, high volume production equipment and lines require stand-alone CIP equipment. CIP for the Bottled Water Industry is an integral part of the sanitation process. The same basic rules apply, meaning that time, temperature, concentration, and mechanical action must be controlled. In addition, to ensure quality and repeatability, proper data acquisition and monitoring are necessary. The effectiveness of CIP is more than just pushing the buttons; it takes plant management involvement, and it must be properly maintained and monitored. CIP has to be on the same level as the plant's processing equipment. If all the proper components are not in place along with trained employees motivated to do their jobs, CIP will become "Circulate in Place", not "Clean in Place".

CIP systems use fixed pipes, spray devices, valves, tanks, sensors, and controls, to provide closed circuit cleaning and improve the efficiency and repeatability of the cleaning and disinfection process. CIP systems offer significant advantages over other cleaning methods, including reduced labor, energy, and water costs, while providing better results due to the

ability to use higher temperatures and concentrations. The automatic programming feature of most CIP systems provides a degree of repeatable performance not found in other methods. In addition, since the processing equipment does not need to be taken apart and reassembled, the risk of re-contamination is greatly reduced.

An effective CIP system delivers some significant advantages:

- reduced labor;
- energy control;
- water control;
- consistent results (repeatable with automated controls);
- higher concentrations when needed;
- higher temperatures;
- safety – employees do not have to touch hot surfaces or come into contact with chemicals.

To achieve desired results, several choices must be made, to include location and type of system, hydraulics, spray devices, and programming. CIP systems must be integrated into the process design.

In the 1920s, two trade associations and one professional society joined together to formulate uniform standards for dairy equipment. These standards became known as “3A standards”. Today, equipment fabricators, equipment users (food processor), and regulatory officials work together to develop and set sanitary standards for food processing equipment of all types. Equipment that meets the design criteria is permitted to use the “3A” symbol. In the global market, “3A” works with the International Organization for Standardization (IOS), Technical Committee 199, and the International Dairy Federation (IDF) Group of Experts B3 for Sanitary Standards.

Once it is known that the equipment and affiliated piping are designed correctly, it is necessary to determine which type of CIP system is right for the operation, and the hydraulics and spray devices required.

Most regulatory agencies require a minimum velocity of 1.5 m (5 ft) per second through all parts of the CIP system. This velocity through a pipe creates turbulent (rather than laminar or straight line) flow. In piping, if the diameter is smaller than 7.5 cm (3 in), 1.5 m (5 ft) per second is acceptable for turbulent flow, and for 7.5 cm (3 in) and larger, 2.4 m (8 ft) per second is required. This provides the necessary scrubbing action inside the piping (see Fig. 8.5 and Table 8.3).

In vessels, spray devices achieve complete coverage and provide the hydraulics. The flow required depends upon the vessel shape and the means by which this is calculated is shown in Appendix 1.

If performed correctly, these calculations will give the flows required to clean both lines and storage vessels. However, CIP is more than just a matter of putting water in; in order to achieve good hydraulics, proper solution return is needed to complete the loop. To obtain balance, the return should be slightly faster than the supply, otherwise water building up



Fig. 8.5 Laminar and turbulent flow.

Table 8.3 Typical cleaning flow.

Typical cleaning flow				
Pipe size		Velocity ft/sec.	Flow GPM	Time to fill 10 gal. can
O.D.	I.D.			
1.5	1.40	5 fps	24 gpm	25 sec.
2	1.87	5 fps	43 gpm	14 sec.
2.5	2.37	5 fps	69 gpm	9 sec.
3	2.87	8 fps	163 gpm	4 sec.
4	3.83	8 fps	288 gpm	2 sec.

Table 8.4 Tank outlet valve flow.

TOV flow		
Pipe size		Gravity flow through TOV
O.D.	I.D.	
1.5	1.40	40 gpm
2	1.87	75–80 gpm
2.5	2.37	115–120 gpm
3	2.87	190–200 gpm
4	3.83	250–275 gpm

will cause “puddling”, inhibiting the cleaning process. Other factors to consider when CIP cleaning vessels are shown in Table 8.4:

- *Tank outlet valves:* suitable size.
- *Return pumps:* 12–18 inches (0.3048–0.4572 m) below tank outlet.
- *Tanks pitched:* 3/4 inch per ft (19 mm/0.3048 m).

The selection of spray devices is also critical, as it is important to have complete coverage and flow rate compatible with the vessel. The spray device should be self-draining, self-cleaning, and made of sanitary materials (304/316 stainless steel). Fixed and rotating spray devices are both commonly used; the fixed types have no moving parts and are the most widespread in use today. They come in a variety of sizes and shapes (Fig. 8.6).

Spray devices must provide proper coverage at designed flow rates to make it possible to use large tanks and vessels that could not otherwise be cleaned manually. Effective and repeatable CIP cleaning depends upon the proper selection of the spray device, based on the size and configuration of each tank and vessel. If the correct spray device is installed, cleaning will take less time, which saves water and chemicals and minimizes effluent charges. Fixed devices have advantages over rotating ones, in that they have no moving parts to break. All spray devices can clog with foreign materials such as gasket pieces, etc., even if a strainer is in line. Checking for clogging should be a regular part of CIP preparation.

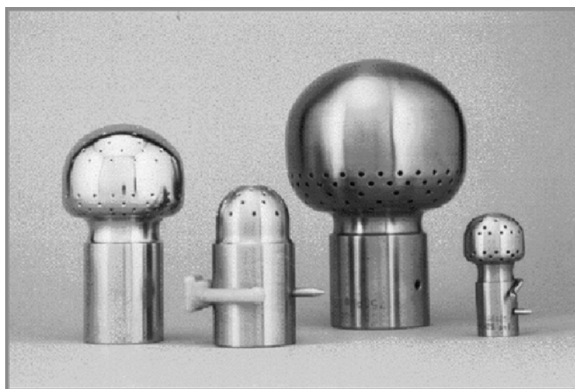


Fig. 8.6 Selection of fixed spray devices.

Having addressed the minimal CIP flow requirements, it is necessary to choose between manual Vs mechanical (automatic) systems. Manual CIP can only be relied upon for the simplest of circuits, generally referred to as pot-and-pump applications. Even then, there is likely to be little or no documentation to ensure proper cleaning. With the many regulations covering the bottled water industry, it is essential to know that the proper time, temperature, concentration, and mechanical action are achieved each and every time. This can only be done successfully with modern CIP systems designed for the plant's cleaning needs and that will be capable of repeatable cleaning performance. Automation is the only way to meet these standards, and the choice will be in determining the right kind of system and controls that best fit the plant.

It is crucial that all processing equipment, including storage tanks, piping, filter housings, UV units, contact tanks, fillers, and tanker trucks be properly cleaned and sanitized to maintain high product quality and shelf-life, and to prevent the spread of microorganisms.

Filling machinery in most cases will be integrated into the CIP system. Most fillers will require a pressure ring or CIP cup attachment for cleaning. It is important that filling equipment be designed for the CIP process with parts that are compatible with the temperature and chemical concentrations needed in CIP programs. Gaskets should also be the subject of a selection and maintenance program and be compatible with the water to be bottled, cleaning chemicals, and methods used. When integrating fillers and other specialty equipment into the CIP system, it is important to consult the equipment manufacturer for recommended cleaning protocols, programming, and flow requirements. The plant Quality Assurance department and chemical suppliers both need to be part of the CIP process to ensure chemical capability and efficacy.

8.5.1 Automated CIP

Consistent CIP results were made possible in the early 1950s, largely with the advent of the automated valve, which in the bottled water industry are usually air operated, sanitary valves. They are used to control the direction of the flow in the circuit or to block or shut off flow (Fig. 8.7).

The simplest is the 2-way (shut-off or blocking) valve, in which the actuator opens and closes to stop flow. This is used for simple tasks, and a typical application would be for a

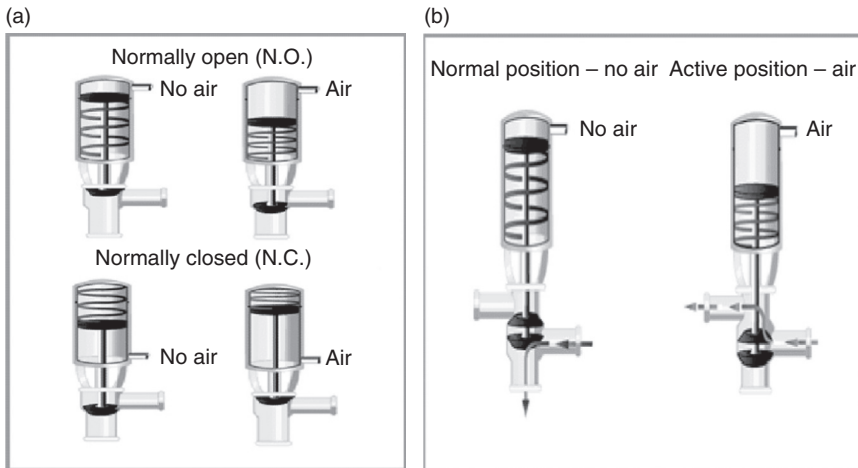


Fig. 8.7 Automated valves: (a) shut-off or blocking valve; (b) three-way valve.

tank outlet valve. The 3-way valve is used for directional flow control, but without stoppage of flow; this valve is commonly used and referred to as a divert valve. The flexibility provided by using these valves in various configurations gives the ability to move water and other liquids to any filler from any storage vessel in the plant.

Valve matrices that have been put in modern facilities require special programming and valve routing during cleaning. Each valve must be cleaned and sanitized on both sides, the valve seats, stems, o-rings, and seals being cycled so that each valve is cleaned on all surfaces.

The plant also has the responsibility to prevent cross-contamination and deadlegs that could allow product to sit idle for hours at a time, jeopardizing both safety and quality. Several methods have been designed to prevent this, and some allow idle lines to be cleaned or purged while the rest of the plant is operating. The most common method is the block and bleed configuration. In this case, flow is stopped and then diverted to drain or the CIP return. Double block and bleed allows an atmospheric air break to ensure that product and unlike fluids (e.g. product in one circuit and CIP chemicals in another) cannot be mixed. To eliminate the extra valves needed, new sanitary valves have been designed for mix-proof operation. These allow two different products to flow through one valve, allowing cleaning on one side and product on the other. The valve consists of two bodies, which are welded together. The seats for the upper and lower plugs are located between the bodies, two independent plug seals forming a leakage chamber between them. Any leaking product from one side or the other flows into the leakage chamber and is discharged through the leakage outlet. The cost is much greater but this valve allows more flexibility in cleaning and production.

8.5.2 Types of CIP systems

CIPs systems are of four common types: single use, re-use, solution recovery, and multi-use. There are advantages and disadvantages to each, so it is important to know the process, equipment, and environment in deciding which to use.

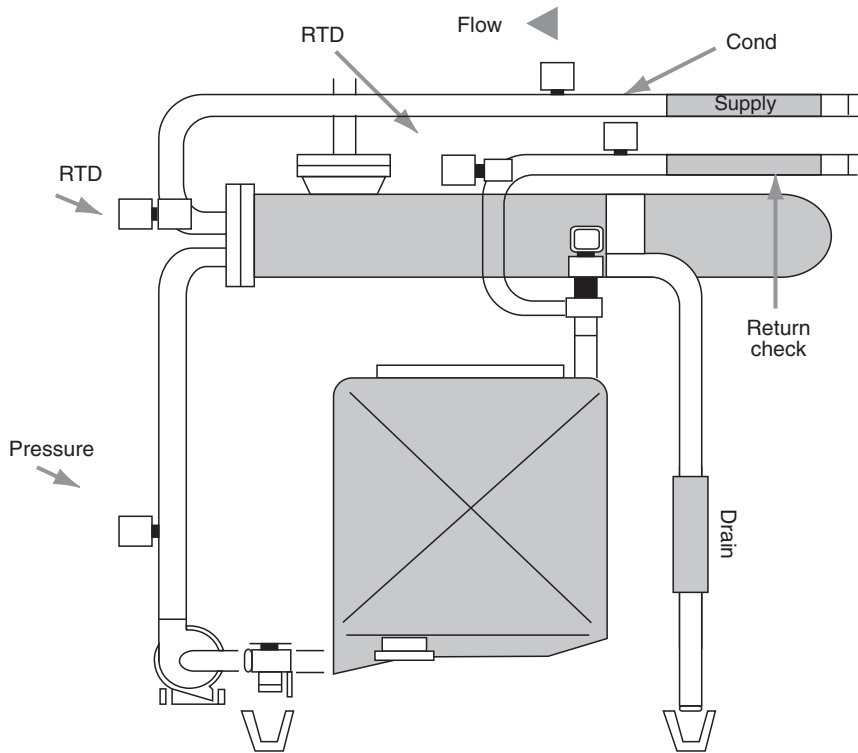


Fig. 8.8 Flow diagram for single use CIP system.

- (i) *Single use system:* a fresh cleaning or sanitizer solution is prepared for each cleaning cycle and then discharged to the drain (Fig. 8.8).

Advantages	Disadvantages
• Versatile • Multiple detergents/concentrations • Fresh wash solutions • Low volume wash water • Multiple temperatures • Less thermal shock	• High water use • High detergent use – Line circuits • Longer delay to temperature

- (ii) *Three tank re-use CIP system:* separate tanks are used for fresh water and for each cleaning solution needed. They continually use the same wash solution from CIP circuit to CIP circuit. The wash solution must be boosted for each use to maintain the specified concentration. The tank must be drained regularly to remove the accumulated soil, and refilled with fresh water and fresh detergents. A fresh sanitizer solution is prepared for each cleaning cycle and discharged to drain (Fig. 8.9).



Fig. 8.9 Three tank re-use CIP system.

Advantages	Disadvantages
• Easy to use • Effective • Low detergent use • Short delay to temperature	• Single detergent/concentration • Limited wash temperatures • High sanitizer costs • Heat shock

- (iii) *Solution recovery*: a recovery tank is used to recover the wash solution and post-rinse, which is then used for the second and third pre-rinses on the next CIP circuit (Fig. 8.10). This type of system can be used in connection with a multi-tank (re-use) or a single use CIP system.

Advantages	Disadvantages
• Versatile • Reduced water use • Some energy savings • Better pre-rinse	• Detergent use – Higher than re-use

- (iv) *Multi-use CIP system*: through the use of 3 or 4 tanks and extra valves, CIP systems can be set up to operate either as a re-use or single use, with or without solution

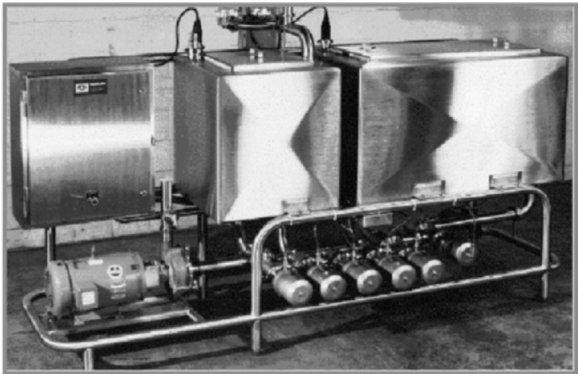


Fig. 8.10 Solution recovery CIP system.

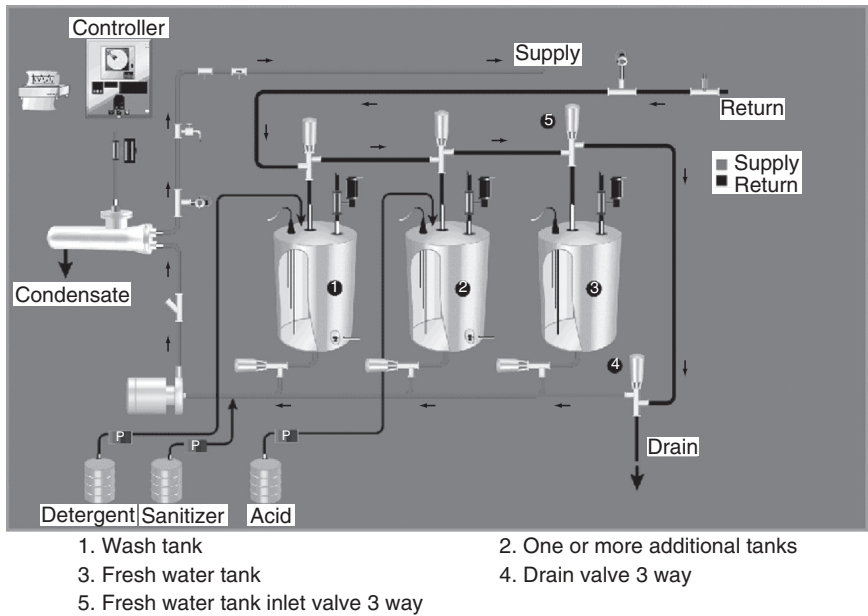


Fig. 8.11 Flow diagram for multi-use CIP system.

recovery. By using different programming techniques, selected programs can be run in any of the different modes (Fig. 8.11).

Advantages	Disadvantages
● Multi-use/Single use re-use/solution recovery ● Circulate sanitizer/hot water ● Optimize programs ● Optimize water, energy, chemical use	● Higher equipment costs

8.5.3 CIP control and data acquisition

If the need is for one CIP system, multi-use is the best option. The controller will activate the pumps and valves control the heating, flow control, and safety interlocks. Controllers are available in several types, ranging from old-fashioned drums, cams, and electronic sequencing devices to Programmable Logic Controllers (PLCs) and dedicated PC microprocessors. A dedicated microprocessor has CIP logic programmed in, and recognizes, for example, what valves to open or close to accomplish each step. The latter are today's choices; with them, it is possible to record performance data – time, temperature, concentration, and mechanical action. The table in Appendix 2 poses some questions of relevance to help in choosing a dedicated controller or PLC based controller. The choice will depend on plant expertise available and/or local support for the controller requirements.

The wash program consists of clearly defined sequences or steps; for example, a “three-step” program consists of: (i) Pre-rinse; (ii) Wash; and (iii) Post-rinse. This could be hot or cold, depending on the utilities supplied to the CIP system.

8.5.4 CIP program and programming

During each CIP cycle, there is a subset of actions that must occur. In a rinse, the tank outlet valve (TOV) opens, the CIP supply pump turns on, the routing valves open so water goes down the designated pipe line, the return valves open to drain, the fresh water valve opens, level controls in the rinse tank turn on, etc. Keeping track of this activity is difficult, so it is advisable to use a pin chart and a drawing with the CIP circuits highlighted to see solution path and identify valves that need to be sequenced.

Pin charts generally contain: program, CIP function, CIP component (on/off), values (time, temperature, volume (water, cleaner, and sanitizer), and flow rate.

The example below is of a pin chart for a simple 4-step line wash. It is a combination of the 3 steps above, with a sanitizer step added (Table 8.5).

Along with the “pin chart”, the programmer often provides a control description document, which provides a common language, and the example below is typical of the steps one would expect in a program. In most plants, these programs are more complex, and valve sequencing will be involved. If there are any sub-routes in the line circuits, each leg should run approximately 8 to 10 minutes at a concentration and temperature to ensure proper cleaning. A sanitizer step must be directed down each leg for the proper contact time recommended for the sanitizer.

In tank programs, the rinse part of the program is “pulsed” to ensure effective draining. Three pulses are recommended and this can be accomplished by shutting off the supply pumps while leaving on the tank return pump. This will evacuate all the water and remove any residual from the bottom of the tank.

The chemical supplier may have standardized checks that both they and the plant operators can use. Chemical suppliers should train plant employees in testing so that the right detergent and sanitizer concentration is used in each circuit.

What data should be collected from CIP systems, and how, is sometimes determined by the regulatory agencies under which the plant manufactures. In general, all plants will benefit from knowing the date, circuit ID or name, operator, time, temperature, flow rate, concentration, and pressure. In addition, other components may be added to the system, such as a flow meter, conductivity sensor, and pressure gauge. Some of the data from these devices can be recorded with a simple chart recorder, showing time, temperature, and

pressure; the operator is required to fill in date and circuit information and sign at the end of each shift. They can also record chemical concentrations on the chart, which should be reviewed daily by management and then filed. By doing this the plant will have a history of the system and performance data on wash frequencies.

Today's modern PLC and dedicated processors can also perform data acquisition, and the plant will want to look at the regulatory guidelines for electronic data collection to make sure it is in compliance; in the USA, 21 CFR part 11 is a good starting place. The list below is not all-inclusive, but gives a general idea of what to look for in electronic data acquisition and management:

- direct wiring to PLC;
- automatic report generation upon conclusion of CIP;
- ability to have printed statement of what is being cleaned (e.g. Tank 1, Transfer Line, etc.);
- graphical representation of conductivity, supply temperature, return temperature, and flow rate, with some markers showing the initiation and conclusion of distinct steps;
- summary stating CIP start time, finish time, total cycle time, time since last CIP completed, and for caustic circulation, acid circulation, and final rinse: average flow rate, average conductivity, and average return temperature;
- ability to show any alarms (e.g. CIP aborted, steps skipped, exceed of maximum time for temperature, conductivity, cycle time);
- historical data back-up via a memory card or PLC.

The CIP System in bottled water facilities today is a matter of routine. There are many choices, from the design of the transfer piping to the right system and controls. However, no matter what is chosen, it is only as good as the operator's ability to run and maintain it properly. The operators need to know the system and programs well enough to monitor the results. Performance checklists should include but are not limited to CIP performance checks for lines and CIP performance checks for vessels. Without well-trained, well-motivated employees, no sanitation program will ever be successful.

8.5.5 Hot CIP safety precautions

- Never operate the CIP system in a manner for which it is not designed. Always operate well within safe parameters. Always verify that all equipment to be cleaned can tolerate the temperature, concentration, pressure, and flow rates generated by the units. Always be cautious to allow proper venting of atmospheric tanks by opening the manway during the CIP process. Never allow microfilters and UV lights to be subject to water hammer or high pressures.
- The CIP system uses highly corrosive chemicals as a cleaning medium that can cause burns to the skin and eyes. Always wear personal protective equipment (chemical resistant gloves, apron, goggles or face shield, and boots) when making and breaking flow panel connections or removing equipment for maintenance. This is especially important when opening and handling chemical drums and taking samples.
- Be careful when maneuvering chemical drums, portable return pumps, and other heavy objects/equipment. Always get help or use proper equipment such as forklifts to prevent back strains and other forms of personal injury.
- Never by-pass the safety features of an electrical panel while the unit is in operation, and obtain the help of a qualified electrician when troubleshooting electrical panels.

- Always keep guards on rotating equipment in place. Never operate any equipment without proper safety precautions in place. Never allow any CIP circuit to be operated, knowing that there is damaged or defective equipment in line.
- Never operate the CIP system prior to proper calibration of all instrumentation. Never adjust or “tweak” any equipment or instrumentation without completely reading and understanding the maintenance and operating manual first.
- Communicate to all personnel that a CIP cycle is running and minimize excess employee traffic in the area where CIP circuits and equipment are located.
- Remember that the CIP system can start and stop remote equipment automatically without warning. Never do maintenance or place yourself in a dangerous situation without following appropriate equipment electrical isolation procedures.
- Always completely walk the CIP circuit during the pre-rinse to identify potentially dangerous leaks prior to chemical addition and heat-up.
- Never enter the tank of a CIP system or place any part of your body inside without following your plant’s confined space entry procedures. Never open the manway of any CIP tank or tank to be cleaned while the unit is running.
- The CIP system may use high temperatures to aid in the cleaning process. Always be cautious of hot surfaces and never touch any CIP equipment unless the unit is shut down and allowed to cool. Always be extremely cautious of steam piping. Wear suitable clothing when working with hot CIP surfaces, circuit piping, and equipment.

8.6 GENERAL GUIDELINES FOR CONDUCTING A CLEANING AND SANITATION VALIDATION

Cleaning and sanitation is an important process step, validation ensures that the cleaning and sanitation cycles effectively remove residues to a predetermined level of acceptability and in an efficient manner. Validation must take into account the worst case scenario, i.e. new line, new process, or lines have not been validated for a long time. Validation is essential to ensure food safety for the following reasons:

- to ensure a consistent product quality by optimal cleaning and sanitation process;
- to reduce the use of chemicals, water and energy;
- to adjust the cleaning approach to new technologies;
- to increase the understanding of cleaning;
- to increase the safety of the personnel carrying out cleaning tasks.

The mindset about importance of cleaning and awareness needs to be developed at all levels. Factors for a successful validation:

- (i) *Planned allocation of time*: the validation of cleaning is not a quick one-day study. Factory complexity has an influence on time and number of people required.
- (ii) Clearly defined responsibilities.
- (iii) A validation team with an expert as leader.
- (iv) Provision of adequate monitoring tools.

- (v) Use of the operators' input during the prerequisite study time.
- (vi) Coaching of people involved in cleaning.

Phase 1 is planning and preparation of the validation study with personnel, communicate with sanitation manager and to explain the purpose of the validation. During the planning stage, availability of any necessary modification must be confirmed. Everyone involved must understand the basic concepts of cleaning validation.

The preparatory step is to collect the necessary information on all elements of the CIP process and to document these elements. This should include the mapping of the CIP circuits for both product and chemical lines with all details of valves and pumps listed, and review of the instrument calibration, history of the CIP circuits, and documentation.

Phase 2 is performance qualification, in which it is verified that the selected cleaning system delivers and circulates cleaning solutions according to the pre-selected parameters in the standard operating procedure. The sanitation schedule is reviewed to confirm that all equipment is soaked, cleaned, and sanitized. The appropriateness and effectiveness of the cleaning equipment and chemicals are assessed by monitoring the flow rate, chemical concentration, contact time and temperature for cleaning and sanitation, the effectiveness for both alkaline cleaner, and sanitizer steps can be evaluated. This will confirm, for example, whether the water temperature for the alkaline rinse step achieves 60–71°C (140–160°F) necessary for the prevention of any biofilm formation.

Phase 3 of the validation study is a synthesis of the results and the establishment of an action plan. All results of the validation study need to be evaluated, to check if they comply with the acceptance criteria and to identify deviations or problems, and to correlate observations with documentation of problems and microbiological counts. The following types of sampling are appropriate:

- *Direct surface sampling*: physical with swab methods for wet cleaning and visual inspection for all cleaning. The swab method is useful for difficult to clean parts.
- *Indirect sampling*: use of rinse solutions post CIP.
- Time, temperature, concentration, and flow rate are within the operating parameters.

If the results comply with the acceptance criteria, the CIP is validated and the routine monitoring and verification are scheduled. If deviations or problems are found, an action plan is prepared to correct potential sources of problems, with dates and plans for re-validation.

Phase 4 is the follow-up after validation; this should be an agreed plan between production and quality assurance to develop the daily or routine monitoring plan. Operators should be trained to ensure they understand tests and deviations to report.

Validation of cleaning and sanitation needs to be followed up by regular monitoring and by verifying at least once a year if the results of the standard operating procedures are consistent and meet the acceptance criteria. The involvement of chemical suppliers is recommended, as their experience and expertise can complement the in-house knowledge. The supplier can also give advice on the compatibility of chemicals with a particular material or equipment parts, or provide key monitoring tools specifically required for the validation.

8.7 THE DO'S AND DON'TS OF CLEANING AND DISINFECTION

THE DO'S

1. Become familiar with products and their applications, because misapplication can cause explosive chemical reactions or discharge dangerous vapors.
2. Read the labels on all products, and become familiar with their applications and properties, so that you will be aware of their compositions and potentially hazardous capabilities.
3. Know what antidotes to use when someone becomes injured so you can assist in directing immediate first aid and minimize injury.
4. Know the limitations and capabilities of products so you will understand the seriousness of injury that could occur when skin tissue is brought into contact with specific detergents.
5. Know the maximum operating temperature of products so that when preparing cleaning procedures or observing cleaning operations you will know when temperatures exceed that maximum.
6. Know which products are acidic or alkaline so that instant first aid action can be taken in case of injury.
7. Always mix detergents in "use" dilution – not their concentrates.
8. Wear and instruct employees to wear necessary protective clothing, such as goggles and/or facemasks, when dispensing detergents.
9. Wear footwear appropriate to the environment, which protects from moisture and provides non-skid soles.
10. Always provide detailed written instructions when training personnel on the safe use of products to minimize misunderstanding and prevent unsafe action.
11. Teach safety by example, as a picture is worth a thousand words.
12. Use equipment that allows safe sampling and dispensing into test equipment when sampling solutions that usually are at elevated temperatures.
13. Check solution temperatures with a thermometer, which gives maximum protection to its user from high solution temperatures.
14. Know the conditions of application and chemical characteristics of sanitizers you are using to prevent injury to personnel and equipment.
15. Know safety as applied to Bulk Handling Programs so that you can observe an installation and know that safety is being practiced concerning eyewashes, showerheads, and bulk tank labeling.

THE DON'TS

1. Do not mix acid and chlorine products, because this releases poisonous chlorine gas.
2. Do not use a liquid chlorinated cleaner on an automated OVERRIDE program, because of the potential release of chlorine gas.
3. Do not permit "override" cleaning without instructions, because of the possibility of damage to equipment or personal injury from chemical reaction.
4. Do not add water to a pail of powdered caustic to dissolve the powder because of flashback, caused when water is added to powder. Rather, add caustic to a pail of cold water.
NEVER ADD WATER TO CONCENTRATED CHEMICALS!
5. Do not use a lightweight plastic pail when dissolving caustic chemicals, because heat generated by the action of water and caustic will soften the pail.
6. Do not use hose stations where hot water is produced by mixing cold water and steam unless you have knowledge of the hot water generation process, because this can pose a real danger of blowing live steam.
7. Do not try to remove caked powders from shipping containers, because of the hazard of product flying into the eye or making contact with the skin.
8. Do not mix wetting agents and nitric acid products in concentrated form, because the oxidizing reaction of acids and wetting agents can cause a violent chemical reaction and flashback.
9. Do not charge detergent reservoirs that are at or above eye level, because of the danger of splash back of product or product spilling back on the person.
10. Do not mix detergents without knowledge of their compatibility, because of the danger of reaction and flashback.
11. Do not dispense products from shipping containers that are not labeled, because of the possibility of misapplication of detergent, causing personal injury or damage to equipment.
12. Do not store products in unlabeled containers, because any person cleaning up may not know what product is in use, resulting in misapplication.
13. Do not use a drum pump for dispensing two different products, because the pump may not have been properly rinsed, resulting in the possible mixing of two incompatible products, causing a chemical reaction or flashback.
14. Do not pressurize a shipping container for dispensing product, as no shipping container is designed to withstand more than atmospheric pressure.
15. Do not dispense highly concentrated caustics or acids into open containers, but rather into a closed system to prevent personal injury from splashed products.

(continued)

16. Do not transport liquid products, especially highly corrosive types, in open containers, because of splashing and spillage potential.
17. Do not add detergents to hot water unless procedures are written with precautions, because of the potential hazard of flashback.
18. Do not start circulating hot water containing detergent without establishing circulation and checking for leaks, as leaks in such systems are dangerous.
19. Do not add concentrated detergents directly to processing equipment. Rather pre-dissolve, or have water in a vessel, because of the potential for chemical reaction with product contact surfaces of equipment.
20. Do not enter any closed vessel immediately after cleaning, before venting, or changing the air supply within. Use the "buddy system", because of the potential presence of carbon monoxide gas.
21. Do not use detergents at concentrations in excess of recommendations, because of the potential for damage to equipment and personnel.
22. Do not use cleaning solutions above recommended temperatures, because of the potential of pumping problems and splashing of solution causing injury.
23. Do not dispense a detergent from a shipping container or into a point of application without protective goggles and clothing.
24. Do not perform a hazardous task without a planned route of exit to a safe area, in case unexpected things happen.
25. Do not substitute detergent unless you have a thorough knowledge of the substitute product as equipment damage, cleaning failure, or personal injury may occur.
26. Do not wear pant legs on the inside of boots. Rather wear them outside of boots to prevent detergent from going into an open top boot in case of spillage.
27. Do not give verbal instructions on cleaning procedures, because of the potential for misunderstanding. In addition, verbal instructions leave no document for future reference or review.
28. Do not dispense used solutions at the end of a cleaning cycle to the floor where flooding will occur, because floors become slippery when detergents are discharged to them and not properly rinsed.
29. Do not swing discharge lines carelessly to the floor or drain when discharging spent solution, because of the danger to other employees who may not be expecting your action.
30. Do not manually clean equipment when it is operating.

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APPENDIX 1 – CALCULATIONS FOR ESTABLISHING MINIMUM FLOW RATES FOR CLEANING CYLINDRICAL VESSELS

Horizontal tanks or vessels: cleaning flow rate – 0.12–0.30 gpm/sq ft of surface area

- *Cylindrical tanks:* use the following formula to calculate surface area:

$$\pi (3.14) \times r^2 (\text{radius}) = \text{area of one end}$$

$$\pi (3.14) \times d (\text{diameter}) \times l (\text{length}) = \text{area of wall}$$

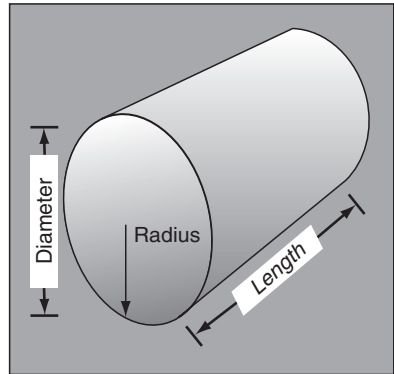
For example: the surface area of a cylindrical tank 7 ft in diameter (3.5 radius) and 10 ft long is equal to

$$\text{Ends: } 3.14 \times 3.5 \times 3.5 = 38.5 \times 2 = 77 \text{ sq ft}$$

$$\text{Wall: } 3.14 \times 7 \times 10 = 220$$

$$\text{Total surface} = 297 \text{ sq ft} \times 0.12 \text{ gpm/sq ft}$$

$$\text{Recommended minimum flow rate} = 36 \text{ gpm.}$$



- *Vertical tanks or vessels:* cleaning flow rate – 2.5–3.5 gpm/ft of linear circumference

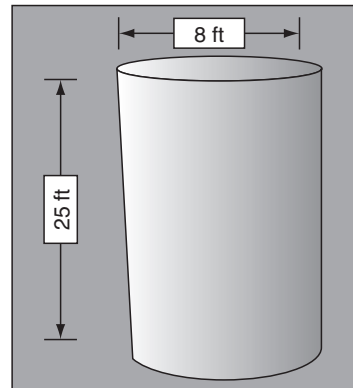
$$\text{Circumference: } \pi (3.14) \times \text{diameter} = \text{circumference}$$

For example: a silo that is 25 ft high with diameter of 8 ft

$$\text{Circumference: } 3.14 \times 8 = 25.12 \text{ ft}$$

$$25.12 \text{ ft} \times 2.5 \text{ gpm/ft}$$

$$\text{Recommended minimum flow rate} = 62.8 \text{ gpm}$$



APPENDIX 2 – QUESTIONS TO ASK WHEN CHOOSING BETWEEN A DEDICATED CONTROLLER AND A PLC BASED CONTROLLER

What level of internal expertise/support available?

- A PLC requires an individual with expertise, programming software, and PLC communication hardware to a laptop or a PC.
- Dedicated is easy for a non-programmer to support.

Do you need the ability to fine-tune CIP cycles?

- A PLC can have CIP step variables made on the keypad; however, a remote PC with programming software is required for significant revisions.
- Dedicated can have all CIP cycles fine-tuned from either a touch-screen or from a remote PC.

What control flexibility is required?

- PLC controls the CIP unit and can control return pumps and line valve sequencing. Standard controls do not include process control.
- Dedicated controls the CIP unit and can control return pumps and line valve sequencing. It cannot control process operations.

Are interlocks required between process and CIP?

- PLC can have starter run interlocks programmed and alarmed. These must be specified for proper design and programming.
- Dedicated can have start or run interlocks programmed and alarmed. These must be specified for proper design and programming.

Will the CIP controller need to interface to other controllers?

- PLC can interface via DH+ standard or RIO/Ethernet system selections.
- Dedicated can interface via DH+ system selection.

What communication protocol?

- PLC can communicate via DH+, RIO, or Ethernet by system selection.
- Dedicated can communicate via DH+ standard system selection. Other communication options require Electrical Design review.

Will CIP controller pulses process equipment?

- PLC controls process valve sequencing via communication with process controller or custom programming per application requires Electrical Design review.
 - Dedicated control process valve sequencing via discrete I/O or communication with process controller.
-

APPENDIX 3 – GLOSSARY OF TERMS

Antimicrobial agent: a chemical agent that kills or suppresses the growth of micro-organisms.

Biofilms: are composed of a collection of bacteria that have attached to surfaces and have excreted an extracellular polysaccharide, or slime layer. This slime layer protects the cells from adverse environmental conditions.

BOD (biological oxygen demand): a measure of the pollution present in water, obtained by measuring the amount of oxygen absorbed from the water by the micro-organisms present in it.

Chelate or Chelators: chemicals that are incorporated into the detergent formulation and that prevent scale build-up, i.e. the precipitation of calcium and magnesium salts onto the equipment surfaces.

Cleaner: a substance that breaks the bond between the soil and the surface being cleaned. Not only must it remove the soil, it must hold it in suspension and allow it to be flushed away.

Cleaning: the process that will remove soil and prevent accumulation of residues, which may decompose to support growth of disease or nuisance causing organisms. It must be accomplished with water, mechanical action, and detergents.

Denaturation: the process that changes the form of proteins, hardening them and making the protein less soluble. An example is the way that heat acts on egg white, causing it to solidify.

Detergent: see Cleaner.

Disinfectant: a chemical agent that is capable of destroying disease causing bacteria or pathogens, but not spores and not all viruses. In a technical and legal sense, a disinfectant must be capable of reducing the level of pathogenic bacteria by 99.999 % during a time frame of more than 5 but less than 10 minutes, as tested by the Association of Analytical Communities (AOAC) method. The main difference between a sanitizer and a disinfectant is that at a specified use dilution, the disinfectant must have a higher kill capability for pathogenic bacteria than that of a sanitizer.

Disinfection: the killing or inactivation of all micro-organisms, except for some spore forms. The efficacy of disinfection is affected by a number of factors, including the type and level of microbial contamination, the activity of the disinfectant, and the contact time. Organic material and soil can block disinfectant contact and may inhibit activity. Therefore, cleaning must precede all disinfection.

EDTA (Ethylenediaminetetra-acetic acid): a molecule that can bind to metal ions; used as a chelator in detergent chemistry.

Emulsification: a measure of a detergent's ability to break down fats and oils into smaller particles that are removed more easily during rinsing.

EPA – Environmental Protection Agency: the United States agency that it is responsible for the actual definition and regulated uses of both sanitizers and disinfectants.

Peptize: mechanical action combined with a surfactant, resulting in two immiscible liquids. Peptizing breaks down the protein bond and stabilizes it in suspension.

pH scale: a logarithmic scale, which is used to measure the acidity or alkalinity of a solution. The pH of pure water is 7, with lower values indicating acidity and higher values indicating alkalinity.

Pin chart: pin chart refers to a chart used in programming. Historically, electrical controllers used pins to turn on electrical switches and a grid was used to assign the steps in order of operation, so that a programmer knew where to put the pins in the sequence. The term pin chart has carried over as a programming term in CIP applications.

QAC (Quaternary ammonium compounds): sometimes referred to as Quat sanitizers.

Sanitation: the term used to describe the complete plant cleaning and sanitizing program protecting public health.

Sanitize: to reduce the number of micro-organisms to a safe level.

Sanitizer: the AOAC test method requires that a sanitizer is capable of killing 99.999 % (5 log reduction) of a specific bacterial test population, (*Staphylococcus aureus* and *Escherichia coli*) within 30 seconds at 25°C (77°F). A sanitizer may or may not necessarily destroy pathogenic or disease-causing bacteria, as is a criterion for a disinfectant.

Sterilant: an agent that destroys or eliminates all forms of life, including all forms of vegetative or actively growing bacteria, bacteria spores, fungi, and viruses.

Sterilization: is the complete destruction of all forms of life.

9 Quality Management

Dorothy Senior and Nicholas Dege

9.1 INTRODUCTION

Good quality is never achieved by accident, nor is it achieved or sustained simply by one department ‘taking responsibility’ for quality. It is only achieved as a result of several things; an understanding of the needs of the consumer and the customer, raw materials and processes capable of consistently supplying those needs, and the cross-functional teamwork of people with the knowledge, competence and desire to make it happen. In this chapter, an attempt has been made to outline the key areas and activities to be controlled and monitored in a factory producing bottled water. It does not claim to be exhaustive, but it will, we hope, provide some guidance for anyone intending to set up a quality system for water bottling, and also some insight gained through practical experience in the business of bottling water.

9.2 DEFINING QUALITY

In order to address quality management, it is important first of all to consider what is meant by quality. Defining quality may involve many routes but, for the purpose of producing goods, it is generally accepted to mean ‘meeting specifications’. Specifications for a product may be defined by legislation, by the manufacturer of the goods or by the demands of the consumer. Bottled waters are no exception to this and, rather than being influenced by only one of these factors, the specification is usually a result of all three. Importantly for bottled waters, as is the case with all foodstuffs, this specification will include the essential requirement for food safety.

9.3 QUALITY POLICY

Commitment to a quality policy is necessary from the highest level within a company. Ideally, it is to this level that a quality manager will have a direct reporting line, providing confidence to senior executives through the management of a range of technical areas relevant to a water bottling company. Through this function, a quality management system can be developed, involving people working together towards a common goal. A comprehensive quality management system enables a company to control its processes of production and to

influence those of its suppliers and distributors, thus ensuring that their product reaches the consumer fit for purpose and meeting specifications.

There are several formally recognised standards for quality systems, of which the best known is ISO-9001 which has proved useful to many companies in providing a structure within which to work – a skeleton on which to build their own specific ways of doing things. For those companies certified, it also demonstrates to the outside world a commitment to consistent and verifiable approach, and one that is validated by ongoing third-party certification. Whichever quality system is chosen however, they all generally specify what will be done and place emphasis on the need to record the fact that it is done. ‘Say what you do; do it. Do what you say; prove it.’

Whether or not a bottler decides to go for a fully fledged quality management system, the following key elements should be considered as a minimum:

- supplier evaluation and monitoring of performance against agreed specifications;
- a traceability system for incoming materials and finished goods;
- procedures for receipt of raw materials (water and any additional ingredients) and for incoming packaging materials;
- a system for management of food safety, and in particular for the evaluation and management of materials and process-related food safety hazards (HACCP). In many parts of the world, it is also essential (and in some cases mandatory) to also develop a Food Defence Programme in order to combat potential acts of ‘bio-terrorism’;
- an effective pest control programme;
- documented procedures for ensuring consistent operations (cleaning and disinfection, materials handling, bottling, full goods management);
- a good manufacturing practices (GMP) policy and appropriate training for all personnel;
- a monitoring (testing) programme for all steps in the production process. All test results to be recorded, and with systematic calibration of all inspection and test equipment;
- a formal system for releasing finished product that ensures that no non-conforming product makes it to the market. This should also include specific instructions for the handling and disposition of non-conforming product;
- an agreed (and periodically tested) procedure for product recall;
- a crisis management procedure.

In addition to quality, other issues that reputable companies address are those relating to health and safety and to the environment. Although not necessarily a requirement of legislation, it is beneficial to document the management system. This serves several purposes: it defines procedures and forms useful training material for employees; it provides confidence to suppliers, distributors and customers; and it demonstrates ‘due diligence’ to enforcement authorities.

9.4 FOOD SAFETY STANDARDS AND HAZARD ANALYSIS CRITICAL CONTROL POINT

In most developed markets, bottled waters are classed as ‘food’ and are thus required by legislation and by regulators not only to meet the quality expectations of their customers and consumers but also to do everything reasonable to protect the health of the consumer. As an essential part of this strategy, bottled water businesses in most markets are required

by law to undertake a risk assessment of their processes and products, and the system customarily used for such an assessment is Hazard Analysis Critical Control Point (HACCP).

During the first decade of the twenty-first century however, a series of contamination incidents in various different food sectors resulted in an increased awareness on the part of the public, and greater scrutiny by regulators concerning food safety. At the same time, major retailers, conscious of the damaging impact of such events and uncomfortable with the level of control being exercised by some of their existing or potential suppliers, worked to establish tighter standards and expectations for everyone in the food supply chain. Thus, new standards, such as ISO 22000:2005 (Standard for Food Safety Management Systems) have been developed. In addition, collaborative schemes such as the Global Food Safety Initiative (GFSI), coordinated by the Consumer Goods Forum and sponsored by seven major retailers, have come into being. The GFSI's stated mission is '...continuous improvement in food safety management systems to ensure confidence in the delivery of safe food to consumers', and initially recognised four food safety schemes – British Retail Consortium (BRC) Standard for Food Safety Issue 5, International Featured Standard (IFS) Food Standard Issue 5, Dutch HACCP and Safe Quality Foods (SQF), administered by the US-based SQF Institute. Meanwhile, the food industry itself has not stood idly by; a consortium of major food manufacturers worked with the British Standards Institute (BSI) to develop Public Accessible Specification (PAS) 220 Food Safety: 2008, which is a standard concerning the development of prerequisite programmes (PRPs) and operational prerequisite programmes (OPRPs), to be used in conjunction with ISO 22000.

Since the development of PAS 220 in 2008, GFSI has now also recognised the combination of ISO22000 and PAS 220 as an additional food safety scheme. Thus, by adding PAS 220 certification, companies which had previously been certified only to ISO22000 were able to meet the requirements of the GFSI.

As a system of food safety assurance, based on prevention of food safety problems, HACCP still remains the key activity in providing a structured approach to the control of hazards. Essentially, three types of hazards are considered: microbiological, physical and chemical. Although the system may also be applied to quality aspects, clear distinction needs to be made between what are considered to be food safety concerns and those related to meeting product specifications. Such decisions will contribute to the terms of reference. *Codex Alimentarius Food Hygiene Basic Texts* describe a seven-point HACCP, the principles of which are:

- (i) Conduct a hazard analysis.
- (ii) Determine the Critical Control Points (CCPs and OPRPs).
- (iii) Establish the critical limit(s) for CCPs.
- (iv) Establish a system to monitor control of the CCPs.
- (v) Establish the corrective action to be taken when monitoring indicates that a particular CCP is not under control.
- (vi) Establish procedures for verification to confirm that the HACCP system is working effectively.
- (vii) Establish documentation concerning all procedures and records appropriate to these principles and their application.

HACCP can be applied not only to the company's existing product range but also to build product safety into new products/packaging formats. The system should also be

reviewed in the events of installation of new equipment, technical developments and personnel changes. Though the principles of HACCP can be demonstrated through a generic plan, it is important to apply them to separate, specific operations. CCPs identified for a particular product, running down a particular line, may be different for another line or packaging format. HACCP involves people in the business, giving them responsibility for food safety. Senior management commitment to the system is fundamental.

Having defined the scope of the plan, it is recommended that a multidisciplinary team, with appropriate skills and/or knowledge of the process, prepare the HACCP plan. Operators involved in the production process may be required to undertake controls at CCPs. It is important that at least some members of the team are trained in the principles and application of HACCP to provide guidance for the implementation of the system. It is helpful to put together a product description, which will include:

- type of water;
- whether it is still or sparkling;
- whether it is receiving treatment and, if so, what kind of treatment;
- type of packaging format being used;
- which line it will run down;
- prescribed shelf-life;
- storage and distribution conditions;
- intended use of the product.

A confirmed flow diagram for the process, identifying each stage, will form the foundation for listing all potential hazards. Based on the judgement of the team and use of a decision tree, CCPs are identified, i.e. steps at which control is applied to prevent or eliminate food safety hazards, or to reduce them to acceptable levels.

Ideally, acceptable levels will be measurable in some way and these will be the basis upon which monitoring of the CCPs is established. Should a CCP deviate from its determined limits, the team must prescribe corrective action to be taken to restore the CCP to its safe control.

To determine whether the HACCP is effective, it is important to audit and test it by reviewing the system and its records and confirming that CCPs are in control. The frequency of this verification and validation, which may be carried out internally or by a third party, may be at regular, defined intervals, or unannounced. It is essential to document HACCP procedures and to establish suitable record keeping. These will form the basis upon which verification and validation are performed.

Periodically, a review of the HACCP system is required. The frequency of this may be determined based on risk factors and on any changes in the operation of the business.

The above description gives a skeletal overview of establishing a HACCP system, and as well as the above Codex publication, Campden & Chorleywood Food Research Association (CCFRA) publication – *HACCP: A Practical Guide* – can also be recommended.

Some of the benefits of HACCP are:

- It moves towards a preventative quality assurance (QA) approach.
- It is complementary to other quality management systems.
- It covers all aspects from incoming materials to final product use.
- It focuses technical resources into critical parts of the process.
- Its application leads to reduced product loss.

- International authorities promote HACCP for ensuring food safety.
- It facilitates international trade.
- Its implementation can support a defence of ‘due diligence’.
- It complies with legal requirements.

Two important elements to stress for the success of a HACCP plan are management commitment (alluded to in Section 9.3) and a prerequisite programme. Prerequisites are the site-wide activities, which need to be managed well in order to underpin the product process and food safety; they vary from one operation to another but may typically include:

- product and packaging specifications;
- approved suppliers;
- operating procedures;
- process control;
- quality assurance (QA);
- quarantine arrangements;
- positive release system;
- shelf-life testing;
- handling of customer complaints;
- traceability;
- calibration;
- waste management;
- record keeping;
- auditing;
- pest control;
- compressed air;
- lighting;
- lubricants;
- maintenance schedules;
- cleaning-in-place (CIP) and other cleaning schedules;
- chemical storage;
- COSHH or local equivalent (COSHH is an acronym for the UK legal requirements on ‘control of substances hazardous to health’);
- *training*: induction, food safety and hygiene, health and safety, refresher.

This list is not exhaustive but gives some pointers for areas to be included (see also Chapter 6). A quality management system, covering a HACCP plan and a prerequisite programme, can be endorsed as well as audited by a third party, giving confidence to the company, customers and enforcement authorities (see Fig. 9.1).

9.5 PROCESS CONTROL

Process control is that element of quality management to which operators within the operation contribute, by monitoring and recording performance and measurements for the part of the operation for which they are trained and responsible, and this may well include the monitoring of CCPs. Though not essential, the bottler may also want to consider a more systematic analysis of testing results, in order to ‘fine tune’ the activities, and in some cases

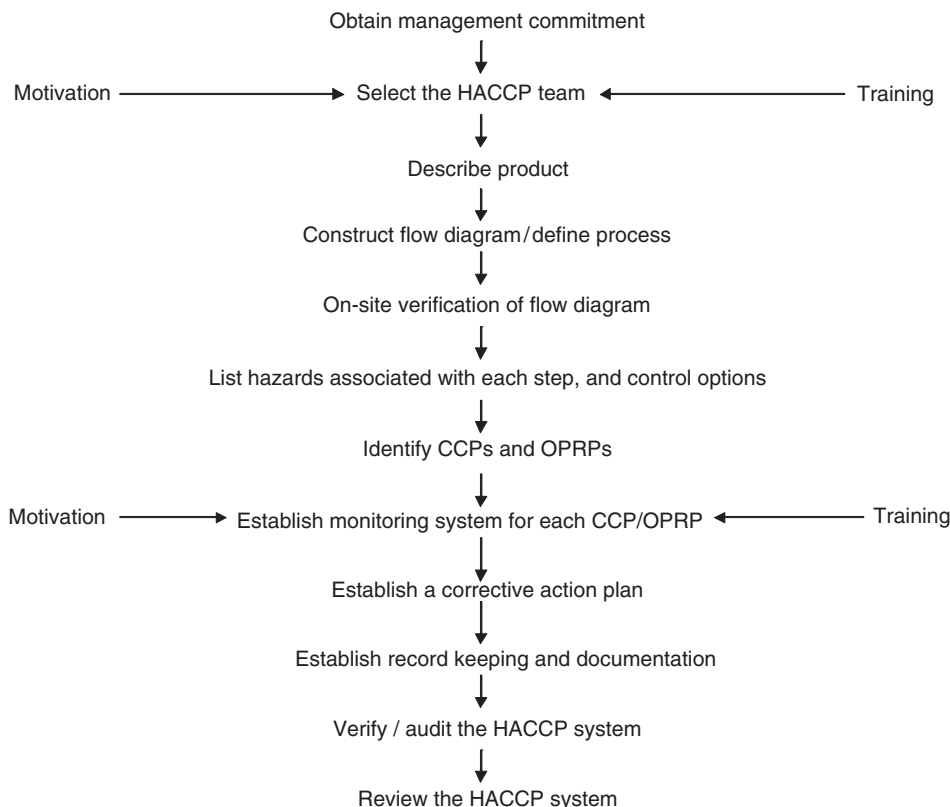


Fig. 9.1 Summary of the HACCP route.

even to reduce the number and frequency of tests. To this end there is an increasing number of electronic software packages available, allowing 'paperless' records, and modern operations and improved automatic data collection enable better evaluation of the capability of equipment to produce consistently and with minimal waste. The use of statistical process control (SPC) is becoming routine in many areas, applied to 'measurable' activities – whether these be inputs (process conditions) or outputs (product attributes). This and other continuous improvement tools, in particular structured problem solving tools, such as the well-known Define-Measure-Analyze-Improve-Control (DMAIC) method, are also becoming an increasingly essential requirement for businesses wanting to remain competitive in today's market.

Process control can be broadly split into two: packaging materials in process and product water in process.

9.5.1 Packaging materials in process

First, there will be some assessment of delivered packaging materials to ensure that the consignment meets expectations and is accompanied by a certificate of conformance from the supplier. The water bottling company will decide what form such an assessment will take based on confidence in the supplier, on past history and on the particular packaging material characteristics. At the very minimum however, an assessment should be made

prior to delivery of the materials; both the vehicle interior and the materials should be undamaged, clean, dry and free of odour. Any delivery not meeting these criteria should not be accepted.

9.5.1.1 *Bottle handling and filling*

Increasingly, water bottlers are manufacturing their own bottles, most particularly when using PET. In many cases, they purchase preforms from a third-party supplier and use in-house blow-moulding equipment to convert to bottles, and in other cases they purchase PET resin and also manufacture the preforms in-house (see also Chapter 7).

In some markets, bottlers also use glass and HDPE bottles, both of which can either be shipped in from remote manufacturing locations or conveyed from an adjacent building occupied by a 'through the wall' supplier.

Whether purchased or self-manufactured, bottles must be made to meet tight tolerances, and should be subject to appropriate measurement and testing to confirm compliance with specifications. Minimum testing requirements for bottles are:

- visual appearance;
- weight;
- wall thickness;
- top load (ability to withstand weight);
- neck finish accuracy.

PET bottles will also need to be checked to establish that their 'profile' (i.e. the distribution of material within the mould) is correct, in order to maximise top load strength.

In addition, PET bottles should periodically be tested for the presence of acetaldehyde (a compound formed as a result of the shear forces imposed during injection moulding of the preforms). This substance, though not of food safety or regulatory concern, can impart an unpleasant taste to the product, and its presence should be avoided.

It is at point of use on the bottling line that the packaging is really put to the test. There are various possible ways in which bottles might become damaged during their progress along the filling line, and careful operatives will be alert to this occurring. Typically, for plastic bottles, damage may occur while going into or coming out of various machines, for example fillers, cappers, labellers, and as filling speeds increase, only very small mis-alignments can result in major damage, both to bottles and machinery. Transfer from incoming air-conveyors to the filler, if not precisely tuned, can cause bottle neck support rings to be shattered; for glass bottles in particular, the worm feed can be a culprit if not set appropriately, resulting in breakages, food safety risks from glass fragments, and consequent downtime. Glass conveyors also need to be designed and set up to minimise bottle-to-bottle contact and the risk of impact damage.

During the bottling of carbonated water, occasional bottles can burst in the filling process. This may be due to flaws in the bottle, which fails through the internal pressure from the carbon dioxide gas. A strict procedure must be implemented on these occasions, which minimises the risk of foreign body contamination from broken glass reaching other containers. In practice, this may mean stopping production, thoroughly cleaning the filler to remove glass fragments, and the destruction of all bottles that were filled on the same and on adjacent filling heads.

9.5.1.2 Closure application

Closure application is monitored in various ways:

- (i) *Torque test*: This measures the tightness of application against the specification for that closure. This can be measured using a spring torque meter. Different closure manufacturers provide different specifications for the 'release torque', but it is important that the bottler does not simply accept such a specification without verifying that the closure can easily be removed by the consumer. It is highly frustrating for a consumer who is unable to remove the closure without resorting to the use of tools.
One other point to take into account is that closures made of different materials may perform differently over time – some closures for example are known to 'relax' over time and thus to have a lower removal torque after 24 hours than they had at the time of bottling. In this case, it is important to establish the relationship between the 'time zero' release torque and that which will be experienced by the consumer.
- (ii) Visual examination can also be carried out to ensure integrity of the tamper-evident seal, making sure no bridges are broken and, in the case of aluminium rolled-on-pilfer-proof (ROPP) closures, that the thread is formed correctly with no splits. The tuck-under of metal closures should also be examined to ensure that this has been completely rolled under. One additional check applicable to PET bottles is to ensure that the underside of the neck support rings on the bottles is not being cut by the 'anti-rotation' grippers on the capping machine. If not controlled, this can give rise to sharp burrs on the neck support rings that can actually injure consumers attempting to open the bottle.
- (iii) Manual removal of closures to simulate consumer use, carried out routinely, will provide confidence in satisfactory cap application.
- (iv) In the case of carbonated waters, the seal can be subjected to internal pressure to test its security with the container. This test is carried out within a pressure vessel.

9.5.1.3 Label application

Traditionally, labels have been made of paper, but increasingly, other materials, such as oriented polypropylene (OPP) are being used. Paper labels are applied as individual units, stacked typically in packs of 1000, while others are 'roll fed'. In any case, labels should be applicable to the product being bottled. They should be applied squarely and firmly without excess adhesive. An approved adhesive compatible with both bottle and label paper should be used, and examination of the adhesive pattern from the labelling machine will enhance confidence in the efficiency of label application.

Care needs to be taken to ensure that applied labels are not damaged along conveyor lines or in the process of packing bottles into trays and cartons. Particular care should also be taken that damage does not occur to labels as the goods are palletised.

Finally, it should not be assumed that the labels will remain adhered to the bottle for the entire shelf-life, or in all conditions. If bottles are placed in chilled display cabinets, for example, the adhesive may fail and the labels become detached; it is important therefore to test the likelihood of this occurring prior to manufacturing and shipping product.

9.5.1.4 *Coding*

As water is bottled, it is identified with a batch code and often the time of bottling. A Best-Before-End (BBE) or expiration date is also given. Such coding may be applied to closures, bottles or labels on individual units and may also be repeated on multipacks, outer cartons and pallets.

Process control can ensure that these codings are legible and relevant for the date of bottling. It is particularly important to ensure that coding is correct at the start of a shift and to monitor it throughout its duration.

The coding assists in traceability of product and packaging materials, in the event of any query, as well as informing the consumer of its durability.

9.5.1.5 *Packing, wrapping and stacking*

Operators can ensure that cartons and trays are correctly assembled and that glue application is satisfactory.

Shrink-wrap is applied to protect and secure a selected number of bottles in a pack. A firm pack should be achieved that is not too tight, and there should be no holes in the shrink-wrap material that could later lead to disruption of the pack. The shape and formation of the holes created at either end of the pack (known as 'bulls'-eyes') can also be indicative of the integrity of the pack. The bulls'-eyes should be evenly formed, without excessive wrinkling, and small enough to ensure that all bottles are retained, even when the pack is roughly handled by the consumer.

Stacking of pallets is done for convenience for the distribution of goods. It should be done neatly, preferably with pack coding visible on all four sides of the pallet, though this may not be possible if the code is only on one face of the pack.

Stretch-wrap is applied to stacked pallets to secure packs in readiness for distribution. This needs to be firm enough to maintain integrity of the stack without pulling in at the corners. Some bottlers (particularly those exporting product over long distances) alternatively use a 'shroud', which is large enough to encompass the entire pallet, and which is then shrunk on to provide maximum stability.

9.5.2 Product water in process

Looking now at the process – the water itself – there are a number of checks that can also be made as part of process control.

9.5.2.1 *pH*

Each source of water has its typical pH. Testing the pH is a means of monitoring the integrity of the water. Carbonation of water reduces the pH to about 4.5. If a bottling line has been running on carbonated water and is changed over to still water, it can take quite a lot of flushing through to remove this acidity and to establish the water's natural pH. Also importantly, pH is an extremely useful indicator of things going wrong – in particular, if a CIP cycle is incomplete, a pH check may be the first indication. Of all the routine checks to be performed in a water bottling plant, pH is perhaps the simplest, and probably the most important.

9.5.2.2 *Conductivity*

Each source of water has a typical conductivity, which reflects the level of dissolved salts in the water. Where more than one source of water or a blend of waters is bottled, conductivity readings will ensure that the correct source is being bottled.

9.5.2.3 *Chlorine*

If a chlorine-based sanitiser (a combined detergent and disinfectant) is used for cleaning and sterilising bottling equipment, it is important to carry out regular checks, especially at the start of shifts, to ensure that no traces of chlorine are present in the product water.

Where other cleaning or disinfecting agents are used, these should be the focus of monitoring, and a formal procedure for checking and signing-off for the absence of chemicals is strongly recommended.

9.5.2.4 *Organoleptic evaluation*

Nosing, tasting and visually examining the water regularly, especially at the start of shifts, will provide confidence in the organoleptic integrity of the water.

9.5.2.5 *Filling volumes and levels*

Filling volumes and levels are checked to ensure that, on average, the contents are as declared on the label and that levels are consistent.

Bottles may be overfilled provided that levels are consistent and that appropriate vacuity is maintained for any expansion of product through temperature changes. The latter is particularly important for glass bottles containing carbonated liquids, where increased pressures brought about by external storage conditions may cause enough expansion of the liquid to cause the bottle to explode.

Plastic bottles may be measured by weight to check the volume content. In the case of glass bottles that are declared measuring container bottles, templates may be used over fitted closures to check volume content. Both these tests are nondestructive.

9.5.2.6 *Carbonation*

Where the product is being carbonated, it is recommended to carry out regular checks throughout production to ensure that carbon dioxide volume is consistent and to the level prescribed for the product.

9.5.2.7 *Reference samples*

It is good practice to keep bottles from each day's production as reference samples for the duration of the product's shelf-life. These bottles should be representative of the production run, i.e. labelled, capped and appropriately coded.

Reference bottles can be useful in the event of any enquiry relating to a particular batch of product, and for any work aimed at evaluating the shelf-life of the product.

9.6 QUALITY ASSURANCE

Some areas of quality management are more suitably addressed by appropriately trained and skilled technicians.

9.6.1 Microbiological assessment

Water is a vulnerable product and highly susceptible to microbiological contamination. There is no visible evidence of this and therefore routine microbiological assessment is essential to ensure and confirm that hygiene standards are achieved and legislative criteria are met. It is recommended to have laboratory facilities on site to undertake microbiological monitoring.

It is suggested that sampling points for water in process be at any location where something changes. For example, the first point would be at the source itself. Following the route of the water, the next sampling point would probably be on the pipeline or on the tanker that transports the water from source to the bottling plant. (Note: for some categories of water in some countries, tankering may not be permitted.) If the water then flows into buffer tanks, these would be the next area to sample. (Note: it may be inadvisable to retain water in buffer tanks for more than 24 hours before bottling.) From here, the water is likely to be filtered or treated and samples will be taken before and after this stage. Finally, product water in bottle would be sampled. By testing at all stages along the flow of water in process, any nonconformance can be traced more easily to its point of origin.

Sampling frequencies will depend on the output from the bottling plant, historical microbiological records and the confidence level in a sustainable satisfactory status. To demonstrate due diligence, daily samples are likely to be taken at points on the route from source to filtration or treatment and several samples, including the start-up of shifts and end of run, for the bottling process.

Sampling points at source, on pipelines and tanks, may be of varying types. They may simply be fitted with small taps to allow water to be procured for testing. Sanitary sampling ports may be preferred however, as these can be sterilised prior to use, and hence reduce the likelihood of 'false positive' results. On this basis, information on status relates only to the time of sampling. There are also valves, which are designed to provide representative samples throughout a period of time.

9.6.1.1 Microbiological analyses

Total viable count (TVC) or heterotrophic plate count (HPC)

The TVC is a nonselective test that provides the means to culture single organisms of mixed species into visible colonies of bacteria and thus facilitates counting them. These colonies grow on a sterilised nutrient jelly-type medium (agar), which has been formulated to provide optimum nutrient and growth conditions for the target organisms. Plates are either prepared through the 'pour plate' method (in which the agar is mixed in its warm, molten state with a measured volume of sample water in a sterile Petri dish), or using the membrane filtration method. In this case, a measured volume of the sample is drawn under vacuum through a sterile membrane filter, and the filter disc placed on the agar (which has previously been allowed to set in the Petri dish). In either case, the Petri dish is then placed in an incubator at a controlled temperature. Through defined periods of time at specific incubation temperatures, living (viable) bacteria present will multiply and develop into colonies.

Table 9.1 Microbiological criteria for bottled waters in Europe.

Analyses	Maximum concentration			
	NMW /SW		Other bottled water	
TVC at 37°C for 24 h ^a	20	cfu/ml ^b	20	cfu/ml
TVC at 22°C for 72 h ^a	100	cfu/ml	100	cfu/ml
Total coliforms	0/250	ml	0/100	ml
<i>E. coli</i>	0/250	ml	0/100	ml
Faecal streptococci	0/250	ml	0/100	ml
<i>P. aeruginosa</i>	0/250	ml		
Sulphite-reducing anaerobes	0/50	ml	0/20	ml

^a To be tested within 12 h of bottling.^b cfu, colony-forming units.

For the purpose of this test, it is assumed that one colony develops from each separate organism originally present in the sample. The resultant colonies are counted to give the number of bacteria in the measured volume of water at the time of testing. The incubation temperature and time may vary, depending on the organisms being sought, and may also be dictated by the local legislation. For example, in the European Union, two Petri dishes are prepared for each sample, one of which is incubated at 37°C for 24 h and the other at 22°C for 72 h, whereas in the United States, according to the Standard Methods, one plate is prepared and incubated at 25°C.

Selective examination

Other microbiological analyses are carried out to examine the water for the presence or absence of specific organisms or groups of organisms within a specified sample size. Membrane filtration techniques are usually employed, as quite large sample sizes (up to 250 ml) are involved. The tests are performed using selective media that provide optimum conditions for the growth of a particular species, while inhibiting the growth of others.

The particular organisms, or groups of bacteria specified, are often termed 'indicator organisms' since, if they are found to be present, they can indicate that some form of pollution or contamination has taken place. Typically, coliforms and particularly *Escherichia coli* are tested for, and also faecal streptococci, *Pseudomonas aeruginosa* and sulphite-reducing anaerobes.

Taking the most conservative approach, bottled water should be held within the control of the producer until completion of all microbiological analyses, i.e. three days. Once satisfactory results from these tests have been obtained, the bottled product can then be positively released. However, once the bottler has established a high level of confidence in the hygiene of the equipment and the efficacy of the cleaning and operational regimes, the decision may be made to allow release of the finished product before all the results of such tests are available.

Microbiological criteria for bottled waters are specified by legislation. In Europe, this is determined by the Directive 2009/54/EC on the exploitation and marketing of natural mineral waters. This Directive also contains the requirements for exploitation of spring water, although spring waters are additionally required to comply with the provisions of the Drinking Water Directive 98/83/EC (see Table 9.1).

Where positive results are obtained on selective examination, confirmatory testing may be advisable to determine more precisely the identity of allochthonous species.

In addition to the specific microbial parameters described above, there is in some markets a requirement for groundwaters, bottled without treatment, to demonstrate an absence of *Cryptosporidia* and other protozoa. As a general rule, it is inadvisable to undertake analyses for these within the bottling premises. Samples for this testing can be supplied on a regular basis to government or other suitably equipped and qualified laboratories.

9.6.1.2 *Plant, equipment and packaging materials*

In addition to the microbiological assessment of product water, it is also good practice to monitor the standards of hygiene in filling rooms, and of bottling equipment and primary packaging materials.

Environmental monitoring can be carried out by the use of settle plates – poured plates of sterile nutrient agar are exposed to the air for a controlled period of time in selected areas of the plant and on a regular basis. The Petri dishes are then recovered, closed and incubated. Resultant colonies are counted. Automatic air samplers for both microbes and particles are also available. These draw in air and enable a count to be established per measured volume of the air being sampled.

Swabbing is carried out on, for example, filler and rinser nozzles. After swabbing of equipment, the swab is streaked onto poured plates, which are then incubated. Here test results are recorded according to the degree of growth (low, medium or high) rather than individual colonies.

Microbiological assessment of bottles and caps is carried out using a known volume of sterile rinse. In the case of bottles, the rinse is poured into a test bottle, shaken around the bottle and then plated out in known aliquots with nutrient agar. After incubation, the colonies are counted. The result is multiplied, according to the proportion of rinse cultured, to give a number of bacteria per test bottle. Similar bottles can be assessed before and after production line bottle rinsing to indicate efficacy of this process.

For caps, a known number of caps is placed into a sterile container with a known volume of sterile rinse. These are shaken and the recovered rinse is plated out as above and the resultant colonies are multiplied to give a number of bacteria per known number of caps.

In some cases, the bottling company will set its own acceptability standards for these tests, and in others, such as the United States, there may even be regulatory requirements.

9.6.2 **Assessment during shelf-life**

As well as monitoring bottled water on the day of production, it is also beneficial to assess the product throughout its prescribed shelf-life and perhaps also beyond it. Through this, knowledge is built up of how primary packaging performs, what the microbial activity is and whether the organoleptic integrity is maintained up to the point of sale.

Different types of bottle and different sizes may give differing results over time, particularly in retention or loss of carbon dioxide in sparkling products.

9.6.3 **New product development**

QA technicians will play an active role in any new product development (NPD) – researching and evaluating any proposed new packaging formats or components.

Assessments will also be made of any deviations from the norm as a result of any process or equipment changes or developments, and any modifications to distribution and storage of product.

9.6.4 Sensory evaluation

There is clearly more to water than knowing the levels of its constituent composition or its lack of certain elements. It is the way in which all the components and factors involved work together, rather than merely their presence or absence, which brings about the whole quality of the water. Consumers buy and drink bottled water because they enjoy its taste and perceive it to be of good quality. Alert consumers learn more about water quality from their sense impressions than from a compositional report. Our taste buds are on the surface of the tongue and around the mouth and throat, and are capable of distinguishing a wide variety of characteristics, the major ones of which are salty, sweet, sour and bitter. However, a multitude of other tastes and odours are detectable, sometimes related to environmental or process conditions, and sometimes to the packaging materials. The human capability for sensory evaluation is exemplary and very difficult for a machine to emulate and, for this reason, taste panel input is an important aspect of QA. Sensory science is rapidly gaining industry acceptance as a QA and NPD tool.

Sensory skills vary greatly from person to person, but it is possible through training and practice to improve the ability of individual tasters to identify particular taste and odour characteristics. An individual's interpretation may vary from day to day, or even from hour to hour, which is why taste panels need to involve several people (recommended 4 minimum).

Sensory evaluation is a subtle blend of odour and flavour/taste. The environment in which sensory evaluation takes place should be separate from other activities, so that noise and odours can be minimised. Tasters should be able to sit down and be isolated from each other to enable them to concentrate. There should be no discussion on the tasting until all sensory evaluations are complete.

Presentation of the samples should be consistent. Water should always be at ambient temperature for tasting, and all samples at the same temperature. The containers may be clear, odour-free plastic – used once and discarded – or they may be glass. If the latter, care must be taken in cleaning glass containers to remove all/any detergents used and to make sure they are odour-free for use. Glassware should be dedicated to sensory evaluation and be kept scrupulously clean.

It is necessary for at least one person to have training in setting up taste panels and in addition, some training given to those selected for the panel.

It is best to keep tests simple: for example, the direct comparison between two samples, or triangle tests where three samples are given – two the same and one different. Panellists are asked to select the odd one and to describe the difference; duo-trio tests where three samples are given – one is identified as a reference sample (R) and the other two are coded, one of which is the same as R. Panellists are asked to taste R, then the others and identify which of the others is different from R. There are also preference tests where panellists choose their preferred sample from two or more samples.

Sensory evaluation plays its part in shelf-life monitoring, comparing the same product just bottled with samples during shelf-life. It can assist in new product development, especially when new packaging components are being selected, or in relation to volume/packaging ratio. It is also a useful way to compare different brands of water.

9.6.5 Auditing

In addition to auditing hygiene standards within the company's bottling facility, QA personnel will be involved in auditing suppliers of primary packaging materials and warehouses where finished goods are stored within the distribution system.

The British Retail Consortium (BRC) and the Institute of Packaging (IoP) produced a *Technical Standard and Protocol for Companies Manufacturing and Supplying Food Packaging Materials for Retailer Branded Products* in 2001. This provides a basis upon which to audit suppliers of packaging materials, and the suppliers can be asked to be accredited to this standard. Through this process, 'due diligence' is passed back up the chain.

If product is contract-packed or co-manufactured off-site, it is essential that this is also audited. Last, but by no means least, it is good to audit product at point-of-sale in the store to ensure that it arrives there in pristine condition.

A documented code of practice for suppliers and for warehouses will provide an understanding of the standards expected.

In addition to the above auditing, a water bottling company may be subject to, or may choose to have, third-party audits (see Chapter 11). These would be undertaken by an independent body or authority, increasingly as a condition of doing business with a customer, or as a prerequisite for membership of a trade organisation.

9.6.6 Calibration

Where pieces of test equipment are used to verify the meeting of specifications, it is important that these are calibrated on a regular basis, either internally using appropriate standards or by external bodies. Examples of such equipment include balances, conductivity meters, pH meters, pressure gauges, secure seal testers, thermometers and torque meters. All operators and/or technicians using the equipment must also be trained and subject to periodic testing. There should also be a procedure in place to ensure that wherever such equipment is located within the factory (and there may be multiple locations), all results are equally valid, regardless of who is doing the testing.

9.6.7 Accreditation

It may be advisable to consider gaining certification/registration through an accredited body for the QA laboratory. In some markets this is mandatory and has the benefit of providing confidence for the bottling company and also credibility to existing and prospective customers as well as enforcement authorities.

9.7 INDEPENDENT OR GOVERNMENT LABORATORIES

Bottled waters are required to have extensive chemical analysis covering at least 50 parameters. Some of this analysis is very challenging as many parameters are at levels close to or below detection limits. In some cases, the analysis is undertaken to demonstrate absence of a parameter as, for example, to show freedom from pollution from pesticides, herbicides and fertilisers.

For some elements there is a maximum legal level, referred to in Europe as the maximum admissible concentration (MAC) and in North America and other markets as the maximum contaminant level (MCL). These apply in particular to toxic substances and for these analyses, since levels of such substances are generally extremely low, sophisticated techniques are needed.

This extensive and exacting analysis is required regularly, though not daily or weekly, and it is unlikely, therefore (with possibly the exception of a very large producer), that bottled water companies will have laboratory facilities or staff to undertake it. Independent

Table 9.2 Parameters in the official analysis for bottled waters.

Parameter	Expressed as
<i>Physical and chemical characteristics</i>	
Dry residue at 180°C	mg/l
Dry residue at 260°C	mg/l
Electrical conductivity (at given temperature)	µS/cm
Hydrogen ion concentration	pH
<i>Radioactivity</i>	
Total alpha activity	Bq/l ^a
Total beta activity	Bq/l
<i>Toxic substances</i>	
Antimony	Sb µg/l
Arsenic	As µg/l
Cadmium	Cd µg/l
Cyanide	Cn µg/l
Chromium	Cr µg/l
Lead	Pb µg/l
Mercury	Hg µg/l
Nickel	Ni µg/l
Selenium	Se µg/l
<i>Cations</i>	
Aluminium	Al mg/l
Ammonium	NH ₄ mg/l
Calcium	Ca mg/l
Magnesium	Mg mg/l
Potassium	K mg/l
Sodium	Na mg/l
<i>Anions</i>	
Borate	BO ₃ mg/l
Carbonate	CO ₃ mg/l
Chloride	Cl mg/l
Fluoride	F mg/l
Hydrogen carbonate	HCO ₃ mg/l
Nitrate	NO ₃ mg/l
Nitrite	NO ₂ mg/l
Phosphate	P ₂ O ₅ mg/l
Silicate	SiO ₂ mg/l
Sulphate	SO ₄ mg/l
Sulphide	S mg/l
<i>Non-ionised compounds</i>	
Total organic carbon	C mg/l
Total carbon dioxide	CO ₂ mg/l
<i>Trace elements</i>	
Barium	Ba µg/l
Bromine	Br µg/l
Cobalt	Co µg/l
Copper	Cu µg/l
Iodine	I µg/l
Iron	Fe µg/l
Lithium	Li µg/l
Manganese	Mn µg/l
Molybdenum	Mo µg/l

Parameter	Expressed as
Strontium	Sr µg/l
Zinc	Zn µg/l
<i>Freedom from pollution</i>	
Pesticides	µg/l
Herbicides	µg/l
Fertilisers	µg/l
VOCs	µg/l
<i>Microbiological</i>	
Parasites	
TVC at 37°C in 24 h	cfu/ml
TVC at 22°C in 72 h	cfu/ml
Total coliforms	
<i>E. coli</i>	
<i>Faecal streptococci</i>	
<i>P. aeruginosa</i>	
Sulphite-reducing anaerobes	

^a Bq= becquerel.

or government laboratories are generally used for this purpose. Table 9.2 shows the usual parameters included in official analysis for bottled waters.

9.8 RECOGNITION OF SOURCE

The hydrogeology influencing a source of water is highly complex and specialist knowledge is needed. An appointed hydrogeological consultant would define the catchment area for the source and advise on all matters relating to the identification and protection of the source and its exploitation.

In Europe, there is a recognition process for a new source of natural mineral water, which may take about two years. During that time, many samples of the water will be submitted to an independent or government chemist for analysis. The intention is to establish from this that the water is stable in its composition, allowing for slight seasonal fluctuations, that it demonstrates freedom from pollution and that it is safe to drink without treatment.

Once enforcement authorities are satisfied that the water meets legislative requirements, notice of recognition is published in the *European Journal* and in equivalent publications of the member states. Following recognition, full analysis is still required on a regular basis but not as frequently as during the recognition process.

In the case of Spring Waters, although they are not required necessarily to have a stable composition and therefore do not go through the recognition process, they are required to be registered through local enforcement authorities, and tend to be subject to analysis against a list the same as or similar to that shown in Table 9.2.

9.9 INDUSTRY NETWORKING

Since the original publication of this book, the bottled water industry worldwide has grown and developed, and the legislation has also evolved, but in developed markets at least, there are now established standards for all water types. Techniques for controlling quality,

and quality assurance methodologies continue to develop however, and it can be of enormous benefit for individual bottlers to stay abreast of such developments. There are trade associations in all the major markets (details to be found in other chapters of this book) and membership can provide a forum through which technical developments and other advances can be discussed with others within the industry. This also facilitates lobbying opportunities, where appropriate.

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10 Bottled Watercoolers

Michael Barnett

10.1 INTRODUCTION

The bottled watercooler industry is closely related to the bottled water industry as a whole and has enjoyed parallel growth since the middle of the last century. In recent years, with increasing attacks from the environmental movement on bottled water in small plastic disposable bottles, the watercooler has emerged as arguably the more environmentally friendly approach to dispensing bottled water. By utilising the large 18.9-litre ('5 gallon' US) reusable plastic bottle, substantial savings can be made and, once beyond their service life, the larger plastic bottles are recycled into other non-food related products.

A further evolution of the bottled watercooler in response to the environmental lobby has been the plumbed-in watercooler able to dispense chilled municipal water. This has in many countries taken a substantial market share from the established bottled watercooler base.

The compactness and elegant design of the modern watercooler, its availability on a rental basis, coupled with the guaranteed quality of bottled water, provided an ideal recipe for the growth of the industry at a time of ever-increasing concern about the quality of municipal water supplies for drinking purposes. This growth has been strongly assisted by the dramatic growth of the market for water in smaller bottles. This in turn resulted from interest in healthy lifestyles, supported by strong brand advertising and promotion by the large national and international bottled water companies competing for market share.

10.2 WORLD MARKETS

10.2.1 Europe

While bottled water in small containers can be traced back many hundreds of years, the bottled watercooler market as we know it today did not start until the mid-1980s, when the American bottled watercooler concept was first imported into the United Kingdom and offered to a booming commercial sector as the latest in modern office equipment.

Despite the recession of the early 1990s, the watercooler market in the UK grew steadily at some 15–20% p.a. until 2002, when growth slowed to achieve a peak of some 550 000 watercoolers by the end of 2004. The market decreased to about 430 000 in 2008, resulting

Table 10.1 Bottled watercooler units per 1000 population in 2008. (Reproduced with permission from Zenith International.)

Cooler units per 1000 population	
Ireland	11.0
Greece	9.5
Portugal	9.1
Belgium	8.3
UK	7.0
Norway	6.4
Netherlands	5.4
Spain	5.3
Switzerland	5.1
France	4.0
Italy	3.8
Denmark	3.4
Austria	2.9
Sweden	2.7
Finland	2.6
Germany	1.7

Source: Zenith International.

in the main from competition from plumbed-in watercoolers, which have shown significant growth since the early 2000s, mainly at the expense of bottled watercoolers. The UK still substantially leads the European market in the number of installed watercoolers (source: Zenith International). The residential market for watercoolers is not yet developed and accounts for less than 2% of the total market.

This growth of the 1980s and early 1990s was not paralleled on mainland Europe, owing to restrictive legislation, particularly in France, Italy, Spain and Germany, and referred to as the '2-Litre Rule', which was not revoked until the mid-1990s. As a result, the development of the watercooler market in Europe was delayed and restrained in its development for some eight years, when compared to the UK. In other countries, such as Ireland, Denmark, Sweden, Norway, Holland and Belgium, the watercooler industry commenced in the early 1990s and enjoyed an equal success to that experienced in the UK. Watercooler popularity in 2008 is shown in Table 10.1.

West European watercooler placements at the end of 2008, excluding the UK, are estimated at 1 430 000 watercoolers and are expected to grow to about 1 620 000 watercoolers by the year-end 2013 (source: Zenith International). It is interesting and significant to note that both of the traditional European bottled water companies, Nestle and Danone, established in supplying water in small bottles, only entered the bottled watercooler market as late as 2000, primarily by the acquisition of existing watercooler companies. Both companies had left the market by 2008.

Since Glasnost in 1989, and the liberalisation of the Soviet Union and other Central European and East European economies, bottled watercoolers have seen dynamic growth. These markets accounted for 1 120 000 bottled watercoolers in 2008, with a further estimated 500 000 non-chilling water dispensers such as tilters and crocks (see Section 10.3) in use. It is forecast that bottled watercooler installations will grow to 1 420 000 by 2013. Leading countries are Russia with 650 000 and Poland with 430 000 bottled watercooler installations in 2008 (source: Zenith International).

10.2.2 Middle East

The Middle East, with its arid lands and the restricted availability of water has long been a natural market for water in small bottles, but it has mainly been a client market for imported brands, usually from Europe. Some local bottlers of purified and both natural mineral and spring water do exist; however, the generally low income level of the population has meant that it was a luxury product and imported brands were generally perceived as being of better quality and prestige. The watercooler market, however, utilising local water sources, often purified, is a more recent phenomenon and can be traced back to the late 1980s.

Israel, with an estimated 200 000 bottled watercoolers, is a significant watercooler market in the Middle East, after Saudi Arabia. Saudi Arabia and the Gulf states have been desalinating and purifying drinking water for many years, to support both their fast economic and industrialisation programmes and their growing populations. The supply of drinking water has been a matter of a need to survive, rather than a desire for contaminant-free, good drinking water, as was the driving force for the industry in America and Europe.

An aspect of these markets, except for that of Israel, is that watercoolers are not normally part of a rental programme as they are in America and Europe. The traditional bargaining and purchase of equipment in the souks and also more modern stores prevails and bottling companies are simply involved in providing the bottled water product. This is particularly evident where the watercooler is intended for residential or small business purposes. The lending of watercoolers to large commercial users in return for a bottled water supply contract is also a common practice.

Egypt, Jordan, Lebanon and Syria are relatively recent emergent watercooler markets and, despite Israel's meteoric growth in the late 1980s, Saudi Arabia currently remains the largest bottled watercooler market in the Middle East with Egypt, promising to be the most significant future growth market in the region.

10.2.3 Asia

Asia has traditionally boasted some of the largest bottled watercooler companies in the world, with vast demand for good-quality drinking water free from contamination. Fast economic growth and related industrialisation have meant the contamination of many natural water sources, and hence purified water is favoured for bottling. Unlike in Europe, water companies and breweries supply bottled water in small containers as well as in the 18.9-litre reusable bottle; they also often provide watercooler services. The vast demand for watercoolers also meant that the market has attracted some companies that do not pay sufficient attention to water quality and hygiene issues, so care must be taken to ensure that only water from the most reputable companies is consumed.

Although Japan is a very large and long-established market for bottled water in small bottles, the bottled watercooler market commenced only in the late 1980s, with natural spring water as the main source of supply. The market has not enjoyed the expected growth, apparently owing to public concern about bacteria entering the watercooler's open reservoir and the size of a traditional watercooler relative to the small size of the average urban residence.

Until the early 1990s, the South Korean government had banned the sale of 18.9-litre bottles intended for use with watercoolers to Korean citizens, on the grounds that the local water quality was of a good standard. The bottled watercooler market that evolved however,

was focused on the demand of the small foreign resident population, mainly US military personnel and diplomats. Since the rescinding of the law, many companies have entered the watercooler market and have been successful in establishing a thriving demand for both bottled water and locally manufactured watercooler appliances.

In the years since liberalisation, the Chinese market for watercoolers has seen a slower than expected growth rate, mainly due to poor distribution logistics in the main conurbations and poor profitability due to very low pricing. It is not known how many watercoolers are in service but the number is thought to be approaching a million, with at least 10 major bottling companies supplying demand, which is in the main for distilled water. The unusually high demand for bottled water generally and distilled water in particular, reflect both the public's distrust of drinking water, other than purified water and water shortages in the municipal water system due to frequent drought conditions.

The neighbouring market of Hong Kong is a mature bottled watercooler market with an estimated 200 000 watercoolers, with one bottler having been established for some 30 years playing a leading role in both the small bottle and bottled watercooler market. As in China, purified water is the most popular product and there appears to be distrust by the population of local spring water or the municipal water supply.

Taiwan is traditionally a similar market to China, but has shown a much slower growth. There does not appear to be the usual acceptance of the rental philosophy with respect to the watercooler and as such, watercooler purchase and the supply of bottled water are not usually handled by the same company. This has probably been assisted by the preponderance of local watercooler manufacturers who sell bottled watercoolers through retail distribution to the public. It is estimated that there may be over 50 000 bottled watercoolers in place, supplied by four major bottlers.

The Philippines, Singapore and Malaysia have developed slowly since the early 1990s, but aggressive cut-price competition has resulted in very low margins that are insufficient to offer a quality delivery service to the consumer. In the Philippines, watercoolers are frequently lent to customers free of charge. These economic constraints have led to private vending machine operators installing what are locally called 'filling stations', supplying water to consumers who bring their own bottles, becoming the major source of drinking water. A lack of water quality standards and control has exacerbated the situation.

Indonesia and Thailand are very large and well-established bottled water markets, with over 1000 companies offering bottled water in all sizes of bottles. As many as 2000 of these secondary suppliers are said to exist, to supply bottled water on a seasonal basis. Several large bottlers dominate the markets and distribution patterns, offering both water in small bottles and for bottled watercoolers. Here too, aggressive competition has driven prices to levels that result in questionable quality and hygiene standards for many of the smaller bottlers. Poor road conditions outside of the larger cities have also militated against the growth of the watercooler market.

10.2.4 Australia and New Zealand

The Australian watercooler market is a mature market that began in the mid-1980s, with most growth having been achieved in the 1990s. There are thought to be over 150 000 bottled watercooler placements, with one company dominating the market. Local demand has encouraged local watercooler production, which supplies the greater part of demand. Spring water is the major source of water supplied to this market, with only very small volumes of purified water supplied.

New Zealand has a very small market for watercoolers focused around the capital Auckland. It is estimated that some 20 000 watercoolers are in service.

10.2.5 Central and South America

These markets have become established since the 1950s and have adopted the watercooler concept for both commercial and residential consumers as a substitute for the poor quality of the municipal supply.

Mexico has a very large bottled water market, both in small bottles and in the large reusable 18.9-litre watercooler bottles. There are some 20 major bottlers supplying demand; however, the generally low income level of the population has dictated that in the majority of cases, bottled water from 18.9-litre bottles is not dispensed from bottled watercoolers but is dispensed using other equipment, such as tilters and crocks (see Section 10.3) that do not cool the water.

Brazil boasts the largest bottled water consumption per capita in South America, but bottled watercoolers are a relatively recent growth market, as they are also in the remainder of the sub-continent. It is estimated that some 200 000 bottled watercoolers are in service.

10.2.6 North America

North America is the place of origin of the bottled watercooler and its development can be traced back over 100 years. As would be expected, it is now a stable market in an advanced state of maturity with an estimated 4 600 000 bottled watercoolers, 40% in commercial and 60% in residential locations. The market is forecast to decrease by 2013 to some 4 100 000 bottled watercoolers, possibly as a result of adverse media publicity about the environmental impact of bottled water (source: Zenith International), but equally importantly, as a consequence of the global recession. (The watercooler business is inevitably affected when businesses close or decide to reduce costs). Most bottled water companies supply water in small containers as well as the 18.9-litre watercooler bottle and brand names and market share play a significant role. Despite this, with the vastness of the continent, there are some 300 bottlers, encompassing both small businesses trading on a local basis and multi-national companies.

The Canadian market has consolidated over the past ten years from many small bottlers to just one major truly national brand operating in all ten provinces. There are a further four large regional brands. It is estimated that there are some 750 000 bottled watercoolers in service, equally divided between commercial and residential consumers who also source water watercooler bottles from supermarket chains. Over the past five years many residential customers have purchased their own watercoolers.

10.3 EQUIPMENT DEVELOPMENT

10.3.1 Dispensers

It is not known precisely when in history earthenware vessels for the storage of drinking water were first fitted with a simple on/off valve to dispense water. It would have been much later in the development of man and most probably in the dry and hot equatorial regions of the world, where drinking water is very much a precious resource, that the storage of drinking water in earthenware vessels became commonplace.

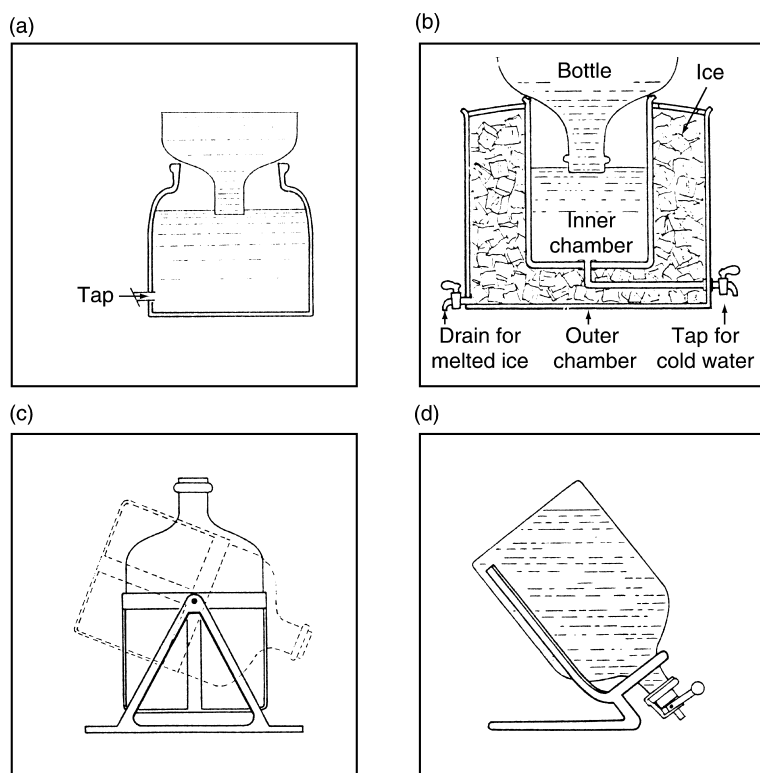


Fig. 10.1 Early and simple forms of water dispenser: (a) ceramic crock; (b) icer; (c) filter; and (d) stand.

Some forms of non-cooling water dispenser are illustrated in Fig. 10.1, from the ceramic crock to the late nineteenth-century icer and the simple tilter and stand.

As Fig. 10.2 illustrates, while drinking water dispensers have undergone many changes in the past 150 years, the last 30 years have been the most active period of their development. It is not envisaged that this will continue at the same rate in future years.

The more recent developments of bottled watercoolers did not occur in isolation, but paralleled the development of its related service industry – the delivery of bottled drinking water to the home and office.

Modern health and safety considerations for the short-term storage and dispensing of bottled water, and in particular microbiological considerations, have had significant influence on the development of watercoolers in the 1990s. One area of particular focus has been the interface of the water bottle and the watercooler. Traditionally, the neck of the bottle was immersed in the open-topped cooling reservoir of the watercooler and the water level maintained until some water was drawn off from the dispensing tap. At that time, as the water level in the reservoir fell and the neck of the bottle became exposed above the water level, water flowed out of the bottle and into the reservoir and was replaced in the bottle by air that flowed in through the gap between the water level in the watercooler reservoir and the bottle. When the water level in the reservoir rose to once more cover the bottle neck, the flow of water out of the bottle would stop.

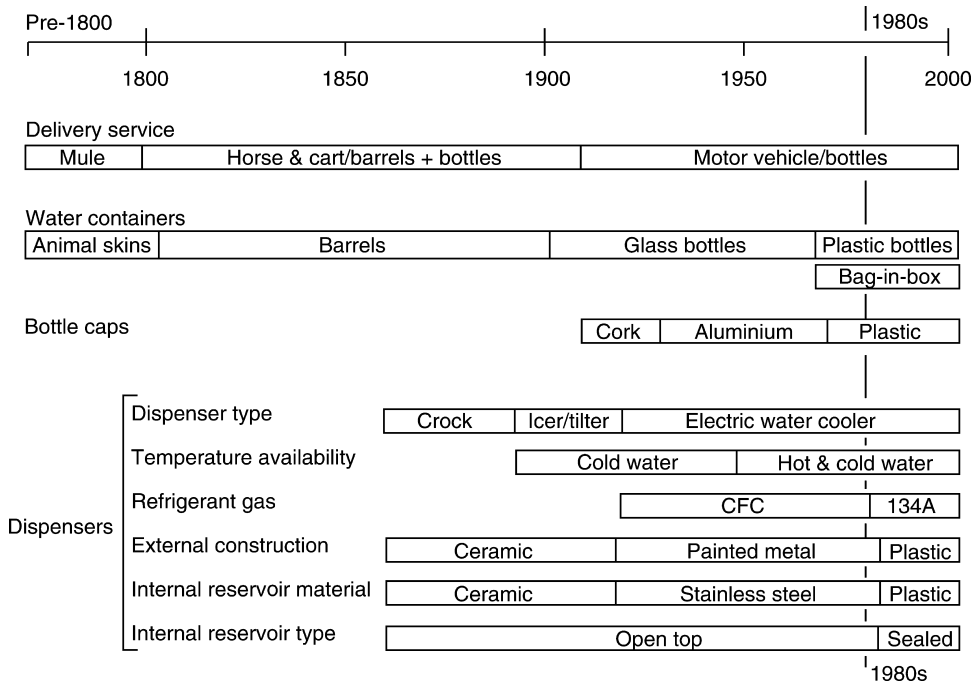


Fig. 10.2 Development of watercoolers.

US Patent 1,142,210, filed by Walter Wagner of Chicago, Illinois, USA on 29 February 1912, but not developed and put into production until nearly 80 years later (see Fig. 10.3), addressed many of the microbiological contamination and usage issues related to the open reservoir system, which were:

- external surface of the bottle neck immersed in drinking water in the internal reservoir;
- airborne contamination of the drinking water as air is drawn into the reservoir and bottle;
- open and exposed reservoir at the time of bottle changing;
- water spillage when inverting the bottle over the cooler;
- contamination of the open topped empty bottle after use.

The Watersafe bayonet-and-valve (BV) closed-reservoir system was first introduced by Elkay Manufacturing Company, USA, for its bottled watercoolers in 1990. This innovation interpreted and commercialised the original patent using modern materials and technology (Fig. 10.4).

The BV device requires that the bottle cap, which traditionally acted simply as a closure to contain the water in the bottle during storage and transit, and was removed prior to loading onto the watercooler, now plays a vital role in the dispensing operation. To this end, it has been redesigned as an integral component of the BV system, so that it is not removed from the bottle prior to loading it onto the cooler. The valve mechanism built into the BV cap is opened by the bayonet component on the watercooler and water flows from the bottle through apertures in the bayonet and into the now sealed cooling reservoir. When the empty bottle is lifted and removed from the watercooler, the valve in the bottle cap closes, thereby preventing any contamination from entering the bottle on its way back to the bottling plant for refilling.

W. WAGNER.
LIQUID DISPENSING DEVICE.
APPLICATION FILED FEB. 29, 1912.

1,142,210.

Patented June 8, 1915.

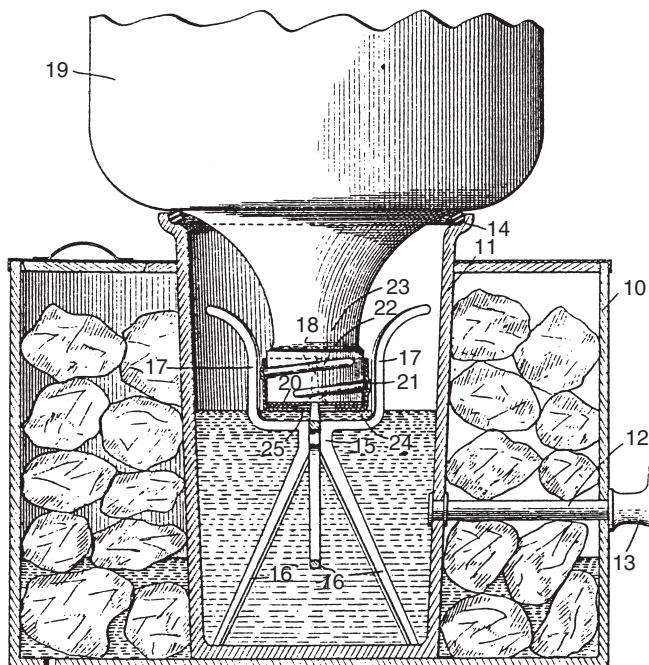


Fig. 10.3 US patent 1,142,210, filed on 29 February 1912.

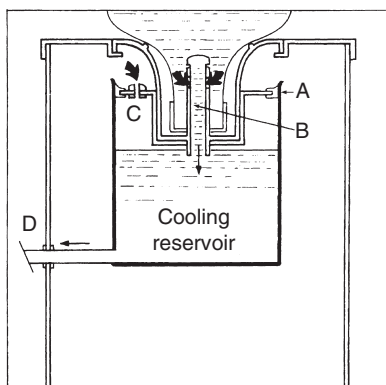


Fig. 10.4 Typical bayonet-and-valve device fitted to a bottled watercooler.

In addition to eliminating external airborne contamination by sealing the cooling reservoir and introducing the bayonet, the BV device incorporates a sub-micron (0.5 micron) air filter to remove airborne spores and bacteria from the incoming air supply, which bubbles into and replaces the water in the bottle at the time of dispensing water from the water-cooler.



Fig. 10.5 (a) Ebac watercooler, ca. 1994; (b) Sip-Well watercooler, ca. 2003.

Focus on the microbiological integrity of bottled water having left the bottle, initiated by introduction of the BV system, continued by reviewing the remaining water contact surfaces up to and including dispensing, namely the cooling reservoir, piping/tubing and dispensing taps.

Since the days of the first electric watercooler in the 1920s, the internal cooling reservoir has been made of stainless steel. This material has many benefits in terms of its corrosion resistance, good heat transfer from the refrigerant coils surrounding it, and good surface finish that denies bacteria (biofilm) an anchorage facility and imparts no taste taint to the water. However, with the evolution of synthetic plastic materials as a spin-off from space technology, it was only a matter of time before the dominance of stainless steel as the only material for the cooling reservoir was challenged by plastics.

The challenge came in the mid-1990s with the introduction of a revolutionary new concept from a new entrant to watercooler manufacturing – Ebac – a British company and an established market leader in the manufacture of dehumidifiers. The 1994 Ebac watercooler (Fig. 10.5) was both revolutionary and evolutionary, since it set out to address the requirements of modern-day bottled water cooling and dispensing by incorporating features from information gained through extensive research of bottled watercooler distributors.

The most innovative aspect of the 1994 Ebac watercooler was its disposable Watertrail – all water contact components from the watercooler to bottle interface to the dispensing taps. The Watertrail commences with a BV system incorporating an air filter assembly that is connected by flexible silicone rubber tubes to a plastic bag that acts as a bladder and replaces the traditional rigid stainless steel cooling reservoir. In this manner the water is in close proximity to the surrounding refrigerant coils and is only separated from them by a thin

layer of plastic. Out of the plastic bag, exit tubes that route the water to the dispensing taps and on some dispensers to the water heater. The complete Watertrail is a relatively low-cost disposable item that is easily and quickly removed from the watercooler and replaced with a new one, the old one being disposed of. Sanitation of the watercooler is not required after installation of a replacement Watertrail, since each one is assembled and packed in a sterile clean-room environment.

Further innovations incorporated into the design of the 1994 Ebac watercooler were built-in dispensing taps, external all-plastic panels, offering easy exchange for multi-colour options, rear wheels for portability, built-in cup dispensers and covered drip tray incorporating a water level indicator.

The innovative disposable Watertrail and the focus on watercooler hygiene triggered the development by several watercooler manufacturers of a plastic, rigid, removable and reusable water cooling reservoir, to replace the traditional stainless steel reservoir. The objective being that, instead of having to sanitise the watercooler reservoir within the watercooler, it could be removed from the watercooler and exchanged for one previously sanitised; the one removed could be taken away to be cleaned and sanitised ready to be used again. A further benefit claimed for the removable plastic reservoir is that, in most cases, its removal from the watercooler also removed the dispensing taps attached to it, thereby replacing all the water contact surfaces in one operation, as in the Watertrail.

An alternative design for cooling the water in the reservoir, the Oasis concept, utilises a cooling metal probe, inserted into the centre of a rigid plastic cooling reservoir, which cools the water radially outwards. The refrigerant coils are embedded into the probe, as opposed to surrounding the external surfaces of the reservoir, and are said to be substantially more efficient in abstracting heat from the water and reducing losses to the surroundings.

Taps for dispensing water from the very early earthenware crocks of ancient times have not changed much in engineering terms. These taps utilised the alignment of two apertures, to obtain flow through the valve. Some taps in use today in other consumer appliances still use this principle.

As materials technology evolved and rubber seals were invented, metal taps became the norm, usually made of chrome-plated brass. Today, with the evolution of plastics and synthetic seals, the modern watercooler tap uses the principle of a spring-loaded plunger to operate a plastic diaphragm to seal an aperture that is opened by lifting the diaphragm away from the aperture's face.

The 1994 Ebac watercooler introduced the concept, since adopted by other modern watercoolers, of squeezing a plastic tube with a spring-loaded roller to the point where flow is stopped. To allow flow, the roller is lifted clear of the tube by the use of levers.

While focusing on watercooler hygiene, research into external means of watercooler contamination has shown that the dispensing tap is a vulnerable component. Owing to frequent hand contact at the time of dispensing, there is potential for contamination of both the tap body and outlet nozzle through which the water is dispensed. To overcome this, some manufacturers have introduced remote activation of the taps using both mechanical and electrical actuators or levers, and protecting the dispensing nozzles from hand contact with covers. Some even surround the tap nozzle area with beams of Ultra Violet light.

The first watercooler providing hot water, as well as chilled water, appeared in the late 1940s, offering instant piping hot water at a temperature in the range 83–87°C, adequate for instant coffee, soups, etc. The heating took place in a built-in brass or stainless steel tank fitted with an electric heating coil. A requirement of the European consumer, particularly from the tea-drinking English, was for the achievement of a higher water temperature.

By the mid-1990s, while electric heating coils remained relatively unchanged, temperature control of water could be achieved by electronic solid-state technology, resulting in water temperatures as high as 97°C being attained with reliability and safety. To complement these higher temperatures, dispensing taps were modified to incorporate tamper-proof handles to ensure that only purposeful activation of the tap would provide hot water, avoiding accidental dispensing and scalding of the user.

Like the cooling reservoir, the traditional metal hot-tank also underwent modernisation, with its material changed from metal to an engineering plastic that can withstand boiling water without deformation, as well as not facilitating the build-up of scale with the use of hard water.

As sophistication and demands of the consumer have increased, so has the technology employed by manufacturers; the watercooler has not been an exception. Modern watercoolers are also available offering the facility to dispense chilled carbonated water, as well as chilled still water. Essentially, this is the same appliance as a standard watercooler, but additionally includes within its construction a carbonation chamber and a CO₂ gas cylinder. Electronic solid-state circuitry controls the process and the normal chilled still water is carbonated, one cup at a time, on demand. The simple push of a button operating an electric solenoid valve is all that is required to obtain a refreshing cup of chilled sparkling water.

Watercoolers have evolved to dispense water supplied in various specialised containers originally made of glass and subsequently of plastic in a multitude of shapes and sizes. One such development, in the early 1970s, was the adaptation of the standard watercooler to dispense water supplied in a container known as bag-in-box (see Section 10.3.2.3). Although watercoolers required only a minor adaptation to enable them to dispense water from this container, they have not gained wide acceptance, because the packaging system often introduced a taste taint to the water.

In some European countries, a regulation prohibited the sale of natural mineral water in bottles larger than 2 litres. To overcome this barrier to the use of watercoolers, an innovative Italian watercooler manufacturer produced an external water reservoir for its watercoolers, which replaced the traditional bottle. This external reservoir was located on the watercooler where the bottle would normally be placed and combines a housing and an adaptor for the location of 6 bottles of 2 litres each. These bottles empty into the upper reservoir, which in turn fills the internal cooling reservoir, as would a standard 18.9-litre bottle.

Thermoelectric watercoolers offer several benefits over traditional watercoolers. They have no compressor or refrigerant gas and operate using a 12-volt solid-state thermoelectric module (TEM) utilising the Peltier effect, which was discovered in 1834. This effect occurs whenever an electric current passes through a circuit of two dissimilar conductors and, depending on the current direction, the junction of the two conductors will either absorb or release heat. The compactness of TEMs offers scope for original design and it is anticipated that advances in technology will increase the output and efficiency of these modules in the future, allowing them to compete effectively with the presently dominant refrigerant gas-compressor technology. In the meantime, this technology is primarily utilised in small-capacity watercoolers aimed at the residential market.

Watercooler manufacturers are under pressure to reduce watercooler size for both the office and residential consumers; however, restrictions imposed by contemporary compressor technology limit this for the present. Traditionally, watercoolers have been floor-standing appliances, but since the mid-1970s, counter-top versions have been available. In essence, these are cut-down versions of the floor-standing models, where the space between the compressor and the internal cooling reservoir has been substantially reduced.

The thermoelectric module offers the best opportunity for size reduction and it is anticipated that, once their operating parameters have been improved, these coolers will dominate the compact cooler market.

Water cooling has also found application in the traditional coffee brewing industry, with multi-function appliances dispensing fresh-brewed coffee as well as chilled and hot water from a bottled water source. They are increasing in popularity in America by virtue of their compactness. These appliances are not intended for large-volume water dispensing and utilise the thermoelectric module as the cooling source for the water.

10.3.2 Bottles

10.3.2.1 *Wood and glass*

In the period of over 100 years since the home delivery service of drinking water for other than therapeutic reasons commenced, containers used have themselves undergone a metamorphosis. In America, the mid-1800s saw the horse-drawn wagon carrying several large 50-gallon wooden casks, bound together with rope, delivering water to homes on a regular daily route basis. This practice continued until the development of large glass bottles in the 1890s. These glass bottles were of thick-walled, clear glass, round in cross-section and more akin to the traditional small glass bottles used in the beverage industry than the now standard 18.9-litre watercooler bottle. It was not until the 1920s that the unique 18.9-litre glass bottle intended exclusively for use on a bottled watercooler was introduced. This bottle closely resembled the modern plastic bottle. The most significant difference was its weight, which averaged 6 kg when empty and about 25 kg when filled with water.

10.3.2.2 *Plastic containers*

For many years and through most of the twentieth century, the glass bottle prevailed until the evolution of thermoplastics in the years following the World War II. First, PVC evolved as the multi-purpose thermoplastic, in both coloured and clear forms. At the time, it was considered to be the ideal mass production material and in the bottled water industry it replaced, in many cases, the small glass bottle for packaging still water. The dark green glass bottles were retained for packaging carbonated waters.

The evolution of plastics appeared to offer the solution to many of the watercooler industry's problems relating to both weight and safety. Despite this, it was not until the early 1970s, and after over 10 years of research, when the Reid Valve Co., USA, introduced the first polycarbonate 18.9-litre ('5-gallon' US) plastic bottle, that the modern age of the watercooler bottle had arrived. It was the product the watercooler industry had been waiting for. It was light, an empty bottle weighing approximately 750 g, an eighth of the weight of a glass bottle, and was strong and durable. It also demonstrated excellent long-term chemical characteristics for the packaging of food, without the migration of undesirable chemicals from the material into the product. Polycarbonate is also an environmentally friendly material, fulfilling the three R's of the modern packaging industry: reduce, re-use and recycle.

Typically, the service life of an 18.9-litre polycarbonate bottle is about 40–60 round trips, from the bottling plant to the consumer and back. In that time, the one bottle will have dispensed, via the watercooler, about 950 litres of water; i.e. a re-use ratio of approximately 950:1. This far outperforms the one-time-use plastic bottles used by the small-pack bottled

water industry, which have been at the forefront of attacks from the environmental lobby, government and the media.

Despite the ideal properties exhibited by polycarbonate as a material for the 18.9-litre bottles, the 1980s saw the re-development of PVC bottles, particularly in emergent economies, such as Mexico, Argentina, Brazil and Asian countries. The main reason was related to cost but, although the initial capital outlay for the PVC bottle was indeed less, the long-term cost with respect to durability shows little or no savings owing to its shorter service life.

Also the increasing use of ozone for the disinfection of bottled water and its dissolved residual content in the water after bottling have a detrimental effect on PVC, embrittling, crazing and discolouring the material. Polycarbonate bottles appear to be immune to the effects of ozone.

The advent of polycarbonate, PVC and more recently multiple use polythene watercooler bottles has demanded new materials for their washing and sterilisation prior to refilling. The very hot caustic wash solutions that were employed on glass bottles are detrimental to the polycarbonate material and new, non-caustic, low-temperature (55–60°C) wash solutions were developed. Similar sanitising solutions to those used on glass bottles for disinfecting prior to refilling are used for polycarbonate bottles, but their concentrations have been adjusted to suit the new plastic material.

Automated handling equipment in the bottling plant and storage racks on the delivery trucks have been developed to prolong the service life by reducing the flexing of the bottle sides during transit.

The modern polycarbonate bottle has further developed over the past 30 years through advances in both manufacturing and materials technology. New blow and injection moulding techniques have reduced the wall thickness of the bottles and have consequently reduced the weight of the bottles by some 10–20%, but without reducing their strength. Advances in materials technology have improved the clarity of the material and its flow characteristics in the mould, allowing for innovative bottle design and decoration. One such benefit has been the availability of built-in handles, which are now almost a standard in East and West Europe. Durability of the material has also improved, increasing service life and, in parallel, the environmental benefits of re-use.

Health & Safety concerns for delivery personnel, as well as convenience for the end consumer during bottle exchanges on the watercooler, have increased the demand for bottles with built-in handles. Similar considerations may also influence bottle size and therefore weight in future.

There have been recent concerns expressed in the media about traces of Bisphenol A, an alleged endocrine disruptor, found in water dispensed from polycarbonate bottles. These traces, however, are of such minute concentrations that leading world health experts, organisations and governments do not consider their presence to be harmful to human health.

Plastic re-usable watercooler bottles are available in 22.7-, 19.0-, 17.0-, 15.0-, 12.0- and 10-litre sizes, and in a variety of shapes (Fig. 10.6), though the larger 22.7-litre bottle has almost been totally phased-out both in East and West Europe and in the North American market.

In the past few years, PET plastic watercooler bottles in 15.0- and 10.0-litre volumes and one-way-use have found some popularity with the residential sector and the supermarket chains. Whilst they simplify the logistics of the industry in there being no empty bottles to collect, they are not as environmentally friendly as the polycarbonate multi-use bottles. However, there is also a growing migration to returnable PET bottles, which may ultimately replace polycarbonate.

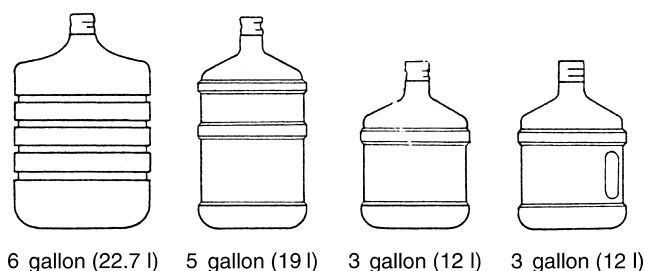


Fig. 10.6 Watercooler bottle shapes and capacities. (The capacities are also referred to as '6-', '5-' and '3-gallon', with reference to the US gallon).

10.3.2.3 *Bag-in-box containers*

Bottles are not the only means by which drinking water may be packaged for dispensing through a watercooler. In 1961, Liquibox, a leading American company in the packaging of liquids, invented the bag-in-box concept for the milk industry. It was to fulfill the needs of being light in weight, stackable, non-returnable (disposable) and aseptic. In simple terms, this is a plastic bag contained within a sealed carton, with the liquid contained being dispensed via a specialised in-built valve.

Unlike the bottle, this means of packaging does not require that air be introduced into the space above the water as water is dispensed from the cooler. The bag simply collapses as the water volume reduces. This feature provides for aseptic dispensing of the water and has created substantial interest from Japan, where the microbiological integrity of the water is of cultural as well as a medical concern.

In the 1970s several American bottled water companies introduced the bag-in-box packaging for their watercooler products; however, after a short period these were discontinued. At the time, the main reason for their lack of popularity was related to a taste taint of the water, usually introduced by the packaging material; however, recent advances in material technology are said to have overcome this problem. It is anticipated that with time this method of packaging will gain further market acceptability especially in the residential, hospital, school, specialised industry and military markets.

10.3.2.4 *Caps*

From the time when glass bottles were introduced for the supply of water for watercoolers, the means of closing the bottles to guarantee the quality of the bottled product have improved substantially.

The plastic cap of the type introduced to coincide with the Watersafe bayonet-and-valve (BV) system by Elkay Manufacturing Co. in 1990, owes its origin to the same US Patent 1,142,210, filed on 29 February 1912. Despite taking nearly 80 years to reach the market-place, this patent with its implications for both the cooler and the bottle cap has revolutionised the bottled watercooler industry. To summarise from the original patent, the inventor's intentions were to allow for a water bottle to be inverted over a watercooler without spillage and to avoid hand contact with the mouth of the bottle for reasons of hygiene.

Recent improvements to the original invention to add further to the safety and hygiene aspects of the cap and bottle are a tamper-evident seal over the valve in the cap, and the closing of the valve as the empty bottle is removed from the watercooler. Figure 10.7 shows the cap with valve. The loading of a new full bottle onto a watercooler entails removal of the

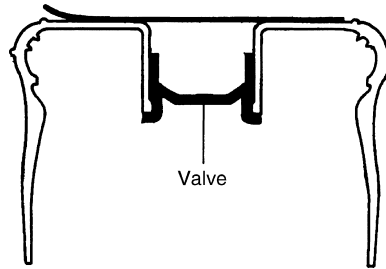


Fig. 10.7 Watersafe cap with valve.

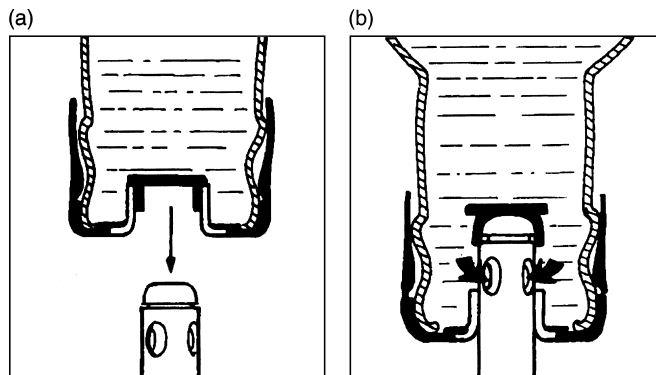


Fig. 10.8 Operation of bayonet-and-valve cap.

tamper-evident seal on the cap to expose the valve below it. The bottle is then upturned over the bayonet on the watercooler top cover, which locates into the valve in the cap, as shown in Fig. 10.8a. As the bottle is lowered over the bayonet, the central section of the valve is lifted out of the cap and mounted onto the bayonet. Apertures in the bayonet direct the water into internal waterways that open into the watercooler's reservoir, as shown in Fig. 10.8b.

Several caps incorporating this, or similar valve design are available today from a number of suppliers, each with a slight technical variation so as not to infringe each others' patents.

There are also several novel inventions designed for insertion into the bottle neck that have some of the non-spill benefits of the BV cap and are intended for watercoolers not fitted with the BV system, or for use with a crock.

10.4 WATER CATEGORIES FOR WATERCOOLERS

Bottled water dispensed from watercoolers may originate from many sources, but there are two major categories used (see also Chapter 3):

- (i) *Natural mineral water and spring water:* These are waters emanating from underground geological rock formations and are collected for bottling either from boreholes or emerging springs. Legislation in each country often differentiates further between these two types of water and stipulates strict naming and labelling criteria based on natural source protection, total dissolved solids, and the amount of processing the water may undergo prior to bottling.

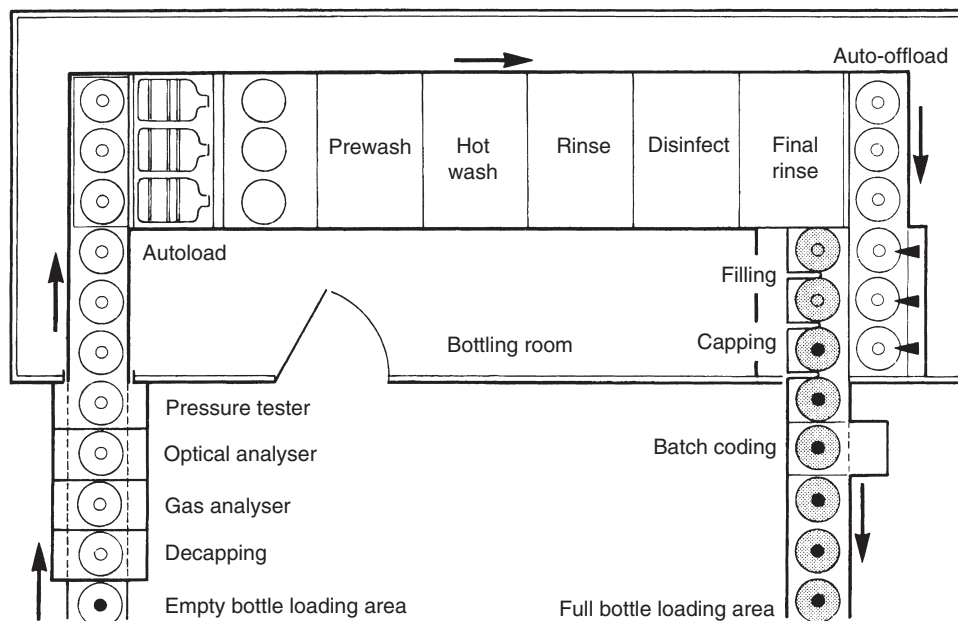


Fig. 10.9 Schematic diagram of bottling plant.

- (ii) *Purified water*: This water may be from a groundwater source or from the municipal water supply and is produced by any one of several methods of purification, including reverse osmosis, distillation, de-ionisation and filtration. This water is also often treated by ultraviolet light or ozone for microbiological reasons and re-mineralised by the injection of soluble inorganic salts.

Water processing is described in detail in Chapter 5.

10.5 THE BOTTLING PROCESS

The bottling of water in large re-usable water bottles, such as the 18.9-litre bottle, is different from the bottling of water in small bottles, intended for single-trip use. The difference is not only related to the volume of water filled into the bottle, but more importantly to the fact that the bottle is a re-usable one that may be refilled over 50 times during its service life.

The polycarbonate bottle is now universally accepted as being the norm (see Section 10.3.2.2). On arrival of the empty bottles for refilling at a modern bottling plant, they will usually undergo some, or all of the following processes (Fig. 10.9):

- (i) *Visual inspection*: manual determination of suitability for re-use, e.g. scratches, labels, etc.
- (ii) *Decapping*: removal of the cap, either manually or automatically.
- (iii) *Gas analysis*: detecting the presence of organic contaminants in the bottle.
- (iv) *Optical analysis*: detecting foreign bodies inside the bottle.
- (v) *Pressure testing*: detecting crack and pin-hole leaks.
- (vi) *Auto-loading*: loading onto the wash conveyor.

- (vii) *Pre-wash*: removal of surface grime and internal lime-scale deposits.
- (viii) *Hot wash*: externally and inside of the bottle.
- (ix) *Rinse*: externally and inside of the bottle.
- (x) *Disinfection*: sterilising from bacterial contamination.
- (xi) *Final rinse*: product water rinse, externally and internally.
- (xii) *Auto-offloading*: unloading onto the filling conveyor.
- (xiii) *Filling*: volumetric or timed filling of the bottle.
- (xiv) *Capping*: sealing of the bottle.
- (xv) *Coding*: production batch number and best-by date: with inkjet/stamping/paper label.

Bottling equipment has undergone many stages of development as new technology has evolved in the electronic and mechanical fields, often as a spin-off from other related industries.

Traditionally, bottle washers and bottle fillers were separate items of equipment installed adjacent to each other in the bottling plant. As increased awareness of hygiene issues related to potential areas of contamination developed, the bottle filling operation was isolated and housed in its own 'clean-room' environment connected to the bottle washer by a conveyor belt. In time, the conveyor belt itself was seen as a potential area for contamination of the washed and sterilised empty bottles and it was either enclosed in a tunnel, or covered over, to prevent foreign matter from falling into the bottles.

By 1990, equipment design had evolved to the point where one fully automated piece of equipment undertook all the operations from stages (vi) to (xv) previously detailed. Even the clean-room environment was built-in by creating a positive pressure area (PPA) for the bottle filling. Today, this design of machinery prevails in most modern plants operating at up to 2000 bottles per hour capacity. Faster production rates usually still depend on the separate bottle washer and filler concept connected together by a covered PPA conveyor system.

An important aspect of the bottling of water in large re-usable bottles for dispensing through watercoolers is the frequent use in some markets of ozone gas for its disinfecting properties. With respect to bottling and the sterility of the final product, ozone's role is related to the final disinfection of the washed bottle in readiness to accept the product at the filling stage. Although the bottles have undergone many separate efficient washing and disinfection operations in their passage through the bottle washer, it is still possible for a single bacterium to have survived on the internal faces of the bottle. Once the bottle is filled with water, this one bacterium may multiply, thereby prejudicing the purity of the product. To overcome this, the water is ozonated just prior to bottling so that a residual of the ozone gas, in the range 0.2–0.4 mg/litre, remains dissolved in the water at the time the bottle is capped. This residual ozone in the water is sufficient to sterilise the bottle's internal surfaces on direct prolonged contact. This method has been found to be so successful that sampling of the product water within 12 hours of bottling will not yield any bacterial count (TVC).

A further application of the ozonated water is often made by spraying the inside faces of the bottle cap just prior to the cap being placed on the bottle. The residual ozone in the water is sufficient to give a final sterilisation of the cap surfaces.

Recent improvements in detection equipment, able to measure traces of contaminants in parts per trillion, have brought the focus of attention onto the potential conversion of naturally occurring and harmless bromide (often found in chalk spring water) to bromate (which is a carcinogen) through the process of over-ozonation. To ensure this does not

occur, specialised control systems and plant practices for the safe use of ozone have been introduced into all bottling plants using this gas.

The maintenance of a sanitary condition for the water being bottled is paramount in the filling operation. To ensure that the washed bottles are not contaminated as they pass through the washer to the filling part of the equipment, they are kept in an enclosed area whose air pressure is maintained at a higher level than that of the surrounding area, PPA, and whose air has undergone filtration to remove sub-micron airborne bacteria, spores and other particles.

The chemical washing agents used in the initial stages of the bottling equipment must not be carried over in the empty bottles to the bottle filling area, neither should any be left in the bottle. For this reason the bottles are loaded onto the wash equipment and travel through it in an inverted manner, bottle base uppermost. The water jets in the wash and rinse sections spray upwards into the bottles and the water subsequently drains out easily. Externally, the bottles are washed and rinsed by jets mounted so that they spray the bottles from all directions and with some equipment also by rotating brushes.

Periodically bottles are manually removed from the bottling equipment at random, just prior to the filling stage and a detergent and sanitiser 'carry-over' test is performed to determine whether any residues are present. This verifies the efficacy of the final rinse stage of the equipment and ensures that an unadulterated product is being bottled.

Where once it was required to have different bottling equipment for each size of bottle, or many hours being spent in changeovers, modern equipment is extremely versatile and can normally fill all of the standard bottle sizes and shapes. In the most advanced equipment, it is claimed that all that is required is the push of a button and the equipment will adjust for the new bottle dimensions, while the volumetric filler will adjust itself for the filling volume of the new bottle.

10.6 HANDLING, TRANSPORTATION AND SERVICE

The bottled watercooler industry is a service industry throughout the majority of the Western world, since the product is delivered to the customer's premises and in the commercial sector, the watercooler is maintained at the same time. This element of service is unique to watercoolers, but is a necessary expense that can account for some 50% of the operating overheads of a bottled watercooler company. As such, the efficient handling and distribution of the filled bottles is a prerequisite to a well-run business.

As the large 18.9 litre bottles come off the bottling conveyor, they are immediately transferred, either manually or by automated machinery, into bulk pallet-containers or stillages holding between 16 and 40 bottles, depending on the handling equipment and delivery vehicles in use. In this manner they are then transported or stored in the bottling plant and warehouse. Where a central plant is bottling for several regionally located distribution depots, large trucks transport over 1300 bottles at a time to their destination, to be off-loaded and stacked awaiting distribution to the customers by smaller vans and trucks. The smaller vans delivering to customers, holding under 88 bottles, are usually fitted internally with fixed racks so that individual bottles are loaded manually, while larger-capacity trucks holding up to 256 bottles accept the pre-loaded bottle stillages directly and reduce the loading time required at the depot. The delivery vehicles are also often compartmentalised for the storage of watercoolers and drinking cups that require delivery at the same time as the bottled water.

The weight of the watercooler bottles can be as much as 24 kg for the 22.7-litre bottles and therefore manual handling aids are required for the delivery person in the form of carrying handles and multi-bottle trolleys.

Once at the customer's premises, the bottles of water are normally stacked by the watercooler; however, large users may require delivery to a central storage area where the bottles may be stored in racks, or bottle stillages provided by the watercooler company. Building maintenance staff then attend to the watercoolers and ensure that they always have an adequate supply of water. For the smaller user, there are bottle racks made of plastic or steel, holding from 2 to 8 bottles to minimise the space required to hold sufficient bottles of water until the next scheduled visit.

The bottled watercooler industry differs from the bottled water industry for water bottled in small bottles, in that the former is service based whilst the latter is product based. This difference is very significant to the organisational structure required by the bottled watercooler company. Typically, watercoolers are serviced with water supplies on a regular scheduled basis, which usually repeats on a weekly, fortnightly or monthly basis, but may be more or less frequent dependent on water usage. The number of watercoolers at each location may vary from just one in a small business or home to many hundreds in a modern high-rise office building. There are no hard and fast rules and a typical customer base will have a mixture of all types of customer, watercooler numbers and territories, dictating that a suitable delivery pattern is established to meet all of the requirements.

Limiting factors on the daily bottle delivery capability of each delivery person will be dictated not only by these factors but by the requirement to service the watercoolers at each customer location except in residential locations. This hygiene element involves the maintenance of the external surfaces of the watercooler and dispensing taps using disinfecting sprays and wipes and ensuring that drip trays are empty and free of undesirable matter.

As with all service industries, customer care is of paramount importance, and while the regular delivery schedule will satisfy the majority of the customer base there will arise situations where out-of-schedule water deliveries are required. Similarly, watercoolers will occasionally malfunction and it will be necessary to exchange the appliance. Whatever the nature of the requirement, a speedy and effective response is required from the service organisation. This dictates that in addition to the regular delivery personnel, a support function of service personnel, both office and externally based, is required.

Bottled water delivery personnel are required to deliver a level of service in excess of that normally expected of other delivery personnel, for example in parcel delivery. This results from the intrusive nature of their job function. Theirs is not a door-step delivery service, but one in which they are required to enter the customer's premises, remove the empty bottles, replace these with full ones, in some cases supply cups and maintain the hygiene of the watercooler.

10.7 HYGIENE

The bottled watercooler industry's history owes its success to providing consumers with contaminant-free, good-tasting drinking water. While modern source protection technology and state-of-the-art water technology can guarantee a safe product at the time of bottling, there are opportunities for the bottled water in the bottle to become contaminated on its journey from the bottling plant to the distribution depot and then at the customer's premises.

While under the control of the bottler and distributor, bottled water in small bottles and bottled water in the large watercooler bottles requires the same careful handling and storage. Both normally fall within the regulations that apply to all food products. These regulations also extend to the delivery vehicles, while the bottled water is in transit on its way to the customer. Once at the customer's premises, its storage should be treated with the same care, since external contamination of the bottles may still occur prior to placement on the watercooler.

Unlike bottled water in small bottles which, once opened, is normally consumed within a very short period of time, the watercooler will provide approximately 130–150 cup servings from each 19.0 litre bottle. Depending on its situation, this may take several hours, days or weeks. As such, control of the quality of water in the bottle, while it is on the watercooler and in the internal cooling reservoir, is of paramount importance. Similarly, the dispensing taps have a role to play in the protection of the water at the time of dispensing.

Some of the technology employed by watercooler manufacturers to protect the water as it passes through the watercooler, from the bottle to the cup, is detailed in Section 10.3.

Prior to installation of a new watercooler at the customer's premises, the watercooler must be flushed through and sanitised to ensure that any foreign matter is washed out and any bacteria that may have been introduced to the water contact surfaces during manufacture or subsequent storage are removed. Having been sanitised, the watercooler should be repackaged in such a manner that it is protected from any contamination during delivery and subsequent installation at the customer's premises.

Where watercoolers utilise removable plastic reservoirs, or non-removable stainless steel, it is considered good practice to sanitise these periodically with a proprietary disinfection solution. This will eliminate the biofilm that is caused by natural harmless bacteria present in water and that normally establishes itself on contact surfaces within a short period of time. The same applies to the dispensing taps.

Similarly, particularly in warm and humid conditions, some unprocessed waters exhibit a tendency to turn green after prolonged periods of storage or exposure to bright sunlight. This 'greening' is caused by single-celled organisms known as chlorophytes, a simple form of algae. These are not thought to be of any significance to human health; however, their presence in water is unsightly and will also increase the organic content of the water, thus providing a food source for bacteria, which can impart a taste taint to the water. The presence of chlorophytes in bottled water and watercoolers is therefore undesirable and measures must be taken to eliminate the cause through hygienic operations at the time of bottling, and by good hygienic management of watercoolers.

Many bottled watercooler companies offer their customers a watercooler sanitisation service on a quarterly, six-monthly, or annual basis at an additional cost over and above the normal watercooler rental price. This will entail removal or sanitisation of the internal reservoir and taps, as well as the external cleaning of the watercooler with a bactericidal agent. In the UK, the British Water Cooler Association mandates its members to undertake a quarterly sanitisation of rented watercoolers. This practice (though usually undertaken on a six-monthly basis) has now spread to other European countries, promoted by the European Bottled Watercooler Association through its codes and standards.

A considerable number of spring and natural mineral waters have a high mineral content, in particular of calcium and magnesium bicarbonate. Such water is referred to as being 'hard' and when it is cooled these minerals may come out of solution and deposit on the walls of the cooling reservoir, creating potential sites for bacteria to colonise. Where the watercooler additionally has a hot water facility, this problem is more acute since the formation of the

mineral deposit in the hot tank will not only reduce the efficiency of the heating coil but will reduce flow substantially. In time, all flow from the tap will be blocked. In such instances, the watercoolers should be subject to regular de-scaling with a weak organic acid to ensure that the mineral deposits are removed.

10.8 TRADE ASSOCIATIONS

The International Bottled Water Association (IBWA), now renamed International Bottled Water Association (United States), based in Alexandria, Virginia, USA is a trade association founded in 1958 and has been a major influence on the development and regulation of the bottled water industry in the United States and worldwide. Since the historical evolution of the watercooler has been from that continent, this organisation has played a major role in the watercooler industry.

As well as EPA and FDA standards and regulations governing the production and packaging of bottled water in the United States, the IBWA has established additional standards for its members. A major instrument in the control of bottled water quality is the IBWA Model Bottled Water Regulations, which are not only applicable to its members but have also been used as the basis for bottled water regulations in much of the United States. This model code incorporates:

- definitions/classifications of water by source;
- good manufacturing practices and operational requirements;
- source water monitoring;
- finished product monitoring;
- labelling requirements.

It is also a condition of IBWA membership that bottlers are subject to an unannounced annual inspection programme by a third-party inspection organisation. The IBWA bottling plant inspection programme comprises over 65 items of compliance, of which over 20% are related to the management of critical control points (CCPs): these are items that are deemed essential to maintain production of a safe product. To obtain and retain membership, a minimum score as set by the IBWA is required, which must also exclude any CCP failures.

Up to the middle of the 1990s, IBWA operated outside of the United States through five international chapters: Europe, Middle East, Asia and Australia, Latin America, Canada, and each chapter disseminated information on behalf of the IBWA to its regional members. Today, these chapters have evolved into separate multi-national regional trade associations, each focusing on its specific geographical area, but maintaining the criteria and standards originally set by IBWA. These associations, though now independent, are represented and communicate through the International Council of Bottled Waters Associations (ICBWA).

The IBWA, EBWA and ABWA each hold an annual convention and trade show that attract manufacturers and representatives from the worldwide bottled water industry and act as a platform to both display and view the latest 'state-of-the-art' bottled water equipment and technology. Concurrently, educational seminars promote a better understanding of good manufacturing practices, product quality-related and legislative issues.

The international trade associations also play a vital role in liaising with regional government and both regional and international regulatory agencies to enhance understanding of

bottled water and watercoolers and some of the features that are unique to water dispensed through them.

The website addresses for the respective associations appear in the Acknowledgements at the end of this chapter.

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11 Third-Party Auditing of Bottled Water Operations

Bob Tanner

11.1 INTRODUCTION

Someone somewhere once said we are blind to what we see every day. We develop blind spots as familiarity often leaves us unaware of the reality of a situation. This common human failing can result in even the most diligent and committed managers of bottled water operations becoming complacent and partly explains the value of independent third-party auditing services. We live in a highly competitive world where the difference between success and failure is sometimes small. Our lives are media-led and the investigative journalist may be feared more than the attentions of the food inspector or the Revenue. Concern for brand protection is paramount and is likely to be the root cause of many business managers' sleepless nights. This concern often prompts the involvement of the independent auditing company.

The global financial crisis is having its effects on the bottled water industry, just as it is on most other industry sectors. Budgets are being drastically reduced as sales decline and cash flow becomes a daily problem. Even at grass root levels, managers are under pressure to cut back, reduce workforces, working hours and product runs. Almost inevitably, important aspects of normal operations can suffer. Programmes of cleaning, repair and preventative maintenance may be reduced. Equipment coming to the end of its normal life is having to be patched up rather than replaced. Sampling and testing frequencies may be cut back, or even cut out. In such austere times company vulnerability increases and there is a strong case for more, not less vigilance. For these reasons, the need for competent, independent auditing of bottled water operations takes on even greater value.

That value of independent, external audits has been recognised by many bottled water companies worldwide from major groups to individual companies, but also by bottled water industry associations who now require regular third-party audits as a condition of membership.

The experienced third-party auditor has several advantages over the majority of plant managers simply because, by the very nature of the role, the auditor will have visited countless bottling plants of all types and sizes. This provides a wealth of experience and expertise mostly denied to the plant managers who may have experience of very few plants. Unlike independent auditing companies, plant managers may also not be able to keep fully informed of changes and improvements in bottled water standards and legal requirements, whether national, regional or global.

11.2 CONDUCT OF AUDITS

Confidentiality between auditing company and client must be preserved at all times, even when the auditor is sometimes pressured to reveal how a competitor handles a particular problem or how they fared during an audit. Auditors do need to have access to often highly confidential business information.

Companies using auditors expect the audit to be a rigorous and comprehensive appraisal of their operations, having regard to the agreed audit criteria. Although sometimes designed to emulate regulatory enforcement inspections, 'firm but fair' is the preferred method of conducting audits and a proverbial arm around the shoulder of plant management, rather than a finger in the face, is likely to be more constructive. To gain maximum advantage from the periodic visit of the independent auditor, the audit should be conducted in a spirit of openness and honesty and, wherever possible, the auditor should be accompanied by at least one manager who not only knows the operation intimately and can therefore respond to the auditor's questions, but can also gain most from the auditor's visit.

A decision has to be made in advance of the audit as to whether it should be announced or unannounced. In order to provide greater value, audits are often unannounced so that the auditor sees things on a typical working day without special preparations having been made to enhance the audit results or to cover up aspects likely to be cited. However, a good auditor will see through such cosmetic improvements and, with the experience of many previous audits, will know the trouble spots, typical problems and areas likely to require particular attention. But unannounced audits also run the risk that there may be no production on audit day, key plant personnel may not be available, or that the audit cannot proceed for other valid company reasons.

The first or initial audit should always be by prior arrangement to ensure that the appropriate plant personnel are available, the plant will be in full production and in all other respects it is a normal working day.

On the first visit the auditor must quickly establish credibility with plant management, without which the exercise will lose value. Time must be allowed for a pre-audit meeting to provide an opportunity for the auditor to explain how the audit will be conducted and how the 'checklist' and audit report will be completed and to answer questions. The auditor will invariably find problems plant managers are already aware of but may then also uncover other items of non-conformance (with agreed criteria) of which plant management is unaware.

At the completion of the initial audit, further time must be taken to discuss the auditor's findings with assembled plant managers. There should be clear understanding of the reasons for the items cited by the auditor and of the required corrective action. This clarity is essential if repeat failures are to be avoided. Very rarely are items of noncompliance the result of a deliberate act or omission, but are mostly due to ignorance or oversight. Knowledge of the precise causes will always help to prevent recurrence. Although the audit is advisory, and not intended to replicate a regulatory inspection, issues should not be trivialised and the auditor should make it clear what could happen during a regulatory enforcement visit.

The success of the audit will, to a large extent, be dependent on the competence of the auditor. The better auditing companies take particular care when recruiting auditors and will have training programmes in place to ensure their auditors achieve and maintain the required standards. As well as technical competence, the auditor must be correct and consistent when interpreting and applying the agreed criteria. A good auditing company may also have peer review procedures and will conduct regular 'check rides' in the interests of consistency and

completeness in the provision of high-quality audits. Questions relating to auditor competency are legitimate concerns of companies receiving audits.

11.3 SETTING THE CRITERIA FOR THE AUDIT

There should be no surprises on audit day, and no confusion or doubts about precisely why the audit is taking place. To avoid any confusion, the audit criteria should be described in the contract for services, which should be agreed and signed between the third-party auditing company and the client whose premises are to be audited, well in advance of the audit. A bottled water audit is essentially an independent assessment of compliance, or conformance, with an agreed set of standards, regulations or other relevant criteria, food safety being the fundamental objective.

The criteria for the audit can vary widely but the more common options are described below:

- the company's own internal HACCP-based food safety system;
- the food safety requirements of the company's main customers;
- the requirements of a foreign country to which products are to be exported;
- the requirements of international standards, such as ISO 22000, and the new PAS* criteria in Europe and elsewhere;
- the membership requirements of a trade association;
- the legal requirements of the local food enforcement authority;
- the requirements of a certification organisation, such as NSF International, providing product certification;
- a combination of two or more of the above.

*PAS 220 is worthy of particular mention here. PAS 220 is the product of a joint initiative by a consortium of major food and beverage companies, including Danone, Nestlé, Kraft and Unilever working together under the auspices of BSI (British Standards Institute). This PAS (Public Accessible Standard) builds on the requirements of ISO-22000:2005, which sets out specific food safety requirements for organisations in the food chain. These include the establishment of prerequisite programmes (PRP) and operational prerequisite programmes (O-PRP) to assist in controlling food safety hazards. PAS 220 has no legal status but is a voluntary code specifically to provide detailed requirements in relation to section 7.2.3 of ISO 22000:2005. It does not remove the legal requirement in Europe to comply with HACCP: rather it complements it.

HACCP in the EU is a legal requirement of all food and beverage businesses, whereas PAS 220 only applies to 'inside the factory gate' food and beverage production.

PAS 220 provides detailed requirements to be considered in relation to ISO 22000:2005 under the following categories:

- construction and layout of buildings and associated utilities;
- layout of premises including workspace and employee facilities;
- supplies of air, water energy and other utilities;
- supporting services including waste and sewage disposal;
- suitability of equipment and its accessibility for cleaning and maintenance;
- management of purchased materials;

- measures for the prevention of cross-contamination;
- cleaning and sanitising;
- pest control;
- personnel hygiene;
- traceability and product recall;
- warehousing;
- product information and consumer awareness;
- food defence/biovigilance/bio-terrorism.

The introduction of PAS 220 in Europe has added a new dimension to food safety considerations and several companies have already amended their own internal food safety standards to embrace the new measures, wherever necessary. This trend is also being followed elsewhere, including in the United States, where major retail customers are demanding from their suppliers a more comprehensive approach to food safety. Whilst PAS 220 has certainly added new elements, perhaps to reflect the changing world we live in, such as bio-vigilance and bio-terrorism, the other criteria listed above continue to have important significance.

The NSF International Bottled Water and Packaged Beverage Certification programme pulls together into one comprehensive ‘checklist’ all the major Codes, Regulations and related standards in the bottled water/beverage industry as prescribed by national or regional regulatory agencies. These may include:

- the US Food and Drug Administration Vol. 21 Code of Federal Regulations (as amended);
- European Drinking Water and Natural Mineral Water Directives;
- the EU Food Hygiene Directive;
- Codex Alimentarius Regulations governing HACCP; Food Hygiene and specific bottled water Codes.

Many bottled water companies are registered under ISO-9000, verifying that the company’s quality management system is in compliance with that international standard. The third-party auditor may also be an ISO-9000 assessor, or lead assessor, or may be accompanied by one, and the audit may therefore include an ISO-9000 assessment, in addition to the food safety-related criteria mentioned above. Other combinations are possible, such as ISO-14000, the Environmental Management System standard.

A competent auditing company can bundle related services together for the benefit of clients. This has obvious advantages over separate auditing of an integrated management system.

11.4 THE BOTTLING PLANT AUDIT

Depending on the agreed audit criteria, the size of the plant, location of source or sources, the number of bottling lines and final products, etc., the audit will take at least one full day, usually involving a single auditor. Basic information regarding the bottling plant will have been provided to the auditor in advance so that the necessary time-planning can be completed and agreed.

After arrival and introductions the auditor will lead a short meeting with plant management to confirm the audit process. It is important that the auditor remains focused

throughout the audit and is not led away from the audit plan. There follows a thorough documentation review, prior notice of which may have been communicated to the plant to ensure all the necessary information is readily available. Among the several documents to be reviewed are the following, depending on circumstances:

- Extraction Licence, or similar document, authorising the use of the source water;
- city water management details, if used as 'raw water';
- HACCP Plan or Plans, including the important and detailed flow charts. (Not simple flow diagrams.) Note that, unless the audit is required for HACCP-Certification, this is not a full assessment of the plant's HACCP Plan which takes much longer, but a short assessment to ensure the Plan includes all seven 'Codex Principles', is up to date and is a true working document and not simply the product of a one-off academic study. It must also be reviewed at least annually by the plant's HACCP Team;
- water treatment and product treatment data, including heat-treatment processes and treatment equipment records;
- product specifications and food-grade evidence concerning any ingredients such as CO₂, flavours, etc.;
- current 'sign-off' sheets confirming that all necessary actions in the HACCP Plan are being carried out. This includes records of actions such as cleaning, filter changes and preventive maintenance;
- source water and final product sampling and testing records showing frequencies, purpose and results;
- documentary confirmation that all primary packaging and other water-contact surfaces are food-grade;
- staff training records;
- pest control contract and records;
- product traceability and recall programmes, with evidence that mock recalls are carried out at least annually;
- calibration records of laboratory and other testing equipment;
- transport inspection records.

On completion of the documentation review the physical part of the audit will begin. Typically the auditor will 'follow the process flow' from source water extraction, or delivery, to final product shipping.

11.4.1 The source

Having established the client's right to extract and bottle raw water, the auditor will want to visit the point of extraction whenever practical, whether it is a well, spring or other source. Whilst sources for Natural Mineral Water, Spring Water or other Artesian waters are underground, a surface water source (i.e. river or lake) may also sometimes be used. Unlike underground sources, surface waters may be heavily contaminated and the auditor will be looking at the methods of water purification and treatment in the bottling plant, as well as extraction arrangements at the source.

Some companies using underground water sources have determined the age of their water using carbon-dating techniques, sometimes with surprising results. Underground waters have been found to be many years old, even thousands of years in rare cases. As a general rule, the longer the water has remained in the ground, filtering through the different

geological strata, the purer it will be in microbiological terms. It will also have acquired a distinctive flavour due to the absorption of traces of mineral salts during its time underground.

The auditor will determine whether the water catchment area (the area where the rain falls) and the groundwater extraction point are free from sources of potential contamination. In particular, the auditor will need to establish, on the basis of information supplied by the client, that there is no risk of contamination from nearby habitation or industrial activities in the water catchment area. Agricultural practices, involving the almost inevitable use of agro-chemicals or intensive livestock production, can pose a risk to groundwater and so can roads and railways in the catchment area if herbicides and pesticides are used. A full risk assessment should have been made by the bottling company for any potential problems and remedial actions implemented where necessary. The results of these studies should be made available to the auditor as background information

For underground sources, the point of emergence should be protected from possible sources of pollution such as groundwater infiltration or flooding, and ideally should be housed in a small building or cabinet to protect it from dust, insects, birds and animals. Access should be limited to a small number of authorised keyholders and the entrance should be equipped with an alarm and, if in an isolated location, ideally covered by closed-circuit television (CCTV) cameras where practicable.

Where the 'source' of bottled water is the local piped supply of municipal or other private water, the auditor will ask to see an invoice or other proof and will review submitted test results. Evidence of a good working relationship (contact names, emergency telephone numbers, e-mail address, etc.) between supplier and bottler is essential.

In some bottling plants, water arrives at the source via tankers. This is illegal in the EU (European Union) unless under protected 'grandfather rights' – i.e. if they can demonstrate that they were tankering prior to the implementation of the Directives, which prohibited the practice. However, tankering is frequently used in other markets as the only means of delivering water from remote spring or other sources. Tankering practices, where they exist, will also be reviewed during the audit.

11.4.2 Pipeline and raw water storage

The pipeline carrying water from source to plant may be a few metres long or several kilometres in length. The auditor will want to establish that water-contact surfaces in the pipeline are constructed of food-grade stainless steel or high density polyethylene (HDPE) or other approved materials. Short lengths of cast iron may be acceptable but other materials such as PVC and concrete are not. The pipeline should be laid underground on a sand bed and sufficiently deep to prevent physical damage and weather effects. (The pipe may be above ground but only within land occupied by the bottling company and provided the pipe is fully protected.) There should be a water sampling point at the end of the pipeline, before any storage or treatment. The auditor will pay particular attention to the source water delivery system. In some plants the same source water is used for final product and also for operational purposes such as washing, flushing and even fire fighting. This dual use is acceptable provided that backflow prevention devices have been fitted to prevent operational water flowing back into product lines.

Source water storage arrangements, where they exist, will also be audited. Storage tanks should be of stainless steel, completely air-tight and equipped with sub-micron air filtration. Cleaning in place (CIP) arrangements will typically include spray-ball systems. The auditor

will examine records to verify acceptable cleaning procedures and filter changes, as well as conduct a visual inspection of the storage tanks. Evidence of leaking or drain-out pipes that discharge below flood levels of floor drains are examples of things that will be cited.

11.4.3 Exterior of bottling plant

The auditor will want to see that the area around the bottling plant is well maintained and free from uncontrolled vegetation and other sources of potential contamination. Equipment and materials stored around the building should not provide harborage for rodents or other vermin, and litter should not be allowed to accumulate. However, favourable consideration will be given to storage of materials for recycling or disposal awaiting collection. Ponding of water must be avoided as this will encourage mosquitoes and allow the development of unsanitary conditions. Wind-blown spores and moulds are less well-understood sources of contamination and may result from unkempt exteriors of bottling plants. In some locations, special measures need to be in place to control the risk of dust or sand from blowing into the bottling plant. The experienced auditor will assess the likely risks from the plant's environment and will determine if the plant has any necessary contingency plans.

11.4.4 Plant construction and design

Plant construction, design and layout are important considerations when designing a bottling plant for the production of high-quality and safe bottled water and other beverage products. It is not essential for the building to be brand new and purpose-built to achieve that objective and even converted farm buildings have (following extensive modification) accommodated efficient bottled water operations.

The auditor will assess the suitability of the buildings for bottled water production and will have regard to the functionality of the various rooms. High risk areas will receive careful consideration; 'Is there enough space?' is a primary consideration. All too often, particularly in the water cooler industry, a company starts small but grows quickly and expands its operation with the result that premises are sometimes overcrowded, space is limited and there is inadequate room to facilitate normal operations such as routine cleaning, servicing and pest control. The auditor assesses the construction and condition of the walls, floors, ceiling and roof, remembering that most are 'food rooms' and must meet, at the very least, the requirements of food hygiene law. Are all internal surfaces clean and in good repair, with smooth easily cleanable finishes made of non-absorbent materials? Anything less should be cited by the auditor.

11.4.5 Water treatment and primary packaging

The extent to which raw source water may be treated varies according to locality and governing legislation. Within the EU, treatment of designated Natural Mineral Waters (NMW) is not permitted, except to reduce an excess of certain chemical elements such as iron, manganese and arsenic. The microbiology of NMW must not be altered. Where permitted, such treatment methods must accomplish the intended purpose and this will form part of the auditor's enquiry. Detailed records should be kept of the dates on which the treatment equipment was inspected, of the conditions found and the action taken to attend to any problems. The performance and effectiveness of treatment equipment must be reassessed and recorded regularly. Treatment methods, and treatment equipment, must preclude risk of product

contamination or adulteration. In some plants there may be extensive water treatment and purification procedures and the auditor will spend time examining each one.

Where municipal or public water is the 'source water', other treatments, such as reverse osmosis, UV treatment and ozonation may be allowed. Additional treatment may also include carbon filtration – to remove or reduce chlorine residuals – carbonation (the addition of CO₂) and re-mineralisation involving the addition of minerals.

Primary packaging procedures will be audited. This will involve verification of food-grade materials – such as PET and PC bottles, and PP caps. In larger plants where PET bottles are manufactured from resin or simply 'blown' from preforms, the whole process will be checked, including the integrity of conveyor covers and the condition of silos where blown bottles are stored. Where returnable glass or polycarbonate (and, increasingly returnable PET) bottles are used, the auditor will have particular regard to the washing process. Washing machines must be well maintained and all actions documented, including operating procedures, temperatures, use of detergents and disinfectants, and 'carry-over' testing. Experienced auditors will be very aware that bottle washers can be a source of serious problems, if not functioning correctly. Not only will bottle washing, sanitising and rinsing be inadequate but the washer itself may contaminate bottles because, for example, detergent and sanitiser are not being changed frequently enough, according to suppliers' guidance, or operating temperatures are well below optimum. Placing heavily contaminated bottles – particularly 'green' bottles – in a bottle washing machine must be avoided. Special attention is paid by auditors where glass bottles are being used, particularly during the bottle washing process.

11.4.6 Filling, capping and labelling

Competent auditors are aware that the bottling room, containing the filling and capping equipment, is the 'high risk' area for obvious reasons, as this is where the product water is exposed to the air and where bottles are open and vulnerable to contamination from final rinsing until capping. The auditor will want to determine that the bottling room is physically separated from other plant operations and storage areas.

In smaller plants – particularly for the Home and Office Delivery (HOD) market – bottle washing, sanitising, rinsing, filling and capping may all take place in one machine, referred to as a mono-bloc, contained within a bottling room. In such cases, the mono-bloc itself is the 'high risk' area and should be equipped with its own filtered air supply to provide positive pressure at the filler heads

The bottling room should ideally be self-contained, with self-closing doors and any windows must be unopenable. The room should have tight-fitting walls and ceiling and, where conveyors pass through walls, openings should only be large enough to allow product to pass through and should be closable when not in production. Modern plants may also have mono-blocs, which is a large cabinet containing all filling and capping equipment and provided with air pressure blown into the cabinet through a HEPA (high efficiency particulate arrester) filter.

The auditor will pay particular attention to the filling and capping area and will check to determine whether the air filter is the right size and is changed according to plan. There must be no surplus lubricant or other source of contamination on the filler and capper. The equipment must be clean, well maintained and working correctly. This is why it is so important for audits to take place during production.

Glass bottle filling presents additional challenges because of the obvious risk of glass breakage. Bottles may explode when being filled – perhaps due to thermal shock – scattering glass fragments in all directions. There should be an automatic system in place to reject

a number of bottles, both in front of and behind the broken bottle, as well as a thorough cleaning of the equipment and removal of all glass particles. However, electronic detection equipment placed on the line immediately before the filler will reject any sub-standard bottles. Prior to entering the filler, bottles are normally given a final rinse, which may be of sterile air, ozonated water or final product water.

Cap storage and handling and the capping process will be checked by the auditor as will the labelling and code marking. Labelling machines and code marking equipment – including laser-jets – should not be located inside the high risk filling area.

The filling, capping and labelling processes must be monitored. Regular checks, or automatic equipment, will verify that all bottles are correctly capped and labelled, contain no extraneous matter and that the contents are to the stated volume.

The quantity and type of bottled water products produced in every product run, the date of production, the lot codes used and final distribution to depots, wholesalers, shippers, etc. should also be recorded.

11.4.7 Lighting and ventilation

High-quality lighting and ventilation systems are important in a bottling plant. Lighting levels of at least 50 foot candles must be maintained in the bottling room and at inspection points, toilets and changing rooms and a minimum of 20 foot candles maintained in other areas, including product storage. The auditor will carry a calibrated light meter to determine the adequacy of lighting levels and will look to see that light bulbs or tubes positioned over the filling area or over open bottles or other water-contact materials are of the safety-type, are shatterproof, or are otherwise protected from risk of breakage contamination.

Ventilation systems must be adequate for the purpose and effectively remove steam and prevent condensation build-up on surfaces. Maintaining a positive air pressure in the filling area will help to minimise the risk of dust and other debris. All air movement is thus away from the critical filling point. Ventilation systems must be maintained in a clean condition at all times and air filters must be regularly inspected and changed as necessary and records kept of this action. Above all, it is vital to ensure that ventilation filters are appropriate for the function intended. For example, air being supplied to filling rooms and other open bottle areas must be appropriately controlled and in some cases (depending on the external environment) HEPA-filtered to eliminate the risk of airborne contamination.

11.4.8 Warehouse, product storage and transport

Normally the secondary packaging process is not of particular interest to the auditor, provided there is no risk to the product and that the final package contains adequate and correct product coding data. However, the auditor will audit the product storage and transport arrangements.

Bottled water products may be stored immediately after bottling, as in the Home and Office Delivery (HOD) industry, or may be packaged in a number of ways in the case of 'small pack'. The warehouse, or storage depot may be at the bottling plant or elsewhere but the auditor will need to visit it wherever practicable. Final products should be stored inside a building which is clean, dry and in good repair. External doors should be pest-proof and kept closed when not in use. Storage on racks is acceptable provided they are in good condition. Alternatively products should be stored on pallets – but not for long periods, which will restrict floor cleaning – and placed at least 0.5 m from walls to aid cleaning, inspection

and pest control. The warehouse should be well-lit and ventilated and not used for storage of other products or materials that may pose a threat to stored bottled water products. Bottling plants should have separate and suitable, locked chemical storage facilities well away from other plant operations. The auditor will normally visit the chemical storage facility and will want to see that chemical products Safety Data Sheets are clearly displayed.

Separate and clearly defined areas for products on hold or that are quarantined should be provided in all final product warehouses. A FIFO (first in first out) routine will ensure correct product rotation.

All final product vehicles – including lorries, railway trucks and shipping containers – should be inspected before loading, to ensure there is no risk to products in transit, and the inspections should be recorded. If these logistical arrangements are included on the checklist, the auditor will review relevant documents.

11.4.9 Pest control

Pest control arrangements will be assessed by the auditor who will want to check if all external doors, including dock doors are self-closing and tight-fitting to prevent pest access. Bait boxes containing poison should never be placed inside the plant buildings but located around the exterior next to doors and other entrances. Other devices, such as spring traps and glue boards, are permitted inside the plant provided they are well maintained. Electronic flying insect traps should be installed at suitable locations and visits by the pest control contractor should be logged. The auditor will have reviewed the pest control contract documents, including the site plan showing pest control installations, and will verify the plan's accuracy.

11.4.10 Personnel

'People make the difference' is an old truism, as often the single biggest risk to safe bottled water production is people. What people do or do not do can be significant. The plant will not run without people, no matter how automated it may be, and a high degree of training and supervision, as well as personal cleanliness, are necessary to avoid problems.

Effective staff supervision is essential in all bottling plants and the hygiene of the bottling plant should be under the supervision of one individual whose responsibilities may include personnel supervision in all but the largest plants. Plant personnel must be adequately trained with particular regard to bottled water hygiene so that they fully understand what they are responsible for and how to avoid risks.

The auditor will need to know what arrangements are in place for employees to notify the company when they suffer from a disease or illness that could be transmissible to the product. It is important that the employee does not suffer financial consequences as that is an obvious deterrent to proper notification

Personnel practices will be assessed by the auditor, who will want to see that clean protective clothing is worn, particularly in the filling areas; that hair restraints are worn; that un-cleanable jewellery, such as rings, brooches, studs, pins, clips and other adornments are not worn; that hand-washing practices are acceptable; and that a high degree of personal cleanliness is evident. The cleaning of protective clothing should be done by the bottling plant and not the individual, as the latter is less controllable. Tobacco must not be used in any form, there should be no eating at the workplace, and no chewing gum.

Auditors will check to ensure hand-washing facilities, comprising hand washbasins, with hot and cold water, liquid soap and hand-sanitising solution, nail brush and hand-drying

facilities, are conveniently positioned to aid frequent use, particularly by workers entering the filling room.

Toilets should be of the sit-down design and not the squat-down type, but cultural practices may take preference. All toilets should have automatic flushing.

There must be an adequate number of washbasins adjacent to the toilets with clear signs reminding staff to wash their hands thoroughly after use. Disposable paper towels with foot-operated lidded waste bins, or hot air dryers should be supplied for hand-drying. Cloth roller towels should be avoided. Lockers and lunchrooms, where provided, should be physically separated from plant operations and must be clean at all times and well lit. The auditor will also look for unacceptable personal practices throughout the plant.

11.4.11 Laboratory

Even the smallest bottling plants should have a laboratory so that basic testing can be done on site. Larger plants will have more advanced equipment. The auditor's interest is to see that the laboratory is clean, well lit and ventilated and adequately equipped. It should be staffed by one or more competent technicians who are using recognised test methods and test materials. Certain equipment must be regularly calibrated for optimum performance and records maintained.

External laboratories, used for necessary independent testing and to meet legal requirements, must be Government approved. They may also be ISO-17025 accredited.

11.4.12 Product traceability and bio-terrorism

Audit checklists will today include questions concerning final product traceability and product recall procedures. The auditor will want to verify that the plant keeps full records of the type and volume of product produced per run, per batch or per day on each production line. In addition, there will be related records concerning primary packaging details. Lot codes or bar coding systems will be reviewed, as well as the process for distributing final products.

Of particular interest to the auditor will be the plant's Recall Plan detailing the procedure for recalling product. This plan should be reviewed regularly and an annual mock recall exercise should be made to test its adequacy. The auditor may ask to see evidence of the annual mock recall, the conclusions from which should be fully documented.

An increasing number of audit checklists now include questions relating to bio-terrorism, particularly if products are to be exported to the US. Bio-terrorism refers to the risk of sabotage or other criminal actions intended to harm consumers and/or the company selling bottled water products. The auditor will ask questions on subjects ranging from plant and source security; personnel recruitment practices; access to high-risk areas inside the plant; procedures for dealing with visitors to the plant, including service personnel and contractors; delivery and storage of raw materials; and personnel identification.

11.5 CONCLUSION OF AUDIT AND FOLLOW-UP ACTIONS

Having completed the physical inspection of the bottling plant and source and having reviewed all available records and other documents, the auditor will compile the audit report from detailed notes taken during the audit. Most audit reports today are prepared electronically, with obvious benefits, but a paper copy may still be preferred by some clients.

A final meeting is held with plant management – the exit interview – during which the auditor will report findings, detail any items of non-compliance with the agreed criteria on which the audit was based. Auditors are often accused of concentrating on the negative but this is the intended purpose: to identify those items found to require attention in order to bring operations into full compliance. Spending time praising plant management on the many compliant items will detract from the main purpose of the audit when the focus must be on areas needing attention.

The auditor may use a scoring system to help the client understand how the plant is performing against the agreed criteria. Typically, this will be a percentage score and each item on the auditor's checklist or audit report form will have a numerical value and points will be deducted based on severity or extent of non-compliance. Items of non-compliance with the company's own HACCP plan, particularly its Critical Control Points (CCPs), will be of particular concern and the plant may be said to have failed the audit in such circumstances. However, audit scoring and pass/fail conclusions are less commonly in use today and a straightforward, factual audit report is preferred.

Plant management should always prepare a corrective action (CA) plan to address the items of non-compliance, or non-conformance, in the audit report. This should be submitted to the auditor within a reasonable time, typically 30 days after the audit, depending on their severity, with a timescale for completion. (Some items may require immediate attention to avoid more serious consequences.)

Audits are usually made at annual intervals, unless more frequent audits are required by the client or the poor conditions found during the audit warrant an earlier revisit. Non-submittal of acceptable CA may also require a follow-up visit.

Third-party audits do provide significant added value to bottled water companies. They assist with risk management responsibilities and may help to provide a 'due diligence' defence in times of need. Regular audit reports also encourage progressive improvement but achieving an increased score should not be the sole motivation. The assurances provided by a competent, experienced and internationally respected, independent, third-party auditing company concerning the quality and safety of bottling plant operations have many benefits, not least of all the sleeping patterns of plant management.

12 Microbiology of Natural Mineral Waters

Henri Leclerc and Milton S. da Costa

12.1 INTRODUCTION

The virtues of mineral waters have been expounded by poets and novelists from the times of ancient Greeks and Romans. Since then, numerous establishments have been built in Europe, where people could seek treatment for several diseases from the reputedly beneficial health properties of these waters. It was, therefore, natural that a business based on the bottling and transport of the mineral waters slowly began to take hold in Europe.

The mineral water market has increased dramatically since the 1970s because of the introduction of polyvinyl chloride (PVC) and subsequently polyethylene terephthalate (PET) bottles for water. European regulations were instituted to control bottling and the marketing of Natural Mineral Water (Directives 80/777/EEC and 96/70/EC of the European Parliament and of the Council, recast in 2009 as Directive 2009/54/EC on the exploitation and marketing of natural mineral waters). These Directives were a compromise between the “Southern European” who considered the beneficial action of the water to health and the “Northern European” concept based on the mineral content and/or the presence of gas imparting a pleasant taste to the water.

Natural Mineral Water is defined as a microbiologically wholesome water, originating from an underground water table or deposit and emerging from a spring tapped at one or more natural, or borehole, sources. Natural Mineral Water can be clearly distinguished from ordinary drinking water by its nature, which is characterized by the mineral content, trace element components or other constituents; perhaps by certain beneficial health effects; and by the fact that it has not been treated, preserving the original qualities of the underground water, which has been protected from pollution.

These characteristics, which may make Natural Mineral Water beneficial to health, have to be studied extensively in the context of geological, hydrological, physical, chemical and physicochemical, microbiological, and if necessary, pharmacological, physiological, and clinical characteristics. The composition, temperature, and other essential characteristics of Natural Mineral Water must remain stable over time, within the limits of natural fluctuations, to show that the aquifer is stable and is not affected by surface alterations.

Natural Mineral Waters, like all subterranean waters, contain a natural bacterial flora. The presence of the normal flora of mineral water has given rise to a number of questions and debates about its effect on health, primarily because this flora is not yet very well characterized. However, Natural Mineral Waters cannot be subjected to any type of disinfection

that modifies or eliminates their biological components; therefore, they always contain the bacteria that are primarily a natural component of these waters.

In this chapter we discuss the results that have been published, in the last 20 years, in the area of mineral water microbiology and, as the reader will become aware, show that there is a continuing search for new information on groundwater microbiology and microbial ecology.

12.2 GROUNDWATER HABITAT

Before the 1970s, the study of life in groundwater habitats was relatively limited. In the 1970s, however, it became increasingly obvious that certain waste disposal practices were contaminating subsurface environments with effects on groundwater quality. This led to the current interest in the study of these environments. There has also been an increasing interest in demonstrating that a variety of shallow (Balkwill & Ghiorse, 1985; Madsen & Ghiorse 1993) and deep environments (Balkwill 1989; Frederikson & Phelps 1997) contain substantial numbers of viable micro-organisms, and in using these micro-organisms to degrade potential pollutants, i.e. in bioremediation. Subsurface microbiological research to study microbial community structure, microbial activities- and geochemical properties of groundwater environments has progressed with the development of aseptic sampling techniques (Chapelle 1993; Madsen & Ghiorse 1993; Wilson 1995; Fredrickson & Phelps 1997).

The ecology of micro-organisms is concerned with the relationships between different species and between micro-organisms and the environment. The basic unit of ecology is the community or biocenosis. Both the biotic components – the community – and the abiotic, physicochemical components make up the ecosystem. The major focus of ecological research is to determine how communities are structured, how species in the community interact with each other, and how communities interact with their physical surroundings. When speaking of a particular part of the community, i.e. micro-organisms, the term environment or habitat is often used to designate both the physicochemical and the biotic components of the ecosystem.

12.2.1 Physical component

The terrestrial subsurface is an important component of the geological landscape through which water flows in its cycle between the atmosphere, soil, lakes, streams, and oceans. The most fundamental distinction between subsurface hydrological environments is the difference between the saturated and unsaturated zones. The unsaturated zone is usually divided into three components (Fig. 12.1):

- (i) the soil zone, with the A, B, and C horizons, generally 1 or 2 m thick, which contains living roots and supports plant growth;
- (ii) the intermediate zone, which is the underlying material, consists of sediments or rocks that have not been exposed to extensive pedogenic (soil-forming) processes; and
- (iii) the capillary fringe, which is the boundary between the unsaturated and the saturated zones.

This boundary will fluctuate according to seasons, rainfall, or pumping rates, and this will induce chemical oxidation–reduction reactions. The unsaturated zone is characterized by

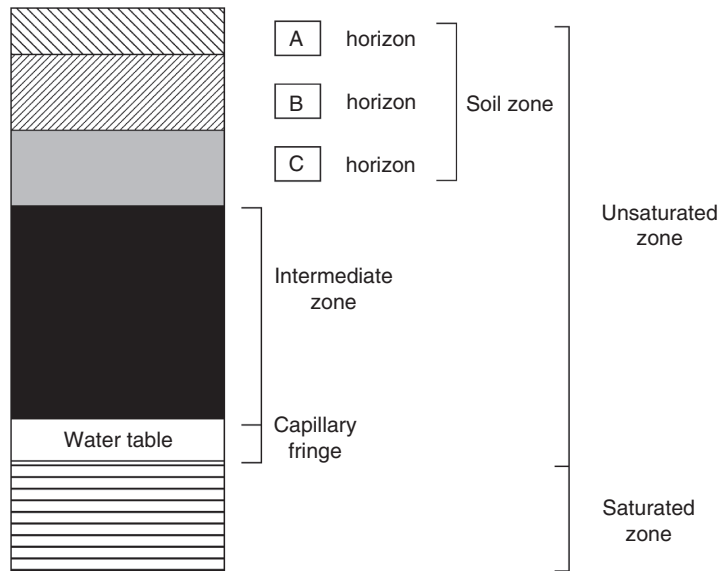


Fig. 12.1 The three components of the unsaturated zone.

pore spaces that are incompletely filled with water. Any pore space that is not filled with water contains gas, and the capillary forces between water and sediment particles prevent water from flowing to wells. Thus, wells drilled into the unsaturated zone do not yield appreciable quantities of water.

For saturated environments, a rigorous distinction between local, intermediate, and regional flow systems, related to the topography of recharge and discharge areas, has been long recognized by hydrologists. According to Toth (1963):

- A local system has its recharge area at a topographic high and its discharge area at a topographic low that are located adjacent to each other.
- An intermediate system is where recharge and discharge areas are separated by one or more topographic highs.
- A regional system is where the recharge area occupies the water divide and the discharge area occurs at the bottom of the basin.

There is an important difference between Toth's classification that depends only on the distribution of recharge and discharge into the hydrological system and the early empirical classification, related to depth as deep and shallow. Thus, Toth's classification can be more universally applied than the empirical classification (Chapelle 1993). These three different hydrological settings are similar to the zonation that had been described empirically by Norvatov and Popov (1961) and that includes an upper zone of active flow strongly influenced by local precipitation events, a medium zone of deeper flow only moderately affected by local precipitation events, and a lower zone of relatively stagnant water unaffected by local precipitation.

In a hydrogeological sense, groundwater refers to water that is easily extractable from saturated, highly permeable geological strata known as aquifers (Davis & De Wiest 1966; Freeze & Cherry 1979). However, to micro-organisms living in microhabitats, all available

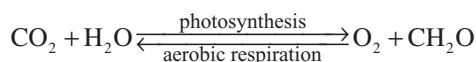
forms of water may be important. Therefore, a broader definition of groundwater that includes capillary water, water vapor, and water within aquifer formations was defined by Madsen and Ghiorse (1993). The groundwater habitat includes part of the unsaturated zone that may contain significant amounts of biologically available water. Also, unsaturated zones may be saturated transiently during recharge events and they may influence both the chemistry and microbiology of the saturated zone. Thus “groundwater refers to all subsurface water found beneath the A and B soil horizons that is available to sustain and influence microbial life in the terrestrial subsurface” (Madsen & Ghiorse 1993).

12.2.2 Chemical component

Within a given environment, such as groundwater environment, most microbial processes are consistent with oxidation–reduction reactions, which can be viewed as the microbial food chain. A compound that is an oxidized end-product for one microbe may be a reduced substrate for another. By sequential coupling of microbial processes, virtually all the energy that is biologically available in a given substrate, or a group of substrates, will be extracted by the microbial population. The electron source, or donor, for the oxidation–reduction couple is organic carbon and is probably the most limiting substrate in groundwater systems. According to Ghiorse and Wilson (1988), allochthonous dissolved organic carbon (DOC), most of which is the recalcitrant fraction of organic substances, might govern subsurface microbial metabolism. This fraction arises from surface plant material (humic substances composed of polyphenolic subunits), delivered through hydrological recharge and groundwater flow.

The most commonly available terminal electron acceptors represent various degrees of oxidation–reduction potentials (Table 12.1). They are inorganic compounds that are relatively stable in water. Oxygen is the electron acceptor that provides the greatest energy yield; in the presence of oxygen, aerobic metabolism dominates. However, aquifers normally constitute a closed environment, and oxygen availability is generally limiting. During aquifer recharge, oxygen rates are fixed via equilibrium with the atmosphere in the unsaturated zone or the capillary fringe. Any additional oxygen entering along a flow path within the aquifer can be considered as insignificant (Smith 1997). When oxygen is present, it is the primary electron acceptor, not only because it has the highest reduction potential but also because it inhibits anaerobic processes such as iron and sulfate reduction, and methanogenesis.

The carbon, oxygen, and hydrogen cycles are driven either by solar energy through photosynthetic fixation of inorganic carbon or, in turn, by chemical energy with the oxidation of organic carbon to CO_2 :



In groundwater systems removed from photosynthesis, the truncation of the cycle leads to depletion of oxygen and the accumulation of CO_2 and CO_2 -derived carbonate species. In the case of local flow systems, characterized by relatively close interaction with the surface, most of the CO_2 generated by oxidation of DOC is readily exchanged with soil gases and, ultimately, liberated into the atmosphere. In contrast, the accumulation of CO_2 associated with intermediate or regional flow systems leads to the formation of effervescent mineral springs. The occurrence of CO_2 -charged waters at the springs is thus an inevitable manifestation

Table 12.1 General characteristics of the electron acceptors most commonly found in groundwater.

Electron acceptor	Reduced product	Level in groundwater (mmol/l)
O ₂	H ₂ O	0–0.4
NO ₃ [−]	N ₂	0–20
Mn(IV)	Mn(II)	Low
Fe(III)	Fe(II)	Low
SO ₄ ^{2−}	S ^{2−}	0–15
CO ₂	CH ₄	0–4

of carbon oxidation under anaerobic conditions. Many naturally carbonated mineral waters get their CO₂ from magma; this can be shown by isotopic analysis.

After oxygen, nitrate is the next most favorable electron acceptor in subsurface environments. Oxygen represses the formation of nitrate and nitrite reductases. If the enzymes have already been induced and the cells are subsequently exposed to aerobic conditions, oxygen will compete with nitrate for electrons delivered by the respiratory chain, and will inhibit the function of the nitrate-reducing system. Through the nitrogen cycle, nitrate produced by oxidation of ammonium (at or near the soil surface) can percolate vertically down to the groundwater system. If the aquifer is aerobic, nitrogen cycling truncates at this point and nitrate accumulates in groundwater. As the groundwater becomes anaerobic, as frequently occurs along the flow path, the nitrogen cycle continues through denitrification and nitrate does not accumulate in the aquifer.

Iron, manganese, and sulfate are naturally abundant in many underground systems. Fe(III) occurs most frequently as insoluble oxides and hydroxides, and as coatings on mineral grains with various degrees of crystallinity and structure. Mn(IV), like Fe(III), may be present in large quantities in an aquifer, which may lead to water containing Mn(II) and Fe(II). Sulfate can be a minor groundwater constituent or an abundant reservoir from sulfate-bearing minerals. Finally, when all other electron acceptors have been depleted, CO₂ becomes the main terminal electron acceptor, being reduced to methane during methanogenesis. In this scenario, however, a considerable supply of degradable organic carbon must be available for methanogenesis to take place.

12.2.3 Biological component: source of microflora

The colonization of subsurface habitats has generated interest and speculation among geologists and microbiologists. Comparisons of microbial communities within vertical profiles extending from surface soil to subsurface sediments have shown that the bacteria found in different geological strata can be morphologically and physiologically distinct, but they do not reveal the developmental history of the subsurface microflora. Several hypotheses have been discussed by Madsen and Ghiorse (1993). It is feasible that the organisms and their descendants may have remained with the sediments ever since initial colonization during surface deposition. Such communities would be cut off from surface influences, perhaps for millions of years and they could have evolved unique phenotypes. Most recent studies have shown that the physiological and morphological characteristics of aerobic heterotrophic bacteria from different deep geological strata and different sites vary extensively with depth,

probably in response to physical and chemical differences among geological formations. It can, therefore, be concluded that the microbial community at each depth in aquifer sediments is very diverse.

However, it is equally feasible that the stratified distribution of subsurface micro-organisms could have been caused by vertical and horizontal colonization patterns of water-borne soil microorganisms via hydrological flow. Virtually all of the experimental evidence to explain the origin of subsurface micro-organisms addresses their transport from surface environments. Laboratory studies suggest that cell surface properties affect transport of micro-organisms through soil (Gannon *et al.* 1991a), and that mineralogy and/or solution chemistry influence attachment of micro-organisms to aquifer material (Scholl *et al.* 1990; Gannon *et al.* 1991b). Factors such as motility, chemotaxis, and metabolism can govern the penetration of bacterial cells into columns packed with sand (Reynolds *et al.* 1989). Other factors, such as sorption kinetics, association between cells and fine particles, and cell surface hydrophobicity, as governed by low-nutrient conditions, are major factors for the dispersal of subsurface bacteria (Lindqvist & Bengtsson 1991). When examining samples of groundwater pumped from aquifers, a third possible source of micro-organisms is direct colonization from the surface (Madsen & Ghiorse 1993).

The drilling process, therefore, can effectively inoculate any aquifer system. For this reason, sediment samples could be preferred to well (borehole) water samples in performing subsurface microbiological investigations. Indeed, the major chemical and physical factors that govern bacterial abundances in soil, such as available organic carbon, nitrogen, phosphorus, sulfur, pH, temperature, light, and biological factors, are strongly modified in the subsurface along the hydrological flow paths. Therefore, the distribution patterns of micro-organisms, especially bacteria that colonize the groundwater and surface soils, are inevitably distinct.

12.2.4 Limits of microbiological studies

To deal with bacterial abundance and distribution in subsurface environments, it is necessary to use specific methods for sampling sediments. The major difficulty in studying these environments is their relative inaccessibility. In most cases the groundwater samples are collected through pumping from the aquifer. Unfortunately, there are several potential problems with such a method. The first is that the drilling process can contaminate the environment under study, and it may be difficult to know whether the bacteria recovered are autochthonous or introduced by drilling. A second problem is the fact that a new environment is created by drilling, and the alteration of the physical conditions may significantly affect microbial processes in the vicinity of the well. A third problem with sampling water from wells is that most micro-organisms in the subsurface tend to be sediment-bound. Thus, the species and the types of free-living micro-organisms may be significantly different from those attached to sediment surfaces.

The question of attached or unattached microbial community was raised by microbiologists during early enquiries into the nature and the distribution of the subsurface microflora. It is generally accepted that the majority of bacteria in most ecosystems are attached to surfaces and are not suspended in the aqueous phase as are planktonic bacteria (Costerton & Colwell 1979; Fletcher 1979; Bar-Or 1990; Savage & Fletcher 1993; Wimpenny *et al.* 1993). Major differences between sediment-bound and unattached bacteria were documented by Kölbel-Boelke *et al.* (1988) and Hirsch and Rades-Rohkohl (1983, 1988, 1990), and this information suggests that unattached and attached groundwater communities are different. Nevertheless, they probably represent overlapping populations of a dynamic community,

and it is likely that a constant exchange of cells exists between sessile and free communities. The most important advances in this respect were made by Kölbel-Boelke *et al.* (1988), who compared a water-bound bacterial community to a sediment-bound community from the same aquifer. There appeared to be important physiological differences in all of the communities, but there were also similarities. It is therefore assumed that water pumped directly from the aquifer through a borehole can conveniently be sampled for microbiological analysis.

It is important also to consider that the data documenting microbiological communities in the subsurface environments are closely dependent on the methods used for study. Micro-organisms can only be observed directly by light or electron microscopy. Fluorochrome (acridine orange (AO) or 4',6-diamidino-2-phenylindole (DAPI)) analysis of sediments revealed that micro-organisms were neither uniformly distributed in the sediment nor capable of dividing *in situ*. Transmission electron microscopy also showed that about two-thirds of the bacterial cells had gram-positive cell walls (Ghiorse & Balkwill 1983; Wilson *et al.* 1983). This observation is a surprising result, because culture methods indicate a preponderance of gram-negative cells.

Culture methods have been the mainstay of microbiology. In investigating the microbial ecology of the subsurface environments, they have demonstrated the phylogenetic diversity of microbial communities in sediments and groundwater samples (Kölbel-Boelke *et al.* 1988; Balkwill 1989), and the preponderance of gram-negative bacteria in these environments (Balkwill & Ghiorse 1985). The most significant disadvantage of culture methods is the selectivity introduced by the media used. Many of the bacteria present in groundwater are not able to grow under the culture conditions. Other bacteria grow so slowly or give only pinpoint colonies that they cease to grow upon repeated transfers into fresh media. The principal conclusion is that the information on diversity and community structure may be grossly biased. For example, caulobacters, as typical freshwater bacteria, should be regarded probably as second only to pseudomonads in breadth of distribution and numbers. *Caulobacter* spp. are oligotrophic, i.e. well adapted to conditions of nutrient limitation, and are probably widely distributed in shallow aquifer systems. Members of this genus have, in fact, been isolated from groundwater by Hirsch and Rades-Rohkohl (1983) using specific enrichment procedures, but many strains may not be recovered using these, and other, growth conditions.

The plate counts can dramatically underestimate the total number of bacteria present in samples taken from groundwater environments. In the late 1970s, several easily performed non-cultural methods (Zimmerman *et al.* 1978; Kogure *et al.* 1979) showed that many of these non-culturable cells were indeed viable and able to metabolize actively, i.e. they are viable but non-culturable (VBNC). A variety of methods may be employed to determine the ratio of a cell population that are in a VBNC state. Most studies compare VBNC cells to total direct counts, as determined by fluorescence microscopy staining of nucleic acid with acridine orange (Daley & Hobbie 1975; Hobbie *et al.* 1977) or DAPI (Porter & Feig 1980; Hoff 1988).

The two most commonly used methods to determine VBNCs are the direct viable count (DVC) originally reported by Kogure *et al.* (1979) and the method using *p*-iodonitrotetrazolium (INT) violet as electron acceptor. In the first procedure, the bacterial population under study is incubated for 6 h or more with small amounts of yeast extract and the deoxyribonucleic acid (DNA) synthesis inhibitor nalidixic acid. If viable, the cells are able to respond to the nutrient addition; they become significantly elongated but are unable to divide. With the second method, the reduction of the soluble INT by metabolizing cells leads to the formation of insoluble INT-formazan in the cell membrane. The newer redox dye

5-cyano-2, 3-ditoyl tetrazolium chloride (CTC) can be reduced to CTC-formazan, which fluoresces red and accumulates intracellularly.

Other techniques using fluorescently labeled monoclonal antibodies, or [^3H]thymidine-prelabeled cells have also been described (Oliver 1993). Such methods showed that some bacteria, in response to certain environmental stresses, may lose their ability to grow on nonselective media, while remaining viable. They are of considerable interest to our understanding of microbial ecology and for detecting pathogens and indicator bacteria in subsurface environments.

To obtain a better understanding of different subsurface micro-organisms, White *et al.* (1983) and Balkwill *et al.* (1988) have introduced biochemical marker techniques. Indeed, it is well-known that different micro-organisms exhibit significant biochemical differences in the fatty acids that constitute cell membranes and internal reserve granules. By direct extraction and characterization of these fatty acids from sediments, data concerning total biomass, cell membrane type, occurrence of eukaryotic cells and nutritional status of the micro-organisms may be derived.

Another alternative to these methods is to evaluate the net effects of microbial processes rather than the species of organisms present. Aquifer materials placed into laboratory containers for measurement of microbial activity are referred to as microcosms. Microcosms have been used extensively for measuring CO_2 production (Chapelle *et al.* 1988) or xenobiotic degradation (Wilson *et al.* 1983). Another possibility is to use groundwater chemistry as an indicator of microbial processes by selecting a series of wells placed along the flow path and sampling their chemical parameters.

The goal of nucleic acid technology is the characterization of natural populations without the need to isolate or cultivate individual community members. In most characterizations based on these methods, there is a requirement for purification of nucleic acids from the microbial population because of contamination by humic materials, but the advantage of nucleic acids extraction is that bacterial populations are more numerous per unit volume than by using other methods. The advent of ribosomal ribonucleic acid (rRNA) sequence analysis has revolutionized bacterial phylogeny and might well revolutionize microbial ecology. When rRNA molecules are the target in hybridization studies, the potential sensitivity is greater because growing cells can contain 10^4 ribosomes per cell. The main approach in application of 16S rRNA gene technology is sequence analysis of "clones" taken from the natural population. The advantage of the probing approach was shown by Giovannoni *et al.* (1988) using kingdom-specific probes targeted for conserved 16S rRNA sequences found in all living cells (universal probes).

By linking these probes with fluorescent dyes, phylogenetic diversity could be analyzed by epifluorescence microscopy and flow cytometry (Amann *et al.* 1990a,b, 1995; Amann 1995; Wallner *et al.* 1996). This new approach can reveal microbial community structures, and it is clear that the use of 16S rRNA gene technology may bring new information in environmental microbiology, especially in the case of microbial communities of Natural Mineral Waters (Wagner *et al.* 1993; Wallner *et al.* 1993, 1995). A limitation of the approach is that phenotypic information is not obtained. Moreover, it is not known whether the sequence was derived from living cells, dead cells or extracellular DNA.

12.2.5 Major microbiological groups

In contrast to surface freshwater, which may be influenced by suspended particles and their attached biota, most groundwater is interstitial, i.e. remaining within a matrix of minerals with variable chemistry, porosity, and degree of saturation. Thus, in groundwater habitat, all life forms larger than micro-organisms are excluded.

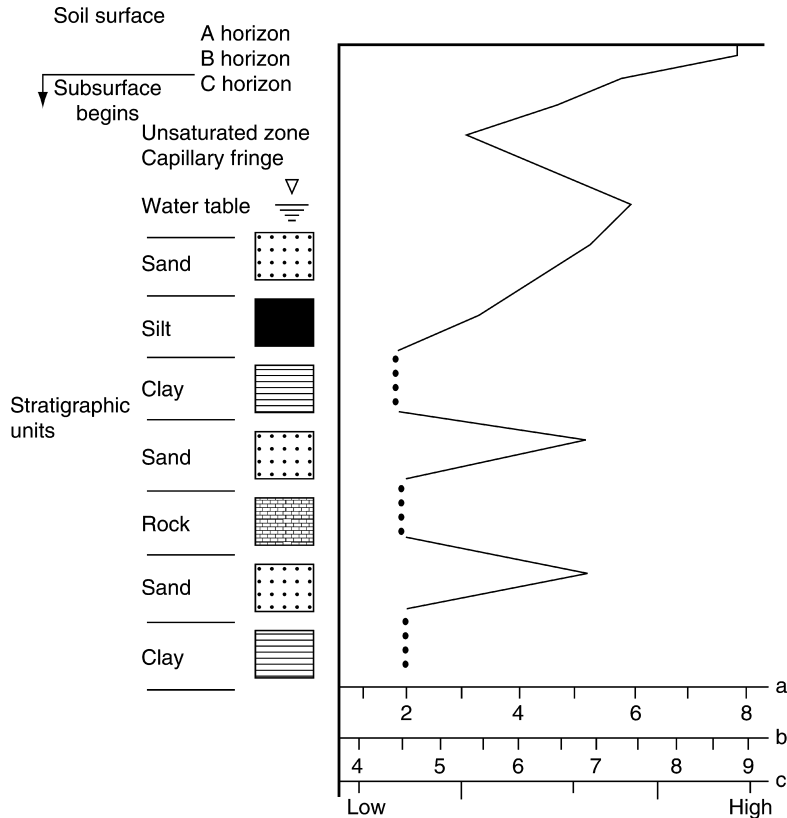


Fig. 12.2 Generalized vertical profile showing the relationship between microbiological parameters and stratigraphy. (Reproduced with permission from Madsen & Ghiorse 1993; published by Blackwell Publishing Ltd.)

Madsen and Ghiorse (1993) have presented a generalized model for the relationship between geological stratigraphy and microbiological parameters (Fig. 12.2). In going across the A and B soil horizons into the C horizon, the bacterial abundance decreases in direct proportion with nutrient levels. The C soil horizon marks the beginning of the unsaturated subsurface zone with considerably fewer bacteria than in the B soil horizon. Below the C horizon, microbial abundance increases substantially at the water table and, just above, in the capillary fringe zone. It can be speculated that the interface zones between the unsaturated and saturated zones may be the sites of oxygen transport and nutrients recharge, especially in shallow unconfined aquifers (Madsen & Ghiorse 1993). Thus, depth *per se* appears not to govern bacterial abundance and activity in the saturated zone. Rather, the abundance of bacteria appears to be related to hydrological, physical and geochemical properties of each stratum.

Within a given environment, the collective result of all microbial processes, most of which are oxidation–reduction reactions, is viewed as a microbial food chain. The process itself is an important indicator for determining the nature of the microbial community in a particular habitat. The food chain in aquifers is primarily heterotrophic, depending on dissolved organic materials. However, according to Madsen and Ghiorse (1993), aerobic chemolithotrophic food chains have not been described in the terrestrial subsurface.

In the most simple cases, as in largely aerobic aquifers, the major bacterial groups are aerobic gram-negative rods with cytochrome oxidase using oxygen as a terminal electron acceptor. Members of the genus *Pseudomonas* and related organisms appear to be particularly common in groundwater systems. Other groups, such as *Caulobacter*, *Cytophaga*, *Flexibacter*, and flavobacteria, are also widely distributed. The most extensive characterization of bacterial distribution in a typical aerobic aquifer has been performed at the Savannah River Site in South Carolina (Balkwill 1989; Frederikson *et al.* 1989; Sinclair & Ghiorse 1989). A major finding was that these sediments contained a significant number of protozoa ranging from below detection to as many as 10^3 /gram of sediment. However, bacterial cell numbers were always higher, with total counts (AO) of 10^6 – 10^8 /gram, while viable counts (colony-forming units (cfu)) of these samples showed large variations.

The three deepest units at the Savannah River Site function as intermediate flow systems but, unlike most intermediate aquifer systems, they are aerobic. Not surprisingly, the microbial community has an activity comparable to that of aerobic bacterial populations. In spite of this largely aerobic environment, anaerobic bacteria are also part of the microflora (Jones *et al.* 1989). The numbers of sulfate-reducing bacteria can attain up to 10^4 cfu/g, and there was also methane production in a number of zones.

Because an aquifer is water-saturated, the oxygen concentration of the bulk groundwater is a good indicator of its availability to free or attached bacteria. There is little likelihood that anaerobic micro-organisms that are common in many soils are important in the groundwater environment. Only at very low oxygen concentrations, below approximately $30\text{ }\mu\text{mol/l}$, is there a potential for nitrate competing with oxygen for available electrons. Thus, the presence of different nitrogen species in groundwater systems depends on the concentration of oxygen. Under aerobic conditions, nitrification may take place and nitrate accumulates. Under anaerobic conditions, nitrate will be converted to nitrite via denitrification, while nitrification is blocked. Denitrification is governed by organisms, such as those belonging to the genera *Pseudomonas*, *Paracoccus*, *Thiobacillus*, and *Bacillus*, among others.

It has long been recognized that micro-organisms play an important role in iron cycling in groundwater systems. Fe(III) oxyhydroxides are reduced by several micro-organisms, including the unclassified strain GS-15 and *Shewanella putrefaciens*, by using Fe(III) as terminal electron acceptor (Chapelle 1993). The oxidation of Fe(II) to Fe(III) at acidic pH can be mediated by representatives of the genera *Gallionella*, *Leptothrix*, and *Thiobacillus*. When sulfate is an electron acceptor, it is reduced to sulfide, and many groups of anaerobic bacteria are capable of carrying out sulfate respiration. The presence of sulfate-reducing micro-organisms in groundwater sediments can be easily observed. These may include species of sulfate-reducing genera, such as *Desulfovibrio*, *Desulfotomaculum*, *Desulfobacter*, and *Desulfonema*.

Intermediate flow systems generally correspond to confined aquifer systems with depths of less than 300 m. Microbial populations are largely dependent upon organic material present in sediments as a primary carbon source. These carbon constituents are often refractory, limiting the growth potential of microbes, and thus environmental conditions are typically oligotrophic. In these anaerobic aquifer systems, counts of total bacteria are in the order of 10^5 – 10^6 cells/g of sediments and those of viable bacteria are in the order of 10^4 cells/g (Chapelle 1993).

Some major characteristics of microbial distribution in shallow and deep subsurface sites can be deduced from several observations:

- The population density of cyst-forming protozoa is low in shallow, pristine aquifer sediments and even lower in deep aquifer sediments; their abundance is related to sediment texture, and the dominant populations are flagellates and amoebae.
- The abundance of actinomycetes and fungi in subsurface habitats appears modest and in the order of 10 cfu/g.
- Bacteria with simple lifecycles are by far the most widely represented organisms in shallow or deep groundwater habitats. There are aerobic gram-negative bacteria of which *Pseudomonas* and related genera are particularly common; the total counts of bacteria range from 10^6 to 10^8 /g, whereas plate counts show large variations.
- Some metabolic groups such as nitrate reducers, Fe(III)-reducers, sulfate reducers, and methanogens can also be isolated from anaerobic aquifer systems.

12.2.6 Nutrient limitations and starvation survival

In shallow or deeper aquifers, the supply of readily utilizable carbon and energy sources may be extremely small. Only the most refractory organic material will survive the long and complex pathways through subsurface sediments. Thus, organic carbon is the most limiting nutrient in these aquifer systems. Low-nutrient environments, termed oligotrophic environments, primarily lack organic matter for the growth of heterotrophic bacteria.

Limitation or starvation for one or more nutrients is common in most bacteria in natural environments such as groundwater (Morita 1997). Even bacteria, such as the enterics that colonize the gut, must be able to survive in another environment as they are transmitted from host to host. Thus, bacteria have evolved mechanisms to cope with a feast-fast mode of existence.

To confront nutrient limitation, bacteria may develop defense mechanisms to enhance their ability to survive periods of starvation. Some differentiating bacteria respond to starvation by marked alteration in their ultrastructure, producing spores or cysts. Spores are essentially dormant, waiting out lean periods to germinate as nutrients become available. Non-differentiating bacteria respond more by an alteration of their physiology rather than developing resistant structural modifications. These organisms have an enhanced capacity for scavenging nutrients and possess many of the resistance characteristics of endospores (McCann *et al.* 1992). The heterotrophic bacteria of groundwater habitats could have this type of survival strategy.

These cells respond to starvation by forming ultramicrocells that can pass through 0.2 μm membrane filters. The size difference between an exponentially growing cell and a starved cell is sometimes very large. For example, actively growing *Vibrio* cells may have a volume of 5.94 μm^3 , while starved cells have a volume as small as 0.05 μm^3 (Moyer & Morita 1989). This miniaturization is due to reductive cell division and a continuous size decrease by breakdown of internal macromolecules. These can be carbon storage polymers, such as glycogen or poly- β -hydroxybutyrate, or constituent proteins and nucleotides. The energy needed for the stress response is derived from extensive degradation of internal macromolecules (Kjelleberg *et al.* 1993).

Bacteria respond to specific nutrient limitation by two mechanisms: first, they produce transport systems with increased affinities for the nutrient most easily exploited; second, they express transport and metabolic systems for alternative nutrients. Thus, these bacteria may be able to escape starvation by more efficient scavenging of a preferred nutrient or by using another, relatively more abundant, source.

Evidence has been accumulating for years that bacteria subjected to nutrient starvation become more resistant to various environmental stresses. It is clear that the stress responses discussed earlier, involving enhanced scavenging capacity, are insufficient to ensure survival. This aspect has been studied rigorously by Matin and coworkers, who showed that, upon exposure to nutrient limitation, bacteria synthesized new proteins that increased their resistance to a number of stresses. This resistance failed to develop if synthesis of starvation proteins was prevented, and increased the longer the culture was allowed to synthesize the starvation proteins (Berg *et al.* 1979, 1984; Reeve *et al.* 1984a,b; Matin & Harakeh 1990). These additional proteins are often referred to as stress proteins. Different sets of genes are expressed and proteins are induced by different stresses. Well-characterized prokaryotic examples include the heat shock response (Neidhard *et al.* 1984; Hightower 1991), the SOS response (Walker 1984), oxidative stress response (Morgan *et al.* 1986), starvation response (Groat *et al.* 1986; Matin *et al.* 1989; Matin, 1990, 1991), response to anaerobiosis (Spector *et al.* 1986), and responses to micropollutants (Blom *et al.* 1992). The term "stress proteins" was introduced to recognize the more general nature of the response. It is most likely that some of them are related with the cell's catabolic activity/energy metabolism (Matin & Harakeh 1990). A major unifying theme that emerged in the last decade is that stress proteins work together to regulate the response, to assemble/disassemble structures and to provide a molecular shuttle service for polypeptides by chaperoning (Hightower 1991).

12.2.7 The viable but non-culturable state

Under certain conditions of metabolic stress such as starvation, bacterial cells may enter into a VBNC state. It has been realized for some time that plate counts can dramatically underestimate the total number of bacteria, determined by AO, present in samples taken from natural environments. In the late 1970s, several non-cultural methods (Zimmerman *et al.* 1978; Kogure *et al.* 1979; Rodriguez *et al.* 1992) were developed to determine cell viability. These studies led to the concept that some bacteria, in response to certain environmental stresses, may lose the ability to grow on media in which they are routinely cultured, while remaining viable. A bacterium in this VBNC state is defined by Oliver (1993) as "a cell which can be demonstrated to be metabolically active, while being incapable of undergoing the sustained cellular division required for growth in or on a medium normally supporting growth of that cell."

Several discoveries have shown that many bacterial cells respond to adverse environmental conditions, such as temperature, salinity (Xu *et al.* 1982), and nutrient deprivation, by entering the VBNC state (Baker *et al.* 1983). In this state, cells are reduced in size, become ovoid, and cannot be grown by conventional bacteriological techniques (Oliver 1993). Minicells or minibacteria have also been observed in some mineral waters (Oger *et al.* 1987). It has been speculated that the VBNC state represents an additional response to starvation displayed by bacteria for survival (Colwell *et al.* 1985; Roszack *et al.* 1987b), and many bacterial species, including pathogens, have been reported to enter this state under laboratory or field conditions (Oliver 1993). This state could have important consequences with regard to ecology, epidemiology, or pathogenesis, since potentially pathogenic VBNC cells could persist in the environment and regain growth capability and infectivity much later than vegetative cells.

The relationship between the starvation response and the VBNC response is complex, but it has been suggested that the VBNC state may be distinct from the starvation response for several motives (Walch & Colwell 1994). A large number of environmental factors other

than starvation, such as temperature, pH, salinity, and osmotic pressure, may be involved in the induction of the VBNC state (Oliver 1993). It is important to note that starved bacteria, after variable periods of time, respond rapidly to nutrients, while VBNC cells cannot grow on conventional bacteriological culture plates. A variety of methods have been described for determining the non-culturable state. The existence of a VBNC state, in response to natural environmental stress, has been observed more often than not with gram-negative bacteria representing members of the Enterobacteriaceae and Vibrionaceae, including *Aeromonas* and some genera, such as *Campylobacter*, *Helicobacter*, and *Legionella* (Oliver 1993). However, little is known about the VBNC state in most representative bacteria living in groundwater habitats.

12.3 BOTTLE HABITAT

Microbiological analysis of Natural Mineral Water at source has always revealed the presence of some bacteria that are capable of growth and that can form colonies in appropriate culture media. After bottling, the number of viable counts increases rapidly, attaining 10^4 – 10^5 cfu/ml within 3–7 days. Buttiaux and Boudier (1960) were the first to describe this phenomenon, which has been largely corroborated by others (Schmidt-Lorenz 1974; Ducluzeau *et al.* 1976a,b; Delabroise & Ducluzeau 1974; De Felip *et al.* 1976; Schwaller & Schmidt-Lorenz 1980, 1981a,b, 1982; Warburton *et al.* 1986, 1992; Gonzalez *et al.* 1987; Oger *et al.* 1987; Bischofberger *et al.* 1990; Morais & da Costa 1990; Ferreira *et al.* 1993; Warburton 1993).

In Fig. 12.3, it can be seen that the colony counts of the water from 5 springs and from the mixed water derived from these springs are less than 1–4 cfu/ml, and in the storage tank and immediately after bottling they are, on average, only slightly higher. During storage at 20°C, bacterial populations increase in numbers, reaching a peak of more than 10^5 cfu/ml by the end of 1 week. During the next 4 weeks, the bacterial counts decrease slowly or remain fairly constant. At the end of the 2 years of storage, colony counts are still about 10^3 cfu/ml. The results of most studies (Yurdusef & Ducluzeau 1985; Gonzalez *et al.* 1987; Morais & da Costa 1990; Vachée *et al.* 1997) are broadly in agreement with the one reported by Bischofberger *et al.* (1990). Some of the results on colony counts from bottled still mineral waters are also described in Table 12.2.

These bacteria, capable of growing on simple organic compounds (principally carbohydrates, amino acids, and peptides) found in culture media such as “plate count agar” or R2A agar (Reasoner & Geldreich 1979, 1985; Reasoner 1990) are heterotrophic. They are also psychrotrophic because they can grow at temperatures as low as 5°C, and their maximum growth temperature is about 35°C (Mossel *et al.* 1995). Therefore, incubation at 20°C for 3 days has prevailed in the monitoring of plate counts of mineral waters. Furthermore, these bacteria do not have growth factor requirements such as vitamins, amino acids, or nucleotides and are, therefore, prototrophic, in contrast to auxotrophic bacteria that require many of these growth factors.

12.3.1 The bottle effect

Organic carbon should be expected to be the most limiting nutrient for growth and activity of bacteria. Many mineral waters contain 0.1–0.2 mg/l of dissolved organic carbon. By taking into account the level of organic carbon metabolism, it is theoretically possible to predict

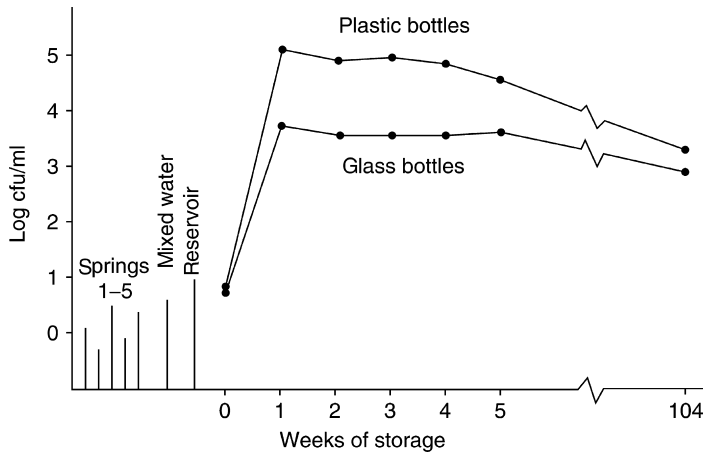


Fig. 12.3 Heterotrophic plate counts (HPC) of non-carbonated mineral water at 5springs of a mineral water source, the mixed water from these 5 springs, storage reservoir, and plastic and glass bottles immediately after bottling and during storage for 104 weeks. After 14 days of incubation at 20°C, cfu were determined by the membrane filtration method on 1:0 diluted plate count agar. (Reproduced with permission from Bischofberger *et al.* 1990.)

Table 12.2 HPC at 22°C from bottled non-carbonated mineral waters sampled at retail outlets.

Source	Number of samples examined	HPC (cfu/ml)					Reference
		< 10 ²	10 ² –10 ³	10 ³ –10 ⁴	10 ⁴ –10 ⁵	> 10 ⁵	
UK	44	18	11	18	36	16	Hunter <i>et al.</i> (1990)
France	23	26	4	34	34	–	Manaia <i>et al.</i> (1990)
Portugal							
Belgium							
France	50	2	8	56	30	4	Leclerc (1994); Vachée <i>et al.</i> (1997)
Italy							
Spain							

the number of culturable bacteria in a bottled mineral water. Carbon accounts for about 50% of the bacterial cell mass. The mass (dry weight) of bacterium is approximately 2×10^{-14} g. If, hypothetically, one admits the incorporation of the total available organic carbon into the bacterium, one will obtain for 0.1 mg/l of organic matter (1×10^{-4} g) a number of bacteria equal to $2[(1 \times 10^4)/(2 \times 10^{-14})] = 1.10^{10}/l$, i.e. $1 \times 10^7/\text{ml}$. These calculations indicate that other limiting factors may exist (e.g. phosphorus). Indeed, as reported by Van der Kooij *et al.* (1982a,b; Van der Kooij 1990), only a small portion of the organic carbon in mineral water is expected to be available as a source of carbon and energy to micro-organisms.

Placing samples into containers terminates the exchange between cells, nutrients, and metabolites with the *in-situ* surrounding environment. Compressed air is used at virtually all stages of the water bottling process. The microbiological quality of the process air must be

of a very high standard. On the other hand, the complexed organic matter present in low concentration can be dramatically modified through bottling, under the influence of increasing temperature and oxygenation. A high increase in cell numbers due to the bottle effect was reported for the first time by Fred *et al.* (1924). ZoBell and Anderson (1936) described the bottle effect (originally named the volume effect) observing that both the number of bacteria and their metabolic activity were proportional to the surface area/volume ratio of the flask in which the seawater was stored. The greater the surface area in relation to the volume of water, the more rapidly growth of bacteria takes place; hence small containers provide considerably more surface area (Bischofberger *et al.* 1990; Morita 1997).

The explanation for this is that nutrients present in low concentration are absorbed and concentrated onto the surface and, thus, can be more available for the bacteria. The similar increase in bacterial numbers occurs when underground surface waters are placed in a container (Heukelekian & Heller 1940). Flask surface adsorption of organic matter is the basis for the adhesion of bacteria to solid surfaces, as demonstrated in both the aquatic environment and in the laboratory, and because of the increased concentration, the nutrients are more available (Morita 1997). It is also possible that many of the more labile compounds, unavailable at the subsurface environments being complexed to lignins, phenolics, or adsorbed to clay minerals, become biodegradable through sampling by interaction at the surfaces. Since a volume effect has been reported, the major portion of the microbial activity should be linked to the attached bacteria. To date, little experimental evidence has been presented to demonstrate an attachment of bacteria with the inner surfaces of the bottles of mineral water. Bischofberger *et al.* (1990) reported no visible colonization with PVC mineral water bottles, using scanning electron microscopy. Low levels of adhesion have been shown by Jones *et al.* (1999). Viable counts on the surface (polyethyleneterephthalate (PET) bottles and high-density polyethylene caps) ranged from 11–632 cfu/cm², representing only 0.03%–1.79% of the total viable counts in the 1.5 l bottles, depending on the brand examined. In contrast, within the studies of Jayasekara *et al.* (1999), who reported considerable variation between bottles for a given producer of water, up to 83% of the total microbial population within a bottle was found to be adhered to the bottle surface, representing a population of about 10⁶–10⁷ cfu scattered over the surface. However, the counts of the attached bacteria were insufficient to constitute a real biofilm as representing an interdependent community-based existence (Davey & O'Toole 2000). The studies cited above are not all directly comparable, because there are differences in sampling and methods used for viable cell numbers. In the mineral water bottle systems studied by Jones *et al.* (1999), surface roughness appeared to be most significant in determining adhesion, while surface hydrophobicity and electrostatic charge had no significant role.

12.3.2 Other factors influencing the plate count

There has been some debate on higher bacterial counts that are generally found in PVC compared with those in glass bottles (Baldini *et al.* 1973; Masson & Chavin 1974; De Felipe *et al.* 1976; Yurdusev & Ducluzeau 1985; Oger *et al.* 1987; Bischofberger *et al.* 1990). According to these authors, the major cause of the lower colony counts of the same mineral water bottled in mechanically cleaned glass than in plastic bottles is due to the bacteriostatic effect of residual cleaning agents. Other possible causes for the different colony counts of the same water bottled in glass and in PVC may be due to the migration of organic nutrients from PVC, higher rates of diffusion of oxygen through PVC, or the rougher surface of plastic bottles promoting adhesion and colonization.

The storage temperature of the bottles has never been thoroughly studied. Usually the maximum bacterial density was observed in samples stored at room temperature (about 20°C). Nevertheless, storage at low temperatures, such as that of refrigeration (4–6°C), does not stop bacterial multiplication.

Photodegradation of dissolved organic matter is a common phenomenon. Thus, the exposure time of recalcitrant organic substances in water samples to daylight, and moreover to sunlight, may again stimulate the growth of micro-organisms since complexed substances, such as carbohydrates, fatty acids, and amino acids, may become bioavailable. Photochemical processes generate low molecular mass, readily biodegradable molecules from high molecular mass humic complexes (Morita 1997).

The count of cultivable bacteria that can be recovered from mineral waters also depends to a large degree on the culture methods used. Counting colonies of bacteria in rich nutrient media, as done in medical microbiology, has dominated past research for a long time. Fortunately, from the 1970s to the 1980s, the concept of substrate shock (too many nutrients) has been successfully addressed (Morita 1997). Thus, when low-nutrient medium such as R2A is used for environmental samples, a significant increase in viable counts can be generally observed compared to the use of regular-strength medium such as standard plate count agar (Reasoner & Geldreich 1985). R2A agar incubated at 20°C has proven to be especially suitable. There is dramatically less or even no bacterial growth at 37°C compared to 20°C. It is possible that high plate counts at 37°C, such as staphylococci, coryneforms, or Gram-positive bacilli, indicate allochthonous populations in the mineral water. These thermotrophic bacteria that can grow in mineral water at 42°C were below 10³/l (Leclerc *et al.* 1985). The choice of incubation time is probably the most important factor for isolating bacteria from bottled mineral water, because many of these organisms are slow-growing. Thus, for species distribution studies it is important to incubate the cultures for longer periods (up to 14 days at 20°C has frequently been used) than for monitoring purposes (3 days).

12.3.3 Growth or resuscitation

Bacteria living in groundwater systems are subject to constantly changing, and frequently stressful, conditions such as reduced temperature, fluctuation in pH, change of osmotic pressure, oxidative shock, and nutrient limitation. In nutrient-poor groundwater systems, autochthonous bacteria survive for prolonged periods under conditions designated starvation survival by Morita (1982, 1987, 1993). They may lose the ability to grow on media in which they are routinely cultured, while remaining viable (VBNC). As mentioned earlier, it is now well established that plate counts of still mineral waters at the source, or immediately after bottling, range between about 1/ml increasing to 10⁴–10⁵/ml within 3–7 days after bottling. This population remains high and is generally stable for months. It remains unclear whether the ultimate large population of culturable bacteria in mineral water is due to resuscitation of a large number of non-culturable dormant (VBNC) cells present in the water source or in the bottling system, or is the result of cell division and growth of a few culturable cells initially present.

Resuscitation is defined here as a reversal of the metabolic and physiological processes that result in non-culturability, i.e. the restoration of the ability of the cells to be culturable in media normally supporting growth of the organisms. Resuscitation would appear to be essential to the VBNC state if this is truly a survival strategy. Whereas the non-culturable state may in some way protect the cell against one or more environmental stresses, resuscitation

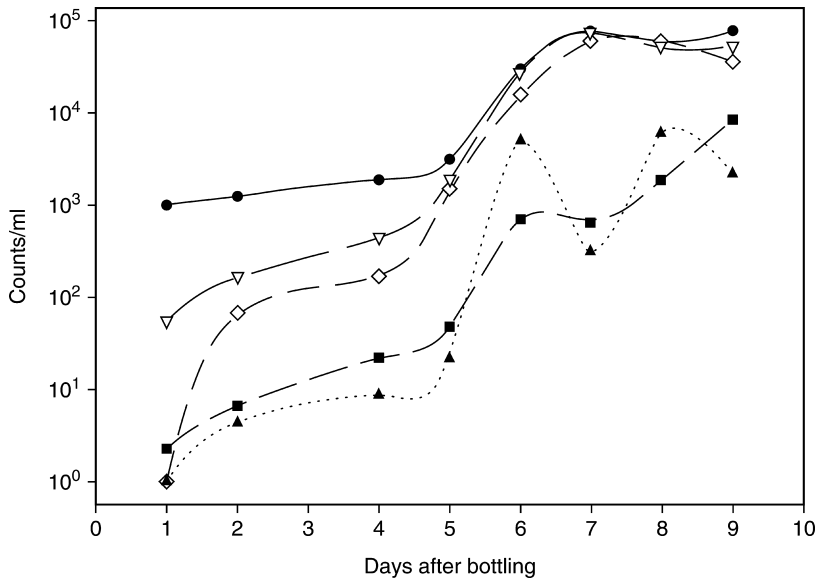


Fig. 12.4 Total counts and counts for active bacteria and bacterial subgroups in French uncarbonated NMW during 9 days after bottling (PET bottles). Total counts (number of bacteria stained by DAPI) (●). Active bacteria (▽); active alpha proteobacteria (■); active beta proteobacteria (◇); active gamma proteobacteria (▲) (number of bacteria detected by respective Cy3-labeled rRNA-targeted probe (From W. Beisker, personal communication.)

of the cell would allow it to compete actively in the environment. However, according to Bogosian *et al.* (1998), recovery of culturable cells from a population of non-culturable cells, via a process of resuscitation, can be confounded by the presence of a low level of culturable cells, which can grow in response to the addition of nutrients and give the illusion of resuscitation. The data of Oger *et al.* (1987) seem to demonstrate that the culturable population arising within one week of storage is derived from a large number of bacteria in a “minicell” state but stainable by AO (approximately 10³ cells/ml) and, therefore, from resuscitation processes. Ferreira *et al.* (1993) assume that such large populations of culturable bacteria are the result of growth from a very low number of organisms enumerated with ethidium bromide, initially present at the source and/or the bottling system.

Compared to cultivation-based methods, nucleic acid probes currently allow the taxonomically most precise and quantitative description of microbial community structures. Over the last decade, rRNA-targeted probes have become a handy tool for microbial ecologists (Amann & Ludwig 2000). The fluorescence *in-situ* hybridization (FISH) with rRNA-targeted probes helps to detect and identify bacteria, even at a single cell level without prior cultivation and purification. This method had been optimized (Wallner *et al.* 1993; Amann *et al.* 1995) and applied to mineral water by combining it with membrane filtration (Fig. 12.4). Probes specific for the bacteria, and the alpha, beta, and gamma subclass of proteobacteria were used. The applied fluorescent probes were targeted to rRNAs and the number of cells detected with fluorescently labeled rRNA-targeted probes was called “probe active count”. The development of the bacterial community in an uncarbonated water sample in a PET bottle was monitored during nine days after bottling, using the FISH method and DNA staining with DAPI (W. Beisker, personal communication):

- As measured by AODC, the number of bacterial cells increased from 1000 ml/l to 8×10^4 within 7 days after PET bottling (Fig. 12.4), which is similar to the others studies (Oger *et al.* 1987; Bischofberger *et al.* 1990; Morais & da Costa 1990; Ferreira *et al.* 1993; Vachée *et al.* 1997).
- As only 5% of total counts (DAPI) were detected on the first day by the bacteria-specific probe, the number of physiologically active bacteria (viable and culturable) can be assumed to be significant while the plate count of still mineral water is generally in the order of a few cfu/ml in the R2A medium (about 1–5 cfu/ml). This portion increases slowly up to day 5, then rapidly between days 5 and 7. It appears that the increase of total count might essentially be due to physiological growing of active bacteria that have been detected by the eubacterial probe. These results suggest that the apparent resuscitation was merely due to the growth of the culturable cells from day 1.
- The appearance of biphasic growth or a double growth cycle (diauxie) is typical of media that contain mixtures of substances. The first substrate will induce the synthesis of those enzymes required for its utilization and at the same time will repress the synthesis of enzymes required for second substrate. The latter enzymes are only produced when all of the first substrate has been metabolized. However, recent results obtained for the kinetics of growth during “mixed substrate growth” suggest that simultaneous utilization of carbon sources will result at the low substrate concentrations present in these systems, which allows growth at very low concentrations of individual carbon substrates (Kovavora-Kovar & Egli 1998).
- The bacterial population in bottled mineral water is dominated by proteobacteria and beta proteobacteria were found to be the most abundant group of detected bacteria (see Section 12.4).

12.3.4 Genetic diversity before and after bottling

Mineral water ecosystems, including those in aquifers, exhibit a high degree of phenotypic and genetic microbial diversity that cannot always be supported by species identification (Chapelle 1993). Phenotypic characteristics that rely on physiological activities have been shown to be less important for estimating bacterial diversity than genetic characteristics, because many metabolic traits may be induced or repressed by different environmental conditions. Restriction fragment length polymorphism (RFLP) patterns of rDNA regions (ribotyping) therefore constitute a more reliable method for assessing genetic diversity within autochthonous bacterial associations of mineral water.

In an investigation on the fate of the bacterial flora at source before bottling and upon bottling, Vachée *et al.* (1997) isolated 890 strains from 5 springs and observed 378 distinct ribotypes. RFLP analysis detected a large number of polymorphisms combined with unequivocal band resolution in all groups, but particularly high in a set of isolates producing a fluorescent pigment (72 patterns for 174 strains). Mineral water samples from the five springs were analysed during one year in order to assess whether the isolates specific for each spring could be separated repeatedly throughout the period of storage. In the case of spring A, 155 isolates provided 75 RFLP patterns.

Indistinguishable or closely related isolates were found 114 times in the samples examined and among these, 103 (90%) isolates had been obtained from samples before and after bottling (Table 12.3). The results from four springs are presented in Table 12.4. These data suggest that, within the ground mineral water bacterial community, a high percentage of

Table 12.3 Isolates from samples before and after bottling.

Isolates	Samples ^a			Ribopattern
	I	II	III	
Number of indistinguishable isolates ^b				
5	–	2	3	b2
3	1	1	1	c3
3	1	1	1	c4
4	2	–	2	c6
2	1	–	1	c7
17	9	5	3	m1
10	5	3	2	m2
3	1	1	1	m3
2	1	–	1	m4
5	1	3	1	m5
2	1	–	1	m6
2	1	–	1	m7
2	1	–	1	m8
2	1	–	1	m9
3	2	–	1	m10
3	2	–	1	m11
3	1	–	1	m12
2	1	–	1	m13
2	–	1	1	m14
2	–	1	1	m15
3	1	1	1	m16
4	3	–	1	m17
Number of closely related isolates ^b				
4	2	1	1	m'1
2	–	1	1	m'2
3	1	1	1	m'3
3	1	1	1	m'4
2	1	–	1	m'5
3	1	1	1	m'6

^a I, source; II, before bottling; III, after bottling.

^b Isolates are designated genetically indistinguishable when their restriction patterns have the same numbers of bands and the corresponding bands are of the same apparent size. The ecological interpretation of these results is that the isolates are all considered to represent the same strain. Two isolates are considered to be closely related when their RFLP pattern differs by one band difference which is consistent with a single genetic event, i.e. a point mutation or an insertion or deletion of DNA.

(From Vachée et al. 1997.)

indistinguishable or closely related isolates (identical ribopatterns) is retained through the bottling system and storage.

12.4 MICROBIAL COMMUNITY

Community structure is generally considered to be related to the types of organisms present in an environment and to their relative proportions. As discussed earlier, many approaches are used to determine community structure for subsurface environments. For Natural Mineral Waters, all the data have been obtained, thus far, by culture methods. It must also

Table 12.4 Indistinguishable isolates (identical ribopatterns) recovered during storage (%).

	A	B	C	D
	155	133	141	173
Indistinguishable isolates recovered more than once	114 (74%)	96 (72%)	93 (70%)	94 (55%)
Indistinguishable isolates recovered before and after bottling	103 (90%)	50 (52%)	62 (65%)	61 (66%)

Source: From Vachée *et al.* 1997.

be stressed that the study of the microbial populations of mineral water will undergo important developments as new molecular biological and other highly technical approaches are likely to be used to study this environment.

Non-carbonated mineral water contains very low numbers of culturable bacteria at the source. However, after bottling, colony counts of more than 10^4 cfu/ml can be enumerated after 1 week of storage at 20°C. Most of the results on the diversity of micro-organisms has been obtained from bottled mineral water, taken from the bottling plant or purchased at retail outlets, and stored for at least one week.

12.4.1 Algae, fungi and protozoa

The microbiological investigations of groundwater systems indicate that prokaryotes are the dominant micro-organisms present and that eukaryotes might be absent altogether or present in low numbers. In subsurface environments, where photosynthesis does not occur, cyanobacteria and algae will not be found, unless the geological stratum is hydrologically connected to surface water. These organisms may be present in the form of cysts or other resistant states of development, and their presence in bottled water is most likely to be the result of contamination during the bottling process.

The occurrence of pathogenic protozoans or slightly thermophilic amebae has never been demonstrated in mineral waters (Dive *et al.* 1979; Rivera *et al.* 1981). The populations of fungi in groundwater habitats appear to be low, but not necessarily absent (Sinclair & Ghiorse 1987, 1989; Sinclair *et al.* 1990; Madsen 1991). Thus, it is possible to isolate fungi from Natural Mineral Water before or after bottling. Because of the possible presence of fungi in groundwater, it is difficult to have accurate knowledge of the origin of these organisms in bottled mineral water (Fujikawa *et al.* 1996).

12.4.2 Heterotrophic bacteria

Because photosynthesis is not possible in groundwater environments, the food chain is primarily heterotrophic, depending either on DOC from the hydrological flow path, or on organic compounds of sedimentary origin. The composition of the bacterial flora that can be recovered depends largely on the culture techniques used and on the physicochemical parameters of the aquifers.

The heterotrophic plate count (HPC) was introduced by the Standard Methods of the USA (American Public Health Association 1985). This method enumerates aerobic and

facultative aerobic bacteria found in potable water that are capable of growth on simple organic compounds found in the culture medium, for a specific incubation period and at specific temperatures. This method has been applied successfully to bottled, non-carbonated mineral water, with some modifications (Bischofberger *et al.* 1990). It is important, for example, to use the surface culture procedure (spread plate) that yields higher counts than the pour plate method (Schmidt-Lorenz 1974; Schwaller & Schmidt-Lorenz 1982). R2A, a low nutrient medium, devised by Reasoner and Geldreich (1985), has proved to be especially suitable, but the 1.10 diluted plate count agar can yield even higher colony counts after an adequate incubation period (Bischofberger *et al.* 1990). An incubation temperature of 20°C has generally prevailed in the monitoring of drinking water. Most laboratories examining bottled mineral water find this temperature to be better suited than higher incubation temperatures for obtaining higher numbers of isolates from mineral water. However, the choice of incubation time is probably the most important factor for isolating bacteria from bottled mineral water because many of these organisms are slow-growing. Thus, for species distribution studies it is important to incubate the cultures for longer periods than for monitoring purposes (3 days), and periods of up to 14 days at 20°C have frequently been used.

The vast majority of the heterotrophic bacteria isolated from Natural Mineral Waters can be classified in a restricted number of phylogenetic divisions. Prosthecae bacteria belonging to the alpha subclass of the proteobacteria, pseudomonads of the alpha, beta, and gamma subclasses of the proteobacteria, members of the *Cytophaga-Flavobacterium-Bacteroides* (CFB) phylum, and gram-positive bacteria of the actinomycetes subclass are the most common bacteria isolated from bottled mineral water.

12.4.3 Prosthecae bacteria

Prosthecae bacteria *sensu stricto* are characterized by a cellular extension (appendage), designated a prostheca, i.e. continuous with the main body of the cell (Staley 1968). Prosthecae bacteria are dimorphic, resulting, upon cell division, in the formation of two cells that are morphologically and behaviorally different from each other. One sibling is non-motile and prosthecae, possessing at least one appendage. In natural habitats, this prosthecae cell is sessile because of an adhesive material associated with a cell pole or with the prostheca. The other sibling is flagellated, bearing (typically) one polar or subpolar flagellum, and is actively motile. This mode of reproduction has an important ecological function as a means of dispersing the population at each generation and thereby minimizing competition between siblings for nutrients (Poindexter 1992). Thus, each normal reproductive event in these bacteria produces two siblings: one to grow, and one to go. This strategy is also consistent with the oligotrophic nature of these organisms, adapted to prolonged nutrient scarcity (Poindexter 1981a). It is experimentally clear that these organisms are highly successful scavengers of very low concentrations of nutrients (Morgan & Dow 1985), and it has been suggested that competitive advantages for an oligotrophic mode of existence are due to efficient uptake of nutrients and the possession of a high surface area-to-volume ratio (Hirsch 1979; Jannash 1979; Shilo 1980; Poindexter 1981b). As typical freshwater nonphototrophic bacteria, prosthecae bacteria such as *Caulobacter* and *Hyphomicrobium* can be regarded as second only to pseudomonads in distribution and numbers (Lapteva 1987).

The occurrence of prosthecae bacteria has rarely been reported in Natural Mineral Waters, but these bacteria have not usually been sought because of their special medium requirements. It is, nevertheless, interesting to note the predominance of appendaged and/or

budding bacteria in all the springs examined in the survey by Gonzalez *et al.* (1987). *Caulobacter* was the most frequently isolated organism in both the bottled water and the water collected at source. A large appendaged and budding bacterium similar to *Hyphomicrobium* or *Hyphomonas* was also recovered from some samples. However, it may be that a low tolerance of decreased oxygen concentration could limit the occurrence of prosthecate bacteria in groundwater habitats.

Sheathed iron-related bacteria, isolated on a specific medium, were observed in all samples collected at one of the springs and in 76% of commercial samples (Gonzalez *et al.* 1987).

12.4.4 *Pseudomonads, Acinetobacter, Alcaligenes*

The classification of gram-negative aerobic rods is becoming more and more complex, owing to the creation of many new genera and the description of large numbers of species. The species of the genus *Pseudomonas* comprise a substantial proportion of the microflora of free-living saprophytes in soils, fresh water, groundwater, marine environments, and many other natural habitats, especially plants. The general characteristics of the genus *Pseudomonas* described by Palleroni (1984) are:

- straight or slightly curved, rod-shaped gram-negative cells;
- many species accumulate poly- β -hydroxybutyrate;
- motile by one or several polar flagella, rarely non-motile;
- aerobic, having a strictly respiratory type of metabolism with oxygen as terminal electron acceptor;
- in some cases, nitrate can be used as an alternate electron acceptor;
- some species are facultatively chemolithotrophic and capable of using H_2 as energy source.

The genus *Pseudomonas* was subdivided by Palleroni *et al.* (1973) into five distantly related rRNA groups (Table 12.5). During the last decade there has been a considerable revision of the phylogenetic relationships of these organisms leading to the description of new groups within the proteobacteria (Fig. 12.5). The major changes in the nomenclature of the pseudomonads can be summarized, as shown in Table 12.5. The most frequently isolated organisms from Natural Mineral Waters belong to the alpha, beta, and gamma subclasses of the proteobacteria and especially to the genus *Pseudomonas* belonging to rRNA group I (Kerstens *et al.* 1996). The species of *Acinetobacter*, on the other hand, are non-motile and oxidase negative, while *Alcaligenes* spp. are motile by peritrichous flagella. All species are aerobic, having a strictly respiratory type of metabolism with oxygen as the terminal electron acceptor.

The organisms most widely isolated from mineral water and representing major groups are shown in Table 12.6. These results were obtained in extensive studies by Schwaller and Schmidt-Lorenz (1981a,b), Bischofberger *et al.* (1990), Manaia *et al.* (1990), Guillot and Leclerc (1993), and Vachée *et al.* (1997). It is difficult to compare the studies because of the different water types and sampling sites, techniques of isolation and identification, and methods of colony selection. However, some features are common to all the studies. By far the most important members of the mineral water flora are fluorescent and non-fluorescent pseudomonad species. The genus *Pseudomonas*, now restricted to rRNA group I, encompasses some genuine *Pseudomonas* species that display genomic and phenotypic relationship to *Pseudomonas aeruginosa* (Moore *et al.* 1996). In some instances, the strains producing

Table 12.5 Major changes in the nomenclature of the pseudomonads isolated from Natural Mineral Waters.

Previous name in the rRNA groups of Palleroni <i>et al.</i> (1973)	New name within the different subclasses of the proteobacteria	Reference
Group I (fluorescent)	Gamma subclass	
<i>P. aeruginosa</i> ^a	Same	Palleroni <i>et al.</i> (1973)
<i>P. fluorescens</i>	Same	Palleroni <i>et al.</i> (1973)
<i>P. putida</i>	Same	Palleroni <i>et al.</i> (1973)
<i>P. syringae</i> ^b	Same	Palleroni <i>et al.</i> (1973)
<i>P. rhodesiae</i> ^b	Same	Coroler <i>et al.</i> (1996)
<i>P. veronii</i> ^b	Same	Elomari <i>et al.</i> (1996)
<i>P. monteilii</i> ^c	Same	Elomari <i>et al.</i> (1996)
<i>P. jessenii</i> ^b	Same	Verhille <i>et al.</i> (1999a)
<i>P. mandelii</i> ^b	Same	Verhille <i>et al.</i> (1999a)
<i>P. gessardii</i> ⁿ	Same	Verhille <i>et al.</i> (1999b)
<i>P. migulae</i> ^b	Same	Verhille <i>et al.</i> (1999b)
<i>P. libanensis</i> ^d	Same	Dabboussi <i>et al.</i> (1999a)
<i>P. cedrella</i> ^d	Same	Dabboussi <i>et al.</i> (1999b)
<i>P. orientalis</i> ^d	Same	Dabboussi <i>et al.</i> (1999b)
<i>P. brennerii</i> ^b	Same	Baida <i>et al.</i> (2001)
<i>P. grimonii</i> ^b	Same	Baida <i>et al.</i> (2002)
Group I (nonfluorescent)		
<i>P. stutzeri</i>	Same	Palleroni <i>et al.</i> (1973)
<i>P. alcaligenes</i>	Same	Palleroni <i>et al.</i> (1973)
<i>P. pseudoalcaligenes</i>	Same	Palleroni <i>et al.</i> (1973)
Group II	Beta subclass	
<i>P. cepacia</i>	<i>Burkholderia cepacia</i>	Yabuuchi <i>et al.</i> (1992)
<i>P. pickettii</i>	<i>Ralstonia pickettii</i>	Yabuuchi <i>et al.</i> (1992, 1995)
<i>P. solanacearum</i>	<i>R. solanacearum</i>	Yabuuchi <i>et al.</i> (1992, 1995)
<i>P. lemoignei</i>	<i>Burkholderia-Ralstonia</i>	De Vos and De Ley (1983)
Group III	Beta subclass	
<i>P. acidovorans</i>	<i>Comamonas acidovorans</i>	Tamaoka <i>et al.</i> (1987)
<i>P. terrigena</i>	<i>C. terrigena</i>	De Vos <i>et al.</i> (1985)
<i>P. testosteroni</i>	<i>C. testosteroni</i>	Tamaoka <i>et al.</i> (1987)
<i>P. delafieldii</i>	<i>Acidovorax delafieldii</i>	Willems <i>et al.</i> (1990)
Group IV	Alpha subclass	
<i>P. diminuta</i>	<i>Brevundimonas diminuta</i>	Segers <i>et al.</i> (1994)
<i>P. vesicularis</i>	<i>Brevundimonas vesicularis</i>	Segers <i>et al.</i> (1994)
Group V	Gamma-beta subclass	
<i>P. maltophilia</i> (<i>Xanthomonas</i>)	<i>Stenotrophomonas maltophilia</i>	Palleroni and Bradbury (1993)
No group	Alpha subclass	
<i>P. paucimobilis</i>	<i>Sphingomonas paucimobilis</i>	De Vos <i>et al.</i> (1989) Yabuuchi <i>et al.</i> (1990)

^a *Pseudomonas aeruginosa* is not a normal component of the microbial flora of Natural Mineral Waters.^b From Natural Mineral Waters.^c From clinical samples.^d From Lebanese springs.

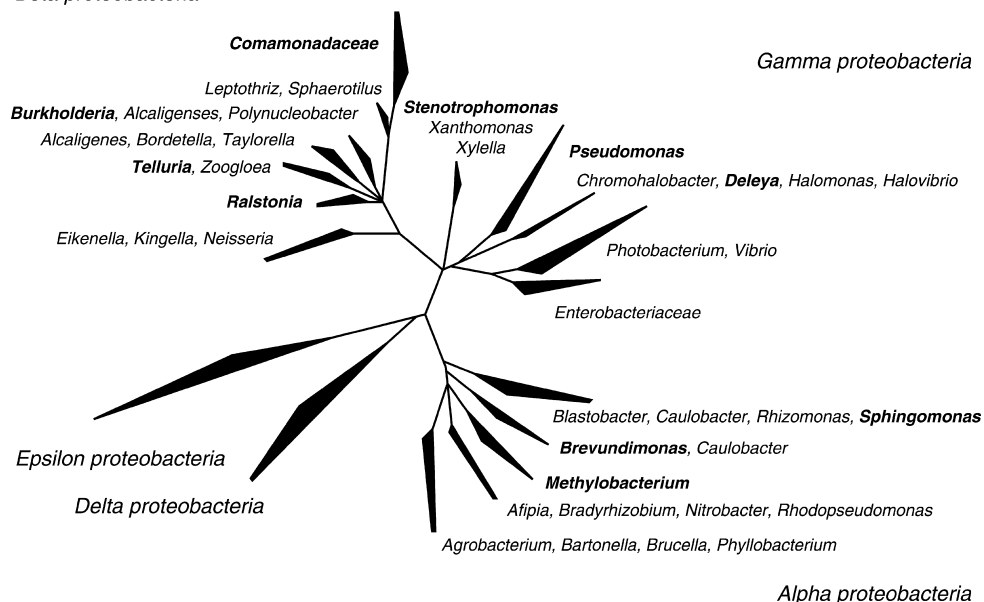
Beta proteobacteria

Fig. 12.5 Phylogenetic relationships of proteobacterial groups (solid triangles) indicating species currently or formerly assigned to the genus *Pseudomonas* (bold). (Reproduced with permission from Kersters *et al.* (1996); published by Gustav Verlag.)

fluorescent pigment constituted up to 50% of all the isolates (Guillot & Leclerc 1993). The strains of the genera *Acinetobacter* and *Alcaligenes* were isolated in all studies in numbers that sometimes rivaled those of the genus *Pseudomonas*. In decreasing order of importance, species of *Comamonas*, *Burkholderia*, *Ralstonia*, and *Stenotrophomonas* were also isolated, followed by species of *Sphingomonas*, *Acidovorax*, and *Brevundimonas*.

In some studies, such as those of Guillot and Leclerc (1993) and Vachée *et al.* (1997), the unidentified isolates reached about 80%. These results are not surprising because of the large phenotypic and genotypic diversity of bacteria from groundwater and the large number of unclassified species in this environment. Furthermore, some common species are remarkably heterogeneous; this is the case with *P. fluorescens*, which can be subdivided by various criteria into subspecies or biovars. The adaptability of *Pseudomonas* and related bacteria makes them ideal candidates for colonizing groundwater systems where organic carbon compounds are largely limited to dissolved organic carbon leaching out of the soil zone above (local flow system) or present in the sediments as a primary carbon source (intermediate flow system).

12.4.5 *Cytophaga*, *Flavobacterium*, *Flexibacter*

It is not uncommon to observe yellow, orange, or brick-red colonies on agar plated with mineral water samples. Sometimes these form films that may cover the whole plate within a few days. In other cases, the colonies expand slowly or remain more or less compact. In few instances, rhizoid growth is also observed. Many of the strains produce flexirubin-type pigments in addition to carotenoids (Reichenbach 1992). These bacteria generally belong to the genera *Cytophaga*, *Flavobacterium*, and *Flexibacter*, which are regularly isolated from

Table 12.6 Major groups of bacteria isolated from Natural Mineral Waters.

Species, genus or group	Schwaller & Schmitz-Lorenz (1980)	Bischofberger <i>et al.</i> (1990)	Manaia <i>et al.</i> (1990)	Guillot & Leclerc (1993), Vachée <i>et al.</i> (1997)
<i>Pseudomonas</i> (fluorescent) ^a	++	++	++	++
<i>Pseudomonas</i> (nonfluorescent) ^b	++	+	++	+
<i>Burkholderia cepacia</i>	–	+	+	+
<i>Ralstonia pickettii</i>	+	–	+	+
<i>Burkholderia-Ralstonia</i> (<i>P. lemoigne</i>)	–	++	–	–
<i>Comamonas acidovorans</i>	+	–	++	+
<i>Comamonas testosteroni</i>	+	+	–	–
<i>Acidovorax delafieldii</i>	+	+	–	–
<i>Stenotrophomonas maltophilia</i>	–	+	+	+
<i>Brevundimonas diminuta</i>	–	–	–	+
<i>Brevundimonas vesicularis</i>	–	–	–	+
<i>Sphingomonas paucimobilis</i>	–	–	+	+
<i>Acinetobacter</i>	++	+	+	+
<i>Alcaligenes</i>	+	+	++	+
<i>Cytophaga</i> , <i>Flexibacter</i> , <i>Flavobacterium</i>	++	++	++	+
<i>Arthrobacter</i> , <i>Corynebacterium</i>	+	++	–	+

+, <10% of isolates;

++, between 10% and 50%;

+++ >50%.

^a *P. chlororaphis*, *P. fluorescens*, *P. putida*, *P. rhodesiae*, *P. veronii*.^b *P. stutzeri*, *P. alcaligenes*.

most Natural Mineral Waters, sometimes even as dominant populations (Schwaller & Schmitz-Lorenz 1981a,b; Quevedo-Sarmiento *et al.* 1986; Bischofberger *et al.* 1990).

The overall characteristics of these groups of bacteria suggest that they can adapt to the groundwater environment, but perhaps more readily to shallow aquifers (local flow systems) where dissolved oxygen concentrations are relatively high and open to sources of nutrients from the surface or from the unsaturated zone.

12.4.6 Gram-positive bacteria

Gram-positive bacteria occurring in Natural Mineral Waters have been frequently reported to belong to “arthrobacter-like” or “coryneform-like” bacteria (Schwaller & Schmidt-Lorenz 1981a; Gonzalez *et al.* 1987; Bischofberger *et al.* 1990), and more rarely to *Bacillus*,

Staphylococcus, and *Micrococcus* (Leclerc *et al.* 1985; Quevedo-Sarmiento *et al.* 1986; Hunter & Burge 1987; Mavridou 1992). However, it is advisable to be cautious in the identification of gram-positive bacteria. When these are isolated from bottled mineral water, it is possible that they are derived from the bottling plant, since gram-positive bacteria such as *Micrococcus* and *Staphylococcus* are common inhabitants on the skin and mucous membranes of mammals. All these bacteria may, indeed, be part of the ambient microflora.

The distribution of gram-positive bacteria is a critical issue in groundwater systems. Transmission electron microscopy showed, in fact, that about two-thirds of the bacterial cells from subsurface environments had gram-positive cell walls, whereas isolation of micro-organisms in culture medium revealed a preponderance of gram-negative cells (Ghiorse & Balkwill 1983). This observation was also corroborated by Wilson *et al.* (1983). In addition to direct microscopic observation, biochemical techniques can also give an indication of the relative abundance of gram-positive and gram-negative micro-organisms in samples. For example, the amount of ribitol, which is a part of teichoic acids of gram-positive bacteria, is a rough measure of their relative abundance. Likewise, the abundance of gram-negative bacteria can be estimated by the level of hydroxy fatty acids in the lipopolysaccharides.

The ability to form endospores, when growing cells are subjected to nutritional deficiency or excessive heat or dryness, is characteristic of some gram-positive bacteria such as *Bacillus* and *Clostridium*. Endospores are particularly well adapted to environments subjected to wide variations in water and low-nutrient conditions such as subsurface environments but, with some exceptions, species of *Bacillus* or *Clostridium* have not been reported widely from aquifer systems (Hirsch & Rades-Rohkohl 1983; Chappelle *et al.* 1988). These observations indicate that spore formation *per se* might not be a major feature for bacteria in groundwater habitats.

12.5 INHIBITORY EFFECT OF AUTOCHTHONOUS BACTERIA

Natural Mineral Water is not subjected to antibacterial treatments of any kind and, after bottling, it is often stocked for several months before it is distributed and sold. To assess public health risks it is therefore important to know the survival capacity of pathogens and indicator bacteria. Much of the early literature on bacterial survival in water suggested that die off or decay was the only functional response of bacteria of fecal origin exposed to marine or freshwater. This was primarily attributed to the “bactericidal” property of seawater (Ketchum *et al.* 1952) or the self-purifying power of freshwater (Leclerc & Mossel 1989). Dilution, light, and temperature, as well as biological parameters such as inhibition, antagonism, and predation, could be important factors affecting the fate of pathogens or indicator bacteria. The use of the terms “die off” or “decay” to describe changes in contaminant bacteria densities over time is probably inappropriate. The apparent reduction of recoverable counts from marine or fresh waters is not only the result of “true” cell death, i.e. cells that become non-viable, but is also a function of physiological adaptation to an adverse environment and complex interactions of physical, biological, and chemical processes. Changes in bacterial density may be expressed as loss of viability, alteration in culturability, persistence, or aftergrowth. Under certain conditions of metabolic stress such as starvation, bacterial cells may enter into a VBNC. In this state the cells are not culturable in standard media but retain certain features of living cells such as respiratory activity (Zimmermann *et al.* 1978) and substrate uptake (Kogure *et al.* 1979). The VBNC state has been suggested to represent an escape strategy for survival (Colwell *et al.* 1985; Roszak & Colwell 1987a,b)

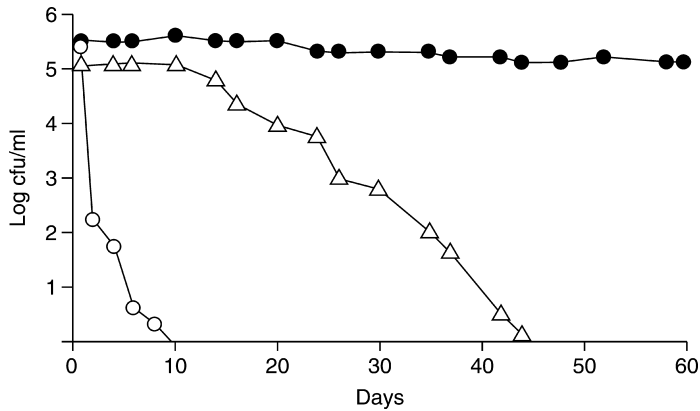


Fig. 12.6 Antagonistic effect of the microbial flora of a mineral water on *E. coli*. Filtered water that had contained the autochthonous flora for 1 week (●); non-filtered water containing the autochthonous flora (Δ); filtered water that had contained the autochthonous flora for 50 days (○). These observations indicate that it takes several weeks before antagonistic substances accumulate in the water in toxic levels sufficient to inhibit the recovery of the target organism. (Redrawn from Ducluzeau *et al.* (1976c).)

and a large number of bacterial species, including pathogens and indicators, have been recognized to enter VBNC states under laboratory or field conditions (Oliver 1993).

The available data on the survival of bacteria in surface waters cannot be extrapolated to bottled mineral waters. It is important, for example, to take into account some specific factors such as the impact of drilling, the bottling stress, the selective attachment of some populations to solid surfaces, the fate of autochthonous populations that can reach very high numbers a few days after bottling, the effect of an enclosed environment (bottle effect), used for influence of PVC, PET, or glass used for bottles.

Ducluzeau (Delabroise & Ducluzeau 1974; Ducluzeau *et al.* 1976a,c; Lucas & Ducluzeau 1990a,b) was the first to study the survival of enterobacteria in mineral water to assess the influence of autochthonous bacteria on indicator bacteria. In the most significant experiment, *Escherichia coli* was inoculated into sterile water at a concentration of 1.2×10^5 cfu/ml. The plate counts of *E. coli* were reduced by less than 1 log over a 3-month period, and more than 10^2 cfu/ml were still detected 5 months later. On the other hand, when this experiment was repeated with mineral water, i.e. in the presence of the autochthonous mineral flora (between 5×10^4 and 5×10^5 cfu/ml), the complete loss of viability of *E. coli* took place between 35 and 55 days, depending on the experiment. The same loss of viability of the test organism exerted by the whole autochthonous flora was exhibited by some strains from the dominant flora. Therefore, it appears that these authors observed an antagonistic activity by autochthonous flora of the mineral water, and not an effect due to the physical or chemical properties of the water itself. The antagonistic activity could possibly be related to an inhibitory substance accumulating in the water during the successive cycles of growth and death of the autochthonous bacterial population (Fig. 12.6).

More recent studies by Moreira *et al.* (1994) with *E. coli* and other coliform indicators such as *Enterobacter cloacae* and *Klebsiella pneumoniae* showed that the viable counts of the three test enterobacteria decreased under all experimental conditions, but the decrease depended on the organism and the conditions in which they were examined (Fig. 12.7). The population of *E. coli* decreased rapidly in mineral water, especially when bottled in PVC,

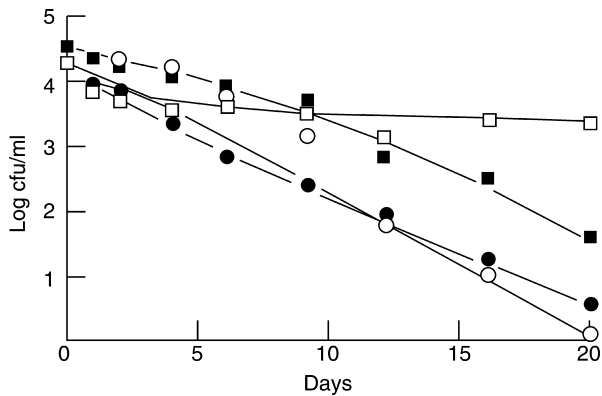


Fig. 12.7 Survival determined by viable counts on triptic soy agar of *E. coli* inoculated in mineral water with the autochthonous flora in PVC bottles (●); in sterile mineral water in PVC bottles (○); in sterile mineral water in glass containers (■); and in sterile tap water in glass containers (□). (Redrawn from Moreira *et al.* (1994).)

irrespective of the presence or absence of autochthonous bacterial flora. In sterile tap water, after an initial decrease, the viable counts remained almost constant during the experimental period. Of the three enterobacteria tested, *E. cloacae* had the slowest decrease in viable counts in any of the conditions examined, although the decrease was slightly more pronounced in sterile mineral water bottled in PVC than in the other test conditions. A small constant decrease in the viable counts of *K. pneumoniae* was observed in mineral water bottled in PVC with indigenous flora and in sterile tap water. On the other hand, this strain was rapidly inactivated in sterile mineral water bottled in PVC and glass, resulting in very low viable counts after the 20-day experimental period. In this study, however, the autochthonous flora of the mineral water, which reached 1.03×10^6 cfu/ml during the experimental period, did not appear to have an effect on the survival of *E. coli* and *E. cloacae*, but it did appear to have an effect on the survival of *K. pneumoniae* compared to the other conditions tested. The contradiction between the results of Ducluzeau and his colleagues and those of Moreira *et al.* (1994) can only be extended to the effect of the autochthonous flora on *E. coli*, since the former authors did not examine the effect of the normal flora of mineral waters on the other coliform bacteria.

Several other studies on the fate of *E. coli* and pathogenic bacteria in mineral water have been performed irrespective of the influence of autochthonous flora. Burge and Hunter (1990) showed that *E. coli* was able to survive in bottled mineral water for about 42 days and that *Salmonella typhimurium*, *Aeromonas hydrophila*, and *P. aeruginosa* persisted for at least 70 days; on the other hand, *Campylobacter jejuni* was recovered for only 2–4 days. In carbonated waters, the survival of the same bacteria was reduced by 25–50%. Another study reported that *E. coli* declined by 1 log every 2 weeks in sterile spring water stored at 4°C; the behavior of *Yersinia enterocolitica* was different from that of *E. coli*, increasing for the first 8 weeks and still being recoverable 64 weeks later (Karapinar & Gönül 1991). Several *E. coli* O157:H7 outbreaks associated with both drinking and recreational water raised concerns about waterborne illness caused by these bacteria (Chalmers *et al.* 2000). The survival characteristics of this pathogen have been described in inoculated drinking and recreational water (Wang & Doyle 1998), bottled water (Warburton *et al.* 1998), and natural mineral water (Kerr *et al.* 1998). Overall, these studies indicate that *E. coli* O157:H7 is

hardly a pathogen that can survive for long periods of time in water. Some contradictory results concerning the survival of enteric pathogens have been found that may be due to the different techniques used between laboratories, different strains used, and different waters (Afonso *et al.* 1998a,b).

P. aeruginosa is frequently isolated from surface water and is also a major concern in mineral water bottling plants, because it is an opportunistic pathogen and can contaminate boreholes and bottling plants. The ability of *P. aeruginosa* to grow in water, even with low concentrations of organic substrates, has been studied in relation to its presence in tap water and distilled water (Botzenhart & Röpke 1971; Favero *et al.* 1971; Botzenhart & Kufferath 1976; Dickgiesser & Rittweger 1979; Van der Kooij *et al.* 1982a), and to define the biological stability of mineral waters (Van der Kooij 1990). In contrast to most enterobacteria, *P. aeruginosa* is able to grow in water. The behavior of *P. aeruginosa* based on the culturability was assessed in still mineral water with or without autochthonous flora (Moreira *et al.* 1994). Immediately after inoculation of this organism in mineral water, there was a sharp decrease in the viable counts. Later, there was a very slow decrease in viable counts in PVC-bottled mineral water with autochthonous flora, whereas the viable counts in sterile mineral water remained constant for the duration of the experiment. Gonzalez *et al.* (1987) showed a significant inhibitory effect of the autochthonous flora of mineral water on *P. aeruginosa*. The bacterial generation time at 30°C was about 19 h in water with intact flora, while it was about 6 h in mineral water sterilized by filtration. The *P. aeruginosa* population became unculturable more quickly as the storage temperature was lowered to 6°C, the initial population of about 100 cfu/ml becoming undetectable after 210 days. On the other hand, at 37°C *P. aeruginosa* density increased from 10²–10⁴ cfu/ml at the end of the 1-year experiment.

The effect of the utilization of laboratory-adapted allochthonous pathogens or indicators, the effect of the size of the inoculum, the biological state of the inoculum and the physicochemical composition of water, are among the concerns of the validity of these studies. Therefore, the antagonistic effect of the autochthonous flora on *P. aeruginosa* was examined in three types of Natural Mineral Water (very low mineral content, low mineral content, rich in mineral content) with an inoculum that gave a final concentration of approximately one organism per ml in the bottled water (Vachée & Leclerc 1995). Four test strains were used: one obtained from a culture collection, one from a patient with septicemia, and two from surface water. The test bacteria were inoculated immediately after sampling from the source of the mineral waters. Overall experimental conditions mimicked natural contamination before bottling. In the filter-sterilized waters, *P. aeruginosa* attained more than 10⁴ cfu/ml a few days after inoculation, and remained almost constant during the 9 months of the experiment. In mineral water with the autochthonous flora, the initial inoculum did not increase at all during the experiment (Fig. 12.8).

The inhibitory ability of the autochthonous flora observed in some experiments cannot be extrapolated to all waters and test pathogens or indicators of fecal pollution owing to the limited number of studies using different experimental conditions, waters with different chemical compositions, and different types of bottling material. In addition to these considerations, the results do not take into account the ability of many bacteria to enter into a VBNC state. It is also important to remember that the predominant bacterial flora of mineral water belongs to genus *Pseudomonas* or related genera, and that these bacteria produce secondary metabolites with toxic or inhibitory activity for competitors (Leisinger & Margraff 1979; O'Sullivan & O'Gara 1992; Budzikiewicz 1993). In contrast to carbohydrates, lipids,

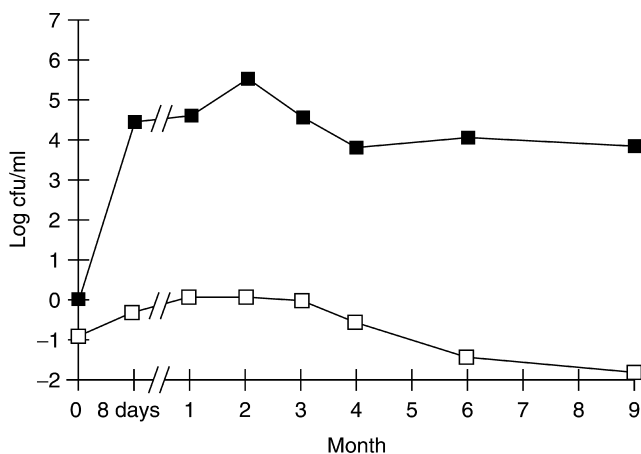


Fig. 12.8 Survival or growth determined by viable counts (cfu) of *P. aeruginosa* (wild-type strain) on a selective medium after inoculation into mineral water maintained at room temperature containing the autochthonous flora (■) and without the autochthonous flora (□). The results show that the normal flora exerts a strong antagonistic effect on a low inoculum of *P. aeruginosa*. (Redrawn from Vachée & Leclerc (1995).)

proteins, or nucleic acids, secondary metabolites are not present during all stages of the growth cycle. They are not important as sources of energy or reserve substances, and they are only slowly metabolized. The two functional classes typical of secondary metabolites of *Pseudomonas* spp. are siderophores and antibiotically active substances.

With rare exceptions, iron is available to micro-organisms only in its trivalent form. Owing to the low dissociation constants of different oxide hydrates, the concentration of free Fe^{3+} at pH 7.0 is at best 10^{-17} mol/l, while about 10^{-6} mol/l would be needed to maintain the necessary supply for the living cells. Soil and water bacteria, as well as those infecting animals or humans (where the iron supply is limited because it is bound to peptidic complexes), produce a variety of complexing agents (usually called siderophores) capable of making inorganic Fe^{3+} available or securing it by transcomplexation. Most known siderophores can be grouped into hydroxamate- and phenolate/catecholate-type structures and have different affinities for ferric iron. Water and soil pseudomonads generally produce fluorescent, yellow-green, water-soluble siderophores named pyoverdins or pseudobactins with both a hydroxamate and a phenolate group.

A total of 916 assays were performed, of which 25% inhibited the growth of one or more target organism in medium without added iron, and only 3.3% inhibited growth in the medium with additional iron.

Antibiotic production by some fluorescent *Pseudomonas* spp. is now recognized as an important factor in microbial competition. The diversity of the antibiotics produced by different species is now being fully recognized (Leisinger & Margraff 1979; Budzikiewicz 1993). Compounds such as phenazines (Thomashow & Weller 1988), pyoluteorin (Howell & Stipanovic 1980), pyrrolnitrin (Howell & Stipanovic 1979), tropolone (Lindberg 1981), pyocyanin (Vandenbergh *et al.* 1983), and 2,4-diacetylphloroglucinol (Keel *et al.* 1990; Shanahan *et al.* 1992) fall into the class of *N*-containing heterocycles and have been shown to originate from intermediates or end-products of the aromatic amino acid biosynthesis. Another important class of secondary products of *Pseudomonas* comprises unusual amino acids and peptides. In addition to these two major groups of secondary metabolites, some glycolipids, lipids, and

aliphatic compounds with a broad spectrum of activity against bacteria and fungi have been isolated from *Pseudomonas* cultures (Lindberg 1981). These observations were substantiated by genetic studies, whereby mutants defective in the production of certain antibiotics were directly compared with their otherwise wild-type parental strains. These reports showed that antibiotic-negative mutants had lost their specific inhibitory activity against pathogenic fungi (Gutterson *et al.* 1986; Gill & Warren 1988; Thomashow & Weller 1988; Shanahan *et al.* 1992).

However, fluorescent *Pseudomonas* spp. have emerged as the largest and possibly most promising group of bacteria because of their potential for rapid and aggressive colonization and for preventing the invasion of detrimental or pathogenic micro-organisms. These organisms have been used in the biocontrol of plant diseases due to bacteria or fungi (Kloepper *et al.* 1980, 1988; Suslow 1982; Keel *et al.* 1990; O'Sullivan & O'Gara 1992). The relative importance of the production of antibiotics, siderophores, hydrogen cyanide, and direct competition for nutrients may differ considerably among strains, and conflicting results have been reported with regard to the role of pyoverdins or antibiotics produced by fluorescent pseudomonads in control of soil-borne pathogens (Hamdan *et al.* 1991; Henry *et al.* 1991; Laine *et al.* 1996; Raaijmakers *et al.* 1997).

12.6 ASSESSING HEALTH RISK FROM AUTOCHTHONOUS MICROFLORA

The qualities of autochthonous bacteria in mineral water, referred to as the “heterotrophic plate count”, and can be investigated by the HPC test, leads us to believe that they do not cause disease. Their metabolism (oligotrophic) and their nutrition (prototrophic) mean that they are not adapted to living in humans or animals. Their psychrotrophy (maximum growth temperature of 25–30°C) renders them particularly vulnerable to invasion of human tissue. The digestive tract with its natural barriers (gastric trap, mucus and gastric mucous membrane, intestinal motricity, intestinal cytoprotection), its complex multiple microbial flora exerting powerful antagonisms, its differentiated lymphoid tissue, and general and local immune response precludes colonization by these stressed bacteria.

Owing to various circumstances, one or more host resistance mechanisms may be lost, thus increasing the probability of infection. The term immunosuppressed host is used to refer to hosts in which (one or more) resistance mechanisms are malfunctioning. Interest has turned to infections that arise with increasing frequency in such “compromised hosts”; such infections have been called “opportunistic infections” by Von Graevenitz (1977). Almost all people at risk to environmental bacteria are hospitalized patients with profound specific defects in the immune system. There are principally two categories of high-risk patients for whom water ingestion is restricted. These include bone marrow transplant patients and those with acute leukemia. It can be recommended that HIV-infected persons who wish to take independent action to reduce the risk of infections such as cryptosporidiosis, microsporidiosis, or disseminated infection with *Mycobacterium avium* complex, possibly occurring in tap water, boil the water for 1 min or use bottled water such as Natural Mineral Water.

There are several approaches to detecting bacterial populations, such as those autochthonous to mineral waters that could have public health importance but are not known to be pathogenic. The methods available include animal model systems and epidemiological studies. Another approach is to search for virulence factors from bacterial isolates.

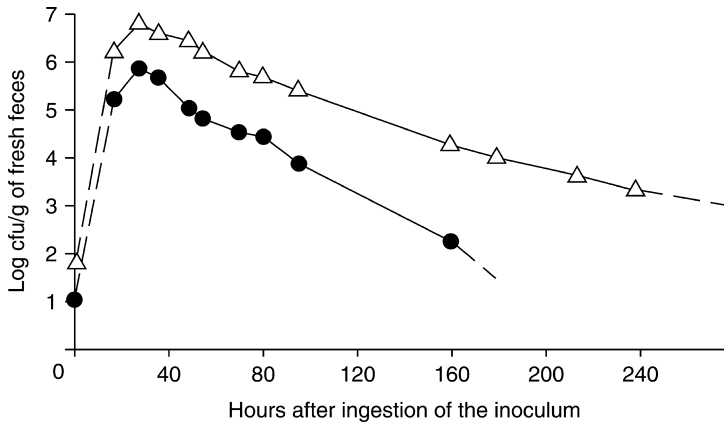


Fig. 12.9 Transit of *Bacillus subtilis* spore markers (Δ) as compared to *Pseudomonas* strain P1 ($\bullet$) through the digestive tract of axenic mice. (Redrawn from Ducluzeau *et al.* (1976b).)

12.6.1 Inoculation of the digestive tract of axenic mice

The purpose of the work carried out by Ducluzeau *et al.* (1976b) was to determine whether the microflora of mineral water was able to establish itself in the digestive tract of axenic mice, to multiply in great numbers, and to entail pathological disorders in mice receiving mineral water or bacterial species from mineral water. In the axenic animal, the “barrier effect” of the digestive microflora does not exist and any bacterial strain potentially capable of growing in the digestive tract reaches, within 12–24 h, between 10^9 and 10^{10} cells/g of fresh feces (Ducluzeau & Raibaud 1974, 1976, 1979). Axenic animals are a first choice for determining whether autochthonous bacteria of mineral water are able to adhere, penetrate, and multiply in epithelial cells or produce toxins or other substances causing tissue damage. The most stringent experiments were devised to compare the transit of an inoculum of several autochthonous strains and that of the spores used as markers (Fig. 12.9). In spite of the presence of an equivalent number of *Pseudomonas* (strain P1) cells and of the inert marker in the inoculum, the maximum number of *Pseudomonas* in the feces was lower than that of the spores, and the former disappeared from the feces more rapidly than the latter. Thus, a partial destruction of *Pseudomonas* P1 was shown during its transit through the digestive tract. Other assays, performed with other strains of *Pseudomonas* or *Acinetobacter* provided similar results.

12.6.2 Randomized trials in infants

The quality of water for the preparation of babies’ feeding bottles is universally recognized as an essential choice. In the past, mineral water conditioned in glass bottles was used. Since 1970, PVC conditioning has been used, and some people have wondered about the modifications in the microbial populations that may have resulted from using water bottled in PVC, as well as effects on the health of babies. To answer this question, a study was carried out from January 1984 to January 1986 by Leclerc (1990), with 2 groups of 30 babies each, using the double-blind method. One group was fed milk made up from mineral water in PVC bottles; the other group was fed milk made up from the same pasteurized mineral water in glass bottles. The babies chosen corresponded to very precise inclusion criteria,

such as the absence of any disease (including icterus or diarrhea), absence of any antibiotic treatment, and babies being exclusively fed on milk. Diarrhea was defined according to the usual criteria, namely the number of stools, consistency, odor, effect on weight of the baby, and hyperthermia (as a criterion of an infectious origin). The bacteriological criteria included the search for pathogenic bacteria from coprocultures, and in particular *Salmonella*, *Shigella*, *Yersinia*, enteropathogenic *E. coli*, and the enumeration of all gram-negative rods to allow the evaluation of a possible modification of the intestinal microbial ecosystem.

In no case was it possible to isolate mineral water-derived bacteria from rhinopharyngeal samples analysed 1 or 2 h after drinking bottled milk. Nor was there evidence for digestive tract colonization from the analysis of the stool samples. On rare occasions, bacteria from mineral water were isolated, but at levels that were 10–100 times smaller than in the original water. The intestinal flora of the neonate acts as a “permissive barrier”. The waterborne bacteria travel through the intestine in low numbers, then disappear little by little when feeding bottles prepared with mineral water are substituted with those prepared using sterile water. It has been demonstrated experimentally that body temperature, transit time, gastric acidity, and the oxidation–reduction potential of the intestine, working in conjunction, result in decrease in numbers of bacteria ingested and their total elimination.

From an epidemiological point of view, no difference could be found in the two groups. Of the 60 babies, 9 showed signs of diarrhea as defined in the protocol, of which 5 received milk prepared with sterile mineral water and 4, milk conditioned with Natural Mineral Water. In no case did the risks appear sufficiently severe to justify the suspension of milk feeding. It may be concluded that there was no difference in the pathology observed in the two groups.

12.6.3 Virulence characteristics of bacteria

The development of an infection is related to three basic parameters (Edberg *et al.* 1997): (i) the number of microbes and the target organ of the host; (ii) the virulence characteristics of the microbe; and (iii) the immune status of the host and target organ (Duncan & Edberg 1995). Several studies have been conducted to test the invasive or cytotoxic activity of drinking water on cultured cell lines (Lye & Dufour 1991; Payment *et al.* 1994; Edberg 1996; Edberg *et al.* 1996). In all cases, a small percentage (1–2%) of bacteria examined were cytotoxic. Payment *et al.* (1994) examined the cytotoxicity from HPC bacteria isolated on blood-containing medium incubated at 35°C, to mimic what was considered nearest to the human physiological environment. A high percentage of the cytotoxic isolates belonged to the genus *Bacillus*, which might be related to low-level gastroenteritis. Only Edberg *et al.* (1997) studied HPC bacteria isolated from bottled water. Health risks were estimated by the determination of cytotoxicity and invasiveness in a human enterocyte cell line. More than 95% of naturally occurring HPC bacteria showed low invasiveness and cytotoxicity. When either invasiveness or cytotoxicity was demonstrated, only a small number of cells from the culture were positive.

A study was conducted in our laboratory to determine the virulence characteristics of natural mineral water bacteria. The tests selected determine the ability of bacteria to attach, invade, and injure Hep-2 cells. The method used was the one described by Edberg *et al.* (1996). A total of 240 representative strains isolated from 5 French springs were selected, including *P. fluorescens* and all new species cited in Table 12.7. Results showed that none of the bacteria studied is capable of growing and attaching to Hep-2 cells or producing cytotoxin at a temperature of 37°C. The detection of bacterial activity in one or several of the tests for putative virulence factors may be useful in showing potential

Table 12.7 Inhibitory activity of strains isolated from mineral water against nine target organisms on King B medium with or without the addition of iron.

Number of strains tested ^a	Target organisms ^b	Activity (%) ^c	
		King B	King B with iron
148	<i>Escherichia coli</i> , ATCC 10536	49.2	3.9
148	<i>Pseudomonas aeruginosa</i> , ATCC 10490	19.1	5.4
80	<i>Staphylococcus aureus</i> , ATCC 65388	67.5	0.0
80	<i>Enterococcus faecalis</i> (clinical isolate)	1.25	0.0
148	<i>Salmonella typhimurium</i> , ATCC 13311	14.0	2.0
102	<i>Aeromonas hydrophila</i> , ATCC 9071	32.3	7.0
102	<i>Shigella sonnei</i> , ATCC 29930	26.0	0.0
54	<i>Yersinia enterocolitica</i> , CUETM 82-52	16.6	0.0
54	<i>Bacillus cereus</i> , CIP 6624	5.5	0.0

^a 382 strains were examined of which 50 belonged to *P. fluorescens*, 20 to *Sphingomonas paucimobilis*, 18 to *Brevundimonas vesicularis*, 10 to *Comamonas testosteroni*, and 154 were unidentified gram-negative rods.

^b ATCC, American Type Culture Collection, Rockville, MD, USA; CIP, Collection de l'Institut Pasteur, Paris, France; CUETM, Collection de l'Unité d'Ecotoxicologie Microbienne, Villeneuve d'Ascq, France.

^c Mineral water strains were grown in nutrient broth (0.5% peptone, 0.3% meat extract) at 30°C. Agar diffusion assays to screen for growth inhibition of the test bacteria were performed in King B medium with or without iron (0.3% ferric citrate).

health hazards posed by bacteria isolated from potable water. Nevertheless, the exact relationship between putative virulence factors and their potential health effects remains to be investigated.

Overall experimental and epidemiological data show that autochthonous bacteria in Natural Mineral Waters have never brought about detectable pathological disorders in humans or animals and, *in vitro*, are incapable of directly damaging human cells in tissue culture. Since the existence of European regulations (EC 1980), no outbreak or single case of disease due to the consumption of Natural Mineral Water has been recorded in the literature or by the health authorities of the countries within the European Community.

12.7 ASSESSMENT AND MANAGEMENT OF MICROBIAL HEALTH RISKS

All microbial hazards occurring in drinking water from distribution systems must be taken into account in the case of Natural Mineral Water. In the past decade, many outbreaks attributed to protozoan or viral agents have been reported in conventionally treated

water supplies, all of which met coliform standards. Viruses have been shown to persist longer in these waters than fecal coliforms and many are more resistant to water and wastewater treatment processes. A similar situation exists for protozoan cysts. These findings repeatedly suggest the inadequacy of treatment processes for safe water and the inadequacy of coliforms as indicators. Natural Mineral Waters are recognized as not being vulnerable to fecal contamination after a strict procedure that requires a few years of evidence to confirm stability of physical and chemical characteristics. The water must also be shown to be microbiologically wholesome, i.e. requiring no treatment. No outbreak or single case of disease due to the consumption of natural mineral water, in line with European microbiological standards, has been recorded. Other epidemiological data including cohort study in infants, animal tests, and cell tests have never showed adverse effects (see Section 12.6).

The most distinctive factor of mineral waters might be the very low amount of DOC with an available fraction and its identifiable compounds such as labile amino acids, carbohydrates, and carboxylic acids (Lacoste 1992). Organic substances in the distribution network water originate from the raw water (generally surface water) used for its production and from materials (pipes, lubricants, joints, sealants, etc.) that may release biodegradable compounds (Geldreich 1996). These nutrients are a major factor for the colonization of pipes by heterotrophic bacteria. The so-formed biofilms are capable of retaining pathogens, including environmental pathogens (*Legionella* spp., *M. avium*), viruses, and protozoa entering a distribution network.

For mineral water sources claiming to be protected, an inherent feature is that the physical and chemical nature of water is constant over time. Therefore, simple measurements such as temperature, ionic strength, anions, cations, and trace elements have great meaning in sampling source water, whereas they would have little meaning when sampling tap water.

Mineral water bacterial communities, identified by culture or with specific probes, are primarily aerobic gram-negative rods. These bacteria belong to alpha, beta, and gamma proteobacterial groups, as well as to the phylum of *Flavobacterium*–*Cytophaga*. In contrast, the general population in water supplies includes many gram-negative and gram-positive bacteria, sporeformers, acid-fast bacilli, free-living amoebae and nematodes, opportunistic fungi and yeasts (Geldreich 1996). Many authors have observed antibacterial activity by autochthonous flora of mineral waters; however, the issue is widely debated (see Section 12.5).

12.7.1 Identifying microbial hazards in drinking water

A large variety of bacterial, viral, and protozoan pathogens are capable of initiating water-borne infections:

- These are primarily the enteric bacterial pathogens, including classic agents such as *Vibrio cholerae*, *Salmonella* spp., *Shigella* spp., and newly recognized pathogens from fecal sources such as *Campylobacter jejuni* and enterohemorrhagic *E. coli*. The survival potential of these bacteria increases in biofilms due to their ability to form a VBNC state.
- Several new bacterial pathogens, such as *Legionella* spp., *Aeromonas* spp., *P. aeruginosa*, and *M. avium* have a natural reservoir in the aquatic environment and soil. These organisms are introduced from the surface water into the drinking water system usually in low numbers. They may survive and grow within the distribution system biofilm.

- More than 15 different groups of viruses, encompassing more than 140 distinct types, can be found in the human gut. These enteric viruses are excreted by patients and find their way into sewage. Hepatitis A and E viruses cause illnesses unrelated with gut epithelium. Another specific group of viruses has been incriminated as a cause of acute gastroenteritis in humans that includes rotavirus, calicivirus, the most notorious being norovirus, astrovirus, and some enteric adenoviruses. These viruses cannot grow in receiving water and may only remain static in number or die off.
- The most prevalent enteric protozoa, associated with waterborne disease, include *Giardia lamblia* and *Cryptosporidium parvum*. In addition, protozoa such as *Cyclospora*, *Isospora*, and many microsporidian species are emerging as opportunist pathogens and may have waterborne routes of transmission. Like viruses, protozoa cannot multiply in receiving waters. With the exception of *Salmonella*, *Shigella*, and hepatitis A virus, all the other organisms can be called “new or emerging pathogens”.

There are a number of reasons for the emergence of these new pathogens, analysed in every detail by Szewzyk *et al.* (2000), including high resistance of viruses and protozoan cysts, a lack of identification methods for viruses, changes in water use habits (*Legionella*), and human populations at risk. Another striking epidemiological feature is the low number of bacteria that may trigger disease. The infectious dose of *Salmonella* is in the range of 10^7 – 10^8 cells, while only around 100 cells are required to cause clinical illness with *E. coli* O157:H7 and *Campylobacter* (Leclerc *et al.* 2002). The infective dose of enteric viruses is low, typically in the range of 1–10 infectious units; it is about 10–100 oocysts for *Cryptosporidium* (Meinhardt *et al.* 1996).

12.7.2 Assessment of microbial risks

The view on the microbiological safety of drinking water is changing. The demand for the total absence of any pathogenic organism is no longer significant in light of the new pathogens, some of which are capable of growing in drinking water systems. According to the new European Union Council Directive 98/83/EC (EC 1998), water for human consumption must be free from any micro-organisms and parasites and from any substances which, in numbers or concentrations, constitute a potential danger to human health. To deal with this issue, the US Environmental Protection Agency for the first time used a microbial risk assessment approach. It has been defined that an annual risk of 10^{-4} (1 infection per 10 000 consumers per year) should be acceptable for diseases acquired through potable water, this value being close to the annual risk of infection from waterborne disease outbreaks in the USA (4×10^{-3}) (Gerba 2000).

Microbiological risk assessment is a major tool for decision-making in the regulatory area. The problem is, however, that the key data to perform this assessment are mostly missing. Few epidemiological studies correlating the incidence of disease with pathogen densities have been reported. Several outcomes, from asymptomatic infection to death, are possible through exposure to microbes. The issue of dose–response relationships is particularly striking: these relationships are only available for a few pathogens. When infectious doses are low, as is the case for some viruses and protozoan cysts, the calculated tolerable concentrations are also low and monitoring of these pathogens in drinking water becomes impracticable.

Natural Mineral Waters are subject to the general rules laid down by Council Directive 2009/54/EC. At source and when sold, a Natural Mineral Water must be free from parasites and pathogenic microorganisms. These requirements are therefore distinct from tap water.

12.7.3 Management of microbial risks

12.7.3.1 *Heterotrophic plate counts*

HPC measurements have been used to gain better information on the effects of water treatment processes and distribution on the bacteriological quality of drinking water. Various methods and the application of HPC monitoring have been analysed in considerable depth by Reasoner (1990). In certain epidemiological studies reported by Calderon and Mood (1988, 1991) and Payment *et al.* (1991a,b, 1997), there is a debate on the potential negative human health from the consumption of treated water containing high HPC levels of bacteria. The available body of evidence supports the conclusion that, in the absence of fecal contamination, there is no direct relationship between HPC values in ingested water and human health effects in the population at large (WHO 2002).

Natural Mineral Waters cannot be subjected to any type of disinfection that modifies or eliminates their biological components; therefore, they always contain the bacteria that are primarily a natural component of these waters. It is also clearly stated that, after bottling, the recoverable bacterial counts should only result from the normal increase of bacteria present in the source. The studies described in Section 12.6 have not been capable of identifying any microbiological risk from examined bottled mineral waters. To date, there has been no association between human disease and the natural bacteria found in Natural Mineral Water.

Measurement of HPC in bottled mineral water is useful for several reasons (Moreau 2001). First, it proves that no disinfection has occurred. Second, it helps to ensure that, from the spring to the finished product, no major quantitative changes have occurred in the microbial status of the water. Indeed modification from counts normally found at a particular location may give an early warning of significant microbial alteration.

The bacterial species that make up HPC in Natural Mineral Water are psychrotrophic. In the study by Reasoner and Geldreich (1979) on treated distribution water, incubation at 20°C yielded the highest counts in all media when incubation was extended to 12–14 days, whereas 28°C appeared to be the best temperature from day 2 through day 6 of incubation. The 37°C plate count was believed to give an indication of the presence of rapid-growing bacteria more likely to be related to pathogenic or fecal types that might be present from sewage pollution. It can be stated that the measurement at 37°C is unsuitable and unnecessary to determine inadequate processing for safety reasons, because there are other appropriate indicators for this purpose, including the indicators of fecal contamination.

12.7.3.2 *Marker organisms and enteric pathogens*

In the microbiological monitoring of water and foods, Ingram (1977) introduced the distinction between “index organisms” for markers whose presence indicates the possible occurrence of ecologically similar pathogens, and “indicator organisms” for those whose presence points to inadequate processing for safety. In short, index markers indicate a potential health risk, whereas indicators reveal process failure. The terms “indicator of fecal contamination” (index) and “indicator of quality” (indicator) are also commonly used. *E. coli* is now the sole recognized indicator of fecal contamination, being a direct public health threat (Edberg *et al.* 2000). The other indicators of quality include coliforms other than *E. coli*, commonly fecal streptococci, *P. aeruginosa* and sulfite-reducing anaerobes: in the case of treated drinking water, they demonstrate treatment effectiveness and water quality in the distribution

system (biofilm development); in the case of untreated groundwater (mineral water), they indicate possible deficiency in natural hydrogeological protection mechanisms (indicator of vulnerability). No indicators can indicate the occurrence of environmental pathogens, such as *Legionella* or *P. aeruginosa*.

Innovative taxonomic approaches in the bacteriology of the coliform group and comprehensive studies of their habitats allowed the ecological positioning of coliforms in one of the three following groups:

- (i) the thermotrophic and true fecal *E. coli*;
- (ii) the thermotrophic and ubiquitous coliforms (e.g. *K. pneumoniae*, *E. cloacae*), which may form part of the intestinal flora of humans and warm-blooded animals, but also occur in the natural environment; and
- (iii) psychrotrophic, purely environmental coliforms (e.g. *Serratia fonticola*, *Rahnella aquatilis*), which proliferate in polluted or pristine waters and mostly originate from vegetable or small animal sources.

From a public health point of view, both the ubiquitous and environmental groups are quality indicators. The controversy over the value of fecal coliform or thermotolerant coliform as fecal indicators, associated with the heterogeneity of the group, has led to the suggestion that the term “fecal coliform” or “thermotolerant coliform” should be redefined to be synonymous with *E. coli* (Leclerc *et al.* 2001).

Basically, an acceptable indicator of pathogens such as *E. coli* must only have two attributes: it must be present when the pathogens are present, and it must be easy to detect and to quantify. It is sometimes important, but not imperative for the protection of the public health, that the indicator is absent when the pathogen is absent. The most significant change over the last two decades is the general recognition that the coliform test including *E. coli* in treated water supply is not so much a measure of sanitary significance but more an indication of treatment effectiveness. Coliform bacteria as well as other bacterial indicators are easily captured and inactivated in conventional treatment processes but the more resistant enteric viruses and protozoan pathogens are not. It is now considered that the use of *E. coli* may be the most appropriate to indicate the presence of enteric bacterial pathogens and that viruses and protozoan pathogens must be analysed separately (Gleeson & Gray 1997).

With Natural Mineral Waters that are untreated, the problem of a relationship existing between marker organisms and pathogens must be discussed specifically, as this relationship is governed by key factors and processes that control the mobility and fate of suspended microbes in soil and groundwater environments. The first category of factors focuses primarily on characteristics of the microbes such as size, adhesion, and inactivation or die-off rate. The second category pertains to abiotic factors such as porous medium characteristics, filtration effects, and water flow. The implication of microbial transport relative to the safety of groundwater has been closely analysed by Robertson and Edberg (1997) and Newby *et al.* (2000). In general, the larger the suspended micro-organism, the more readily it will be physically filtered by the subsurface material. Thus, parasite cysts or oocysts, such as *Giardia* and *Cryptosporidium*, are relatively large and so much more readily filtered than viruses and bacteria. However, the die-off rate of *E. coli* through transport in subsurface environments is certainly higher than that of *Giardia* or *Cryptosporidium* cysts. Taking into account the half-life of *E. coli* as conservatively estimated to be at least eight days under groundwater conditions, Edberg *et al.* (1997) recommended the use of *E. coli* as indicator of fecal protozoan (Gassilloud *et al.* 2003).

The relatively high mobility of viruses in subsurface material is primarily due to their smaller size, lower inactivation, or die-off rates, and physical properties compared with bacteria. Enteric viruses have been detected in many groundwater supplies, usually those in close proximity to surface water or septic tanks (vulnerable groundwater). Thus viral contamination of groundwater is of special concern. There is no absolute correlation between bacterial indicators and enteric viruses, due to the essentially unpredictable behavior of viruses. Coliphages do not yet fulfill enough of the criteria to be reliably employed (Leclerc *et al.* 2000). Viral pathogens, including hepatitis A virus, enterovirus, and calicivirus, should be detectable by a combination of cell culture and molecular methods (awaiting validation by international groups of experts). At present there is a large discrepancy in the results of studies that compare infectivity, molecular, and combined methods (Yates *et al.* 1999; Abbaszadegan *et al.* 1999). The report of Norwalk-like virus sequences in bottled mineral waters, in absence of disease outbreaks, shows the difficulty in choosing appropriate methods and the very high risk of methodological contamination of samples (Beuret *et al.* 2000; Gassilioud *et al.* 2003).

Common bacteria from soil and vegetation, unrelated to fecal contamination, may be the best indicators of the quality of Natural Mineral Waters. In the absence of *E. coli*, their presence in a water sample does not indicate an imminent health threat. However, they are very sensitive indicators of surface contamination and can appear as the first agents of water quality change. Their occurrence in mineral water at source and after bottling should be limited to a low frequency of events and should be followed by a study to determine their origin. A single sampling procedure allows no flexibility in the interpretation of positive findings. There are objections against such a procedure in the sense that it may become technologically impracticable. A three class-sampling plan that incorporates so-called tolerances as used for microbiological safety requirements is much more rational (Codex Alimentarius 1997). The recognition process for a new source of Natural Mineral Water requires a few years' evidence of stability that must be demonstrated by continuous monitoring at the source of physicochemical and microbiological parameters listed in European directives (EC 1980). Monitoring should include periodic sampling of water (at least four times a year) at the source point, with analysis for new pathogens such as *Cryptosporidium* and enteric viruses.

In the light of epidemiological and ecological data, it appears that the combination of two categories of markers, i.e. indicators of fecal contamination and indicators of vulnerability, may be the most appropriate for characterization of a microbiologically safe Natural Mineral Water. However, taking into account the numerous outbreaks occurring in the world, especially in the US, it is recommended that microbiological monitoring be intensified to detect regularly (i.e. once a year), but not routinely, viral and protozoan pathogens.

12.7.3.3 Pathogens growing in water

There is a variety of environmental opportunistic human pathogens that can pass through water treatment barriers at very low densities and take advantage of selected sites in the water supply systems to colonize. They are typical biofilm organisms that grow at the periphery of distribution systems (long pipes leading to dead ends) and throughout the pipe network where the water can become stagnant. The most important organisms to consider are *Legionella*, *P. aeruginosa*, *Aeromonas*, and *M. avium* complex. Their significance in treated drinking water has been discussed in detail by Leclerc (2003).

It is now well established that legionellae are ubiquitous in engineered water supplies plumbing systems of hospitals and other large buildings, being an important cause (5–15%) of community-acquired and hospital-acquired pneumonia (Atlas 1999). Epidemiological and genetic studies demonstrated that environmental amoebae have acted as an evolutionary incubator for the emergence of *Legionella pneumophila* as an opportunistic pathogen for humans (Swanson & Hammer 2000). The occurrence of *Legionella* within biofilms and its ability to enter a VBNC state contribute to its survival. *Legionella* spp. are being looked at as bacteria able to contaminate mineral water. However, the occurrence of *Legionella* has never been reported from mineral water either at source or in bottles. But the problem is highly relevant for the use of mineral water in hydrothermal areas where warm spa water can promote the growth of legionellae (Bornstein *et al.* 1989; Verissimo *et al.* 1991; Rocha *et al.* 1995). Here, various care categories for patients, including nebulizers, hot whirlpool spas, baths, or other aerosols generating mechanical devices, can increase the risk of acquiring legionnaires' disease. Risk assessment has important implications for the maintenance of adequate standards of hygiene, bacteriological monitoring, and clinical surveillance in the establishments.

P. aeruginosa is a ubiquitous environmental bacterium. It can be isolated, often in high numbers, in common food, especially vegetables. Its presence is constant in surface waters and sometimes at low levels in drinking water. Other than certain specific hosts at risk, the general population is resistant to infection with *P. aeruginosa* (Hardalo & Edberg 1997). Since *P. aeruginosa* is capable of growing abundantly in the purest of fresh waters and since it has major opportunistic pathogen capability, its occurrence in Natural Mineral Water should be limited as far as possible. So there are two reasons to monitor *P. aeruginosa* in mineral water: on the one hand, as an indicator of vulnerability and/or poor control of the bottling environment, on the other hand, as an opportunistic pathogen.

Aeromonas are widespread in surface waters. Their presence in sediment accumulated in pipelines in the water supply is an indication of biofilm development. Their significance in drinking water relative to the occurrence of gastrointestinal infections is much debated (Leclerc 2003). *Aeromonas* spp. are sometimes able to contaminate mineral water in low numbers for the same reason as coliforms or *P. aeruginosa*. Their significance is the same as that of quality indicators.

It has been shown recently that members of the genus *Mycobacterium* are present in drinking waters (Falkinham *et al.* 2001; LeChevallier *et al.* 2001; Le Dantec *et al.* 2002); however, the numbers and frequencies of recovery of *M. avium* and *M. intracellulare* are usually low. The occurrence of non-tuberculous mycobacteria such as *M. avium*, *M. kansasii*, or *M. intracellulare* has never been reported for mineral water samples (Covert *et al.* 1999).

12.8 CONCLUSION

The microbiology of Natural Mineral Waters is almost completely dependent on the hydrogeology and the microbial ecology of groundwater. Our knowledge of the natural flora of mineral water also depends on our ability to assess micro-organisms in the environment, and is further compounded by the heterogeneity and the inaccessibility of these subterranean environments. Moreover, the bacteriological methods used to study mineral waters have often been chosen according to public health demands in detriment to our need to understand the ecological aspects of this type of environment.

The study of groundwater microbiology has progressed markedly since the 1970s. It is not, therefore, surprising to find viable microbial communities in the groundwater habitat,

even at enormous depths. Within the limits of water availability, temperature and other factors such as the levels of organic components that affect living cells, groundwater habitats are expected to contain primarily bacteria and to a lesser extent fungi and protozoa. The abundance and diversity of the microbial communities is expected to vary, depending on the geochemical and hydrogeological properties of the aquifer. The bacterial populations, which are by far the most abundant members of the groundwater community, have a large variety of metabolic capabilities that confer selective advantages in this environment. On the other hand, we know almost nothing about the microbiological succession and development of community structure in the groundwater habitat.

Most of the studies on the microbiology of Natural Mineral Waters have been performed on heterotrophic bacteria isolated in standardized growth media for HPC. The majority of these organisms belongs to the genus *Pseudomonas* but cannot be identified at the species level, or to other closely related genera, and may represent the predominant flora at the source. However, other bacterial groups, namely the prosthecate bacteria or species belonging to the genera *Cytophaga*, *Flavobacterium* or *Flexibacter* may also constitute major populations of heterotrophic bacteria in groundwater. The occurrence and, above all, the importance of gram-positive bacteria remain the object of conjecture and further study.

In shallow or deep aquifers, the supply of available carbon and energy sources may be extremely small. Nutrient limitation or starvation is common for most bacteria in groundwater. Starved bacteria may form minicells that are able to escape starvation by more efficient scavenging of nutrients; they may also become more resistant by synthesizing stress proteins. Bacterial cells of Natural Mineral Water aquifers respond to nutrient deprivation by entering the VBNC state, with the probability that the VBNC state represents an additional response to starvation displayed by bacteria for survival.

After bottling, the number of viable and culturable bacteria increases appreciably within 3–7 days, attaining 10^4 – 10^5 cfu/ml. Many factors such as use of glass or plastic containers, storage temperature, the level of organic carbon, incubation temperature of media, and others can influence the fate of the bacterial flora in the bottle. Whether the culturable cells are a result of true resuscitation or of regrowth of a few initial cells remains questionable. It is now fairly certain that the genetic diversity of groundwater bacteria is maintained after bottling, as has been demonstrated by molecular-genetic studies.

The predominant populations isolated from mineral waters, and specifically those of the genus *Pseudomonas* exhibit *sensu stricto* an antagonistic activity on test pathogens or indicators of fecal contamination under some experimental conditions. This antagonistic activity may be due to the synthesis of siderophores or other antibiotic substances.

The bacteria isolated from Natural Mineral Waters do not belong to species known to be pathogenic or to have public health importance. Overall experimental data from animal model systems and epidemiological studies show that these bacteria have never been responsible for detectable pathological disorders in man, and *in vitro*, they are incapable of damaging human cells in tissue culture. After the implementation of European regulations in 1980, no outbreak or disease case due to the consumption of Natural Mineral Water has been recorded in the literature.

Ecological data, especially the diversity and physiological properties of bacterial communities, are essential together with epidemiological studies in order to perform a risk analysis for natural mineral waters. On a continuing basis, the management of microbial risks has to rely on assessment of the HPC and, more specifically, on detection of marker organisms, i.e. the classic fecal contamination indicators that have to be absent and vulnerability

indicators for which the occurrence should be as low as possible. It is also recommended to search regularly, but not routinely, for viral and protozoan pathogens.

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13 Microbiology of Treated Bottled Water

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13.1 INTRODUCTION

Although this chapter examines the microbiology of treated bottled water, it is useful first to ask, “Is it necessary for microbiological reasons to treat bottled water at all?” Since the inherent reason for treating bottled water is to remove undesirable constituents, if none are present then treatment is not needed. In Europe it is a long established principle, which has been substantiated by practice, that high-quality, well-defined, sequestered source waters need not be treated. It is illegal in Europe to treat Natural Mineral Water microbiologically. How can the Europeans be so certain that such waters do not require treatment?

The answer lies in the rigid application of the multiple barrier concept for public health protection. The multiple barrier concept states that safe drinking water can be bottled if sequential high-level barriers to the entry of pathogens into the bottle are employed. Multiple barriers can be divided into the following basic types: source water protection; source water monitoring; ozonation; reverse osmosis; filtration; and distillation. In Europe, Natural Mineral Water sources are highly selected and qualified.

13.2 SOURCE WATER PROTECTION AND MONITORING

Two multiple barriers are employed to ensure safety. First, the hydrogeology of the sources is well studied and established (source water protection). It is well known that the journey of water from rainfall to the aquifer contains numerous elements that naturally bring about pathogen removal. For example, passage through the various soil and clay substrata has profound adsorbing and filtering activities (Hopkins *et al.* 1985). Time of transit itself diminishes microbial viability so that after approximately one year there should be no significant viable pathogens present in the water making its journey into the aquifer. Second, within the category of source water protection is the rigid application of sanitary surveys. The source is protected by precluding human and animal activities that would contaminate it. Thus, the source water protection multiple barrier is very powerful when rigidly applied (Robertson & Edberg 1997).

The second multiple barrier employed in Europe for source water protection of Natural Mineral Water is one of intensive monitoring (source water monitoring). The source water monitoring protocols utilized in Europe are significantly different from the protocols utilized for the monitoring of municipal waters for regulatory purposes. In Europe, source water monitoring has a number of inherent components and goals. First, intensive quality control monitoring is

conducted to ensure that the water that enters the bottle is the same as that which is present in the source. In Europe, in order for water to be certified as Natural Mineral Water, the chemical and microbiological profile of the water in the source must be equivalent to that in the bottle. Second, intensive monitoring is conducted to ensure the water is pathogen free (Leclerc *et al.* 1985). The intensive monitoring conducted for European Natural Mineral Waters is several orders of magnitude larger than that conducted for municipal drinking water under regulatory requirements. For example, in the industrialized countries, the most frequent routine monitoring sampling protocol requires approximately only one sample per 1000 population per month. By comparison, a bottler of Natural Mineral Water in Europe may conduct more than 100 tests per day. Tests will be conducted notably for pathogen surrogates (i.e. total coliforms and *Escherichia coli*) but also for indicators of external intrusion into the system (i.e. sulfite-reducing anaerobes and *Pseudomonas aeruginosa*). Therefore, as applied in the European Natural Mineral Water industry, source water monitoring is a powerful natural barrier (Edberg *et al.* 1997b).

Accordingly, the combination of natural source water protection and intensive source water monitoring in Europe provides two powerful multiple barriers, which when used in sequence, has produced microbiologically safe drinking water for many years.

Another situation exists in which safe drinking water is produced without treatment. In the United States, municipal waters served by sequestered, subterranean sources are not required to disinfect if they demonstrate, through the use of a combination of hydrogeology, sanitary surveys, and monitoring, that there is no intrusion of pathogens. This protocol exists under the Ground Water Disinfection Requirement Act, which is administered by the US Environmental Protection Agency. In effect, groundwaters can avoid disinfection if they demonstrate safety. This municipal water situation should not be confused in one important respect with the European Natural Mineral Water industry. There is no requirement in the United States that there be standards of identity or quality control parameters associated with the final municipal drinking water product. What is required is pathogen-free drinking water.

13.3 WATER TREATMENT

Although it is possible to produce microbiologically safe and wholesome bottled water without product water disinfection (as in the case of European natural mineral waters where the sources are well characterized and source water protection and monitoring have been established over centuries of use and through strict regulation), there are several considerations in other regions that permit or mandate the treatment of water for microbiological quality and safety. In Canada, the definition of spring water and mineral water includes the requirement that they are naturally fit to drink at the source however, and unlike European natural mineral waters, the use of ozone as a disinfectant is allowed and in most cases used to guarantee the microbiological quality of the bottled water. Similarly, in the United States, the Food and Drug Administration has stated that it does not consider it necessary to require disinfection of bottled water and that compliance to microbiological quality standards is the regulatory objective. However, bottled water regulations from individual states and the many types of bottled water defined under federal and state guidelines led to use of disinfection barriers to guarantee the wholesome nature of the bottled water, to minimize the effects of processing and handling on the quality of the product, and to remove the effects of bottled water sources used for different types of water.

If a bottler wishes to disinfect, there are a number of treatment options available. For practical purposes, each of the treatment options can be considered a multiple barrier. Therefore, only those that have wide applicability and provide high levels of anti-pathogen activity will

Table 13.1 Relative effectiveness of treatment types on pathogen groups.

Pathogen group	Effectiveness				
	Ozonation	Ultraviolet (UV)	Reverse osmosis	Filtration	Distillation
Viruses	Good	Good	Good	Low	High
Bacteria	Good	High	Good	Low	High
Protozoa	Fair	Fair	High	High	High

be discussed here. Moreover, unlike municipal tap water, bottled water does not employ multiple barriers that are prone to disinfectant residues, disinfection by-products, and taste and odor problems. For example, chlorine-based disinfection is not used, since it is well known to generate organic disinfection by-products such as trihalomethanes and haloacetic acids and to impart strong taste and odor to the drinking water. One multiple barrier disinfectant exception for bottled water is the use of ozone, which can lead to the formation of bromate, a regulated by-product resulting from oxidation of bromide-containing natural waters, but dissipates within hours of its application and does not generate any taste, odor or disinfectant residues.

There are five basic multiple barrier treatment options employed in the bottled water industry: ozonation, ultraviolet (UV) irradiation, reverse osmosis (R/O), filtration, and distillation. As Table 13.1 demonstrates, each has its own strengths for particular groups of microbial pathogens.

It is important at this level of discussion to define microbiological treatment as the employment of more than one multiple barrier sequentially to produce pathogen-free water. There will always be some number of autochthonous, non-pathogenic naturally-occurring bacteria that enter the bottle. These autochthonous bacteria are not only natural but may actually inhibit other bacteria in the bottle (see Chapter 11).

It is beyond the scope of this chapter to discuss each of the treatment multiple barriers in detail. However, there are some salient points about each that should be considered when evaluating their effect on microbiological activity.

Ozone is a powerful, short-acting, high-energy disinfectant that is generally created on site. There are a number of ways to employ ozone; sufficient for this chapter is to understand the concept of CT: this is a value associated with the disinfecting power of energy-yielding disinfectants such as ozone, chlorine, and monochloramines, in which the disinfecting power of the individual disinfectant is related to the activity concentration of the disinfectant [C] multiplied by the time the disinfectant is in contact with the pathogen [T]. In the literature relating to treatment of municipal water, ozone is said not to have a disinfection residual. A disinfection residual is the effective amount of disinfectant that is available throughout the water distribution system after the mixing of the water with the disinfectant. Because ozone is high energy, rapidly acting, and rapidly dissipated, it is not found in appreciable concentrations throughout municipal distribution systems. Conversely, chlorine, which is of considerably less energy than ozone, can travel and produce an effective residual throughout the distribution system. High-energy ozone is rapidly dissipated as it enters the municipal distribution system, and there is no effective residual. Bottled water presents a different scenario. In effect, ozonated water enters a bottle and is therein sealed. Accordingly, there is an effective disinfection residual for a period of time until the ozone dissipates. Therefore, it is to be expected that the overall CT value for ozone in the bottle will be higher than the value calculated in the ozonator itself. As Table 13.2 indicates,

Table 13.2 Comparison of HPC results by pour plate, spread plate, and membrane filter methods on the same medium within each referenced study. (Reproduced from Reasoner (1990) with kind permission from Springer Science+Business Media.)

Temperature °C	Bacterial count CFU/ml			Ratio			Reference
	PP ^a	SP ^a	MF ^a	PP/MF	PP/SP	MF/SP	
16	3100	6300	–	–	0.49	–	Buck & Cleverdon (1960)
RT ^a	42	–	113	0.37	–	–	Stapert <i>et al.</i> (1962)
37	108	115	–	–	0.94	–	van Soestbergen and Lee (1969)
35	23	110	–	–	0.21	–	Klein & Wu (1974)
	62	200	–	–	0.31	–	
20	170	230	–	–	0.74	–	Means <i>et al.</i> (1981)
35	210	240	–	–	0.87	–	
20	740	3100	–	–	0.24	–	Taylor <i>et al.</i> (1983)
20	1020	–	986	1.03	–	–	Maul <i>et al.</i> (1985)
35	430	510	270	1.59	0.84	0.53	Reasoner <i>et al.</i> (1985)
28	4000	7000	4600	0.86	0.57	0.65	
20	2700	6100	3900	0.69	0.44	0.64	
35	3.3	4.9	–	–	0.67	–	Lombardo <i>et al.</i> (1986)
28	4.0	5.2	–	–	0.76	–	
28	–	5.2	4.8	–	–	0.92	
22	100	710 ^b	–	–	0.14	–	Gibbs & Hayes (1988)

Source: Reasoner (1990).

^a CFU, colony-forming units. PP, pour plate. SP, spread plate. MF, membrane filter. RT, room temperature.^b Based on ratio given in the reference and arbitrarily assigning the value of 100 CFU/ml as the pour plate mean.

ozone is most effective against viruses and bacteria and less so against parasite cysts, in particular *Cryptosporidium parvum*. The more common *Giardia lamblia* cysts however, can be inactivated with CT values 10 to 20 times higher than those for Enterobacteria such as *E. coli* and still within the range of concentrations and contact times used in conventional ozonation systems, especially if the increased CT value for ozonated water sealed in a bottle is considered.

The disinfection efficacy of ozone against various micro-organisms is greatest against bacteria and specifically against gram-negative bacteria. Bactericidal concentrations as low as 0.009 mg/L of ozone have been observed for *E. coli* strains and *Pseudomonas* species, while gram-positive bacteria such as *Staphylococcus* and *Streptococcus* species required twice as long a contact time for similar inactivation. Viruses are in general more resistant than vegetative bacteria to the effects of ozone, but less resistant than fungi (yeast and moulds) and parasitic cysts.

A couple of side effects for the ozonation of bottled water make it necessary to maintain good control of the process and be aware of secondary effects that can lead to bacteria regrowth and consequently possible taste and odor problems. The latter effect is caused by the reaction between ozone and normal organic constituents in the water that breaks them down to produce greater amounts of assimilable organic carbon (AOC). One of the consequences of this reaction is to produce water with a higher AOC concentration, which then serves as food for autochthonous bacteria, increasing the potential concentration of these organisms and their effect on taste and odor. The other effect is the reaction between ozone and the naturally occurring bromide minerals in the water that can lead to the generation of bromate, a regulated by-product and potential carcinogen. One strategy to overcome the formation of bromate and other by-products is the precise and efficient injection of ozone at 5 to 10 times lower dosage levels to achieve disinfection without the unwanted side reactions. Ozone injection systems are specially engineered, as described in Chapter 5 of this book.

Another disinfection strategy that overcomes the potential disinfection by-products and potential bacteria regrowth limitations of ozone treatment is the use of Ultra Violet (UV) irradiation. UV light treatment is a well accepted technology for inactivation of bacteria, viruses, and protozoan pathogens in drinking water. UV treatment is an effective means for water disinfection that has several advantages over other treatment techniques, including ozonation. UV light irradiation does not add any undesirable color, odor, or taste to the water, and it does not generate any harmful or regulated disinfection by-products. UV disinfection is fast, effective, efficient, and environmentally friendly. The mode of action involves the absorbance of UV energy by the deoxyribonucleic acids of the micro-organism genetic material, and the subsequent degradation of the nucleic acids within the bacteria cells to achieve inactivation of the bacteria and ultimately to achieve disinfection. The maximum inactivation effect is obtained at an UV wavelength of 254 nm, which matches the wavelength of maximum absorption for nucleic acids and is known as the “germicidal light” due to its unique properties for inactivating micro-organisms. The standard dose for drinking water disinfection by UV irradiation ranges between 30 000 and 40 000 $\mu\text{J}/\text{cm}^2$ to achieve a 4-log reduction (99.99% inactivation) of bacteria and some viruses. Moulds, protozoans, and other viruses however, may need much higher doses in the range of 100 000 to 200 000 $\mu\text{J}/\text{cm}^2$ to achieve validated inactivation of target micro-organisms, as defined by the US EPA UV Disinfection Guidance Manual (UVDGM).

Reverse osmosis is most commonly employed to change the mineral content of drinking water. Theoretically, it should produce pathogen-free water. However, bacteria can grow on the membranes and break through any small tears therein. In addition, the seals and plumbing associated with the reverse osmosis engineering can, unless carefully monitored, serve as points of intrusion into the system. Accordingly, some manufacturers of reverse osmosis equipment will not certify systems as producing pathogen-free water.

Filtration has been employed for thousands of years to produce safe drinking water. Various types of clay and diatomaceous earth have been part of the civil engineering landscape from the time of the Pharaohs and were extensively employed by Roman water engineers. In the bottled water industry, filtration is generally utilized as a multiple barrier directed against parasites, particularly *Cryptosporidium parvum* and *Giardia lamblia*. A wide selection of technically developed media is now available. Filters for bottled water are divided into two basic types: nominal and absolute. Nominal filters are those that generally exclude particles, but are not rated to do so with a specific rating of certainty. This type of filter is being replaced by absolute filters, which are rated to remove particles of a specific size at a particular efficiency. In the United States, many bottled water companies have begun installing absolute filters of at least 1 μm to exclude *Cryptosporidium parvum*. Some bottled water companies are using filters of sequential sizes down to 0.5 μm . The NSF (Ann Arbor, Michigan; formerly known as the National Sanitation Foundation) is currently in the final stages of developing standards for the certification of absolute filters for retention of *Cryptosporidium* (MMWR 1997).

Distillation should produce sterile water when operated properly. However, it should be noted that the sterile water produced is sterile only at the time it leaves the still. As it travels through the pipes, the water will acquire microflora.

13.4 NATURALLY OCCURRING BACTERIA

After treatment and passage through two or more multiple barriers, bottled water should be pathogen free. However, it will still have an autochthonous flora component; this is a term of European origin, generally referring to naturally occurring bacteria that have evolved an aqueous lifestyle. In the United States, a number of other terms are used to refer to bacteria of this

Table 13.3 Comparison of HPC results using different media (as specified below). (Reproduced from Reasoner (1990) with kind permission from Springer Science+Business Media.)

Temperature °C	Bacterial count			Reference
	PP ^a	CFU/ml ^a SP ^a	MF ^a	
35	3137 (SPC)	–	4273 (m-HPC)	Taylor & Geldreich (1979)
20	170 (SPC)	440 (R2A)	510 (m-HPC)	Means <i>et al.</i> (1981)
20	–	4000 (R2A)	12 (m-HPC)	Fiksdal <i>et al.</i> (1982)
	–	1000 (R2A)	110 (m-HPC)	
35	–	20 (R2A)	6 (m-HPC)	
	–	4 (RDA)	<1 (m-HPC)	
35	277 (SPC)	–	283 (m-HPC)	Green <i>et al.</i> (1982)
20	1123 (NA)	–	1217 (m-HPC)	Maul <i>et al.</i> (1985)
	1192 (NA)	1192 (R2A)		
35	22 (SPC)	200 (R2A)	32 (m-HPC)	Reasoner & Geldreich (1985)
28	80 (SPC)	360 (R2A)	140 (m-HPC)	
20	22 (SPC)	90 (R2A)	47 (m-HPC)	
35	53 (SPC)	–	66.7 (m-HPC)	Fujioka <i>et al.</i> (1986)
	53 (SPC)	–	57.1 (R2A)	
26	590 (SPC)	1550 (R2A)	–	Stetzenbach <i>et al.</i> (1986)
22	100 (YEA)	710 (YEA)	–	Gibbs & Hayes (1988)
	440 (R2A)	–	–	
	100 (YEA)	3900 (R2A)	–	

Source: Reasoner (1990).

^a CFU, colony-forming units. PP, pour plate. SP, spread plate. MF, membrane filter. Media: SPC, standard plate count agar; NA, nutrient agar; YEA, yeast extract agar, R2A medium (Reasoner & Geldreich 1985); m-HPC medium (Taylor & Geldreich 1979) was published originally as m-SPC medium.

nature; those used include plate-count bacteria, standard plate-count bacteria, heterotrophic plate-count (HPC) bacteria, and others. One of the great difficulties in comparing bacterial isolation studies performed in different laboratories is that the numbers and types of the naturally occurring bacteria reported are strongly related to the type of culture media employed, the temperature of incubation, and the culture technique used. Results can vary several thousand-fold with even one of these changes (Reasoner 1990; Hunter 1993). For example, Table 13.3 shows the effect of three different methods on the number of HPC bacteria.

The HPC analyses are conducted in three formats: pour plate, spread plate, and membrane filter. In utilizing the pour plate method, one adds a drinking water sample to liquid agar, pours the liquid agar into a Petri plate, and then counts the colonies throughout the agar after incubation. In the spread plate method, the water sample is added to the surface of already solidified agar and then spread across its surface using a glass rod. In the membrane filter method, a drinking water sample is first filtered through a bacterial-exclusion membrane and the filter is placed on the surface of solidified agar. As Table 13.2 shows, the spread plate method is more sensitive than the pour plate method, and both are more sensitive than the membrane filter method. Table 13.3 demonstrates that the type of culture medium also exerts a profound effect on the number of colony-forming units recovered. In the United States, the low-nutrient R2A agar is now most commonly utilized in performing HPC studies. Even length of incubation time can significantly affect the number of colony-forming units per milliliter (CFU/ml) of HPC isolated, as shown in Table 13.4. A number of non-culture methods are also utilized to generate HPC concentration. These include the use of epifluorescence microscopy, with or

Table 13.4 Effect of length of incubation on HPC results.

Temp °C	Medium and method ^b	Bacterial count CFU/ml ^a Incubation time, days							Reference
		1	2	3	4	5	6	7	
35	SPC-PP	–	2300	–	5000	–	–	6200	Klein & Wu (1974)
35	R2A-SP	–	10	–	–	–	–	20	Fiksdal <i>et al.</i> (1982)
20	R2A-SP	–	0	–	–	–	–	4000	
35	R2A-MF	–	5	–	–	–	–	10	
20	R2A-MF	–	0	–	–	–	–	40	
20	m-HPC-MF	–	190	945	1217	–	–	–	Maul <i>et al.</i> (1985)
	R2A-MF	–	287	904	1192	–	–	–	
	NA-PP	–	389	855	1123	–	–	–	
35	SPC-PP	–	22	–	100	–	110	115	Reasoner & Geldreich (1985)
28	SPC-PP	–	90	–	640	–	950	1000	
20	SPC-PP	–	22	–	130	–	570	900	
35	R2A-SP	–	200	–	340	–	500	510	
28	R2A-SP	–	360	–	2800	–	6700	7200	
20	R2A-SP	–	90	–	1100	–	4700	6100	
35	R2A-MF	–	41	–	200	–	270	280	
28	R2A-MF	–	160	–	2200	–	3500	4000	
20	R2A-MF	–	75	–	650	–	3000	4900	
35	m-HPC-MF	–	32	–	140	–	150	150	
28	m-HPC-MF	–	140	–	1000	–	1700	1900	
20	m-HPC-MF	–	48	–	400	–	1600	2000	
35	PCA-PP	1.3	16.8	–	30.8	34.2	34.8	34.8	Silley (1985)
20	PCA-PP	1.7	21.2	–	101	114.3	121.3	125.8	
22	YEA-PP	–	–	100 ^c	–	–	–	1800	Gibbs & Hayes (1988)

^a CFU, colony-forming units.^b See Table 13.3 for abbreviations used for media and methods.^c Based on plating ratio given in the reference and arbitrarily assigning the value of 100 CFU/ml as the pour plate mean.

without vital or other dyes (Newell *et al.* 1986; Kepner & Pratt 1994) and ATP measurements (Zweifel & Hagström 1995). Generally, the HPC results produced by non-culture methods are hundreds to thousands of times higher than those from culture methods (Suzuki *et al.* 1993).

Accordingly, it is somewhat difficult to make definitive statements concerning the microbial content of bottled water, because the results of any study are highly confounded by many different variables. However, there are certain points of commonality that have emerged. First, the autochthonous flora of treated and non-treated bottled water has a life-style that favors an aqueous and not a human ecology. Second, regardless of the individual species, the number of autochthonous flora undergoes increases and decreases in the bottle after it is sealed (Ducluzeau *et al.* 1976a,b; Gonzalez *et al.* 1987; Manaia *et al.* 1990; Mavridou 1992). Each individual species will increase in number and then decrease once its particular food supply has been exhausted (Schmidt-Lorenz 1976; Quevedo-Sarmiento *et al.* 1986; Hunter *et al.* 1990). As it dies and decays and disintegrates, its constituents are then

Table 13.5 Percentage frequency distribution of total colony counts from studies of bottled water sampled at retail outlets.

Reference	Watertype	Temperature of Incubation °C	Number examined	Total viable count				
				<10 ²	10 ² –10 ³	10 ³ –10 ⁴	10 ⁴ –10 ⁵	>10 ⁵
Hunter & Burge (1987)	Carbonated	22	29	31	17	52 ^a		
		37	29	86	3	10 ^a		
		22	29	90	7	3 ^a		
		37	29	100				
Hunter <i>et al.</i> (1990)		22	44	18	11	18	36	16
		37	44	68	11	11	5	5
Warburton <i>et al.</i> (1986)	Mineral	35	49 ^b	67	16	16		
	Purified ^c	35	41 ^b	41	17	17	15	10

Source: Hunter (1993).

^a Greater than 1000.^b Lots, see text.^c For definition of "purified", see text.

used as foodstuffs for other species of autochthonous flora (Schwaller & Schmidt-Lorenz 1980; Warburton *et al.* 1986; Hunter & Burge 1987; Lucas & Ducluzeau 1990). Consequently, a species of autochthonous bacteria will first be found in low numbers and over time will increase to much higher numbers and then decrease, to be replaced by other species. Accordingly, a sampling of the bottle at any point in time is only a snapshot of events occurring in the bottle (Bischofberger *et al.* 1990; Morais & da Costa 1990). Apparently, if bottled water is stored long enough, it may eventually self-sterilize. For example, bottled water sequestered in the United States during the Korean War was found to be sterile when opened and analysed 40 years later. (Glenn Davis, Abscopure Water Company, Ann Arbor, MI, USA, personal communication.) Professor H. Leclerc has described these events in another chapter of this book and his thorough, considered review will not be repeated here.

13.5 PRODUCT SAFETY

The primary question for consideration now focuses on post-treatment microbiological events that relate to the safety of the final product and, therefore, the next two questions to address are: "What is the post-treatment microbiology of bottled water?" and "What is the pathogenic potential of this microbiological content?"

As Table 13.5 demonstrates, virtually all bottled waters obtained from retail outlets have a microbial content. The microbial content of bottled water is higher than that of municipal water, because of the former's lack of disinfection residual (see Table 13.6). In examining the individual species found in the various bottled water surveys, one is struck by the absence of pathogens that are normally associated with gastroenteritis. Moreover, indicators of these pathogens, such as total coliforms and *Escherichia coli*, are routinely absent. Post-treated and non-treated drinking water have yielded species whose microbes are associated with infection. For example, various species of the genus *Pseudomonas* have been isolated from

Table 13.6 Comparison of the microbial content of drinking water types.

Species	Bottled water (n=150) ^a [Percentage samples with species (concentration range CFU/ml)]	Cooler water (n=81) ^b [Percentage samples with species (concentrations range CFU/ml)]	Tap water (n=150) ^c [Percentage samples with species (concentration range CFU/ml)]
<i>Acinetobacter</i> spp.	5 (2–30)	10 (100–350)	5 (6–21)
<i>Achromobacter</i> spp.	5 (8–31)	<5 (>20)	4 (5–25)
<i>Agrobacterium</i> spp.	2 (7–12)	20 (2–110)	0
<i>Bacillus brevis</i>	0	0	35 (3–360)
<i>Bacillus cereus</i>	0	0	15 (8–90)
<i>Bacillus licheniformis</i>	0	0	25 (15–650)
<i>Bacillus circulans</i>	50 (1900–21 000)	80 (3–17,000)	0
<i>Bacillus firmus</i>	35 (600–39 000)	20 (900–35 000)	45 (8–860)
<i>Bacillus megaterium</i>	15 (21–4500)	20 (55–600)	0
<i>Bacillus polymyxa</i>	15 (18–1700)	20 (80–2100)	15 (5–630)
<i>Bacillus pumilus</i>	0	0	30 (7–260)
<i>Bacillus sphaericus</i>	0	0	30 (2–35)
<i>Bacillus macerans</i>	25 (660–68 000)	30 (200–45 000)	0
CDC Group IV (GNR) ^d	1 (45)	<5 (<20)	0
<i>Corynebacterium</i> spp.	10 (8–40)	30 (20–280)	0
<i>Coryneform</i> spp.	0	0	20 (6–440)
<i>Methanococcus</i>	85 (30–76 000)	60 (120–61 000)	0
<i>Moraxella</i> spp.	10 (3–38)	80 (13–48)	10 (1–10)
<i>Comamonas acidovorans</i>	6 (1–28)	3 (4–12)	2 (2, 18)
<i>Pseudomonas aeruginosa</i>	3 (2–26)	2 (3, 13)	2 (2–16)
<i>Burkholderia cepacia</i>	3 (1–15)	20 (20–40)	5 (1–15)
<i>Pseudomonas fluorescens</i>	12 (1–65)	3 (4–46)	0
<i>Comamonas testosteroni</i>	2 (3–10)	4 (7–38)	0
<i>Staphylococcus</i> spp.	2 (25–600)	2 (6, 19)	10 (3–65)
<i>Streptomyces</i> spp.	0	10 (2)	0
<i>Xanthomonas maltophilia</i>	2 (2–22)	2 (2,4)	0
Total coliforms	2 samples	0	0
	"Supermarket" ^e : (2, TNTC ^f)		

Source: Edberg *et al.* (1996).

^a Bottled water samples obtained from supermarket shelves. ^b Nine water coolers sampled weekly for 9 wks. ^c Tap water samples collected in Na thiosulphate, 50 from the northeast, 50 from the west coast, and 50 from the southeast.

^d Unidentified group of gram-negative rods clustered by biochemical characteristics. ^e "Supermarket" refers to a bottled water made and sold by a supermarket. ^f TNTC=Too numerous to count.

bottled water (Table 13.7). However, it is a classic error to assume that because a bacterial species of a certain name is found associated with a particular infection, the route of acquisition of that infection is via drinking water (Ducluzeau *et al.* 1976a,b). For example, it is well known that *P. aeruginosa* can be a pathogen. However, it has been well established over the last 30 years that only certain patient groups with very specific deficits in their immune capacity are susceptible to infection (Hardalo & Edberg 1997). The reason for this lack of association with drinking water can be found when one examines the equation that describes infection potential.

$$\text{Microbiological health risk} \% \text{ number of microbes} \times \text{virulence} \\ \text{immune status of the host}$$

Table 13.7 Distribution of *Pseudomonas* species in surveys of bottled water.

No. of isolates (percentage of all <i>Pseudomonas</i> strains isolated in study)			
<i>Pseudomonas</i> species	American waters^a	German waters^b	Mainly Portuguese^c
<i>P. aeruginosa</i>			45 (29)
<i>P. stutzeri</i>	30 (24)	22 (27)	24 (15)
<i>P. putida</i>	14 (11)	20 (25)	11 (7)
<i>P. fluorescens</i>	18 (14)	13 (16)	25 (16)
<i>P. diminuta</i>	21 (19)	1 (1)	
<i>P. cepacia</i>	12 (10)	8 (10)	4 (3)
<i>P. acidovorans</i>	7 (6)	6 (7)	
<i>P. maltophilia</i>	7 (6)	3 (4)	7 (5)
<i>P. pickettii</i>	9 (7)		25 (16)
<i>P. paucimobilis</i>	7 (6)	2 (3)	3 (2)
<i>P. alcaligenes</i>			11 (7)
<i>P. pseudoalcaligenes</i>		6 (7)	

Source: Hunter (1993).

^aHernandez-Duquino & Rosenberg (1987);

^bHernandez-Duquino & Rosenberg (1989);

^cManaia *et al.* (1990).

This relationship can be well defined in terms of its individual components (Duncan & Edberg 1995). When examining a microbe such as *P. aeruginosa* for example, one sees that the gastrointestinal tract is not a portal of entry. The changes in immune status necessary to produce infection lie in other, but specific organ systems. For *P. aeruginosa*, the changes in immune status necessary to acquire infection fall into some very well-defined groups. These include cystic fibrosis patients, full-thickness burn patients, patients with polymorphonuclear leukocyte counts of less than 500, and those with intravenous or in-dwelling lines. In none of these cases is drinking water a risk factor. Moreover, clinical microbiology laboratories do not isolate *P. aeruginosa* in patients with diarrhea. Accordingly, one must conclude that gastroenteritis with acquisition via drinking water is not a route of infection by *P. aeruginosa*.

Another component of the infection equation that has been examined in relationship to the microbial content of bottled water is the virulence component of its microbes. Because species identifications are not as accurate from environmentally isolated bacteria as they are from those isolated clinically, a way of looking at health risk is to examine the virulence properties of the bacteria without regard to their identification. According to this strategic pathway, the name of the bacterium is immaterial; what is important is its armamentarium (i.e. virulence factors) against the human host. A number of virulence factors have been described that are associated with the development of infection (Lye & Dufour 1991). Studies that have examined the virulence factors of bacteria isolated from bottled water have not demonstrated significant pathogenic potential (Edberg *et al.* 1996, 1997a). In one study of bacteria isolated on R2A agar, insignificant virulence factors were found from the HPC content (see Table 13.8). Payment further refined the strategic analysis of virulence factors by hypothesizing that those autochthonous bacteria that were able to grow under conditions analogous to the human host would be most likely risk factors (Payment *et al.* 1991a,b). Accordingly, bacteria from bottled water samples were isolated on a high-nutrient medium containing blood (blood agar medium). As Table 13.9 demonstrates, the microbial contents of both natural and post-treated bottled water did not contain significant virulence factors when isolated on a medium that mimicked the physiological conditions of the human body.

Table 13.8 Comparison of virulence characteristics of bacteria isolated from the three water sources.**Percentage of all species having bacteria isolated from the three water sources**

Characteristic	Cooler	Bottled	Tap
Hemolysin	2 ^a	1	1
Proteinase	22	20	23
Gelatinase	4	3	3
Lipase	0	0	0
Elastase	0	0	0
Coagulase	0	0	0
DNAse	3	2	6
Fibrinogen	0	0	0
Acid restraint at pH 3–5	0	0	0

Source: Edberg et al. (1997a).

^a Percentage of all bacteria isolated from this source demonstrating the characteristic.**Table 13.9** Invasiveness activity of naturally occurring HPC bacteria from bottled and tap water.

Species	Invasiveness (>5% per field)		
	Number tested	Stationary phase	Log phase
<i>A. faecalis</i>	4	0	0
<i>A. haemolyticus</i>	2	1	1
<i>A. junii/johnson</i>	5	0	1
<i>Actinomyces</i> spp.	3	0	0
<i>Bacillus licheniformis</i>	3	0	0
<i>Bacillus</i> sp.	5	0	0
<i>Micrococcus</i> spp.	16	0	0
<i>O. anthropi</i>	3	1	3
<i>P. aeruginosa</i>	3	0	0
<i>P. alcaligenes</i>	6	0	1
<i>P. diminuta</i>	5	0	1
<i>P. fluorescens</i>	8	0	0
<i>P. vesicularis</i>	2	0	1
<i>Staphylococcus</i> spp.	8	0	0
<i>Streptococcus</i> spp.	3	0	0
Unidentified GNR	7	0	0
<i>X. maltophilia</i>	2	0	0
Total	85	2	8
Z value of <i>Salmonella typhi</i> ^a	3.92	5.19	

^a The Z test represents the difference between two independent counts. A Z of 1.96 or more is needed for the differences between the two counts to be considered significant at the 5% level.

13.6 SUMMARY

Bottled water is not a sterile product but must be pathogen free. The autochthonous flora is natural and varies in an individual bottle over time. In human terms, the numbers they achieve in the bottle may be considered “high”; however, in bacterial terms, they are merely eating the dissolved assimilable organic carbon available to them and multiplying to numbers based on this food availability. Because all bottled water should be expected to contain various concentrations of autochthonous flora or HPC, health-risk assessment centers around the question: “Are there pathogens present and can these pathogens multiply?” There has been no evidence to date of the presence of pathogens or their multiplication in bottled water that has been subjected to appropriate multiple barriers and meets appropriate regulation.

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14 Formulation and Production of Flavoured and Functional Waters

Fred Jones

14.1 INTRODUCTION

When invited to contribute a new chapter for the third edition of this book, I was provided with a challenge regarding how best to present the subject of formulating flavoured and functional waters.

As any follower of this market category will agree, and particularly when considering functional waters, development rates globally have been rapid and the number of product launches high. Many of these new products started out through what could be described as less conventional development routes, with an increase in general knowledge through the Internet and improved travel helping to drive the desire by entrepreneurs to create something different and new. Many products have been developed outside the familiar environment of the water and drinks industry multinationals, and arguably without the traditional constraints that can bring. This resulted in not just pushing the water category boundaries, but also pushing the technology boundaries for formulations, as new ideas and new concepts have needed to be woven into the products.

From a developer/technologist point of view, this has created challenges, with the drive for category-stretching new products forcing new approaches to finding new ingredients. This has also brought new risks. As markets move so quickly, pressure is on to endorse the technical aspects of a product without sometimes fully understanding the ingredients, their stability when combined in the drink and the extremes of storage conditions the drink may be exposed to.

When it comes to actual production, it is easier to give clear information because flavoured and functional waters fall somewhere between waters and soft drinks and this defines production requirements. It is not possible to manufacture these products in facilities such as those only packing sources of mineral or spring waters, without extremely careful consideration of the issues this would present and for the requirement for some modification of the process plant. Mineral and spring waters are precious and a great deal of effort is put into maintaining the quality and composition of the source, so we must also consider cross-contamination risks in the factory and how to prevent them. In some markets also, it is not legal to produce beverages of any sort on the same production lines on which water is bottled.

From a strictly technical viewpoint and ignoring all the marketing aspects, the purpose of many flavoured and all functional waters is to provide nutrition of some sort to the user and it must not be forgotten that many of these nutrients provide ideal support for microbes

to flourish. As food safety is always our number one priority, production options are driven by the need to remove pathogens and control spoilage organisms.

Once the formulation work has been completed and the production process defined, attention turns to labelling. Ultimate responsibility for this must rest with the company lawyers, particularly when considering local legislation requirements for global brands. However, a technologist must play a part in creating at least the first draft and in guiding marketeers.

So with all this in mind, I have decided that the most useful way I can present this subject is to provide a practical chapter, based on personal experience, on all aspects of the formulation and manufacture of flavoured and functional waters. It is hoped that this will act at the very least as a memory jog for those lucky enough to have responsibility for development in this area, whilst providing a valuable route map to give clear guidance to those new to the subject.

As a reminder, within this category the following product types are typically seen:

- flavoured waters:
 - with only flavourings;
 - with sweetness/body and flavourings;
 - sparkling and still.
- functional waters:
 - mineral, spring or purified water;
 - with only vitamins and minerals;
 - with complex ingredients such as botanical extracts;
 - with flavourings;
 - with colourings.

14.2 COMPOSITION

Flavoured waters can be considered uncomplicated and range from water with just flavourings, to formulations which are the equivalent of soft drinks. Functional waters by definition must contain much more complex ingredients. A point of debate, which is covered later in Section 14.5.2, is whether the functionality can be endorsed by research or through existing knowledge. However, this does not change the fact that for functional waters to succeed in the marketplace, they have to meet consumer expectations for taste, aroma, mouth feel, appearance, point of difference and effect.

14.2.1 Ingredients

The main ingredients used to create flavoured and functional waters are:

- water;
- sweetener (natural sugars and intense sweeteners);
- acids;
- juice and juice concentrates (fruit and vegetable);
- flavourings;
- minerals and vitamins;
- botanical/herbal extracts;
- colour;
- stabilisers;
- preservatives.

Table 14.1 Typical sweeteners used in flavoured and functional waters.

Sweetener	Usage
Sucrose	Inexpensive and readily available. Creates a well balanced clean sweetness.
Fructose	Difficult to store and handle in powder form as it is hygroscopic.
Glucose (dextrose)	Ideal for drinks designed to provide a rapid energy hit.
High fructose corn syrup	Commonly used drinks sweetener in the USA as cost is low. Issue of genetic modification of corn makes this less welcome in healthy style drinks.
Aspartame	Intense sweetener, 200 times sweeter than sucrose with no calorie count impact. Some consumers show intolerance, requiring specific warning on products containing it. Shelf-life depends on pH of drink but is usually fine in the range of flavoured and functional waters.
Acesulfame K	Intense sweetener with similar sweetness to Aspartame and no calorie count impact. Known to have a slight bitter after taste, which some consumers appear to be particularly sensitive to. Often used in combination with Aspartame with synergistic enhancement of overall sweetness.
Sucralose	Recently developed intense sweetener, 600 times sweeter than sucrose with no calorie count impact. Good indications for stability and taste profile but difficult to handle at such intensity.
Deionised fruit juice (Apple or grape)	Processed to give just a sweet character by isolation of the natural sugars. Is more expensive in use than other sweeteners but has good character. Often used as it is seen to be a more natural form of sweetness and for product labelling can be described as fruit extract.

14.2.1.1 Water

The most important ingredient in the drink is the water and the impact of quality and composition is often overlooked. The soft drinks industry has always processed water to achieve a consistent standard of quality, in part because municipal water supply has not always been good enough. It is becoming common to see distilled (and more frequently reverse osmosis) purified waters used as the base for functional drinks, as this creates a totally clean and neutral base to work from. If mineral or spring water is used, it is important to know the composition as this may impact on both final product stability, taste and any claims and declarations made on the pack.

14.2.1.2 Sweeteners

A wide selection of sweeteners is available and their use is a matter of choice between the marketer, buyer and developer. These range from sugars and equivalents through to manufactured high-intensity sweeteners. Factors determining which type to use include calorie count, impact on ingredient declaration, legality in market, taste impact and cost in use. Table 14.1 shows the commonly used sweeteners.

Other sweeteners that will be encountered but are not commonly used for various reasons include:

- *Agave nectar*: sourced from Mexico as an alternative sweetener.
- *Stevia*: naturally derived sweetener but not yet approved for all countries.

Table 14.2 Acids used in flavoured and functional waters.

Acid	Usage
Citric	Originally extracted from citrus fruits but more commonly derived from fermentation and chemical extraction processes. Citric is the most commonly used acid in drinks and is available in both anhydrous and monohydrate form. It is important to specify to production which type has been used in development.
Malic	Originally extracted from apple but also found in other similar fruits. Imparts a mellower type of acid character.
Tartaric	Known well to wine drinkers as this acid is found in grapes and wine. Not often seen in use as an acid but again brings a different acid character to the other two.

- *Honey*: could be considered a functional ingredient as well as a sweetener with distinctive taste.
- *Saccharin*: one of the earliest intense sweeteners but not favoured now.

14.2.1.3 Acids

Acids are needed for two reasons. The first is to add balance to the sweetness and prevent creating a product with a cloying mouth feel. The second is to move the pH away from neutral and hopefully to a position where it assists in creating a commercially sterile product, by preventing the development of spoilage organisms and also to ensure the effectiveness of preservatives when used. In this respect they act as acidity regulators. In practice only three acids are commonly encountered and they are shown in Table 14.2.

14.2.1.4 Juice and juice concentrates

It is possible to obtain every type of fruit and many varieties of specific fruit as juice or juice concentrates. They form a very important ingredient group for the developer as they can bring fullness of body, taste, colour, aroma, functionality, cloud and pulp, acidity, sweetness, consumer satisfaction – and cost!

For a complete list of fruit juices available, the developer needs to talk with their local supplier. The major types are defined and described in Table 14.3.

Use of fruit juices brings additional issues that the developer should be aware of. The employment of pesticides on crops can leave behind unacceptably high residue levels and heavy metal contamination. Legal limits are set for residue levels and supplies should be checked or certified before use. Authenticity and juice adulteration have also been a problem and a great deal of laboratory based work has been undertaken to establish reliable test methods for purity.

It should also be noted that the use of fruit juice may greatly increase product sensitivity and decrease stability. It is always advisable to conduct careful testing of both the stability of the formulation and the effect of external factors such as expected ambient conditions (heat and light) before launch.

14.2.1.5 Flavourings

Flavourings are obviously the essential ingredient in flavoured waters and they are necessary to provide the signature taste and aroma profile of functional waters. Flavours can be extracts of natural plant materials or compounded from chemically derived sources. Natural extracts can be water or solvent based, although for stability all flavourings are provided on solvent carriers.

Table 14.3 Juice type definitions.

Type	Description
Single strength	This is juice that has just been pressed or squeezed from the fruit and undergoes no further treatment beyond stabilising. It is used in Not From Concentrate (NFC) juice drinks and has excellent taste and aroma properties. It is important to remember that for any water-based drink, inclusion levels will be low and the benefit of quality may be outweighed by cost in use.
Juice with pulp	This is usually a concentrate juice with removed pulp added back after the concentration stage. These are more expensive than concentrates and the pulp will create light sediment in the bottom of the pack. They do have good flavour but cannot easily be used in carbonated drinks.
Concentrate	This is an 'all in' concentrate that will dilute out to give some cloud or haze to a drink. This may not be helpful if the cloud starts to sediment out over time and will require a stabiliser to maintain appearance for the shelf-life of the drink.
Clarified concentrate	The most commonly used juice in drinks that dilutes out to produce a clear haze free liquid. Unfortunately this benefit brings with it the drawback that this juice is the most processed and for some fruits will have lost much of the original character.

Natural flavours are not necessarily more expensive than their artificial equivalents but in use more is required as they have less impact and they can fade fast.

Great care is needed when using flavours as even though they are used at very low levels of typically 0.05–0.2% they can cause some quite dramatic effects to the whole drink. Examples of problems commonly seen include terpene oil rings, haze and flavour profile change.

14.2.1.6 Minerals and vitamins

Addition of minerals and vitamins provides a drink with a wide range of established benefits already defined through the health supplements industry. Premixes of various minerals and vitamins are available, which can be dosed during production. Selection of the desired mix to incorporate will be driven by the functionality requirements of the drink. As a general rule, I would consider most non-medicinal ingredients used available in tablet form as an opportunity for inclusion in a functional drink. This fits well with the view that for busy lifestyles a functional drink delivers on many levels. The drawback when adding vitamins to a drink is that whilst tablets provide a very stable format for delivery, water does not, so it is important to take into account reduction with time of the claimed vitamin content. I would include under this heading ingredients such as taurine and caffeine.

It is usual to list the level of a vitamin or mineral as both the amount and the percentage of reference daily intake (RDI). The RDI is a value set by expert panels and is calculated by considering the nutrient needs of individuals within a population and setting a representative figure at a level where it neither causes deficiency nor toxicity. A safe upper limit (SUL) also generally exists, which is the amount that may be taken on a life-long basis without adverse health effects. Developers should be aware that values of RDI and SUL can differ between countries. They should also take into account that vitamin and mineral levels should avoid approaching the SUL value for normal daily consumption levels.

14.2.1.7 Botanical/herbal extracts

Use of botanical extracts provides a means of delivering many of those ingredients associated with detoxification, alertness, body purification, defence, calming and general well being. Care is needed as whilst some ingredients may be confidently linked to known physiological effects, for example Guarana extract (which contains high levels of caffeine and can be linked with alertness) other claims such as body purification may be more difficult to support. It is important to establish the confidence level in any claim and to understand the source of the supporting information. A number of claims can be justified on the basis of past pharmacological studies either during drug development or through patient observation. Results of studies are published giving the proper opportunity for the broader scientific community to debate and challenge any unclear information and to generally reach a consensus of opinion. Be careful if considering using ingredients where claims are based on either local belief or old folklore. There may well be some truth in the story but unless there has been a full and sound study of beneficial effects, careful wording is required for any claim and the potential risks associated with consuming the ingredient should be considered.

Usage levels in the finished drink tend to be low, so flavour impact should not be of great concern. Many of these extracts are very expensive due to raw material costs and the complexity of the gentle extraction processes used for manufacture.

The commercial preparation of botanical extracts is a relatively new area of the drinks industry and it is important to source materials from reputable suppliers. Care is needed to ensure that the material to be extracted has been botanically identified correctly and that the purity of the raw material used for extraction is known. As with fruit juices, the risk of adulteration must be considered and the developer should be satisfied that this is prevented.

14.2.1.8 Colour

Flavoured waters typically do not use colour, even when there is a range of flavours produced under one brand – they are usually differentiated through labelling.

Functional waters do use colours and although artificial colours are available it is usual to achieve the desired effect by using a juice or a concentrated vegetable extract. Colours should be carefully tested before product launch as under certain conditions, particularly when used with vitamin C, colour can completely fade out in a short space of time.

14.2.1.9 Stabilisers

Stabilisers and gums may be required to help prevent some of the separation problems seen, particularly where there are suspended particles from fruit juice or water insoluble ingredients such as terpene oils and vitamins A, D and E.

14.2.1.10 Preservatives

For products that are not being heat treated to destroy pathogens and limit spoilage organisms (more on this in Section 14.4.3), it is necessary to add chemical preservatives. The commonly used preservatives are benzoate, sorbates, and dimethyl dicarbonate. Benzoate should not be used in drinks containing ascorbic acid (vitamin C) as it is known to react to generate benzene, a known cancer causing agent. There is also increasing evidence that benzoate reacts with citric acid in a similar way and its use as a preservative needs to be considered carefully.

Dimethyl dicarbonate is extremely effective against micro-organisms, but reacts with water to break down to methanol and carbon dioxide over a period of 1 to 4 hours, depending on temperature. As the original compound no longer exists and the methanol produced is in very small quantities, it has been common practice in the past not to list it as an ingredient.

14.2.2 Ingredient search

The need to deliver new functional products that fit with current lifestyles and keep pace with food and drink trends requires developers to look beyond their normal sources for inspiration and ingredients. Many ingredient suppliers make efforts to keep pace with recent product launches and to predict future trends, but it is now also necessary for the developer to carry out a fair amount of research for ingredients.

I would advise any developer to start with a visit to their local bookshop and review the section on health and nutrition as products often follow latest thinking in this area. It should be remembered that not every trend will be appropriate to the business or the market, and careful judgement should be exercised before committing to the inclusion of a new ingredient. Caution should be exercised when seeking information from the Internet, as this may not have been properly validated. Many countries also now have approval processes for novel ingredients and it may not be possible to use them until they have been through the process of confirming that they have previously been used as a human food source or have undergone rigorous safety tests.

Further sources of inspiration include the health supplements industry, although they are also under some pressure to provide safe usage data for their products, other food and drink categories and other marketplaces, particularly those where product innovation and introduction is strong.

14.2.3 Ingredient sources and supply

In theory, it is possible to get all the necessary ingredients in all countries, provided they are legal, even if the supplier is located elsewhere and with global trade it is often the case that the supplier will be overseas. Once a source of a particular ingredient has been located it is worth also considering how to handle the material at the production site. There are a number of points to be kept in mind during development, which will help to minimise later problems.

14.2.3.1 *Country of supply*

Most of the recently introduced 'Superfruits', which are fruits with very high levels of vitamin or antioxidant content, have been sourced from South America and in particular the Amazon rainforest. In the ongoing quest for new products, attention is also turning to sub-Saharan Africa. Furthermore, many unusual fruit juices and concentrates are only sourced from one region. Firstly, as already stated, some of these ingredients may require approvals. Secondly, it should be confirmed that the supply source is secure and that the capacity matches forecasted requirements.

14.2.3.2 *Food miles*

If the current debate on environmental impact is considered important for the brand, it may be wise not to source too many exotic ingredients from the other side of the world. It may be that revisiting other options delivers the same impact.

14.2.3.3 *Storage conditions*

Powders such as fructose will pick up water under most conditions and others will do so under high humidity. If powders become difficult to dissolve, they will be rendered unusable.

Many fruit juices are supplied frozen and for the more commonly used juices the minimum volume will be around 200 kg in a drum. If it is planned to use a smaller quantity, alternative pack formats may need to be explored, such as aseptic bags, and this will add cost. The alternative will be to thaw the entire drum and either waste the residual stock or increase production run size, which in turn leads to increased warehousing of finished goods.

Flavours are provided in plastic containers and drums as flammable liquids. These will need to be stored safely and preferably cool to avoid deterioration.

14.2.3.4 *Shelf-life*

The condition of all ingredients, even those stored frozen, starts to deteriorate from the moment they come off the production line, just the same as finished products. Stock rotation is important in production and holding minimum stock levels, if possible, will help reduce the impact of ageing of raw materials. Just as importantly, samples for concept development, product or production approval should never be made using old laboratory ingredient stocks. It will never be possible to reproduce the product, even if it is liked.

14.2.3.5 *Cost*

Ingredient cost is very hard to guess, and this can be significant, particularly with ingredients where raw material cost, extraction efficiencies and yields have a big impact on final price. A worst case price should always be requested.

14.2.3.6 *Seasonality/locality*

Ingredients can be restricted through seasonal harvest or location of crops. If this is the case, it may be required to forward provision enough stock to meet the next year's manufacturing requirement.

14.2.3.7 *Manufacturing pipeline*

Although it may go against the principle of keeping stock levels to an absolute minimum, certain ingredients may have to be contracted ahead of requirement. Key reasons for this are availability of sufficient stock to meet forecast requirements (as is often the case with fruit juices), or long lead times for manufacturing schedules often seen with unique flavours.

14.2.3.8 *Quality*

The extra care needed to source quality assured and certified ingredients when manufacture is remote and not under own control is fairly obvious. However, getting this right is often overlooked, especially when some specifications carry so much information that it is difficult to see what is important. More about this is covered in Section 14.3.5.

14.2.3.9 *Legality of ingredient*

A final point to always keep in mind is that local regulations, for the market in which the product will be sold, must be checked regarding usage of ingredients before the final product is manufactured.

14.3 FORMULATION

There are many approaches to the formulation of flavoured and functional waters. To some extent it is tempting to say: 'do it whichever way suits best' – but that would be reckless and opens up the risk of creating a great product without having any idea of how it was done! In truth, the best way is to follow a clear plan with careful preparation of materials and samples, to make regular evaluations of progress and *write everything down*. Beyond this, the person creating the formulation should not be constrained by what they know – no ground-breaking products were formulated this way – and remain open to suggestions from colleagues, suppliers and customers.

Now for some practical advice – the sub-sections below give guidance on technical aspects of formulations.

14.3.1 Measurements

14.3.1.1 °Brix

The industry standard for measuring the sugar content of a drink is °Brix (degrees Brix) determined by measuring solution refractive index. It is possible to use tables to correlate refractive index to Brix, but most equipment is calibrated to give the Brix figure. The correlation is based on sugar in solution and so allowances should be made for the other ingredients in the solution. Of particular relevance is the acid component, as this reduces the refractive index reading and often needs to be corrected for when quoting sugar content in fruit juice concentrates. Apart from that, in practice, a Brix reading for the completed formulation will be used in production and is acceptable for final specification purposes.

14.3.1.2 *Titrateable acidity*

Used to provide a measure of the total acid content of a drink, and determined by titration with Potassium Hydroxide. The total acid in a drink will come from the acid added and the acid occurring in fruit juices. At production level the measure is used to determine what quantity of acid should be added to make any final adjustments prior to filling.

14.3.1.3 *pH*

It is important to know the pH of the product, as the measured value will indicate how microbiologically safe the product is likely to be after processing. pH is a measure of the acidity of a solution on a scale of 1 to 14, where 1 is most acid and 14 least acid (most alkaline). The important figure for drink developers is around pH 4.0, and it is advisable to always work to pH 3.8 to give a margin of safety. In the range pH 1 to pH 3.8, the growth activity of yeasts and moulds, which are the spoilage organisms found in drinks, are stopped. This does not mean that they are killed, only that they will not grow under these conditions.

There is some recent evidence in the industry of pathogen survival at pH as low as 3.5. If this is the case, it would be more appropriate to consider this as a new target in future development. Developers should keep an awareness of this and conduct testing to assure themselves of the correct final pH for their formulations to achieve food safety.

14.3.1.4 Carbonation

For carbonated drinks, the added level of carbon dioxide is measured either as CO₂ ‘volumes Bunsen’ or g/l. To convert between the scales, 2 g/l CO₂ is approximately equivalent to 1 volume Bunsen.

14.3.2 Usage levels

There are few rules regarding the amount of an ingredient to use in a formulation and it would be difficult to attempt to lay out the matrix of options for combining ingredients. There are sensible limits though – and these derive from consumer likes (or maybe expectations) borne out of what they are familiar with. Around the world there are global brands and products (i.e. Coca Cola – which is expected to be and taste the same wherever it is sold), but based on experience with new products, each market has a preference for particular sweetness and acidity levels. Taste and aroma then become a matter of choice and point of difference.

Quite often the developer does not know where to start, so general usage values for the main ingredients are shown in Table 14.4, to provide some initial guidance.

14.3.3 Ingredient interactions

Functional waters are amongst the most sophisticated formulations in the drinks industry but also unfortunately do not have an inherent stability. The formulations are complex with numerous ingredients, of which many are active, that is, capable of involvement in biological functions and demonstrating a level of reactivity with other ingredients. The only guaranteed method for proving product stability is to run a real-time, real conditions storage test but this does not now commonly happen ahead of product launch. It is impossible to predict all interactions, particularly as new ingredients and new combinations of ingredients are developed, but listed below are some of the regularly seen problems.

14.3.3.1 pH

If the microbiological stability of the product is dependent on maintaining a particular pH, it is wise to check for drift caused by acid reactions. If this is the case an acidity regulator or buffer will need to be added. The usual regulator to use for citric acid-based drinks is sodium citrate.

14.3.3.2 Terpene oil ring

The best citrus flavours get a part of their impact from the use of terpene oils. These do not hold well in water based solutions and rise to the surface often within days of production, with the creation of an oily ring around the neck of the container. This may not be a problem if the ring is not visible but whenever it does prove to be visible, there are two options. First

Table 14.4 Ingredient guideline usage levels.

Ingredient	Usage	Comment
Sugars – All	Up to 10%*	10% close to many carbonated soft drinks - High levels of sugars increase mouth feel
Intense sweeteners		
Acesulfame K/Aspartame	Up to 0.05%	In development it is advisable to prepare a 1% stock solution and use 1 ml portions (0.01 g/ml) to prevent overdosing
Sucralose	Up to 0.02%	
Deionised fruit juice	Up to 14%	Typical values are up to 70 °Brix
Acids	Up to 0.3%	- Fruit juices will provide acidity - High sugar levels will require the higher acid levels
Fruit juices		
Single strength	Up to 10%	- High levels will cause stability issues - Refer to supplier for single strength calculation factors
Concentrate	Up to 1%	
Flavourings	Typical 0.1% Up to 0.25%	- Overdosing flavours will impart an artificial note - Allow for loss during heat processing of natural flavours
Minerals	Up to 100% of RDA**	Usual to provide 25–50% of RDA where one exists
Vitamins	Up to 100% of RDA + 25%	- The extra allows for losses over time to ensure that any declarations are met at the end of declared product shelf-life - Seek advice from supplier if unsure or using complex formulations
Botanical / herbal extracts	Up to 1%	Cost and active content limit usage at higher levels
Colour		
Artificial	Up to 0.0002%	For development work with artificial colours prepare a 0.1% or lower stock solution and use 1 ml portions (0.001 g/ml)
Natural extract	Up to 0.1%	
Stabilisers	Up to 0.1%	Dose rate is formulation and stabiliser dependent. Seek advice from supplier if unsure of use
Preservatives		
Benzoate	Max 150 mg/L	- Figure is as benzoate/sorbate not as sodium or potassium salt - Sorbate limit is reduced when combined with benzoate - High levels of benzoate and sorbate can cause taint
Sorbate	Max 300 mg/L	
Sorbate with benzoate	Max 250 mg/L	
Dimethyl dicarbonate	Max 250 mg/L	

* All percentages are on a weight/volume basis (g/L).

** RDA Recommended Daily Allowance – The amount of a nutrient which should be consumed on a daily basis for maintenance of good health as set by local government departments or Institutes acting under their authority.

is to add a stabiliser, but this is not always successful. The second is to get the flavour supplier to provide a ‘wash’, a term for a flavour that has had its component parts partitioned between aqueous and non-aqueous phases to remove the terpene oil during the flavour manufacturing process. This will, however, reduce some of the flavour impact.

14.3.3.3 *Ascorbic acid (vitamin C)*

Ascorbic acid is one of the most beneficial, but also problematic ingredients to use. The use of benzoate preservatives with ascorbic acid should be avoided, as they react together to produce benzene. There is also a more complicated issue of ascorbic acid reaction with colours. Ascorbic acid is an antioxidant and is regularly used to inhibit browning reactions and colour change in products containing ingredients such as green tea; however, if added to products containing red colours such as strawberry extract it accelerates browning reactions. There is one answer, and that is to test before launch.

14.3.3.4 *Carbonation*

Lightly sparkling drinks have a CO₂ content of around 2.5 volumes and full ‘fizzy’ drinks are in the region of 4–5 volumes. They are clear and pressurised in the bottle. When a carbonated drink container is opened, bubbles appear on the surface of the container and this is partly because the pressure is released and partly because the surface is microscopically rough and provides a site for bubble production. Adding solid material, such as fruit pulp or puree will spectacularly increase this effect, so it is advisable not to use pulp or purees with highly carbonated drinks and think carefully before using any carbonation with these types of drink.

14.3.3.5 *Precipitation*

Clarified juices, botanical extracts and natural colours can all behave unpredictably with time and may throw a precipitate, which can be accelerated in the presence of vitamins. This may not be an issue if the manufacturer makes a point of advising consumers to shake the product before drinking. However, the precipitate may be formed from ingredients for which there is an RDA or inclusion level claim. It will be necessary to take account of this when preparing labelling claims or to reformulate to prevent the change occurring.

14.3.4 **General comments for developers**

Much of this should be obvious, but surprisingly often overlooked:

- Always taste development samples at the temperature at which they are intended to be served.
- Make sure that cross-contamination risks are eliminated from the laboratory, both in the test drink and in the stocks of ingredients.
- If working with juices, keep to one set of standard single strength or concentration factor values.
- Keep in mind the manufacturing process, as it will have an impact on the product and may require formulation adjustment.
- Get a clear understanding of the product brief before starting, to ensure that the formulation and ingredients fit target market expectations.

14.3.5 Ingredient quality

The starting point for confidence in sourcing quality assured ingredients is the supplier specification. The specification will often carry much more information than is required, but may also not have enough, particularly in the case of botanical extracts. It should always be remembered that final responsibility for the product formulation is with the developer and cannot be passed back to the ingredient supplier.

Ingredient specifications as agreed with suppliers can be broken down into four main areas:

- (i) the information that confirms that the ingredient does not exceed legal limits for such things as pesticides, metals and other contaminants;
- (ii) information on the microbiological status and necessary storage requirements;
- (iii) information which characterises the ingredient and is useful to the developer in working out usage. This would include information such as purity, solids content of liquids and total composition;
- (iv) information on the supplier, which should also facilitate product traceability.

Handling information and any special health and safety data should be in the materials safety data sheet (MSDS), which is a separate document and must be provided at the same time as samples.

The specification will form the basis of any contract to purchase future quantities of an ingredient and must be relevant. Legal limits are always measurable, characterisation profiles, such as flavour and aroma definition are often not, so it is important to establish which of the supplied information can be turned into a working control procedure to remove subjective analysis. It may be necessary to change the supplied characterising information; as for ongoing quality control it will not be sensitive enough to indicate change. An example here would be the brix value of a fruit juice concentrate. These are typically around 65 °Brix and provide a measure of consistency of the concentration process, but a lower figure by itself would not confirm that the product is different in taste or appearance. In combination with the acidity value, it would be possible to look at the sugar : acid ratio and if this is constant, confirm that the sweetness level is the same. However, the taste could still be completely different and this could be caused by a change in the raw material processing or storage. The overall point here is to think carefully about what is important on a specification and agree with the supplier as to how it should be measured. If changes in ingredient are not picked up by the testing regime in place, it is appropriate to question the use of the test and identify an alternative test procedure, and important not to sign off specifications carrying useless test information.

If the specification covers compounded ingredients, they must give a compositional breakdown, as hidden surprises are no longer acceptable in today's market.

Finally, specifications give false comfort and are worthless unless the receiver regularly tests shipments of material or has a certificate of analysis from the supplier.

14.4 PRODUCTION

14.4.1 Where to manufacture?

Packing mineral water and packing soft drinks can be considered two ends of a spectrum and it is important to consider where flavoured and functional waters fit and should be packed. It is unlikely that a production unit set up to pack mineral water will have the

batching tanks required to make up functional waters or the heat treatment equipment to render it commercially sterile. Even if the intention is to put this in place, the risk of cross-contamination, particularly at the filler, must be addressed.

If the intention is to work from the other end – that is, for the drink to be packed in a soft drinks factory – the water quality needs consideration. This is not to suggest that soft drinks factories do not have good quality water, as they will all have some form of water purification, but it may be that the drink has been developed with a particular water source and the available supply is not suitable. In this case, it is necessary to address the reverse problem of tankering water to the factory at considerable cost, whilst protecting its integrity during production.

There is no simple answer, as all the factors need to be weighed up.

14.4.2 Packaging options and impact on production choice

Flavoured and functional waters are usually packaged in PET, presumably because they compete with soft drinks in similar packaging and lend themselves well to ‘out of home’ consumption. The usual formats are standard PET for flavoured and hot fill PET for functional waters. Hot fill PET is designed with collapse panels so that as the product cools the panels are able to cope with the stresses generated by the vacuum created in the pack. There is no technical reason why other formats such as glass, cans and pouches cannot be used, but they are not usual and may present an opportunity for the future.

PET is available with various barrier properties against air and light, thus helping reduce product deterioration caused by these effects.

Packaging type to some extent fixes the production process and whilst options remain they start to close down quickly if looking for available contract manufacturers. Table 14.5 shows the normal process options available by pack and drink type.

If cans are considered for packing still products, they will require a slight internal pressure to prevent can damage when handled as the metal is so thin. This is usually achieved by the addition of a drop of liquid nitrogen just before the cans are lidded and sealed.

Pack labels can play an important role in providing protection, particularly against the effect of UV light, which will destroy vitamins, fade colours and change taste profiles. For this to be completely effective shrink wrapped sleeving should be used.

14.4.3 Microbiological safety and commercial sterility

All the ingredients discussed so far will have a certain microbiological loading, and the production environment and operational standards will also contribute extra loading to the product. For this reason, a level of long-term stability in the pack must be achieved by reducing this loading to avoid causing either illness or product spoilage. Illness is caused by pathogens, such as staphylococcus, salmonella, clostridium and streptococcus; spoilage is caused by yeast, mould and bacillus. Stopping microbial activity is achieved primarily through the addition of chemical preservatives and or heat treatment. For a product to be safe and long-term stable, it must be effectively free of pathogens and have a pH capable of rendering any residual yeast and mould inactive and thus termed commercially sterile. Where heat treatment is applied, pasteurisation at temperatures of around 72°C for up to 40 seconds will be effective for high acid products (range 1–3.8). If the acidity is below this value (pH > 3.8) the product will need to be sterilised at around 121°C for 3 seconds. The process of sterilising the product will destroy all

Table 14.5 Process options for major pack and drink types.

	Preserved Cold fill	Pasteurised Cold fill	Pasteurised Clean fill	In pack Pasteurised	Pasteurised Hot fill
Pack type					
Std PET	✓	✓	✓	X	X
Hot fill PET	X	X	X	X	✓
Glass	✓	✓	X	✓	✓
Cans	✓	✓	X	✓	X
Drink type					
Sparkling	✓	✓	X	✓	X
Still	✓	✓	✓	✓	✓

Process descriptions are given in Section 14.4.4.

micro-organisms in the drink but will have enormous impact on the flavour and functional content and is unlikely to be found as a common process in most soft drink factories. It is also possible with some botanical extracts to see problems with spore forming organisms, which can lead to long-term issues of safety and spoilage. The only reliable way to deal with this is to sterilise for longer, but if this is considered necessary it would be more appropriate to reformulate.

It should also be noted that if development samples are to be sent out for large-scale testing or home consumption trials, they should also be preserved or heat processed to ensure their safety.

14.4.4 Production processes

Production processes are always under review in a constant drive to improve product quality, improve line efficiencies and (more recently) to cut energy usage. That said, production lines are costly to install and do not change that frequently, so the descriptions that follow represent the majority of packing lines to be found that are suitable for packing flavoured and functional waters. Production lines vary enormously in size from in-line single head fillers to the large carousel fillers capable of many thousands of packs per hour (see Chapter 7 for more detail).

Much of what follows will be familiar to packers of mineral waters but methods for microbiological control differ and preparation of the drink is an additional step. The production process can be broken down into pack preparation, ingredient batching or syrup preparation, heat treatment and filling. Each of the overall processes described in Table 14.5 represent the options available through various combinations of these steps.

14.4.4.1 Process steps

Pack preparation

PET bottles can be supplied in immediately usable formed bottles, or if the volumes are favourable, they can be stretch blow-moulded from preforms. Hot fill PET, glass and cans are manufactured separately and supplied ready to fill to the factory. It is usual to pre-rinse packs, passing them through an inspection unit before they reach the filler, but this is not always the case. If glass bottles are used, particular care is needed to check the rims for signs of damage.

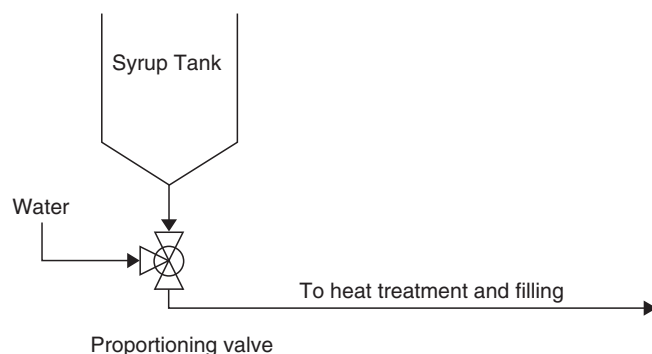


Fig. 14.1 Flow diagram of proportioning system for syrup and water mixing.

Ingredient batching or syrup preparation

A typical size for a batch tank is 5000 litres, but can be much larger, and will be sized to the throughput of the filler to remove the need to make up numerous batches during a production run. By contrast, a 500-litre tank works well for smaller volume products as it reduces the need to produce too much stock in one run. The benefit of creating a batch is that all checks and adjustments, including taste approval, can be made before sending any product to the filler. On the negative side, arguably there could be some variance from batch to batch and operators must spend a lot of time preparing the batches.

An alternative system, essential in high volume production facilities, is the preparation of a syrup concentrate, which is then combined with water through a proportioning system. Proportioning ratios of 1 + 4 or 1 + 5 (syrup + water) are common and they originally worked through manually adjusted flow restrictors and regular offline testing for accuracy of dilution. Newer versions use mass flow meters, continuous brix measurement and feedback loop control systems. The benefit of proportioning over batch preparation is that a batch of syrup can make up to 6 times the volume of finished product and this means filling lines can keep running longer without changeover. A drawback is apparent in that setting up the proportioning system and hence the dilution factor incorrectly, or a change in syrup viscosity, will lead to out-of-specification product. As this is already heading for the filler, in these cases a certain amount of wastage is inevitable. It is also important to understand how to calculate syrup strength correctly to define the dilution required. A simple flow diagram for proportioning systems is shown in Fig. 14.1.

Heat treatment

If chemical preservation has been rejected, it is usual to apply heat treatment to reduce microbiological loading. For our purposes it is usually acceptable to carry out pasteurisation through plate heat exchangers or heat tunnels. Plate heat exchangers consist of three stages, with pre-heat, pasteurising and cooling zones. Heat tunnels allow in-pack pasteurisation and are made up of many heating and cooling zones. Many zones prevent pack failure through thermal shock, either during heating or cooling.

Filling

Changes in filler design and enclosures make it possible to carry out what is known as clean filling. The filler heads are designed to have minimum contact between machine, product and bottle and the air surrounding the filler is passed through HEPA filters. Typically bottles

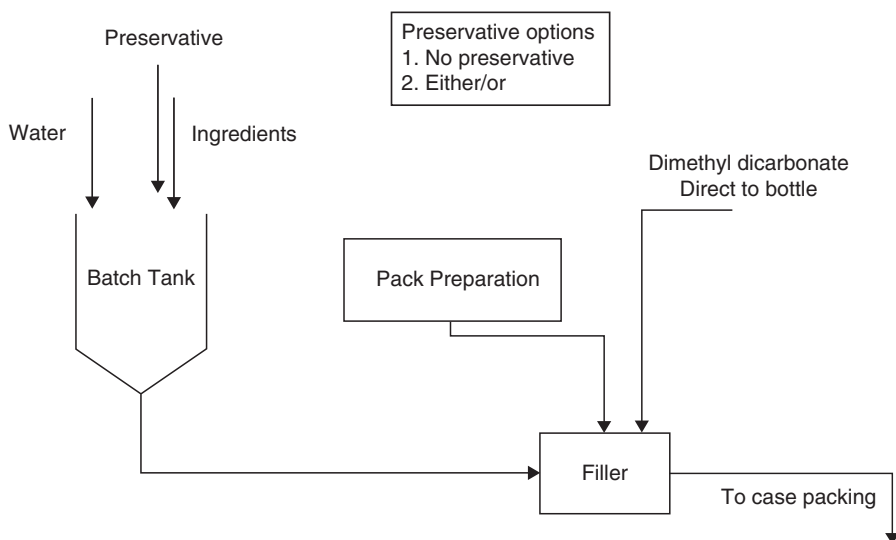


Fig. 14.2 Flow diagram of cold fill production system for preserved drinks.

entering clean fillers are pre-rinsed with peracetic acid and caps are usually exposed to UV light, although other methods are also available.

If the filler is not of this design it should be remembered that at the point of filling it is possible to re-introduce microbiological contamination.

Aseptic packing

None of the above techniques will produce an unpreserved completely sterile (aseptic) product. This requires temperatures of at least 121°C for a minimum of 3 seconds, all holding vessels and filling units to be pre sterilised with steam or hydrogen peroxide and the entire line to remain sterile throughout the production run. Even with modern aseptic systems it is unlikely that vitamins, natural flavours, natural colours and botanical extracts would survive the process enough to provide a reasonable shelf-life. If this process is desired, then form fill seal systems, which produce long-life carton products, should be considered.

Process options

Outline flow sheets of the following processes are shown in Figs 14.2, 14.3, 14.4, 14.5 and 14.6.

Preserved – cold fill

Preservation is achieved by chemical treatment and the product is never heated. As a process this is only suitable for simple formulations where the ingredients used do not carry a high microbiological loading and there is confidence that the preservative alone is capable of effecting stability.

Pasteurised – cold fill

The product is passed through a plate heat exchanger capable of raising the temperature to 72°C and holding it for the required pasteurisation time. Product is then cooled and sent for cold filling. The heat treatment is to reduce any initial microbiological loading in the drink

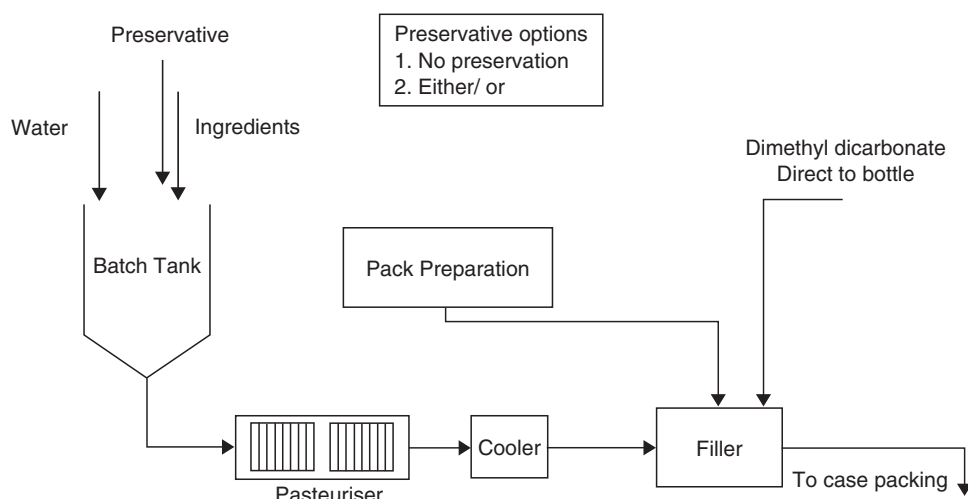


Fig. 14.3 Flow diagram of cold fill production system for preserved drinks requiring pasteurisation.

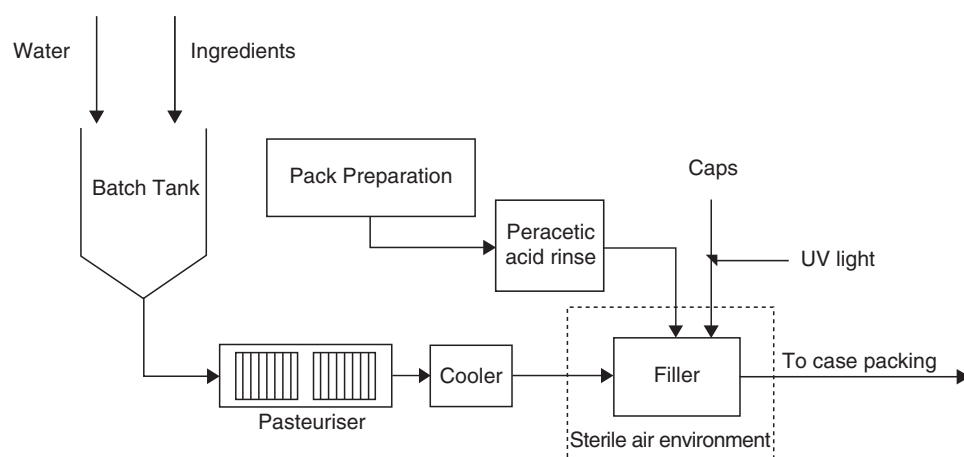


Fig. 14.4 Flow diagram of clean fill production system for pasteurised drinks.

and this is typically used for products containing juice. It is common to add a chemical preservative, as in this system the packs will not themselves be sterilised.

Pasteurised – clean fill

This option removes the need for adding chemical preservatives after pasteurisation as there is very little risk of re-contamination of the product at the filler. As explained previously, this is achieved through enclosing the filler, providing sterile air and reducing contact points at the filler head.

In-pack pasteurised

The product is filled into the final packaging of glass or cans and heat treated through a tunnel pasteuriser. As the product is already sealed in the pack before both are heat treated at the same time, there is no need for chemical preservatives. However, they are sometimes used as an additional safeguard with difficult products.

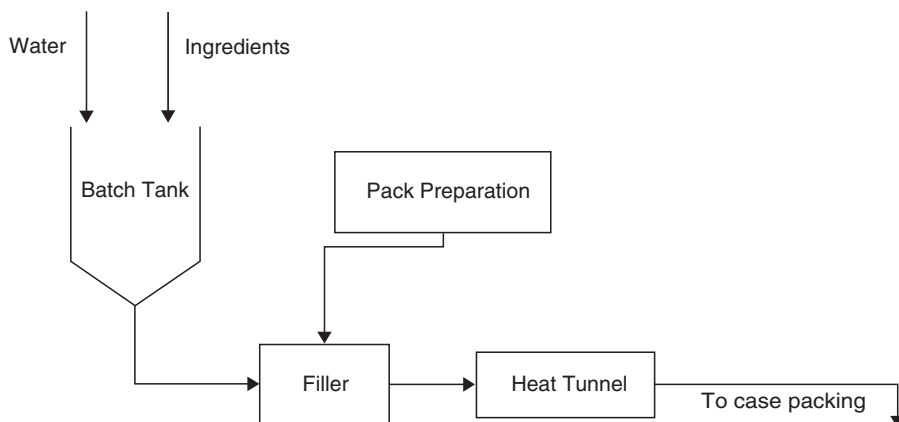


Fig. 14.5 Flow diagram of in-pack pasteurisation system for drinks packed in glass and cans.

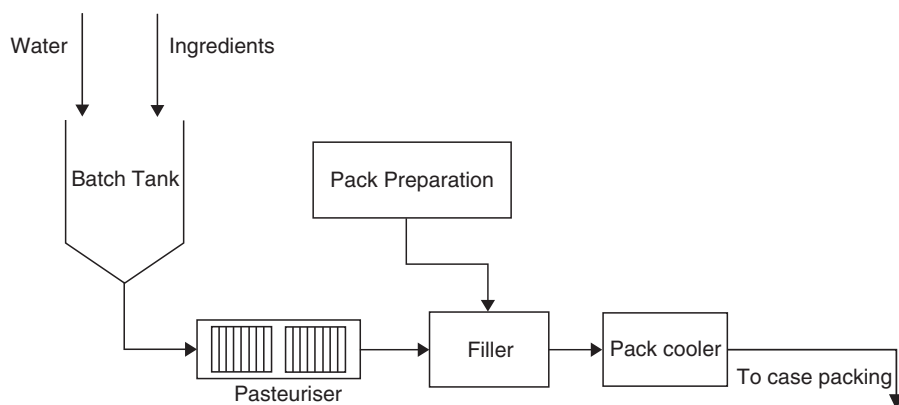


Fig. 14.6 Flow diagram of hot fill production system for pasteurised drinks.

Pasteurised – hot fill

Product is passed through a plate heat exchanger with the final cooling zone set to off. The product passes to the filler at 72°C and the pack is filled and capped. The hot product is used to heat treat the pack. It is usual to invert bottles on the line for the heat to also be applied to the caps. This technique is only suitable for glass or special hot fill PET.

14.4.5 Finished product testing

A finished product specification needs to be provided, along with the recipe to guide preparation of the batch and sign off for finished goods. The specification should capture routine production tests and identify any specific tests to support any content claims. It should also allow some tolerance for slight production variability.

As a bare minimum, factories should have available test equipment for measuring °Brix, pH, titratable acidity and CO₂. Additional equipment may also be required for measuring microbiology, colour and turbidity or haze. If microbiology testing is not available, it is usual to send product for external local laboratory testing, with stock held until cleared, and

certainly until a body of data is built up to provide some history of consistent problem-free production. If specialist testing is required, such as for vitamins, it is probable on larger production sites for chromatographic techniques to be available, and if not, samples will again have to be sent out for specialist testing.

14.5 ON SALE

Awareness of the issues that may present once a product comes to launch will help to design them out in the first instance, and indeed, some must be addressed to meet legal requirements. The guidance comments below are with reference to EU guidelines, but it must be kept in mind that local legislation in other parts of the world may well be different and that regulations are updated from time to time. In particular, declaration and labelling requirements must be checked with a local specialist lawyer or with a local trading standards authority.

14.5.1 Ingredient declarations

All ingredients must be declared in descending order of the amounts in which they are present and everything must be included. There is some debate over the declaration of ingredients that are described as processing aids; an example is dimethyl dicarbonate, which does not remain in the drink after manufacture, although analysis for breakdown residues is possible. In the EU labelling regulations, such process aids do not need to be declared. However, some companies are intending to include a declaration to demonstrate their commitment to transparency on product and production processes. When using processing aids, it is advisable to seek legal advice on local labelling regulations. Compounded ingredients must be broken down into their individual components and placed in the correct order in the overall listing. Flavour regulations have changed in many countries recently, and specific advice should be obtained from the supplying flavour house. There are specific and detailed conditions under which a flavour can be described as natural, otherwise it must be labelled simply as flavouring. Remember that water is considered an ingredient and needs to be listed.

14.5.2 Labelling and functionality claims

As a general rule, unless there is a volume of information or general acceptance or clinical trials to support a claim, such claims should be avoided. If there is an intention to describe a product as suitable for, as an example, defence or detoxification, it should be checked by lawyers first. If an ingredient is generally accepted as providing certain benefits, the wording used on the pack to describe it should be considered carefully.

14.5.3 Allergens

The list of declarable allergens continues to grow and it is not possible to list them all here. It also hardly seems appropriate to develop 'well being' drinks containing allergens, but if so decided, allergens must be listed in a separate declaration to the ingredients listing. Allergen declarations must be supplied for all ingredients intended for use in the final product, and the potential for cross-contamination at the manufacturing location thoroughly evaluated.

14.5.4 Shelf-life evaluation

The developer must often decide on the shelf-life, taking into consideration the production conditions and packaging. If recommended daily allowances are claimed for vitamins and minerals, these ingredients must be present in the product in the quantities declared at the end of the stated shelf-life of the product. Beyond this, determining shelf-life is not straightforward and can be subjective if there is no point at which the product becomes unsafe to consume.

There are two ways of determining shelf-life. The first technique is to decide at what point in time the product no longer represents the values and standards expected for the brand. The second technique is to decide whether the product continues to fit the description on the packaging. These two options may not normally coincide, as the first will presumably come long before the second, as brand guardians will always want the best quality for the brand.

Ingredient interactions (covered in Section 14.3.3) can manifest themselves over time and storage conditions can play an important part in driving some of these. Key issues to consider are exposure to strong sunlight, storage in summer in hot warehouses and cycling of temperatures from night to day.

A question often asked is whether shelf-life testing can be accelerated and the answer is 'yes and no'. Storage at 38°C can, as a very general rule, increase normal deterioration by a factor of 4; hence 3 months in accelerated conditions represents 12 months under ambient conditions. However, the only real test of this is to carry out the accelerated test and compare it to a real-time study for a particular product, which means the correlation can only be demonstrated after the entire shelf-life has passed. Adding to the study, the effects of exposure to sunlight can complicate matters but would be appropriate if light levels are high in the country of product sale. In this case, if used in combination with higher temperature, deterioration can be expected to be faster. The conclusion has to be for the developer to interpret accelerated shelf-life data carefully, because the conditions of study may at best only approximate to those experienced in practice.

14.6 NEW AND DEVELOPING TECHNOLOGIES

14.6.1 Proportioning of ingredients

Development in the area of proportioning systems is making it possible to remove the need to create syrup for blending with water and to introduce all the ingredients as individual components in a continuous stream. Given the complexity of many functional waters, there may still be a need to create compounded syrups of some ingredients.

14.6.2 Ambient carbonation

In a move to cut energy costs, the need to chill drinks before carbonation, to keep the gas in and prevent fobbing during filling, is under review. Designs are moving to ambient fillers to remove the refrigeration plant costs where the filler is being combined with the pack blowers.

14.6.3 Sterile dosing of flavours

Suppliers have been working to provide sterile product that can be 'plugged in' to proportioning and filling systems without increasing microbiological loading. This is of particular interest for flavoured water products in which the only ingredient is the flavour.

14.7 CONCLUSIONS

Flavoured and functional waters form a diverse group that ranges from the simplest formulations of water and flavouring through to very complex nutrient enriched products capable of supporting limited health claims. This often creates a challenge for the developer, but whatever the product type being considered, the following key points need always to be taken into account if a new and innovative product is planned:

- It is advisable to start out with a clearly written and agreed product brief. The brief should include target packaging, as this will influence the direction of the formulation work.
- Legal advice should be sought when considering putting specific health claims on a product. To justify making a claim requires a great deal of supporting material or accepted prior evidence.
- If unusual ingredients are to be used, checks should be carried out to ensure that they will not be subject to scrutiny under novel foods regulations, as this will delay and may even prevent launch.
- New, unusual and rare ingredients may prove difficult to obtain in suitable quantities and this should be considered when formulating new products.
- Checks on local ingredient and labelling regulations should be carried out for each market the product will be launched in. Even within economic zones, such as the EU, some local regulations can cause problems.
- Water is the major ingredient in the drink, and water quality and its specification should not be overlooked.
- Ingredient specifications and testing regimes need careful attention if future conflict with suppliers is to be avoided.
- Ingredient interactions are common and cause many product failures, so it is advisable to conduct testing ahead of launch for the most often seen problems.

Finally, microbiological control is of primary importance and suitable manufacturing processes must be used to prevent both illness and spoilage. This is also relevant when supplying development samples for public tasting.

15 Environment

Tod D. Christenson and John V. Stier

15.1 INTRODUCTION

The significant growth of the bottled water industry worldwide over the past decade has aroused passionate debate concerning the social value and environmental impacts of the production, distribution, and use of bottled water products.

Rising concerns of climate change, increased frequency of water scarcity events, water quality deterioration, natural resource use, hydrogeological impacts, and “plastics” waste, are all front-page environmental topics of concern for bottled water companies. Beverage companies as a whole, and most notably the world’s leading bottled water producers, are taking a pro-active approach in their pursuit of environmental stewardship. The world’s largest bottled water companies – The Coca-Cola Company, Danone, Nestlé Waters, and PepsiCo – are all driving broad agendas with positive impact on the environmental and social impacts of their businesses.

Despite this reality, the producers of bottled water products are receiving extraordinary attention as debate has blossomed over the societal value of bottled water (in lieu of available high quality tap water), local water resources ownership, and alleged depletion of this valuable natural resource. Critics of bottled water often espouse environmental negligence as a means to attack and defame the producers of bottled water. As many in the bottled water industry carry readily recognizable brand names, the environmental impacts and social value debate surrounding bottled water tend to be quickly picked up and polarized by the press and some of the more activist non-governmental organizations (NGOs) looking for attention to their agendas.

From an external perspective, the ability to assess and understand the true environmental implications of bottled water production and use (or that of any other industry sector) is a challenge as the availability of publicly available information and data are seriously lacking. Only recently have a number of leading bottled water companies begun to publish information and data related to their environmental stewardship performance and efforts. The information is generally available in the form of annual sustainability reports and select other market releases. In addition, some trade associations and NGOs are beginning to provide limited information.

This shortage of information may in part be due to the lack of recognized and established metrics, methods, and standards for environmental performance monitoring among

consumer product companies today. The Global Reporting Initiative (GRI) Sustainability Reporting Guidelines offer a framework for companies to follow in their environmental performance reporting; however, the current guidance falls short in providing sector-specific application of definitions or boundary setting guidance needed to assure consistency in measurement and reporting. As a result of this, existing published data should be viewed with some caution, as today's published data are characterized by the following concerns:

- Inconsistent and often differing metrics and quantification methodologies. To date, there are really no recognized beverage-specific standards for measurement that are detailed sufficiently to bring the necessary credibility to the beverage sector.
- Inconsistent application across the industry of existing environmental assessment methodologies (e.g. International Standards Organization, Greenhouse Gas Emission Protocols, etc.).
- Lack of basic, common Beverage Industry definition standards, such as core definitions for what constitutes use or consumption, operational, or boundary definitions (e.g. the scope of what is included or excluded in the measurement), and the factors used in estimating aspects of environmental performance that are difficult to measure directly. The result is an inability to truly compare “apples to apples”.
- Different business operating models (and level of vertical integration) for companies result in quantification that does not carry the same value chain footprint representation from one company to another. Thus, the ability to compare one company performance to another in absolute or normalized terms is difficult; useful industry benchmarks are also lacking.

Much work is needed in the development of industry standards and methodologies, particularly in light of the rapidly growing demand by public policy-makers, customers, consumers, and other stakeholders. The general lack of quality performance data hinders industry's efforts to mitigate the defaming attacks on bottled water producers by hostile third parties who, as a result, apply their own assumptions and generate their own numbers (and use them to create their desired negative perceptions of the industry) or misapply data that are available.

The authors of this text have attempted to organize the limited, available data and utilize, where possible, previously unreleased information and data to provide the reader the ability to baseline current performance on certain environmental aspects.

This chapter is intended to provide bottled water industry practitioners with a broad understanding of the “state of the industry” as it relates to environmental practice and performance. The intent is to build awareness and provide the reader with a current baseline for the rapidly evolving expectations and growing field of environmental performance assessment and reporting to the bottled water industry. We will briefly inspect the following topics:

- environmental standards of performance reporting;
- existing and emerging expectations for corporate environmental stewardship;
- value chain mapping;
- environmental life-cycle assessment (LCA) methodologies; and
- current best practices in managing environmental aspects of water, energy and climate change, and solid waste.

15.2 ENVIRONMENTAL STANDARDS

Emerging governmental policies and regulations from country-to-country around the world are quickly developing and shaping the face of environmental reporting. At the same time, another forum of “policy” development that needs to be considered is rapidly emerging. A number of non-governmental policy development initiatives are in themselves shaping environmental performance and reporting expectations through the development of guidance, protocols, frameworks, and standards development. As with governmental policy, these emerging “policy” formats (i.e. industry standards) are a very important consideration as companies look to deploy their environmental stewardship practices, measure, and report their achievements. These emerging industry standards are beginning to provide the basis for consistent definitions, means of measurement, and reporting.

Assembled in Table 15.1 is a listing of some of the most important existing and evolving global environmental standards applicable to the beverage industry. It is important to note that a large number of beverage companies are active stakeholders in the development process and many more are applying these standards in their practices. The need to work collectively with policy-makers and standards forming organizations is a critical step in the development of meaningful environmental management systems, practical measurement protocols, and informative reporting standards.

15.3 EXPECTATIONS FOR CORPORATE ENVIRONMENTAL STEWARDSHIP

Upon closer inspection of the various developing industry standards discussed in Section 15.2, a common theme is emerging as it relates to corporate environmental performance expectations. Companies are more and more being expected to embrace a larger role in the realm of environmental stewardship. These expectations extend well beyond environmental compliance and beyond the “four walls” of a company’s operations. In fact, in many parts of the world, environmental regulatory compliance is assumed and the basic systems to ensure environmental compliance constitute a minimum of performance. Today, leading companies are gaining a much fuller understanding of the environmental aspects that are under their direct control, integrating environmental performance into all of their business aspects, and delivering material progress in their efforts to mitigate the environmental risks to their operations. Many companies are seeing increased efficiency, reduced costs, innovation in processes/technology, and enhancements to their reputations, as a result of their stewardship efforts.

Environmental stewardship is now entering the realm of implied corporate responsibility or citizenship. It is reflected in changing consumer and customer behavior, policy development; and professional and public attitudes towards companies. Companies are now expected to be responsible stewards of the environment and to apply its resources to the benefit of society as a whole. In response to these expectations, a number of beverage companies such as Nestlé Waters and PepsiCo have established far-reaching business sustainability agendas that incorporate both social and environmental expectations. PepsiCo has created a strategy, “Performance with Purpose”, to address the emerging expectations. “Performance with Purpose” is designed to drive an agenda across three platforms (social and environmental) that include human sustainability, environmental sustainability, and

Table 15.1 Non-governmental environmental performance standards and development initiatives.

Subject matter	Non-governmental organization lead	Description of scope
Social and Environmental Reporting	Global Reporting Initiative (GRI) www.globalreporting.org	The GRI Sustainability Reporting Guidelines are intended to serve as a generally accepted framework for reporting on an organization's economic, environmental, and social performance. The guidance contains general and sector-specific content that has been agreed by a wide range of stakeholders around the world to be generally applicable for reporting an organization's sustainability performance. Sector-specific supplemental guidance material is currently under development for the various industrial sectors.
Climate	UN Caring for Climate Initiative http://www.unglobalcompact.org/Issues/Environment/Climate_Change/	Caring for Climate is a voluntary and complementary action platform for UN Global Compact participants who seek to demonstrate leadership on the issue of climate change. It provides a framework for business leaders to advance practical solutions and help shape public policy as well as public attitudes. Chief executive officers who support the statement are prepared to set goals, develop and expand strategies and practices, and to publicly disclose emissions as part of their existing disclosure commitment within the UN Global Compact framework, that is, the Communication on Progress.
Greenhouse Gas (GHG) Emissions Inventory and Reporting	World Resource Institute (WRI) www.wri.org World Business Council for Sustainable Development (WBCSD) www.wbcsd.org	The Greenhouse Gas Protocol , a decade-long partnership between the World Resources Institute and the World Business Council for Sustainable Development, is working with businesses, governments, and environmental groups around the world to build a new generation of credible and effective programs for tackling climate change. The GHG Protocol is the most widely used international accounting tool for government and business leaders to understand, quantify, and manage greenhouse gas emissions. It provides the accounting framework for nearly every GHG standard and program in the world – from the International Standards Organization to The Climate Registry – as well as hundreds of GHG inventories prepared by individual companies.
GHG Product Life-Cycle Assessment Protocol	British Standards Institute (BSI) www.bsigroup.com	PAS 2050 was prepared by BSI to specify requirements for assessing the life-cycle greenhouse gas emissions (GHG) of goods and services. It was developed in response to broad community and industry desire for a consistent method for assessing the life-cycle GHG emissions of goods and services. Life-cycle GHG emissions are the emissions that are released as part of the processes of creating, modifying, transporting, storing, using, providing, recycling, or disposing of goods and services. The development of PAS 2050 was co-sponsored by the Carbon Trust and the Department for Environment, Food and Rural Affairs (DEFRA).

Beverage Industry Sector-Specific GHG Enterprise and Product Life-Cycle Reporting Guidance	Beverage Industry Roundtable (BIER) http://www.bierountable.com	BIER has published Beverage Industry Sector Guidance for Greenhouse Gas Inventory Reporting (January 2010), a sector-specific guidance that applies to the development of an enterprise- or product-level carbon inventory. Building off existing industry protocols, namely The GHG Protocol and PAS 2050, this guidance represents the first sector guidance to tackle industry-specific nuances to greenhouse gas inventory efforts across the complete value chain. The guidance has been endorsed by more than 12 global beverage companies from across the various beverage sectors, including, non-alcoholic beverages and select producers of bottled water, brewers and distillers.
Water Stewardship	United Nations Global Compact CEO Water Mandate www.unglobalcompact.org Government of Sweden, Ministry for Foreign Affairs www.regeringen.se/sb/d/2059	The CEO Water Mandate grew out of a collaborative partnership between the United Nations Global Compact, the Government of Sweden, and a group of committed companies and specialized organizations dealing with the problems of water scarcity and sanitation. It is designed as a private-public initiative with a focus on developing strategies and solutions to contribute positively to the emerging global water crisis. Its structure is designed to assist companies in developing a comprehensive approach to water management and covers six key areas: direct operations, supply chain and watershed management, collective action, public policy, community engagement, and transparency.
Water Footprinting Methodology	Water Footprint Network (WFN) www.waterfootprint.org	The mission of the Water Footprint Network is to promote the transition towards sustainable, fair and efficient use of freshwater resources worldwide by: (i) advancing the concept of the ‘water footprint’, a spatially and temporally explicit indicator of direct and indirect water use of consumers and producers; (ii) increasing the water footprint awareness of communities, government bodies, and businesses and their understanding of how consumption of goods and services and production chains relate to water use and impacts on fresh-water systems; and (iii) encouraging forms of water governance that reduce the negative ecological and social impacts of the water footprints of communities, countries and businesses.
Water Footprinting Methodology	Beverage industry Roundtable (BIER) http://www.bierountable.com	BIER has an established water footprinting working group to develop and publish specific water footprinting guidelines for the beverage sector (targeted for fall 2010). These guidelines will take into consideration the multiple global efforts underway and be consistent and complementary where possible. The largest usage of water in the beverage sector is embedded in the production of raw materials, i.e. food crops, fibers, and metals. For many beverage companies, raw material production lies far upstream from direct operations, and as a result they may not have access to accurate and reliable water usage data and the impact of that usage on the local ecosystem. The BIER working group is addressing these data and impact gaps and is establishing guidelines representing the best knowledge of the global beverage sector.

Table 15.1 (cont'd)

Subject matter	Non-governmental organization lead	Description of scope
International Environmental Management Standards	International Organization for Standardization (ISO) www.iso.org	ISO has promulgated various standards in the field of environmental management systems and tools in support of sustainable development, including: • ISO Guide 64: Guide for addressing environmental issues in product standards • ISO 14001: Environmental management systems, requirements with guidance for use, general guidelines on principles, systems, and support techniques • ISO 14015: Environmental management, environmental assessment of sites and organizations (EASO) • ISO 14020–1425: Environmental labels and declarations (general principles), self-declared environmental claims (Type II environmental labeling), Type I environmental labeling, Type III environmental declarations • ISO 14031: Environmental management, environmental performance evaluation, guidelines • ISO 14040 series: Environmental management life-cycle assessment, principles and framework, requirements and guidelines, data documentation format, examples of application • ISO 14050: Environmental management, vocabulary • ISO/TR 14062: Environmental management, integrating environmental aspects into product design and development • ISO 14063: Environmental management, environmental communication, guidelines, and examples • ISO 14064: Greenhouse gases, specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals, specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements, specification with guidance for the validation and verification of greenhouse gas assertions • ISO 14065: Greenhouse gases, requirements for greenhouse gas validation and verification bodies for use in accreditation or other forms of recognition
Environmental Performance	European Union (EU) http://ec.europa.eu	The EU Eco-management and Audit Scheme (EMAS) is the EU's voluntary program designed for companies and other organizations committing themselves to evaluate, manage and improve their environmental performance. EMAS offers a systematic approach, and adds four pillars to the requirements of the international standard for environmental management systems (ISO 14001): (i) continual improvement of environmental performance; (ii) compliance with environmental legislation ensured by government supervision; (iii) public information through annual reporting; and (iv) employee involvement. EMAS is designed to help organizations improve their environmental performance and in turn, help them improve their competitiveness (e.g. through better use of resources.)

talent sustainability. Nestlé Waters, the largest water bottler in the world, has also created a strategy called “Creating Shared Value” that has established pillars of performance focusing on nutrition, water, and rural development.

It is expected that companies take accountability for environmental performance and consequences throughout their value chain. For instance, bottled water companies, other beverage companies, and consumer products companies are more and more being held accountable for the end-of-life disposition of product packaging (e.g. plastic bottles) and products themselves (e.g. electronics). As in the case of beverage companies, the general public (rightly or wrongly) feels the producer is responsible for plastic bottle litter and for the landfill space (and non-degradability) consumed by plastic bottles. At the same time, the consumer is also looking for easy and efficient ways to recycle in order to eliminate unwanted waste and litter.

Although these emerging expectations today fall mainly into the category of a voluntary initiative, leading companies are realizing that to drive long-term business vitality and prosperity, and to avoid public backlash or unforeseen operating costs, they need to understand the nexus between their business activities (including that of their complete value chain), the environment, and society. The challenge is to identify the environmental aspects that are germane to the company and assess vulnerabilities and opportunities. Direct control operations are the natural starting point for driving environmental benefit and efficiency, since these are under a company’s direct control. However, looking beyond direct operations to supply chain partners and their behaviors is important to mitigating a broader range of emerging business environmental risks and seizing long-term business opportunities. Understanding and acting on the scope of environmental business risk through the complete value chain is fast becoming a business imperative. According to “Supply Chain Report 2010” from the Carbon Disclosure Project (CDP), more than one-half (56%) of CDP members surveyed said that in the future they would cease doing business with suppliers who do not manage their carbon.

Growing customer expectations (especially from major retailers and supermarkets, i.e. Wal-Mart, Tesco, etc.), competitive pressures, and shareholder and other third-party stakeholder expectations are also growing quickly. Emerging customer action includes detailed environmental information requests, extending clear expectations for transparency, and demonstration of improvement in environmental performance. It is possible to envision product retail discrimination in the future as the large-box retailers work to position themselves as environmental stewards, in part by influencing the behavior of their suppliers. This process is quickly pushing down to the supply chain. An example of this trend is the recent “sustainable product index” initiative launched in the USA in 2009 by Wal-Mart Stores, Inc. Using an index based on 15 leading questions about its suppliers’ environmental stewardship practices and performances in the areas of Energy and Climate Change, Material Efficiency, Natural Resources, and People and Community. Wal-Mart is proving to be a driver for environmental value chain stewardship. Some suggest this index will soon expand to include health and social dimensions.

Another way to articulate the emerging expectations as they relate to environmental stewardship is embodied by the global CEO Water Mandate, a global framework of corporate commitments and expectations that extend beyond traditional business boundaries. Although this framework is specific to driving water sustainability, this industry and NGO-developed framework can be viewed more broadly as representing the emerging expectation across the complete spectrum of corporate environmental stewardship. The Mandate has its Climate analog, the United Nations (UN) Caring for Climate initiative. Both are under the

auspices of the UN Global Compact and provide a framework that conveys basic expectations for environmental engagement and performance. The beverage industry, including the top 4 bottled water producing companies, are among the 11 beverage companies that are signatories to the CEO Water Mandate (out of a total 60).

Best practice today for environmental stewardship is defined by those companies that pursue agendas that yield a “shared value,” meaning that they yield tangible business value and also contribute societal (including social and environmental) benefit (Porter & Framer 2006). The tangible business benefits that are driving the pursuit of “shared value” and responsible behavior include such items as:

- mitigation of environmental business or legal risks along the value chain;
- reduction of direct operating costs and total cost of ownership (TCO);
- natural resource use efficiency;
- shift to using more sustainable resources;
- enhanced reputation (brand);
- resource sustainability;
- customer/consumer loyalty; and
- favorable community standing.

Societal benefits that result from the assumption of corporate responsibility and environmental stewardship include a number of benefits, namely:

- improved health and life-style of our communities;
- eco-system preservation and expansion;
- environmental impacts mitigation and restoration;
- natural resource conservation and protection; and
- social prosperity and economic development.

The emerging corporate environmental stewardship expectations build on the concept of shared value (economic, social, and environmental), and can be seen to be inclusive of company efforts related to seven categories of engagement:

- (i) *Direct operations*: Involves taking responsibility for all aspects of the business and associated environmental impacts that are under direct control. It relates to environmental protection, restoration, conservation, and resource use efficiency efforts within the four walls of manufacturing. Also included in this category is the development of awareness and appreciation for the environment across the employee base.
- (ii) *Eco-system*: This aspect requires an understanding of operational sensitivities and impacts on the local eco-system and environment in and across the value chain. This includes understanding the environmental impacts. For example, consumption and use of natural resources (e.g. water consumption and use in the context of the local watershed), and discharges (air, water and waste) in the context of environmental capacity (including municipal infrastructure) at each point along the value chain.
- (iii) *Supply chain*: The supply chain aspect speaks to taking proactive steps to drive environmental stewardship performance across the complete supplier base. For instance, understanding of the sources of ingredients and the direct and indirect impacts to environment of the related sources (natural availability, sustainability, and supplier performance) and working with suppliers to mitigate their operational

- impacts. In addition, understanding product use and end-of-life aspects (i.e. packaging disposal) is an increasing expectation of external stakeholders.
- (iv) *Community*: A company's participation in "local" community efforts to build awareness and advance environmental stewardship and behavior across the communities in which they operate. Interestingly enough, community engagement often yields an added benefit of improved employee morale and satisfaction through engagement and volunteerism.
 - (v) *Collective action*: Relates to the application of technical expertise, financial or human resources collectively with others to enhance environmental stewardship. The actions typically take the form of partnerships (global, regional, and local) that are externally managed and focus on specific environmental issues or challenges.
 - (vi) *Public policy*: Public policy relates to company actions that are focused on the development of effective global, regional, and local environmental governance structures with the right incentives for environmental protection, natural resource use, efficiency, and allocation. Environmental stewardship is fast rising to the top of the international policy agenda as governments, multilateral organizations, and other stakeholders (including civil society) debate the challenges. Businesses and industries have an opportunity to help shape this agenda and in fact are increasingly expected to participate as a part of their social responsibility.
 - (vii) *Transparency*: This is at the heart of accountability and relates to the reporting (internal and external) on environmental performance. Reporting requires a sound description of the business objectives, actions, and achievements, as well as a commitment to be open and honest in dealings with government and the public on environmental issues. Traditionally, transparent communication consisted of reporting anecdotal performance. This has transitioned to an increasing need for robust and quantitative reporting of metrics.

Companies positioned to anticipate, mitigate, and adapt their businesses to the various aspects of environmental stewardship will be best positioned to continue to hold a "social licence to operate" and prosper. The performance expectations presented above should serve as a guiding framework as a company sets its long-term environmental sustainability strategy and action plans.

15.4 BOTTLED WATER VALUE CHAIN

An important initial exercise to help begin to identify environmental-related business vulnerabilities and direct the focus of stewardship efforts involves the mapping of the company value chain. This exercise serves as a critical baseline activity useful in understanding the full scope of environmental impacts and sustainability-related business risks, both direct and indirect, along the complete business or product value chain.

In order to assist environmental and sustainability practitioners in their assessment and management of environmental risks, we will briefly introduce the basic elements of the value chain as they apply to the bottled water industry (both natural and "other" waters), discuss general value chain process mapping, and discuss the benefits and application of this exercise.

Figure 15.1 generically introduces the value chain elements and individual considerations for each element, beginning with the sourcing of materials and inputs, through to the

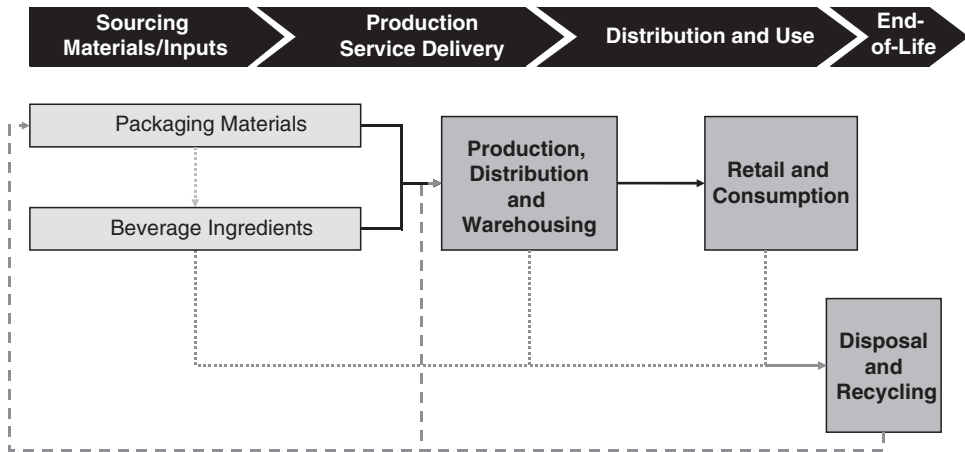


Fig. 15.1 Beverage product value chain elements.

end-of-life element of the product value chain. The primary considerations along the value chain include:

- packaging materials;
- beverage ingredients and the raw materials used to produce these ingredients;
- production, distribution, and warehousing processes;
- retail distribution and consumer consumption;
- end-of-life disposal and recycling; and
- all the embedded travel systems between each element component.

Further breakdown of the packaging and beverage ingredient components are illustrated in Fig. 15.2 and Fig. 15.3. What is important in these more detailed presentations is the accounting for all sourcing materials or inputs from virgin material through input processing to the production facility.

The general exercise of value chain mapping supports a number of business sustainability analyses. From an environmental perspective, value chain mapping can be used in establishing a baseline framework for subsequent data collection and vulnerability analysis for such aspects as:

- materials availability and sourcing reliability;
- water use, consumption, and waste water discharge;
- energy consumption and carbon impacts; and
- product/non-product waste generation and final disposition.

The process of value chain mapping can be applied to the business overall, or to specific products. Once the value chain has been mapped and material and service suppliers have been identified at each node, companies will begin to collect primary (direct measurement at the source) or utilize secondary data sources (and thus make reliable estimates) to quantify the material or consumptive aspects of interest (inputs and outputs) at each phase along the value chain. Data are usually tied to an individual, specific supplier and corresponds to

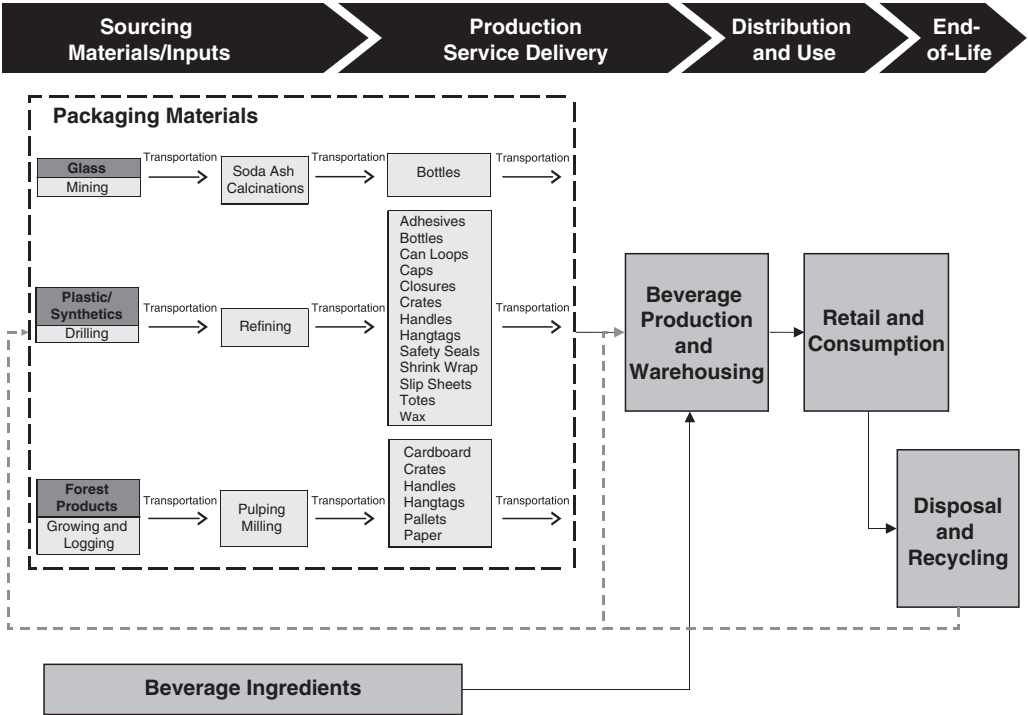


Fig. 15.2 Packaging value chain considerations.

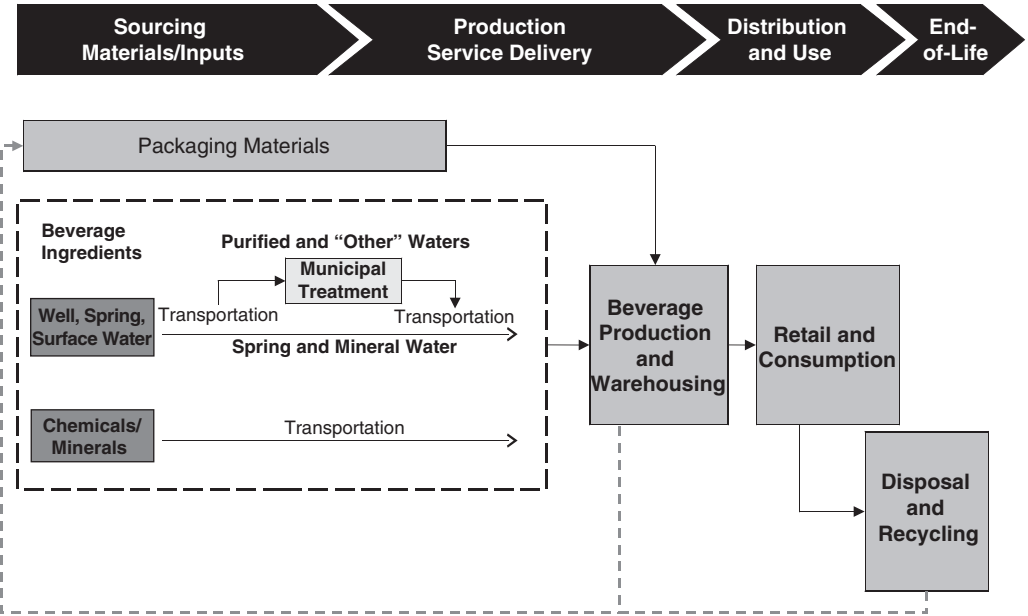


Fig. 15.3 Ingredient value chain considerations.

the company weighted share or proportional quantity consumed or procured. To conduct this baseline inventory, most often companies will use Excel workbooks to support data collection, calculation, and aggregation.

What is the value of performing this exercise from an environmental sustainability perspective? The primary objectives are to obtain a holistic perspective on a wide range of current and potential future environmental-related business risks and vulnerabilities. Value chain mapping provides a methodical and fact-based means to expand understanding of business vulnerabilities (short-, mid-, and long-term). The results provide direct input to help set priorities and guide company environmental stewardship agendas. This self-learning exercise aids in directing limited company resources to those value chain elements or environmental aspects that are the most impactful. The knowledge gained, if acted upon, can lead to direct operating cost reductions (i.e. efficiency), reduced total cost of ownership, financial and legal risk avoidance, reputational or brand damage avoidance (and thus consumer or customer loyalty), and innovation.

15.5 LIFE-CYCLE ASSESSMENT METHODOLOGIES

The process of value chain mapping is an excellent exercise and a first step in evaluating the environmental aspects of bottled water production, usage, and disposal. One of the most common, and detailed, analytical approaches to assess the varied environmental impacts across a product's life-cycle is a life-cycle assessment (LCA) or life-cycle impact assessment. Conducting an LCA allows for a deeper analysis of product sustainability improvement opportunities, assessing cause and effect of potential product and packaging design alternatives, quantifying specific environmental aspects impacts across the value chain, and assessing supply chain change impacts. In addition, LCA results can be valuable to facilitating communication and building awareness. An LCA utilizes the value chain mapping work process discussed previously and represents a specific analytical activity that can be applied to specific product categories or individual products.

Figures 15.4 and 15.5 illustrate samples of output from an LCA study performed on an unnamed (anonymous) bottled water product. Our purpose here is purely illustrative in nature, showing how an LCA can contribute to the understanding of environmental impact categories' significance across various life-cycle phases (Fig. 15.4). Figure 15.5 illustrates for a single environmental aspect (in this case CO₂) the impact along the value chain phase. Similar outputs can be generated for the variety of environmental impact categories.

A number of software tools have been developed and marketed to support execution of LCAs. The products typically vary in terms of ease of use, robustness of analysis, environmental aspects categories included, and function and quality of outputs. All require some baseline materials information and assumptions on use and various life-cycle phase parameters.

The International Organization for Standardization (ISO) has published principles and frameworks for conducting LCAs under ISO 14040. The basic elements in conducting an LCA can be summarized as follows:

- *Goal and Scope:* The goal should be to state the intended application, the reasons for the study, the intended audience and whether the study will be used for comparative purposes. The scope should consider the functional units to be evaluated, the boundaries of the value chain included, the data requirements, and any assumptions made.

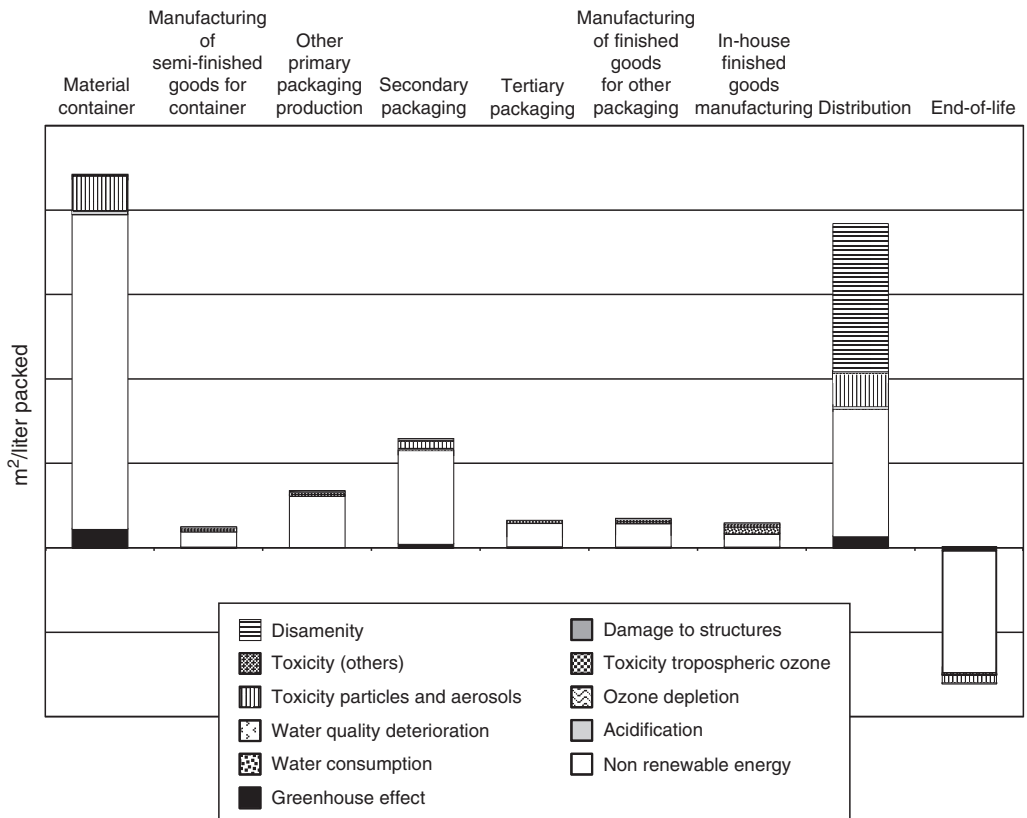


Fig. 15.4 Contribution of the impact categories to the total weighted impacts of each phase.

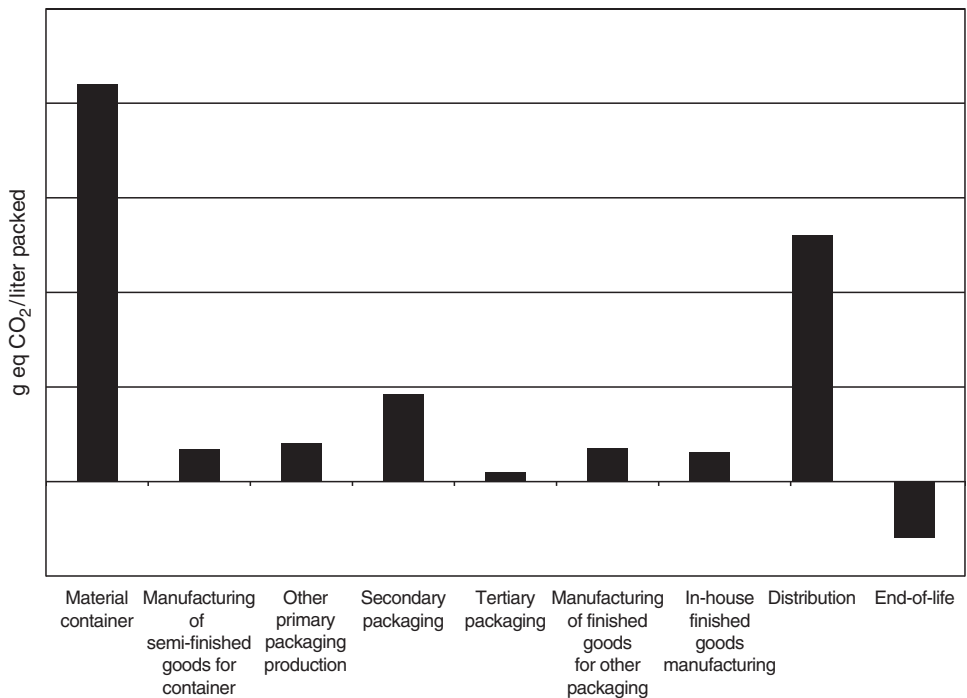


Fig. 15.5 Greenhouse gases effect.

- *Life-Cycle Inventory (LCI) Phase:* Qualitative and quantitative data will be collected for each process that is identified in the scope boundary. For example, data could be collected for the releases to air, water, and soil for the process of transporting primary packaging materials from the supplier to the bottled water production site. All calculations and assumptions should be clearly stated and outlined.
- *Life-Cycle Impact Assessment:* This phase should include the selection of impact categories and indicators, the assignment of LCI results to the impact categories, and the calculation of category indicator results.

It is completely up to the user to follow the ISO standard or to deviate from it. However, deviations will cast doubt on any claim of following international standards and may make it more difficult to convince others of the validity of the results.

Limited studies conducted to date have attempted to compare the environmental impact of bottled water vs. tap water as a result of production, packaging, and transportation. One study performed by Jungbluth and Faist (2005) used a life-cycle analysis to compare the environmental impacts of tap water with that of various bottled waters. The life-cycle inventory included water extraction, treatment, packaging, distribution, transportation to the end consumer, and treatment by the consumer. It did not include the drinking receptacle or disposal of waste water. The analysis comparing consuming water from a tap to unrefrigerated bottled water consumption shows an environmental impact of tap water that is less than 1% than that of bottled water. However, the study further concluded that reducing one's consumption of bottled water provides a relatively small contribution to lessening one's environmental impact, as the consumption of water accounts for only a small portion of overall environmental impact.

15.6 PRIMARY ENVIRONMENTAL ISSUES

The environmental aspects currently dominating the discussions surrounding the production of bottled water are water usage, climate change and energy, and solid waste management. Each of these aspects can be mapped along the value chain to determine the largest areas of relative significance.

Although publicly available and consistently presented environmental performance data related to the production of bottled water are in short supply, there are a few performance aspects that can be discussed.

The availability of data and understanding of solid waste management related to the bottled water industry is fairly well developed through the publication of solid waste generation, disposal practice, and plastics/glass recycling data.

Only recently are industry energy and carbon footprint data beginning to become available through the publication of sustainability reports by reputable companies, including, Nestlé Waters North America, FIJI Water and NIKA Water. In addition, an article published in the February 2009 journal *Environmental Research Letters* presents the results of the Pacific Institute's work on estimating the energy footprint for bottled water (Gleick & Cooley 2009). This work is further discussed in Section 15.9.

Subsequently, we intend to frame the issues related to each of these environmental aspects, share quantitative data where available, and to discuss current best practices being applied by industry leaders to mitigate or address these environmental aspects.

15.7 WATER RESOURCES

The extraction and usage of water in the production process is a key environmental impact category, and obviously the source of and reliability of water for consumption is also a critical process parameter. In this section, current data on water use in the production facility and conservation best practices will be discussed, followed by a discussion on water risk assessments, and finally the emergence of water footprinting methods and practices.

15.7.1 Water use and conservation practices

The use of water in the bottled water industry starts with a thorough hydrogeological investigation focused on finding and defining safe aquifer yields. Once extraction and production begins, water is used at various points within the production facility, and here most values quoted for water usage are presented in liters of water used per liter of product packaged. Theoretically, it might be assumed that slightly more than one liter of water would be needed for every liter packaged. Additional water is used within the production facility to produce the final packaged product, and the ratio between the two is often used as a measure of production efficiency or waste. For example, one facility operating at a ratio of 3 to 1 is not considered as water efficient as a facility that is operating at a ratio of 2 to 1.

Table 15.2 and Fig. 15.6 illustrate 2006–2008 data from a Beverage Industry Environmental Roundtable (BIER) benchmarking study, representing the amount of water usage per liter of finished product for bottled water. For the purposes of the study, the bottled water category includes all bottled waters including spring water, water (produced by distillation, deionization, reverse osmosis, or other processes), mineral water, or sparkling bottled water.

Across all types of bottled water facilities worldwide (130 in total for 2008), the weighted average water use ratio was 1.66 (standard deviation of .91). The range varied from 1.09–3.0. The scatter in water use performance is most pronounced at smaller production volume facilities (<200 000 kL annual production). Water use efficiency does improve as facilities' annual production levels increase. This is due in part to greater efficiencies in process (typically emanating from larger production runs, fewer cleaning cycles due to product changeovers, more efficient treatment, greater level of automation, etc.) and less weight on the ratio from fixed water use aspects (i.e. cleaning and sanitary uses, landscaping, etc.).

Although the data suggest that bottled water facilities are variable from year-to-year in their efficiency, this trend is largely due to the change in mix of actual facilities reporting into each of the annual datasets. This mixed performance is due to the dynamic data set. In the BIER benchmarking study, there were 83 facilities ($n = 83$) reporting data for each of the 3 study years; these 83 facilities' volume-weighted average water use ratio reduced 5% (from 1.67–1.59) from 2006 through 2008.

Lastly, it should be noted that facilities with the lowest water use ratios in the water category tend to be represented by facilities producing spring or mineral waters almost exclusively. With these types of bottled water, the process steps from extraction to filling of containers is much more simplified, with fewer process steps.

As a point of relative reference for the bottled water beverage category to other beverage types, we offer the following reported water use ratios for other companies producing predominantly other beverage types. The data in Table 15.3 were taken from beverage company sustainability reports. It is clear that the production of different beverages require

Table 15.2 BIER benchmarking study 2008 – water use efficiency ratio (WUR).

Annual production	2006		2007		2008	
	n	WUR	n	WUR	n	WUR
<50 000 kL	40	2.41	44	2.71	42	2.25
50 000 – 200 000 kL	54	2.11	53	2.05	51	1.85
200 000 – 500 000 kL	15	1.61	22	1.64	24	1.69
>500 000 kL	9	1.48	10	1.55	13	1.48
All Facilities	118	1.75	129	1.76	130	1.66

n = number of facilities, WUR = Water Use Ratio.

(Data courtesy of Beverage Industry Environmental Roundtable.)

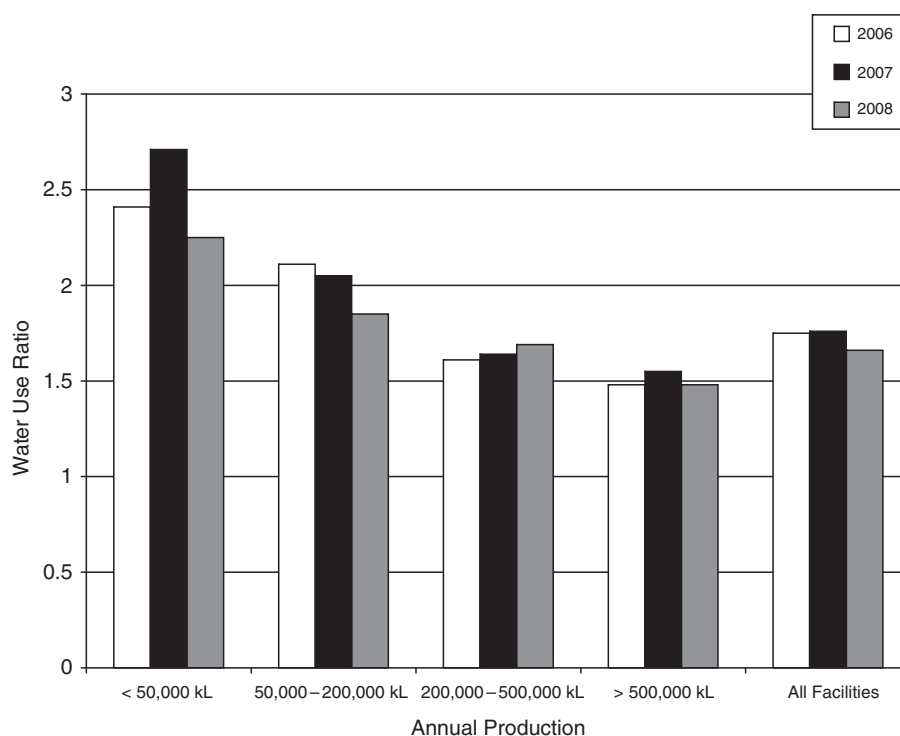


Fig. 15.6 BIER Benchmarking Study 2008 – Water Use Efficiency Ratio (WUR). (Data courtesy of Beverage Industry Environmental Roundtable.)

varying levels of water use. The principal factor that drives water use for beverage type is the production process itself, which is uniquely characteristic for the various beverage types. For example, in brewing we have the water intensive fermentation stage, distillation processes in the distilled spirits sector, etc. In addition, many other factors can affect water use efficiency performance for a given company or facility. Some of the additional factors affecting water use may be related to company culture and employee behavior, age of

Table 15.3 Sample of publicly reported water use ratios for select beverages.

Beverage category	Company	Reported water use ratio (liters/liters)*
Alcoholic beverages	Diageo	7.2
	Foster's	2.91 (beer)
	Heineken	5.1
	SABMiller	4.5
Non-alcoholic beverages	The Coca-Cola Company	2.43
	Coca-Cola Enterprises	1.73

* Data as reported in most recent corporate sustainability reports. Absolute comparison is not recommended due to variances in scope and breadth of quantification boundaries applied by each company in their reporting. In addition, these companies produce a variety of beverage types within their specified category so that a company's water use ratio represents a weighted average value across their complete beverage product production.

equipment in place, use of recycled containers, the level of process optimization, and water re-use/recycling applications within facilities.

The water professional should be familiar with these ratios and recognize that it typically represents the water usage within the manufacturing facility unless specifically stated. It normally will not include all water used across the value chain, for example, embedded water used in packaging materials production.

Water conservation efforts have focused on a number of processes, including cleaning, cooling, and packaging efficiency. These efforts have not only resulted in substantial improvements in water savings, but have also reduced operating costs.

The pursuit of water use reduction efforts and efficiency enhancements typically follow a hierarchy that involves focusing on minimizing water *use*, *re-use* of water in the same manufacturing process, and *recycling* of water for use in other manufacturing processes. Following this hierarchy generally implies no or low cost efforts as a first priority (use), moderate capital intensive efforts (re-use), and finally higher capital and infrastructure intensive opportunities characteristic of recycling opportunities.

Minimizing overall use typically involves identifying opportunities to eliminate water use applications entirely (e.g. changing over to "dry-lube" types of conveyor lubricant), maintaining good housekeeping (e.g. fixing leaks and optimizing applications that involve water), and minimizing water use (e.g. changing facility landscaping needs or modifying clean-in-place processes). Re-use, by definition, involves the treatment and re-use of waste waters from a specific application back into the same application (e.g. final rinse "clean-in-place" water, used for the "first rinse" cycle).

A number of opportunities exist within the water treatment, utilities, and packaging areas of a bottling plant to re-use water. To identify these opportunities, it is helpful to conduct a detailed water mass-balance, identifying specifically where water is used and where waste water streams are generated. Subsequently, waste water streams can then be quality characterized with re-use or recycling applications identified. Recycling by definition implies waste water streams are treated and used in different applications. Currently, companies are looking for opportunities to apply various recycling streams to cooling applications, gray water applications where less rigorous treatment requirements may facilitate recycled water use to such applications as non-product contact cleaning uses (e.g. floors, vehicles, toilets, etc.), landscaping, and off-site uses such as nearby agricultural use.

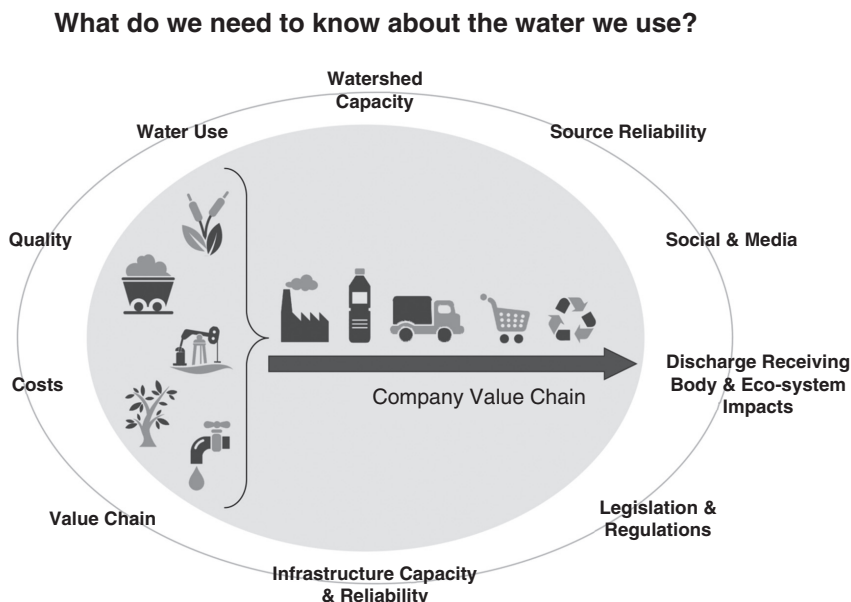


Fig. 15.7 Water-related business risks.

15.7.2 Water-related business risks

In order to accurately assess business water risks and opportunities across the complete value chain, a comprehensive water accounting of direct and indirect water use and wastewater discharge can be conducted. This water use analysis can then be overlain against a number of potential environmental risk drivers. The points of business intersection can be identified, evaluated, and prioritized for attention. Figure 15.7 illustrates a few of the drivers that should be considered when conducting an assessment of water-related business risk.

15.7.3 Water footprinting

The concept of a “water footprint” has been introduced to address both the quantity and impacts of water usage (and discharge) for many consumer products. The water footprint concept is in the development stage at the time of this writing, but is quickly gathering momentum as a standard for reporting and measuring water usage. A number of organizations are working on the development of water footprint methodologies, most notably the Water Footprinting Network (WFN), the Beverage Industry Environmental Roundtable (BIER), and the International Organization for Standardization (ISO). Table 15.1 should be referenced for further discussions on these initiatives.

In addition to understanding the “water foot size” (i.e. the amount of water used across the various value chain aspects), are the potential spatial and temporal impacts of the various uses and discharges. It is this combined analysis of water quantity and local impacts that constitutes the determination of a company or product “water footprint.”

One basis for water footprint reporting has been introduced by A.Y. Hoekstra at the UNESCO-IHE Institute for Water Education and further developed at the University of Twente in the Netherlands (Hoekstra 2009). A water footprint is more than a calculation of the total water volume used; it looks specifically to the type of water use and where and

when the water was used. Water usage is measured in terms of water volumes consumed (evaporated) and the amount of water polluted (made unusable without further treatment). One suggested methodology is to view water usage in three components: (i) consumptive use of rainwater (green water); (ii) consumptive use of water withdrawn from groundwater or surface water (blue water); and (iii) pollution of water (gray water).

The first question is which inputs should be included and which inputs can be excluded when conducting a water footprint. Should the indirect water use of common office materials like pens and paper be included? The general answer would be to include every individual input to the business that in itself is expected to contribute at least 1% or some other defined percentage to the total supply-chain water footprint. But in practice, it would be most helpful if for various sorts of businesses, guidelines were available that tell what should be included and what can be excluded. Obviously the aim should be to include the items that are most significant in their contribution to the overall supply-chain water footprint. These results are often expressed in terms of water usage per liter or kilogram of product.

An excellent case example for a water footprinting study was published by the brewer SABMiller in 2009. SABMiller provided a water footprint analysis for two of its beer products: Castle Lager, South Africa's iconic brand, and Pilsner Urquell, a Czech Republic beer that is distributed worldwide. What makes this publication uniquely valuable is that not only did SABMiller provide a prototype for current water footprinting methods of calculation (i.e. Hoeksstra 2006) and the calculated results, but also provided a useful demonstration of how such an analysis can be applied to the development of a meaningful water stewardship strategy and action plan. The business implications due to each product's unique "water footprint" offer significant insights into where SABMiller may most effectively mitigate business risk and drive stewardship efforts related to two of its beverage products.

The results for two SABMiller beer products varied remarkably, with water footprints of 155 l/l and 45 l/l for the Castle Lager and Pilsner Urquell, respectively. The study indicated the primary driving force for the variance between the two footprints lies in the differences related to ingredient crop production conditions. Roughly 98% (98.3%) of the Castle Lager water footprint is related to crop growth in South Africa, where evaporation is higher and reliance on crop irrigation predominates (SABMiller and WWF-UK 2009).

In summary, to evaluate and effectively address business water risks, companies should take the following actions:

- Measure the company's water footprint throughout its value chain, including suppliers and product use.
- Assess the physical, regulatory, and reputational risks associated with the water footprint.
- Integrate water issues into a strategic business plan and governance structure.
- Engage key stakeholders (e.g. local communities, non-governmental organizations, government bodies, suppliers, and employees) as a part of water risk assessment, long-term planning, and implementation activities, and
- Openly disclose and communicate water performance and associated risks.

15.8 CLIMATE CHANGE AND ENERGY

The consumption of energy represents a significant operating issue given the volatility in energy prices over the past few years. With the emergence of serious concern over the issue of climate change, energy (and related carbon emission impacts) has become one of the top

environmental issues facing manufacturing today. Beyond the direct cost implications associated with energy consumption, climate concerns are quickly driving energy and carbon legislation. For example, the CRC Energy Efficiency Scheme (formerly known as the Carbon Reduction Commitment) is the UK's mandatory climate change and energy saving scheme. The CRC basically legislates the largest energy consumers to quantify, report, and reduce energy consumption. Economic incentives and penalties, combined with annual reduction of available carbon emission credits, are all intended to drive desired results. In many parts of the world, such legislative or regulatory pressure is expected to continue to grow, as more and more countries elect to participate in mitigating the global impacts on climate change.

Understanding the energy (and carbon) footprint along the value chain, optimizing energy efficiency, understanding alternative energy choices, and the related business risks embedded within the supply chain have all become top priorities.

15.8.1 The energy and carbon footprint of bottled water

Recent work by Gleick and Cooley with the Pacific Institute offers the first published analysis of the energy footprint for bottled water from production through use (Gleick & Cooley 2009). Gleick and Cooley evaluated the energy inputs related to the most predominant bottled water serving format, the single-serve plastic bottle. In addition, they evaluated the energy inputs under three scenarios:

- (i) bottled water produced and used in Los Angeles;
- (ii) water bottled in the South Pacific and shipped by cargo ship to Los Angeles; and
- (iii) water bottled in France and shipped in various ways to Los Angeles.

The study results can be generally applied to understanding the dominant energy footprint aspects associated with purified or locally produced bottled water and consumed spring waters (Scenario 1) and the more uniquely, locally produced natural mineral and spring waters distributed globally or on a large geographic scale.

The total energy required for bottled water, as estimated by Gleick and Cooley, will typically range from 5.6–10.2 MJ l⁻¹. Their analysis indicates that the largest drivers for bottled water energy footprint include the manufacturing of the plastic bottle and transportation, the latter emerging as the largest aspect for those bottled water products distributed large distances from where they are produced. The production of the water, bottling, secondary packaging materials, and refrigeration aspects represent a much smaller contribution to the overall energy footprint. Table 15.4 illustrates in more detail the footprint elements as measured by Gleick and Cooley.

Information made available recently by several water bottlers illustrates a similar footprint pattern, when Nestlé Waters North America, FIJI Water, and NIKA Water published carbon footprint emissions information related to the production of their bottled water products. Although each of these individual company presentations vary in the aspects of the complete value chain assessed and the depth of results published, they do offer valuable insight to the energy and carbon footprint driving aspects.

Figure 15.8, taken from Nestlé Waters North America's 2008 corporate citizenship report, shows that the footprint aspects relate to production of the plastic (PET) bottle, followed by transportation associated with product distribution and electricity consumed within the bottling facility.

Table 15.4 Total energy requirements for producing bottled water.

	Energy intensity ($\text{MJ}_{\text{th}} \text{ l}^{-1}$)
Manufacture plastic bottle	4.0
Treatment at bottling plant	0.0001–0.02
Fill, label, and seal bottle	0.01
Transportation: range from three scenarios	1.4–5.8
Cooling	0.2–0.4
Total	5.6–10.2

(Note: we assume here an average ratio of three kWh (thermal) per kWh (electrical) and 3.6 MJ kWh⁻¹.) (Reproduced with permission from Gleick and Cooley; published by Environmental Research Letters.)

2006 Greenhouse Gas Emissions by Activity Over Product Lifecycle

Based on total emissions of 1,696,000 metric tons CO₂e

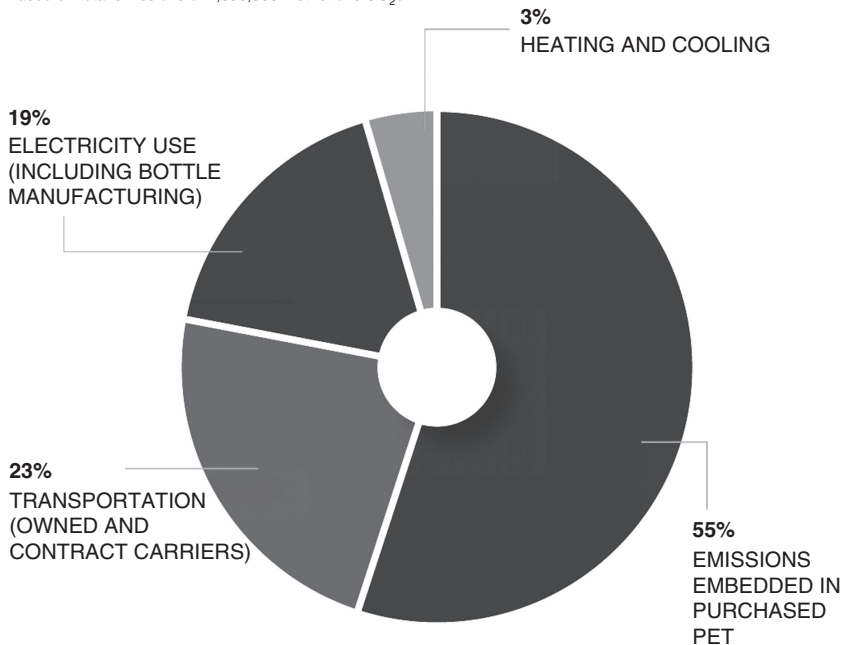


Fig. 15.8 Nestlé Waters North America 2006 Greenhouse Gas Emissions by activity over product life-cycle. (Reproduced with permission of Nestlé Waters North America.)

The results of FIJI Water's carbon footprinting efforts, as illustrated in Fig. 15.9, offer a more in-depth look. As the FIJI footprint data indicates and as suggested with the work of Gleick and Cooley and Nestlé Waters North America, the largest footprint aspects are embedded within the manufacturing of the primary package material (29%), transportation and distribution (43%), and bottling (20%).

Not surprisingly, NIKA Water's carbon footprint is very similar. Figure 15.10 indicates that transportation is the single largest contributor, followed by raw materials inception (e.g. packaging components), and manufacturing to the product footprint.

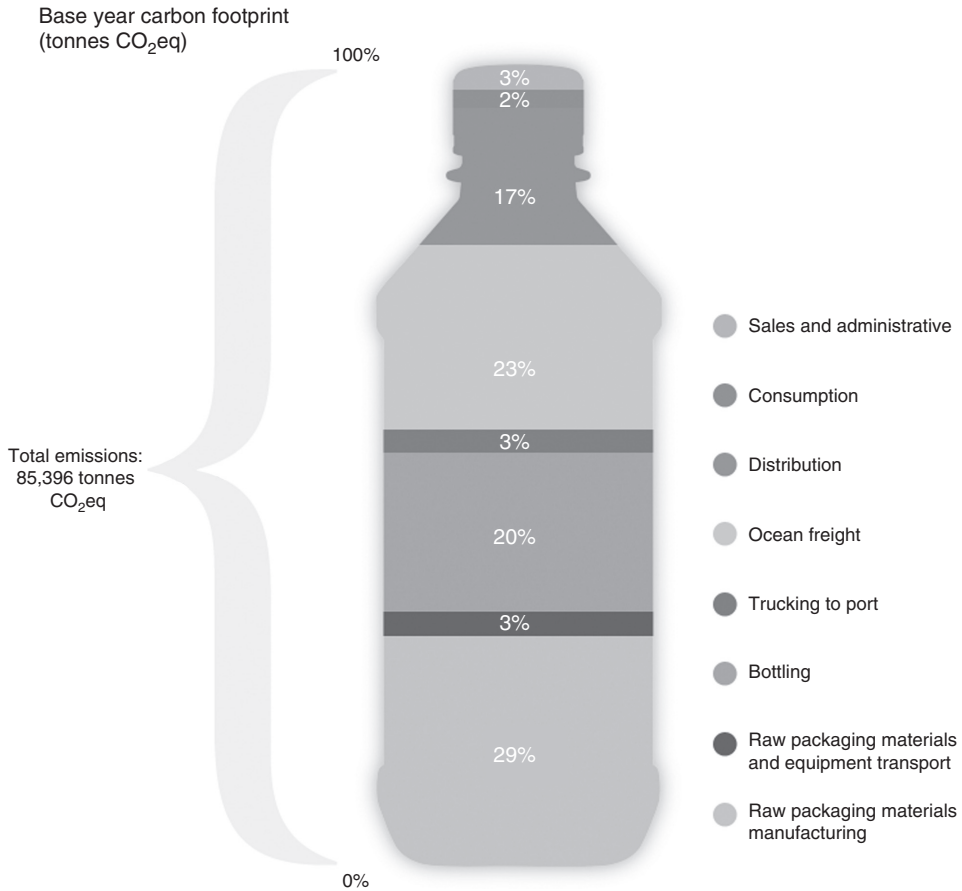


Fig. 15.9 FIJI Water base year carbon footprint. (Reproduced with permission of FIJI Water Company LLC.)

Understanding the energy and carbon footprint offers valuable insight and offers a means to prioritize investment and activities related to reducing energy costs (direct or in-direct), reducing the carbon footprint, and thus the impact on climate change.

15.8.2 Energy and carbon reduction best practice efforts

Leading bottled water companies (as well as other beverage companies and industry trade-related organizations) are actively pursuing innovation and best practice in the following areas:

- *Optimizing transportation:* The effort to optimize transportation occurs through the reduction of “kilometers” involved with transport and distribution, evaluating the modes of transport across the complete supply value chain, and looking at the sourcing of materials and proximity to the bottling facility.
- *Packaging:* Significant effort is being devoted to reducing packaging weight. Bottled water companies are investing heavily in packaging weight reductions, as illustrated

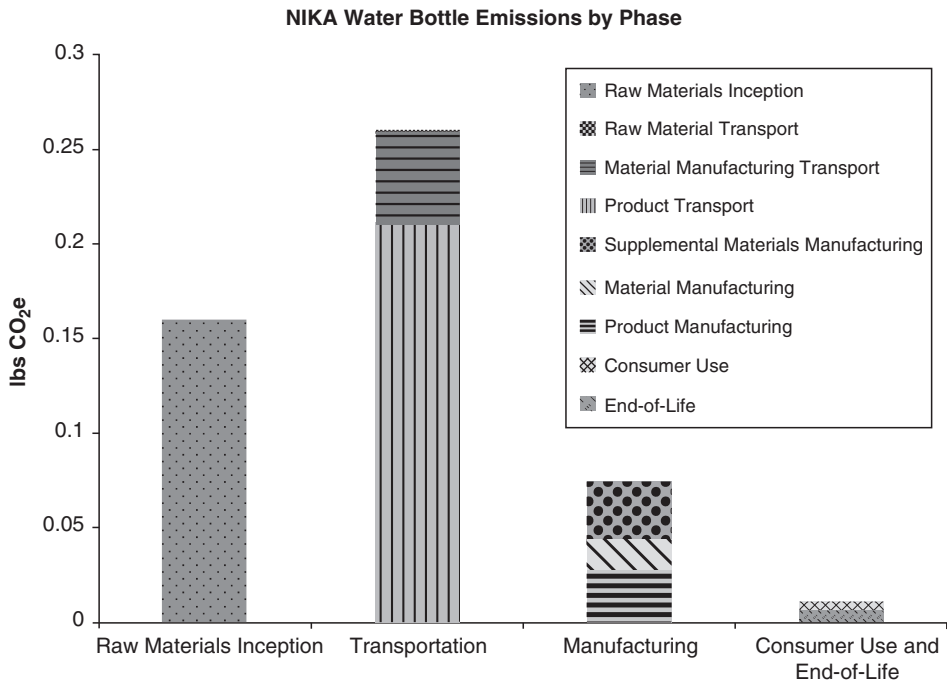


Fig. 15.10 NIKa water bottle emissions by phase. (Reproduced with permission of Nika Water Company, LLC.)

by recent study results from the International Bottled Water Association (IBWA) made available to the authors in January 2009. The study indicates that a 26.7% reduction in the average gram weight of the 0.5 liter PET bottle was achieved from 2000 to 2007. The 0.5 liter PET bottle is the most popular single-serve container utilized in the industry today.

Additional efforts also focus on reducing the quantity of raw material used (for both primary and secondary packaging materials), material substitutions, innovating alternative, more renewable packaging materials, and incorporating the use of recycled content into packaging. All of these efforts will have a positive impact on the energy use and the carbon footprint for bottled water products.

- *Reducing energy use everywhere:* Driving energy conservation and efficiency across production and manufacturing facilities, warehouses and distribution centers, and offices, and evaluating fleet efficiency should be part of energy reduction efforts. Working externally with suppliers also offers an opportunity to realize cost savings and make a positive impact on overall value chain energy consumption.
- *Enhance the waste recycling systems:* Leading beverage companies are working very hard to drive the development of plastic (PET) waste collection and recycling systems. A number of bottled water companies have set goals for the use of recycled PET (rPET) in their packaging mix as a means to reduce their carbon footprint, make meaningful contribution to society and be viewed as responsible corporate citizens.

- *Alternative energy supply:* Many advances are being made in technologies associated with alternative (non-carbon based) energy generation and availability. Leading companies are constantly looking for applications that will yield desired business and environmental benefit.
- *Buy offsets:* As another means of reducing the carbon impacts to the business enterprise, companies are buying carbon offsets, directing funding to the establishment and maintenance of renewable, and less carbon intensive energy supplies.

By understanding the energy and carbon “footprint” of the business and specific products, companies will be in a position to prioritize and focus best practice efforts. To facilitate progress in this regard, a number of multi-stakeholder collaborations have formed, focusing on benchmarking, defining best practices, and creating innovative solutions to the energy and carbon aspects most germane to the bottled water industry. These offer a very good opportunity for companies to accelerate the learning and application of solutions to achieve energy and carbon reduction. As a result, companies can cut costs, reduce total cost of ownership, and mitigate future environment-related business risk.

15.9 SOLID WASTE MANAGEMENT

The LCA of bottled water will identify solid waste issues across the value chain. The aspects and impacts of PET containers have been well documented, particularly in relationship to roadside litter and the shrinking availability of landfill space. Although solid waste, including paper, cardboard, wood, and other non-hazardous waste, is generated at various points along the value chain, the focus of this discussion will be on PET containers.

In the familiar hierarchy of reduce, re-use and recycle, bottled water companies continue to look for more ways to reduce the amount of PET in each package through light weighting initiatives. A good example of these industry initiatives is demonstrated by PepsiCo. In 2008, PepsiCo introduced a new, half-liter bottle for Aquafina flavored waters, Lipton Iced Teas, and Tropicana juice drinks. The new bottle contains 20% less plastic than the previous bottle, and its label is 10% smaller than before. These innovations are taking nearly 6 million kilograms of packaging out of the system each year. PepsiCo has trimmed the amount of plastic used in the bottles, caps, and labels of the half-liter Aquafina bottle by 35% since 2002. Nestlé Waters North America has reduced the weight of its typical half-liter bottle from 18–9.7 g.

In addition, bottled water companies continue to look for ways to increase the amount of recycled PET (rPET) in their containers. Mountain Valley Spring water claims to use 25% rPET in its PET bottles. Nestlé Waters North America Inc. reports launching a new natural spring water in the US packaged in bottles consisting of 25% rPET, and is working hard to increase this to 50%.

The final step in the process to reduce solid waste is through recycling. PET container recycling typically occurs either through voluntary curbside collection, drop-off site collection, or venue (away from home) collection. However, some government entities require consumers to pay a mandatory deposit (in addition to the container’s retail purchase price) on designated beverages.

Curbside recycling in North America is by far the most convenient way to recycle a wide variety of waste materials today. These programs continue to increase as communities become more engaged in addressing this issue. However, the economics of curbside recycling are usually not favorable and may have to rely upon community funding to be sustainable.

Drop-off recycling centers are located primarily in urban neighborhoods, where they serve multi-family housing areas that cannot be served by curbside recycling programs. Drop-off recycling centers are prevalent in both North America and Europe. They are also located in rural areas where curbside recycling service does not make economic sense due to the high cost associated with providing these services in sparsely populated rural areas. These centers have had mixed success since the consumer often views this recycling opportunity as inconvenient compared to curbside service.

Venue recycling refers to recycling that occurs in a specific setting where beverage consumption occurs (i.e. as sports and concert events, airports, etc.). The IBWA reports it is also the type of recycling on which bottled water companies can have a huge impact – by working as a partner with their customers or local government. Venue recycling allows consumers to recycle their beverage containers (including bottled water containers) where they consume the beverage. Venue recycling provides consumers with a convenient means by which to recycle instead of throwing the beverage container in the trash. As consumer consumption patterns continue to evolve from the home to other locations and activities, it becomes increasingly important for groups such as the bottled water industry to understand how venue recycling works and how it can be supported.

Near double-digit growth continued through 2008 for PET water containers, but was somewhat offset by significant lightweighting efforts. In the United States, for example, according to a 2008 report by the National Association for PET Container Resources (NAPCOR), the total number of pounds of PET bottles and jars available in the United States for recycling in 2008 was approximately 5.4 billion pounds. The amount of post-consumer PET bottles collected for recycling and sold in the United States was approximately 1.45 billion pounds. The post-consumer PET bottle recycling rate continues to increase over the last six years. This increase can be attributed to a number of factors, including an increase in community and commercial collection programs. As shown in Table 15.5, the post-consumer bottle gross recycling rate in 2008 was 27.0%, an increase of approximately 10% over 2007.

In Europe, numbers released by Petcore show that in 2008, post-sorting PET collection reached 1.26 m tonnes, an increase of more than 11% on 2007. The overall collection rate in 2008 rose by nearly 5%, from 41–46%, of all PET bottles on the market. These recycling rates are nearly double that of the United States.

There are a growing number of market forces, which are beginning to increase post-consumer PET bottle recycling activity, including:

- *Energy pricing:* As energy prices increase, potentially related to carbon regulation, the higher price of virgin PET will force companies to re-examine the economics of using rPET.
- *Corporate policy:* A significant portion of the business community is adopting principles of sustainability as a core business strategy. This strategy includes evaluating the cost efficiencies of increasing the use of rPET and developing a strong external consumer message.
- *Public policy:* An increase in publicly initiated collection programs reflects the desire of citizens to do something proactive to combat roadside litter and address the shrinking landfill dilemma. For example, in Europe, the Waste Framework Directive (2008/89 EU) mandates that there should be 50% recycling or reuse of plastics from household streams by 2020.
- *Valuable feedstock:* As recycling increases and market conditions make virgin PET less attractive, rPET will become an even more reliable and sought-after feedstock in the PET

Table 15.5 PET Gross Recycling Rates. Reproduced with permission of NAPCOR.

Year	Total US bottles collected (mmlbs.)	Bottles on US shelves (mmlbs.)	Gross recycling rate
1996	697	2198	31.7%
1997	691	2551	27.1%
1998	745	3006	24.8%
1999	771	3250	23.7%
2000	769	3445	22.3%
2001	834	3768	22.1%
2002	797	4007	19.9%
2003	841	4292	19.6%
2004	1003	4637	21.6%
2005	1170	5075	23.1%
2006	1272	5424	23.5%
2007	1396	5683	24.6%
2008	1451	5366	27.0%

value chain. In 2007, Chinese traders purchased more USA post-consumer PET bottles than did USA reclaimers. This has forced USA reclaimers to import additional bottles to meet their demands. This has stifled the investment in additional USA reclamation capacity. This lack of investment is the most critical issue facing the industry moving forward.

In summary, there is a growing gap between the demand for post-consumer PET bottles and the available supply worldwide. This will certainly drive an increased focus on recycling efforts. The need to recover a greater quantity of this asset and reduce waste/litter generation is driving some unique partnerships and efforts across the industry. Two examples are noted below.

One company that is working to drive the use of rPET and help meet its goals is The Coca-Cola Company. The Coca-Cola Company plans to boost the recycled content of its PET bottles to 10% by the end of 2010, thanks in part to a new joint venture with a recycling plant in Spartanburg, South Carolina, USA. The plant, named New United Resource Recovery Corp. LLC, is a joint venture with Spartanburg-based recycler United Resource Recovery Corp., LLC. When completed, it is expected to be the largest PET recycling plant in the world that makes food-grade resin. When fully operational, the plant will produce approximately 100 million pounds of food-grade rPET plastic each year. The Spartanburg plant is modeled after a Toluca, Mexico, food-grade PET recycling plant built in 2005, which was also a Coca-Cola investment.

A second example in the United States is Project Warmth, a large-scale recycling effort that will distribute 100 000 fleece jackets containing recycled plastic bottle material to needy children. In this program, Sam's Club teamed with Aquafina as part of the Great American Clean-up.

Bottlers, distributors, and suppliers need to continue to work together with packaging industry representatives and local recycling coordinators to encourage more recycling. By doing so, the industry will be doing its part to increase recycling, by diverting materials from the landfill that can be used again to make a wide variety of value-added products, and also divert plastic bottled water containers from the litter stream.



Beverage Industry Environmental Roundtable

The mission of the Beverage Industry Environmental Roundtable (BIER) is to bring together leading global beverage companies to define a common framework for stewardship, drive continuous improvement in industry practices and performance, and inform public policy in the areas of Water Conservation and Resource Protection, Energy Efficiency and Climate Change Mitigation.

The pursuit of our mission will be founded upon three pillars:

- ◆ Data Collection & Benchmarking;
- ◆ Best Practice Sharing; and
- ◆ Internal & External Stakeholder Communication.

Fig. 15.11 Beverage Industry Environmental Roundtable.

15.10 BEVERAGE INDUSTRY ENVIRONMENTAL ROUNDTABLE

The Beverage Industry Environmental Roundtable (BIER) warrants further introduction as a unique and relatively new approach to advancing environmental sustainability across an industry sector (Fig. 15.11). As epitomized by its founding in early 2006, BIER represents a unique industry sector-specific, technical coalition of beverage companies (non-alcoholic, brewing and distilled spirits beverage companies) convening to advance environmental stewardship to the benefit of each individual company, but more importantly, the industry as a whole.

At the time of this writing, BIER's membership includes the four largest global bottled water producers; The Coca-Cola Company, Danone, Nestlé Waters, and PepsiCo.

BIER's agenda is focused on three primary environmental stewardship aspects: water stewardship, energy and climate change mitigation, and informing public policy. Briefly, the technical agenda currently associated with each of these aspects is as follows:

- **Water Stewardship:**
 - best practice sharing of production processes with a focus on water conservation;
 - quantitative and qualitative benchmarking, including water use and efficiency, and practices related to watershed, community, partnership, and conservation practices;
 - beverage industry sector water footprinting methodology and guidance development.
- **Energy and Climate Change:**
 - publication and distribution of Beverage Industry Sector Guidance for Greenhouse Gas Emissions Reporting (January 2010); and
 - conducting product GHG (carbon) footprinting comparative analyses to further knowledge and drive best practice sharing.
- **Informing Public Policy:**
 - external, non-governmental policy development and associated stakeholder engagement;
 - public policy development by providing technical support to the various industry trade associations.

15.11 CLOSING

As we review available information related to environmental issues and performance within the bottled water industry, it has become clear that much work is yet needed to develop clear methodologies for environmental performance assessment and quantification, drive consistency in all manners of reporting, and develop meaningful industry standards or benchmarks from which to drive improvements across the bottled water industry. This situation is not unique to the bottled water or beverage industry. In fact, the beverage industry through its collaborative efforts in such activities as BIER, participation in working groups on such things as the WRI/WBCSD Product GHG Product Protocol, WFN and ISO water footprinting methods development forums, the many global partnerships the beverage companies are engaged in to advance environmental stewardship and numerous other social and environmental actions, places the beverage sector clearly as a leading industry sector. External rating organizations (i.e. Dow Jones Sustainability Index, Pacific Institute, CERES, etc.) routinely place the beverage sector at or near the top in terms of its environmental stewardship leadership position.

With the rapidly changing expectations, bottled water companies will need to continue to advance work to manage environmental-related business risks and make a meaningful contribution to addressing society's environmental issues. Companies will need to continue to build on their base of knowledge of their own operations and extend those learnings to influence performance along the entire value chain. It begins by assessing the value chain, identifying the business-environmental (and business-social) intersects that are germane to the enterprise, and then acting upon these findings. It is about understanding the "environmental footprint", quantifying the natural resources and materials consumed and wasted, and taking action on these findings.

The business benefits of active environmental stewardship on the part of private industry are becoming very clear. The opportunity is to take action and create shared value; and for each business, find the point where economic-environmental-social benefits co-exist and are mutually inclusive of long-term business vitality and prosperity.

"Action is the foundational key to all success" – Pablo Picasso.

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