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FLOW CHARACTERISTICS OF PLANTED SOIL FILTERS

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ABSTRACT

Various water tracers were used for the determination of flow characteristics such as residence time, velocity of flow, and dispersion phenomena especially under the aspect of stagnant water regions. The tracers applied were bromide, uranin, eosin, lithium salt, and in one case tritiated water as a reference. Bromide as a chemically very stable anion with no detectable retardation proved under these conditions as very reliable. Uranin and eosin showed low retardation but were subject to losses by sorption, degradation, and photolysis in uncovered regions. Lithium can not be recommended for such applications.

The results showed that the mean residence time in the filter was between 6 and 40 days with respect to hydraulic load, evapotranspiration, soil material and the hydraulic gradient. The determined conductivity of the filters was approximately 10^{-4} to 10^{-5} m/s and did not vary during the investigation period.

KEYWORDS

Constructed wetlands; planted soil filter; tracer tests; hydraulic parameters; residence time; dispersion; hydraulic conductivity.

INTRODUCTION

Constructed wetlands are natural systems used for wastewater treatment. In general, these systems are applied in Germany for purification of wastewater from single houses or smaller drainage areas up to 1,000 population equivalents. Planted soil filters are artificial wetlands with horizontal subsurface flow. The biological, chemical, and physical processes of wastewater purification take place in the granular material filter body, planted with helophytes. The soil filters in use vary in permeability, construction, and soil substratum.

The purification efficiency of soil filters is strongly dependent on hydraulic characteristics. Short cuts and dead zones of flow reduce the effective reaction volume in the filter and thus the purification efficiency. Heterogeneously distributed permeability and short cuts create undesired strong variation of residence time distribution.

Variations in hydraulic conductivity are reported to be a problem often experienced in many subsurface flow constructed wetlands (Brix, 1987; Fisher, 1990). The presence of preferred flow paths in horizontal sub-surface artificial wetlands has been reported by Bowmer (1987) and Fisher (1990).

DESCRIPTION OF THE EXPERIMENTAL SYSTEMS

Hydraulic investigations have been carried out at the two filters of the Germerswang pilot plant (near Munich) and at the planted soil filter at See (located east of Nuremberg). Further information on these treatment plants, such as purification efficiency, is provided in the paper "Factors affecting nitrogen removal in horizontal flow reed beds(Platzen and Netter, 1994)" in these proceedings.

In each planted soil filter, sampling points were installed and used for the determination of the flow characteristics. For further details about the construction of the sampling points see Netter and Bischofsberger (1990). Flow rates in the influent and effluent were monitored by magnetic inductive flow meters.

On a two-week basis, the rain falling directly on the soil filter was up to 29% of the applied inflow. Evapotranspiration losses ranged from 0 to 88% of inflow.

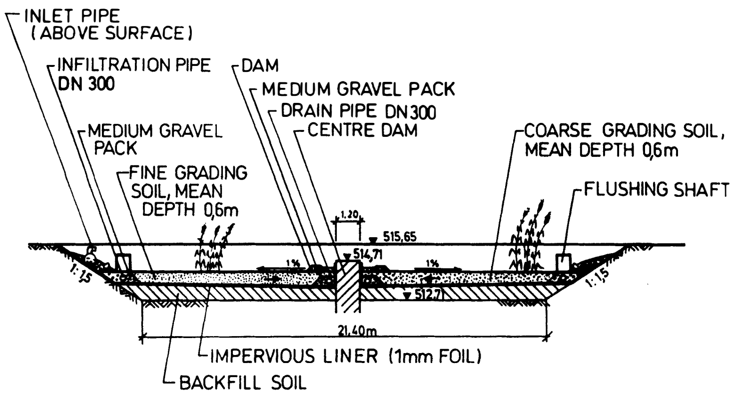

Fig. 1. Cross section of the Germerswang pilot plant.

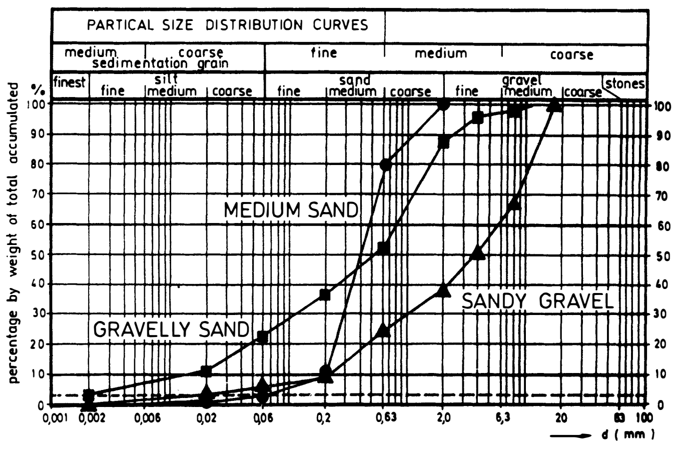

Fig. 2. Particle size distribution curves of the three filter media.

Germerswang Pilot Plant

The Germerswang pilot plant (see Fig. 1), constructed in 1986, consists of two 500 m^2 planted soil filters. They are filled with different, homogeneously mixed granular media. The material of the fine grading filter consists of gravelly sand with a uniformity coefficient of 49, and the other material is sandy gravel with a uniformity of 29 (see Fig. 2). Both filter materials contain fractions of clay and silt.

The filter beds with a mean depth of 0.6 m are sealed underneath with an impervious liner. The different kinds of helophytes which originally had been planted in the filter bed were reed (*Phragmites communis*), yellow flag (*Iris pseudacorus*), cattail (*Typha latifolia*), sweet flag (*Acorus calmus*) and bulrush (*Schoenoplectus lacustris*). In the course of years, the reed pushed back the others to a small remainder.

The pretreated wastewater can be applied above surface as well as below (Fig. 1). The subsequent underground passage through the filter body has a minimum length of 10 m. The biological treated sewage is collected on the opposite side of the filter bed by a drain pipe. The hydraulic gradient can be regulated by a movable weir.

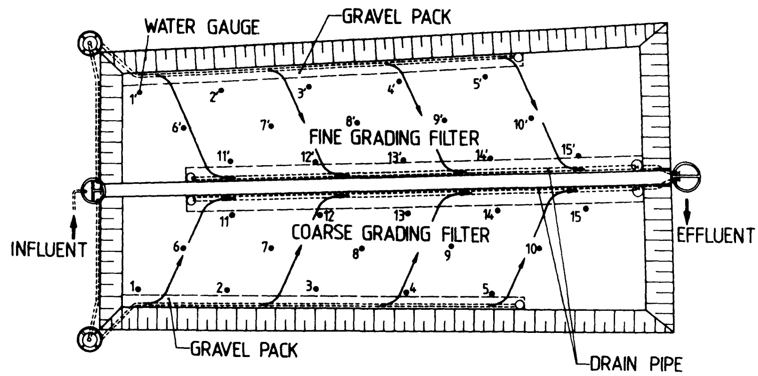

Fig. 3. Position of the sampling points in the soil filter and the theoretical direction of flow.

See Planted Soil Filter

The planted soil filter at See, constructed in 1984, consists of a filter bed with an area of 940 m^2 and a mean depth of 0.6 m. A natural loam layer (2 m) seals the soil filter from the karstic bed rock. Design capacity is 100 population equivalents.

Pretreated wastewater is introduced into the system by a subsurface infiltration pipe which lies in a gravel pack. The sewage is distributed over the total width of the plant. The filter bed is divided into three regions by two dams. The first region, with 410 m^2 surface area, is a submerged infiltration area that equalizes the variation of the hydraulic loading. The subsequent underground passage through the filter (regions two and three) has a minimum length of 13 m. A deep-seated drain pipe at the effluent side of the bed collects the biologically treated sewage and transports it to a height-variable outlet. Depending on the sewage quantity and the season the water seeps, evaporates, or is used for irrigation.

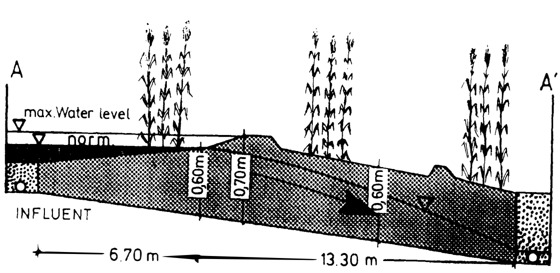

Fig. 4. Cross section of the planted soil filter See.

The soil material is a very ferruginous aeolian sand. This medium sand contains rounded iron ore particles of limonit and haematit. The uniformity coefficient of the material is smaller than 5 (see Fig. 2). The plants which originally grew in the infiltration area were cattail (*Typha latifolia*). The non-infiltration area is planted with reed (*Phragmites communis*). In the course of the years the reed has pushed back the cattails to a small remainder.

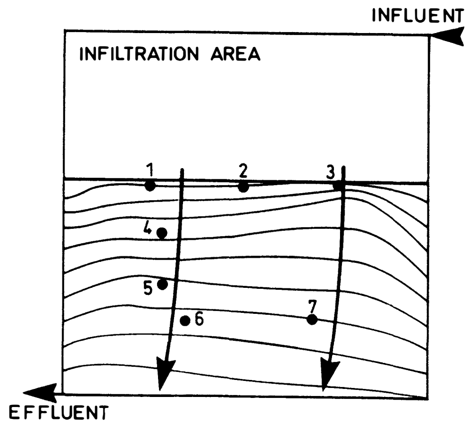

Fig. 5. Position of the sampling points and the monitored direction of flow.

MATERIALS AND METHODS

Pulse (Dirac) injection of the tracers, rather than continuous injection was chosen. The lower consumption of tracer materials in this case entails smaller density effects. In the case of pulse injection, the tracer response curve reflects directly the residence time distribution of the traced material. Mean residence time is obtained from the centre of gravity of the concentration versus time curve (if flow-rate is constant) or mass versus time curve (Netter and Behrens, 1992).

The tracers (see Table 1) were injected simultaneously in order to compare their behavior under planted soil filter conditions (Netter and Behrens, 1992).

TABLE 1. Injected Tracers, Analytical Detection and their Limits

Tracer substances	Test 1	Test 2	Methods of analytic	Limits of detection
Lithium (LiCl)	100 g	200 g	atomic-absorption spectroscopy	0.5 ppm
Bromide (NaBr)	-	1000 g	ion chromatography	0.1 ppm
Uranin	2 g	2 g	spectrofluorometry	0.01 ppb
Eosin	5 g	5 g	spectrofluorometry	0.03 ppb
tritiated water	1 mCi	-	liquid scintillation	100 pCi/l

Bromide was chosen as a chemically very stable tracer material of extremely low sorptive properties (Behrens, 1983). The purpose of the injection of lithium was to obtain information on the behavior of this cationic tracer under constructed wetlands conditions. The fluorescent dyes uranin and eosin were tested under the aspect that they sometimes have shown sensitivity to microbial degradation (especially uranin) and to some sorption (eosin). As a constituent of the water molecule, tritium was regarded as a reference tracer.

In each of the planted soil filters at Germerswang two runs were conducted (test 1 and 2) with two different hydraulic loadings (46 mm/d and 16 mm/d). For detection of tracers water samples were taken and analysed in the laboratory. The effluents of the two filters were sampled by automatic samplers. At intersections, samples were manually taken from different sampling points (see Figs. 3 and 5).

Further tracer tests were carried out at the planted soil filters of Germerswang and See to investigate possible time variation of the hydraulic parameters.

RESULTS

Evaluation of Tracer Properties

Detected tracer concentrations in the effluent of test 1 at Germerswang (filter with sandy gravel) are shown in Figure 6. Data derived from all the tracer breakthroughs of the tests at Germerswang are given in Table 2.

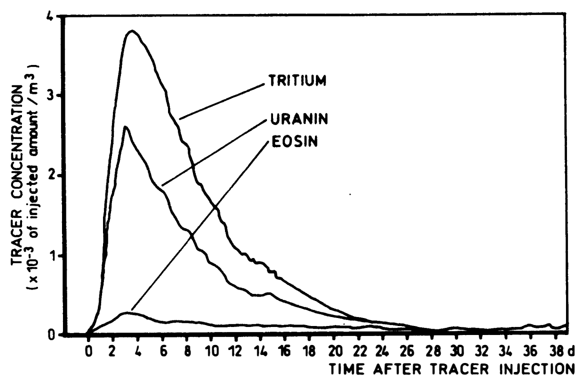

Fig. 6. Breakthrough of tracers in test 1 at Germerswang, filter with sandy gravel.

TABLE 2. Mean Residence Time and Recovery of the Injected Tracer Substances

Hydraulic loading	Tracer substances	Gravelly sand Mean residence time	Recovery	Sandy gravel Mean residence time	Recovery
46 mm/d	Lithium	11 d	63%	9 d	100%
	Uranin	12.4 d	48%	11.5 d	50%
	UV	10.1 d	87%	7.4 d	80%
	Eosin	15.1 d	6%	13.4 d	7%
	Tritiated water	12.1 d	87%	11.1 d	80%
16mm/d	Lithium	-	15%	24 d	45%
	Bromide	20 d	60%	19 d	87%
	Uranian	32 d	48%	23 d	44%
16 mm/d	Bromide	17 d	56%	19 d	91%
16 mm/d	Bromide	16 d	87%	14 d	47%
16mm/d	Bromide	21 d	86%	18 d	99%
30 mm/d	Bromide	9 d	92%	11 d	47%
30 mm/d	Bromide	10 d	64%	9 d	76%

Except for lithium in test 1, all other tracers yielded to more or less identical residence time distribution curves. However, distinct differences were observed in the concentrations of tracers (height of breakthrough curves, normalized with respect to injected tracer amounts). Thus, the different recoveries of the individual tracers expressed corresponding losses. In the case of tritium, evaporation could possibly be a reason for some losses. Larger losses were observed for uranin and even more for eosin. Microbial degradation may be regarded as a reason for uranin losses while the eosin, which is more stable in this respect, was probably lost by sorption. However, some losses of the latter two tracers should also be attributed to photolysis at the partly flooded surface of the planted soil filters (Netter and Behrens, 1992).

Test 2 confirmed the tendency of the results of test 1, proving bromide as the tracer with the highest recovery.

Flow Characteristics

The results of tracer tests revealed the preferred flow path and stagnant regions in the filter beds. Tracer passage curves were observed in the many observation points in the filter beds at Germerswang and See. Detected tracer concentrations in a filter bed containing sandy gravel (shown in figure 7) revealed heterogeneous flow through the filter body. The peaks of the concentration curves (see Fig. 7) for points 11 to 15 and points 6 to 10 seem to be earlier than for points 1 to 5. This shows the influence of a high loading rate and therefore partly surface flow.

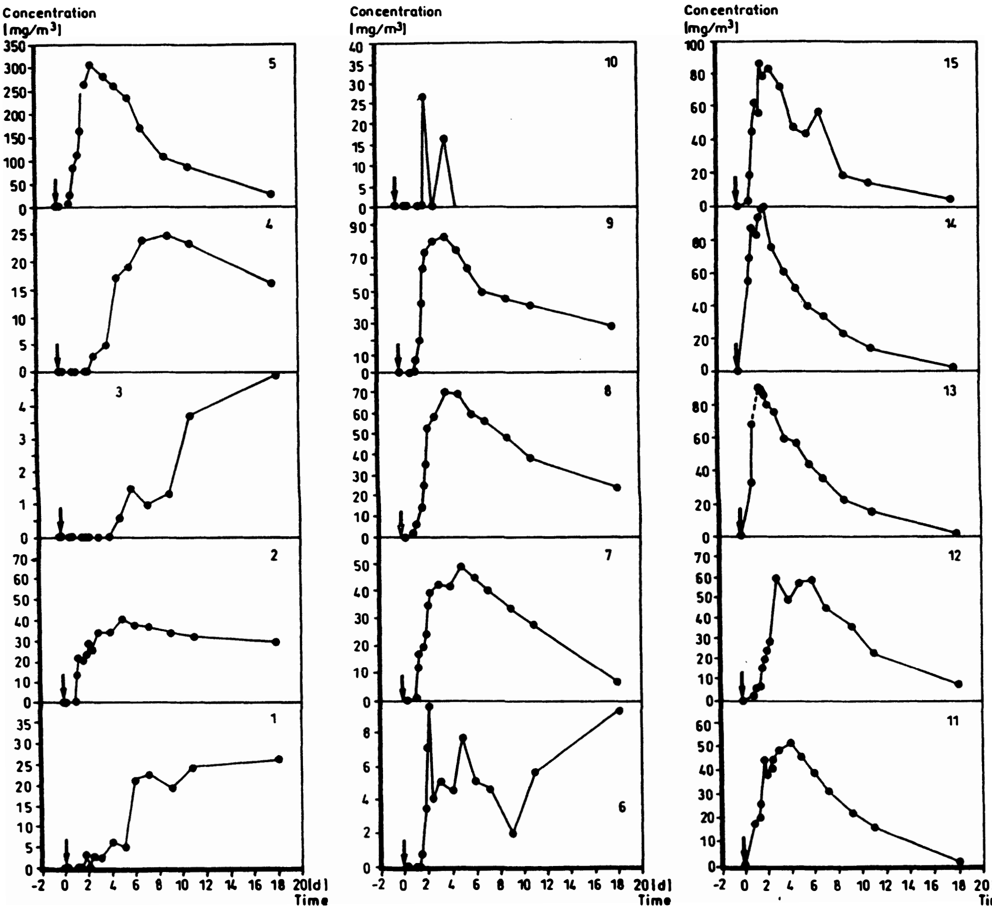

Fig. 7. Breakthrough of the tracer in the 15 observation points in the filter with sandy gravel.

Sewage flows mainly into the bed near observation points 2 and 5. In the middle of the filter (between observation points 7 and 9) we find the preferred transport path. The effluent region of the bed is passed homogeneously whereas the mean passage is around point 13 to 15. The soil filter with the filling of gravelly sand also showed a variable distribution of flow. On the contrary, the flow through the soil filter at See is homogeneous.

Hydraulic Conductivity

The permeability coefficient describes the frictional resistance to flow through cohesionsless material. It depends on the water and the aquifer, and is only determinable when there are laminar ranges of flow. Darcy's law describes the relationship between the coefficient of permeability, the hydraulic gradient and the filter velocity (Netter and Bischofsberger, 1990).

The interpretation of six tracer field tests (at Germerswang) with a rate of application of 16 mm/d and two tests with 30 mm/d showed an average permeability of 0.8 to 3.0 x 10^{-4} m/s for the filter with gravelly sand and 0.9 to 1.2 x 10^{-4} m/s for the filter with sandy gravel (see Table 3). The investigation with a hydraulic loading of 30 mm/d showed that the soil filter filled with gravelly sand has an increased hydraulic conductivity. This shows that an increase in hydraulic loading leads to additional effective transport paths in the flow regime.

The two tracer field tests at See showed an average permeability of 2.5 x 10^{-5} m/s. The good reproducibility of the values indicates that the method is practicable for soil filters which have no surface run-off.

TABLE 3. Coefficient of Permeability of the Soil Filters in Germerswang

Test	Hydraulic load [mm/d]	Gravelly sand [m/s]	Sandy gravel [m/s]
2	17	7.8 x 10^{-5}	8,7 x 10^{-5}
3	15	10.5 x 10^{-5}	10,8 x 10^{-5}
4	18	8.3 x 10^{-5}	12 x 10^{-5}
5	15	16 x 10^{-5}	9,6 x 10^{-5}
6	30	18 x 10^{-5}	9,6 x 10^{-5}
7	30	30 x 10^{-5}	11 x 10^{-5}
Average	-	15 x 10^{-5}	10 x 10^{-5}

CONCLUSIONS

The hydraulic investigations at the three planted soil filters at Germerswang and See have shown a mean residence time between 6 and 40 days with respect to the hydraulic load and gradient, and the hydraulic conductivity of granular material. The determined hydraulic permeability was approximately 10^{-4} to 10^{-5} m/s and did not vary during the investigation period of four years. The planted soil filters showed significant plug-flow regimes with some longitudinal dispersion.

Different hydraulic loadings in heterogeneous soil filters lead to different total hydraulic conductivities, since with higher water levels additional transport passages are available to the flow.

Variations in the hydraulic loading of the filter can be equalized by a submerged area in one region of the filter. Rain which falls directly on the filter area increases the flow-rate of the effluent more than does a variation in the hydraulic loading.

Besides tritium, bromide was found suitable for investigation of water transport in constructed wetlands. At Germerswang, the tracer tests revealed heterogeneous distribution of flow and permeability and partly stagnant zones which affect performance of the soil filter. In contrast, the tests at See showed a homogeneous flow and permeability distribution.

Tracer methods are confirmed as a valuable tool for determination of hydraulic parameters, and the identification and corresponding elimination of shortcomings of constructed wetlands under development.

ACKNOWLEDGEMENTS

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