PREDICTION OF MINE DRAINAGE QUALITY BY KINETIC TESTS

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ABSTRACT

Kinetic test is one of the methods to predict acid mine drainage. The test shows the acceleration of natural oxidation rate over those observed in the field. This may have the advantage of condensing time, and providing earlier insight into the potential for acid generation. Generally, kinetic test evaluates the changes in pH, sulfate, acidity and host of potential metals. However, the test also has high degree uncertainty. To minimize the uncertainty it needs to calibrate and validate the model of kinetic test by comparing prediction model with actual field sampling results. As field data availability for validation is limited, it is strongly suggested that researcher should make a continuous research from the prediction and the actual sampling using many methods.

Keywords : Kinetic test, acid mine drainage, prediction

1. INTRODUCTION

Since acid mine drainage (AMD) is a significant and costly environmental concern in the mining industry, it is very important to predict the AMD quality prior to starting mining activities. This concern has developed because of the interval time at existing mines between waste emplacement and observation of an acid drainage problem. The issue of long-term or continuous care of acid drainage at historic mines and some active mines has focused attention on the need for improving prediction methods and for early assessment of the potential during the exploratory phase of mine development.

There are many tests to predict the AMD such as static and kinetic test, geology and geography comparison, as well as mathematical modeling. The test will be discussed in this paper is the kinetic test that have developed in predicting acid mine drainage since 1949.

Kinetic test differ from static one in natural oxidation reactions. The test includes simulation of mine drainage production from samples that might be affected by mining activities. It is followed by chemical analyses of effluent quality produced from the simulated conditions. The test is integrated by dynamic elements of physical, chemical, and biological systems and processes that control the production of acidic or alkaline mine drainage.

Physical factors in kinetic test include size, shape, and structure of the apparatus that are used to conduct the test; volume, texture, and particle size distribution of the sample to be tested; and the volume, pathway, and resultant saturation conditions of the fluids introduced into or removed from the apparatus for analysis.

Chemical factors include mineralogical composition of rock samples, composition of influent and effluent fluids solubility controls on the acidity- and alkalinity-generating processes, interrelationships between these processes and other constraints that affect kinetic reactions and composition of gaseous phases (e.g. partial pressures of oxygen and carbon dioxide) in the fluids and void spaces within the kinetic test apparatus.

Biological factors include the presence and relative abundance of bacteria (e.g. *Thiobacillus*,) that catalyze the AMD producing reactions; the availability of nutrients and other life-supporting ingredients; and the interrelationships among controls on the biological system, such as temperature and pH, which determine whether various organisms flourish, barely survive or die (Brady, 1998).

Specifically, this test is designed and conducted to deal with the kinetic reaction, rates and mechanisms of chemical reactions that lead to the production of acidic or alkaline mine drainage. Kinetic test typically requires larger sample volume and much longer time for completion than static test. It also needs a variety of apparatus. Therefore, it is usually conducted in the laboratory. Results of the test provide information on the rate of sulfide mineral oxidation and therefore acid production, as well as an indication of drainage water quality.

There are many tests called as kinetic test. Those are humidity cell, column, soxhelet extraction, British Columbia Research Confirmation, Batch Reactor (shake flask), and field scale. Methods for those tests are described below.

2. METHODS

2.1 Sampling

Sample selection has important implications for subsequent acid prediction testing. Samples must be selected to characterize the type and volume of rock materials and also account for the variability of materials that will be exposed during mining. Another important consideration is time to collect samples for testing. Researchers agree that sampling and testing should be concurrent with resource evaluation and mine planning (Lapakko 1990, British Columbia AMD Task Force 1989).

Number of representative samples that should be collected from a mining field is very important. The more sample collected, the more accurate the test. However, the test cost may be high. There are many opinions concerning the number of samples to be collected in a fixed-frequency sampling program. Schafer in U.S. EPA (1994), recommends about 8-12 samples of each 1 million tons at a minimum. The significant rock type represents one or two percent of the total mine rock volume. Gene Farmer of the U.S. Forest Service suggests that one sample (about 1,500 grams) be collected per 20,000 tons of waste rock, or about 50 samples for each 1 million tons (USDA Forest Service in U.S. EPA, 1994). These samples would be collected by compositing from individual drill hole cuttings prior to blasting. The British Columbia AMD Task Force (1989) recommends a minimum number of samples based on the mass of the geologic unit, as shown in Figure 1.

Number of samples should be taken is a function of rock mass, not a linear function. For example, it is recommended 8 samples for a unit of 100,000 tons geologic minimum or 1 sample every 12,500 tons while for a unit of 10 million tons, the minimum sample number is 80, or 1 sample every 125,000 tons. For a large scale of mines it is better to adopt the British Columbia AMD Task Force recommendation because it makes easier to analyze.

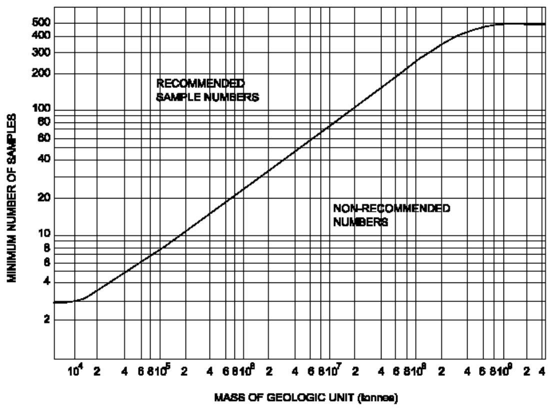

Figure 1. Minimum number of samples as a function of rock mass recommended (BC AMD Task Force, 1989)

2.2 Kinetic Test

A brief of methods of humidity cell, column, soxhelet extraction, British Columbia Research Confirmation, batch reactor (shake flask), and the field scale tests will be described below.

a. Humidity Cell Tests

Tests are conducted in a chamber resembling a box with ports for air input and output (Figure 2). In the past there was no standard for humidity cell test. However, in 1996 the laboratories servicing the mining industry had adopted a standarditation. In designation: D5744-96 standard test method for accelerated weathering of solid materials using a modified humidity cell, (ASTM, 1996 in Mills, 1998). A cell performing 203mm in height and 102mm in diameter is specified for material crushed to 6.3mm (crushed core or waste rock or coarse tailing), and a cell of 102mm in height and 203mm in diameter is used to pass 150 µm fine tailing. Air supply system should be capable to deliver a controlled rate of 1 to 10 l/min, and required for flow rate measurement. The ASTM procedure requires a minimum test duration of 20 weeks, while Price recommends a minimum of 40 weeks (Mills, 1998).

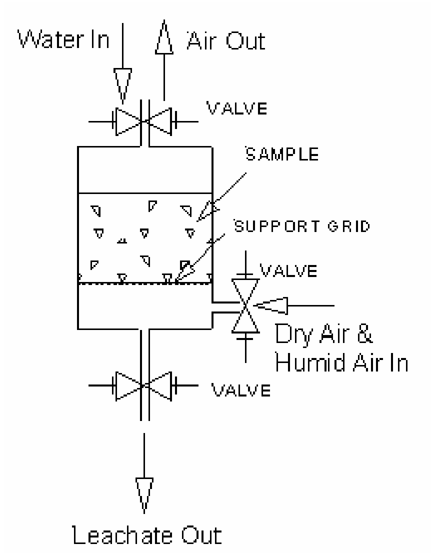

Figure 2. Schematic Arrangements of Humidity Cell (Mills, 1998).

b. Column Tests

Column tests are conducted by loading the waste or material in a cylinder or similar device. Wetting and drying cycles are created by adding water and then allowing the column to dry. Each of the cycles may occur over a period from several days to a week or more, though they typically last for three days each. Caring must be taken to avoid piping along the sample-wall interface when packing the column. Water added to the column is collected and analyzed to determine current oxidation rate, sulfate production, metal release, and other parameters. (U.S. EPA, 1994). Column arrangements is shown in Figure 3.

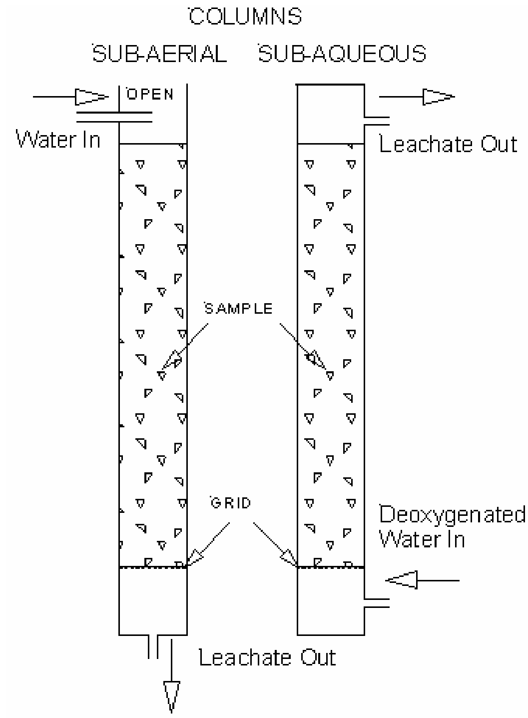

Figure 3: Schematic arrangements of column sub aerial and sub aqueous (Mills, 1998).

c. Soxhelet Extraction Tests

This test simulates geochemical weathering using a soxhelet extraction apparatus to re-circulate solution through the sample. The sample is placed in a thimble in the unit and solution is circulated from a reservoir. In the modified soxhelet extraction test as described by Sobek in U.S. EPA (1994), the sample is leached using distilled water at 25°C over a period of six weeks (duration of the procedure may vary). This test conditions are more extreme than other kinetic tests. However, it is a shorter test and may be useful in simulating long weathering trends in a relatively short test time. Drawbacks include the complex equipment required and the more complex nature of the test in general.

d. British Columbia Research Confirmation Test

This test is intended to determine the ability of bacteria to catalyze enough reaction to suffice their acid demands. The sample volume used by researchers in the range of 15 to 30 grams of material passing a 400 mesh screen (Lapakko, 1993).

The sample is shaken for four hours and acid is added to maintain a solution pH between 2.5 and 2.8. The sample is then inoculated with *Thiobacillus ferrooxidans* and the flask weighed. The flask is plugged with cotton, incubated at 35ºC, and shaken continuously. The pH and metals in solution are monitored for the first three days and the pH maintained below 2.8. Distilled water is added to maintain constant weight. When the pH is established below 2.8, monitoring for pH and the metal is performed every second day until microbiological activity stops. This occurs when pH and metal values remain constant. Additional sample material is then added to the flask and this is shaken for 24 hours. When tested, if the pH is 3.5 or higher, the test is terminated.

If the solution pH is less than 3.5, more samples are added and shaken for 24 hours. The pH is tested; if it is greater than 4 or less than 3.5, the test is terminated. If the pH is less than or equal to 4, or greater than or equal to 3.5, the sample is shaken for 48 more hours and a final pH reading is taken. If the bacteria are sustained in the sample, there is a strong possibility that acid drainage will be generated in the waste unit being characterized. If insufficient acid is produced, the solution pH will approach the natural pH (above 3.5), and the sample is determined to be non acid producing material. If the solution remains below 3.5 then there is a strong possibility that the sample will be an acid producer. (U.S. EPA, 1994).

The initial acidification of the sample in this test presents conditions significantly different than in a typical waste unit. The test does not examine mineral/bacterial reactions above a pH of 2.5 (2.8 as described above). Reactions above these levels may be a major influence in determining if acid drainage is generated. Other disadvantages are that the test ignores neutralization potential and sulfide oxidation rates (U.S. EPA, 1994).

e. Batch Reactor (Shake Flask) Tests

In the batch reactor test, like the British Columbia Confirmation test, a mine sample and water are slurred together in a flask. The solution is usually distilled water; however, nutrients may be added. Sample size and solution volume are determined by the user. Coastech in U.S. EPA (1994), conducted tests using 250 g of waste and 500 ml of distilled water. Flasks are shaken continuously during the test. Water samples are taken at regular intervals to determine water quality parameters such as pH, sulfate, and metals in solution. Sampling for water quality analysis during longer tests may require addition of water to maintain volume. This would complicate interpretation of test data. Data from the tests are used to estimate the rate of sulfide mineral oxidation and release of contaminants, such as metals. The batch reactor is relatively simple and allows examination of multiple factors, such as pH and temperature, which can be tested simultaneously. The influence of bacteria and control measures may be used as test parameters.

f. Field Scale Test

Field scale test is similar to nn-site rock piles described by British Columbia AMD Task Force, use large volumes of material to construct test cells in ambient environmental conditions, typically at the mine site in question. These tests are very different from laboratory tests where the experiment is conducted under controlled conditions. Sample size varies and may be as much as 1000 metric tons or more, depending on space availability. Particle size of the test material is not usually reduced for the test to better approximate field conditions. The sample is loaded on to an impervious liner to catch solutions and a vessel is used to collect the leachate. The volume of solution is determined and an aliquot is analyzed for pH, sulfate, dissolved metals, and other parameters. Consideration of climatic conditions is important when evaluating results from field scale tests. Climatic effects must be distinguished from the rate of sulfide oxidation, acid generation, neutralization, and metal dissolution as determined by analysis of the leach solution. This is necessary because climatic effects, especially precipitation, determine the flushing rate but do not influence either reaction rate or the subsequent chemical composition of the leachate (British Columbia AMD Task Force 1989).

This Field scale test is unlike other kinetic methods in which do not accelerate environmental conditions. Field scale test consequently will provide information on acid generation potential for a mine waste unit for that amount of time that they are started before waste emplacement begins. For some operations this may be 10 years or more and test results may be used to optimize reclamation design.

3. RESULTS AND DISCUSSION

All kinetic tests are monitoring sulfate and dissolved metal loads to track both the oxidation reaction and metal mobility. When using all of the kinetic tests above, there are two important points. First, the taken sample should be kept properly so there will be no significant reaction before the test began. Second, the test period should be long enough to minimize incorrect acid potential prediction.

Each of kinetic test methods has an advantage and disadvantage as shown in Table 1. It shows that the lowest cost is British Columbia Research Confirmation test. The field test is the most expensive one in order to initial construction. All kinetic test methods are subsequently subject to a high degree of uncertainty. As a result, from the entire kinetic test detailed above, there is no one test that is preferred because the preferences, experiences and understanding are changes with time but there is one or more test which is most widely used.

U.S. EPA reported that according to Ferguson and Erickson in 1988, the British Columbia Research Confirmation test was considered to be the most widely used and in 1991 article by Ferguson and Morin stated that the use of humidity cells was becoming more common. This is shows that the preference for the kinetic test is change as time changes. US EPA, (1994) reviewed that modified humidity cell and column type test seem to be a trend toward.

Humidity and column tests seem to be a trend in the future because it is relatively simple apparatus component compared to soxhelet extraction. It is easily modified to test control options, such as the addition of limestone, the influence of bacteria, and water saturation.

Acid drainage control mechanisms, such as increasing alkalinity by adding lime, may also be examined using kinetic tests. It is helpful to supplement kinetic tests with an understanding of empirical data characterizing the sample. Examples include analysis of specific surface area, mineralogy, and metals. Such information may affect the interpretation of the test data and is important when making spatial and temporal comparisons between samples based on the test data. As with static tests, it is important to consider the particle size of the test sample, particularly when comparing test results with field scale applications.

Results from kinetic tests are used to classify mine wastes on the basis of their potential to produce/generate acid. Kinetic tests are often conducted to confirm results of static tests and estimate when and how fast acid generation will occur. The test provides insight on the rate of acid production and the water quality potentially produced and is used to evaluate treatment and control measures. Unlike static tests, there is no standardized method for evaluating test results. Data are examined for changes through time and water quality characteristics.

According to the British Columbia AMD Task Force (1989), samples with pH values less than 3 are considered strongly acid; between 3 and 5 the sample is acid generating and there may be some neutralization occurring; at pH values >5, the sample is not significantly acid, or an alkaline source is neutralizing the acid.

4. CONCLUSIONS AND SUGGESTION

Kinetic tests results are used to classify mine wastes on the basis of their potential to generate acid and estimate when the acid generation will occur. Kinetic test is also facing the high degree of uncertainty of kinetic methods. Therefore waste characteristics, hydrologic and geochemical should incorporate to kinetic test model structure.

To obtain the closest model of kinetic test it is need to calibrate and validate the models; which is requires comparison of model prediction with actual field sampling result. Because of the availability of field data for validation is limited, it is strongly suggested that researcher should make a continue research from the prediction and the actual sampling with many methods.

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Table 1. Summary of some kinetic test methods, costs, advantages and disadvantages

HUMIDITY CELLS	SOXHELET EXTRACTION	COLUMN TEST
SUMMARY OF TEST METHOD		
-2.38 mm particle size 200g of rock exposed to thre days dry air, three days humidified air, and rinse with 200 mL, on day seven Cost: 425-850	particle size not presented T=70 ^oC (Singleton and Lavkulich, 1978) T=25 ^oC (Sullivan and Sobek, 1982) Water passed through sample and distilled and recycled through sample cost: 212-425	variable particle size Columns containing mine waste are leached with disctere volumes or recirculating solutions cost:dependant upon scale
ADVANTAGES AND DISADVANTAGES		
Models AP and NP model and models wet/dry approximates fields conditions and rate of acidity per unit of sample Moderate to use, results take long time, and some special equipment moderate case of interpretation large data set generated	simple, results in short time, and assesment of interaction between AP and NP moderate to use, and need special equipment moderate in interpretation in developmental stage and relationship to natural process not clear	models AP and NP models effect of different rock types, models wet/ dry, and models different grain size diffucult interpretation not practical for large num ber of samples large volume of sample lots of data generated long time, and potential problems: uneven leachate application, channelication

Table 1. Summary of some kinetic test methods, costs, advantages and disadvantages

BC RESEARCH CONFIRMATION TEST	BATCH REACTOR	FIELD TESTS
SUMMARY OF TEST METHOD		
-400 mesh particle size 15-30g added to bacterially active solution at pH 2.2 to 2.5, T=35°C	-200 mesh particle size Sample/water slurry is agitated 200g/500mL	field scale particle size 800 to 1300 metric ton test piles constructed on liners flow and water quality sata collected
if pH increases, 1/2 original sample mass is added in each of two increments		tests began in 1977 and are ongoing
Cost: 170-340	cost: 425-850	cost: initial construction is expensive, subsequent costs are comparable
ADVANTAGES AND DISADVANTAGES		
simple to use,	able to examine many samples simultanously simple equipment	uses actual mine wate under environmental conditions
low cost,		can be used to determine drainage volume
assesses potential for biological leaching		mitigation methods can be tested
Moderate to use	subject to large sampling errors and lack of precision	expensive initial construction
results take long time, and some special equipment moderate case of interpretation large data set generated		long time

Source: Lapakko, 1993