GEOTEST®: Development of Field Geochemical Cells for On-site Acid Mine Drainage Monitoring

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Abstract

Acid Mine Drainage is typically predicted using a series of laboratory static and kinetic tests which are developed with small-scale samples, during weeks or months under controlled laboratory conditions. As water drains from full-scale massive mine wastes, under natural and variable conditions, prediction of drainage chemistry and contaminant mobility is a major challenge in terms of scale and time.

GEOTEST® are geochemical on-site medium-scale cells designed for determining the capacity of acid/neutral drainage generation from waste rock dumps and for monitoring the geochemical dynamic evolution of the system through time under real mine site conditions.

A pilot GEOTEST® is operating at a mine site in the north of Chile. Results from the first eight cycles of artificial irrigation are presented. After every cycle, leachate is collected and analysed *in situ* for critical physical-chemical parameters. Samples are collected for further laboratory geochemical analysis. Results showed that oxidation processes are in a first stage, where pH and alkalinity values are gradually decreasing, sulphate concentration is increasing and certain metals are been released. Results of these tests will give important insights on drainage chemistry and will help to better understand and predict its changes through time.

Key Words: massive mine waste, prediction, waste rock dump, medium-scale cells, mine site, on-site kinetic test

Introduction

The geochemical characterization of massive mine waste for acid mine drainage (AMD) prediction is typically developed from a series of preliminary laboratory static and kinetic tests that allow for determinations of potential risks and mobility of contaminants associated with acidic drainage. Static tests include Acid Base Accounting (ABA), Net Acid Generation (NAG) and Synthetic Precipitation Leaching Procedure (SPLP). Kinetic tests include humidity cells and leach columns. Both types of test are typically completed on small-scale samples, with fine material, over a period of weeks or months, and conducted under controlled laboratory conditions.

One of the greatest challenges in minesite drainage chemistry is adjusting predictions from small-scale samples to full size mine components, such as mined-rock piles, tailing impoundments, and mine walls (Morin and Hutt, 2007), where water drains from components that are millions to billions of tonnes in size, reaching up to 100 meters high and developed under natural and variable conditions.

On-site field tests are carried out to evaluate the behavior of sulfidic wastes under field conditions and can allow for calibration of the result of kinetic testing completed in the laboratory. They usually involve field measurements and observations of an application of interest with in situ monitoring including internal physical-chemical parameters measurements, runoff and groundwater monitoring, waste characterization, and other sampling and analysis (MEND Manual, 2009).

There are different scales in which prediction of AMD can be studied, and observations can be made at micro, meso and macro-scale. A micro-scale approach can be as complex as considering physical aspects like water flow paths passing over the surface of every particle of material or sequences of minerals. In meso-scale observations (hand-size or intermediate size), predictions based on test like ABA are typically checked against results of similarly scaled kinetic tests like humidity cells or leach columns (Morin and Hutt, 2007). In a full-scale approach (mine site components) several studies have found that there are many factors that can cause drainage chemistry to change relative to predictions made in smaller scales. Examples of these factors are oxidation and precipitation of iron, oxidation of thiosalts, interactions with substrate materials including ion exchange, and daily fluctuations in downstream temperature (e.g., Dinardo, 2003; Jones *et al*., 2004, Shope et al., 2006, and Morin, 2003).

In order to develop a tool for on-site monitoring of AMD in mine materials, and to approach and study the scaling factor, an on-site geochemical test was designed: GEOTEST®. This technology is intended to be an intermediate scale test between laboratory standard test and real conditions. This paper presents the methods and preliminary results of a pilot GEOTEST® implemented at the Compañía Minera Doña Inés de Collahuasi (CMDIC).

Geological Setting

The Collahuasi district is located in northern Chile on the western slope of the Central Andean Cordillera Occidental. It represents the northernmost identified cluster of known large deposits associated with the Domeyko Fault System, the district comprises the Quebrada Blanca, Ujina and Rosario porphyry Cu-Mo deposits, several epithermal deposits including the high-sulfidation La Grande Cu-Ag-(Au) and Rosario Cu-Ag and the Moctezuma low-sulfidation Ag-Au veins, all of which have been historically mined, as well as the Huinquintipa exotic Copper Deposit (Urqueta *et al*. 2009).

Meteorology

In the Collahuasi district the rainfall is highly seasonal, with a wet season from December to March. For the Rosario minesite, meteorological data is available from 2004 to 2010. Since 2004, the highest monthly rainfall recorded corresponds to 181 mm in January of 2006. During January 2008 a total of 171 mm of rain was recorded. The daily precipitation does not exceed 45 mm, which was registered the same year. Most rainfall events do not exceed 10 mm per day. Data from February 2012 recorded an average of 68 mm/day of precipitation and evaporation rates calculated on-site range between 2 mm/day in winter and 28 mm/day in summer.

Methodology

This geochemical on-site medium-scale tool was designed with the objective of evaluating and monitoring the drainage leached from a full scale mine waste material previously selected and for monitoring the geochemical evolution of the system through time under (1) natural conditions and (2) enhanced precipitation.

GEOTEST® consists in a 3 x 3 x 2 meter cell filled with the material of interest (run-of-mine waste), made with an external iron structure and a wooden box-shaped container in the interior, protected by a HDPE membrane (Figure 1). The design and dimensions of the cell can hold up to fifty tons of material. Two cells were installed in CMDIC, one of them operated under natural conditions (i.e. the only irrigation that the test receives is precipitation and snow) and the other one under enhanced irrigation, simulating rain rates according to the meteorological conditions of the mine site.

After the water drains through the cell, leachate is collected in cubes through holes made in one side of the cell. The leachate is then immediately analyzed for physical-chemical parameters and subsequent samples

are taken for further chemical laboratory analysis, like sulphate and metal concentration, with the objective of determining the chemical balance of the system.

Figure 1. (Left) Geochemical cells installed in the field. (Right) Natural and enhanced precipitation systems.

To study internal humidity conditions, each test was instrumentalized with fifteen suction sensors, distributed in five depth levels of three sensors each. Also, to control leachate volume and meteorological conditions, tipping buckets and a meteorological station were installed. The determinations of these parameters will be used to obtain the water balance of the system.

Additionally, given that this field test is designed to last over twenty years, it can be used to evaluate the behavior of massive mine waste and drainage as it changes through the lifetime of the mine. Also these tests can be used to validate laboratory results and AMD prevention and control methods initially proposed on the basis of laboratory test results.

Selection of Material

In order to properly define the material to be studied, it was first necessary to identify the geological units of the deposit and their probable acid generation potential. To achieve this, the geochemical information of the materials from the waste rock dumps, provided by CMDIC, was analyzed. The information analyzed included the mineralogical classification of the materials, alteration and mineralization, total mass, ABA test results, sulfur percentage, among others.

The lithology of the selected material correspond to a dacite with chlorite-sericite alteration from the primary pyritic zone of the deposit (which correspond to a 34% of the total mass of the waste rock dump), with approximately a 4% of pyrite and with a high potential of acid generation according to ABA test previously done.

Once selected, the material of interest was extracted directly from the mine and loaded into the cells by using a front loader (fresh material). The maximum size of the material loaded corresponds to 15 inches approximately.

After the material was selected, a series of laboratory analysis were carried out in order characterize the initial composition of the. These test included ABA and NAG Test, optical microscopy and X-Ray diffraction.

ABA and NAG Analysis

Static tests predict the quality of acid drainage by comparing the acid and neutralization potential of the material. The potential acid generating components of the sample (AP) are determined based on the chemical analysis of total sulfur and sulfur as sulfate. The neutralization potential (NP) represents the total neutralization capacity of the minerals present in the sample, expressed as it $CaCO_3$ equivalent.

Finally, the net neutralization potential (NNP = NP-AP) is calculated and interpreted as follows. If NNP>20, the sample is unlikely to generate acidity, if -20<NNP<20 the acidity generation is uncertain, if -60<NNP<-20 the sample is likely to generate acidity and if NNP<-60 the sample is likely to generate significant acidity (Guía Metodológica sobre el Drenaje Ácido en la Industria Minera, 2002). Table 1 shows the results of ABA analysis in the sample.

Table 1. ABA Test results for the material of interest.

Sample ID	S(T) %	SO^{2-}_4 %	Calculated Sulfide %	Kg $CaCO_3$ equivalent/tonne of material			
				NP	AP	NNP	NP/AP
Cell material	1.91	0.017	1.89	9.7	59.2	-49.5	0.16

As shown in Table 1, the sample analyzed presented a high acid drainage generation potential. This result was lately confirmed by the NAG Test results. This test is used to determine the net potential of acid generation, by an accelerated oxidation of sulfur, to finally calculate the final amount of acid available after the acid consumption from gangue minerals. The results of this test are presented in the Table 2, and they confirm the acid generation potential of the sample.

Table 2. NAG Test Results for the material of interest.

Sample ID	Sample Weight (gr)	Water Volume (ml) (15% V/V)	NAG pH	NAG (+) kg H2SO4/ tonne
Cell material	2.5	250	2.68	13.28

Irrigation System

To estimate the volume of irrigation water, a water retention curve was made and information like meteorology, retention capacity of the material and humidity cells was analysed. As a result, a volume of irrigation water (fresh water) of approximately 800 liters was estimated for the first cycle, in order to exceed the water holding capacity of the material and to ensure the collection of the sample. For the subsequent cycles, 300 to 400 liters were added, to avoid dilution of the sample and to simulate actual precipitation rates.

Irrigation frequency was preliminary set between 15 to 20 days. At present, eight irrigation cycles have been completed. After the twenty cycles, the mining company will continue monitoring the leachate from both natural and enhanced precipitation systems.

Preliminary Results

Results from the first eight irrigation cycles from the enhanced precipitation system are presented. In the case of the natural system, at the moment no leachate sample has been obtained despite the falling water, probably because the system has not yet passed the water holding capacity.

Figure 2 shows the humidity front inside the enhanced precipitation system. In all cycles the test show similar behaviour, where the superficial layer is drier and it saturates during the irrigation. Deeper layers show constant saturation, with the exception of the central part of the bottom of the cell which is drier, probably due to preferential flowpath of the irrigation water.

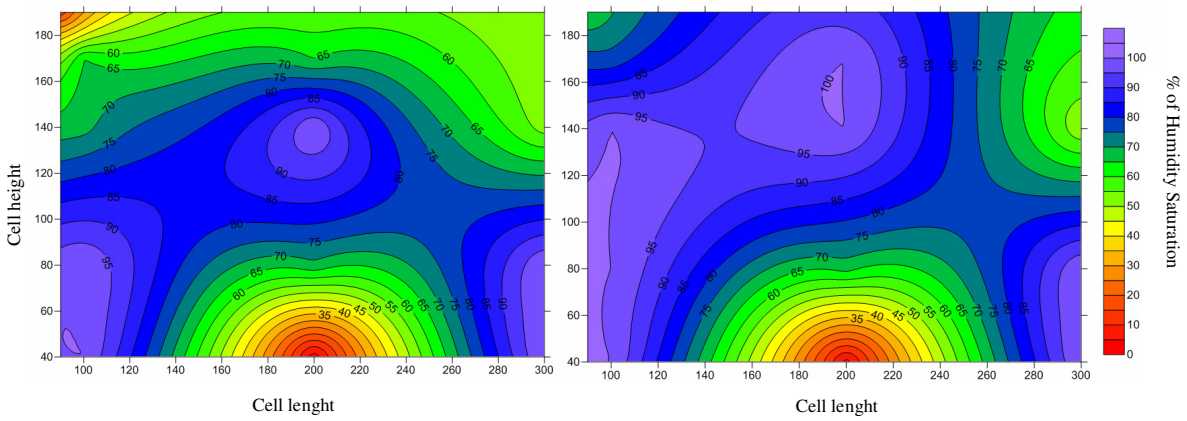

Figure 2. Distribution of the humidity front in the interior of the cell for the seventh cycle. (Left) Transverse profile of GEOTEST® before the irrigation in (cycle 8). (Right) Transverse profile of GEOTEST® after the irrigation (cycle 8).

For all samples, major ions showed a calcium-sulphate type of water. As shown in Figure 3, pH of samples is neutral to slightly acid ranging between 5.98 and 7.40 in the first eight cycles (C1 to C8). It is possible to observe a decrease in pH in the last irrigation cycles, probably being a product of the CO_2 absorption by the irrigation water added to the cell, which reacts generating carbonic acid. On the other hand, total alkalinity is decreasing progressively in time from 40 mg $CaCO_3$/l to 13 mg $CaCO_3$/l.

In the case of sulphate concentration and electrical conductivity (EC), results showed a non linear increase (Figure 3). This trend could be related to the weathering of the material as it interacts with irrigation water. Similar results are observed for other major ions like Ca^{2+}, Na^{+}, Mg^{2+} and K^{+}.

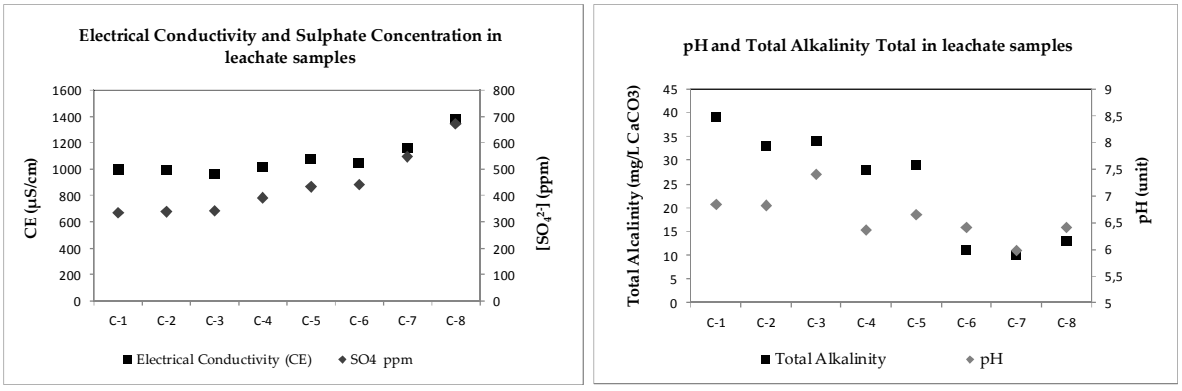

Figure 3. (Left) Electrical conductivity and sulphate concentration in leachate samples from the first eight cycles of the irrigation system. (Right) pH and Total Alkalinity of leachate samples.

Compared with the fresh water used for the irrigation, leachate has increased its total dissolved solid concentration, with a difference of 300 parts per million in some cases. This could respond to water-rock interaction processes and transport of fine particles in the initial stage of the experiment. Particularly,

given the amount of water irrigated in the initial state of the experiment, these results must be corroborated with future results.

In the case of total concentration of elements, there is not a general tendency, but different behaviour within different elements. As shown in Figure 4, some elements show an increasing trend in time, like copper and zinc, while others present a decrease, like iron (Fe) and aluminum (Al). This decreasing trend is observed in other elements of interest like arsenic (As) and lead (Pb). The decreasing trend of these elements could be due to precipitation of compounds in the interior of the cell, particularly, iron compounds like hydroxides, which have the capacity to adsorb elements like As and Pb. However, these results correspond to the first eight cycles, of a projected total of approximately twenty. Also, it is important to note that total concentration include the colloidal fraction, which is important in the case of elements that are likely to be adsorbed in this particles.

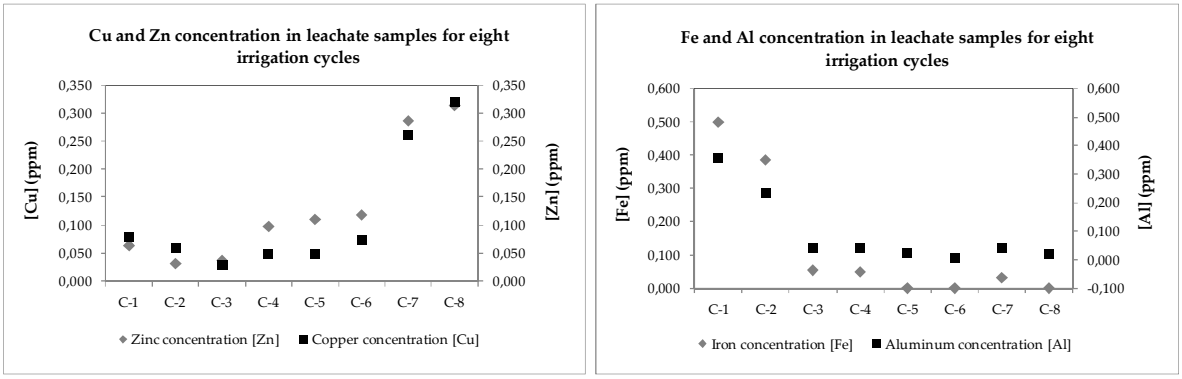

Figure 4. (Left) Copper and Zinc concentration in leachate samples from the first eight cycles of the irrigation system. (Right) Iron and Aluminum concentration in leachate samples.

Discussion and Conclusion

Results from the first eight irrigation cycles of a medium-scale geochemical on-site test for acid prevention and characterisation developed and implemented for Collahuasi in northern Chile are presented. The material selected for the GEOTEST® showed to be acid generator in previous laboratory test. The results, although preliminary, show an increase in the concentration of some elements and compounds in the percolating solution, with a slightly decrease in pH along the eight cycles. Results of these tests will give important insights on drainage chemistry and actual on-site data from fresh material that will be deposited in waste rock dumps, and will be a complement to better understand and predict changes of drainage chemistry through time.

Regarding to the chemistry of the percolating solution, it is possible to indicate that oxidation processes are in a first stage where pH values range between slightly basic to slightly acid. In this part of the process, there is a balance between alkaline minerals consumption and acid formation from pyrite breaking. Also, an increase in sulphate concentration, a gradual decrease in alkalinity and the release of certain metals, like copper and zinc are observed, reflecting water-rock interaction. On the other hand, iron and aluminum concentration decrease in time probably due to precipitation of compounds inside the cell. This is consistent with pH values of the percolating solution, where ferric iron can easily precipitate.

Although the scale of these tests was design to represent an intermediate scale between laboratory testing and full-scale mine site components, the order of magnitude of dimensions and weight of these last is a limitation factor that needs to be better understood. Although currently there are no data from the natural

irrigation GEOTEST® cell (natural precipitation), results in time will give information about real time reactions and compared rates between the two systems. Also, because these tests are the first field cells instrumentalized in Chile, the results will bring information about the optimum number and distribution of the sensors inside the cells, that ultimately allow for better understanding of the wet front of the material.

On the other hand, particle size of the filled material should also been studied. Massive mine wastes are characterised for having a wide range of sizes. As these tests are filled with one type of material, the chosen material should be adequate for the proposed objective. In this sense, results through time will give important information of massive mine waste management and it is likely to operate as an on-site laboratory for mining companies through lifetime.

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Acronyms

ABA	Acid Base Accounting
AMD	Acid Mine Drainage
CMDIC	Compañía Minera Doña Inés de Collahuasi
EC	Electrical conductivity
ICP-MS	Inductively coupled plasma mass spectrometry
MEND	Mine Environment Neutral Drainage Program
NAG	Net Acid Generation
SPLP	Synthetic acid Precipitation Leaching Procedure