ACID MINE DRAINAGE CHARACTERIZATION AND TREATMENT AT LA MINE DOYON

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ABSTRACT

The South Waste Dump at La Mine Doyon, Rouyn-Noranda, Québec, has been generating acidic drainage since 1985, two years after dump construction was started. Between 1991 and 1994, the South Waste Dump has been the subject of extensive studies carried out through the MEND program primarily by Groupe de Recherche en Environnement et Géo-Ingénierie (GREGI), Laval University, Québec City. One of the objectives of the study was to measure physical and chemical properties of an acid generating waste rock dump and to identify and model the key processes contributing to the generation of acid mine drainage (AMD). The site investigation included geochemical, mineralogical and microbiological characterization of the waste rock dump, chemical analysis of porewater and surface run-off, hydrology and water balance studies, the analysis of thermal processes, and modeling.

AMD from the South Waste Dump is characterized as having very low pH (2.5), high acidity (60 000 mg $CaCO_3$/l) and high iron (15 000 mg/l) and sulfates (62 000 mg/l) concentrations. Runoff from the acid generating waste dump is collected and treated through a High Density Solids (HDS) water treatment plant. The HDS process, developed by Tetra Technologies, is an improved neutralization technique which reduces the large volumes of sludge produced by conventional lime treatment of AMD. Currently, some 3 million m^3 of AMD are treated annually on the property at an average lime consumption of 2,42 kg of CaO/m^3.

Keywords : Acidic Drainage, Waste Rock Dump, Characterization and Monitoring, AMD Treatment, High Density Solids

INTRODUCTION

La Mine Doyon is a joint venture between Barrick Gold Corporation and Cambior Inc. Each partner has a 50% interest in the property, and Barrick is the mine operator. Production at La Mine Doyon began in 1980, with the main zone surface pit. From 1980 to 1989, 7,5 million of tonnes of ore and 47 million tonnes of overburden and waste rock were placed in two waste dumps, designated as the South Waste Dump and the North Waste Dump (shown on Figure 1). Results from exploration programs were very encouraging, and a decision was taken to sink a 650 meter deep shaft, which was completed in 1986. In 1989, the open pit production stopped, and the mill feed of 3 300 tonnes/day has since been provided by the underground mine. Current reserves (1997) at La Mine Doyon are sufficient for at least thirteen years of additional production.

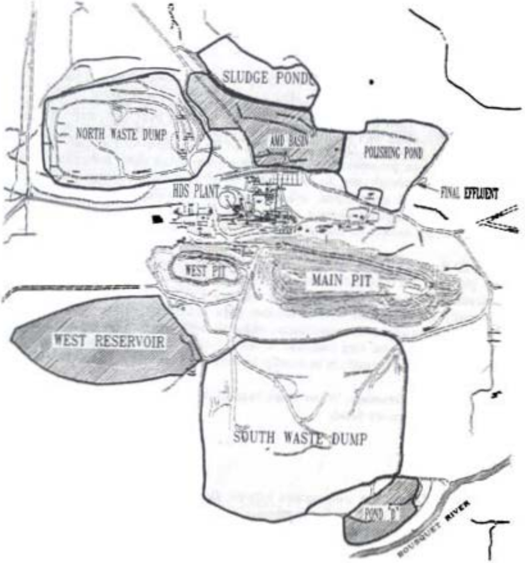

Figure 1 - Surface Map of La Mine Doyon

In 1985, acidic runoff was observed for the first time from the North and South Waste Dumps. (Firlotte et al., 1991). The initial treatment system involved collection of acid runoff from the waste dumps in strategically located ponds, conventional lime neutralization and management of the resulting sludge. In 1989, an agreement was reached with Groupe de Recherche en Environnement et Géo-Ingénierie (GREGI, Laval University) to undertake a long term project on the characterization of the South Waste Dump at La Mine Doyon through the Mine Environmental Neutral Drainage (MEND) Program. The results of the studies have been incorporated in eight reports that have been published by MEND and are available from the MEND Secretariat.

This paper presents a general synthesis of some of the physical and chemical processes observed by GREGI and documented in MEND reports and does not intend to reflect the entire work undertaken under MEND at La Mine Doyon between 1991 and 1994. Aspects of AMD treatment are described with over six years of data related to the operation of High Density Solids (HDS) water treatment technology presented.

LOCATION

La Mine Doyon is located in the western part of the Province of Quebec, Canada, along highway 117, 40 kilometers east of the town of Rouyn-Noranda (30 000 population) and 70 km west of the town of Val d'Or (30 000 population).

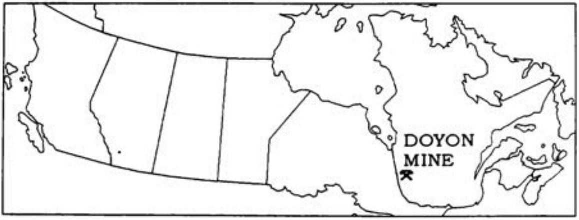

Figure 2 - Location of La Mine Doyon

REGIONAL TEMPERATURE AND PRECIPITATION

Temperature ranges from a mean low of -16,8 °C in January to a mean high of 23,3 °C in July. Total precipitation averages 933,8 mm which includes 623,4 mm rainfall and 310,4 mm (water equivalent) snowfall. The evapotranspiration for the period of May through September averages 510 mm, resulting in a net positive water balance of 424 mm per year. The months with the greatest precipitation are from July to September, with approximately 100 mm. Snowfall typically begins near the end of October and continues through to the beginning of April, with persistent snow cover through most of this period. The average number of frost-free days is 97.

CHARACTERIZATION OF THE SOUTH WASTE DUMP

Mineralogy of the South Dump

The South Waste Dump covers a rectangular area of approximately 600 m x 900 m and extends 30 to 40 m above the surrounding ground surface. The total mass of the dump, taken from the mine records, is about 21 million tonnes and occupies an estimated volume of 11,5 millions cubic meters. Therefore, the dry density value is estimated at 1 826 kg/m^3.

Three main rock types have been identified in the South Waste Dump: sericitic schists, intermediate tuffs and felsic volcanoclastics. The sericitic schists constitute about 50% of the waste rock volume. They are composed of quartz and muscovite with up to 30% weathered alumino-silicates. Secondary minerals are pyrite (7%), rutile and some chlorite. The intermediate tuffs account for about 30% of the pile and have a low pyrite content (≈2%). The felsic volcanoclastics have a pyrite content of 5,5% and account for 15% of the dump. Sulfides in the waste rock dump consist mainly of pyrite, with minor amounts of chalcopyrite and sphalerite (less than 1% of the sulfides). The total mass of pyrite in the South Waste Dump is estimated at 1,05 million tonnes, which translates to an average pyrite content of 4,5 %.

The net neutralization potential (NNP) of the unweathered waste rock has been calculated from chemical analysis. The sericitic schists and felsic volcanoclastics are net acid producers with NNP values of -100 kg $CaCO_3$/t and -71 kg $CaCO_3$/t respectively. The intermediate tuffs showed a NNP of +25 kg $CaCO_3$/t. Given the relatively low pyrite content of the waste rock, the reactivity and high oxidation rates are attributed to the friable nature of the sericitic schists. Mechanical resistance and abrasion testing showed rapid breakdown of the schists in the presence of water (slaking) and the exposure of the fine grained pyrite covering the planes of schistosity.

Field instrumentation and monitoring

In order to gather more data on the oxidation conditions prevailing inside the South Waste Dump, field instrumentation was installed in 1990 and 1991 and a monitoring program was put in place. A total of 6 boreholes were drilled through the South Waste Dump. Each borehole was equipped with two monitoring wells, a string of thermistors (11 in a typical borehole) and polyethylene gas sampling tubes (at 8 different depths). Twelve gravity lysimeters were installed in two 5 meter deep excavations and 3 groups of suction lysimeters were added later. Runoff from the South Waste Dump is collected in three surrounding ditches and directed to storage ponds. Three weir stations were installed at the discharge of the ditches to record the flowrate and the conductivity of the acidic runoff. Figure 3 shows the location of the field instrumentation.

Boreholes

Table 1 presents typical chemical analysis of the leachate sampled in the saturated zone of the monitoring wells. It can be seen that Borehole 4 is located in a less reactive area. The high Al concentrations in Boreholes 2 and 3 could be the result of extensive reaction of the leachate with aluminosilicate minerals present in the sericitic schists. Some borehole water samples have shown a

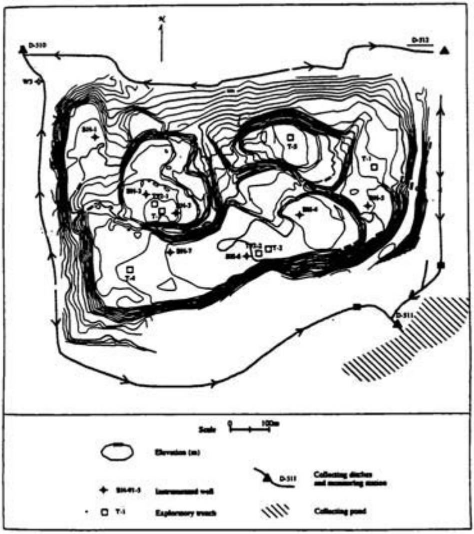

Figure 3 - Plan of South Waste Dump (from Gélinas et al., 1994)

slight increase in acidity with time since 1991, while Fe concentrations have been decreasing slowly in most boreholes.

Borehole	pH	Acidity † ($mgCaCO_3/l$)	TDS (mg/l)	Al (mg/l)	SO_4^{2-} (mg/l)	Fe^{2+} (mg/l)	Fe^{3+} (mg/l)	Fe tot (mg/l)
2	2,52	93 387	142 443	9 630	106 419	10 742	2 975	13 717
3	2,47	134 969	198 575	12 367	130 967	13 950	2 545	16 495
4	4,45	2 639	4 425	54	3 401	260	0	260

† Calculated values from TDS

Table 1 - Water Quality in Boreholes at the Base of the South Waste Dump (April 1996)

Thermistor values are recorded monthly. The fact that pyrite oxidation is exothermic causes temperatures within the waste pile to be higher than on surface. Values as high as 65°C have been recorded from inside the dump. Seasonal variations have been observed in the first 8 m from the surface. No significant variation can be seen below that point. Through the rock pile, temperatures increase rapidly from the top to the upper half of the dump then decrease slowly toward the base. Results compiled over the past 6 years clearly show a cooling trend in the waste pile. Temperature drops of 30 degrees or more have been observed. Figure 4 presents the temperature profile for the borehole BH-6 over a 5-year period.

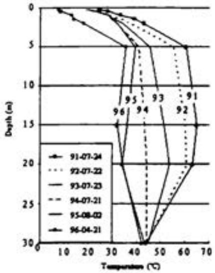

Figure 4 - Temperature Profiles in BH- 6.

Weir stations

Each weir station consists of a small dyke with a V-notch weir and is equipped with a water conductivity meter, a flow meter and a data logging system. Measurements are taken every 5 minutes. As shown in Figure 5, higher AMD flowrates have been recorded during the spring thaw and the higher precipitation season in the fall. The total drainage from the South Waste Dump between 1991 and 1996 averages 200 000 m^3 annually. Runoff is more important at station D-510, which collects the drainage from an area covering 62% of the South Waste Dump surface.

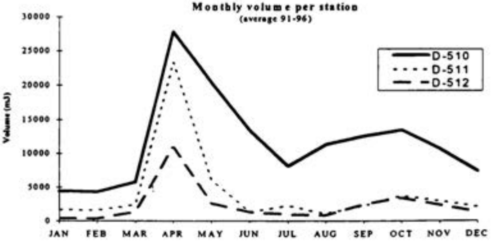

Figure 5 - Average Monthly Drainage from the South Waste Dump at Three Monitoring Stations

Regular seasonal variations have been observed in water quality. Higher acidity corresponds to periods of low flow, i.e. during the winter and the summer dry season, and lower acidity values are observed during periods of high flow, i.e. during the spring thaw and higher precipitation season in the fall. Figure 6 shows that when the AMD is diluted, as during the spring runoff, total acid mass production, expressed in kg $CaCO_3$, is higher.

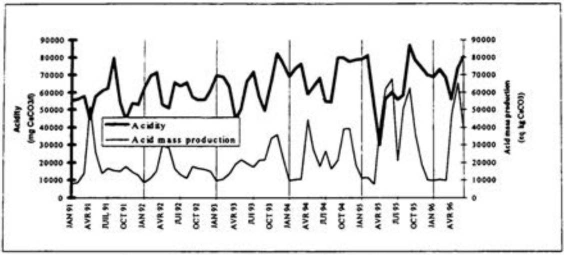

Figure 6 - Acidity and Mass of Acid Production vs Time

Bacterial activity

From the drill cuttings, 4 types of microorganisms were isolated: *Thiobacillus ferrooxidans*, *Leptospirillum ferrooxidans*, *Thiobacillus thiooxidans* and *Thiobacillus acidophilus*. Bacteria traps, which consisted of chunks of local sulfides, were also inserted in the boreholes for a 40-day period to collect microorganisms. From field observations, it has been concluded that intense oxidation (driven by bacterial activity) is occuring. This is especially true in the upper 10 metres of the waste dump where moderate temperatures (less than 35 °C) prevail and oxygen is available to bacteria through air convection.

Air convection

Thermally driven convection is the key mechanism controlling oxygen flow through the waste rock dump. Field observations of the South Waste Dump during the cold season showed the presence of hot air chimneys and snow-free spots, frequently located near the edges of the top of the slopes. An airborn infrared thermographic survey confirmed that important air entry occurs at the base of the dump and hot air exits at the upper rim all around the dump. Pressure measurements, oxygen sampling and temperature profiles in the boreholes all suggest that air convection is playing a major role in the oxidation process. This evidence has lead to the development of a conceptual model of the air convection patterns within the dump (Gélinas et al., 1994). As illustrated on Figure 7, two different convection regimes exist in the dump: a rapid convection, close to the surface and slow air movement in the heart of the dump.

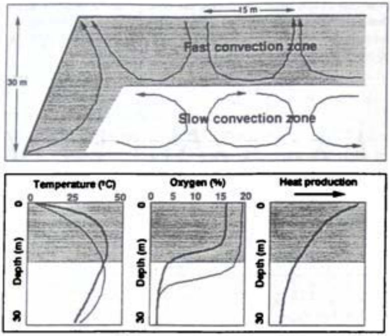

Figure 7 - Schematic Diagram of Air Convection Patterns (from Gélinas et al., 1994)

WATER MANAGEMENT

Drainage from the South and the North Waste Dumps is collected in ditches surrounding the dumps and directed to storage ponds. Except during the winter months, AMD is pumped from the storage ponds to the treatment pond which feeds the water treatment plant. The three main sources of AMD on the property are the South Waste Dump, the North Waste Dump and the open pit. With respect to this latter source, AMD is largely caused by the reaction of the South Pit Wall which is predominantly composed of sericitic schists. Mine water, which represents an annual volume of 900 000 m^3, is slightly acidic and is pumped directly to the treatment pond. On a yearly basis, 3 million m^3 of AMD is collected, treated and discharged to the environment. About one third of this volume is produced during the spring thaw in April and May.

Although the South Waste Dump drainage reporting to collection ditches accounts for only 1/15 of the total AMD volume collected and treated, it is the principal source of acidity for the site. Using three years of chemical analysis results for the South Waste Dump, it has been calculated that it is responsible for approximately 85% of the acidity, 88% of the iron and 64% of the sulfates generated. Runoff from the North Waste Dump (similar in quality to water pumped from the open pit) has lower concentrations of most parameters than the South Waste Dump because it was primarily constructed with overburden and waste rock having lower acid generation potential.

WATER TREATMENT PLANT

Between 1985 and 1989, AMD from the North and South Waste Dumps, the open pit and the underground mine was collected in perimeter ditches and directed to two conventional lime treatment plants. One plant was located north of the property and the other south of the South Waste Dump. In 1988, La Mine Doyon initiated discussions with Tetra Technologies Inc. regarding their patented High Density Solids (HDS) technology. In 1989 it was decided to construct an HDS plant to better regulate pH and lime consumption and to significantly reduce the production of iron hydroxide and gypsum sludge (Morrison and Pfeiffer, 1989).

The yearly lime consumption associated with AMD treatment during the 1985 to 1996 period is presented on Figure 8. It shows that in the period 1986 to 1989, when the conventional lime neutralization plants were in operation, annual lime consumption rapidly increased from about 5 000 tonnes per year to about 20 000 tonnes per year in 1988 and 1989. This was due to a sharp increase in the generation of acidity. Since 1991, the first full year of HDS plant operation, lime consumption has averaged 8 590 tonnes per year.

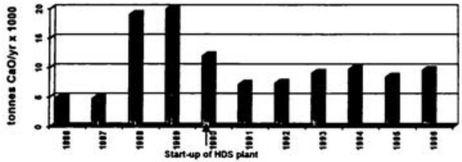

Figure 8 - Annual Lime Consumption - 1986 to 1996

The HDS process is an improved neutralization technique developed to reduce the large volumes of sludge produced by the conventional lime treatment. Compared to conventional neutralization, the HDS process reduces the volume of sludge requiring disposal by up to a factor of 8. The principal differences between conventional neutralization and the HDS process are:

- recycling of a controlled volume of settled sludge; and
- mixing of recycled sludge with lime in a reactor prior to the neutralization and separation steps.

The HDS plant flowsheet of La Mine Doyon is shown on Figure 9. The plant is fed from the treatment pond pumping station through a 40,6 cm HDPE pipeline. Three reactors are used in the neutralization process. The incoming water is met by a recycle stream of thickener underflow sludge in the first reactor (ferric reactor), where the pH is maintained at 4,3 to precipitate the ferric ions as ferric hydroxides. A mixture of hydrated lime and recycled sludge is used to adjust pH to 8,5 in the second and third reactors (ferrous reactors). Air is added to the ferrous reactors to aid in the conversion of Fe^{+2} to Fe^{+3}. The neutralization treatment is followed by flocculant addition and thickening. When sludge density reaches 20% to 22%, a bleed pump automatically removes sludge from the circuit and discharges it in a sludge storage pond. Operation of the pump stops when the sludge density decreases to 15% to 18%.

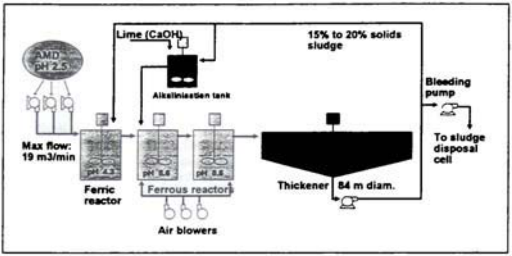

Figure 9 - HDS Plant Flowsheet

The HDS plant was designed for a rated capacity of 1 135 m³/h. The plant feedrate averages 340 m³/h, with peaks of 1 000 m³/h during the spring thaw and lows of 180 m³/h during the colder winter months. Lime consumption varies seasonaly from 150 tonnes/month during the winter to 1 300 tonnes/month during the spring thaw. Average annual consumption has been 8 590 tonnes (average over the past 6 years). Figure 10 shows lime consumption over the past 5 years of operation. Neutralization efficiency, the ratio of the acidity of the HDS plant influent to the annual lime consumption (both expressed in tonnes CaO/yr), has averaged 0,85 over the past 3 years.

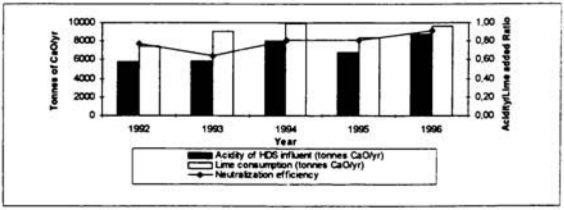

Figure 10 - HDS Plant Neutralization Efficiency (acidity / lime consumption)

Approximately 45 000 m^3 of high density sludge, averaging 20% solids, is produced annually and disposed of in a storage pond. Typically, the sludge is composed of 52% gypsum, 24% ferric hydroxides, 12% aluminum hydroxides and 6% magnesium hydroxides. Conventional solid waste leachate tests (with acetic acid) and modified leachate tests (with H_2SO_4 /HNO_3 - 60%/40%) have been conducted on the sludge. Results of both test protocols have shown that the leachates comply with the provincial requirements for solid waste. Leachate tests conducted at pH greather than 5,0 showed very low metal concentrations in the leachate, often below detection limits. In addition, the sludge was shown to have a low neutralization potential indicating low residual lime and good plant efficiency.

The HDS plant is highly automated and requires only one operator hour per shift, primarily to conduct routine inspections and to perform necessary maintenance on the lime slaker and pH meters. Final effluent discharge provincial limits are consistently met. Water quality before and after treatment is presented in Table 2.

Sampling point	pH	Acidity (mg $CaCO_3$/l)	Fe total (mg/l)	Suspended Solids (mg/l)
HDS Plant Influent	2,5	3 350	775 †	N/A
HDS Plant Effluent (to polishing pond)	8,4	-22	3,0	25
Final Effluent (polishing pond discharge)	7,5	-18	0,87	6

† : 80% of the iron as Fe^{+3}

Table 2 - HDS Plant Influent and Effluent Water Quality (1996 average)

CONCLUSION

The South Waste Dump characterization and monitoring undertaken by the GREGI as a MEND project contributed significantly to the understanding of the physical, chemical, mineralogical, hydrological and microbiological processes involved in the formation of acid mine drainage within a waste rock dump.

Based on six years of operating data, the Tetra Technologies HDS process has proven to be an effective and economic method of treating AMD at La Mine Doyon.

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