Interpretation of column leach characteristics of Brunner Coal Measures for mine drainage management

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Abstract

Column leach testing of acid release rates and determination of the time lag to acid onset for overburden associated with the Brunner Coal Measures (BCM) has been conducted by several mining companies over the last 10 years. These tests can be used to characterise the typical leaching properties of BCM rocks. In general, PAF rocks with low ANC release acid rapidly so that acid leaching will be substantially diminished after ~18 months to 5 years. Rocks that have substantial ANC have a time lag before significant acid release but during the lag period a variable amount of acid can be released at lower rates. Trace elements are released at a relatively steady rate or slightly decreasing rate with time in column leach tests.

This data can be used to predict worst case scenario acid release rates for BCM rocks. This scenario indicates an acid load based somewhere between 90% of potential acid (MPA) released over 2 years or 60% or potential acid released over 5 years. In addition these tests indicate that time lag to acid onset is variable but are possible (though not always present) in rocks with ANC > 2 kgH\textsubscript{2}SO\textsubscript{4}/t.

Column leach testing is part of the process required to predict, manage, monitor and treat AMD during resource development, extraction and mine closure. Column tests fit naturally into pre-extraction work phases because they can be completed on relatively small samples such as drill core. However, column testing might also be useful during early phases of mine drainage mitigation studies. Once mine operations are in progress, mine drainage predictions can be improved by other kinetic tests such as lysimeters, leach pads, large scale trials, and detailed monitoring.

Keywords: kinetic test, column leach test, Brunner Coal Measures, acid mine drainage, waste rock.

Introduction

Column leach tests are a kinetic (rate dependant) test used to determine weathering characteristics and leachate chemistry of rocks that are exposed by mining. There are many different types and configurations of column leach tests or other similar tests that are designed to obtain similar information (ASTM, 2012).

In the early 2000s Solid Energy adopted a standard column leach testing method (Smart et al., 2002) to provide laboratory scale column leach test information. Subsequently CRL Energy followed this method and a similar standardised approach for field scale column testing (Pope et al., 2011) in research work. In addition, these standardised approaches were adopted in CRL Energy consultancy work for Pike River Coal, NZ Coal and Carbon, Bathurst Resources and Stevenson Mining. Therefore, almost all laboratory scale leach testing and many field column tests that have been conducted on coal measure rocks in New Zealand over the last decade use similar methods (Pope et al., 2011; Weber and Crombie, 2013 in press; Weber et al., 2013) and are directly comparable. Column leach test results have also been correlated with standard acid base accounting testing to characterise rocks with different leaching characteristics (Weber et al., 2006; Weber and Crombie, 2013 in press).
We present general trends in leach data from a compilation of 18 laboratory and field column leach tests conducted on Brunner Coal Measures (BCM) over the last 10 years. We identify the appropriate level of interpretation that can be applied to column leach testing and fit this into a framework of kinetic testing and monitoring for mine drainage prediction and management.

**Methods**

Rock types that represent a deposit are selected for kinetic testing based on geological information and interpretation of acid based accounting analyses. For BCM, typically this might include coarse and fine grained potentially acid forming (PAF) rocks, non-acid forming (NAF) rocks or rocks that contain substantial acid neutralising capacity (ANC) and rocks that are typical or average for the deposit. Companies might also chose to use column leach testing to trial site specific acid management strategies by adding neutralising agents or submerging the rocks to examine minimisation of acid generation rates.

The laboratory scale column leach test method adopted (Smart et al., 2002) uses open Buchner funnels with a known mass (usually 1-2kg) of crushed (-4mm) rock, a mass normalised distilled water weekly rinse and a mass normalised distilled water four weekly flush. Following the flush, all leachate is measured, sampled and analysis varies depending on the purpose of the column test. The funnels are set up in standardised racks under heat lamps on a 12 hour cycle to encourage capillary processes. In general, the objective of this type of test for BCM rocks is to:

- maximise weathering rates to assess the proportion or the maximum potential acidity (MPA) that is released during weathering.
- provide mine drainage chemistry information that can be appropriately diluted into water management models including acid, alkaline and trace element loads.
- assess the influence of any acid neutralising capacity (ANC) on the rate of acid release.
- mimic worst case field weathering conditions where oxygen, water and reactive surface area are at maximum possible conditions.

The field column methods adopted use a similar free draining leach column approach to the laboratory columns, but are set up with 10-30 kg of coarser crushed rocks (~20mm). The objective of this kind of test is to:

- identify any changes in leachate chemistry under mine site temperature and rainfall conditions.
- identify any changes in leaching rate under mine site temperature and rainfall conditions.
- provide information on difference in leach rate based on available reactive surface area.

Several of the column leach trials reported here are continuing and different companies have commissioned many more columns leach experiments than are reported here to investigate site specific acid management or acid minimisation strategies.
Results

Acid release from Brunner Coal Measures rocks

Acid release rates are calculated from sample masses, leachate volumes as well as either pH, Fe and Al analyses or acidity titration (pH – 7) data. A selected data set is presented that reflect representative rock types from the Brunner Coal Measures. These data are interpreted in relation to related acid base accounting data for the column leach sample (Table 1).

<table>
<thead>
<tr>
<th>Description</th>
<th>Mass</th>
<th>MPA</th>
<th>ANC</th>
<th>NAPP</th>
<th>NAG</th>
<th>NAG pH</th>
<th>Paste pH</th>
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<tbody>
<tr>
<td>Acid forming samples with low ANC</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
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<td>0</td>
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<td>4</td>
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<td>6</td>
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<td>224</td>
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<td>2.3</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
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<tr>
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<td>Carbonaceous mudstone</td>
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<td>16.8</td>
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</table>

Lag samples or NAF samples

<table>
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<tr>
<th>Description</th>
<th>Mass</th>
<th>MPA</th>
<th>ANC</th>
<th>NAPP</th>
<th>NAG</th>
<th>NAG pH</th>
<th>Paste pH</th>
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<td>10</td>
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<td>10</td>
<td>4</td>
<td>3.9</td>
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<tr>
<td>Sandstone</td>
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<td>2.5</td>
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<td></td>
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<tr>
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<td>40</td>
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<tr>
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<td>2</td>
<td>6</td>
<td>0</td>
<td>6.8</td>
<td>5.7</td>
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In general, these rocks can be split into two groups based on their acid base accounting data (Table 1) and their acid release profile, rocks that form acid rapidly and rocks that have a lag period before acid release. Rocks that form acid rapidly typically have zero or low ANC and MPA >> ANC. Rocks that have a lag period before acid release or do not produce substantial acidity have ANC > 2 kg(H₂SO₄)/t, low or moderate MPA, and paste pH values > ~6. These trends have been identified and interpreted in several other studies using site specific data sets (Pope et al 2011, Weber and Crombie, 2013 in press).

Acid Forming Rocks with low ANC

Column leach data indicates acid release from PAF low ANC BCM is commonly most rapid for the first 1-2 years. In columns that go beyond 18 months to 2 years there is commonly a gradual decline in the acid release rate (Fig. 1). Acid release rates from PAF low ANC BCM is commonly between 0.1 and 0.5 kgH₂SO₄/t per month before the rate of acid release declines. However, the acid release rate can be very rapid, up to several kg H₂SO₄/t per month. Leachates from columns where rapid acid release occurs commonly have pH from 1.8-2.5, dissolved Fe concentrations of 1000-4000mg/L and dissolved Al concentrations of 200-600mg/L. There is no grain size dependence on the rate of acid release in the data collected to date. Both mudstones and sandstones can release acid rapidly.
In general, after 1 year of leaching about 15-40% of the available acid (based on MPA) will have leached from BCM rocks under column leach conditions (Fig. 2). By extrapolating the acid release curves about 30-70% of the available acid will be leached by 2 years. For rocks that demonstrate a declining acid release profile with time, about 60% to 90% of the MPA will be released (Fig. 2) before the acid release rate diminishes. Declining acid release within 18 months to 2 years happens in both mudstones and sandstones, although not all rocks have a declining acid release rate within this timeframe.
Rocks without acid or a time lag to acid formation

Rocks that have ANC > 2 kgH₂SO₄/t (Table 1) are likely to either be NAF over an 18 month to 2 year period (Fig. 3) or have a time lag to acid release (Fig. 4). It is unclear if the rocks that have not formed acid (pH > 4) over an 18 month to 2 year period will eventually form acid. Rocks that have a lag period before most rapid acid release have variable leaching chemistry (Fig. 4). In some rocks the lag a slow release of acid which then ramps up quickly, in other rocks the acid release increases but only gradually or slightly over the periods for which data has been collected.

Figure 3. pH of leachate from rocks where leachate remains circum-neutral (>4), all sandstone.

Figure 4. Time lag to acid onset before increasing acid release
- sandstone, ▲ - mudstone, ■ - rock blends.
Trace element release

Trace element release from acid forming rocks for which the most complete datasets are available do show mixed trends with time. The concentration of Zn (Fig. 5) released from rocks during column leaching can be high at any time and is weakly related to acid release and more strongly correlated to SO₄ release. The concentration of Ni (Fig. 6) released from rocks during column leaching shows a weak decrease in concentration with time. These trace elements are associated with sulphide minerals in the Brunner Coal Measures (de Joux and Moore, 2005; Weber et al., 2006) and therefore might be expected to be released in parallel with SO₄. Other trace elements have similar lack of relationship to leaching time or a weak decrease in concentration with time.

![Figure 5. Zn concentrations released from 4 different BCM rocks (■, ▲, ●, ●)](image1)

![Figure 6. Ni concentrations released from 4 different BCM rocks (■, ▲, ●, ●)](image2)
Discussion

The rate of acid release from PAF BCM rocks with low ANC under column leach conditions is rapid and begins to decline in as little as 18 months (Fig. 1). Extrapolating the acid release curves indicates that for many of these rocks, acid release will be complete between 2-5 years and between 60-90% of the potential acid (MPA) is available to be released (Fig. 2).

The acid release rate in column tests on PAF BCM rocks with low ANC is an approximation of the worst case scenario for acid mine drainage from these rocks. Therefore the worst case scenario for acid loads is between 90% of MPA released in 2 years and 60% of MPA released in 5 years. This could occur in a waste rock dump where no (or unsuccessful) management options are in use and where oxygen is freely available, such as the surface zone or a zone where drafting of air replenishes oxygen. Acid mine drainage seeps that reflect a wide range of acid release rates have been identified in the field (Pope, 2010) sometimes with chemistry similar to column leach tests releasing acid at average rates for PAF BCM rocks. Rarely, acid mine drainage seeps with chemistry reflecting very rapid acid release rates have been identified (McCauley, 2010).

Lag period to acid onset in rocks with ANC or lack of acid from NAF rocks provide options to minimise or mitigate AMD formation. If these rocks can be successfully identified, then they can be used for capping materials, or for minimisation of acid formation throughout a mine site.

Trace element release is either steady throughout the acid release process (e.g. Zn) or slightly decreasing as acid release progresses (e.g. Ni). With either trace element release pattern, trace element treatment and management is required as part of mine drainage management throughout the acid release process.

Limitations

There are scale up factors such as grain size, oxygen availability, slaking and weathering of materials, flooding, large scale capillary processes and dilution that make direct application of these worst case scenario column leach tests difficult. In addition, at most active mine sites, operations could see freshly mined rocks co-disposed with partially leached rocks and acid minimisation strategies are practiced which also make direct application of column leach data difficult. If a mixture of rocks that contain ANC and acid are disposed of without segregation then the presence or absence of a lag period is difficult to predict and, the length of time that a lag period lasts for in the laboratory is difficult to correlate directly to field conditions.

Applications

The worst case scenario acid loads identified here have direct application for calculation of acid load from unmanaged PAF rocks. Depending on the overall acid management programme applied at a site this scenario could be useful to consider. For example, at a site where the overall acid management programme includes construction of an oxygen excluding cover, there might be a period of time for which maximum acid loads are released before the cover is in place. Or a site might anticipate management of worst case acid load from an external layer of a dump with a thickness defined by dissolved or gaseous oxygen diffusion concentrations (Weber et al, 2013).
Column leach testing is most importantly applied during resource development when kinetic testing that uses larger samples cannot be completed because of limited sample availability. Once mining occurs, then large scale trials, such as lysimeters, leach pads, trial dumps, and monitoring programmes can be completed to more accurately predict acid release rates and AMD chemistry. If these programmes are designed properly, then best practice management strategies will be refined from initial mine plans and accurate forward prediction of acid release rates and mine drainage chemistry used for closure and post closure strategies will be developed.

**Future work**

This paper characterises leach testing of common rocks from BCM and it is likely that future testing of common BCM lithologies would produce results similar to those presented in this paper. Future column leach testing in BCM would most usefully be focussed on site specific rock types, or prediction of the success of acid management strategies such as addition of neutralising agents or submerging rocks.

**Summary**

Relatively uniform column leach testing methods have been applied to BCM rocks by several mining companies over the last 10 years. In general terms, acid release rates from PAF rocks are rapid and the worst case scenario release rate is between 90% of the available acid in a 2 year period or 60% of the available acid in about 5 years. The time lag before acid production can be present in rocks with ANC>2 kg H₂SO₄/t. The lag periods are variable between a reduced rate of acid release until ANC is consumed and release of leachate that is circum-neutral for the leach periods tested to date. Zn and Ni are commonly released at a steady rate throughout acid release process although in some samples there is a decreasing release of these trace elements with time. Other trace elements are present in lower (though still elevated) concentrations in BCM AMD and are released throughout the acid release process with occasional spikes in concentration.

These data are useful for identification of worst case scenario modelling of mine drainage from waste rock. Therefore this dataset can be applied to an uncapped area or an area where atmospheric oxygen availability has been measured.

It is likely that the common BCM rock types will produce leach profiles that are similar to those presented here. Therefore future column testing for mines hosted in BCM would be most usefully directed at site specific rock types or investigation of acid management strategies.

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References


