

COMPOSTED ORGANIC WASTES AS ANAEROBIC REDUCING COVERS FOR LONG TERM ABANDONMENT OF ACID-GENERATING TAILING¹

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Abstract: While organic amendments have been well documented for revegetation of acid-generating tailing and waste rock, it is recognized that they do not prevent tailing oxidation and therefore are not a permanent solution to the acidic drainage problem. Laboratory research presented here compared three compost cover layer models that employed fresh and mature municipal solid waste compost. Fresh compost covers on tailing established low redox potential under anaerobic conditions that not only prevented further tailing oxidation, but also reversed the processes that generate acidic mine drainage. Reductive dissolution of previously oxidized and precipitated trace metals was seen, but this may be a transient phenomenon. Further laboratory studies and preparations for a field research program are ongoing.

Additional Key Words: acid mine drainage, compost, municipal solid waste, oxygen barrier

Introduction

The prevention or treatment of acid mine drainage (AMD) resulting from the oxidation of sulphides in waste rock and tailing is one of the most significant environmental problems facing the mining industry and various government agencies. In Ontario, Canada, recent amendments to the provincial Mining Act requiring the filing of long term Rehabilitation Plans with financial assurance to complete them, has added impetus to the efforts to find more cost effective and permanent strategies to prevent AMD. Revegetation efforts improved the aesthetic qualities of mine wastes but have done little to ameliorate the AMD problem (Davé and Michelutti 1989).

It is recognized that metal sulphides in tailing and waste rock react with oxygen and water to produce sulphuric acid and release associated trace metals. Some of the strategies currently being investigated to stop the AMD processes include preventing oxygen, water, or both, from contacting the tailing. It is also recognized that the bacterium *Thiobacillus ferrooxidans* plays a significant role in accelerating the tailing oxidation process. Thus, stopping oxygen penetration into the tailing will reduce the activity of *T. ferrooxidans*.

One of the promising areas of research by industry and government is the use of various covers to prevent the oxidation of tailing sulphides. Unfortunately, most effective cover designs have proven to be prohibitively expensive to implement (Davé and Lim 1989, Nicholson *et al.* 1989). Recently, a number of studies have recognized that there are natural conditions of low oxygen concentration and redox potential that could be adapted to stop the AMD processes and perhaps actually reverse it (Pierce 1992). Anaerobic conditions found in landfills and wetland organic sediments are populated by reducing bacteria that produce methane gas and reduce dissolved sulphate, nitrate and metals, returning them to a solid state as sulphide precipitates. Other organic materials, such as Municipal Solid Waste (MSW) compost, share many of the characteristics of landfills and wetland sediments and it is hypothesized that a designed

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compost cover may also be able to maintain reducing conditions in acidic tailing.

The disposal of municipal wastes is a major environmental problem and cost facing many urban centres. The organic fraction can be 30% of MSW but its use in the production of clean, high-grade compost can be ten times more expensive for a municipality to manufacture than the present cost of landfilling the MSW. Land reclamation uses by the mining industry may represent a large and reliable market for MSW compost, especially if the compost could be less mature and contain gross contaminants such as glass, ceramics, plastics, wood chips, concrete and other wastes that are difficult and expensive to remove in making agricultural-grade compost. Large quantities of low-grade compost could be diverted from a MSW compost plant early in the manufacturing process and would therefore be much cheaper to produce and dispose of -- at a significant saving to the municipal taxpayers. Recognizing the potential "win-win" situation for municipalities and the mining industry, Falconbridge Limited initiated a research program to study the benefits of using MSW compost as an ameliorative cover layer on acidic tailing sites.

Benefits of a Compost Cover Layer

A literature review of what is known about the physical and chemical characteristics of MSW compost and other organic materials (Pierce 1992), revealed that a compost layer on sulphide tailing could be beneficial in five ways in the suppression of tailing oxidation and acidic mine drainage. First, the compost could maintain sufficient water saturation to produce a physical oxygen barrier. Second, the continued decomposition of compost would create a large biological oxygen demand that acts as a sink for atmospheric oxygen or dissolved oxygen. Third, compounds and decomposition products in the MSW compost that leach into the tailing may inhibit the growth and metabolism of sulphate-producing bacteria. Fourth, organic constituents and reducing bacteria in the MSW compost could cause the reductive dissolution of ferric oxides and prevent indirect ferric sulphide oxidation and acid generation. Fifth, compaction of the compost layer could reduce the hydraulic conductivity and prevent infiltration of precipitation, thus decreasing tailing groundwater flow.

Project Objectives

Three major lines of investigation were undertaken during the laboratory phase of the research program-

1. Determine the potential leachate characteristics of fresh and mature compost.
2. Evaluate the physical characteristics of compost that determine its ability to maintain water saturation and anoxic conditions.
3. Evaluate the chemical processes and changes within compost and tailing when compost is placed on acidic tailing.

In this paper we present the results of a six month laboratory simulation experiment comparing the effects of fresh and mature compost used in three cover layer designs on oxidized acidic mine tailing.

Methods

Tailing material utilized in this research was obtained from the Nickel Rim site of Falconbridge Ltd., near Falconbridge, ON, Canada where it was deposited in the early 1950s (Blowes *et al.* 1991). The material was taken from the oxidized tailing zone approximately 10-30 cm below the surface layer of sandy, revegetated soil. Mature and fresh MSW compost was obtained through Dr. Lambert Otten at the University of Guelph, and was produced in a pilot plant from source-separated, organic, kitchen and yard waste collected from 900 suburban homes (Otten 1993). The fresh compost obtained was four weeks old, had a strong odour, and contained numerous twigs, stones and bits of plastic that had passed through a 7.5 cm screen sieve. The 14-week-old mature compost was sieved through 12 mm screen and had a fine texture like potting soil and very little odour.

Compost Leachate Composition

Several tests were done to evaluate the risk of using MSW compost on mining lands. Standard

chemical leachate analyses on compost to satisfy regulatory requirements of Ontario Regulation 347, Environmental Protection Act, regarding waste classification. The analyses included Ni, Cu, Pb, Zn, Cd, As, Cr, Co, Mo, Se, Hg, and the organics PCB, Aldrin, Dieldrin, Chlordane, DDT, Endrin, Heptachlor epoxide, Methoxychlor, Toxaphene, 2,4-D and Silvex. The Toxicity Characteristic Leaching Procedure was also performed on compost to determine the leachate characteristics under simulated acid rain conditions. Both Regulation 347 and TCLP procedures were repeated on compost that was spiked with ten times greater a concentration of organic chemicals and trace metals than that allowed by the Ontario Compost Quality Guidelines (Ontario Ministry of the Environment 1991) in order to simulate worst case conditions for MSW compost contamination.

Chemical Processes and Changes in Tailing

The physical and chemical characteristics of the tailing were determined before and after compost cover layer treatments. The investigations included-

1. Characterization of the crystallinity of oxidized tailing and the distribution of adsorbed trace elements with the tailing by x-ray diffraction.
2. Evaluation of the effects of redox potential and acidity changes on solid phase chemical speciation and the composition of tailing pore water and leachate through a standard sequential leaching analysis (5 fractions), and by mixing tailing with standard solutions of chemical reducers, such as sodium dithionite. Trace metals were analyzed by Inductively-Coupled Plasma spectrophotometry (ICP).
3. Determination of the effects of compost on solid phase chemical speciation and the composition of tailing pore water and leachate. This was accomplished by mixing compost with a slurry of tailing, followed by ICP analysis on filtrate (0.2 μm membrane), and analyses of samples obtained from the compost cover layer simulation experiment (see below).

Compost Cover Layer Simulation

Leaching columns were employed over several months to investigate the potential benefits that were suggested for three compost cover layer models, using fresh and mature compost treatments. The objectives of the simulation experiment were-

1. Study the effects of compaction pressure and compost maturity on the physical properties and water retention by the compost layer. The physical measurements included degree of compaction, water saturation, dry bulk density, porosity, and saturated hydraulic conductivity.
2. Measure the oxygen concentration profiles within the compost-tailing columns to determine the extent of anoxic conditions.
3. Determine any changes in tailing and compost pore water and gas quality through the simulation period, including relative measurements of redox potential, oxygen, carbon dioxide, carbon monoxide, methane, and dissolved sulphate, nitrate, iron, nickel, copper, zinc, cobalt, and manganese.

Experimental Treatments. Three cover layer designs were investigated using leaching columns to contain a vertical column of tailing and compost. The simplest cover treatment, called the Compost model, was a 95 cm layer of compost placed directly on a homogeneous layer of oxidized tailing (fig. 1A). In the Ploughed model (fig. 1B), a 20 cm layer of compost mixed with tailing (1:1 ratio by volume) was first placed on the tailing layer, followed by a 30 cm layer of compost. The Sand model consisted of a 5 cm layer of coarse aquarium sand on tailing to hydraulically isolate an upper 30 cm layer of compost from the tailing layer (fig. 1C). All columns contained an 88 cm layer of oxidized tailing to simulate the drainage characteristics of the tailing site. Two grades of compost (agricultural-grade, mature, 14-week-old compost, and coarse, fresh, 4-week-old compost) were used as contrasting treatments to investigate the relative benefits of compost maturity and quality. The six types of treatments were constructed in triplicate, giving a total of 18 leaching columns. The compaction pressure of a layer of revegetation medium was simulated by placing a weighted piston on the top of each compost layer (fig. 1).

Leaching Column Design. Leaching columns were constructed from clear acrylic plastic tubes 185 cm high and 10 cm outside diameter with 3 mm walls (fig. 1). The clear tube walls allowed examination of the quality of packing of tailing and compost in the tube, as well as monitoring of visible changes in the material during the simulation experiment, such as porosity and colour changes in the compost, and in the

oxidized tailing as a result of reduction of iron oxides. Compaction of the compost in the leaching columns was achieved using a piston made of a 9.4 cm diameter disk of 13-mm-thick acrylic plastic attached to a pine post that reached above the top of each tube. Each disk had eighteen 3 mm holes drilled through it to allow the free passage of gases and water. Lead fishing net weights were attached to the top of the pine posts. In the Compost model (fig. 1A), a 9-Kg lead weight applied a pressure of approximately 12.5 KPa (0.125 atm) to the top of the compost in order to simulate the weight of a revegetation layer of about 50 cm. In the Ploughed and Sand models (fig. 1B-1C), 36 Kg of lead weights were attached to the top of each post by chains to give a pressure on the compost of 50 KPa (0.5 atm). This amount of weight was applied to simulate the effect of a surface revegetation layer of about 2 m of gravel and sandy soil.

After the compaction pistons were inserted, all columns were flooded with distilled water. The leaching columns were mounted vertically inside a 2.5 m-tall plywood cabinet and seated into polyethylene funnels supported on a bottom shelf. Each column was supported near the top by sticking through a hole in an upper shelf. Doors on the cabinet were closed during the experiment to keep the experimental material in darkness.

To gain access to the compost and tailing material inside the leaching columns, two vertical lines of sample holes were previously drilled through the tube walls and sealed with rubber stoppers. The vertical lines of holes were separated by 90 degrees around the circumference of the tube. These holes were used to extract compost and tailing material for chemical and gas analyses. Another vertical line of six sampling holes was made on the backside of each tube at the level of the compost layer, with the holes mid-way between the other sampling holes. These holes were used near the end of the experiment to extract cores of compost in order to determine the degree of water saturation, bulk density, and gas-filled porosity.

Sampling Methodology. During the simulation experiment, small samples of tailing and compost were taken periodically for gas analysis and relative redox potential (Eh) measurement. To avoid the introduction of atmospheric oxygen into a column when a stopper was removed from a sampling hole, it was necessary to establish an anoxic atmosphere around a portion of the column before removing the rubber stopper. An acrylic plastic glove box was constructed to fit half-way around the column and provide access to the two sampling holes at each level (fig. 1). Inside the glove box were placed a 4 mL glass vial, a 15 mL plastic tube (containing 5 mL of distilled, deoxygenated water), a redox potential probe and a cork borer with wooden plunger. Both containers were pre-weighed. The glove box was flooded with nitrogen gas fed into a port on the top for about a minute before sampling to establish anoxia in the box. Using the cork borer, the experimenter extracted a 1- to 2-cm core of material. Half of the material was put in the glass vial and sealed with a rubber septum and screw cap. The rest of the material was inserted into the plastic tube containing deoxygenated water. The tube was gently agitated for about 30 s before a redox potential probe was inserted into the liquid. The Eh was recorded after three minutes, and then the tube was capped. Both containers were removed from the glove box and reweighed. After gas

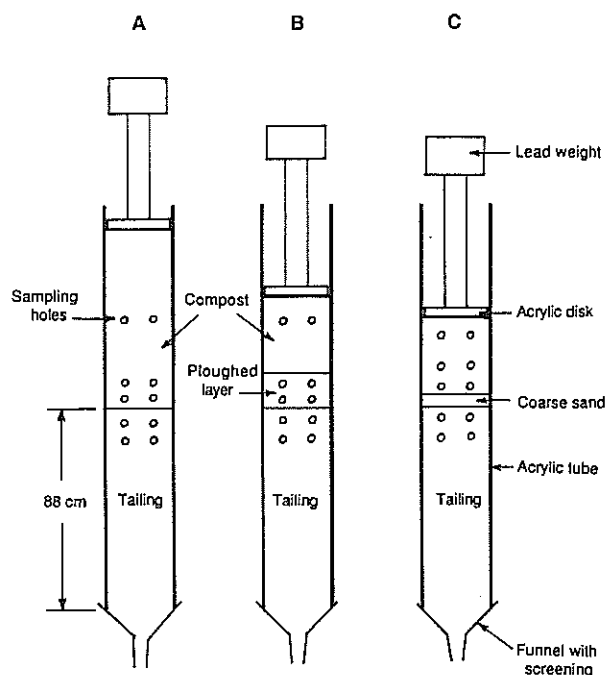


Figure 1. Diagrammatic view of the leaching columns used in the compost cover layer simulation, showing: (A) Compost model, (B) Ploughed model, and (C) Sand model.

analyses were completed, the glass vial and solid sample was oven dried at 75°C overnight to determine the dry weight of material sampled.

The Eh measured is a relative redox potential value since the redox transformations in the compost-tailing system would be complex and thus could not be calibrated against a redox potential standard. The redox probe was checked periodically against a standard solution to guard against malfunction and drift in its response. The redox probe was too fragile to insert directly into compost or tailing material so the method to measure an equilibrium Eh between a solid sample and deoxygenated water was devised. Therefore, the redox potential measurements made in the compost and tailing material are a relative Eh, consistent between experimental samples. Similarly for acidity measurements, since pore water was not being extracted, an accurate measurement of in situ sample pH could not be obtained. However, a relative pH was measured in the deoxygenated water used to determine relative Eh for the solid core samples. We are assuming that a similar equilibrium situation existed between the solid phase and the deoxygenated water in all the core samples.

Gas Analysis Technique. The glass vials containing compost or tailing samples were transported to another lab for gas chromatography and ion chromatography analyses. To avoid the possibility of contamination error, only as many samples were collected from the columns as could be analyzed the same day, and vials were stored in the refrigerator until shortly before starting gas analysis to minimize further chemical changes. A precision syringe was used to sample 100 µL of gas in the vial. This sample was injected into a gas chromatograph equipped with a thermal conductivity detector and a column designed for low molecular weight gases. Gases of interest to this study that could be measured with this instrument include oxygen, carbon dioxide, carbon monoxide and methane.

Anion Analysis. The levels of nitrates and sulphates were analyzed in each sample of deoxygenated water using a high pressure liquid chromatography system controlled by the Millennium 2010 software.

Results and Discussion

Unfortunately, space limitations permit presentation of only some results of the cover layer simulation portion of the project. Major conclusions of the compost leachate analyses and the characterization of chemical processes and changes in oxidized tailing are presented. A complete presentation of data and analyses for the project is available in a detailed report to MEND Ontario (through the Ontario Ministry of Northern Development and Mines) entitled "Reclamation of Sulphide Tailing Using Municipal Solid Waste Compost: Laboratory Studies Final Report".

Compost Leachate Composition

All fresh and mature compost samples met the Ontario Compost Quality Guidelines. No detectable concentrations of common toxic organic compounds were found in either the fresh or mature compost. Both the Regulation 347 and TCLP leaching tests showed similar patterns in the availability of trace metals and nitrogen compounds. Trace metals in compost leachate met the latest Municipal Industrial Strategy for Abatement (MISA) regulatory concentration standards for discharge from mining lands in Ontario. While the tests indicated elevated concentrations of nitrogen compounds, it is expected that these will not be of concern in the compost-tailing system where nitrate-reducing bacteria are active and will produce harmless nitrogen gas. Compost quality standards for agricultural use must be stringent to prevent uptake of toxins into the human food chain. However, this study suggests that leachate from contaminated compost will not be a risk to water quality outside the tailing site. As such, the application of MSW compost to mining lands would involve a low level of environmental risk.

Chemical Processes and Changes in Tailing

The sequential extraction analyses of oxidized tailing material before treatment by a compost cover layer showed that high concentrations of Fe and Ni that are associated with amorphous or recently formed oxyhydroxides. These elements could be released from the solid phase under reducing conditions since iron oxides and oxyhydroxides can be dissolved and release Fe(II) and the trace metal adsorbed onto

them. A significant proportion of Cu and Zn was associated with organic or sulphide solids. Mn, Cu and Zn show a strong presence in the residual component of the extraction procedure, and thus would not be expected to mobilize under oxidizing conditions. Other metals, such as Cr, Co and Pb were extracted only in relatively low concentrations. These elements adsorbed or precipitated in the oxidized tailing may be resolubilized as iron changes from the ferric precipitate to the soluble ferrous state under reducing conditions. Strong reducing conditions, however, may recreate stable sulphides thus immobilizing most trace metals. Sequential extraction analyses of tailing following the compost cover layer treatment are not complete at the time of this report. Preliminary compost-tailing slurry experiments using mature compost as a reducing agent in oxidized tailing material suggest that chemical interactions with mature compost will produce weak reducing conditions.

Compost Cover Layer-Tailing Simulation

The transparent walls of the leaching columns provided a view of the chemical changes that were occurring in the compost-tailing system during the simulation. At approximately three weeks into the experiment, a blackening of the tailing and compost material appeared near the compost-tailing interface in the fresh compost treatments. This material was identified as iron sulphide precipitate. Similar darkening from iron sulphide also appeared several weeks later in some of the mature compost treatments. These visual observations confirm that anoxia became established, especially under the fresh compost, and created reducing conditions strong enough for the formation of iron sulphide precipitate.

Compost Layer Physical Changes. Fresh compost layers compacted 10% to 20% more than those of mature compost, although fresh compost showed a significantly higher total porosity and lower dry bulk density under the same compaction treatment. Fresh compost maintained a higher water content than mature compost as a result of its greater porosity. Since gas-filled porosity was found to be strongly correlated to total porosity and inversely correlated to bulk density, the variability and importance of pore water volume were relatively small. Therefore, we concluded that a compaction pressure of 50 KPa, approximately equivalent to a two metre cover of soil, was not effective in squeezing pore space out of the compost matrix under these experimental conditions. However, as the experiment progressed, voids developed in all the fresh compost layers, presumably due to the accumulation of decomposition gases.

Saturated hydraulic conductivity for the different compost-tailing systems ranged over several orders of magnitude (fig. 2), from a maximum of 4.4×10^{-4} cm/s in mature compost to a minimum of 2.2×10^{-6} cm/s for fresh compost columns. By contrast, tailing and ploughed (mixed) layers had much higher saturated hydraulic conductivities of 1.3×10^{-3} cm/s and 0.6×10^{-3} cm/s, respectively. Three fresh compost columns still held a shallow head of water above the compost layer 48 days after rewetting, indicating that their conductivities had dropped to a value near zero. Buttler *et al.* (1991) concluded that the low hydraulic conductivity of peat is determined by the blockage of pore space by trapped methane gas bubbles. We could not determine the basis for the low hydraulic conductivities in the fresh compost in this case. If a fresh compost cover layer could be kept wet and in a state of anaerobic decomposition, it is possible that this extremely low conductivity could be maintained. The result would be very poor water flow through the compost layer and the maintenance of near-saturated conditions and anoxia.

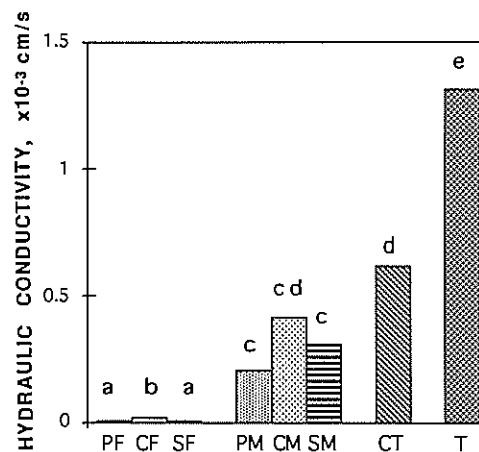


Figure 2. Saturated hydraulic conductivity of the compost cover layer-tailings system. Each bar is the average of three replicates and the same bold letter indicates no significant difference at the $p=0.2$ level. (treatments: PF - Ploughed Fresh, CF - Compost Fresh, SF - Sand Fresh, PM - Ploughed Mature, CM - Compost Mature, SM - Sand Mature, CT - Compost and Tailings mixture, T - Tailings).

Chemical Changes. Oxygen concentrations measured through the simulation experiment (fig. 3) indicate that the mature and fresh compost covers led quickly to anoxic conditions in all cover covers studied. None of the oxygen concentrations measured was zero; however, the low concentrations detected are believed to be the result of oxygen contamination due to sampling technique, and not due to the presence of detectable amounts of oxygen inside the columns. The few high oxygen concentrations measured are believed to be the result of either an error in sample handling or an air leak into the column past an improperly seated stopper.

The creation of anoxia led quickly to a large decrease in Eh. The relationship between Eh and water content for all the samples of the simulation run is shown in figure 4. It is clear that the highest water contents and lowest Eh were found in the fresh compost layer (fig. 4, solid squares), and the lowest Eh in tailing was produced under this cover (fig. 4, solid circles). The ploughed layer, with an equal mixture of compost and tailing (fig. 4, triangles), shows an Eh-water relationship intermediate between the compost and tailing. Some of the tailing treated under fresh compost had Eh values as low as those in fresh compost samples. This suggests that the properties of the cover layer, rather than just chemical processes, produced the low Eh in the tailing layer.

The progress of Eh in the tailing layer is shown in figure 5. Tailing under the fresh compost treatments showed a continuous Eh decrease from one sampling period to another, while the tailing under the mature compost cover layer demonstrated little decrease until much later. The water content of the tailing samples was little modified by the rewetting of the columns or by the drying periods.

Analyses of gas samples in equilibrium with the solid phase samples revealed patterns that were consistent with the relative redox potential and oxygen concentration results. In all three cover layer models employing fresh compost, methane and carbon dioxide production showed a general increase with time in the compost and tailing regions of the profile. Profiles of methane concentration in the Compost model are shown in figure 6 at three sampling points during the simulation. Methane concentration increased in the tailing layer during the run, but was virtually absent in the

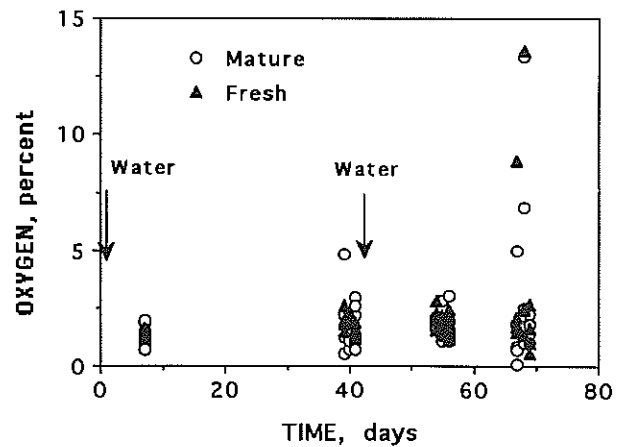


Figure 3. Oxygen concentrations measured in compost and tailings samples during the first four sampling periods of the simulation experiment. Arrows indicate days when water was added to the columns.

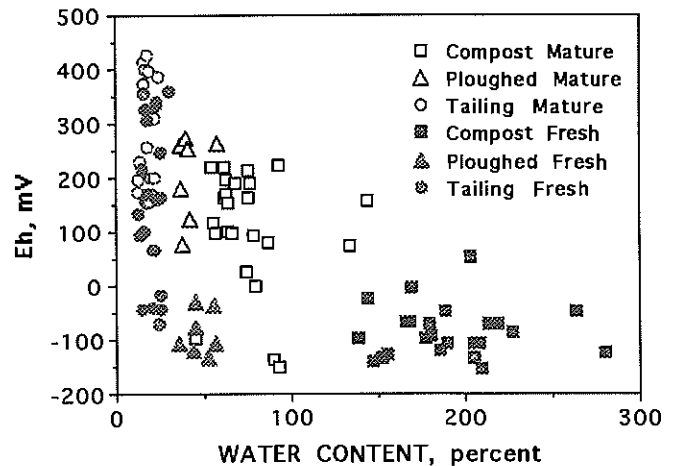


Figure 4. Relationship between relative redox potential (Eh) and water content for the six cover layer treatments.

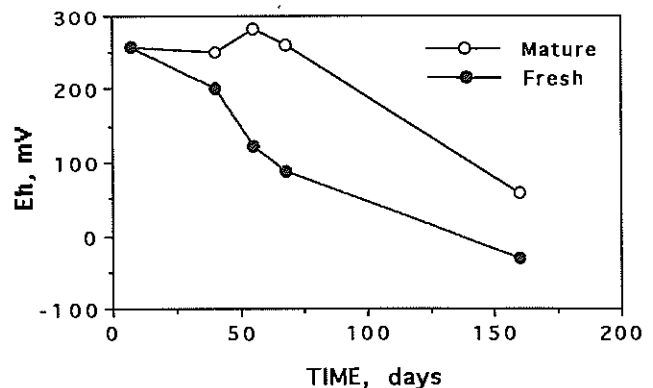


Figure 5. Changes in tailing layer relative redox potential (Eh) during the simulation under fresh and mature compost treatments.

mature compost treatments. These patterns are consistent with the decrease in Eh found in the tailing layer and the establishment of sufficiently strong reducing conditions for the observed methane and iron sulphide production. Carbon dioxide concentrations were greater in 80% of the fresh compost samples than in the matching mature compost samples. Methane and carbon dioxide are both decomposition products of anaerobic bacterial breakdown of organic substrates that are provided here in abundance by the compost and its leachates. Our gas chromatography system could not measure hydrogen sulphide, however, since the iron sulphide observed is formed from the reaction of hydrogen sulphide with Fe (II), it is certain that H₂S gas was present in the tailing-compost interface zone where iron sulphide precipitate was found. Hydrogen sulphide is produced by anaerobic sulphate-reducing bacteria that utilize small organic molecules as substrates.

Acidity and Trace Metal Analyses. Under aerobic conditions, iron and other trace metal sulphides in the oxidized tailing are mobilized due to oxidation by oxygen or ferric ion to produce sulphuric acid. In the sequential extraction analyses of the Nickel Rim oxidized tailing material, iron and nickel were associated with amorphous or recently formed oxyhydroxides that can easily dissolve to release Fe (II) and any metals adsorbed onto them. Copper and zinc were also present in significant amounts, probably as sulphides or associated with organic matter. Under anoxic conditions, sulphate-reducing bacteria use small organic molecules as substrates to reduce sulphate and produce hydrogen sulphide (Stumm and Morgan 1981). Hydrogen sulphide reacts readily with iron and other metals to form sulphide precipitates, and in the process, consumes acidity. Thus, the pH of the tailing should rise as Eh decreases when an anaerobic, reducing environment is established in the tailing.

Figure 7 shows that an inverse relationship exists between relative pH and relative Eh for the compost and tailing samples taken on day 160 of the simulation experiment. The Ploughed model samples showed the highest acidity and Eh. This trend is consistent with the expected rise in pH as reducing conditions become established. We conclude from these patterns that decomposition products in the fresh compost were fuelling a high rate of sulphate and iron reduction by sulphate-reducing and

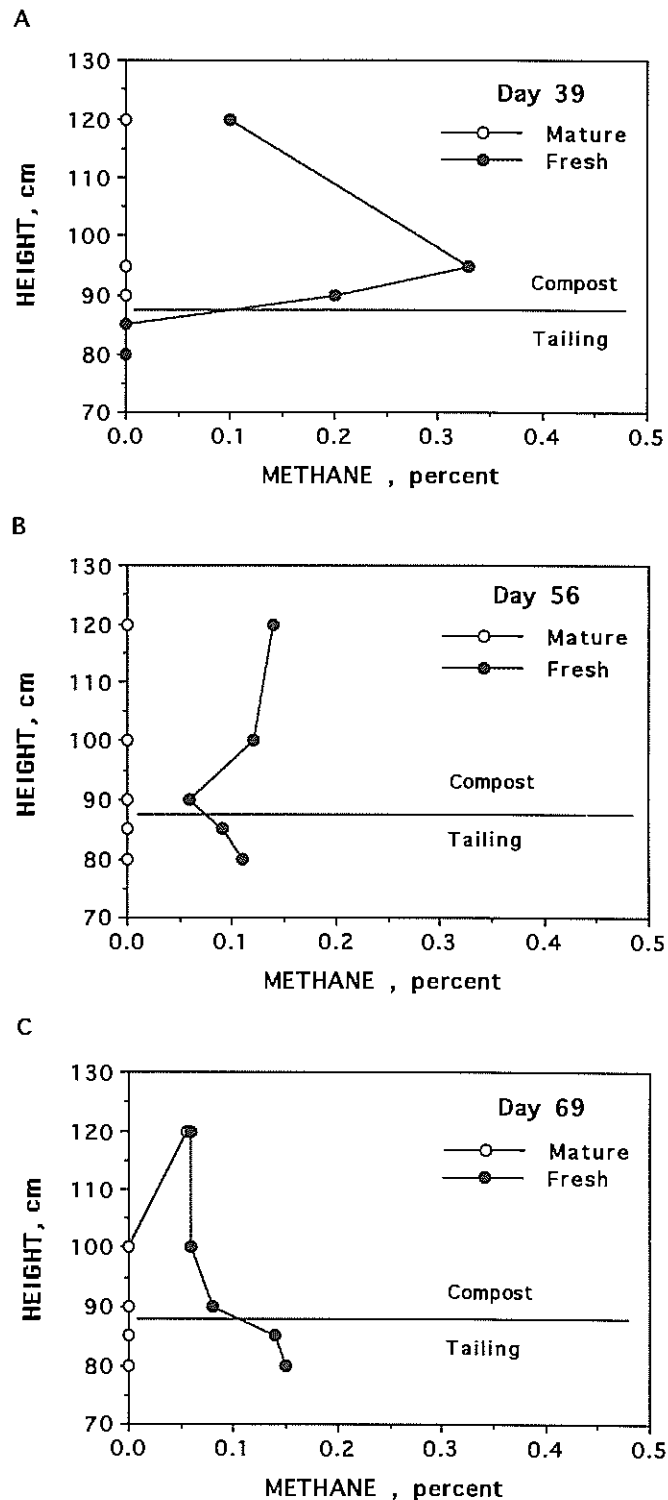


Figure 6. Profiles of methane in the Compost model mature and fresh compost treatments during the simulation experiment. (A) Day 39, (B) Day 56, (C) Day 69. (Note: The tailing-compost interface is at 88 cm)

iron-reducing bacteria. The formation of iron sulphide precipitate seen in the region of the tailing-compost interface also indicates that reductive dissolution of iron oxides and sulphate compounds was proceeding from approximately six weeks into the simulation experiment. Since the oxidized tailing is rich in iron, the reductive processes will reflect a dominance by Fe(III) reduction until the iron is nearly all gone from solution (Rowell 1988). In an environment with limited organic substrates, sulphate-reducing bacteria are often competitively inhibited by the activity of iron-reducing bacteria (Hedin *et al.* 1989), but that limitation seems unlikely in the ploughed layer or in the upper tailing layers in this simulation that must have received some organic leachate from the compost layer above it.

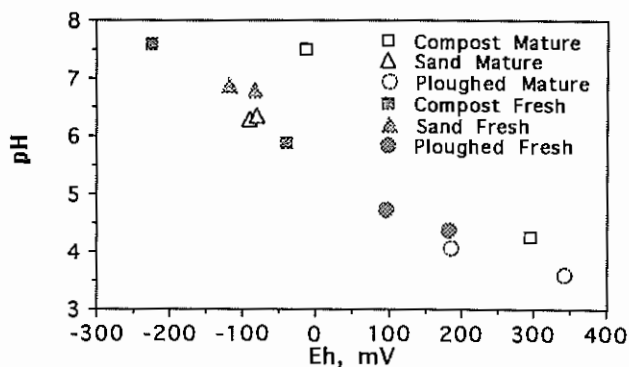


Figure 7. Relationship between relative redox potential (E_h) and relative acidity (pH) for tailing samples in the six cover layer treatments on day 160 of the simulation.

Trace metals other than iron were found only in low concentration in the six cover layer treatments and predominantly under acidic conditions and at high redox potentials. Five trace metals Ni, Cu, Zn, Co and Mn were present at somewhat higher concentration only when the relative E_h is above 100 mV and the relative pH is below 6. The magnitudes of these relative pH and relative E_h measurements cannot be directly applied to the in situ conditions in the column, but it seems clear that, as reducing conditions become stronger and pH rises under a compost cover layer, we can expect a decrease in the concentrations of trace metals in the tailing pore water as reductive dissolution shifts to reductive precipitation.

Conclusions

From the results of this preliminary study of compost cover layers on acid-generating tailing we have concluded-

- The Compost and Sand cover layer models were better at maintaining anoxic or other ameliorative conditions in the tailing than was the Ploughed model, during the six month simulation.
- Fresh compost treatments are much more effective than mature compost in maintaining high water content and strong reducing conditions in the region of the compost-tailing interface, and this was also shown by the formation of iron sulphide precipitate and methane.
- Fresh compost cover layers showed a great resistance to the conduction of water, that along with the maintenance of high water content, would seal off the tailing from infiltration of atmospheric oxygen, precipitation and surface water, thus forming a physical oxygen barrier.
- The mobilization of iron and sulphate was enhanced by the establishment of strong reducing conditions and the availability of organic substrates for the reductive dissolution of iron oxides by reducing bacteria. This may be a transient condition until iron and sulphur become immobilized as less soluble precipitates, such as sulphides. Trace metals become less mobilized with the development of strong reducing conditions and low acidity.
- Compost quality tests show that leachates from mature and fresh compost present a low environmental risk for use on mine lands. The cover layer simulation results indicates that in the compost-tailing system nitrates and metals will be quickly reduced. Additionally, the very low hydraulic conductivity of the fresh compost cover layer will inhibit vertical water flow through the compost layer and thus reduce the potential for the leaching of nitrogen compounds, acids, and metals from the compost-tailing system.

The experimental work has shown that a cover layer of MSW compost can be of benefit in the reclamation of oxidized tailing. However, the conclusions that we reached were based on a relatively short-term laboratory experiment that lacked natural environmental conditions and variability. Comprehensive, long-term field work should now be done to follow up on the potential benefits identified, and also those benefits that may have been overlooked by the current study.

References

- Blowes, D.W., W.D. Robertson, and J.A. Cherry 1991. Nickel Rim Mine tailings investigation. Progress report, Nov. 30, 1991. Waterloo Centre for Groundwater Research, University of Waterloo.
- Buttler, A.J., H. Dinel, M. Levesque, and S.P. Mathur. 1991. The relation between movement of subsurface water and gaseous methane in a basin bog with a novel instrument. *Can. J. Soil Sci.* 71:427-438. <http://dx.doi.org/10.4141/cjss91-042>
- Davé, N.K. and T.P. Lim 1989. Wetlands and their role in treating acid mine drainage - a literature review. Report MRL 89-107 LS, Elliot Lake Laboratory, CANMET.
- Davé, N.K., and R.E. Michelutti 1991. Field evaluation of wet cover alternatives of high sulphide tailings. Final Report. In Proceedings of the Second International Conference on the Abatement of Acidic Drainage, Montreal, Sept. 16-18, 1991. Vol. 3. pp. 61-81.
- Hedin, R.S., R. Hammack, and D. Hyman 1989. Potential importance of sulphate reduction processes in wetlands constructed to treat mine drainage. In Hammer, D.A. (ed.), Constructed wetlands for the treatment of acid mine drainage. Report of the U.S. Bureau of Mines. p. 508-514.
- Nicholson, R.V., R.W. Gillham, J.A. Cherry, and E.J. Reardon 1989. Reduction of acid generation in mine tailings through use of moisture-retaining cover layers as oxygen barriers. *Can. Geotech. J.* 26:1-8. <http://dx.doi.org/10.1139/t89-001>
- Otten, L. 1993. Experimental and theoretical study of the Guelph pilot scale solid waste composter. RAC Project 501G. Report prepared for the Ontario Ministry of the Environment and Energy by the School of Engineering, University of Guelph. May 1993.
- Pierce, W.G. 1992. Reclamation of sulphide tailings using municipal solid waste compost: literature review and recommendations. Report prepared for Falconbridge Ltd. by the Centre in Mining and Mineral Exploration Research, Laurentian University, Sudbury, ON. July 1992.
- Rowell, D.L. 1988. Flooded and poorly drained soils. In A. Wild (ed.) Russell's soil conditions and plant growth. Eleventh ed. Wiley, New York. p. 899-926.
- Stumm, W. & J.J. Morgan 1981. Aquatic chemistry. Second ed. Wiley, New York.

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