Standard and Adapted Laboratory Test for Acid Drainage Prediction in Arid Zones

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Abstract

A study conducting adapted leaching column tests was developed to (1) validate results of standard tests, (2) simulate geochemical weathering processes in arid conditions, (3) evaluate acid generation and weathering kinetics, and (4) predict quality of drainage from mine waste. The materials analyzed in this study include waste rock, low-grade sulphides, slag and tailings from a Chilean mine site.

Results of standard and adapted test indicate that the sample from the tailing dam could produce a high mobility of contaminants as it interacts with water from sporadic intense precipitation events. In the case of the leached waste sample, both tests showed that its capacity for neutralization is partly exhausted.

The low-grade sulphide sample retained its ability to neutralize acid intact. Despite its high content of pyrite, the standard test showed a low reactivity, which indicates that this material could pose a risk in terms of mobility of contaminants only if subjected to intense weathering, and if the kinetics of acid generation processes are particularly slow.

The adapted leaching column tests are useful tools to validate results of standard tests in terms of simulating geochemical weathering processes in local environmental conditions, although the limitation of their design must be considered in interpretations.

Key Words: mine waste, sulphides, weathering, mobility, acid generation potential, neutralisation potential.

Introduction

Acid mine drainage is inorganic contamination derived from the oxidation and weathering of metallic sulphides. It is characterized by having an acid pH and high contents of dissolved ions (metals and other elements). Current standard tests were conducted on various selected materials from a northern Chilean mine with the main objective of evaluating the kinetics of weathering processes and to predict the quality of drainage,. Standard tests are laboratory methodologies used to predict acid mine drainage, and whose procedures and guidelines are described elsewhere (Price, 1997; Sobek et al, 1978; GARD Guide, 2008). These tests are subdivided into three groups depending on the information they provide: static, kinetic and extraction tests. The static test determines the geochemical properties of the tested material, establishing the maximum acid generating potential. Extraction tests of leachate can be used to determine the total amount of soluble components available under different extraction conditions. Finally, kinetic tests can be used to determine the geochemical behavior of the material through time.

A characterization study of different types of mining wastes was designed (Table 1), with the objective of determining the contaminant mobility and acid generating potential of the materials. In the context of this study, adapted leach column tests were developed at different scales in a selected group of samples previously analyzed and characterized with the purpose of simulating geochemical weathering to evaluate acid generation and quality of drainage water for specific arid humidity and meteorological conditions.

Methodology

Standard test and characterization

An initial characterization of samples was performed. Samples were sent to an external laboratory for X-Ray diffraction analysis (XRD) for mineralogy, for QEMSCAN for particulate mineralogical analysis, and total element concentrations were determined by ICP through acid digestion. Also, paste pH determination (Ridge and Seif, 1998) was performed in the Fundación Chile Laboratory.

Standard test were conducted by an external laboratory with the aim of performing an exploratory study of acid generating potential in the samples. The static tests performed were the Modified Acid-Base Accounting or Modified ABA (Lawrence and Wang, 1997), and the Synthetic Precipitation Leaching Procedure or SPLP (EPA Method 1312). In addition, kinetic tests (humidity cells, ASTM D5744) were also performed. Table 2 shows the analyses made of each sample.

Table 1. Type of materials studied and samples identification.

Material	**Sample ID**	**Material**	**Sample ID**
Low-grade sulphide stockpile	CT-2	Intermediate age waste	CT-4
Old age waste	CT-1	Tailing Dam	G-1
New age waste	CT-3	Slagheap	EC-1

Table 2. Type of materials studied and laboratory analysis.

Analysis	**Sample ID**
X-ray diffraction, ICP	CT-1, CT-2, CT-3, CT-4, G-1,EC-1
QEMSCAN	CT-1, CT-2, CT-3, CT-4, EC-1
Paste pH	CT-1, CT-2, CT-3, CT-4, G-1, EC-1
ABA Std. Test	CT-1, CT-2, CT-3, CT-4, G-1, EC-1
Humidity cell	CT-1, CT-2, CT-3, CT-4, G-1, EC-1
Bench scale leach column test	G-1
Laboratory pilot scale leach column	EC-1
Field pilot scale leach column	CT-1, CT-2, CT-3, CT-4

Adapted test

Leach Columns

The leach column test was developed with the objective of simulating the geochemical weathering of the tested materials to evaluate acid generation and the quality of drainage water. The experimental design considered the study of local environmental conditions. For this purpose, different scales were used in the experiments: bench scale, laboratory pilot scale and field pilot scale. Figure 1 shows the columns considered in the study.

To perform this test, a known amount of material is placed in the column and distilled water or aqueous solution is run through the sample. Water samples, from leached water or supernatant portion, were collected periodically and analyzed chemically.

Figure 1. Leach column test at different scales of work. From left to right: bench scale, laboratory pilot scale and field pilot scale.

Bench scale columns

One kilogram samples of tailing materials taken from different sections of the mine were loaded in bench scale columns using a rain-sprinkler system. The experimental design includes polypropylene columns packed with sample mixed with inert carrier material (0.4 to 1.5 mm diameter quartz) to increase the permeability of the fluid and the kinetics of mineral leaching. Although this distribution does not necessarily represent the reality of the tailing dam, the characteristics and grain size of this material did not allow the collection of the leachate sample without the inert material. The water enters the packed column from top and flows to the base by gravity where the leachate samples are collected. A weekly monitoring plan of column operation was conducted for five months. During this period, physical-chemical parameters were measured in addition to sulphate, copper, molybdenum and iron. All these parameters were measured in the Fundación Chile laboratory. Subsamples were also sent for complete analytical determinations in an external laboratory.

Laboratory pilot scale columns

Given the characteristics of the slag samples, they were analyzed in laboratory pilot scale columns. A leach column was assembled in Fundación Chile packed with the slag material (40 kg)from the most current activity of the foundry. A weekly monitoring plan of column operation was conducted for five months, including measurement of physical-chemical parameters plus sulphate, copper, molybdenum and iron.

Field pilot scale columns

Field scale columns were built in the geology laboratory at the mine. These fibreglass columns consist of two sections joined by flanges. According to the experimental design, the columns were loaded as shown in Figure 2, where the sample being investigated is located in section two. With the objective of improving the permeability and of the sample, porous, inert material was added in sections one and three.

The water was introduced by pumping and irrigation by sprinkling. The water volume used for these essays is equivalent to 300 mm of column water, during five days. This amount corresponds to 0.25 L/min for one hour per day. Leachate samples were collected at the bottom for further analysis. The monitoring plan was the same as that for the other columns.

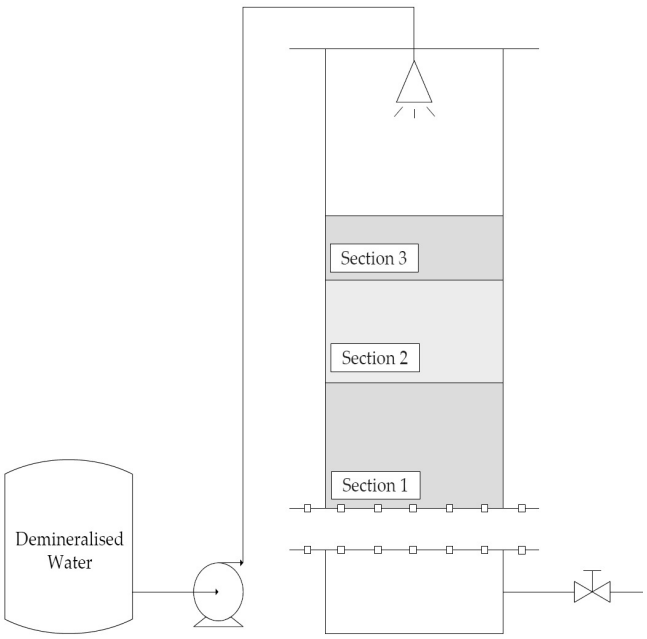

Figure 2. Load distribution scheme of the pilot-scale field column. Section 2 holds the material being investigated, whereas sections 1 and 3 correspond to inert material.

Results and Discussion

With the objective of evaluating the acid generating potential and the contaminant mobility potential of the tailing, waste, slag and stockpiled ore from different parts in the mine, the main results of this study are presented below.

Mineralogical analysis

The main minerals identified in the samples with X-ray diffraction and QEMSCAN are discussed by sample typed. In the tailing sample (G-1), minerals identified were: quartz, muscovite (sericite), illite, plagioclase, kaolinite and gypsum. In the slag sample (EC-1), the results revealed that carbonate and sulphide (pyrite and chalcopyrite) constitute 29.2% and 5.4% by weight respectively. XRD also detected fayalite, diopside, and maghemite. In the case of the low grade sulphide stockpiled ore sample (CT-2), the high content of sulphides was sufficient to be detected by X-ray diffraction, unlike waste samples. QEMSCAN analysis confirms the presence of a large amount of pyrite, which was quantified at 8.82% (making this material a potential acid generator). Finally, the leaching waste samples analyzed show similar mineralogy (quartz, albite and biotite), although the older sample (CT-1) had more gypsum, a sign of the greater degree of alteration and of the reactions between gangue minerals and acid.

Acid generating potential (ABA Test)

Static tests predict the quality of acid drainage by comparing the acid generating and neutraliziing potential of the material. The potentially acid generating components of the sample (AP) are determined on the basis of the chemical analysis of total sulphur and sulphate sulphursulph. The neutralization potential (NP) represents the total neutralization capacity of the minerals present in the sample, expressed as their $CaCO_3$ equivalent. Finally, the net neutralization potential (NNP = NP-AP) is calculated. If NNP>20, the sample is not expected to generate acidity, if -20<NNP<20 the acidy generating potential is uncertain, if -60<NNP<-20 the sample is expected to generate acidity and if NNP<-60 the acid generating

potential of the sample is considered significant (Guía Metodológica sobre el Drenaje Ácido en la Industria Minera, 2002). Table 3 shows the results of paste pH and ABA analysis of the samples.

Table 3. Summary of results of paste pH and ABA analysis for all samples. AP, NP and NNP values are expressed in kg $CaCO_3$/t

Sample	Paste pH	S_{total}(%)	SO_4^{2-}(%)	S^{2-}(%)	AP	NP	NNP
G-1	3.11	6.27	8.5	3.43	107.2	-30.8	**-137,9**
EC-1	8.56	0.7	0.04	0.68	21.3	20.8	**-0,5**
CT-2	8.32	5.48	0.0	5.48	171	13	**-158**
CT-1	7.62	1.18	3.29	0.08	3	12	**9**
CT-3	8.09	1.04	2.97	0.05	1.6	6	**4**
CT-4	8.56	1.33	3.29	1.11	35	-17	**-52**

As Table 3 shows, the tailing dam sample (G-1) had a very high sulphur content that cannot be compensated by its neutralization potential, making this material a very high-potential acid generator. The high neutralizing potential observed in the ABA test for the foundry slag sample (EC-1) is consistent with the significant presence of carbonates, which neutralize acid generating potential of the oxidation of sulphides and give the sample an uncertain risk level for acid generation. In the case of the low-grade sulphide stockpiled ore sample (CT-2), QEMSCAN analysis revealed a high sulphide content, which together with the relatively low neutralization potential results in a high acid generating potential. In the case of waste samples, the concentration of total sulphur is similar but proportion of sulphate in the CT-1 is much larger, sulphand sulphide sulphur represents only a 7% of total sulphur. In the case of sample CT-4, acid consumption is moderate but higher than expected, considering that this material was experienced acid leaching. With respect to net neutralization potential, this sample appears to have acid generating potential, whereas the CT-1 and CT-3 samples remain in the zone of uncertainty.

Humidity cells

After the humidity cell test, the tailings exhibited clear characteristics of acid generating potential. The effluent pH of humidity cell was maintained during the entire period between 2.5 and 3.5. In the accelerated weathering process, a sustained increase in sulphate dissolution was observed, remaining high throughout the process. For the foundry slag sample, the accelerated weathering in the humidity cell initially has alkaline pH with a solution effluent pH exceeding 8.0. However, over time, the pH begins to decrease, finally reaching approximately 6.5. This decline can possibly be explained by a small amount of acid generation due to the hydrolysis of dissolved iron from the slag and from acid generation due to the oxidation of pyrite and chalcopyrite. Both in the humidity cell and in the leach columns, it should be noted that the dissolution and recovery of sulphate, although low, exceeded expectations given the low sulphate content (0.04%), suggesting that some of this recovered sulphate corresponds to the oxidation of sulphides. The stockpiled ore sample (CT-2) showed no generation of acidic effluent, despite the high pyrite content and high acid generation potential. The oxidation of pyrite during these 20 weeks did not generate a sufficient amount of acid for reducing the neutralizing capacity. The pH remained neutral during the 20 cycles. In fact, variations in both the AP and the NP were not sufficient to cause differences between the composition of header and waste; a slight increase observed in both cases, may be within the limits of analytical error. These results suggest, then, that despite its strong potential for acid generation, this material is not very reactive and that the kinetics of acid generation are particularly slow, at least in the initial stage.

Leach columns (adapted test)

In the tailing sample (Figure 3), after the initial rapid dissolution and the subsequent decrease in the rate of sulphate generation, an increase in rate was observed, possibly due to the activation of biological catalysis

of oxidation reactions. The increasing rate of oxidation is likely to continue, generating increasingly acidic conditions and therefore greater mobility of ions, confirmed by the increasing sulphate desorption curve and the decreasing pH of effluent from the adapted leach column. The leachate from the foundry slag sample has dissolved sulphate concentration, far exceeding the head value close to 0.4 mg/g. Considering the very low sulphate content in the solid head, the high concentration detected may be due to oxidation and dissolution of copper and iron sulphides (Figure 3). The copper begins to dissolve slowly and only appears after a few weeks. For the stockpiled sample (CT-2), sulphate appears slowly with a dissolution rate that tends to increase during the first five weeks and then falls again. Chemical analysis of adapted leaching columns led to the conclusion that all sulphur is found as sulphide, so this material has not yet been affected by the weathering process, keepingg its ability to neutralize acid intact. It should be noted that according to the whole rock analysis, the sulphate content is greater than indicated in the earlier analysis. Nevertheless, dissolution (desorption) of sulphate exceeds the initial amount of sulphate, confirming that there is oxidation of sulphides. For the CT-1 sample (Figure 3), according to ABA analysis, nearly all sulphur is found as sulphate, with a total sulphate concentration of 3.29%, corresponding to 32.9 mg/g. It should be noted, however, that according to the whole rock analysis, the sulphate content would be much lower. In this test, the sulphate is recovered almost at 12 weeks. The dissolution decreases and after these 12 weeks, there was only a slow dissolution of sulphfate, which corresponds to the oxidation of residual sulphur. Finally, for the samples CT-3 and CT-4, according to ABA and whole rock analysis, much of the sulphur is still sulphide. However, there is a significant sulphate dissolution, which exceeds the concentration of sulphate initially present; suggesting that oxidation of sulphur is occurring.

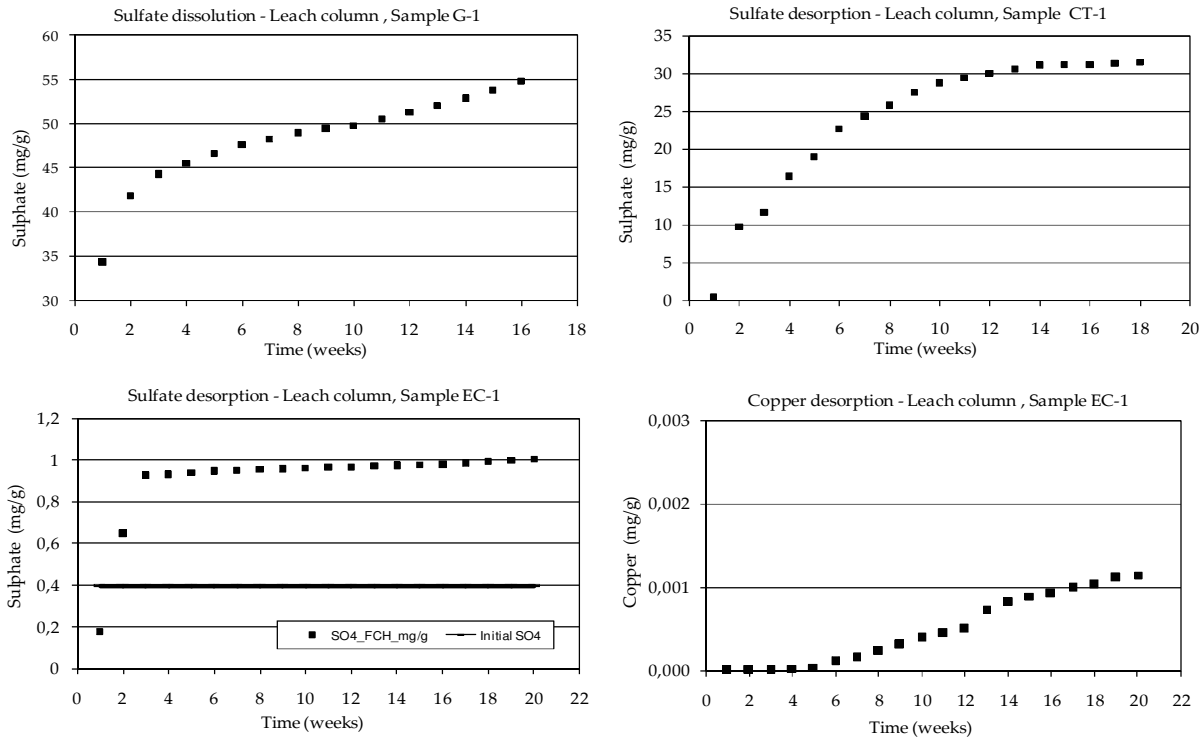

Figure 3. Sulphate and copper dissolution (or desorption) in some of the samples analyzed. Concentration unit used (mg/g) indicates the concentration of the element (copper) or compound (sulphate) relative to the weight of total sample.

Conclusions

1. The sample from the tailing dam revealed both in standard and adapted analysis a high potential to generate acid drainage. The weathering process was at a relatively advanced stage in which the material has exhausted some of its capacity of neutralization, which results in low values of pH in the effluent. Under these conditions, the mobility of potentially polluting elements significantly increases, particularly with the interaction with fluids generated by sporadic heavy rainfall events.
2. Low-grade sulphide sample retained its ability to neutralize acid intact. Despite its high content of pyrite (high acid generating potential), standard test showed a low reactivity, which indicates that, this material could pose a risk in terms of mobility of contaminants only if subjected to intense weathering.
3. Leached waste, unlike other types of waste, showed both in standard and adapted leach column tests that samples partly exhausted their capacity for neutralization, presenting a clear risk of mobilization of contaminants, not only by oxidation of sulphides and residual acid generation, but simply by remobilization of soluble compounds generated in the leaching process and associated with solids.
4. The standard ABA test results for foundry slag sample reveal a significant sulphur as sulphide content (0.68%) associated with copper and iron sulphides, although the high presence of carbonates neutralize the acid generation product of the oxidation of sulphides. Both in the humidity cell (standard test) as in the leach columns (adapted test), the dissolution and recovery of sulphate, although low, exceeded expectations given the low sulphate content, suggesting that some of this recovered sulphfate corresponds to the oxidation of sulphides.
5. Adapted leaching column tests are useful tools to validate results of standard tests in terms of simulating geochemical weathering processes in local environmental conditions, although the limitation of their design must be considered in subsequent interpretations.

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Acronyms

ABA	Acid Base Accounting
AP	Acid Potential or Acid generation Potential
ASTM	American Society for Testing and Materials
EPA	Environmental Protection Agency
ICP	Inductively coupled plasma spectrometry
NNP	Net Neutralization Potential
NP	Neutralization Potential
QEMSCAN	Quantitative Evaluation of Minerals by Scanning electron microscopy
SPLP	Synthetic Precipitation Leaching Procedure
XRD	X-ray diffraction