

A METHOD OF PREDICTING THE POLLUTION POTENTIAL OF
SURFACE MINING BACKFILL

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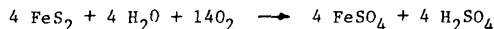
ABSTRACT

The paper describes a quick and effective method of predicting the acid ferruginous pollution potential of surface mined backfill on sites where the groundwater is likely to rebound through the fill on cessation of mining activity. Continuous cores of the strata to be mined were taken and analysed in the laboratory in order to identify the strata which are potentially acid producing and conversely strata which had a high acid neutralizing capacity which could be used to eliminate acid production. In this way it is hoped that during the mine planning and operational phase steps can be taken to prevent the problem developing. Some of the chemical and physical methods of prevention are also briefly discussed.

INTRODUCTION

With greater excavation depths and strata pollution controls affecting surface coal mining in the United Kingdom some sites have experienced considerable water problems. Many of these problems have now been overcome during the operational phase through the judicious use of advance dewatering techniques resulting from thorough hydrogeological and geotechnical investigation during the mine planning process. However, at some mines once pumping has ceased, the voids are backfilled and the area restored to agriculture there is the possibility, where the original groundwater table was high, of springs appearing at surface formed by water that has passed through the backfill. The breakdown of iron pyrites is greatly increased in the presence of oxygenated water.

Whether these springs will be of acid ferruginous water will depend on a number of coincident factors. Most important of these will be the nature of the backfill material through which the water flows. It is generally agreed[2,3] that the major cause of pollution is the pyrites content of the spoil which reacts with oxygenated water in the following manner :-



Other reactions involving bacterial attack on pyritic minerals also take place and after further oxidation the ferrous sulphate is converted to Ferric hydroxide $\text{Fe}(\text{OH})_3$ which gives rise to the familiar red acid discharge at surface. The amount of pyritous material and the physical conditions within the fill will control the amount of pollution of the groundwater which in some instances may already be slightly contaminated by passage through abandoned underground mine workings in the surrounding solid strata.

In order to evaluate the possibility of predicting whether pollution would take place a research project was undertaken at a future surface mine site. Air-flush drilling methods were used to obtain core samples of the full sequence of strata to be excavated. These were then given a full geological description and further sub-divided into samples for analysis in the laboratory. Each sample was analysed for pH, Moisture Content, Acid Neutralising Capacity (A.N.C.) and Sulphur Content.

BICO QUALITY DESIGNATION R.O.D.	THICKNESS (m.)	CORE DESCRIPTION	DEPTH (m.)	LEGEND	CORE LOG No. & RECOVERY %	ANALYSIS SAMPLE No.	SAMPLE THICKNESS (m.)	ANALYSIS RESULTS									
								pH	SULPHUR TOTAL %	POTENTIAL ACID PRODUCTION SULPHUR %	(a) INTERPOLATED ACID NEUTRALISING CAPACITY % CaCO ₃	(b) ACID NEUTRALISING CAPACITY % CaCO ₃	ACID REACTION POTENTIAL a - b	EXCESS POTENTIAL ACID CAPACITY b - a			
	0.70	PEAT	0.70														
	2.85	BOULDER CLAY	3.55														
	0.70	SOFT SANDSTONE	4.25														
47	1.45	SANDSTONE Coarse Grained, fairly well sorted, moderately well bedded, occasional thin clayey sand bands, slightly indurated.	5.70			① 100	1.1	0.50	7.1	0.36	0.32	1.00	1.65	—	0.65		
							1.2	0.45	7.3	0.25	0.23	0.72	1.61	—	0.89		
							1.3	0.50	7.1	0.04	0.04	0.12	1.58	—	1.46		
53	1.80	SANDSTONE Very Coarse Grained, fairly bedded, indurated.	7.50			② 100	2.1	0.95	5.4	0.78	0.73	2.28	0.44	1.84	—		
86	0.50	SANDSTONE Fine Grey, Less Coarse Grained, Current Bedded.	8.00				2.2	1.50	4.8	0.12	0.11	0.34	0.23	0.11	—		
43	1.73	SANDSTONE Fine, Medium Grained, Pale Grey, Buff, Fossiliferous.	9.73			③ 100	3.1	1.50	6.4	0.13	0.12	0.37	0.73	—	0.36		
	0.04	MUDSTONE Dark Grey, Buff, Fossiliferous.	9.77				3.2	0.27	4.7	0.22	0.20	0.62	0.65	—	0.03		
							3.3	0.08	4.8	1.76	1.40	4.37	0.97	3.40	—		
63	1.23	SANDSTONE Pale Grey, Coarse Grained, Firm.	11.00				3.4	1.06	5.7	0.20	0.18	0.56	0.71	—	0.15		
40	1.90	SANDSTONE Coarse Grained at Top, Clay, Fairly Compacted.	12.90			④ 98	4.1	0.77	5.1	0.19	0.17	0.53	0.26	0.27	—		
	0.20	MUDSTONE Dark Grey, Firm, Fossiliferous.	13.10				4.2	1.23	4.2	1.18	1.08	3.37	0.76	2.61	—		
	0.10	CLAY Dark Grey.	13.20				4.3	0.28	7.2	0.14	0.13	0.41	3.81	—	3.40		
100	0.25	SANDSTONE Very Coarse Grained.	13.45				5.1	0.51	7.3	0.37	0.33	1.03	5.72	—	4.69		
62	1.17	LIMESTONE Hard Grey, Crystalline on Bedding, Sandy to Base.	14.65				5.2	0.90	7.5	0.18	0.16	0.50	53.49	—	52.99		
100	0.42	LIMESTONE Very Hard.	15.07			⑤ 100	5.3	1.01	7.4	0.48	0.45	1.40	11.24	—	9.94		
56	0.73	SANDSTONE Medium Coarse Dark Grey, hard and Firm, Bedding.	15.80				5.4	0.30	7.0	0.62	0.61	1.90	3.37	—	1.47		
89	1.13	SANDSTONE Medium/Fine Grained, Moderately Sorted from Dark Grey.	16.93				6.1	0.65	7.0	0.41	0.37	1.16	5.89	—	4.73		
	0	SANDSTONE as above, indurated.	17.31			⑥ 94	6.2	0.26	7.1	0.51	0.51	1.59	5.63	—	4.04		
	4.6	SANDSTONE Dark Grey.	17.48				6.3	0.22	7.0	0.08	0.07	0.22	3.60	—	3.38		
	0	SANDSTONE Dark Grey.	17.50				6.4	0.37	6.9	0.03	0.03	0.09	3.21	—	3.12		
	0	SANDSTONE Dark Grey.	17.70				6.5	0.26	7.0	0.25	0.23	0.72	4.01	—	3.29		
							6.6	0.12	7.2	0.83	0.79	2.47	11.24	—	8.77		

Figure 1 Geological section and analysis results for borehole No. 3139 from 0.0m to 17.70m depth.

From these analyses the quantities of potentially acid producing material could be calculated as a proportion of the whole backfill volume. The actual effect of this material is difficult to ascertain as the weathering effect on the different rock types cannot be accurately assessed. Other factors such as the rate of flow of the groundwater, the permeability of the various layers of fill and the geometry of the void will also effect the rate of the chemical process.

DRILLING AND SAMPLING

The site under investigation lies in a hilly district with an average rainfall of 1400mm/annum. The water table in the area to be excavated appears at surface in the form of natural springs which are non-polluting. The groundwater passes through the strata^[4] to be excavated via the natural pore spaces in the rock and also through abandoned mine workings in some of the seams to be worked. As these old working spaces are waterlogged then it is assumed that little oxygen is present in the groundwater and that little iron or sulphur is picked up by the groundwater. As the water table level is high then all the strata sampled can be expected to have groundwater flowing through it and possibly issuing at surface.

The strata to be excavated was drilled using air-flush rotary methods and strata cores of 92.1mm diameter were logged with a full geological description in the field. The cores were taken in positions where the strata was considered to be representative of the complete strata to be excavated on site. Core recovery averaged over 95% except where old workings occur. The core was then transported in core boxes to the laboratory where the strata was further sub-divided into sample units based on lithology and a hand specimen assessment of the sulphur content.

The strata concerned is from the Carboniferous System Limestone Group and as can be seen from the sections in Figures 1 to 7 the strata consists of fine to medium grained sandstones, shaley mudstones, coal and seathearts with the occasional limestone.

LABORATORY ANALYSIS

The principles involved in the laboratory assessment were based on those described in Costigan, Bradshaw and Gemmell in^[5] their assessment of the acid producing potential of colliery spoil. The acid producing potential of the material, measured by its pyritic content was related to its Acid Neutralising Capacity (A.N.C.) as measured by reaction with hydrochloric acid.

In this way it was hoped to identify not only the strata which are potentially acid producing, but to estimate the theoretical lime dosage required to neutralise any acid products of oxidation. In addition it was hoped to identify any strata, e.g. limestone or dolomite, with a high Acid Neutralising Capacity which could be blended with the potential acid producing strata thus reducing, if not eliminating, the need for inmixing additional lime or limestone.

The samples from the core drilling were split into subsections which were dried and crushed to minus 3mm size particles. Where necessary the samples were then reduced systematically to give a representative weight of not more than 500g for each subsection. These samples were then further crushed to -0.2mm for analysis.

Rock Quality Description No.	Core Dia mm	Core No.	Borehole No.	Sheet	CORE DESCRIPTION	DEPTH (m)	LEGEND	CORE BOX No. IN RECOVERY	ANALYSIS SAMPLE No.	SAMPLE THICKNESS (cm)	ANALYSIS RESULTS										
											pH	SULPHUR TOTAL % S	POTENTIAL ACID PRODUCING		ACID NEUTRALIZING CAPACITY % CaCO ₃	ACID NEUTRALIZING CAPACITY % CaCO ₃	ACID NEUTRALIZING CAPACITY % CaCO ₃	ACID NEUTRALIZING CAPACITY % CaCO ₃	ACID NEUTRALIZING CAPACITY % CaCO ₃	ACID NEUTRALIZING CAPACITY % CaCO ₃	ACID NEUTRALIZING CAPACITY % CaCO ₃
													% S	% CaCO ₃							
93	0.72				SANDSTONE	18.43			7.1	0.72	7.0	1.70	1.55	4.96	5.88			0.92			
0	0.44				MUDSTONE	18.92		① 100	7.2	0.78	6.9	2.93	2.69	8.40	4.78	3.62					
0	1.81				MUDSTONE	20.90			7.3	0.50	6.9	2.29	2.14	6.68	4.37	2.31					
									7.4	0.60	6.8	2.73	2.55	7.96	4.83	3.13					
29	1.25				MUDSTONE	22.95			8.1	0.52	6.8	2.82	2.65	8.27	5.13	3.14					
	0.08				MUDSTONE	22.81		② 100	8.2	0.36	7.1	2.63	2.43	7.59	5.05	2.54					
0	0.94				MUDSTONE	22.95			9.3	1.00	6.7	2.36	2.19	6.84	4.79	2.05					
									8.4	0.37	6.8	1.36	1.31	4.09	4.32		0.23				
0	1.50				MUDSTONE	24.53			9.1	0.95	6.9	0.66	0.63	1.97	4.50		2.53				
88	0.45				MUDSTONE	24.52		③ 100	9.2	0.53	7.0	0.70	0.65	2.03	4.10		2.07				
									9.3	0.64	7.1	0.91	0.86	2.68	4.66		1.98				
22	1.01				MUDSTONE	25.95			9.4	0.88	6.9	0.96	0.87	2.72	4.79		2.07				
									10.1	1.20	7.0	0.88	0.83	2.89	5.20		2.61				
34	1.66				MUDSTONE	27.81		④ 100	10.2	0.48	7.1	0.90	0.84	2.62	11.22		8.60				
100	0.75				LIMESTONE	27.85			10.3	0.27	7.1	1.14	1.08	3.37	10.08		6.71				
12	0.74				MUDSTONE	28.50			10.4	0.73	7.0	1.14	1.10	3.43	10.19		6.76				
									11.1	0.52	7.0	0.09	0.09	0.25	80.36		60.11				
100	1.35				LIMESTONE	28.95		⑤ 100	11.2	0.83	7.1	0.05	0.05	0.16	61.62		61.46				
4.6	0.31				LIMESTONE	29.95			12.1	0.80	7.0	0.17	0.15	0.46	80.63		60.17				
8	0.33				LIMESTONE	30.95			12.2	0.30	6.9	1.34	1.24	3.87	45.51		41.64				
33	0.36				LIMESTONE	31.95			12.3	0.40	6.4	2.70	2.51	7.84	12.08		4.24				
0	0.17				MUDSTONE	32.81		⑥ 100	12.4	0.26	6.2	3.48	3.13	9.77	5.03	4.74					
100	0.47				MUDSTONE	31.95			12.5	0.20	6.7	3.29	3.56	7.99	5.14	2.85					
100	0.38				MUDSTONE	32.53			12.6	0.58	6.7	1.21	1.26	3.93	1.89	3.04					
100	0.19				CGAL	32.53			13.1	0.66	6.3	0.70	0.69	2.15	1.30	0.85					
100	0.63				SANDSTONE	32.53			13.2	0.86	7.2	0.09	0.08	0.25	4.05		3.80				
63	0.42				SANDSTONE	32.97			13.3	0.56	6.8	0.06	0.05	0.16	2.08		1.92				
								⑦ 100	13.4	0.52	6.5	0.03	0.03	0.09	0.82		0.73				
54	1.58				SANDSTONE	34.53			13.5	0.19	6.4	0.17	0.15	0.47	0.85		0.68				
									13.6	0.22	6.8	0.03	0.03	0.09	1.53		1.44				

Figure 2 Geological section and analysis results for borehole No. 3139 from 17.70m-34.45m depth

ROCK QUALITY DESIGNATION B.O.D.	THICKNESS (m)	CORE DIA mm	BOREHOLE No.	SHEET	DEPTH (m)	LEGEND	CORE NO. No. & RECOVERY %	ANALYSIS RESULTS										
								ANALYSIS SAMPLE No.	SAMPLE THICKNESS (m)	pH	SULPHUR TOTAL % S	POTENTIAL ACID PRODUCING SULPHUR % S	(a)		(b)		ACID SOLUBLE CAPACITY % CaCO ₃	EXCESS ALKALINITY CAPACITY % CaCO ₃
													HYDROLYZABLE % CaCO ₃	ACID HYDROLYZABLE CAPACITY % CaCO ₃	HYDROLYZABLE % CaCO ₃	ACID SOLUBLE CAPACITY % CaCO ₃		
100	0.84		SANDSTONE	Silty, dark grey fine grained coarse sand, occasional transition mudstone	55.34			20-1	1.03	3.9	0.03	0.03	0.09	0.03			0.74	
100	0.15		SILTSTONE	Dark grey	55.49			20-2	0.30	6.7	0.04	0.04	0.12	0.03			0.80	
50	0.28		MUDSTONE	Silty, dark grey of fine sand to silt	55.79			20-3	0.76	7.0	0.01	0.01	0.03	1.10			1.07	
100	0.84		SANDSTONE	Pale grey medium coarse grained fully impure, laminated	56.63			20-4	0.72	6.8	0.03	0.03	0.09	1.63			1.54	
100	0.50		SANDSTONE	Pale grey, coarse grained	57.13			21-1	0.80	7.0	0.04	0.03	0.09	1.75			1.66	
0.96			SANDSTONE	Dark grey, medium grained	57.35			21-2	0.52	7.5	<0.001	<0.001	<0.003	4.54			4.54	
67	0.16		SANDSTONE	Dark grey, medium grained	57.51			21-3	1.48	7.1	0.08	0.07	0.22	1.53			1.31	
					60.15													
96	2.80		SANDSTONE	Coarse grained, pale grey current bedded carbonaceous and micaceous laminae	60.95			22-1	1.37	6.6	0.28	0.18	0.56	2.05			1.49	
					62.37			22-2	1.06	6.5	0.05	0.05	0.16	1.48			1.32	
					62.97													
					64.55			22-3	0.05	7.1	0.06	0.05	0.16	1.33			1.17	
72	0.25		SILTSTONE	Dark grey mudstone	64.75			22-4	0.27	6.5	0.06	0.05	0.16	0.67			0.51	
100	0.28		SANDSTONE	Silty, at the bottom bedded	65.03			23-1	0.80	6.8	0.04	0.04	0.12	1.06			0.94	
67	1.26		SANDSTONE	Pale grey, coarse grained	66.27			23-2	0.75	5.9	0.05	0.05	0.16	1.15			1.35	
					66.75													
0.50			CAVITY		66.75													

Figure 4 Geological section and analysis results for borehole No. 3139 from 54.45m to 66.75m depth

ROCK QUALITY DESIGNATION T.M.C.D. (1)	CORE DIA Ø 931	BOREHOLE No 3141	SHEET 1	DEPTH (m)	LEGEND	CORE BOX No & RECOVERY	ANALYSIS SAMPLE No	SAMPLE THICKNESS (cm)	pH	ANALYSIS RESULTS							ACID POTENTIAL A - B D - G % CaCO ₃	EXCESS POTENTIAL B - G % CaCO ₃	
										SULPHUR TOTAL % S	POTENTIAL ACID PRODUCT % S	[G]		[D]		ACID POTENTIAL A - B D - G % CaCO ₃			EXCESS POTENTIAL B - G % CaCO ₃
												SULPHUR % S	INERTIAL % CaCO ₃	INERTIAL % CaCO ₃	INERTIAL % CaCO ₃				
CORE DESCRIPTION																			
—	1.30	BOULDER CLAY		1.30															
—	1.00	SANDY BOULDER CLAY		2.30															
—	0.55	SANDSTONE		2.85															
10	1.00	SANDSTONE Medium Coarse Grained Moderately indurated hard - well jointed		3.85															
40	1.20	SANDSTONE Medium Coarse Grained Moderately indurated in parts hard - fine medium bed 0.47 from top		5.05	① 100	1.1	2.20	7.0	0.20	0.18	0.56	2.77				2.21			
43	0.82	SANDSTONE Medium Coarse Grained Moderately indurated hard - well jointed		5.87		2.1	0.72	8.9	0.05	0.05	0.16	0.89				0.73			
5	0.18	COAL Dark Grey Laminated fine bedded - dark clayey		6.05															
0	0.64	COAL Medium bed indurated		6.76	② 100	2.2	0.93	9.9	0.43	0.39	1.22	0.81	0.41						
0	0.32	MUDSTONE Grey fine bedded		7.08		2.3	0.32	4.6	0.06	0.05	0.16	0.85				0.49			
0	0.23	COAL Bright		7.31		2.4	0.52	5.8	0.92	0.56	1.75	0.94	0.81						
0	0.33	MUDSTONE Dark, Moderate Dark Grey		7.62		2.5	0.51	4.5	0.01	0.01	0.03	0.42				0.39			
100	0.18	SANDSTONE Dark Grey		8.05															
66	0.72	SANDSTONE Medium Grained Light Grey Moderately Laminated		8.77															
8	0.18	SANDSTONE Moderately Bedded Clay Yellow		8.95															
81	0.87	SANDSTONE Medium Grained Off white		9.78	③ 100	3.1	1.82	4.4	0.13	0.12	0.37	1.02				0.65			
25	0.40	MUDSTONE Silty, Plant Remains		10.18															
0	0.29	COAL Bright Charcoal, indurated		10.48		3.2	0.38	3.8	0.37	0.33	1.03	0.82	0.21						
0	0.07	MUDSTONE Silty		10.77		3.3	0.39	3.6	5.32	4.37	13.64	0.53	13.11						
50	0.22	SANDSTONE Medium Grained		10.99		3.4	0.40	4.0	0.19	0.17	0.53	1.47				0.94			
0	0.18	SANDSTONE Dark Grey		11.27															
3	0.17	SANDSTONE Dark Grey		11.44															
3	0.17	SANDSTONE Dark Grey		11.61															
3	0.17	SANDSTONE Dark Grey		11.78															
3	0.17	SANDSTONE Dark Grey		11.95															
3	0.17	SANDSTONE Dark Grey		12.12															
3	0.17	SANDSTONE Dark Grey		12.29															
3	0.17	SANDSTONE Dark Grey		12.46															
3	0.17	SANDSTONE Dark Grey		12.63															
3	0.17	SANDSTONE Dark Grey		12.80															
3	0.17	SANDSTONE Dark Grey		12.97															
3	0.17	SANDSTONE Dark Grey		13.14															
3	0.17	SANDSTONE Dark Grey		13.31															
3	0.17	SANDSTONE Dark Grey		13.48															
3	0.17	SANDSTONE Dark Grey		13.65															
3	0.17	SANDSTONE Dark Grey		13.82															
3	0.17	SANDSTONE Dark Grey		13.99															
3	0.17	SANDSTONE Dark Grey		14.16															
3	0.17	SANDSTONE Dark Grey		14.33															
3	0.17	SANDSTONE Dark Grey		14.50															
3	0.17	SANDSTONE Dark Grey		14.67															
3	0.17	SANDSTONE Dark Grey		14.84															
3	0.17	SANDSTONE Dark Grey		15.01															
3	0.17	SANDSTONE Dark Grey		15.18															
3	0.17	SANDSTONE Dark Grey		15.35															
3	0.17	SANDSTONE Dark Grey		15.52															
3	0.17	SANDSTONE Dark Grey		15.69															
3	0.17	SANDSTONE Dark Grey		15.86															
3	0.17	SANDSTONE Dark Grey		16.03															
3	0.17	SANDSTONE Dark Grey		16.20															
3	0.17	SANDSTONE Dark Grey		16.37															
3	0.17	SANDSTONE Dark Grey		16.54															
3	0.17	SANDSTONE Dark Grey		16.71															
3	0.17	SANDSTONE Dark Grey		16.88															
3	0.17	SANDSTONE Dark Grey		17.05															
3	0.17	SANDSTONE Dark Grey		17.22															
3	0.17	SANDSTONE Dark Grey		17.39															
3	0.17	SANDSTONE Dark Grey		17.56															
3	0.17	SANDSTONE Dark Grey		17.73															
3	0.17	SANDSTONE Dark Grey		17.90															
3	0.17	SANDSTONE Dark Grey		18.07															
3	0.17	SANDSTONE Dark Grey		18.24															
3	0.17	SANDSTONE Dark Grey		18.41															
3	0.17	SANDSTONE Dark Grey		18.58															
3	0.17	SANDSTONE Dark Grey		18.75															
3	0.17	SANDSTONE Dark Grey		18.92															
3	0.17	SANDSTONE Dark Grey		19.09															
3	0.17	SANDSTONE Dark Grey		19.26															
3	0.17	SANDSTONE Dark Grey		19.43															
3	0.17	SANDSTONE Dark Grey		19.60															
3	0.17	SANDSTONE Dark Grey		19.77															
3	0.17	SANDSTONE Dark Grey		19.94															
3	0.17	SANDSTONE Dark Grey		20.11															
3	0.17	SANDSTONE Dark Grey		20.28															
3	0.17	SANDSTONE Dark Grey		20.45															
3	0.17	SANDSTONE Dark Grey		20.62															
3	0.17	SANDSTONE Dark Grey		20.79															
3	0.17	SANDSTONE Dark Grey		20.96															
3	0.17	SANDSTONE Dark Grey		21.13															
3	0.17	SANDSTONE Dark Grey		21.30															
3	0.17	SANDSTONE Dark Grey		21.47															
3	0.17	SANDSTONE Dark Grey		21.64															
3	0.17	SANDSTONE Dark Grey		21.81															
3	0.17	SANDSTONE Dark Grey		21.98															
3	0.17	SANDSTONE Dark Grey		22.15															
3	0.17	SANDSTONE Dark Grey		22.32															
3	0.17	SANDSTONE Dark Grey		22.49															
3	0.17	SANDSTONE Dark Grey		22.66															
3	0.17	SANDSTONE Dark Grey		22.83															
3	0.17	SANDSTONE Dark Grey		23.00															
3	0.17	SANDSTONE Dark Grey		23.17															
3	0.17	SANDSTONE Dark Grey		23.34															
3	0.17	SANDSTONE Dark Grey		23.51															
3	0.17	SANDSTONE Dark Grey		23.68															
3	0.17	SANDSTONE Dark Grey		23.85															
3	0.17	SANDSTONE Dark Grey		24.02															
3	0.17	SANDSTONE Dark Grey		24.19															
3	0.17	SANDSTONE Dark Grey		24.36															
3	0.17	SANDSTONE Dark Grey		24.53															
3	0.17	SANDSTONE Dark Grey		24.70															
3	0.17	SANDSTONE Dark Grey		24.87															
3	0.17	SANDSTONE Dark Grey		25.04															
3	0.17	SANDSTONE Dark Grey		25.21															
3	0.17	SANDSTONE Dark Grey		25.38															
3	0.17	SANDSTONE Dark Grey		25.55															
3	0.17	SANDSTONE Dark Grey		25.72															
3	0.17	SANDSTONE Dark Grey		25.89															
3	0.17	SANDSTONE Dark Grey		26.06															
3	0.17	SANDSTONE Dark Grey		26.23															
3	0.17	SANDSTONE Dark Grey		26.40															
3	0.17	SANDSTONE Dark Grey		26.57															
3	0.17	SANDSTONE Dark Grey		26.74															
3	0.17	SANDSTONE Dark Grey		26.91															
3	0.17	SANDSTONE Dark Grey		27.08															
3	0.17	SANDSTONE Dark Grey		27.25															
3	0.17	SANDSTONE Dark Grey		27.42															
3	0.17	SANDSTONE Dark Grey		27.59															
3	0.17	SANDSTONE Dark Grey		27.76															
3	0.17	SANDSTONE Dark Grey		27.93															
3	0.17	SANDSTONE Dark Grey		28.10															

ROCK QUALITY DESIGNATION	THICKNESS (m)	CORE DIA (mm)	BOREHOLE No	SHEET	DEPTH (m)	LEGEND	CORE BOX No. & RECOVERY	ANALYSIS SAMPLE No	SAMPLE THICKNESS (m)	pH	ANALYSIS RESULTS									
											SULPHUR TOTAL %S	POTENTIAL ACID PRODUCING %S	(a) INHERENT ACID NEUTRALISING CAPACITY % CaCO ₃	(b) ACID NEUTRALISING CAPACITY % CaCO ₃	ACTN PRODUCING POTENTIAL G - b % CaCO ₃	EXTRA NEUTRALISING CAPACITY b - a (% CaCO ₃)				
CORE DESCRIPTION																				
72	2.23										6.1	0.42	6.9	<0.01	<0.01	<0.03	4.36		4.32	
											6.2	1.05	7.2	<0.01	<0.01	<0.03	5.77		5.75	
					19.98						6.3	0.85	6.7	<0.001	<0.001	<0.003	2.85		2.85	
35	0.34				20.32						6.4	0.65	6.6	0.34	0.31	0.97	2.41		1.44	
	0.43				20.75						7.1	0.79	6.5	0.07	0.06	0.19	2.40		2.21	
0	1.41				22.16						7.2	0.78	6.7	0.06	0.05	0.16	2.16		2.00	
					22.59						7.3	0.73	6.2	0.24	0.22	0.69	1.31		0.62	
50	0.74				23.32						8.1	0.55	5.6	0.25	0.23	0.72	1.70		0.98	
					23.92						8.2	0.83	6.1	0.65	0.60	1.87	1.33	0.54		
					24.64						8.3	0.24	6.1	0.19	0.17	0.53	1.46		0.93	
					24.91						8.4	0.18	6.2	0.04	0.04	0.12	1.88		1.76	
					26.87						9.1	2.12	6.3	0.16	0.14	0.44	0.75		0.31	
85	2.12				27.40						9.2	0.53	6.3	0.16	0.14	0.44	1.12		0.68	
					28.16						10.1	0.74	6.6	0.03	0.03	0.09	1.91		1.82	
0	0.93				28.38						10.4	0.40	6.5	0.76	0.73	2.28	2.02	1.71	1.90	
					28.73						10.5	0.16	6.3	0.26	0.23	0.72	1.67		0.95	
0	0.30				28.91						10.6	1.05	4.2	2.73	2.56	7.93	2.09	5.90		
					29.31						11.1	0.46	4.8	3.34	3.10	9.68	0.68	9.00		
100	0.19				30.00						11.2	0.30	6.4	0.45	0.41	1.28	0.80	0.48		
					30.40						11.3	0.58	6.5	0.42	0.38	1.19	1.29		0.10	
					30.76						11.4	0.45	6.3	0.13	0.12	0.37	0.84		0.47	
					32.41						12.1	0.66	4.6	0.18	0.16	0.50	0.27	0.23		
					32.62						12.2	0.41	4.4	1.00	0.66	2.06	0.68	1.38		
					32.81						12.3	0.49	6.0	0.15	0.14	0.44	0.40	0.04		
100	0.44				33.25						12.4	0.49	6.6	0.05	0.05	0.16	0.35		0.19	
0	0.30				33.45						13.1	0.73	6.7	0.02	0.02	0.06	2.21		2.15	
0	0.10				34.67						13.2	0.43	6.9	0.16	0.14	0.44	2.07		1.63	
0	0.25				35.13						13.3	0.13	6.9	0.75	0.74	0.66	1.76		1.29	
0	0.19				35.38						13.4	0.77	6.3	0.87	0.48	1.50	1.21	0.29		
0	0.10				35.61															
0	0.23				35.98															

Figure 6 Geological section and analysis results for borehole No. 3141 from 17.75m to 35.98m depth

ROCK QUALITY DESIGNATION	CORE DIA. mm	CORE THICKNESS (m)	BOREHOLE No.	SHEET	DEPTH (m)	LEGEND	CORE BOX No.	ANALYSIS No.	SAMPLE THICKNESS (mm)	pH	ANALYSIS RESULTS					
											SULPHUR TOTAL % S	POTENTIAL ACID PRODUCING SULPHUR % S	INDUSTRIAL SULPHUR % S	ACID NEUTRALISING CAPACITY % CaCO ₃	ACID PRODUCING POTENTIAL a - b % CaCO ₃	EXCESS NEUTRALISING CAPACITY b - a % CaCO ₃
			3141	3												
			CORE DESCRIPTION													
100	0.18		SILTSTONE	From Next Blasts Dark Grey	36.08											
85	2.62		SANDSTONE	Medium to Coarse Grained Silty Micaceous Laminar	38.70		100	14.1	2.80	6.3	0.32	0.29	0.91	1.86		0.95
92	1.32		SANDSTONE	Med Grey Silty Micaceous Shaly & clay	40.03		97	15.1	1.32	5.8	<0.01	<0.01	<0.03	2.71		2.65
0.41			COAL	Broken Black	40.53											
0.06			MUDSTONE	Coarse Black Pellet	41.10											
0.61			COAL	Clayey	41.70			15.2	1.58	5.6	1.02	0.63	1.97	0.88	1.09	
0.02			MUDSTONE	clayey	41.70											
0.58			COAL		41.70											
0.08			MUDSTONE		41.70			16.1	0.24	6.8	0.08	0.07	0.22	1.06		0.84
0.16			SILTSTONE	Dark Grey Firm	41.95											
87	1.44		SANDSTONE	Med Grey Coarse Grained Silty & Micaceous Laminar	43.38		100	16.2	1.44	7.4	<0.01	<0.01	<0.03	4.72		4.70
86	1.12		SANDSTONE	Silty Dark Grey Abundant Pellet Remains Silty Micaceous Laminar Sub Vertical joints	44.50			16.3	1.12	7.0	0.06	0.05	0.16	2.73		2.57

Figure 7 Geological section and analysis results for borehole No. 3141 from 35.09m to 44.5m depth

Analysis

- In order to measure pH 8g of the crushed sample were shaken with 20ml 0.01M CaCl_2 for 45 minutes and the pH determined using a glass electrode.
- The moisture content of each sample was determined by drying to constant weight at 105°C under oxygen free nitrogen in a minimum free space oven. All sulphur and A.N.C. results were expressed on a dry basis.
- Acid Neutralising Capacity (A.N.C.) was determined by taking a known weight of the material which was refluxed with 0.25M - HCl and the resultant suspension titrated to pH 8.3 with 0.1M Na OH. The A.N.C. was calculated as the amount of acid, expressed as % CaCO_3 , neutralised by the sample.

The blank tests (sample plus water without acid, and acid without sample) described by Costigan, Bradshaw and Gemmell were carried out on a cross section of the samples which had either a higher sulphur content or which gave a lower pH. However the blank values obtained made negligible difference to the final results, possibly due in part to lack of oxidation of any sulphur present. These blank tests were accordingly omitted for the rest of the samples in order to minimise the laboratory work-load. [4]

- The total sulphur content of each of the samples was determined using a Leco SC32 Sulphur Analyser (See Note below). "Forms of Sulphur" were then determined on a cross section of the samples as follows :
- In order to assess Organic Sulphur about 2g of sample, weighed accurately was refluxed with 100ml boiling 2M - HNO_3 for 30 minutes to extract both sulphate and pyritic sulphur. After extraction the suspension was cooled, filtered, and washed through a weighed glass fibre filter under vacuum, the remaining solids then being dried and weighed. The sulphur content of the dried solids was then determined on the Leco SC32 and the result calculated to the original basis, allowing for loss in weight during the acid extraction.
- Organic plus pyritic sulphur - the above procedure was repeated, this time 5g of sample being refluxed with 50ml 5M - HCl to extract the sulphate sulphur. The remaining pyritic plus organic sulphur was determined on the Leco SC32, corrections again being made for loss in weight during the extraction.

For samples containing no or low amounts of carbonaceous matter it is essential to add about 1 - 2g V_2O_5 powder (see Leco SC32 instruction manual) to ensure full release of the Sulphur.

The most effective procedure was found to be:-

1. Spread on thin layer of V_2O_5 over the bottom of the combustion boat.
2. Weigh sample into boat and thoroughly mix with about 1g V_2O_5
3. Spread a thin layer of V_2O_5 over the sample mixture
4. Note total weight of V_2O_5 used in order to apply correction for its inherent sulphur content.

These were indications in tests carried out and two of the samplers that the use of V_2O_5 was not essential on the acid extricated residues in the "Forms of Sulphur" analyses, but this has yet to be confirmed.

The individual "Forms of Sulphur" were then obtained as follows :-

- (i) Total Sulphur - determined directly.
- (ii) Sulphate Sulphur - Total Sulphur - (Organic and Pyritic Sulphur).
- (iii) Pyritic Sulphur - (Organic and Pyritic Sulphur) - Organic Sulphur.
- (iv) Organic Sulphur - determined directly after extraction.

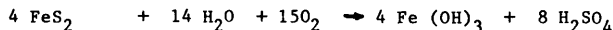
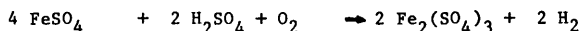
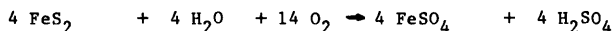
As stated above "Forms of Sulphur" were estimated on a cross-section of the samples[6]. From these samples it was seen that the sulphate content was consistently low, even where some oxidation might have been expected.

Number of Sulphate determination - 20.
Range of Sulphate content - Nil - 0.06.

% Sulphate Sulphur	No. Samples
NIL	5
0.01	5
0.02	5
0.03	1
0.04	2
0.05	1
0.06	1

Table 1
Distribution of Sulphate Sulphur Sample Analysis

Because of the large number of samples involved it was accordingly decided that no further sulphate estimations be carried out. Also, because of the workload involved it was decided that, in addition to the samples already analysed, organic sulphur would only be determined where the total sulphur was 0.5%, and that the ratio of organic to total sulphur be calculated. This ratio was found to be 0.1 and it was then assumed that the pyritic sulphur was (0.9 x Total Sulphur) for all samples with total sulphur contents of less than 0.5%. It was also assumed that all the pyritic sulphur would be oxidised to sulphuric acid and the % CaCO_3 required to neutralise this acid was calculated.



i.e. 1g sulphur would produce 3.059g H_2SO_4 which would then require 3.121g CaCO_3 for neutralisations (i.e. 1% Sulphur = 3.121 A.N.C.). The following table shows the values obtained for pH, sulphur and A.N.C. values, together with the figure taken for Potential Acid Producing Sulphur. This latter figure is also shown as the theoretical % CaCO_3 required for neutralisation.

Where this figure is greater than the A.N.C., the difference between them is taken as the "Acid Producing Potential". Where the A.N.C. is greater than the % CaCO_3 required for neutralisation of the acid products the difference is taken as the "Excess Neutralising Capacity".

Although these average figures show that there is a theoretical overall excess of Neutralising Capacity, examination of the individual results shows that for BH.3139 there are 12.41m and for BH.3141, 5.22m of potentially acid producing strata. Coal subsections or part sections were excluded from the calculations as it was assumed all coal would be excavated and not used for backfilling.

B.H. No.	Average Potential Acid Producing Sulphur %S	(a) Average Theoretical Neutralisation Requirement % CaCO_3	(b) Average Acid Neutralising Capacity - A.N.C. % CaCO_3	Average Excess Neutralising Capacity (b - a) % CaCO_3
3139	0.52	1.63	6.12	4.49
3141	0.26	0.82	1.90	1.08

Table 2 - overall average values, in proportion to sample thickness, for the potential acid producing sulphur, theoretical neutralisation requirement, acid neutralising capacity and excess neutralising capacity.

B.H. No.	Total Thickness (m) (excluding coals)	Average Potential Acid Producing Sulphur %S	(a) Average Theoretical Neutralisation Requirement % CaCO_3	(b) Average Acid Neutralising Capacity - A.N.C. % CaCO_3	Average Acid Producing Potential (a - b) % CaCO_3
3139	12.41	1.43	4.46	2.26	2.20
3141	5.22	1.01	3.42	1.16	2.26

Table 3 - potential acid producing strata - average values in proportion to sample thickness.

SUMMARY OF RESULTS

The average theoretical Acid Producing Potentials of these particular strata on their own are greater than those which are known to give severe acid ferruginous pollution.

Assuming that the thickness found in the borehole core samples are representative of the site as a whole then this represents $124,100\text{m}^3$ of potentially acid producing material per hectare of site surface area identified in BH.3139 and $52,200\text{m}^3$ potentially acid producing material per hectare identified in BH.3341. Assuming an in situ bulk density of between 1.8 and 2.0 tonnes/m^3 for the strata then there could be between 223,400 and 248,000 tonnes of material with an average Acid Producing Potential of 2.20% as CaCO_3 and between 93,960 and 104,440 tonnes with an average Acid Producing Potential of 2.26% as CaCO_3 , per hectare of site area.

The total CaCO_3 equivalent required to neutralise these tonnages could therefore be between about 7,000 and 7,800 tonnes per hectare of site surface area (this is equivalent to the production of between about 6,800 and 7,600 tonnes sulphuric acid per hectare of site surface area).

However, strongly neutralising strata were also identified, particularly in BH.3139, where there were 5.96m with individual Excess Neutralising Capacities greater than a pH of 6.0. The average of these, in proportion to sample thickness was 35.66% as CaCO_3 . Of this 5.96m, 3.35m had an average Excess Neutralising Capacity of 56.89% as CaCO_3 . Assuming an in situ bulk density of 2.0 tonnes/m^3 for these strata this gives a total CaCO_3 equivalent of 42,500 tonnes/ha for the 5.96m strata and 38,120 tonnes/hectare for the 3.35m strata on its own.

Even this latter, lower, figure is theoretically more than sufficient to neutralise the total amount of acid which could be produced. Ochreous deposits on large pieces of limestone would seal off all but the thin surface layer and render the remainder ineffective.

In order to ease the workload on the laboratory, and to produce the results fairly quickly several assumptions were made at various stages, the principle being:-

- That in samples of 0.5% of total sulphur, the pyritic sulphur was $0.9 \times \text{Total Sulphur}$.
- That all "pyritic" sulphur would be oxidised.
- Similarly, that the theoretical A.N.C. obtained in the laboratory would be achieved in practice.
- Average results were taken in proportion to sample thickness, the specific gravity of the materials not being protaken into account.
- Similarly the bulk densities the in-situ matmaterial were assumed.
- In addition no allowance could be made at this stage to the Acid Neutralising Capacity for the effect of long term exposure to possibly slightly acid, peaty water which could occur on site.

However it is felt that these assumptions were reasonable within the context of the exercise and do not invalidate the results which have not only identified potentially acid producing material but have shown possible methods of treatment, should it not prove possible to dispose of this potentially polluting material in such a way as to eliminate contact with water.

CONCLUSIONS

The results of the particular site under analysis have shown that, although there are individual strata which have a high pollution potential, the average analysis for the full strata sequence to be excavated show an excess of neutralising capacity i.e. the resultant backfill should not be

polluting. The possibility of acid ferruginous springs forming at this particular site if the groundwater table rebounded to surface on cessation of mining is therefore remote. The strata with the highest acid producing potential were the ironstone bands usually containing both siderite and iron pyrites. Ironstone bands are quite common in coal-bearing strata and at mines where they predominate in the sequence then a quite high overall acid producing potential can result. Quite often the major iron bearing strata has been worked in the past using pillar and stall underground mining methods. The workings allow oxygenated air to circulate round the iron rich cavity walls and pillars resulting in acid ferruginous groundwater flow within the voids that may connect through high walls in the surface mine.

Where a pollution potential has been identified from laboratory analyses then remedial measures will need to be planned for in the mining process. These remedial measures can take the form of either preventing the groundwater from rising through the backfill or physically affecting the fill so that it becomes non-polluting. Much more research is needed in this respect and to be effective should be large-scale, on-site investigations of the different methods available.

Usually the pavement of the excavation area is a fireclay or seatearth occurring below the lowest seam to be worked and this would be naturally impermeable as long as it was not severely disrupted by blasting or vehicular movement. A possible method of reducing pollution would be to induce the groundwater springs to issue at surface either before it reaches the backfilled void or after it has only passed through a small part of it. This could be done by raising the final surface contours on restoration of the site with an impermeable layer of drift superimposed on the fill. However, it is important not to inhibit the flow within the fill by too much as this slower rate would give the groundwater a greater opportunity to pick up polluting chemicals from the material.

Bactericides have been used on a small scale in the United States [7] but the authors do not think the method would be cost effective in larger surface coal mining environments.

It would appear that the best method of success would be a permutation of some or all of the above methods and each mine environment would need to be treated as a separate entity.

The research project as outlined in this paper has shown that it is possible to analyse the pollution potential of strata at a proposed future mine site and that the determination of the pyritic content of the material to be excavated can be applied as a matter of routine. Once further research into cost effective remedial matters has been completed then it should be possible to eliminate the possibility of pollution on groundwater rebound by judicious mine planning.

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