EVALUATION OF A COMPOSITE SOIL COVER TO CONTROL ACID WASTE ROCK PILE DRAINAGE[1]

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Abstract: Acid mine drainage (AMD) research under the MEND program has been ongoing since 1988 at the Heath Steele Mines waste rock piles including sulfide material, outside Newcastle, NB. In 1989 approximately 10,000 mt of waste rock was placed on a prepared sand base with an underlying impermeable membrane. The waste rock pile was heavily instrumented for oxygen concentrations and temperatures measures. In September 1991, a composite soil cover designed for the Heath Steele climatic conditions using local soils was placed over the pile, creating a totally enclosed system. Moisture content and oxygen probes were installed within the composite soil cover to monitor changes within the soils over time, while two large-size lysimeters were installed below the cover to monitor the hydraulic conductivity of the cover. The waste rock site has been monitored on a monthly basis since installation of cover for performance of both cover and waste rock. The monitoring shows very clearly that the placement of the composite soil cover has had a major impact on the generation of AMD. Major reductions in temperature and oxygen concentrations within the waste rock pile indicate that the cover has significantly inhibited the oxidation reaction that generates the AMD. Performance data have shown that the cover has maintained its integrity under the climatic conditions of the area.

Additional Key Words: acid mine drainage, acid waste rock pile cover, waste rock oxidation reduction.

Introduction

The Heath Steele Mine site in northeastern New Brunswick provides a unique opportunity to evaluate management techniques for acid waste rock under practical field conditions. The massive sulfide deposits at Heath Steele were developed in the late 1950's before the implications of acid drainage were fully appreciated. The highly pyritic waste rock encountered in the course of mining operations was stockpiled at various locations across the site and in some instances was used in the construction of haul roads and other infrastructure. Currently there are more than 20 acid-generating waste rock piles of various sizes and configurations located across the site.

A recent study of acid waste rock management at Canadian base-metal mines (Nolan, Davis 1987, Bell 1988) identified the need for field performance data on waste rock pile covers and other management systems. The Heath Steele Waste Rock Study is designed to address this need, as well as to aid in the development of practical reclamation measures for mine sites in northeastern New Brunswick, where the combination of massive sulfide ore bodies and the sensitivity of local salmon resources to acid and metal toxicity pose an especially difficult challenge to mine reclamation.

In 1989, a program was initiated by Brunswick Mining and Smelting Corp. Ltd. (BMS) to develop and test strategies for long-term management of several acid generating waste rock piles located at the Heath Steele Mine (HSM) site. The program was conducted in four phases under the auspices of Mine Environment Neutral Drainage

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(MEND), Canada's national task force for acid rock drainage research. The four phases comprise the selection of several waste rock piles for field trials, definition of physicochemical characteristics of the selected piles, identification and evaluation of suitable candidate soils for a composite soil cover, and the design, installation, and monitoring of the composite soil cover on a selected pile.

This paper deals with the design, installation, and monitoring of the composite soil cover installed on selected waste rock pile 7/12. The results of 2 yrs. of monitoring both prior to and after placement of the cover are presented. The interpretation of the monitoring results indicate, how effective the cover has been in the control of acid rock drainage.

Project Setting

HSM site is located approximately 50 km northwest of Newcastle and about 60 km southeast of Bathurst, NB, within the drainage basin of the Northwest Miramichi River (fig.1). Presently, approximately 750, 000 mt of potentially acid-generating waste rock and reject ore are stockpiled in more than 20 piles at the HMS site. The total projected waste-rock inventory at closure in 1994 (including waste rock from active operations) is 2.3 million mt.

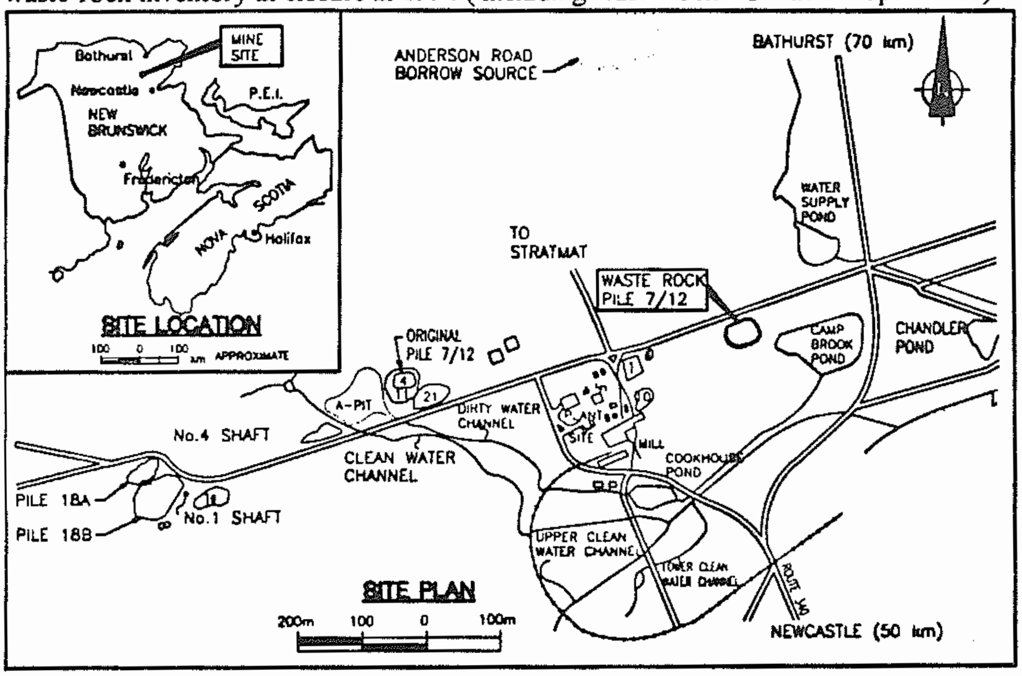

Figure 1. Site plan - Heath Steele Mines.

In 1989, approximately 10 000 mt of acid-generating waste rock was relocated from other areas of the HSM property to pile 7/12. Pile 7/12 is located approximately 1 km from the Heath Steele mill complex off the main haul road (fig.1) and has been sited so that it is isolated from the influence of any neighbouring topographical features. The relocated waste rock was placed on a prepared sand base, underlain by an impermeable membrane, by truck end dumping from the perimeter and pushing towards the middle with a loader. Pile 7/12, which covers an area of 0.25 ha in plan, has a maximum depth of 5 m. The pile was contoured to a uniform pile configuration having a maximum slope of approximately 3:1 (H:V). The final pile configuration is designed to minimize any shape-induced effects on the monitoring results and also to facilitate the placement of monitoring instrumentation.

Table 1. Physicochemical characteristics of relocated waste-rock pile 7/12.

Description	Value
Surface area	2 100 m2
Average depth	2.9 m
Maximum depth	5.0 m
Estimated volume	6200 m
Estimated tonnage	10 700 mt
Sulfide mineralogy,%	
Pyrite	7-10
FeS	5-7
Pyrrhotite	<1
Other sulfides (galena, sphalerite, etc.)	<1
Total sulfate	5
Theoretical acid production (as CaCO3)	210.7 kg/mt
Acid consumption (as CaCO3)	0.4 kg/mt

The predominant constituent sulfide mineral of pile 7/12 is pyrite (FeS_2), with total sulfur content averaging about 5%. The physicochemical characteristics of the pile are presented in table 1.

Pile 7/12 was instrumented with seven sets of thermocouples and six sets of pore-gas samplers. The typical instrumentation cluster at each sampling location consists of a piezometer installed to 5 m depth with a series of pore gas monitoring tubing (5 mm diameter nylon) attached to the exterior of the piezometer at various predetermined depths. Temperature probes, consisting of type K thermocouples, were installed at the same depths as the pore gas monitoring tubing in holes located within 1 m of the pore gas monitoring piezometers.

The underlying impermeable membrane has made possible the collection of leachate from the waste rock pile at the base of the pile both before and after placement of the soil cover. A perimeter ditch was constructed to allow for separate collection of surface runoff.

Composite Soil Cover Design

A soil cover for controlling acid drainage must effectively retain a high degree of water saturation as well as have a low hydraulic conductivity. While a saturated fine-grained soil layer, having a hydraulic conductivity of 10^{-7} cm/sec or less, can provide an effective barrier to the movement of both water and oxygen, studies indicate that a single soil layer that is initially saturated will, when placed on a waste rock pile, ultimately desaturate by drainage and moisture losses due to evaporation. As the soil desaturates, the diffusion coefficient of oxygen will increase with time, resulting in increased oxygen diffusion into the pile. Furthermore, a single soil cover designed to have a low hydraulic conductivity could dry out and crack over time, especially if the soil has a high clay content. As part of the Heath Steele Waste Rock Study, several soil-cover design scenarios were investigated for use on pile 7/12.

The design philosophy for the pile 7/12 soil cover, was based on the concept of the capillary barrier, where a coarse-grained soil layer, underlying a fine-grained layer, such as glacial till, is relied upon to reduce moisture loss in the latter by drainage. The underlying granular layer will drain faster and reach residual saturation long before the glacial till, thus maintaining saturation in the glacial till during summer dry conditions. At residual saturation, the hydraulic conductivity of the granular layer is minimum, so that it is no longer able to transmit negative pressures required to drain the till. If the glacial till is compacted at a moisture content slightly wetter than optimum, it can be expected to have a low hydraulic conductivity and hence to be an effective moisture barrier as well. To reduce evaporation and hence cracking of the surface of the fine-grained soil cover, an overlying coarse-grained granular layer is also required. In addition to acting as an evaporation barrier, the upper granular layer also promotes replenishment of moisture to the glacial till. During infiltration, the granular soil provides storage of water and reduces runoff, thus allowing more water to reach the glacial till.

The capillary-barrier concept, using a three-layer cover design, was evaluated in a series of detailed laboratory investigations at the Noranda Technology Centre (NTC). On the basis of the testing and analysis carried out, NTC proposed a composite soil cover for pile 7/12 consisting of a fine-grained saturated glacial till sandwiched between two coarse-grained granular layers. The thickness of the soil layers in the NTC composite soil cover design is 30 cm base

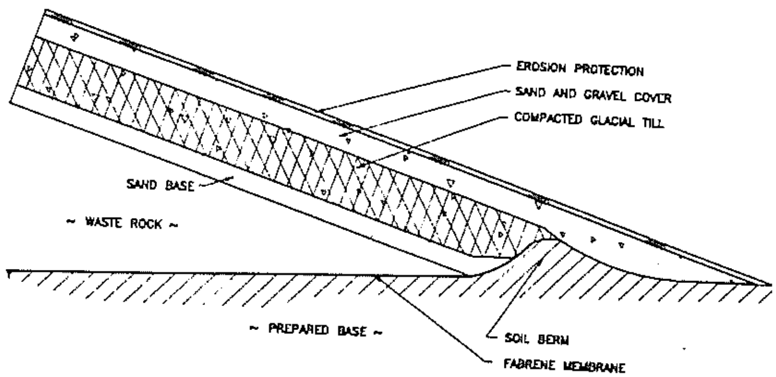

Figure 2. Cross section of composite soil cover.

granular layer, 60 cm saturated glacial till, and 30 cm overlying coarse granular layer. A final 10 cm thick surficial layer of coarse grained was also included for erosion protection. The proposed layer thicknesses, which are designed to keep the glacial till saturated for a minimum of 50 days without precipitation, provide effective oxygen and hydraulic barriers for the waste rock. A cross section of the completed composite soil cover is presented in figure 2.

Composite Soil Cover Construction

A 130 cm thick composite soil cover, consisting of a 30 cm thick sand base, 60 cm thick compacted glacial till, a 30 cm thick granular layer, and a final 10 cm thick erosion protection layer was placed over pile 7/12 during the period August 15-September 19, 1991. Following is a summary of the specific tasks associated with this cover construction.

Surface Preparation

The initial task in the placement of the cover was the preparation of the surface of pile 7/12 by levelling the top of the pile and removing high points on the side slopes. Voids and depressions were filled with excavated waste rock and non-acid-generating crushed rock. A total of 50 mt of crushed rock was used for surface preparation.

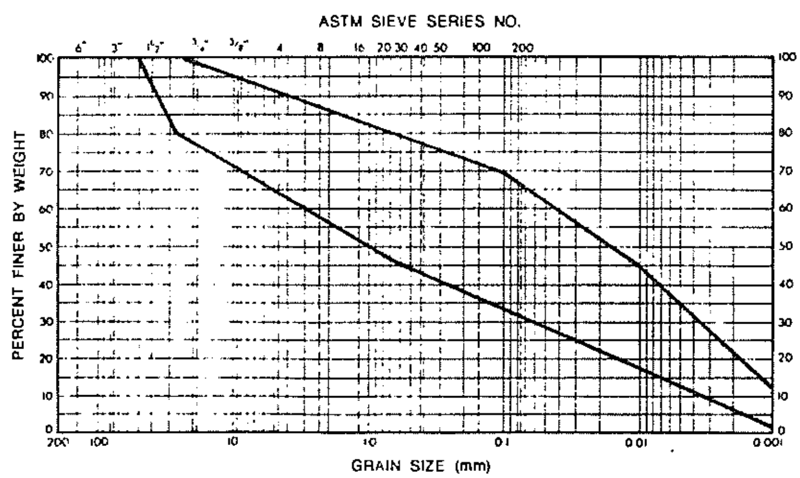

Figure 3. Grain size distribution - glacial till.

Sand Base

The prepared pile 7/12 surface was covered with a minimum 30 cm thick layer of medium to coarse sand consisting of 4% gravel particles, 90% sand, and 6% silt and clay-size particles and compacted to 95% of its modified Proctor density.

Glacial Till

The glacial till consisting of 10% to 33% gravel, 18% to 45% sand, 28% to 44% silt, and 7% to 23% clay-size particles was placed over the pile during the period September 4-14, 1991. The range of grain-size distributions obtained on several till samples is presented in figure 3. Atterberg limits of the glacial till ranged from 27% to 28% for the liquid limit and 5% to 6% for the plasticity index. The average optimum moisture content of the glacial till was 13.5% and a maximum dry density (ASTM D1557) of 1.96 mt/m^3.

The glacial till was placed in maximum 20 cm thick lifts and compacted with a 5 mt vibratory roller. A total of 94 in situ density tests were carried out on the compacted glacial till; results indicated that the degree of compaction ranged from 93% to 101% of the modified Proctor density at moisture contents ranging from 14.5% to 20.3%, averaging 17.0%. Field hydraulic conductivity tests, performed in the till using a single-ring infiltrometer similar to the type described by Fernuik and Haug (1990), indicate hydraulic conductivity of 1.0×10^{-6} cm/s or less.

Granular Cover

A granular cover consisting of clean sand and gravel was placed over the entire pile and compacted to 95% of its modified Proctor density. Grain-size analyses indicated the granular cover to consist of 40% gravel, 58% sand, and 2% silt and clay-size particles.

Erosion Protection

A final 100-mm layer consisting of a well graded gravel was added to the covered pile to provide erosion protection.

Instrumentation/Monitoring Results

The evaluation of the effectiveness of the composite soil cover involved the performance monitoring of both the waste rock and the soil cover itself. For the covered waste rock, the temperature and oxygen concentrations within the pile were measured on a monthly basis, using the sample temperature and pore gas sampling ports and protocols used prior to placement of the cover. In addition, because the cover pile is an enclosed system, the total volume of leachate generated by the encapsulated waste rock was captured with the drains were installed beneath the pile and along the perimeter of the pile.

The performance of the composite soil cover itself was also monitored on a regular basis after placement, including measurement of soil suction, soil temperature, water content, and oxygen concentration at a number of points throughout the pile. Heat-dissipation sensors and electrical-resistance sensors (gypsum blocks) were used to measure soil suction, time-domain reflectometry (TDR) was used to measure water content, and thermocouple sensors were used to measure temperature. In addition, two large-size lysimeters located directly below the cover have been used to evaluate the hydraulic properties of the cover by collecting water that percolated through the cover.

Oxygen and Temperature Monitoring

The measurement of oxygen concentrations throughout pile 7/12 has been ongoing since 1988. Figure 4 presents the results of this monitoring for one of the six pore-gas-monitoring locations.

The results of oxygen measurement presented indicate the following:

1) Prior to placement of the cover, oxygen concentrations that station 3 ranged from 7.3% to 20.8%. The overall range of concentration in the other monitoring stations was 3.2% to 20.8%.

2) The oxygen levels, particularly near the surface of the pile, are influenced by the weather, decreasing in the winter.

3) In summer, as temperatures in the pile increase, thermal convection of oxygen into the pile causes oxygen levels to increase.

4) After cover placement in September 1991, there was a dramatic decrease in oxygen concentrations throughout the pile. At station 3 oxygen concentrations ranged from 8.2% to 14.5% immediately prior to cover placement. In October 1993, oxygen concentration at station 3 ranged from 0.2% to 0.7%.

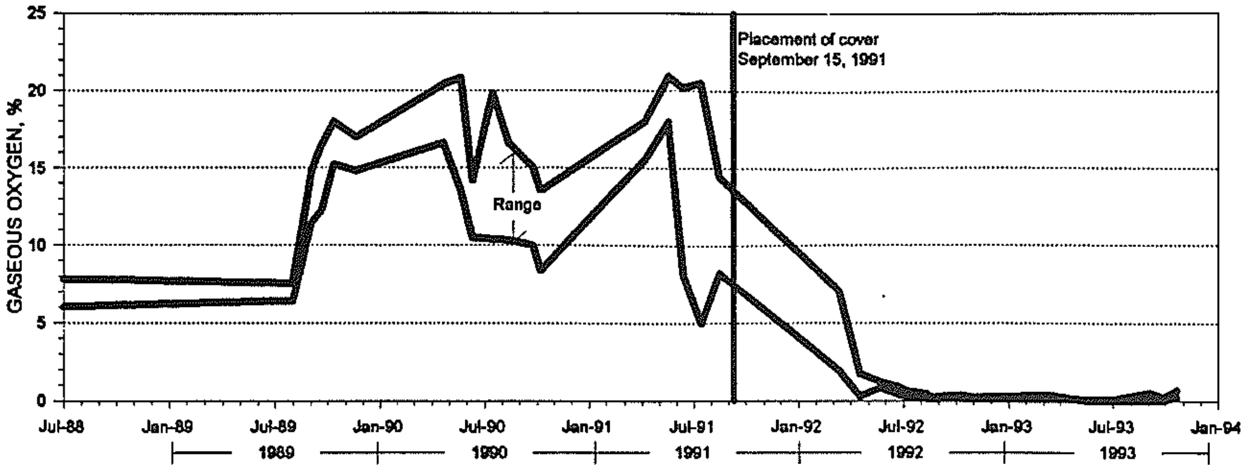

Figure 4. Gaseous oxygen versus time, pile 7/12, station 3.

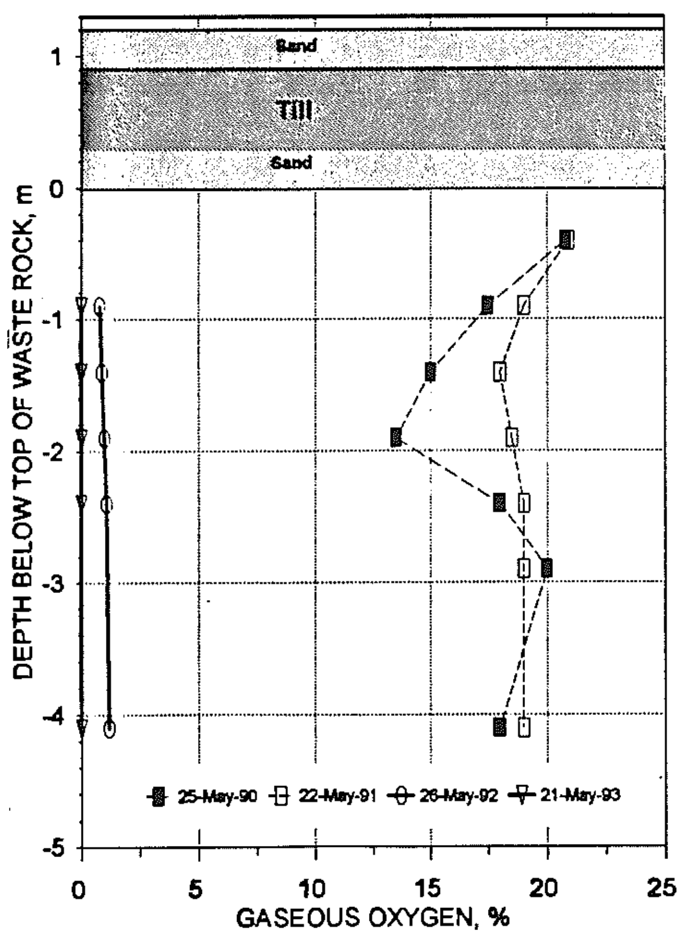

Figure 5. Gaseous oxygen profile pile 7/12, station 3. Cover placed Sept. 15, 1991.

The magnitude of the change in oxygen concentration is more clearly illustrated in figure 5, where the oxygen profiles are plotted for May 1990 and 1991 (prior to cover placement) and May 1992 and 1993 (after cover placement). It is apparent from figure 6 that the most significant decrease in oxygen occurred within several months after cover placement. However, monitoring results indicate oxygen within the system is still being depleted. The oxygen concentration dropped from 18.0% to 20.9% in May 1991 to 0.8% to 1.1% in May 1992 and 0.1% to 0.2% in May 1993.

The presented temperature monitoring results (figure 6) indicate the following:

1) In 1989 very high temperatures (50°C) were noted, which are indicative of the very rapid establishment of the endothermic oxidation process.

2) By 1990, temperatures decreased to under 40°C, indicating a stabilization of the reaction process.

3) There is a direct correlation between temperatures and weather conditions.

4) Temperatures at station 3 prior to placement of the cover ranged from 17.1°C to 24.0°C. One month after cover placement, temperatures dropped to 14.1°C to 18.3°C.

The magnitude of the temperature change prior to or after cover placement is more clearly illustrated in figure 7, which shows temperature profiles measured in May 1990 and 1991 before cover placement and May 1992 and 1993 after cover placement.

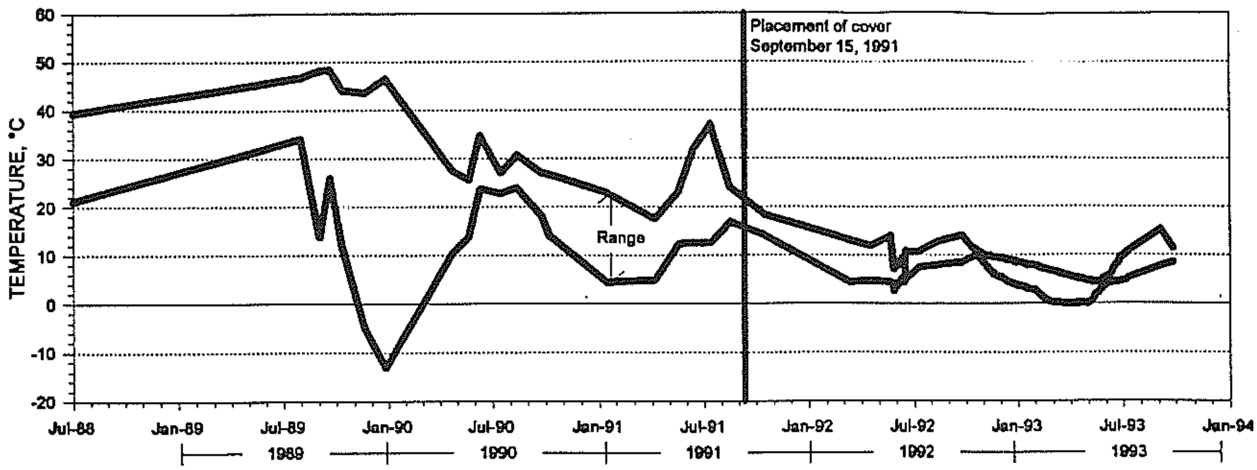

Figure 6. Temperature versus time, pile 7/12, station 3.

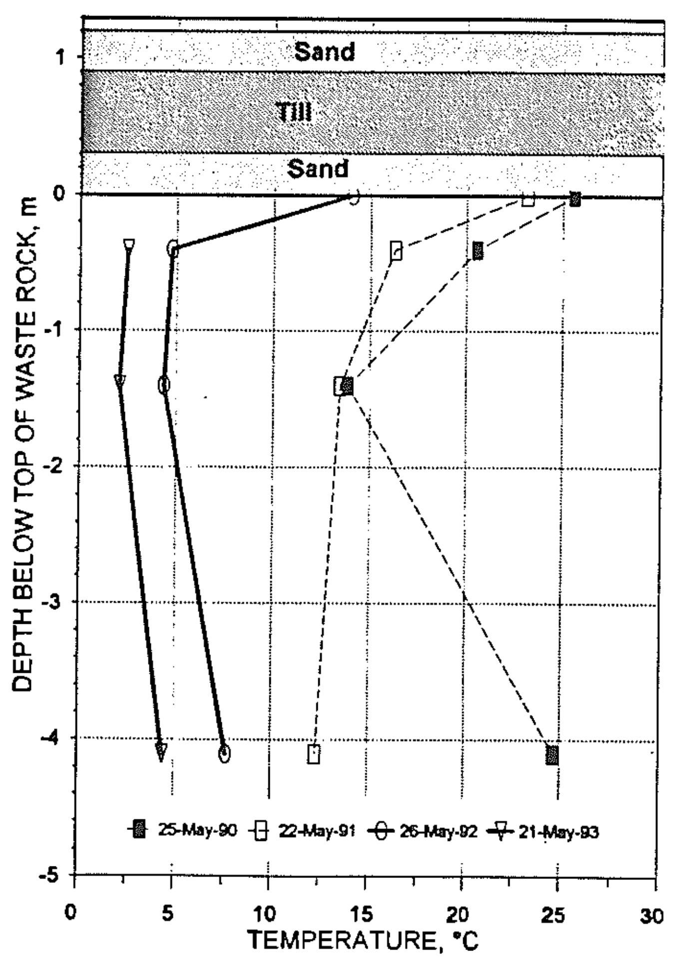

Figure 7. Temperature profile, pile 7/12, station 3. Cover placed Sept. 15, 1991

As with oxygen concentration, the most significant decrease occurred within several months after cover placement. However, temperatures are still decreasing throughout the pile but at a much reduced rate. For all temperature probes installed in pile 7/12 there has been a significant temperature decrease on a year to year basis since placement of the cover.

The results of analytical testing of leachate monitoring to date for pile 7/12 are presented in table 2. Since the system is closed system, the leachate collected after placement of the cover represents the total volume of leachate that has moved through the pile. In the 2 yrs since cover placement, a total of about 1,000 L has been recovered.

Performance monitoring of instrumentation to measure soil suction and moisture content in the composite soil cover has shown that the cover is performing as designed, with moisture content in the till showing little change from measurements taken immediately after cover placement. Soil suction measures show the expected evaporation rates from the surface of the cover.

The Lysimeter discharge data shown in table 3 indicate that only a small portion of the rainfall percolates through the cover.

Table 2. Water quality data for pile 7/12 leachate.

	July 1989 - Oct 1990	1992	1993
Ph	2.1 - 2.8	2.3 - 2.9	3.0 - 3.2
Acidity(CaCO3), mg/L	15,800 -73,250	15,800 - 54,450	NA
Sulfate, mg/L	12,700 - 43,440	5,140 - 71,042	9,970 - 73,854
Dissolved iron, mg/L	3,510 - 13,767	15,800 - 54,000	5,000 - 30,844

NA: Not available.

Table 3. Lysimeter measurements

	Rainfall		Lysimeters	
Date	Depth, mm	Volume, litre	Volume, litre	Ratio, %
June 24 - August 18, 1992	198	2455.2	50.3	2.0%
May 21 - July 13, 1993	188	2331.2	20.0	0.9%

Note : Total areal surface of lysimeters = 12.4 m^2

Discussion

The effectiveness of the composite soil cover based on the results of data collected to date is summarized below:

- Results indicate a reduction in gaseous oxygen concentrations in the pile from 20%+ before cover to less than 1% 2 yrs after cover placement. The decreased oxygen penetration implies reduced oxygen flux and acid production.

- Temperatures in the pile have decreased following cover installation but appear to be more influenced by climatic variability than by a decrease in heat production and hence sulfide mineral oxidation.

- Observed discharge from two lysimeters installed below the cover indicates infiltration of 2% of precipitation during a 55 day period when rainfall was heavy. In 1993, the infiltration was less than 1% of precipitation during a 53 day period.

- The quality of leachate shows signs of improvements with a definite trend toward increasing Ph, indicative that it has become less acidic since cover installation.

- There has been no noticeable change in the moisture content of the glacial till since cover placement.

Although pile 7/12 has a maximum height of only 5 m, precover temperature and gaseous oxygen data indicated behaviour similar to that of large waste rock dumps (of 20 m or more in height) such as those found at the Rum Jungle site in Australia (Harries and Ritchie 1981, 1985). Prior to cover placement, oxygen concentrations within the pile were high enough (20%) to allow oxidation to occur. Elevated temperatures tended to occur at locations where low oxygen concentrations were observed, confirming the exothermic nature of the oxidation process. In addition, thermal convection was found to be an important mechanism for oxygen transport into the pile through the base. The placement of the cover has resulted in a depletion of oxygen within pile 7/12 to less than 1%, thus stifling the oxidation process. Lower temperatures in the pile confirm this. Thus, while pile 7/12 is small compared with other waste rock piles in the world, the results of this study show potential for developing effcive treatment for larger waste rock piles.

Acknowledgments

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