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BIOLOGICAL AMELIORATION OF ACIDIC SEEPAGE STREAMS

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ABSTRACT

Wetland and lake sediments provide conditions where microbial sulphate reduction and biomineralization occur. These processes can assist in the amelioration of acid mine drainage emerging from pyritic mining wastes. The biological neutralization of mine water however, requires specific conditions that allow anaerobic and aerobic decomposition of organic materials to take place, together with alkalinity generation and sulphate reduction.

This paper reports on the work leading up to the construction of a test facility in Sudbury, Ontario, Canada. A 4-cell test system was installed where flow can be controlled from a minimum of 1.4 - 3 L/min to a maximum of 150 - 200 L/min. The seepage characteristics in the system have been determined in order to define the physical, chemical, and biological requirements for the process.

Keywords: Bacterial sulfate reduction, biomineralization, alkalinity generation, anaerobic decomposition.

INTRODUCTION

Acid mine drainage (AMD) from pyritic wastes produced by mining operations is a major environmental problem. Field and laboratory investigations have been carried out since 1986 to define conditions that facilitate microbial alkalinity generation, the natural counterpart to microbial acid generation.

AMD waters are nutrient poor, high in heavy metals (10^1 to 10^3 mg/L) and high in acidity (10^2 to 10^3 mg $CaCO_3$ equiv/L). These conditions are significantly different than those found in natural sediments, where alkalinity generation, in part caused by sulphate-reducing bacteria, can take place (Mills et al., 1989. Davison and Woof, 1990). Sulphate-reducing bacteria are reported to require pH conditions of at least 4.2 for their growth (Trudinger, 1979). Most of the AMD seepages from base metal wastes arc commonly less than pH 3.

For a microbial ecosystem to generate alkalinity within these AMD waters, the bacteria initially colonizing the AMD environment must be tolerant of its harsh chemical conditions. Therefore, until it can be established that colonization of these conditions by alkalinity-generating communities is possible, a biotechnological approach to the amelioration of AMD remains in question. Colonization of organic matter by the required bacterial community was reported in coal AMD (Kalin et al., 1990; Tuttle et al., 1969; Hedin et al., 1988; Hammack and Hedin, 1989; Mclntire and Edenborn, 1990). Similar results have been limited to pilot scale tests for AMD from base metal operations (Wildeman et al. 1990).

This paper reports on the tests carried out in various AMD seepages, which led to the construction of a test facility for the ARUM process (Acid Reduction Using Microbiology) in AMD from a tailings area near Sudbury, Ontario, Canada, as a component of Canada's Mine Environment Neutral Drainage Program (MEND) (Filion et al., 1990).

With this test facility, it is hoped to define the chemical, physical and biological parameters under which the ARUM process could be utilized to ameliorate AMD.

Organic Amendment Tests

In 1985, a seepage creek on a pyrrhotite-covered tailings area near Sudbury was divided into sections, to test different organic materials as microbial growth amendments. One of the sections in the creek, which had received straw, produced positive results in *1986.* The red-coloured seepage containing ferric iron turned clear, indicating that the ferric iron had been reduced to ferrous iron. Once straw/hay had been identified as a suitable substrate in this pyrrhotite-based seepage, field tests were initiated at other mine sites (coal, uranium, and nickel). Different substrate combinations (organic and inorganic) were used to increase the surface area for microbial colonization and, at the same time, allow flow through the amendment. The amendment was mixed with different sized rocks and plastic cooling tower balls and placed in cages made out of snow fencing. After 3 months, no pH increases were noted in the cages with the amendment.

The contents of the field cages from all sites were collected and brought to the laboratory, where they were placed in 4.2 L glass jars. Within 10 days, the pH started to rise, and simultaneously, blackened areas developed on the material. pH was monitored for eight months. The delineation between blackened and clear regions in the jars was used to differentiate the location at which pH readings were taken.

In Table 1, data from the field cages and laboratory observations are summarized. At all field locations, with the exception of the seepage from nickel tailings (Makela), pH values were 3 or lower. The differences in pH were evident between different treatments and AMD origin. For example, treating uranium AMD with a mixture of small rocks and amendment showed only a small increase in pH from 2.4 to 3 in the blackened region. By comparison, the AMD from pyrrhotite produced pH increases of 2 to 3 units in the blackened region in 5 out of 8 treatments. No clear regions remained in the jar at the end of the experiment. In coal AMD, 2 of 5 treatments produced pH improvements, whereas the seepage from nickel tailings, which was only partly oxidized at the time of collection, produced a pH range of 5.4 to 7.9 in both the clear and blackened regions of the jar.

Although these are only qualitative observations, the results indicated that it should be possible to define those conditions that allow alkalinity génération in base metal AMD. Further discussion of these experiments is given by Kalin (1990). No pH increases were found when the material was placed in seepages, where the flow conditions could not be defined. However, when retained in enclosures, the microbial community appeared to generate alkalinity. Therefore, a test facility was required where the flow could be controlled.

Site Selection

Seepages are frequently associated with tailings dams. They are generally collected in ponds and pumped to a treatment area, or the water is recycled to the tailings ponds. Along the Copper Cliff tailings dam (Inco, Sudbury), several pumping stations exist and intermittent and/or continuous flows are collected. Based on a survey of these flows carried out in 1988, the Makela seepage area was determined to be most suitable for the construction of the experimental test cell system.

MINE SITE/TREATMENTS	Clear Water			Blackened Water		
URANIUM	pH	Temp (C)	Cond(25C)	pH	Temp (C)	Cond(25C)
At Cage placement: Jul 19,89	2.35+/-0.11(N=19)					
At cage collection:Sep 28,89	2.1					
At jar setup: Sep 30,89	2.0 (Control)					
At jar takedown:June 7-11,90						
Straw	2.4	21	5400	2.6	22	6360
Flax (C)	2.4	23	6032			
Small Rocks(Straw)	2.4	23	6136	3.0	23	6136
Large Rocks(Straw)	2.4	23	5720	2.5	24	4590
Spheres & Straw	2.0	25	4400			
Old Flax	1.9	23	6188			
PYRRHOTITE	pH	Temp (C)	Cond(25C)	pH	Temp (C)	Cond(25C)
At Cage placement: Jul 19,89	3.0					
At cage collection:Sep 29,89	3.0					
At jar setup: Sep 30,89	2.9 (Control)					
At jar takedown:Jun 15-18,90						
Large Rocks(Straw)				5.1	23	4368
Straw				3.4	22.5	3098
Flax & Spheres				5.3	22	3095
Flax (C)				6.1	22	2025
Small Rocks(Straw)				3.3	23	3120
Straw & Spheres				5.4	22.5	3255
Flax B1 1				7.5	22	1611
Flax B1 2	2.6	22.5	1985	3.1	23	1966
Old Flax	2.7	23	2257			
COAL	pH	Temp (C)	Cond(25C)	pH	Temp (C)	Cond(25C)
At Cage placement: Jul 25,89	2.8					
At cage collection: Sep 6,89	2.2					
At jar setup: Sep 7,89	4.5 (Control)					
At jar takedown: Jun 6, 90						
Small Rocks(Straw)				3.7	23	1820
Straw				6.8	22	435
Spheres & Straw	3.3	22	1908	3.8	19	2094
Spheres & Straw	5.1	20	1265	5.9	21	1318
Large Rocks(Straw)	3.3	22	1961	3.5	21	2030
NICKEL	pH	Temp (C)	Cond(25C)	pH	Temp (C)	Cond(25C)
At Cage placement: Jun 20,89	5.4					
At cage collection:Sep 29,89	5.4					
At jar setup: Sep 30,89	6.0 (Control)					
At jar takedown:Jun 12-14,90						
Flax (C)				7.7	23	1144
Large Rocks(Straw)				7.4	21	1092
Small Rocks(Straw)				7.5	22	943
Flax & Spheres	7.7	22	657	7.7	22	689
Spheres & Straw				7.9	21	756
Straw	7.7	22	620	7.5	22	737
Mak Flax				7.4	22.5	2783
Seepage Flax				7.6	22	2703

TABLE I: Enclosed jar experimental results from uranium, pyrrhotite, coal and nickel AMD.

Test Cell System

The test site covers an area of approximately 1800 m^2, is about 90 m long, and is situated parallel to the toe of the dam, with a width of about 20 m. The conditions at this site were far from ideal for construction of cells with flow control. However, they reflect typical conditions at the toes of tailings dams with AMD seepages. The cell system and its flow control mechanisms are presented in Figure 1.

The rate of "through flow" in the test cell system is determined by the discharge of the seep, and the seepage front from the toe of the tailings dam entering the bypass channel. A weir in the bypass channel (A) facilitates control over inflow into the system.

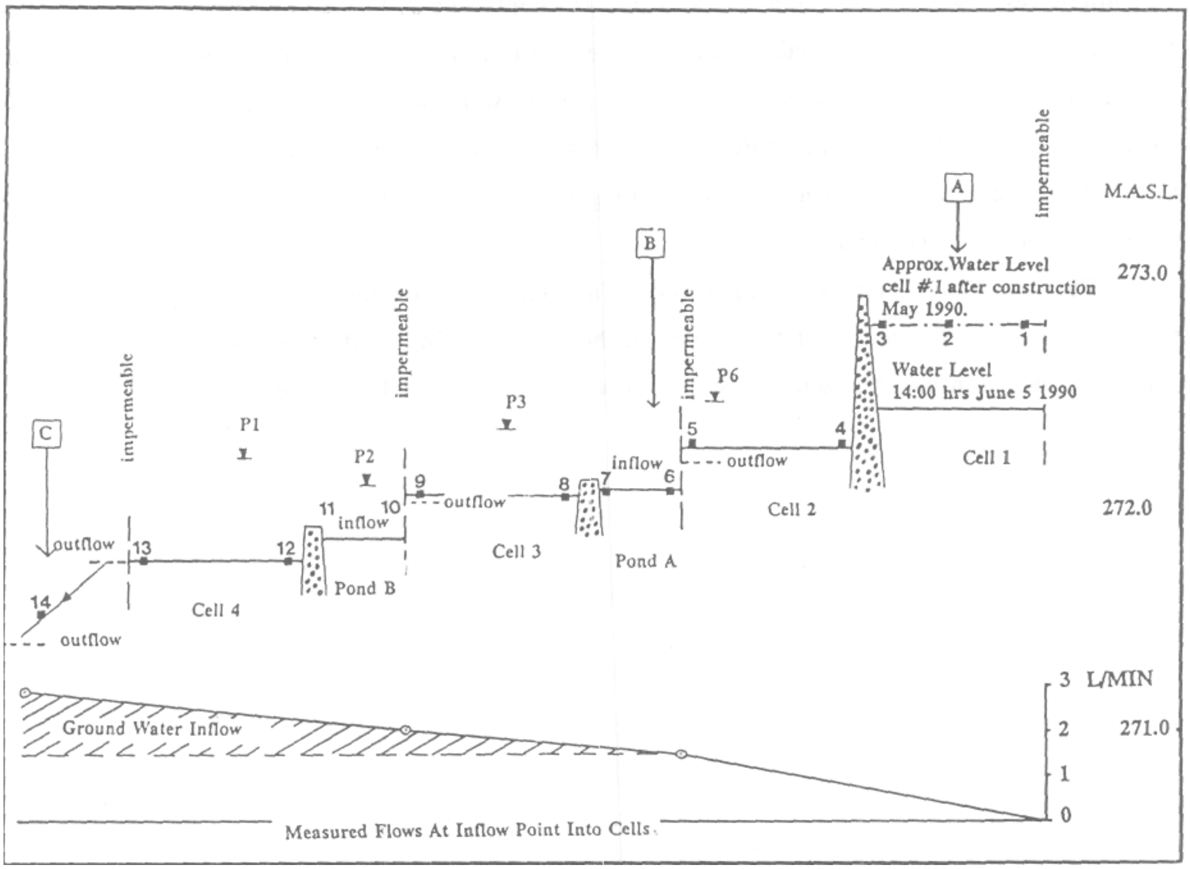

FIGURE 1: Schematic of the Makela test site showing waters and flows in the test cells prior to entry of seepage into the system on June 6, 1990. P numbers are piezometers, numbers are fixed sampling locations. See text for further explanations.

When no flow enters cell 1, ground water contribution in cell 4 can be as high as 3 L/min. In order to control the rate of flow through the system, the water level at (A) can be adjusted, but primary flow control occurs at control valve at (B), and seasonal adjustments can be made with riser pipes at the impermeable dam at (C) (Figure 1). Fine tuning the system took a considerable amount of trial and error, details of which are given in Kalin (1990). The minimum flow that can be obtained is 1.4 L/min, whereas the maximum flow is 150 - 200 L/min. Testing of the system with amendment placement started at a flow-through rate of 3 L/min.

Organic Amendment Placement

The jar experiments with amendment contained a volume of 4.2 L of AMD. An average cell (depending on water level) can be assumed to contain about 40 m^3, with a total system volume of 300 m^3. Thus, differences in scale between the laboratory and the field test cells had to be addressed. Reaction vessels, referred to as ARUMators, were fabricated from used 19OL plastic drums after extensive washing. On site, they were allowed to stand in AMD seepage for 1 h, and the water was discarded. Pipes (ABS, 3.8 cm diam.) were installed as sampling ports at different levels (top, middle, bottom). Five iron rods of 60 cm lengths (rebar; 1.3 cm) were placed in each ARUMator along with flax straw, small rocks and AMD water. The drum was sealed with silicon caulking.

The ARUMators serve several purposes. They allow measurement of microbial activity through gas evolution, sampling of water at different levels in the drum and finally, after alkalinity generation has been established, the drums can be used as a microbial seed for the test cells at large.

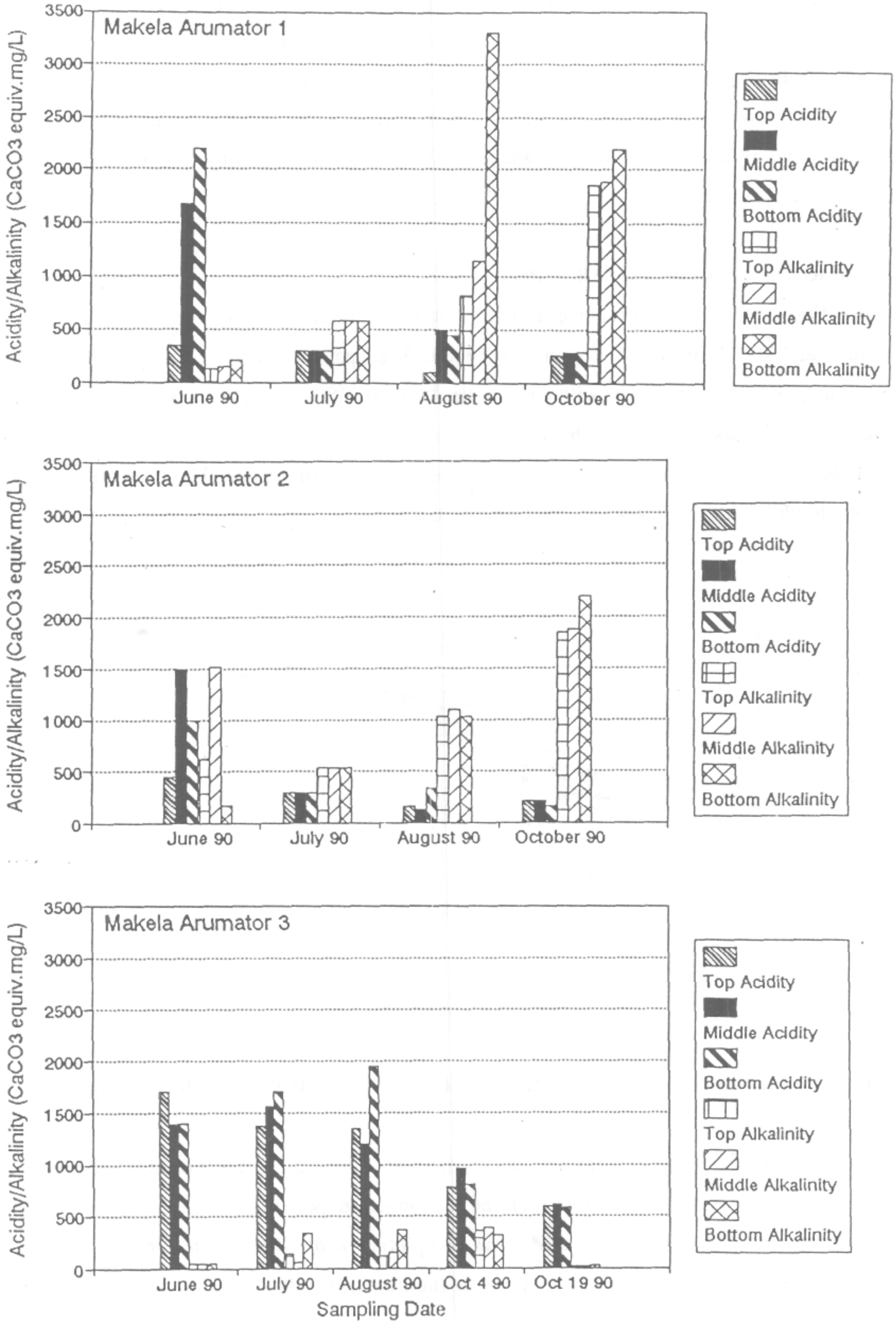

FIGURE 2: Acidity and alkalinity values for ARUMators at the Makela test site, Sudbury, at 4 different times in *199(1* A) ARUMator 1, B) ARUMator 2, C) ARUMator 3.

In Figures 2a-c, the replacement of acidity with alkalinity in the AMD is presented for three ARUMators. ARUMators 1 and 2 are 190 L drums, whereas ARUMator 3 contains 540 L of AMD with amendment, as an inner sleeve in a 2270 L Fiberglas tank. This ARUMator was installed at the outflow of the test cell system in order to batch treat AMD. Essentially, all the acidity was replaced by alkalinity between June and October 1990 in ARUMators 1 and 2. In ARUMator 3, the onset of alkalinity generation was somewhat slower (Figure 2c).

Water Characteristics of the Test Cell System

Acidification of mine drainage is a function of the total Fe content, the ferric/ferrous ratio, temperature and the diffusion of oxygen. In Figure 3, seepage behaviour is depicted, under laboratory conditions, upon continuous stirring with a magnetic stirrer at 23^0C. It can be seen that complete acidification of the seepage water takes 216 h, at which time the pH has dropped to a value of 2.3. A decrease in acidity occurred due to the oxidation of Fe^{2+} to Fe^{3+} without precipitation of $Fe(OH)_3$. The pH values in the test cell system should similarly reflect the flow-through conditions.

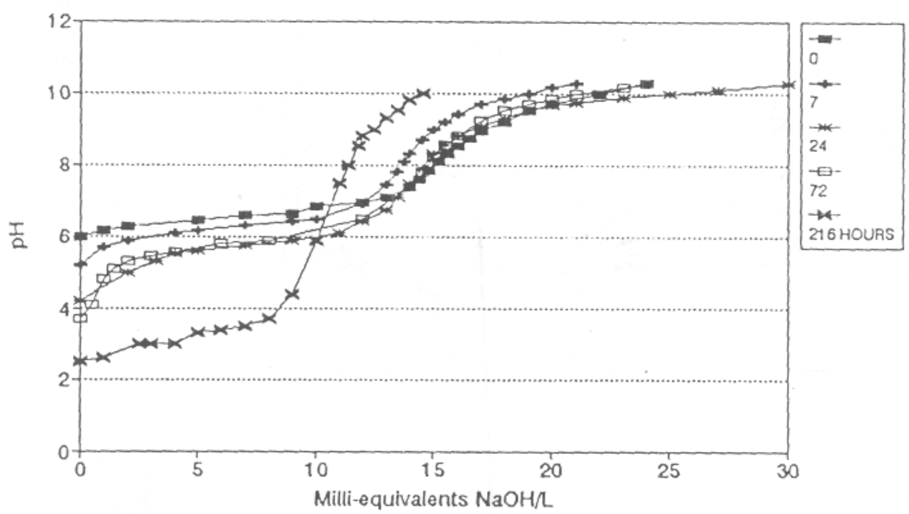

FIGURE 3: Makela seepage acidity titrations after vigorous stirring for different lengths of time.

In Figure 4, pH values measured in the system before flow control was established are given. At the outflow, station 14 (location given in Figure 1), the pH ranged (depending on the season) from 4.8 to 4. After flow control was established at 3L/min, AMD was completely oxidized before leaving the system (Figure 5). The precipitation of iron hydroxide was confined to the first two cells in the test system.

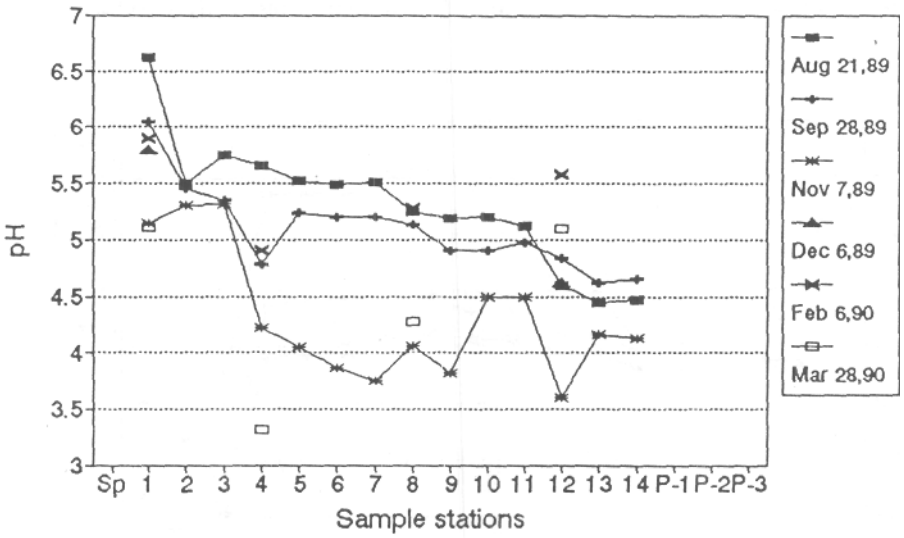

FIGURE 4: Bulk water pHs in the Makela test system between August 21, 1989 and March 28, 1990, before flow control was established.

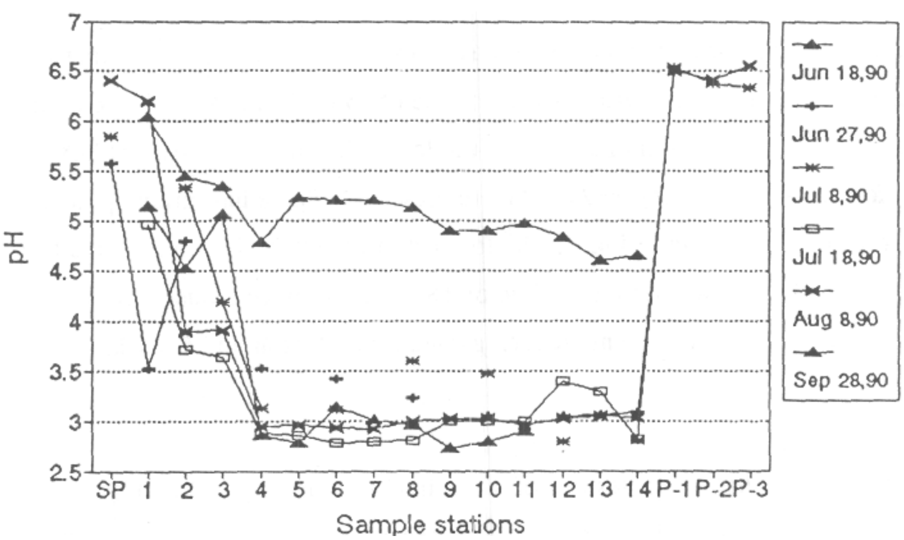

FIGURE 5: Bulk water pHs in the in the Makela test system between June 18 and September 28, 1990, after flow control was established at 3L/min.

The concentrations of the metals Q), Cu, Ni and Zn in the test cell system are given in Figure 6. Between the inflow and the outflow of the system (Station SP and Station 14) Co concentrations remained steady, while the Cu ranged from 0.06 to 2 mg/L, Ni ranged from 15 to 20 mg/L, and Zn ranged from 0.5 to 4.0 mg/L. These metal concentrations represent background data, while reductions in their concentrations are expected upon establishment, in the future, of a microbial system in test cells 3 and 4.

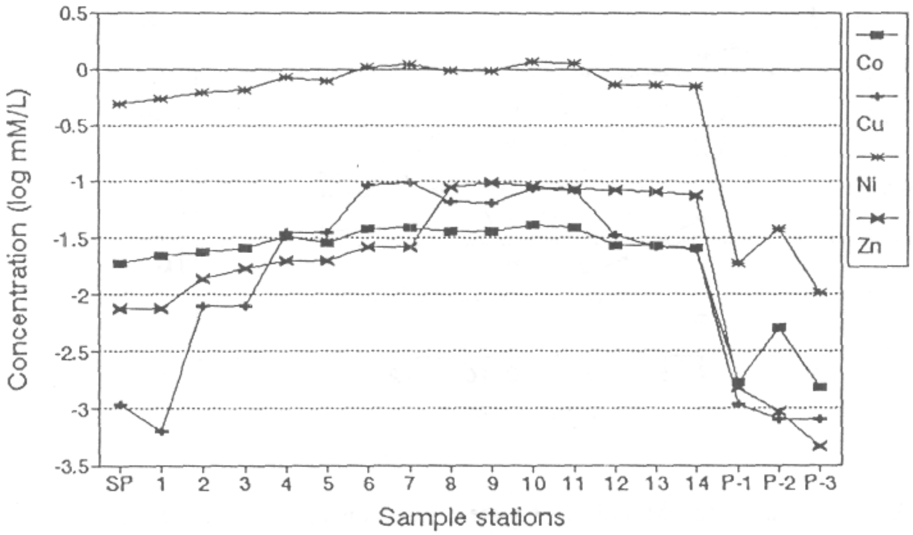

FIGURE 6: Trace metal concentrations in the Makela test cells on August 8, 1990.

Amendment Placement in Test Cells

In the test cells, the organic amendment was distributed in curtains consisting of 8 bales of flax between snow fencing material. Each curtain has a volume of about 3 m^3. A total of 6 curtains were placed in the two amendment cells. The system has been at the low flow status since August 1990. In Figure 7, the pH and Eh values for the system on August 24, 1990 are presented. Some indication of the onset of microbial alkalinity generation can be noted in cell 4. In the lower part of cell 4, pH values range from 4.0 to 6.5, as compared to the surface sheet flow, with a pH value of 2.8. The Ehs were reduced from 603 m V to 193 mV. An Eh value of less than 300 mV represents reducing conditions (Gotoh and Patrick, 1974).

CONCLUSIONS

The results indicate that, in enclosures of 4.2 L in the laboratory and in 190 L drums in the field, acidity in AMD from base metal tailings can be replaced with alkalinity. A test cell system has been constructed, and at low flow conditions (3 L/min), alkalinity generation appeared to have been present on August 24, 1990.

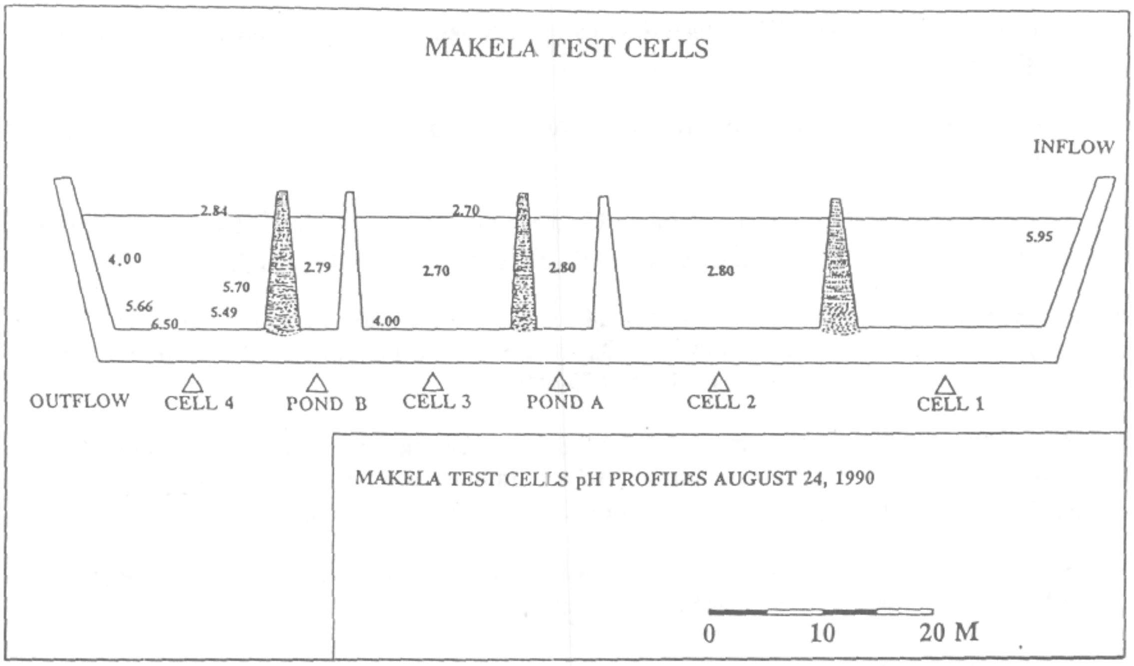

FIGURE 7: Bulk water pH and Eh values from profiles taken on August 24, 1990

The microbial alkalinity generation demonstrated in the ARUMators and the first indication of pH increases and reducing conditions in the cells in the field lead to the conclusion that AMD amelioration may be achieved through biotechnological means by continued research, furthering the understanding of the parameters that control the ARUM Process.

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