Alkalinity producing caps for minimisation of acid mine drainage generation in waste rock dumps

W. Olds¹, P. Weber¹ and M. Pizey²

¹ O’Kane Consultants (NZ) Ltd., PO Box 8257, Christchurch 8440, wolds@okc-sk.com
² Solid Energy New Zealand Ltd., 15 Show Place, Christchurch 8024, mark.pizey@solidenergy.co.nz

Abstract

Potentially acid forming (PAF) waste rock overburden dumps at the Stockton Coal Mine on the West Coast of New Zealand are capped with a blend of low-permeability cement kiln dust (CKD) and weathered granite to reduce atmospheric oxygen transfer into underlying acid-producing material. Typically permeability rates of ~$10^{-6}$ to $10^{-7}$ m/s are achieved. This reduces the rate of pyrite oxidation and thus the subsequent acid generation rates, leading to a decrease in the severity of acid mine drainage (AMD) from waste rock dumps. A secondary benefit of CKD-blended caps is that the CKD has an inherent alkalinity content of ~650 kg CaCO₃ eq./t, which is steadily dissolved by the percolation of rainfall through the CKD/granite cap providing neutralisation to any acidity created, or present, in the underlying PAF material.

Two field trials replicating a 300 mm thick cap, having a ratio of 1:4 CKD:granite (by vol.) exposed to normal rainfall conditions at the Stockton Mine showed leachate alkalinity rates stabilised at around 500 mg CaCO₃ eq./L after 31 weeks, which was down from initial leachate alkalinitities of 3000 – 4000 mg CaCO₃ eq./L. The measured alkalinity was converted to an alkalinity yield based on leachate volumes collected and the surface area of the trial, resulting in a long-term alkalinity yield of 11.9 t CaCO₃ eq./ha/yr. Theoretical calculations based on the acid generation from an uncapped PAF waste rock dump of 28.4 t CaCO₃ eq./ha/yr showed the alkalinity yield from a CKD:granite cap offset over 40% of the acid generated.

A net present value (NPV) calculation was undertaken to compare two options; capping the waste rock dump with CKD:granite caps and treating the subsequent lower acid loads versus not capping the waste rock dump and treating higher acid loads, with the capital expenditure of cap construction as the main variable. Provided leachate alkalinity is maintained at 500 mg/L, from an NPV perspective the capping and not capping options have an equal value after 8 years, making alkaline capping the best option for PAF waste rock dump management in the medium- to long-term.

Keywords: alkaline capping, alkalinity, acid mine drainage, cement kiln dust.

Introduction

Acid mine drainage (AMD) is one of the major environmental impacts of coal mines that disturb pyritic overburden on the West Coast of the South Island of New Zealand (Pope et al., 2010). Pyrite oxidation generates AMD through Equation 1.

$$FeS_{2(5)} + \frac{7}{2}H_2O + \frac{15}{4}O_2 \rightarrow Fe(OH)_{3(5)} + 2SO_4^{2–} + 4H^+ \quad \text{Equation 1}$$

The total sulphur content at the Stockton Mine varies, with some rock dumps having an average of up to 1.75 wt.% total sulphur (Elder et al., 2011), and this sulphur is predominantly present as pyrite. With a disturbed area of ~1000 ha at the mine, AMD management is therefore a significant issue.

A key aspect of mine closure is the design of final engineered landforms (ELFs) and cover systems to minimise long-term maintenance liabilities (Bronstrom et al., 2012). Rehabilitation of waste rock overburden dumps at Stockton Mine is a three-step process. First, the surface of
the dump is reshaped from the tiphead angle of repose (~ 38°) to a final landform slope of around 22°, with construction of benches at regular intervals to control surface water runoff velocity and reduce erosion. Second, a 300 mm thick cap of blended cement kiln dust (CKD) and granite gravel (at a ratio of 1:4 CKD:granite by volume) is placed over the waste rock dump final surface and compacted, producing permeabilities of ~ 10⁻⁶ to 10⁻⁷ m/s. Finally, the dump is re-vegetated to provide a long term stable cover system, either through vegetation direct transfer (VDT) or by top-soiling (400 mm layer) and replanting.

The aim of engineered caps is to limit influx of atmospheric oxygen and water (Bonstrom, 2012; O’Kane and Ayres, 2012), impeding the oxidation of pyrite (Equation 1). The use of CKD increases the finer fraction of the CKD:granite blend, filling voids in the coarse, weathered granite and reducing water permeability to around 10⁻⁷ m/s. This has benefits for oxygen transfer rates as the diffusion coefficient decreases with lower porosity. The low water permeability also means the cap holds moisture, further reducing oxygen transfer, as the effective oxygen diffusion coefficient decreases with an increasing degree of saturation (Aubertin et al. 2000).

Conceptually, alkalinity generating caps work first by minimising oxygen transfer and percolation into the waste rock dump and, second, by ensuring water that does seep into underlying reactive materials is alkaline (Taylor et al., 2006). Miller et al., (2003) showed that alkaline capping (with 2m of limestone) of a failed PAF/limestone blended dump resulted in recovery from pH 3 to pH 4-6 after 2.5 years. These results were replicated in the lab using column leach tests (Smart, 2010). After stabilisation at pH 6 in the field trial the leachate alkalinity stabilised at around 100 mg CaCO₃ eq./L. By maintaining alkaline leachate, the oxidation of sulphides in ARD wastes was reduced by 90% (Smart et al., 2010). Taylor et al., (2006) recommended using magnesium alkaline materials with superior solubility and dissolution kinetics for construction of alkaline caps to minimise short-, medium- and long-term acid discharges.

This paper focusses on the benefit derived from using alkalinity generating caps, from an acid base accounting perspective, rather than oxygen exclusion. The work was undertaken at the Stockton Mine using CKD as the alkaline amendment. The locally sourced CKD has a typical ANC of ~650 kg CaCO₃ eq./t. The generation of alkalinity in water seeping through such cap adds alkalinity to the system, reducing the net amount of acid generated by a waste PAF dump.

Methods and materials

Field trials were set up at the Stockton Mine to determine the alkalinity yield from the standard CKD:granite cap used for rehabilitation on site. The top was cut off two 200 L plastic drums, with a 600 mm diameter. Both drums were then filled with approximately 18 L (26 kg) of CKD and 72 L (130 kg) of granite gravel (blended in a wheelbarrow), resulting in a 300 mm deep layer across the base of both drums. This ratio of CKD to granite was used to replicate the 1:4 CKD:granite ratio (by vol.) used to cap engineered landforms at the mine. A further 114 L (180 kg) of topsoil was added to one of the drums (CKD cap + Topsoil) to simulate a 400 mm topsoil layer, while the other drum contained only the 300 mm CKD:granite blend (CKD cap).

The drums were set up on racks about 800 mm off the ground at the mine and left open to be naturally irrigated by rainfall. Five overflow holes were drilled in the side of each drum at the
height of the topsoil or CKD:granite surface to prevent ponding of water within the drum. Thus, only water which would naturally infiltrate through the cap reported as leachate.

Leachate was collected through a hole in the base of the drum. The drainage hose was bent into a ‘U’ shape to create an air lock, preventing oxygen ingress into the drums from the outlet. The drainage hose drained into collection buckets with an up to 43 L capacity for each drum.

The trial was monitored weekly over a period of 31 weeks. The pH and total volume of water collected in the bucket was measured in the field. An unfiltered and unpreserved 1 L sample was then taken from the collection buckets for each drum and sent for alkalinity analysis. The alkalinity was determined by titration using the APHA method 2320B.

Results and discussion

The weekly volume of leachate collected from each drum is shown on Figure 1.

![Figure 1: Leachate volume (L) collected for CKD cap + Topsoil (blue bars) and CKD cap (red bars) drums over the 31 week trial.](image)

The volume collected ranged from 0 (weeks with no rain) to 43 L. The leachate pH steadily decreased from pH ~13 to ~11 over the 31 week trial period for both trials, as shown in Figure 2.

![Figure 2: Leachate pH for CKD cap + Topsoil (blue diamonds) and CKD cap (red squares) drums over the 31 week trial.](image)
Field trial alkalinity

The weekly leachate alkalinity is shown on Figure 3A.

The leachate alkalinity from the CKD cap + Topsoil drum dropped from 4000 mg CaCO₃ eq./L to ~ 500 mg CaCO₃ eq./L over the 31 week trial. The CKD cap alkalinity decreased from 3000 mg CaCO₃ eq./L to ~ 400 mg CaCO₃ eq./L. A power trendline was fitted to the alkalinity data from each drum with the equations shown on Table 1. These equations were used to generate the modelled curves (Mod. CKD cap + Topsoil and Mod. CKD cap) shown on Figure 3A. The stabilised CKD leachate alkalinity of > 400 mg CaCO₃ eq./L is still significantly higher the 100 mg CaCO₃ eq./L expected from limestone (Smart et al. 2010), which means CKD has a higher alkalinity yield than limestone, which is likely to be associated with the oxide and hydroxide components present in the CKD.
Table 1: Alkalinity decay rate and weekly leachate volume model inputs for CKD cap + Topsoil and CKD cap

<table>
<thead>
<tr>
<th></th>
<th>Alkalinity decay (mg CaCO₃ eq./L)</th>
<th>Leachate vol. (L/week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CKD cap + Topsoil</td>
<td>Y=3306.2e⁻⁰.⁰⁵₆w</td>
<td>11.1</td>
</tr>
<tr>
<td>CKD cap</td>
<td>Y=2193e⁻⁰.⁰₅₄w</td>
<td>12.8</td>
</tr>
</tbody>
</table>

The cumulative alkalinity loading (Fig. 3B) was derived from the product of the weekly leachate volume and the corresponding alkalinity concentration. Figure 3B shows the CKD cap + Topsoil drum is continuing to release more alkalinity than the CKD cap drum. However, the modelled leachate alkalinity curves on Figure 3A show the alkalinity released from the two drums is converging at around 500 mg CaCO₃ eq./L. Therefore, eventually the two cumulative alkalinity loading curves may become parallel.

The modelled cumulative alkalinity loading was determined as the product of the modelled weekly leachate alkalinity and the average weekly volume of leachate generated (11.3 L), and extrapolated out to the end of the first year. The modelled cumulative alkalinity curve fitted the actual data relatively well, particularly from the CKD cap drum. Modelled data is used in further discussion as it evens out weekly fluctuations in alkaline load.

The acid neutralising capacity (ANC) of the CKD used at the Stockton Mine is approximately 650 kg CaCO₃ eq./t, as determined using the method described in the AMIRA P387A Project ARD Test Handbook (IWRI and EGi, 2002). X-ray diffraction testing has shown the ANC is predominantly from oxides (e.g. CaO, MgO, etc.), which explains its ability to produce leachate at pH 11-13. Given 26 kg of CKD was used in each drum, the total alkalinity of each drum would be 16.9 kg CaCO₃ eq. The modelled cumulative alkalinity loading showed that after one year, a cumulative 733 and 484 g CaCO₃ eq. of alkalinity was collected from the CKD cap + Topsoil and CKD cap columns respectively, corresponding to leaching of 4.3 and 2.9 wt.% of the total ANC. It is postulated, although not confirmed, that the difference between the two trials and elevated alkalinity from the CKD cap + Topsoil drum is due to the soil layer excluding atmospheric CO₂, thus limiting the formation of CaCO₃, and enabling slightly higher, ongoing oxide and hydroxide dissolution when a soil cover is in place compared to the CKD cap drum.

Theoretical acid offset – CKD cap + Topsoil

The Mangatini catchment at the Stockton Mine has been significantly disturbed by both historic and more recent mining, with 232 ha of the total 319 ha catchment disturbed. The catchment produces 6600 t CaCO₃ eq./yr of acidity, which is neutralised by ultrafine limestone dosing (Elder et al. 2011). This corresponds to a simplistic acid generation rate of 28.4 t CaCO₃ eq./ha over the disturbed area.

The surface area of the drums used in this trial was 0.25 m². The cumulative 733 g CaCO₃ eq. of alkalinity released from the CKD cap + Topsoil drum over the first year was extrapolated to 29.8 t CaCO₃ eq./ha. The alkalinity generation rate of 29.8 t CaCO₃ eq./ha over the first year is approximately equal to the acid generation rate (due to a peak alkaline first flush effect in the geochemical pre-stabilisation period), theoretically resulting in no net acid generation over the first year.
Figure 3A shows the alkalinity generated from the CKD cap + Topsoil drum stabilises at around 500 mg CaCO$_3$ eq. / L after one year. This corresponds to a lower alkalinity yield of 11.9 t CaCO$_3$ eq./ yr., over a third of the pre-capping acid generation. This alkalinity yield is expected to last many years after cap construction.

Planning for mine closure requires consideration of the capital and operational costs associated with managing acid mine drainage in both the short- and long-term. Many mine operators choose to minimise capital expenditure early in a project and actively treat acid mine drainage in perpetuity, creating operational expenses over time frames in the order of 100 years, which delivers significant savings from a net present value (NPV) perspective. While effective capping and rehabilitation of waste rock dumps is capital intensive, the decrease in acid production and subsequent treatment costs reduces longer term operational expenses.

Net present value (NPV) methods essentially discount the future costs associated with treating acid mine drainage to a value in today’s terms. The various parameters and assumptions used for this paper are shown on Table 2.

### Table 2: NPV analysis parameters and assumptions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capping Capital expenditure</td>
<td>$55,000 /ha Pers. Comm. (Nathan Thompson)</td>
</tr>
<tr>
<td>Capping Operational expenditure</td>
<td>0</td>
</tr>
<tr>
<td>Limestone treatment Capex</td>
<td>0</td>
</tr>
<tr>
<td>Acidity decay rate after capping</td>
<td>40% over first 7 years 0.62% pa thereafter Pers. Comm. (Phil Lindsay)</td>
</tr>
<tr>
<td>Acidity decay rate without capping</td>
<td>0.62% pa Pers. Comm. (Phil Lindsay)</td>
</tr>
<tr>
<td>Inflation rate</td>
<td>2.03% Pers. Comm. (Dave Thomas)</td>
</tr>
<tr>
<td>Discount rate</td>
<td>4.76% Pers. Comm. (Dave Thomas)</td>
</tr>
<tr>
<td>Ultra-fine Limestone treatment cost</td>
<td>$ 337.60 /t CaCO$_3$ eq. neutralised Pers. Comm. (Dave Thomas)</td>
</tr>
<tr>
<td>Alkalinity yield</td>
<td>29.8 t CaCO$_3$/ha in first year</td>
</tr>
<tr>
<td></td>
<td>11.9 t CaCO$_3$/ha/yr. thereafter</td>
</tr>
</tbody>
</table>

The results of the NPV analysis are shown on Figure 4.

Two breakeven points are shown on the graph. The first occurs at year 8 where the NPV of not capping and treating the full acid load of the catchment is equal to the cost of capping and treating the residual acid load of the catchment once the leachate alkalinity has been deducted from the total acid load. The second breakeven point occurs at year 24 where the NPV of not capping and treating the full acid load is equal to the NPV of capping and treating the residual acid load of the catchment without deducting the leachate alkalinity from the total acid load. The difference in the two breakeven points is due to the long-term alkalinity generation rates of the CKD:granite cap. If the long-term alkalinity generation rate is less than 500 mg CaCO$_3$ eq./L the break-even point will be pushed out beyond 8 years, but will not reach 24 years unless alkalinity generation from the cap ceases abruptly after year one.
Conclusions

Construction of alkaline caps using alkalinity amendments such as CKD results in the generation of alkaline leachate and low permeabilities that decrease oxygen flux to underlying PAF material. Field trials showed the alkalinity generation rate stabilised at 500 mg CaCO₃ eq./L from a 1:4 CKD:granite cap blend. This alkaline leachate offsets the acid production of PAF waste rock dumps from an acid-base accounting perspective, with alkalinity generated at approximately one third the acid generation rate in the Mangatini catchment on an area basis. While capping is expensive from a net present value perspective, the reduction in AMD treatment costs from dumps capped with an alkaline cap results in a breakeven point of 8 to 24 years after cap construction, depending on long-term alkalinity generation rates.

References


of the 6th International Conference on Acid Rock Drainage (ICARD), Cairns, Australia, 14-17th July 2003. American Society of Mining and Reclamation.
