

CONTRIBUTIONS OF CARBONATES AND SILICATES TO NEUTRALISATION OBSERVED IN LABORATORY TESTS AND THEIR FIELD IMPLICATIONS

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ABSTRACT: Correct estimation of available neutralisation potentials (NP) plays a key role in the prediction of lag time before acid mine drainage (AMD) occurs from tailings or waste rock. Under certain circumstances a precise prediction of lag time is desired for designing the waste management plan for a mine operation. However, chemical procedures such as the Sobek method, the Modified method and the BC Research Initial Test often provide incorrect estimates of available NPs, indiscriminate use of which leads to inaccurate predictions of lag times. This paper discusses why the chemically determined NPs are sometimes false representations of available NPs through a case study where the contributions of both carbonate and silicate minerals throughout the acidification process in laboratory humidity cells are inferred from the weekly leachate chemistry. The calculated mineral depletions are then compared with post-humidity cell chemical and mineralogical determinations and the two are found to agree reasonably well, suggesting the validity of the inference method. The findings are discussed under the context of field conditions. Techniques, pitfalls, and cautions in conducting and interpreting humidity cell tests for maximum prediction benefits are also discussed.

Key Words: acid mine drainage, neutralisation, NP, carbonates, silicates, humidity cell, tailings, lag time.

INTRODUCTION

Two major tasks of acid mine drainage (AMD) prediction are that of (1) the lag time before the onset of acid generation, and (2) the intensity and duration of acid generation after the onset of AMD. Humidity cell tests¹, in conjunction with acid-base accounting (ABA) remain a major tool for empirical AMD prediction for waste rock and tailings today. The objectives of humidity cell tests are to determine the primary rates of sulphide oxidation and neutralising mineral dissolution. These rates are extrapolated into the future and compared with inventories of acid producing minerals, collectively expressed as acid potential (AP), and acid-consuming minerals, collectively expressed as neutralisation potential (NP). If the NP outlasts the AP, the material is non-potentially acid-generating; else it would eventually become an acid-generator. In the latter case, the period during which the material remains neutral is the lag period, the length of which (lag time) is predicted from the neutralisation rate in conjunction with the NP. Usually a higher sulphide oxidation rate exists for the post-NP depletion period, which, along with the residual AP, is used to predict the intensity and duration of acid generation. AMD prediction for humidity cells constitutes the first step of AMD prediction for the field. To predict AMD in the field, adjustments are made with respect to temperature, humidity, freezing conditions, and the frequency and amount of precipitation. The resulting field predictions apply to tailings surface or exterior of waste rock dumps where oxygen supply is unrestricted.

A correct prediction of lag time is crucial under some circumstances for designing the waste management plan for a mine operation, and the consequence of a false prediction could be costly. Unfortunately, there is no consensus among practitioners as to what NP value to use for such a prediction. Lawrence² demonstrates that the standard Sobek ABA procedure³ consistently over-evaluates the NP of a sample when compared with the Modified procedure¹ and recommends the use of the latter. Morin⁴ advocates the subtraction of 10 to 15 kg CaCO₃ eq./t from the NP to account for “unavailable NP”. Lapakko⁵ proposes the use of an NP determined by an (usually) lengthy titration of the sample to an end pH of 6.0.

Despite the different practices in the selection of NP for use in the prediction of lag time, it is generally agreed that the available NP before acid generation is essentially provided by carbonate minerals. When the waste carbonate mineralogy is simply composed of carbonates of calcium and magnesium, the carbonate NP (CNP) usually equals

the available NP. When the carbonate mineralogy is more complex, however, the relationship between CNP and the available NP becomes site-specific and material-dependent. The present paper illustrates the pH dependence of complex carbonate dissolution. Techniques, pitfalls, and cautions in conducting and interpreting humidity cell tests are also explained. Finally the findings are discussed under the context of field conditions.

The present paper includes partial results of a study conducted at Noranda Inc., Technology Centre (NTC) as part of a Noranda-MEND project.

SAMPLING AND EXPERIMENTS

Four weekly composite samples were taken from the milling circuit at a Canadian base metal mine during a continuous one-month period in May-June, 1995, representing the total mill tailings at that time. These samples were consecutively designated as S-1 to S-4 and were used in eight duplicate humidity cell tests (identified with suffixes A and B after the sample name) at NTC.

The humidity cell tests were operated for a total of 80 weeks from September 1995 to April 1997. Into each cell was put a 200 ± 5 g tailings sample and 200 mL deionised water was added once a week. After a two-hour soak leachate was recovered and measured for volume, pH, conductivity, redox potential, acidity, and alkalinity. Filtered leachate was preserved and sent for ICP (21 elements) and Fe(III) analyses. Upon completion, the solids were homogenised, sub-sampled, and analysed for ABA, geochemistry, and mineralogy. The geochemical analysis included total metals, total sulphur, soluble sulphate, elemental sulphur, CO_2 , and major oxides. Mineralogical examination included optical microscopy of polished thin sections, secondary electron microscopy (SEM), and x-ray diffraction (XRD).

A post-humidity cell leach was performed for each cell according to the procedure given by Morin and Hutt⁶ with minor modifications. A 10-g sub-sample was sealed with 1.5 L of deionised water in a 2-L plastic container. The mixture was agitated for 24 hours in an end-over-end fashion and the supernatant was sampled, filtered, and analysed. The objective of this post-humidity cell leach was to dissolve all possible soluble secondary minerals such as gypsum which have not been completely removed by weekly flushing.

RESULTS AND DISCUSSION

Humidity Cell Result Interpretative Calculations

Primary oxidation and neutralisation rates are calculated from the weekly leachate chemistry under the following assumptions: (1) after the initial flush-out of accumulated sulphate and prior to the onset of acid generation, no sulphate accumulation occurs in the humidity cell as solid precipitates; all newly-generated sulphate is solely from sulphide oxidation and is flushed out at the end of each cycle. (2) For the pre-acid generation period, the alkalinity in the leachate is comprised of bicarbonate alkalinity only. (3) All dissolved Ca, Mg, Na, K in the leachate are from dissolution of neutralising minerals, either carbonates or silicates.

With these assumptions, the basis for interpretative calculations is as follows. Essentially, the starting point is the unspiciated electrical neutrality of the leachate solution. Ignoring components having insignificant concentrations for the present case, it takes the following approximate form:

$$2\{\text{SO}_4^{2-}\} + \{\text{HCO}_3^-\} = 2\{\text{Ca}^{2+}\} + 2\{\text{Mg}^{2+}\} + \{\text{K}^+\} + \{\text{Na}^+\} + 3\{\text{Al}^{3+}\} + 3\{\text{Fe}^{3+}\} + 2\{\text{Fe}^{2+}\} + 2\{\text{Mn}^{2+}\} + 2\{\text{Cu}^{2+}\} + 2\{\text{Zn}^{2+}\}$$

Equation 1

where the braces “{ }” indicate unspiciated concentration in mmol/L. Converting the concentration unit in Equation 1 to mg CaCO_3 equivalent/L and applying a constant factor to all concentration terms to convert from a per L leachate to a per kg sample basis, and neglecting the ferric contribution for the pre-acid generation period, the equation can be rewritten as

$$[\text{SO}_4^{2-}] + [\text{HCO}_3^-] = [\text{Ca}^{2+}] + [\text{Mg}^{2+}] + [\text{K}^+] + [\text{Na}^+] + [\text{Al}^{3+}] + [\text{Fe}^{2+}] + [\text{Mn}^{2+}] + [\text{Cu}^{2+}] + [\text{Zn}^{2+}]$$

Equation 2

where the square brackets “[]” indicate loadings in the weekly leachate expressed in mg CaCO₃ equivalent/kg sample/week. The loading terms in Equation 2 can be grouped and interpreted as follows:

$$\begin{aligned} [\text{SO}_4^{2-}] &= \text{total acidity produced from sulphide oxidation} \\ [\text{HCO}_3^-] &= \text{residual alkalinity in the leachate} \\ [\text{Ca}^{2+}] + [\text{Mg}^{2+}] + [\text{K}^+] + [\text{Na}^+] &= \text{total alkalinity produced from dissolution of carbonates and silicates} \\ [\text{Al}^{3+}] + [\text{Fe}^{2+}] + [\text{Mn}^{2+}] + [\text{Cu}^{2+}] + [\text{Zn}^{2+}] &= \text{residual acidity in the leachate} \end{aligned}$$

Equation 3

Thus Equation 2 can be re-stated as

$$\text{Total acidity production} + \text{Residual alkalinity} = \text{Total alkalinity production} + \text{Residual acidity}$$

Equation 4

or

$$\text{Total acidity production} - \text{Residual acidity} = \text{Total alkalinity production} - \text{Residual alkalinity}$$

Equation 5

In actual calculations, the residual alkalinity is taken as that measured by titration of the leachate to an end pH of 4.3 with HCl. The residual acidity is obtained according to Equation 3 using leachate dissolved metal concentration and cross-checked with the acidity measured by titration of the leachate to an end pH of 8.3 with NaOH. The total acidity production and the total alkalinity production calculated according to Equation 3 respectively corresponds to the primary sulphide oxidation rate and the NP consumption rate, the two parameters sought in humidity cell tests. Finally, given the AP and NP of the starting material, percent AP and NP depletion at any given time of the humidity cell test can be calculated from the accumulated total acidity and total alkalinity production, respectively.

Humidity Cell Test Result Interpretation

Results of the interpretative calculations are graphically illustrated for sample S-3 in Figure 1. The initial spike in “total acidity production” actually reflects the flush-out of the accumulated oxidation products. This phase lasted about five weeks for all eight cells. The initial five weeks are therefore excluded from the calculation of average sulphide oxidation and average neutralisation rates. The initial flush is followed by a gradual decline of acidity production rate and then by a phase characterised by stabilised acidity production rate. The onset of acid generation, defined in this paper as the point where the leachate pH drops below 4.0, arrived at week 35. Before the onset, the rate of total alkalinity production from neutralising minerals is basically equal to that of total acidity production from sulphide oxidation, thus keeping the leachate pH nearly neutral. After the onset the alkalinity production rate can no longer keep in pace with the sulphide oxidation rate, resulting in the residual acidity rising sharply and the leachate pH dropping quickly.

Figure 1 also shows that, after the onset of acid generation, the total acidity production rate (i.e. sulphide oxidation rate) increased by a factor of about 2 to 4, in agreement with ranges reported in the literature. The total acidity production peaked around weeks 52 to 55 then started to decrease. This decrease is believed to be due to the cementing of the tailings material by oxidation products (such as ferric hydroxide) and neutralisation products (such as gypsum that has not been removed by weekly flushing). The cementation of tailings reduces the sample porosity, increases the sample tortuosity, and prevents effective evaporation of moisture during the dry cycle. All these factors act to block the diffusion of atmospheric oxygen to unreacted sulphide particles, resulting in the observed decline in total acidity production rate. The resurgence in total acidity production rate was due to weekly sample bed stirring and breaking, which began at week 66 and lasted until the completion of the humidity cell tests. With the help of sample bed agitation, the total acidity production recovered to and remained at the maximum rate of about 1600 to 2000 mg CaCO₃ eq./kg/week.

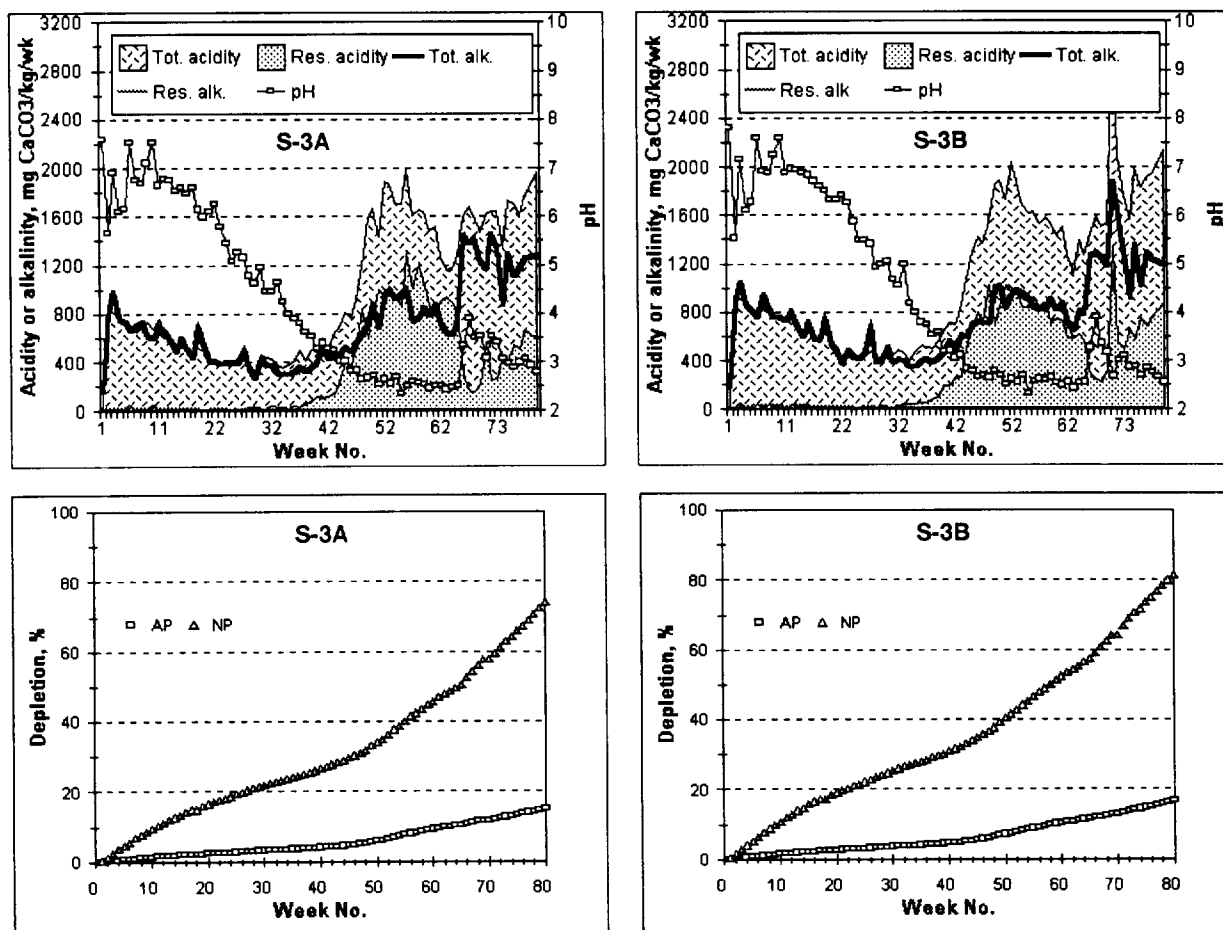


Figure 1. Variations in rate of total acidity production from sulphide oxidation and in rate of alkalinity production from neutralising mineral dissolution during the duplicate humidity cell tests S-3A and S-3B. Also shown is the cumulative AP and NP percent depletion.

After the onset of acid generation, the production of alkalinity did not drop to near-zero rates but continued to be available and even exhibited an increase with the rise of total acidity production rate. This indicates that the neutralising minerals were not depleted at the onset of acid generation. The sharp rises in leachate pH and alkalinity production rate at week 66 suggest that stirring of the sample bed also made available more neutralising minerals.

The cumulative depletion graphs in Figure 1 show that at the onset of acid generation (week 35), only about 23% of the Sobek NP (75 kg CaCO_3 eq./t) was used. Had we used this NP value and the average NP depletion rate (calculated using weeks 6 to 27 for S-3A and S-3B), we would have predicted the lag time to be 114 weeks, which is 3.3 times the real lag time observed in the laboratory! This gross prediction error is due to the fact that not all of the Sobek NP is available before the onset of acid generation. The reason for the partial unavailability of the Sobek NP is found in the neutralising mineralogy, as will be explained later.

Calculation of Carbonate and Silicate Dissolution

Generally, individual mineral depletion cannot be calculated from weekly leachate chemistry. In the present case, this becomes possible because of the particular mineralogy. Three minerals in the tailings provide NP: Mg-ankerite, Mg-Mn-siderite, and clinocllore. Experimentally-determined chemical compositions of these minerals have been used for calculation. Since Mg-ankerite is the only neutralising mineral containing Ca, all Ca in the leachate is attributed to its dissolution and thus its depletion can be calculated. Next, two neutralising minerals - Mg-ankertie and Mg-Mn-siderite - contain Mn; all Mn in the leachate is thus attributed to the dissolution of these two minerals. The depletion of siderite is calculated from leachate Mn concentrations after correcting for the contribution of

ankerite, whose depletion is known. Finally, the depletion of clinocllore is computed from leachate Mg concentrations after correcting for contributions by ankerite and siderite dissolution (both now known). This computation scheme requires that each of the three minerals, when dissolving, congruently releases its Ca, Mn, and Mg contents into the leachate. The results of calculation for S-3 and S-4 are given in Figure 2.

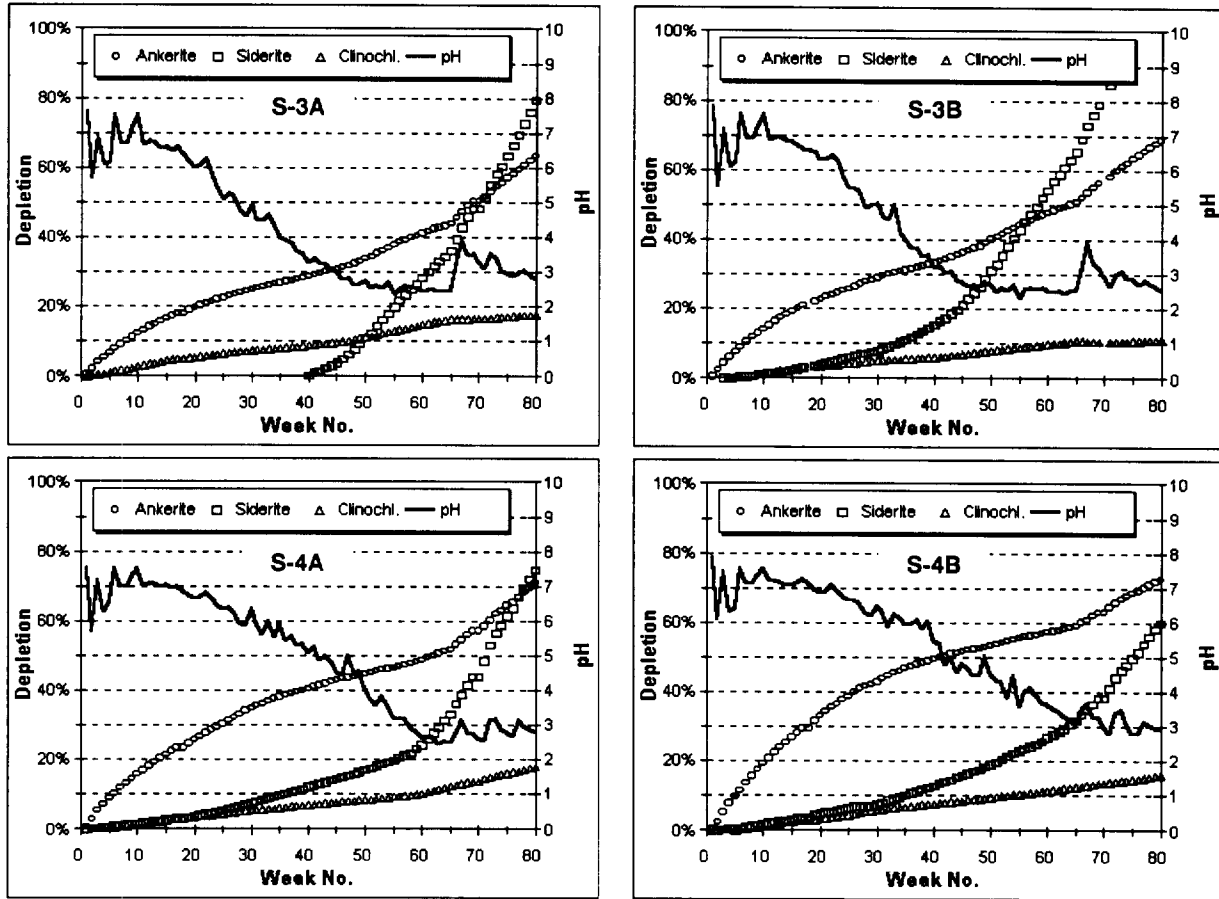


Figure 2. Percent neutralising mineral depletion for S-3 and S-4 calculated from leachate chemistry.

Figure 2 shows that the dissolution of clinocllore (a Mg end member of chlorite) is quite constant, pH independent, and its final contribution to the total alkalinity production is in the 15 to 20% range. The dissolution of Mg-Mn-siderite is activated by a leachate pH drop below approximately 3.5. The dissolution of Mg-Mn-siderite contributes to NP because of its Mg content; ordinary siderite (FeCO_3) does not affect the NP at all. The contribution of Mg-Mn-siderite to total alkalinity production is very small at high leachate pH (i.e. before acid generation) and increases to 15 to 20% range for S-3 and S-4 by the end of the humidity cell tests. The Mg-ankerite is the most reactive neutralising mineral in the samples and its NP is derived from its Ca and Mg content. It dissolves to produce the majority of the total alkalinity during the lag period. The Mg-ankerite is however unlike calcite in that its dissolution is not equilibrium-controlled. Dissolution of calcite is equilibrium-controlled because in a sample containing this mineral the leachate pH will not become acidic before the calcite is completely depleted. In contrast the Mg-ankerite remains available at acidic conditions (below 3.0) and is still not totally depleted at the end of the humidity cell tests. It can be postulated that dissolution of this Mg-siderite is kinetically-controlled, with its dissolution rate somewhat dependent on the leachate pH. The shape of the Mg-ankerite depletion curve (i.e. gradually decreasing slope from beginning up to week 66) suggests that the particles of this mineral are passivated by armouring and cementing actions due to precipitation of sulphide oxidation and acid neutralisation products. After week 66, some of the passivated Mg-ankerite particles are re-exposed by sample stirring, the depletion rate (the slope of the depletion curve) of this mineral hence exhibited an abrupt jump.

The reason why the Sobek NP is inappropriate for use in lag period prediction is now clear. First, because of the constant, pH-independent dissolution rate of clinochlore, its actual contribution to NP would depend on the length of the lag period. Due to the short duration of the Sobek procedure, it would probably under-value the contribution to NP by clinochlore. Second, the contribution of the Mg-Mn-siderite to NP would be very small in reality because the mineral dissolves very slowly at near-neutral leachate pH. However the strong acid attack of the Sobek method likely dissolves most of this mineral and thus fully accounts for this mineral in the NP. Third, the highly acidic conditions in the Sobek method would prevent the armouring and passivation of the Mg-ankerite and over-estimate its contribution to NP. Overall, the Sobek NP significantly over-estimates the NP of the samples used in this study.

The Modified ABA procedure faces the same problems as described above, although to a lesser extent due to the reduced acidity during the digestion process. It too over-evaluates the NP of the samples significantly.

Use of Binary Mole Fraction Diagram

The pre- and post-humidity cell whole-rock chemical analyses of the solids can be used in an unique mole fraction binary diagram (Figure 3) to reveal information about net dissolution of various carbonates during the test period. In this diagram, the shifting of the pre-humidity cell points to the post-humidity cell points indicates carbonate dissolution. The slope of a line ($\Delta\text{CaO}/\Delta\text{CO}_2$) shows the nature of the carbonate being dissolved. The lines marked with and representing the dissolution of pure minerals of calcite, ankerite (or dolomite), and siderite (coinciding with x-axis) have slopes of 1, 0.5, and 0, respectively. The intercept obtained by extrapolating this line indicates the CaO in the sample unassociated with carbonates. If the intercept is zero, all CaO is hosted by carbonates.

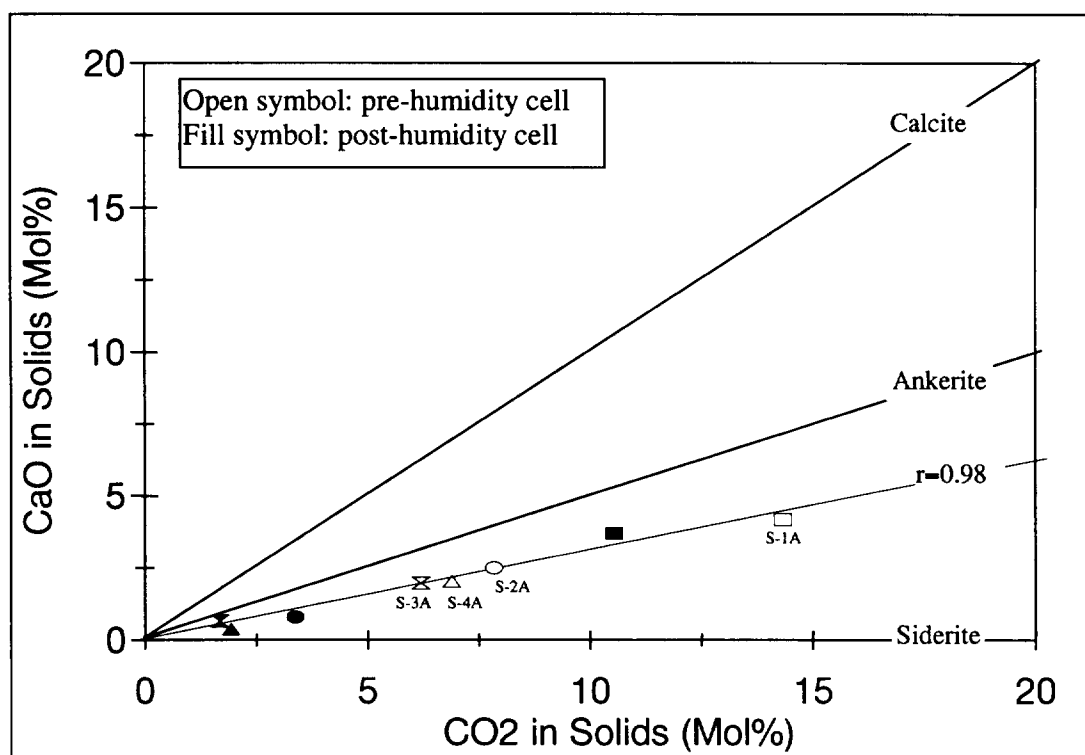


Figure 3. Mole fraction CaO-CO₂ binary diagram for pre- and post-humidity cell test solids

Figure 3 shows that the eight points fall on a straight line having a slope between that characteristic of ankerite and siderite. The linear regression line ($r=0.98$) has a slope of 0.32 and an intercept of zero. This slope gives rise to the proportions of the carbonates dissolved as 75% ankerite and 25% siderite, assuming ideal mineral compositions. The zero intercept indicates that all Ca in the samples is associated with carbonates. These values compare favourably with the humidity cell test findings just discussed above.

Verification of Mineral Dissolution Calculations by Post-Humidity Cell Mineralogy

To verify the mineral dissolution calculations employed above, the percent mineral dissolution for a few selected minerals are derived in two ways. First, the total amounts of minerals dissolved during the humidity cell tests (as calculated from the weekly leachate chemistry data) plus the total amounts of mineral reacted during the storage period after the humidity cell test but before the mineralogical analysis (as calculated from the post-humidity cell leach data) are compared with the mineralogy of the starting samples to obtain the first set of % minerals dissolved. Second, the post-humidity cell mineralogy is compared with the pre-humidity cell mineralogy to drive the second set of % minerals dissolved. Because of the net mass changes occurred during the humidity cell tests, for the two sets of mineralogical data to be comparable, the post-humidity cell normative mineralogy was first adjusted to an anhydrous basis and then normalised to a constant quartz basis. The two sets of % minerals dissolved are compared in Figure 4 for humidity cell tests S-3A and S-4A.

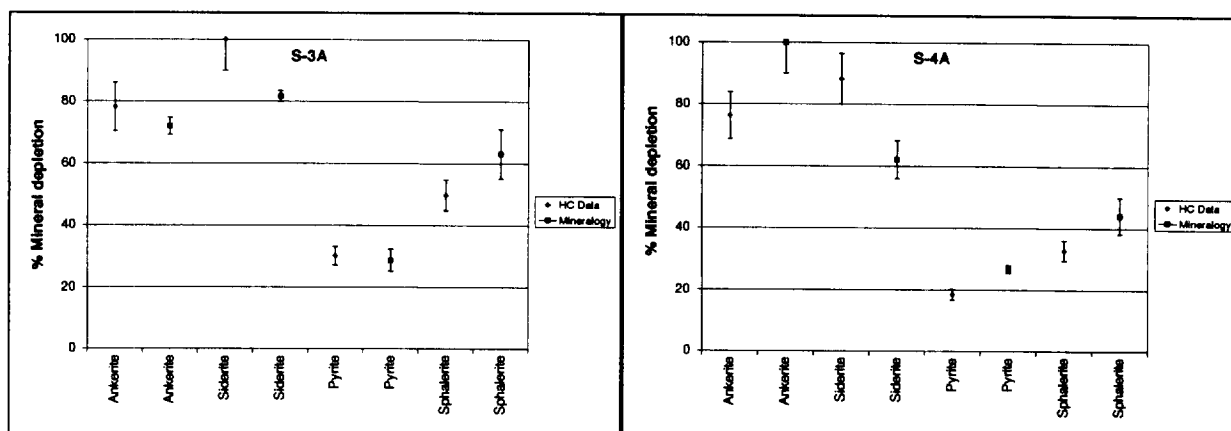


Figure 4. Comparison of % mineral depletion calculated from humidity cell leachate chemistry (HC Data) with those obtained from post-humidity cell mineralogical analysis (Mineralogy) for tests S-3A and S-4A. The error bars shown are estimated $\pm\sigma$.

Considering the uncertainties in the pre- and post-humidity cell normative mineralogy, especially for low-content minerals such as the carbonates (approximately 7 to 10%), the agreement shown in Figure 4 between the two independent sets of % mineral depletions are quite reasonable. This lends strong support to the methodology used for the calculation of individual carbonate mineral dissolution and depletion rates. Unfortunately, insufficient data exist to allow for such an independent verification for the mineral clinocllore.

Suggestions for Conducting and Interpreting Humidity Cell Tests

Based on the results of this and other studies, the following suggestions are offered for conducting and interpreting humidity cell tests for tailings:

1. In addition to total acidity, total alkalinity of weekly leachate should also be determined. The data are required for appropriate interpretation of leachate chemistry and calculation of acidity generation and neutralisation rates.
2. When necessary, the sample bed should be periodically (e.g. weekly) agitated to ensure access of atmospheric oxygen to all sulphide particles and availability of all neutralising minerals to neutralisation reactions. This is especially important if the humidity cells are conducted beyond the onset of acid generation. This will reduce armouring and cementing of sulphide and neutralising mineral particles and help the acquisition of stable primary reaction rates.
3. During the dry cycle, it is preferred to direct the dry air directly and uniformly toward the tailings to ensure quick drying of the wetted tailings. Lack of drying would slow down the oxidation rates by reducing the oxygen diffusion into the tailings.
4. For the leaching cycle, it is preferable to use a high water to solid ratio (e.g. 5 to 1) and a longer contact time (e.g. overnight) to ensure complete dissolution of all soluble oxidation products (e.g., gypsum).

5. Besides the routine quality assurance and quality control (QA/QC) procedures on weekly leachate chemical data, the ionic charge balance of the leachate solution should be calculated to identify any major dissolved constituents that may be missing from the parameter list and to evaluate the precision of the analytical data. The acidity data should be used to cross-check the total concentration of dissolved metals that contribute to acidity.
6. Both pre- and post-humidity cell solid analyses should be conducted to complete the mass balance cycle along with the leachate chemical data.
7. It is imperative that mineralogy of the tailings be known to validate the interpretation based on weekly leachate chemistry and solid chemical analyses.
8. The initial flushing period should be excluded from average rate calculations to avoid bias. An alternative to this approach is the use of pre-flushing of the solids before the commencement of the humidity cell tests. In such a pre-flushing, the tailings to be tested are washed with a large amount of deionised water to remove the accumulated oxidation products.
9. For lag period prediction, the data acquired after the onset of acid generation should not be used for calculation of average sulphide oxidation rates and neutralising mineral dissolution rates.
10. The NP selected for lag period prediction must be justified on the basis of mineralogy and kinetic experiment observations.

Field Implications

Compared with field conditions, the sulphide oxidation reactions in laboratory humidity cells are considered accelerated because of the higher room temperature, frequent flushing to remove oxidation and neutralisation products to expose fresh sulphide surfaces, and wet-dry cycling. This means that, in the field, the sulphide oxidation would be slower than that observed in the laboratory. The primary effects of field conditions in comparison with laboratory conditions are to increase the length of the lag period, as explained below.

If the NP of the tailings consists entirely of fast-dissolving carbonate minerals such as calcite, the dissolution rate would primarily be controlled by equilibrium: the pH of the leachate would not become acidic before the carbonate NP is depleted. Hence all the NP is available before the onset of acid generation. Suppose that the laboratory-measured average sulphide oxidation rate, expressed as acidity production in mg CaCO₃ eq./kg/week, is R_{lab} . Further suppose that the laboratory-measured average NP dissolution rate is $a_{lab} \cdot R_{lab}$, where a_{lab} is factor slightly greater than 1 (e.g., 1.2) on account of the fact that NP is consumed faster than AP. The lag time for laboratory humidity cells would be $[NP_{lab}/(a_{lab} \cdot R_{lab})]$ weeks, where NP_{lab} is expressed in mg CaCO₃ eq./kg tailings. Now for the field, suppose that the acceleration factor for the laboratory humidity cells is n , the field sulphide oxidation rate would then be $R_{field} = (1/n) \cdot R_{lab}$; the field NP consumption rate would be $a_{field} \cdot R_{field} = a_{field} \cdot (1/n) \cdot R_{lab}$, and the field lag time would be $[NP_{field}/(a_{field} \cdot R_{field})] = n \cdot [NP_{field}/(a_{lab} \cdot R_{lab})]$. If we assume that $NP_{field} = NP_{lab}$ and $a_{field} = a_{lab}$, the field lag time would be $n \cdot [NP_{lab}/(a_{lab} \cdot R_{lab})]$. That is, the field lag time is n times the laboratory lag time. According to the past experience of the authors and case studies reported in the literature, the common range for the value of n is 1 to 3. Generally, in cases where calcium and magnesium carbonates are the sole neutralising minerals, the ratio of the field lag time to the laboratory lag time is the same as the sulphide oxidation acceleration factor n in laboratory humidity cells relative to the field.

If the NP of the tailings is composed of more complex mineralogy, as in the samples of this study, the prediction of field lag time from humidity cell tests becomes more involved and site- and material-specific. The main reason is that NP_{field} would be quite different from NP_{lab} . Now suppose that the laboratory oxidation rate is R_{lab} ; the neutralisation rate is $a_{lab} \cdot R_{lab}$; and the lag time is $[NP_{lab}/(a_{lab} \cdot R_{lab})]$. The rate $a_{lab} \cdot R_{lab}$ is contributed by dissolution of three minerals: Mg-ankerite, Mg-Mn-siderite, and clinocllore. That is, $a_{lab} \cdot R_{lab} = \bar{R}_{clino,lab} + \bar{R}_{sid,lab} + R_{ank,lab}$. As pointed out earlier, the dissolution rates of clinocllore and Mn-Mg-siderite at near-neutral pH (i.e. during the lag period) appear to be constant. This is indicated by the bar on top of the letter R in the designations $\bar{R}_{clino,lab}$ and $\bar{R}_{sid,lab}$. The contribution from Mg-ankerite, which is the most reactive of the three neutralising minerals, would be $R_{ank,lab} = a_{lab} \cdot R_{lab} - \bar{R}_{clino,lab} - \bar{R}_{sid,lab}$. This shows that $R_{ank,lab}$ depends on the oxidation rate, R_{lab} .

Now for the field conditions, the neutralising mineral consuming rate is $a_{field} \cdot R_{field} = \bar{R}_{clino,field} + \bar{R}_{sid,field} + R_{ank,field}$. Under normal circumstances, we would have $a_{field} < a_{lab}$, $\bar{R}_{clino,field} < \bar{R}_{clino,lab}$, and $\bar{R}_{sid,field} < \bar{R}_{sid,lab}$. To simplify the following deductions, we can assume that, to a first approximation, $a_{field} = a_{lab} = a$, $\bar{R}_{clino,field} = \bar{R}_{clino,lab} = \bar{R}_{clino}$,

and $\bar{R}_{sid,field} = \bar{R}_{sid,lab} = \bar{R}_{sid}$. We further assume that $R_{field} = (1/n) \cdot R_{field}$. Substituting these assumptions into the first equation of this paragraph, we obtain $(1/n) \cdot a \cdot R_{lab} = \bar{R}_{clino} + \bar{R}_{sid} + R_{ank,field}$ and thus $R_{ank,field} = (1/n) \cdot a \cdot R_{lab} - \bar{R}_{clino} - \bar{R}_{sid} = R_{ank,lab} - (1-1/n) \cdot a \cdot R_{lab}$. This shows that the field ankerite dissolution rate is smaller than the laboratory ankerite dissolution rate by $(1-1/n)$ times the total laboratory neutralisation rate.

Now let us look at the laboratory and field NPs. For the laboratory humidity cell tests, $NP_{lab} = NP_{clino,lab} + NP_{sid,lab} + NP_{ank,lab}$. Let the fractional contributions of the three neutralising minerals to NP_{lab} be x , y and z , respectively, where $x+y+z=1$, we have $NP_{lab} = (x+y+z) \cdot NP_{lab}$. For the field, $NP_{field} = NP_{clino,field} + NP_{sid,field} + NP_{ank,field}$.

Now we introduce the nomenclature $T_{field} = NP_{field}/(a \cdot R_{field})$ = field lag time, $T_{lab} = NP_{lab}/(a \cdot R_{lab})$ = laboratory lag time, and $k = T_{field}/T_{lab}$ = lag time magnification factor in the field. Since the dissolution rates of Mg-Mn-siderite and clinocllore are constant, we have $NP_{clino,field} = k \cdot NP_{clino,lab}$ and $NP_{sid,field} = k \cdot NP_{sid,lab}$. Further, because of the higher reactivity of Mg-ankerite, we make the approximation of $NP_{ank,field} = NP_{ank,lab} = NP_{ank}$.

Employing the above relationships, after mathematical manipulation we obtain

$$k = \frac{T_{field}}{T_{lab}} = n \frac{NP_{field}}{NP_{lab}} = n \frac{1 - (x + y)}{1 - n(x + y)}$$

Equation 6

For the sample S-3, which is the most acidic of the four samples tested, the average laboratory-measured parameter values are approximately as follows: $T_{lab} = 35$ weeks, $x = 0.17$, $y = 0.08$ (hence $z = 0.75$). Substituting into Equation 6 and assuming $n=2$, we obtain $k = 3.0$, $T_{field} = 105$ weeks = 2.0 years, and $NP_{field}/NP_{lab} = 1.5$. That is, for the tailings represented by sample S-3, the field lag time is about 2 years, which is triple the laboratory lag time. The available NP during the lag period for the field is 1.5 times that for laboratory. Essentially, the tripling of the lag time in the field is a result of two contributing factors: the increase in available NP by a factor of 1.5, and the reduction in sulphide oxidation rate (hence the reduction in neutralising mineral consumption rate) by a factor of 2. Observations of the disposed tailings in the field at the mine to date have not contradicted this field lag time prediction.

CONCLUSIONS

Using a Canadian base metal mine tailings test results as examples, this paper illustrates several interpretative techniques and offers suggestions for conducting and interpreting laboratory humidity cell tests for maximum prediction benefits. A method of predicting field lag time on the basis of laboratory test data is presented. Results indicate that NP available during the lag period is strongly dependent on the neutralisation mineralogy and the selection of the available NP for use in lag time prediction must be backed up by mineralogical analysis and justified by laboratory kinetic testing. If the neutralising carbonates are not fast-reacting and their dissolution is not equilibrium-controlled, it is possible to have acid generation before carbonate depletion, as in the case examined in the present study. In applying laboratory humidity cell data for field predictions, it should be recognised that both available NP and sulphide oxidation rate can change and that such changes are often site-specific and material-specific.

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