10. Minimizing Concentrations of Acid-Producing Minerals in Tailings Piles

DIFFUSION OF OXYGEN THROUGH A PULP AND PAPER RESIDUE BARRIER
Cabral, Alexandre; I. Racine; F. Burnotte; G. Lefebvre
Canadian Geotechnical Journal, Vol 37 No 1, p 201-217, 1 Feb 2000

Acid mine drainage can be curbed or reduced significantly by covering tailings sites with an oxygen barrier. In this study, the ability of pulp and paper residues, more specifically deinking residues, to function as such a barrier was investigated. Field data from two sites show that O2 diffusion through the barriers can be greatly reduced. To better understand how oxygen migrates through deinking residues and to develop prediction tools for future design with deinking residues, one-dimensional effective diffusion coefficients (D e) were determined by fitting laboratory experimental curves (O2 concentration versus time data) to curves obtained from computer simulations. The results obtained confirmed the behaviour observed in soil covers: the effective diffusion coefficients are highly dependent on the degree of saturation (Sr) of the compacted material. The D e values obtained in this study compare well with those published in the literature for several materials compacted at similar Sr. The D e values varied from 8.3 × 10-9 m2/s (Sr approximately 91%) to 9.7 × 10-7 m2/s (Sr approximately 76%). The O2 consumption by biodegradation appears to be an important factor in the reduction of the O2 flux that can reach the bottom of the barrier.

INVESTIGATION ON THE PLACEMENT OF LIME NEUTRALIZATION SLUDGE ON ACID GENERATING WASTE ROCK
Coleman, M.M.D.; T.J. Whalen; A. Landva
NB Coal Limited, Minto, NB (Canada)
Fourth International Conference on Acid Rock Drainage, 31 May-6 June 1997, Vancouver, Canada
CANMET, Natural Resources Canada, Ottawa, ON (Canada). Vol 3, p 1163-1175, 1997

A study is described that examines the utilization of lime neutralization sludge for capping acid generating rock in the reclamation of a coal mine site. Dissolution of the metal hydroxides in the neutralization sludge and the permeability of the sludge to oxygen are examined. The chemical composition, net neutralization potential, morphology, geotechnical properties of the sludge, leachate quality, and the physical penetration of the sludge into the waste rock are measured. The results show that the sludge is not suitable as a low permeability capping material. Relocation of the sludge, however, provides alkalinity benefits to the waste rock and a slight decrease in its permeability.

EVALUATION OF ACID GENERATING ROCK AND ACID CONSUMING ROCK MIXING TO PREVENT ACID ROCK DRAINAGE
Day, S.J., Norecol, Vancouver, British Columbia (Canada)
Proceedings of the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, 24-30 Apr 1994, Pittsburgh, PA
Report No: BUMINES-SP-06B-94. NTIS: PB96-113493. Vol 2, p 77-86, 1994

Mixing acid generating and acid consuming rocks is an attractive and potentially low cost alternative for in situ prevention of acid generation in waste rock piles at some mine sites. In addition to the practicalities of day-to-day management of mixed waste rock piles, the success of the mixing will probably depend on the proportion of acid-consuming material, the availability of the acid consuming minerals, and

the intimacy of mixing. A 5-yr column study was initiated in 1988 to evaluate limestone requirements to prevent acid and metal release from waste rock stockpiles. Limestone content in five columns varied from zero (control, net neutralization potential = -58 kg/mt CaCO3) to 6.6% (NNP = 7 kg/mt CaCO3). Four of the columns generated acid. The column containing the highest concentration of limestone did not release acid, although residues in the upper part of the column were acidic and sulfate concentrations in leachate were gradually increasing. It was concluded that (1) the actual quantity of limestone required to prevent acid drainage in perpetuity would probably be at least twice that determined by conventional acid-base accounting, (2) limestone availability was not reduced by ferric hydroxide coatings, (3) the time required for marginally acid generating rock to release acidity increased exponentially as the quantity of limestone increased, and (4) the time required for zinc release to begin increasing was linearly proportional to the neutralization potential. Limestone addition was therefore highly effective in delaying acid release but was less effective in delaying zinc release.

APPLICATIONS OF METHODS FOR DELAYING THE ONSET OF ACIDIC DRAINAGE
Delaney, T.; D. Hockley; D. Sollner
Steffen Robertson and Kirsten, Inc., Denver, CO
Fourth International Conference on Acid Rock Drainage, 31 May-6 June 1997, Vancouver, Canada
CANMET, Natural Resources Canada, Ottawa, ON (Canada). Vol 2, p 795-810, 1997

The objective is to review techniques for delaying the start of acidic drainage and metal discharge from mine rock and to compile case histories from mine sites that have attempted to do this. The following methods are examined: bactericide application, alkali addition, low permeability covers, and organic oxygen-consuming covers. No field applications were found for three additional methods that were reviewed (phosphate application, freezing, and inorganic oxygen-consuming covers). The results show that simple soil covers, organic covers, and bactericide application to metal mines support further study.

FIELD PERFORMANCE OF TWO LOW INFILTRATION COVER SYSTEMS IN A SEMI ARID ENVIRONMENT
Durham, A.J.P.; G.W. Wilson (Univ. of Saskatchewan, Saskatoon, SK); N. Currey (Kidston Gold Mines, Cairns, QLD, Australia)
Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 3, p 1319-1326, ©2000

Two low water flux test covers were placed on acid generating waste rock dumps at the Kidston Gold mine in Queensland. The study was initiated to develop a cover system to restrict infiltration. The design of the cover required optimization of water storage and evapotranspiration. Instrumentation was installed on both dumps to measure infiltration, moisture conditions and climatic parameters. Field measurements over three years indicate that both covers are performing satisfactorily. Selection of the final cover for closure is described.

PYRITE OXIDATION CONTROL
Evangelou, V.P.
Acidic Mining Lakes: Acid Mine Drainage, Limnology, and Reclamation
Springer, New York. ISBN: 354063486X. p 419-422, c1998

REMEDIATION OF ACID DRAINAGE THROUGH SURFACE COATING OF IRON SULFIDES. U.S. GEOLOGICAL SURVEY (USGS) WATER RESOURCES RESEARCH ACT GRANT PROGRAM ANNOUNCEMENT 7846
Evangelou, V.P.; Y.L. Zhang; E. Portig, E.
Kentucky Agricultural Experiment Station, Lexington. Dept. of Agronomy.; Geological Survey, Reston, VA. Water Resources Div.
NTIS: PB98-115694INZ. 150 pp, Aug 1995

SILICATE COATING TECHNOLOGY TO PREVENT ACID MINE DRAINAGE
Fytas, F.; P. Bousquet (Laval Univ., Quebec City, PQ); B. Evangelou (Iowa State Univ., Ames, IA)
Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 1, p 87-96, ©2000

Acid mine drainage (AMD) is a serious environmental problem that preoccupies the Canadian mining industry. Considerable amounts of money are spent every year in an effort to prevent or reduce the acid mine drainage phenomenon. AMD occurs when sulfide minerals (ex. pyrite) contained in rock are exposed to air and water and subsequently oxidize to produce low pH water. This acid effluent has the potential to mobilize any heavy metals contained in the rock. Coating the sulfide minerals with silicates is a new promising technology to reduce AMD. Pyrite is treated with a solution containing H2O2, sodium silicate and a buffering agent. H2O2 oxidizes a small part of pyrite producing ferric iron (Fe3+) ions. These ions subsequently react with the silicate ions to produce ferric hydroxide-silica that precipitates on the pyrite surface producing a passive coating. This silicate coating can protect the grains of pyrite from oxidation. This paper presents a series of experiments that confirm that silicate coating can considerably reduce AMD.

A NOVEL TREATMENT FOR ACID MINE DRAINAGE, USING A WOOD-WASTE COVER PREVENTING SULFIDE OXIDATION
Germain, D. (Hydrogéochem Environnement, Québec); N. Tassé (INRS-Géoressources, Sainte-Foy, Québec)
Fifth International Conference on Acid Rock Drainage (ICARD), 21-24 May 2000, Denver, Colorado
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 1, p 987-997, ©2000

At the East Sullivan site, pore-waters underlying a wood waste cover that prevents sulfide oxidation are characterized by an anoxic environment, abundance of dissolved organic substrates, and near neutral pHs. Such conditions favor sulfate reduction and base metals precipitation as sulfides, as well as carbonate-metal precipitation. Pore-water composition from 1992 to 1998 shows a significant Fe2+ decrease. Therefore, the restoration strategy of that site capitalizes on these alkaline and reductive properties. Since 1998, a novel treatment of acid effluents, based on the recirculation of water discharged around the impoundment through the organic cover, is tested on the site. Available data gathered in 1998 and 1999 shows that the pH of recirculated water flowing within the wood waste cover increases by 2 to 4 units and that Fe total concentrations decrease by a factor greater than 6.

TREATMENT: DEALING WITH AN ACID PROBLEM
Jones, David (david.jones@north.com.au), ERA Environmental Services

Groundwork, No 1 Vol 2, Sep 1998 (Available online at http://www.ameef.com.au/groundwk.htm)

The generation of metal-rich and often acidic seepage water at mines is a legacy of the oxidation of sulphide minerals contained within waste materials. The ultimate aim of measures such as wet and dry covers and barrier technology is to minimize the oxidation rate and thereby the acid and metal loading of seepage. This new technology is progressively being implemented by the mining industry. However, there is a substantial legacy of sites where the production of acid drainage, and the possible need for treatment, remains an ongoing issue. This paper provides an overview of the current techniques for the treatment and control of acid drainage.

WAYS OF CONTROLLING ACID BY ECOTECHNOLOGY
Klapper, H.; K. Friese; B. Scharf, et al.
Acidic Mining Lakes: Acid Mine Drainage, Limnology, and Reclamation
Springer, New York. ISBN: 354063486X. p 401-418, c1998

REDUCTION OF PYRITE OXIDATION IN BROWN COAL OVERBURDEN IN FIELD EXPERIMENTS
Kringel, R., Ruhr-Univ. Bochum, Germany
Proceedings of the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, 24-30 Apr 1994, Pittsburgh, PA
Report No: BUMINES-SP-06B-94. NTIS: PB96-113493. Vol 2, p 418, 1994

Large scale open-pit mining for brown coals of Miocene age and its conversion to electrical energy near site characterizes the western regions of the federal state Northrhine-Westfalia, Germany. The acidification of a lake in the vicinity of closed and refilled open-pit workings has brought the problem of acid rock drainage into focus. The acid-forming potential is contained in the overburden. These are unlithified fine to middle grained quartz-sands of marine origin, and may contain up to 0.26 wt.% pyrite-sulfur with little acid neutralizing capacity. Pyrite oxidation is taking place on temporary surfaces, which are constant renewed and buried during mining operations. Approx 14% of the total pyrite inventory of the open-pit-mines are oxidized during normal operations. It was the task of a research project (currently ongoing) to explore methods to minimize pyrite oxidation and prevent the acidification of the overburden, thus reducing the quantity of oxidation products and improving the quality of leachate, contributing to groundwater recharge. Representative overburden-material was mixed with finely ground limestone, calcium oxide, fly-ash and alkaline fertilizer-phosphates with different mass ratios of up to 1.5 wt %. The mixture was deposited in experimental dumps in the pit-mine and exposed to weathering. In 110 days 42% of the pyrite in a reference dump were oxidized, while only between 8% and 37% were oxidized in the treated dumps. Acidification was prevented in all treated dumps. Analyses of the leachate showed high concentrations of iron and sulfate in the
reference dump, while only moderate amounts of sulfate and no iron were mobilized in the treated dumps. Investigations of the sediments showed that pyrite surfaces in the treated dumps (where little oxidation occurred) were coated with secondary minerals, presumably iron-hydroxides.

LAYERED CO-MINGLING FOR THE CONSTRUCTION OF WASTE ROCK PILES AS A METHOD TO MITIGATE ACID MINE DRAINAGE—LABORATORY INVESTIGATIONS
Lamontagne, A.; S. Fortin; R. Poulin (Laval Univ., Ste-Foy, PQ, Canada); N. Tasse; R. Lefebvre (INRS-Georesources, Ste-Foy, PQ, Canada)

Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 2, p 779-788, ©2000

This paper presents the results of a laboratory investigation aiming to verify the concept of co-mingling of waste rock with layers of compacted tailings. Overall, co-mingling is expected to delay the onset and reduce the magnitude of acid mine drainage (AMD) production in waste rock. To demonstrate the efficiency of the method proposed, five different column tests have been set-up. Columns were fed with deionized water at the top and drainage waters were collected and analyzed. Bacteria counts were done on the tailings and waste rock after the column tests. Permeability in saturated conditions and capillary parameters were measured for the tailings. The results obtained show that the co-mingling method would be effective in mitigating AMD by maintaining nearly water-saturated conditions in compacted tailings, thus reducing oxygen supply in waste rock by preventing thermal air convection and minimizing oxygen advection and diffusion.

MIXING OF LIMESTONE WITH FINELY CRUSHED ACID-PRODUCING ROCK
Lapakko, K.A.; D.A. Antonson; J.R. Wagner
Minnesota Dept. of Natural Resources, St. Paul, MN. Div. of Minerals
Fourth International Conference on Acid Rock Drainage, 31 May-6 June 1997, Vancouver, Canada
CANMET, Natural Resources Canada, Ottawa, ON (Canada). Vol 3, p 1345-1360, 1997

The purpose is to determine the limestone loadings required to neutralize acid produced by iron sulphide mineral oxidation in mine rock and to reduce the oxidation rate to a level that can be neutralized by the host rock minerals at final closure. The results are described for the first 397 weeks of measurements of the effects of five different loadings of -10 mesh limestone, mixed with rock, on the quality of the drainage from Duluth Complex rocks. The results show that all limestone loadings reduce sulphide mineral oxidation rates. At a loading of equal weight of limestone to sulphur, a level is reached where the silicate dissolution in the host rock is adequate for neutralization of the acid produced. It is concluded the method has excellent potential for neutralizing the acid produced both as an interim measure and for long-term mitigation.

DESIGN GUIDE FOR THE SUBAQUEOUS DISPOSAL OF REACTIVE TAILINGS IN CONSTRUCTED IMPOUNDMENTS
MEND Secretariat CANMET, Ottawa, Ontario. MEND Report 2.11.9, Mar 1998

The Design Guide is directed at a wide range of audiences including regulatory agencies in the developed and developing world, small, intermediate and large mining companies, environmental consultants, non government organizations (NGOs) and the general public. As some of these groups are not highly experienced in the technical issues relating to tailings systems, very broad and general coverage has been included in areas such as the geotechnical aspects, hydraulic design and risk assessment This information is included in order to illustrate how the detailed geochemical design information can be integrated to yield a complete design package. References are provided to documents that contain information on detailed design procedures and standards for such factors as risk assessments and geotechnical and hydraulic designs which are described in general terms in this Guide.

REVIEW OF SOIL COVER TECHNOLOGIES FOR ACID MINE DRAINAGE: A PEER REVIEW OF THE WAITE AMULET AND HEATH STEELE SOIL COVERS

MEND Secretariat CANMET, Ottawa, Ontario. MEND Report 2.21.3, Jul 1997

Prototype in situ covers were constructed at two mine sites, Heath Steele and Waite Amulet, as a part of the Mine Environmental Neutral Drainage (MEND) program. An independent study was undertaken by the Unsaturated Soils Group at the University of Saskatchewan to critically review the sites with respect to selection of soil materials, design, construction, instrumentation, performance, and economics. This work was funded by Cominco Ltd. The study had the following objectives: 1) to undertake a literature review of fundamental processes and methods of analyses required for the evaluation and design of dry covers; 2) to identify the key aspects of the design of soil cover systems; 3) to complete an inventory of other "dry cover" sites and their performance; 4) to undertake a critical scientific review of the Heath Steele and Waite Amulet sites; 5) to analyze alternative means that identify the essential components of soil cover systems, while at the same time, minimize the construction costs; and 6) to provide recommendations as to critical research needs in the areas of design, construction, monitoring, and analysis of soil cover systems.

CONSTRUCTION AND INSTRUMENTATION OF A MULTI-LAYER COVER: LES TERRAINS AURIFÈRES

MEND Secretariat CANMET, Ottawa, Ontario. MEND Report 2.22.4a, Feb 1999

Since January 1997, Barrick Gold Corporation's Les Terrains Auriferes (LTA) tailings site has been the subject of a detailed study - MEND Project 2.22.4 - aimed at assessing the performance of a composite cover placed on the acid-generating tailings impoundment. The full-scale composite cover was built in the winter of 1996 on the 60-hectare site. Alkaline tailings were used for the fine material layer. In addition to being the first full-scale cover of this type (e.g. oxygen barrier) in Canada (and possibly elsewhere), this project offers the added advantage of using mine tailings, a waste product. The main objective of this report is to describe the various phases of the LTA project, from the initial conceptual design of the cover to the final construction and monitoring. The theory behind composite covers and design methods have already been thoroughly discussed in the literature; the present report will, therefore, be a practical field application example of this technology.

FIELD PERFORMANCE OF THE LES TERRAINS AURIFÈRES COMPOSITE DRY COVER

MEND Secretariat CANMET, Ottawa, Ontario. MEND Report 2.22.4be, Mar 2000

During the decommissioning of Les Terrains Aurifères (LTA-Barrick-Bousquet) site at Malartic, the preferred option for the rehabilitation of the acid-generating tailings impoundment consisted of constructing a composite cover. The cover was set up during the winter of 1995-1996 and completed in the fall of 1996. The site has been the subject of a monitoring study, within the frame of NEDEM 2000, for almost three years, with the involvement of Barrick, the Ministry of Natural Resources of Quebec and CANMET through the Canada-Quebec agreement on mineral development. A first report, concerning the construction and the instrumentation of the multi-layer cover (NEDEM 2.22.4a 1999) is available. Since that time, a new set of monitoring stations have been installed on the site in order to get a better in situ spatial representation of the present conditions, particularly in the slopes. The present report concerns the performance of the cover during the period of 1996 to 1998. The main findings emanating from the present project are that, by capillary effect, the cover remained practically saturated over a period of three years, on the slopes as well as on top, and that the reduction of the average tailings oxidation flux was shown to be 95% over the three years of observation.

EVALUATION OF THE USE OF COVERS FOR REDUCING ACID GENERATION FROM

STRATHCONA TAILINGS

MEND Secretariat CANMET, Ottawa, Ontario. MEND Report 2.25.3, Sep 1997

The results of a one year pilot project designed to evaluate the effectiveness of various organic cover materials at limiting or reducing the impact of acid generation on the environment from acid generating tailings are summarized within this report. Lakefield Research Limited were contracted by Falconbridge Limited, with funding support provided by the MEND program, to perform this work. Three organic cover materials were tested: lime stabilized sewage sludge (LSSS), municipal solid waste compost and peat. Desulphurized tailings, an inorganic cover material, was also included in the study, both for comparative purposes and due to the potential for production of large volumes of this material at operating mining properties. The test program included three components of study: characterization of tailings and cover materials, salt migration column tests, and pilot scale cell tests. Both the salt migration column tests and the pilot cell tests enabled cover-tailings system evaluations.

MONITORING PROGRAM 1995-96 PHASE V: COMPOSITE SOIL COVER ON WASTE ROCK PILE 7/12 AT HEATH STEELE, NEW BRUNSWICK

MEND Secretariat CANMET, Ottawa, Ontario. MEND Report 2.31.1c, Feb 1998

A waste rock pile at the Heath Steele Division of Noranda Mining and Exploration Inc. was covered with a composite soil cover to test the ability of the cover to limit the rate of sulphide mineral oxidation. The experimental waste rock pile was constructed in 1989. Measurements of pore-gas oxygen, temperature and leachate water quality were conducted for two years, with the composite soil cover placed on the pile in 1991. The cover was designed to impede the ingress of water and oxygen to the pile. After construction of the cover, monitoring continued for another five years to assess the effectiveness of the cover. Additional measurements during the post-construction period included cover water content, soil suction, hydraulic conductivity and infiltration. Results showed reductions in gaseous oxygen concentrations in the waste rock pile after the cover was built, indicating reduced oxidation rates. Similarly, temperatures in the pile have decreased, now appearing to be controlled primarily by climatic conditions rather than sulphide oxidation rates. These findings indicate that oxidation rates are being controlled by the cover.

EVALUATION OF TECHNIQUES FOR PREVENTING ACIDIC ROCK DRAINAGE

MEND Secretariat CANMET, Ottawa, Ontario. MEND Report 2.35.2b, Jan 1997

The management of waste rock produced from mining of sulphitic ores poses a challenge to the mining industry. Acid generation occurs when sulphide minerals (principally pyrite and pyrrhotite) contained in the rock are exposed to air and water. In the absence of sufficient alkaline or buffering minerals, the resulting leach water becomes acidic, and is characterized by high sulphate, iron, and metal concentrations. This water, sometimes called acid rock drainage (ARD), can contaminate surface water and ground water courses, damaging the health of plants, wild life, fish and, possibly, humans. A study was initiated by Noranda Technology Centre (NTC) and the Centre de recherches minérales (CRW) to evaluate the relative effectiveness of various techniques for controlling ARD in waste mine rock. This study was undertaken at NTC as part of the MEND (Mine Environment Neutral Drainage) Program. The techniques investigated were water cover, soil cover, wood bark cover, and addition of limestone and phosphate rock (apatite).

BLENDING AND LAYERING WASTE ROCK TO DELAY, MITIGATE OR PREVENT ACID ROCK

DRAINAGE AND METAL LEACHING: A CASE STUDY REVIEW
MEND Secretariat CANMET, Ottawa, Ontario. MEND Report 2.37.1, Apr 1998

As a long term means of preventing the onset of acidic drainage, potentially acid generating and acid consuming waste rock can theoretically be blended or layered to produce a geochemically benign composite. This report presents the general theory behind blending and layering for prevention and control of acid rock drainage (ARD), and presents selected case studies on the use of this technique at mines in Canada, United States, and other parts of the world. The focus of this report is the blending, mixing and layering of waste rock, and, to some extent, the addition of limestone and other alkaline materials. The addition of alkaline materials was initially considered beyond the scope of this MEND sponsored project (Project2.37.1). However, the scope was expanded as very few case studies were found which exclusively examined blended waste rock, especially in the coal fields. Both coal and metal mines are covered in the review.

CONTROL OF ACIDIC DRAINAGE IN LAYERED WASTE ROCK: LABORATORY STUDIES AND FIELD MONITORING
MEND Secretariat CANMET, Ottawa, Ontario. MEND Report 2.37.3, Sep 1997

This study represents another contribution in the MEND series on the prediction and control of acidic drainage from waste-rock dumps. The Samatosum Minesite in southeastern British Columbia implemented full-scale layering of acid-generating and acid-neutralizing rock in its waste-rock dump, based on a series of column tests. This study has reviewed existing information, reinterpreted old data, and obtained new data for the layered waste-rock dump at Samatosum and the column tests that simulated it.

COVER SYSTEM PERFORMANCE IN A SEMI-ARID CLIMATE ON HORIZONTAL AND SLOPED WASTE ROCK SURFACES
O'Kane, M. (O'Kane Consultants, Inc., Saskatoon, SK); D. Porterfield; A. Weir; L. Watkins (BHP Iron Ore, Newman, WA, Australia)
Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 2, p 1309-1318, ©2000

BHP Iron Ore initiated a program in January 1995 at their Mt. Whaleback operation in Newman, WA, Australia, to develop a decommissioning plan for the waste rock material. The primary research program includes the development of technology for the long term performance of the waste rock dumps with respect to vegetation, slope stability, surface runoff, erosion, and water infiltration. This paper evaluates field performance of cover systems constructed on a horizontal and a sloped waste rock surface. The cover system is constructed using suitable run-of-mine waste material. The moisture is released to the atmosphere as evapotranspiration. Rainfall entering the waste material is buffered. The objective is to control acid rock drainage by preventing moisture movement into and through the waste rock material.

PREVENTION OF ACID ROCK DRAINAGE THROUGH THE APPLICATION OF IN-PIT DISPOSAL AND ELEVATED WATER TABLE CONCEPTS
Orava, D.A.; G.A. Tremblay; P.A. Tibble; R.V. Nicholson
Fourth International Conference on Acid Rock Drainage, 31 May-6 June 1997, Vancouver, Canada
CANMET, Natural Resources Canada, Ottawa, ON. Vol 3, p 971-987, 1997

EFFECTS OF ACID MATERIAL HANDLING AND DISPOSAL ON COAL MINE DRAINAGE QUALITY

Perry, E.F.; M.D. Gardner; R.S. Evans
U.S. Office of Surface Mining, Pittsburgh, PA

Fourth International Conference on Acid Rock Drainage, 31 May-6 June 1997, Vancouver, Canada
CANMET, Natural Resources Canada, Ottawa, ON (Canada). Vol 3, p 1007-1025, 1997

Special handling techniques are used at surface coal mines in northern Appalachia to prevent oxygen or water from contacting sulphide mineral wastes. Seven mining sites that use special handling techniques were studied to evaluate various factors relevant to handling acid forming materials. The following techniques are examined: segregation, rock blending, water management, and use of lining and capping. Net alkalinity is used as the main indicator to assess post-mining water quality. Predicted and actual water qualities are evaluated against mining practices. The findings for the seven sites are described.

ON THE CO-MINGLING OF MINE WASTES AND TAILINGS

Poulin, R.; R.J. Patterson; J. Hadjigeorgiou
Univ. of British Columbia, Vancouver, BC (Canada)

The Third International Conference on Environmental Issues and Waste Management in Energy and Mineral Production, 30 August-1 September 1994, Perth (Australia)
Brodie-Hall Research and Consultancy Centre Pty. Ltd., Curtin Univ. of Technology, Perth, WA (Australia). ISBN: 1-8634-2-292. p 599-606, 1994

Co-mingling mine waste with mill produced tailings has the potential for controlling the generation of Acid Rock Drainage. The influence of stratified waste rock placement with dewatered tailings has been investigated in a series of controlled column tests. The development methodology, monitoring results and long term implications of co-mingling, as part of an integrated mine waste management programme, are discussed.

ASSESSMENT & MANAGEMENT OF RISKS RELATING TO COVERS FOR METAL LEACHING AND ARD MITIGATION

Robertson, A. MacG.; C. Wels, Robertson GeoConsultants, Inc., Vancouver, BC

Fifth Annual Metal Leaching/ARD Workshop, 9-10 December 1998, Vancouver, BC

This paper examines the risks associated with the design, construction and long-term performance of covers placed on waste rock or tailings in order to control acid rock drainage. The various potential problems in using covers including difficulty of access (for construction), slumping, erosion, consolidation and biotic activity will be reviewed and illustrated using recent field examples. The influence of site specific conditions (climate, available materials, biota) on cover design and risk of failure are discussed. Risk and risk management is evaluated and reviewed for cover design, cover construction, and cover disruption during post-construction operation. The nine slides from this presentation are available at http://www.infomine.com/rgroup/rgc/papers.html

EVALUATION OF THE EFFICIENCY OF MEASURES FOR SULPHIDIC MINE WASTE MITIGATION

Schippers, A.; P.-G. Jozsa; W. Sand

Applied Microbiology and Biotechnology, Vol 49 No 6, p 698-701, 25 Jun 1998

To control the environmentally detrimental impact of acid rock drainage, two different

countermeasures, layers of acid-buffering materials and sodium odecyl sulphate addition, were tested for their efficiency in laboratory percolation experiments. In the experiment with a layer of calcium bentonite, only the iron output was reduced. The experiments with layers of concrete grains demonstrated a decrease of the microbial activity as well as a precipitation of heavy-metal ions, whereas the cell numbers did not decrease. Furthermore, finely grained concrete (1-5 mm) formed a water-tight hardpan (self-sealing layer). In the experiment with 1 mM sodium dodecyl sulphate, all the microorganisms were killed and hence metal sulphide dissolution was stopped. With 0.1 mM sodium dodecyl sulphate only a short, transient inhibition of leaching was achieved. The bacteria remained
alive.

THE POTENTIAL FORMATION OF ACID MINE DRAINAGE IN PYRITE-BEARING HARD-COAL TAILINGS UNDER WATER-SATURATED CONDITIONS: AN EXPERIMENTAL APPROACH
Schü, J.; et al.
Environmental Geology, Vol 31 No 1/2, p 59-65, 26 May 1997

Annually, an amount of approximately 13 million cubic meters of hard-coal tailings must be disposed of in the German Ruhr Valley. Besides the waste of land in a densily populated region, the disposal of the pyrite-bearing material under atmospheric conditions may lead to the formation of acid mine drainage (AMD). Therefore, alternative disposal opportunities are of increasing importance, one of which being the use of tailings under water-saturated conditions, such as in backfilling of abandoned gravel pits or in the construction of waterways. In this case, the oxidation of pyrite, and hence the formation of AMD, is controlled by the amount of oxygen dissolved in the pore water of tailings deposited under water. In case the advective percolation of water is suppressed by sufficient compaction of the tailings, oxygen transport can be reduced to diffusive processes, which are limited by the diffusive flux of dissolved oxygen in equilibrium with the atmospheric pO2. Calculations of the duration of pyrite oxidation basedon laboratory experiments have shown that the reduction of oxygen is mainly controlled by the content of organic substance rather than the pyrite content, a fact that is supported by results from oxidation experiments with nitrate. A worst case study has lead to the result that the complete oxidation of a 1.5-m layer of hard-coal tailings deposited under water-saturated conditions would take as much as several hundred thousand years.

SOME INSIGHTS INTO THE PERFORMANCE OF AN EXPERIMENTAL SOIL COVER NEAR LONDON, ONTARIO
Simms, Paul. H.; Ernest K. Yanful
Canadian Geotechnical Journal, Vol 36 No 5, p 846-860, 1 Oct 1999

An experimental soil cover constructed near London, Ontario, 23.2 m × 15.2 m in plan area, has been monitored for 2 years for percolation and water-content data. The cover was a multilayer system consisting of a compacted till barrier soil placed between evaporation and drainage barriers of sandy gravel. Half of the cover was capped with coarse stone to prevent erosion and the other half was covered with topsoil to facilitate revegetation. High percolation rates and substantial desiccation of the barrier soil were reported under the topsoil protection layer. Unsaturated-saturated liquid and vapour flow modelling shows that the topsoil may act as a capillary barrier to infiltration, thereby promoting desiccation of the underlying compacted till. Percolation through the cover was measured using lysimeters filled with 5-16 cm (2-6 in.) diameter stone placed directly underneath the compacted till. Though the field lysimeters report water and laboratory tests show no evidence of flow partitioning between coarse stone and gravel, two-dimensional unsaturated-saturated liquid flow modelling of the
lysimeter-cover interaction predicts that the lysimeters should not report significant water. Phenomena not

simulated by the modelling, which include macrostructure flow in the barrier soil, trickle flow in the coarse stone, and vapour diffusion, are investigated and discussed. Consideration of vapour flow yields results that are inconsistent with the predictions of the liquid flow modelling.

HANDBOOK OF TECHNOLOGIES FOR AVOIDANCE AND REMEDIATION OF ACID MINE DRAINAGE

Skousen, J., et al. ... and members of the Avoidance and Remediation Working Group of the Acid Drainage Technology Initiative (ADTI)

The National Mine Land Reclamation Center, West Virginia Univ., Morgantown, WV. 135 pp, 1998

An array of techniques have been developed during the last several decades to abate or control pollution by acid mine drainage (AMD) from coal and metal mines. Although most of these techniques are successful in eliminating or decreasing the deleterious effects of AMD in some situations, they are unsuccessful in others. Due to the inherent variability between mines and environmental conditions, no one abatement or treatment technique is effective on all sites, and selection of the best method on each site is difficult given the array of methods available. The techniques also vary in the type and size of problem they are capable of handling. Their individual costs, effectiveness, and maintenance are also important considerations. Therefore, accurate information is needed to understand the limitations of the various methods and their response to various site variables. This Phase I document summarizes the technologies and provides some relevant case studies collected by the various members of the ADTI. The initial focus has been on AMD from coal mining, mainly in the eastern U.S., although much of the discussion in this manual also applies to metal mine drainage. The manual is available at http://www.neetc.org/adti/handbook_2.htm

EFFICIENT PREVENTION OF SULFIDE OXIDATION BY AN ORGANIC COVER: FOR HOW LONG CAN A REACTIVE BARRIER BE REACTIVE?

Tasse, N., INRS-Georesources, Saint-Foy, PQ

Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO

Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 2, p 979-986, ©2000

Reactive barriers, which consume oxygen, are prospective though unconventional alternatives to physical barriers for Acid Mine Drainage prevention. However, a reactive barrier implies a problem of duration. Pore gases were analyzed in several wood waste piles in order to understand the factors that control wood degradation and help to determine the effective life span of such a cover. Long term efficiency seems to strongly depend on the degree of water saturation at the bottom of the pile, likely because the development of a microbial biomass in such an environment helps to keep the amounts of nutriments and readily metabolizable organic substrates at a high level, which in turn promotes oxygen consumption.

ORGANIC-WASTE COVER OVER THE EAST SULLIVAN MINE TAILINGS: BEYOND THE OXYGEN BARRIER

Tassé, N. (INRS-Géoressources, Sainte-Foy, Québec); D. Germain; C. Dufour; R. Tremblay

Fourth International Conference on Acid Rock Drainage (ICARD), 31 May-6 June 1997, Vancouver, BC, Canada

MEND Secretariat CANMET, Ottawa, Ontario. Vol 4, p 1627-1642, 1997

Covers used to control acid mine drainage are intended essentially to stop acid-producing mine

wastes from contact with oxygen. In the case of an organic cover, atmospheric O2 is consumed by carbon oxidation before it reaches the problem-causing sulphides. The practicality of the concept is well demonstrated by the ligneous covering of the East Sullivan mine tailings, where forestry wastes, laid down since the mid-80's, cover almost 75% of the 136 ha tailings impoundment (end of 1996). This paper summarizes the major characteristics of the tailings pile and of its wood waste cover, reviews and integrates data regarding how the cover presently functions, and presents a strategy by which such an organic cover could also be used to treat contaminated solutions generated before cover placement. Field studies at East Sullivan have demonstrated that a 1 m wood waste cover can lead to full anaerobic conditions, with methanogenesis. The decomposition of the barrier results in a marked increase in the alkalinity of the underlying groundwater, and it constitutes a large reservoir of organic compounds which drive redox reactions. Absence of oxygen and interruption of sulphide oxidation, however, does not mean an immediate cessation of acid mine drainage. Oxidation prior to restoration has released acid and acidity to pore waters, and that acid-prone water must be first purged from the tailings pile before the positive effects of alteration control can be observed. At East Sullivan, hydrogeologic modelling indicates that the production of acidic discharge could continue for 5 to 10 years after cover completion. Conceptually, the organic cover could be used for the treatment of the residual water during that transition period, by simple recirculation through it. Thanks to its alkalinity and organic composition, it could assume the same function than passive treatment devices such as anoxic limestone beds and reducing wetlands. Organic covers, such as forestry wastes, have therefore a specific attraction, compared to other types of covers, in that they can assume a double role: that of an oxygen barrier, and that of an alkaline and reducing system, for the interim treatment of residual, acid-producing, waters.

COMPOSITION OF INTERSTITIAL GASES IN WOOD CHIPS DEPOSITED ON REACTIVE MINE TAILINGS: CONSEQUENCES FOR THEIR USES AS AN OXYGEN BARRIER
Tassé, N.; M.D. Germain; M. Bergeron, INRS-Géoressources, Sainte-Foy, Québec
Environmental Geochemistry of Sulfide Oxidation
American Chemical Society, Symposium Series 550, p 631-644, 1994

Interstitial gases were measured within a 1 m thick wood-chip cover on top of base-metal mine tailings in northwestern Québec, Canada, to evaluate the efficiency of the cover as an oxygen interceptor. The oxygen concentration decreases sharply to less than 5 vol. % below 50 cm, as O2 is consumed by organic-matter oxidation. At these depths, CO2 and CH4 concentrations inease to > 20 and > 10 vol. %, respectively, as a result of oxidation and methanogenesis. Profiles measured three times within a month show that gas generation is sensitive to surface temperature. The calculated rates of biomass removal are so high that they jeopardize the long-term effectiveness of such a cover. Moreover, the potential for methylation of heavy metals, as a consequence of metanogenesis, must be considered.

INNOVATIVE METHODS OF MANAGING ENVIRONMENTAL RELEASES AT MINE SITES
U.S. EPA, Office of Solid Waste
EPA 530-R-94-012, NTIS: PB94-170255. 111 pp, 1994

The report describes source reduction and recycling practices and innovative techniques for waste management currently used in mining. EPA's intent is the identification of these practices and the fostering of technology and information transfer throughout the mining industry. Source reduction can include process control to produce a purer product while reducing hazardous constituents in the waste stream and production of a new saleable product while reducing hazardous constituents in the waste stream. Recycling opportunities unique to mining are slag reprocessing, tailings reprocessing, pipe recycling/reuse, and

recycling mine tires. The other practices section addresses topics of a more general nature and includes a description of best management practices for water management and the facility pollution prevention plan prepared by the Cyprus Baghdad Mine. This document and other mining waste reports are available at http://www.epa.gov/epaoswer/other/mining.htm

SEMINAR PUBLICATION : MANAGING ENVIRONMENTAL PROBLEMS AT INACTIVE AND ABANDONED METALS MINE SITES
U.S. EPA, National Risk Management Research Laboratory
EPA 625-R-95-007. 91 pp, 1995

Basic fundamentals of acid mine drainage, known and probable effects on the public health and environment, and control technologies known and under investigation are presented. Some of the techniques included bioremediation, composting, and innovative approaches being investigated by EPA and others. The document can be ordered online at http://www.epa.gov/ttbnrmrl/Sempubs.htm

THE CO-DISPOSAL OF WASTE ROCK AND TAILINGS
Wilson, G.W.; L.L. Newman (Univ. of Saskatchewan, Saskatoon, SK); K.D. Ferguson (Placer Dome North America Ltd., Vancouver, BC)
Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 2, p 789-796, ©2000

Traditional methods for mine waste management produces two waste streams and the construction of separate disposal facilities. Tailings impoundment design is usually controlled by physical stability problems. Alternatively, the waste rock offers high stability characteristics but hydraulic properties that create ideal conditions for oxidation. The problem of oxidation is significantly reduced for tailings due to a fine texture that augments water saturation. This paper introduces concepts for the co-disposal of tailings with waste rock and evaluates the physical behavior of an integrated waste system. The potential benefits of co-disposal are shown for a typical mine.

RECENT FINDINGS FROM THE HEATH STEELE WASTE ROCK COVER TEST SITE
Woyshner, M.R.; M. Patterson; L.C. St.-Arnaud
Sudbury ‘99: Mining and the Environment II, September 12 - 16, 1999, Sudbury, Ontario, Canada
Centre in Mining and Mineral Exploration Research (CIMMER), Laurentian Univ., Sudbury, ON

FIVE YEARS AFTER COVERING TAILINGS AND WASTE ROCK WITH A COMPOSITE SOIL COVER: A CASE REVIEW AND WATER QUALITY PREDICTIONS AT THE MILLENBACH SITE NEAR ROUYN- NORANDA, QUÉBEC
Woyshner, Mark R.; C. St.-Arneault; L.C. St.-Arnaud
Fourth International Conference on Acid Rock Drainage (ICARD), 31 May-6 June 1997, Vancouver, BC, Canada
MEND Secretariat CANMET, Ottawa, Ontario. Vol 4, p 1673-1690, 1997

FIRST YEAR FINDINGS FROM SOIL COVER TEST PLOTS ON KIDD CREEK THICKENED TAILINGS NEAR TIMMINS, ONTARIO
Woyshner, M.R.; B. Swarbrick
Fourth International Conference on Acid Rock Drainage (ICARD), 31 May-6 June 1997, Vancouver, BC, Canada
MEND Secretariat CANMET, Ottawa, Ontario. Vol 3, p 1075-1091, 1997

MODELLING AND FIELD MEASUREMENTS OF WATER PERCOLATION THROUGH AN EXPERIMENTAL SOIL COVER ON MINE TAILINGS
Woyshner, M.R.; E.K. Yanful
Canadian Geotechnical Journal, Vol 32, p 601-609, 1995

OXYGEN DIFFUSION THROUGH SOIL COVERS ON SULPHIDIC MINE TAILINGS
Yanful, E.K., Mineral Sci. Lab., Noranda Techn. Ctr., Pointe-Claire, Quebec
Journal of Geotechnical Engineering, Vol 119 No 8, p 1207-1228, Aug 1993

Engineered soil covers are being evaluated under Canada's Mine Environment Neutral Drainage (MEND) program for their effectiveness in prevailing and controlling acid generation in sulphidic mill tailings. A critical parameter for predicting the performance of these covers is the diffusion coefficient of gaseous oxygen in the cover materials. Laboratory experiments conducted to determine the effective diffusion coefficient of a candidate cover material, a glacial till from an active mine site, are described. The diffusion coefficient is determined by fitting a semianalytic solution of the one-dimensional, transient diffusion equation to experimental gaseous oxygen concentration versus time graphs. Effective diffusion coefficients determined at high water saturations (85%-95%) were of the order of $8 \times 10\text{-}8$ m^2/s. The diffusion coefficients decreased with increase in water saturation as a result of the low diffusivity of gaseous oxygen in water relative to that in air and the low solubility of oxygen in water. Placement of soil covers in high saturation conditions would ensure that the flux of oxygen into tailings underneath such covers is low, resulting in low acid flux. This is confirmed by combined laboratory, field, and modeling studies.