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Approaches to acid and metalliferous drainage management — implications of short-term trials for long-term remediation

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Abstract

Several waste rock (WR) acid and metalliferous drainage (AMD) management options have been tested at Brukunga Mine site for their long-term ability to suppress or minimise acidity loads emanating from the WR. A 12–24 month field demonstration assessed alkaline caps (enhanced caustic magnesia, and natural limestone), and limestone blends in their long-term capacity to control acidity loads.

The first 12 months of the trial suggest alkalinity producing covers may have significant potential as an effective and sustainable AMD minimisation strategy. Acidity load produced by the test pile (TP) capped with enhanced caustic magnesia was considerably decreased when compared with baseline. These results suggest alkaline covers allow inert neutralisation precipitates to coat preferential flow pathways, minimising the interface between water and acid salts. Blended limestone did not sustain long-term minimisation/suppression of acidity loads emanating from the WR, regardless of the ratio of limestone to WR or grain size. Even though limestone blended test piles showed the highest quality leachate measured throughout the trials, all test piles showed signs of impending leachate acidification during the latter half of the trial. In particular, the quality of leachate from all limestone blended test piles showed increasing acidity and sulphate concentrations, and a decreasing alkalinity and alkalinity to acidity ratio. Little residual alkalinity remained in the leachate from the limestone blended test piles after 12 months of the trial. The trend clearly shows, that in the long term, blended test piles are likely to produce leachate of quality comparable to untreated test piles.

This trial illustrates the necessity for mine closure managers to be cautious in their application of short-term findings when planning for the longer term, in relation to management of contaminants such as AMD. These trial results signify that whilst testing of approaches is necessary, the longer the time frame the better the likely prediction of long-term outcomes. A hasty approach might well result in a failure of remediation, an inability to complete mine closure, and a hefty cost with little positive outcome.

1 Introduction

AMD is potentially a significant, long-term environmental contaminant resulting in risks to ecosystems, agricultural and human food systems, and local and broader (state) economies into perpetuity. Appropriate management of acid producing material and AMD in Australia is a legal requirement (EPAct), and integral to mining industry integrity. The Brukunga Mine, located east of Adelaide, produces AMD as a consequence of pyrite and pyrrhotite mining from 1955 to 1972, which supplied feedstock for sulphuric acid production for the South Australian fertiliser industry. The mining legacy at site consists of two large WR piles (8 Mt at 2–3 wt% sulphide), a tailings storage facility (3.5 Mt at 1.7 wt% sulphide), mine benches and a highwall. Bennett (1994) predicted production of AMD to continue for a minimum 300 years, potentially requiring leachate treatment for generations to come.

The South Australian Government has been responsible for site management since 1972, including the operation of an acid treatment plant, costing approximately A$1 million per annum. The original remediation strategy for the Brukunga site developed in 2000/01 (PIRSA, 2001), included a proposed blending of WR with imported limestone to suppress AMD production. In 2007, the Department of Primary Industries and Resources South Australia (PIRSA), appointed a technical advisory group (TAG) with the mandate to identify a 'whole of site' remediation strategy. Since WR piles were the major source of AMD on-site (52–82% of acidity load), PIRSA also commissioned field trials to determine the most effective long-term strategy for management of the AMD. In particular, blended neutralising material (limestone) was compared with capping/cover methods using enhanced caustic magnesia (EMgO), limestone or soil. This paper reviews the major outcomes from the trials and discusses their implications in relation to proposals for AMD management at Brukunga, and future strategies for remediation and mine closure.

2 Methods

2.1 Rationale for AMD management options trialled

The trial programme was designed to assess the performance of alkaline capping, limestone blending, and soil covers, as industry-recognised AMD management options in controlling AMD generation. Only a brief description of the AMD management options trialled at Brukunga is presented (Taylor et al. (2009) for a detailed discussion of the alkaline capped test piles, and to Earth Systems Pty Ltd (2008) for a detailed description of the test trial), with the performance of soil covers not included in this discussion.

The use of alkaline capping material is a new technology in AMD management involving placement of alkalinity producing materials over sulphidic WR piles. This placement avoids surface passivation of the alkaline amendment, as the alkaline capping material does not come in direct contact with acid generating material. As rainwater infiltrates through the cover materials, it interacts with the alkaline capping and transports soluble alkalinity into the WR pile. Alkalinity-rich water reacts with acidic salts that it encounters, resulting in acid neutralisation and metal hydroxide and oxy-hydroxide precipitation within the wastes. The purpose of the alkaline amendment is not to treat all the acid salts within the WR pile, but to coat reactive sulphide grains and line preferential flow pathways with inert neutralisation precipitates. In effect, the technique is designed to surface passivate sulphide grains and flow pathways in order to retard sulphide oxidation and minimise ongoing dissolution of stored acid salts. In the long term, WR treated with alkaline caps should produce leachate of improving water quality thus decreasing acidity loads.

An alkaline blending approach traditionally blends alkaline generating materials, e.g. limestone ($CaCO_3$), dolomite ($Mg,Ca(CO_3)_2$), and magnesite (MgO), with acid generating rock to decrease the acidity load of the leachate. Commonly, a significant excess of the alkaline material is added to the WR to account for potential acidity and slow dissolution rates of added materials. However, as water within WRs generally migrates along preferential flow pathways, large amounts of alkaline material remains isolated from water. At the same time, the alkaline material located along preferential pathways is rapidly consumed and/or rendered ineffective by surface passivation, i.e. coated by neutralisation precipitates. Therefore, while in the early stages of treatment, leachate from blended WR may show no signs of AMD, exhaustion of alkalinity over time, will result in increasing leachate acidification which might eventually match that of non-treated waste.

Key issues for alkaline amendments to successfully treat acid generation, which affect both blending and capping approaches, relate to the solubility and dissolution rate of the alkaline material used. As naturally occurring alkaline materials, e.g. limestone, dolomite, are characterised by low solubility and dissolution rates, the slow kinetics of the dissolution reactions tends to limit the effectiveness of capping WRs with such materials, unless exceptional climatic and geological circumstances are invoked (Miller et al., 2003). However, alkalinity loads delivered to WR can be enhanced by: increasing surface area (using fine-grained material); using a high alkaline material/WR ratio; and by using materials engineered to have high solubility and dissolution rate. Each of these enhancements was employed in the Brukunga trials, including the use of enhanced caustic magnesia, an engineered amendment characterised by high surface area, high solubility and fast dissolution rates (Taylor et al., 2006).

2.2 Test pile design and construction

The trials involved the construction of seven, 1,000 t WR test piles (TP1–TP7). Of the seven test piles, one received no treatment thus providing a baseline, while the remaining six were designed to compare AMD management approaches, either with variations of alkaline capping, with cover material or with alkaline blending (Table 1).

Table 1 WR test pile management methods trialled at Brukunga

Test Pile	Management Method	Description
1	Alkaline cap	Caustic magnesia selected as the capping material.
2	Alkaline cap	Ultra-fine grained limestone selected as the capping material (< 8 µm).
3	Cover material	Impermeable cover applied to isolate WR from rainfall.
4	None	Test ‘control’, representative of baseline conditions.
5	Alkaline blending	Blended with 100 t of fine grained limestone (10% mix, grainsize < 2 mm).
6	Alkaline blending	Blended with 20 t of ultra-fine grained limestone (2% mix, grainsize < 8 µm).
7	Alkaline blending	Blended with 100 t of ultra-fine grained limestone (10% mix, grainsize < 8 µm).

Each test pile consisted of an inward draining, square clay pad base, fitted with a narrow trench to facilitate drainage collection. The clay was covered with a thin layer of clean, coarse, quartz sand, overlain by a liner of high density polyethylene (HDPE), with a polyethylene pipe welded into the liner to collect drainage via the trench, and enable sampling from the pipe outlet. Additional sand covered the liner and pipe to prevent damage from rock.

WR was sourced from the site and mixed prior to emplacement to ensure compositional homogeneity between each test pile. One thousand tonnes of homogenised WR was placed onto the protective sand layer to produce a truncated pyramid with a footprint of 17 × 17 m, a core height of approximately 3 m, and an upper surface area of 9.5 × 9.5 m (Figure 1).

Seepage from each test pile was captured by the HPDE liner, collected in the sump area and drained by gravity, allowing water monitoring and sampling. Contingency drainage pipes were fitted in addition to the main seepage collection and drainage pipe. All test piles were covered with a layer of sand and fitted with an irrigation system (Figure 1).

Figure 1 From left to right: construction of test pile; capping of TP1 with EMgO; irrigation system installed on top of a test pile

2.2.1 Test pile capping and blending

The top surface of each test pile was levelled, but not compacted, to facilitate percolation of water. TP1 and TP2 were capped with a thin surficial layer of alkaline material (Figure 1) representing approximately 40% of the total surface area of the test pile. The remaining 60% was uncapped and therefore exposed to direct interaction with incident rainfall. The low proportion of the total surface area capped (40%) was associated with the small scale of the test piles (high ratio of batter surface area to top surface area) relative to typical large scale WR piles at mine sites. The alkaline capping material was excluded from the batter surfaces, to minimise the generation of highly alkaline leachate (that would result from limited interaction between infiltrating water and acid salts in the test pile) and prevent alkaline material from reporting directly to the HDPE liner.

TP5, 6 and 7 were individually blended with different volumes and or grades of limestone prior to being emplaced (Table 1). Extensive blending of WR and limestone amendment was carried out prior to emplacement to ensure homogenous distribution of the amendment within the WR.

2.2.2 Irrigation system

Each test pile was fitted with an irrigation system to augment natural precipitation, and provide constant leachate production during drier months. An irrigation protocol was designed to encourage regular wet-dry cycles, therefore optimising the potential for acidity generation and flushing, as well as enhancing alkalinity infiltration. An irrigation system comprising multiple lines of porous hose was installed across the surficial sand layer on each test pile, and fitted with a meter for accurate monitoring of irrigation volumes. The sand layer facilitated uniform distribution of irrigation water (Figure 1).

In this discussion, ‘infiltration volume’ refers to the amount of water received by each test pile via irrigation and rainfall. The assumptions are that a) the liner captures runoff from the piles, with no loss of water through evaporation, and b) the daily infiltration volume equals the daily leachate volume production.

2.3 Geochemical analyses

2.3.1 Characterisation of test pile material

Grab samples of WR from each test pile were collected for geochemical characterisation. Geochemical analyses for all test piles included:

- Al_2O_3, BaO, CaO, Cr_2O_3, Fe_2O_3, K_2O, MgO, MnO, Na_2O, P_2O_5, SiO_2, TiO_2, S, Ag, As, Cd, Co, Cu, Mo, Ni, Pb, Sb, Zn, Bi, Hg, Se, Sn, Te, Tl.
- Total C, organic C, and total S.
- Loss on ignition (LOI).

2.3.2 Leachate quality

Leachate generated by each test pile was regularly collected throughout the trial for field monitoring of general water quality parameters and laboratory analysis of detailed water chemistry. Leachate was monitored in situ, on a weekly basis for pH and temperature.

The performance of each AMD remediation approach was assessed by monitoring the leachate quality from the test piles, and the extent to which acidity loads had been minimised/suppressed. Leachate samples were collected monthly, for 12 months, and analysed for:

- pH, total dissolved solids (TDS), EC, ORP, Cl, F, P, HCO_3, SO_4.
- Major dissolved cations: Ca, Mg, Na, K (Inductively Coupled Plasma Mass Spectrometry (ICP-MS)).
- Key metals: As, Cd, Cr, Cu, Ni, Pb, Zn, Mn, Al, Fe, Sr, Si (inductively coupled plasma mass spectrometry (ICP-MS)).
- 2.3.3 Calculating acidity/alkalinity

Monthly acidity (Equation (1)) and monthly alkalinity (Equation (2)) loads were calculated as follows:

$$\text{Monthly acidity load} = 30 \times \text{acidity} \times \underline{\text{daily infiltration volume}}$$

$$(\text{kg/unit time}) = 30 \times (\text{mg/L}) \times 10^{-6} \tag{1}$$

$$\text{Monthly Alkalinity Load} = 30 \times \text{alkalinity} \times \underline{\text{daily infiltration volume}}$$

$$(\text{kg/unit time}) = 30 \times (\text{mg/L}) \times (\text{L/unit time}) \times 10^{-6} \qquad (2)$$

Daily acidity values were calculated by linear interpolation of monthly acidity values determined by laboratory analysis. Alkalinity values of 200 mg/L $CaCO_3$ and 15 mg/L $CaCO_3$ were used for the saturated solubility of EMgO and ultra-fine grained limestone, respectively (Taylor et al., 2006).

3 Results

3.1 Baseline geochemistry and infiltration volumes of test piles

The bulk geochemical composition of all test piles showed a high degree of homogeneity, with major and minor element concentration variation contained within one standard deviation, illustrating that the pre-mixing process had been effective and that test piles were comparable in terms of leachate chemistry and acidity load. In particular, sulphur contents varied from 2.98 wt% (TP4) to 3.44 wt% (TP6); the average sulphur content of 3.17 wt% was approximately 1 wt% higher than the average value reported by Blesing et al. (1974) for the entire volume of WR at Brukunga. Of the trace elements present in the WR, the most abundant were As, Cu, Pd, and Zn. These elements were most probably hosted in arsenopyrite, chalcopyrite, galena, and sphalerite respectively.

The total infiltration volume (rainfall plus irrigation) for each test pile was approximately 368 kL for the 12 months of the trial. This value corresponds to approximately 2.2 years of average annual rainfall.

3.2 Leachate chemistry

The performance of each AMD management treatment is presented firstly, according to changes in acidity and sulphate as measured over 12 months of the trial, relative to the trend observed for the baseline (TP4), and secondly, in relation to observed alkalinity trends for TP5–7. Performance of the test trial is presented in terms of the key parameters acidity and alkalinity, as these two variables can fully describe oxidation and neutralisation reactions occurring within the test piles. In particular, as acidity is a measure of both hydrogen ion concentration (pH) and mineral acidity (generated by the oxidation and subsequent hydrolisation of multivalent ions, e.g. Fe, Al, Cu), acidity trends will mirror concentration trends for all major metals present in the leachate.

3.2.1 Acidity and sulphate concentration

Baseline acidity values (TP4) ranged from 9,900 mg/L $CaCO_3$ in December 2007 to 17,600mg/L $CaCO_3$ in March 2008 (Table 2) with an average acidity value of approximately 13,000 mg/L $CaCO_3$ equivalent.

The following general trends for acidity were observed relative to the baseline (TP4) trends. TP1 (EMgO cap) maintained acidity values below those of the baseline test pile for sustained periods. TP2 (limestone cap) showed an overall trend towards increasing acidity values, which were generally maintained at values slightly above those of the baseline test pile. Limestone blended test piles (TP5–7) were characterised by low acidity values well below the baseline test pile. However, in January 2008, acidity for TP6 (2% ultra-fine limestone) started an upward trend, and a similar trend followed for TP5 (10% fine limestone) and TP7 (10% ultra-fine limestone).

Similar trends have been observed for sulphate concentration (Table 3).

Table 2 Acidity for leachate over 12 months: TP1, TP2 and TP4–7

Parameter	Unit	Sampling Event (d/m/yy)	Test Pile ID and Waste Amendment					
			TP1 – EMgO Cap	TP2 – Limestone Cap	TP4 – Baseline	TP5 – 10% Fine Lime-stone	TP6 – 2.0% Ultra-fine Lime-stone	TP7 – 10% Ultra-fine Lime-stone
Acidity as calcium carbonate	mg/L	13/7/07	13,700	13,400	15,100	1,780	1,920	2,360
		20/8/07	16,100	15,200	13,200	266	730	282
		13/9/07	8,570	16,300	12,900	339	388	771
		15/10/07	7,510	11,300	10,300	186	195	272
		19/11/07	17,800	15,200	12,600	945	1,250	980
		14/12/07	11,500	13,200	9,990	238	250	343
		15/1/08	11,800	15,200	11,300	84	805	315
		13/2/08	9,560	14,200	13,500	265	2,150	165
		17/3/08	9,240	17,600	17,600	885	4,300	270
		16/4/08	9,200	15,200	13,500	285	4,360	312
		16/5/08	16,000	16,200	11,400	220	3,860	555
		16/6/08	14,600	17,100	13,700	145	3,880	1,870

Table 3 Sulphate concentration for leachate over 12 months: TP1, TP2 and TP4–7

Parameter	Unit	Sampling Event (d/m/yy)	Test Pile ID and Waste Amendment					
			TP1 – EMgO Cap	TP2 – Limestone Cap	TP4 – Baseline	TP5 – 10% Fine Lime-stone	TP6 - 2.0% Ultra-fine Lime-stone	TP7 - 10% Ultra-fine Lime-stone
Sulphate	mg/L	13/7/07	14,400	14,600	16,300	1,810	3,360	3,780
		20/8/07	18,100	17,100	15,000	1,980	3,990	4,800
		13/9/07	10,500	19,100	14,400	2,080	4,590	4,710
		15/10/07	9,000	13,500	11,500	2,210	4,200	4,500
		19/11/07	19,300	16,600	13,300	2,410	4,560	5,430
		14/12/07	12,400	13,800	11,400	3,060	4,020	5,490
		15/1/08	12,800	15,700	12,200	4,110	6,570	6,240
		13/2/08	10,900	15,500	14,700	4,830	8,730	5,700
		17/3/08	10,900	18,000	16,300	4,710	12,700	4,770
		16/4/08	10,300	17,600	14,400	4,200	9,810	4,320
		16/5/08	17,200	20,000	13,900	3,810	11,000	4,020
		16/6/08	16,800	19,300	11,200	3,810	10,500	4,320

3.2.1.1 Alkaline capping

In general, acidity values for TP1 decreased during the trial with values maintained below those of the baseline test pile (TP4). TP1 was 30% lower in acidity than baseline for the sampling interval September to October 2007, and as much as 47% lower than baseline during the sampling interval January to April 2008. Acidity levels peaked for TP1 in November and May 2008, correlating with the rainfall to irrigation ratio (Figure 2), when upward trends in acidity generally corresponded to high rainfall to irrigation ratios. Acidity values decreased promptly in response to low rainfall to irrigation ratios. In general, acidity values for TP2 slightly increased throughout the trial and maintained values at or slightly above those observed for the baseline test pile.

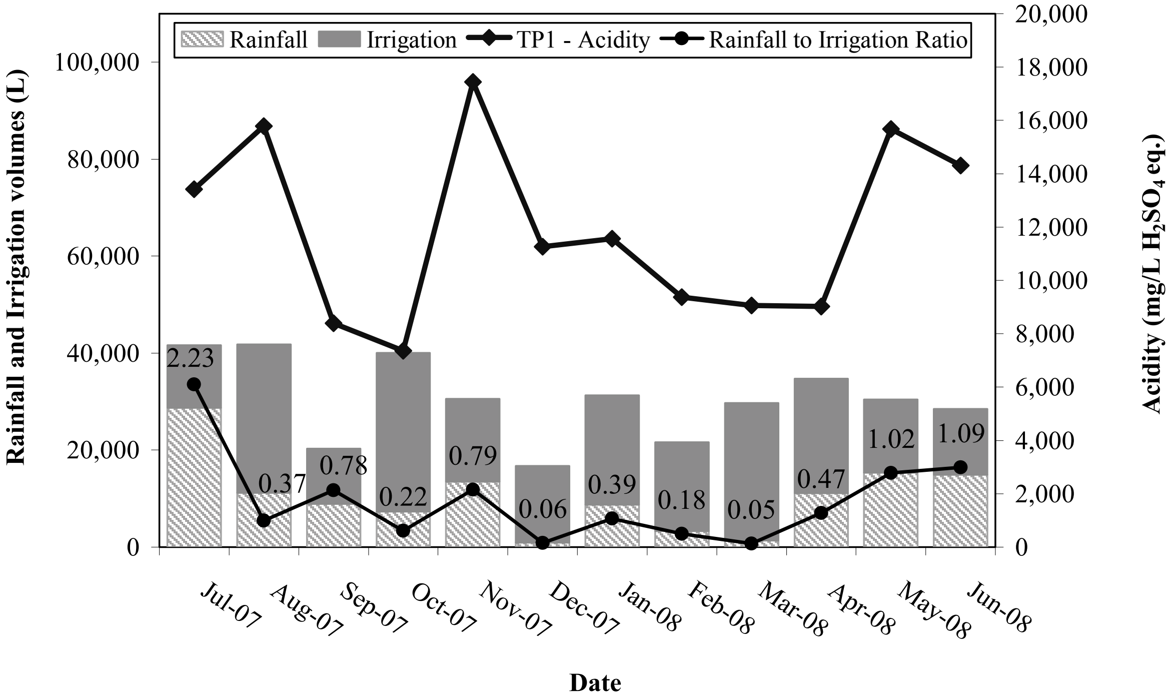

Figure 2 Relationship between acidity trend and rainfall to irrigation ratio, for TP1

3.2.1.2 Limestone blending

Limestone blended piles (TP5–7) maintained acidity below those observed for the baseline test pile (TP4) for the duration of the test trial (Table 2, Figure 2). However, signs of leachate acidification were observed in all limestone blended test piles during the trial. For example, TP5 (10% fine limestone) showed intermittent signs of leachate acidification, with peak acidity values observed during November 2007 and March 2008. Commencing with sampling during December 2007, acidity values for TP6 (2% ultra-fine limestone) increased, stabilising at the sampling interval March to June 2008. Acidity values for TP6 thus increased approximately 15 fold within 6 months. Similar signs of leachate acidification were observed for TP7 (10% ultra-fine limestone) commencing from the May 2008 sampling event with acidity values increasing approximately six fold within 2 months.

3.2.2 Alkalinity

Alkalinity was observed only in the leachate for the limestone blended test piles. In particular, for TP5–7 (Figure 4) during the first few months of the trial (June to August 2007), leachate alkalinity showed a trend towards increasing concentration, reaching peak concentration in July to August 2007. From August to September 2007, leachate alkalinity for these test piles decreased rapidly. Alkalinity concentration had approached zero for TP 6 (2% ultra-fine limestone) and TP5 (10% fine limestone) in January and February 2008 respectively. The rate of alkalinity loss in the leachate was different for each test pile.

TP6 (2% ultra-fine limestone) experienced the most rapid loss in alkalinity, followed by TP5 (10% fine limestone) and TP7 (10% ultra-fine limestone).

During the first six months of the trial, the highest alkalinity values were observed for TP7 (10% ultra-fine limestone, 1,600 mg/L), followed by TP6 (2% ultra-fine limestone, 1,360 mg/L) and TP5 (10% coarse limestone, 1,060 mg/L) (Figure 3). However, both TP6 and TP5 had exhausted most of their available alkalinity by January and February 2008 respectively, with relatively small amounts of alkalinity recorded for the remainder of the trial. On the other hand, leachate from TP7 maintained alkalinity at approximately 800 mg/L from December 2007 through to May 2008. Nevertheless, this is approximately 50% of the value observed at peak alkalinity, and values for the June 2008 sampling are indicative of a new trend towards decreasing alkalinity.

Figure 3 Variation in alkalinity (as $CaCO_3$) for leachate over 12 months: TP 5, 6 and 7

3.2.3 Alkalinity loads for TP1 and TP2

Alkalinity load inputs for TP1 and TP2 were also estimated, with TP1 (EMgO cap) producing significantly more alkalinity than TP2 (limestone cap). The alkalinity released by the EMgO cap (TP1) over 12 months was estimated to be equivalent to 48 kg $CaCO_3$/year, i.e. approximately 3.8 kg $CaCO_3$/month. This is sufficient to neutralise a total of 47 kg H_2SO_4 equivalent/year, or 3.8 kg H_2SO_4 equivalent/month. The alkalinity released by the limestone cap (TP2) over 12 months was estimated to be equivalent to 3.6 kg $CaCO_3$/year, i.e. approximately 0.3 kg $CaCO_3$/month. This is sufficient to neutralise a total of 3.5 kg H_2SO_4 equivalent/year, or 0.3 kg H_2SO_4 equivalent/month.

4 Discussion

The trial demonstrated that the EMgO alkaline capping (TP1) showed distinct improvement in leachate quality relative to TP4 (control pile) during two sampling intervals, with marked decreases in acidity, sulphate and all soluble metals (Tables 2). These periods were interrupted by strong rainfall events that caused a surge of poor quality leachate to discharge from the test pile. Monthly acidity loads for TP1 were lower than the baseline (TP4) for the interval September to October 2007 and from February to May 2008. For these sampling intervals, the monthly acidity loads were as much as 30 and 40% lower than the corresponding values for the baseline test pile.

However, during other sampling intervals, monthly acidity loads for TP1 were higher than baseline. Acidity values (and acidity loads) for TP1 correlated with the ratio of rainfall to irrigation volume. During rainfall events, alkalinity was released to the test pile from approximately 40% of the surface area of the test pile since the alkaline cap was present only on the top surface, while the remaining 60% of the surface produced untreated leachate that reported to the sump. The surge of untreated leachate produced by 60% of the surface area of the test pile overrode the positive effect on leachate quality generated by the limited alkaline cap area. When the rainfall to irrigation volume decreased, leachate quality improved with acidity loads decreasing again compared to the baseline test pile. Consequently, the design of the test piles appeared to be a factor in their performance, in addition to the presence of the alkaline cap. In typical WR piles, significantly greater coverage could be achieved by an alkaline cover due to the smaller contribution of batter surface area to the total WR pile surface area. Furthermore, alkaline capping materials could be applied to batter surfaces in real WR piles, which would enable significantly better coverage of sulphidic waste material than was achieved in this trial.

Over the duration of the trial, the acidity load discharged from TP1 (EMgO cap) was approximately 490 kg H_2SO_4 less than from the baseline test pile. This significant decrease in acidity load generated by TP1 was achieved despite the fact that during the same period the alkalinity released by the EMgO cap was only sufficient to neutralise approximately 47 kg H_2SO_4 equivalent. This comparison between acidity load reduction and alkalinity load release highlights the potential for alkalinity generating covers to sustain lower acidity discharges from sulphidic wastes, resulting in more cost-effective management (Figure 4).

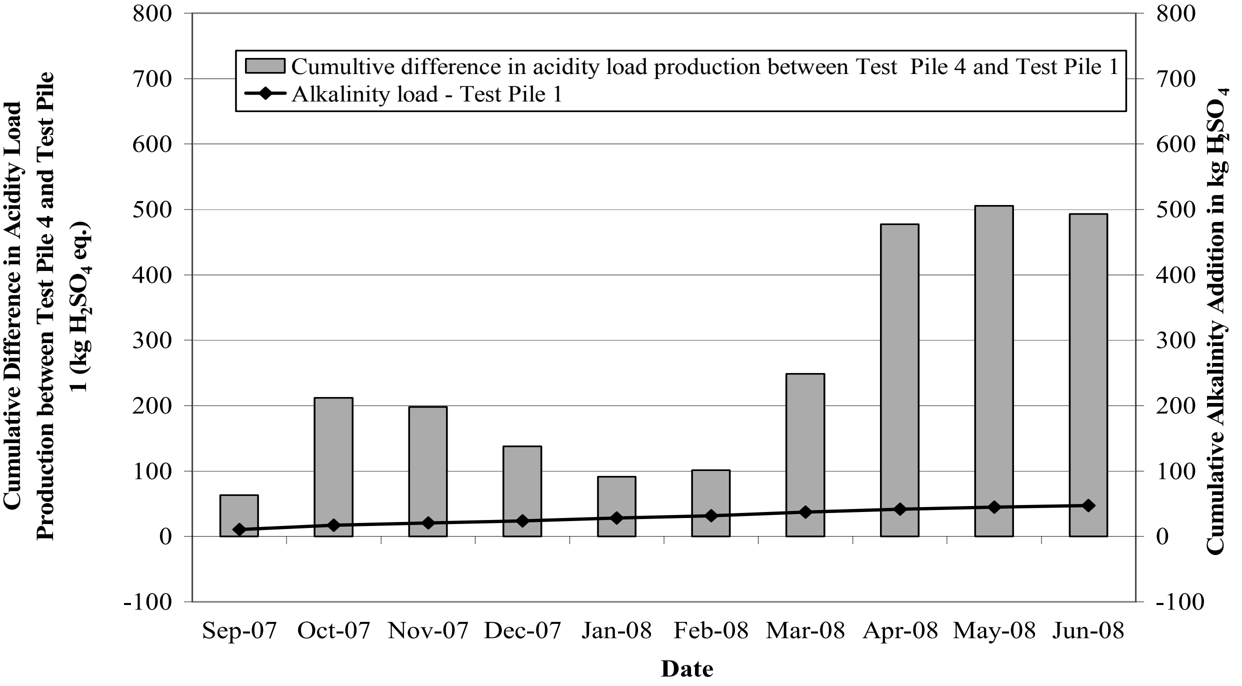

Figure 4 **Cumulative difference in acidity load production between TP4 and TP1 (kg H_2SO_4 equivalent). The black solid line illustrates the Cumulative Alkalinity addition produced by the EMgO cap (kg H_2SO_4 equivalent)**

The average weekly trends in acidity load from TP1 and TP4 show similar behaviour. In the course of the demonstration, the weekly acidity load from TP1 never exceeded that of the baseline test pile (Figure 5). In particular, during the months of January to April 2008, average weekly acidity loads from TP1 decreased while those from the baseline test pile increased sharply, with this trend being interrupted by the onset of the wet season (Figure 5). Until the April 2008 sampling event, the average monthly acidity load from TP1 was approximately 45 kg H_2SO_4 equivalent/month lower than for TP4, while during the same timeframe the EMgO cap released enough alkalinity to neutralise approximately 3.8 kg H_2SO_4 equivalent/month.

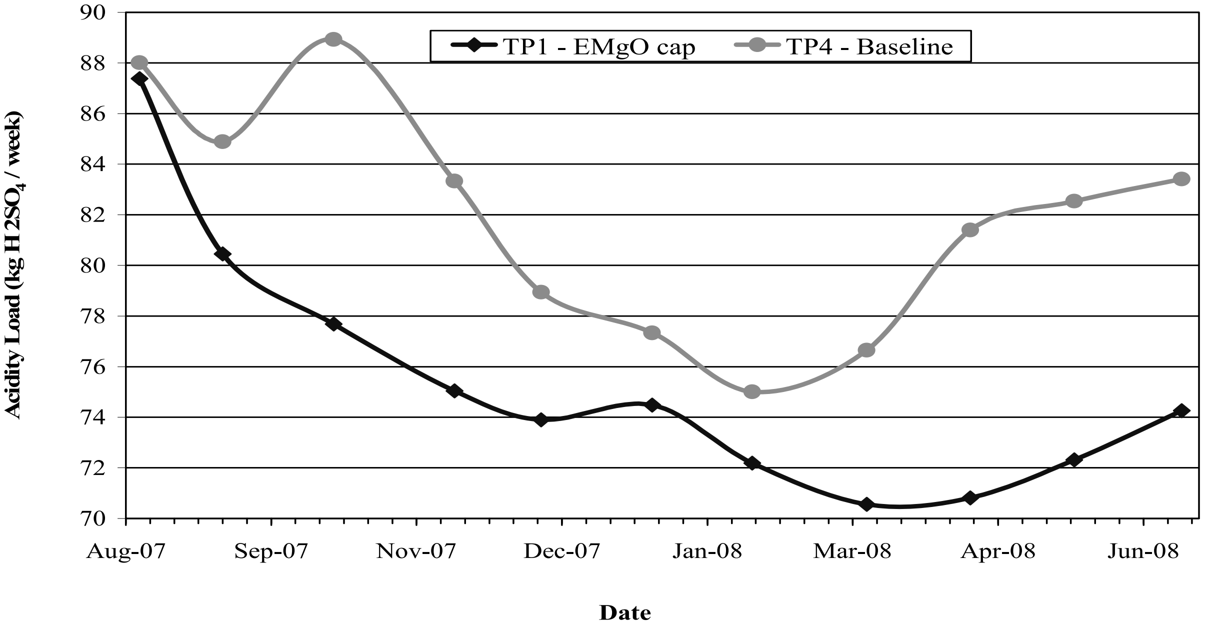

Figure 5 Variation in acidity load calculated on a weekly basis for TP1 and TP4 (kg H_2SO_4/week)

Compared to the EMgO capping, the leachate quality from TP2 (limestone capping) showed only marginal and recent improvement by the addition of alkalinity released from the limestone cap. Presumably this was due to the lower solubility of limestone compared to the EMgO. Over time, TP2 would be expected to show similar improvement in leachate quality to those achieved in TP1. Given sufficient time, the entire fluid-flow network within alkaline capped WR piles could become coated with inert precipitates, thus significantly minimising or potentially avoiding the requirement for downstream leachate treatment.

The disproportionate decrease in acidity load compared to the alkalinity addition from the EMgO cap, suggests that these alkaline covers have the ability to coat preferential fluid flow pathways with inert neutralisation precipitates, thus minimising interaction between seepage and acid salts. Surface passivation of sulphide grains is also possible. Again, given sufficient time, there is potential for all fluid flow pathways (or exposed sulphide grains) within the WR to become coated with inert precipitates, resulting in a significant reduction in the mobilisation of acid salts. Ultimately, leachate from EMgO capped WR may require little or no treatment. The difference in performance between the EMgO and limestone covered test piles indicates that specialised alkaline material such as EMgO, characterised by relatively high solubilities and rapid dissolution rates, may provide a means of rapid control of acidity release rates from sulphidic mine wastes via reactive mineral and pathway passivation.

Limestone blending produced the highest quality leachate throughout the trials (TP5, TP6 and TP7). However, during the latter half of the trial, the quality of leachate from all limestone blended test piles showed signs of acidification, i.e. increasing acidity and sulphate concentrations, Tables 2 and 3, and a decreasing alkalinity (Figure 3) and alkalinity to acidity ratio. Little residual alkalinity remained in the leachate from the limestone blended test piles after 12 months from the commencement of the trial. Although significant quantities of limestone was blended within these test piles, increasing acidity values in the leachate suggests large amounts of limestone remain isolated within the WR. This is most likely related to water migration along preferential pathways, as well as surface passivation of larger limestone grains with inert neutralisation precipitates. It is probable therefore, that acidity loads from limestone blended WR piles may in the long term, progressively increase and return to levels similar to untreated waste. Notably, leachate generated by 10% fine grained blend limestone (TP5), showed signs of substantial alkalinity reduction several months before it was observed at similar levels in 10% ultra-fine grained limestone (TP7). Clearly the alkalinity was more readily available from ultra-fine grained (i.e. higher surface area) limestone, presumably as a result of higher dissolution rates of the ultra-fine grained amendment compared to the coarser ones.

The blending of WR and alkaline material, while effective in the short term, has been shown to be an ineffective AMD management strategy in any long-term management of AMD, since limestone blended test piles showed signs of leachate acidification within a year. The remediation strategy originally proposed for Brukunga (PIRSA, 2001) included a substantial component of limestone blending. The findings from this trial suggest this strategy would have been unsuccessful in managing AMD acidity loads in the long term and possibly led to a return to pre-treatment levels of acidity in WR over the long term. In addition, the AMD management programme (PIRSA, 2001) may have incurred significant cost for potentially little positive result, thereby perpetuating damage to downstream ecosystems, and incurring considerable loss of time to any remediation outcomes.

The implications of the trial findings, even with the obvious limitations in trial design, have two significant ramifications for future development of long-term management strategies in relation to AMD. First, the trial highlights the need to test management or remediation options in the field over a pre-considered length of time before outlaying large sums of money on management plans based on conceptual models without adequate field trialling. Second, even field trials are not a remedy or panacea, since they are often short term, limited by design relative to the real world and to the residual timeline of AMD. They may provide a guide to predictions and assist in the development of methods and strategies. Arguably, field trials should be conducted over variable time frames, such that longer term outcomes can be more accurately predicted and subsequently built into conceptual models of AMD management.

Nevertheless, trials do provide substantial information to industry, to community, to government and to regulators enabling improved planning and management of AMD. Ultimately, remediation of AMD or other significant contaminating waste for the purpose of mine closure requires a conservative approach be taken by mine closure managers and planners. The risk for industry is to rely too heavily upon early trial results in closure planning resulting in remediation approaches that may fail in years to come. If regulators in turn relied upon these results or models and remediation fails and mine closure does not eventuate, then liability for mine sites may enter murky waters. The government may be left an environmental and potentially a social and economic disaster. When this occurs, the community develops a highly negative perception of the mining industry and is less likely to be receptive to and supportive of new mining ventures.

5 Conclusions

The change in leachate quality observed over a 12 month period during the field trial highlights two important trends: 1) alkaline-capped test piles (EMgO in particular) have experienced leachate quality improving over time; 2) limestone blended test piles have shown a steady decrease in leachate quality over time, even though for the duration of the trial they produced the best leachate quality; non the less, this trend clearly indicates that over time leachate quality from these test piles is likely to collapse.

There is currently insufficient data to confirm whether the alkaline capping approach remains a viable WR rehabilitation strategy for the Brukunga site. However, of the approaches to AMD management from WR material trialled at Brukunga, the most significant improvement in leachate quality over time was associated with alkaline capping. Although the trial time was short and only 40% of the available surface area of the capped piles was covered by alkaline capping, acidity loads from the test pile capped with EMgO decreased considerably relative to the baseline test pile. The difference in acidity load generation between the EMgO and baseline pile was sustained. Findings are consistent with the hypothesis that fluid pathways in the capped test piles are being coated with inert precipitates. It is possible that over time, the entire fluid network within alkaline capped WR could become coated with inert precipitates, thus potentially reducing or avoiding the requirement for downstream leachate treatment.

While there are many and varied solutions to managing AMD and acid producing material, this trial demonstrates the importance of ensuring that data collection is undertaken over sufficient and most probably a substantial period of time to be indicative of any long-term effect. Early results of trials may be deceiving and reliance upon such results may provide short-term remediation without long-term closure. If remediation fails, liability for mine sites may be relinquished by the mining company, leaving the government with a potential environmental, social and economic disaster. Perhaps mine closure managers should take a conservative approach with an eye to the future and thus model for the long term.

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