Strategies to reduce AMD liability treatment costs at Stockton Coal Mine, New Zealand.

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Abstract

At the Stockton Coal Mine on the West Coast of New Zealand. Acid Mine Drainage (AMD) is a significant environmental liability associated with historic (since 1896) and current mining of pyrite-bearing overburden. Management and treatment of AMD is expected to persist for ~100 years. The current approach employs ultrafine limestone (UFL).

Additional research has been conducted to optimise neutralant dosing, including identification of the most reactive limestone proximal to site, sludge characteristics and trials to compare effects of UFL to hydrated lime. Further work has been undertaken to reduce the treatment liability including vertical integration of the UFL supply chain.

Key words: AMD, Stockton, neutralent, reagent, ultrafine limestone, hydrated lime, supernatant, treatment, liability, supply.

Introduction

Background

Stockton Opencast Coal Mine (Figure 1), on the West Coast of the South Island 35 km north of Westport, is owned by Solid Energy New Zealand Ltd and operated by Stockton Alliance, a partnership between Solid Energy and Downer EDI Mining Ltd. It is the largest opencast mine in New Zealand with an active mining area of ~930 ha; ~180ha of which is rehabilitated. Stockton mine has sufficient economically recoverable resources to continue producing for at least another 20 years and delivers high-quality steelmaking coal for export.

The mine is on a plateau, a dynamic environment which generates many challenges for coal mining, including rare and endangered fauna, high rainfall and mountainous terrain as well as acid-forming rock. Annual precipitation at the coast is ~3000 mm/year, increasing to ~6000 mm/year at the mine; frequent rain events with daily rainfall exceeding 200 mm can occur at any time throughout the year; and mean annual temperature is ~9°C (Davies et al., 2011). The amount and intensity of rainfall at the mine has significant implications for water management and is critical for the control of adverse effects in waterways draining the plateau, including low pH, dissolved metals (including iron and aluminium), and high suspended solids.

Coal on the Stockton Plateau is present within the Eocene estuarine Brunner Coal Measures (BCM) as thick seams of bituminous coal. These coal measures are overlain by marine sediments, mainly mudstones, with some marginal-marine sandstones near the contact with the coal measures. Pyrite is abundant (up to 5 wt%) in the upper portions of the coal measures and the lower parts of the overlying marine sediments (Hughes et al., 2006; Weber et al., 2006; Pope et al., 2010). Interaction between rainfall, oxygen, and pyritic waste rock results in acid mine drainage, or AMD (Alarcon Leon and Anstiss, 2002; Black et al., 2005; McCauley et al., 2010; Pope et al., 2010).

Compared to natural drainages, the AMD at Stockton contains abundant dissolved Al and Fe, and elevated concentrations of trace metals (Alarcon Leon and Anstiss, 2002; Black et al., 2005; de Joux and Moore, 2005).

AMD liability reduction strategy

Stockton Mine currently uses a significant amount of processed limestone, commonly referred to as UFL (ultrafine limestone being as a minimum 90% < 106μm) for the neutralisation of acidity generated within the Mangatini Catchment. The limestone dosing plant for this catchment currently uses ~12,000 tpa and it is forecast that, as the mining effort moves to new catchments, the Stockton Plateau could require up to an additional 10 – 12,000 tonnes per annum (tpa) starting from the 2013/2014 financial year. This demonstrates a need for between 12 – 24,000 tpa of UFL (see Table 1).

Using 12,000 tpa, this equates to a cost of $ 1,776 k NZD* pa (at $148 per tonne). A preliminary cost/benefit analysis has indicated that Solid Energy can obtain product delivered to site as Aglime (< ~2.5mm) and then mill to UFL for approximately $100 per tonne or ~$ 1,200 k pa. This is thus a savings of $576k pa.

Table 1 *Forecast UFL requirements for the Stockton Plateau. Cypress and Millerton are estimates.*

Site	**Lower limit (tonnes)**	**Upper Limit (tonnes)**	**Estimated Average (tonnes)[1]**
Stockton – Mangatini Catchment[2]	11,000	13,000	12,000
Stockton – St Patrick's Catchment[3]	2,000	3,000	2,500
Millerton WTP[4]	3,700	4,700	4,250
Cypress (including McCabes and Mt William)	1,400	3,900	2,500

[1] These figures are all UFL tonnages based on the calculated acid loads below.

[2] Assumes the Mangatini Catchment has an acid load of ~ 5,000 tonnes per annum,

[3] Assumes the St Patrick's Catchment has an acid load of ~ 1,500 tonnes per annum

[4] Assumes the Millerton Catchment has an acid load of ~ 2,500 tonnes per annum

* All currency figures are in $NZD

There are no sources of limestone on the Stockton Plateau. The nearest potential sources of high quality limestone are listed below (Table 2) along with respective transport costs, which are a significant component of the delivered price. Ten different limestones (including two2 manufactured fine limestones) and two manufactured lime products were tested and evaluated.

The purpose of this research has been to assess 12 different alkaline reagents, including burnt (CaO) and hydrated lime ($Ca(OH)_2$), 8 known prospective sources of limestone proximal to the site, and two less proximal limestone sources with the potential for use to treat acidic runoff. An additional sample was neutralised using a 90% blend of fine limestone (Murchison) and 10% hydrated lime.

Table 2 *Quarry distances from the Stockton Plateau. Transport cost is a significant component of the delivery price for limestone where aglime (AP < 2.5) sells for $25-30 per tonne NZD.*

Potential Limestone Source	**Distance by road from Stockton (km)**	**Estimated Transport Cost per tonne** (based $3.50/km for 28 tonne loads)
Holcim Quarry, Cape Foulwind	58	$7.25
Charleston	65	$8.13
Oparara Quarry, Karamea	84	$10.50
Lyell-Ironbridge Deposit, Buller Gorge	98	$12.25
Murchison Limeworks Quarry, Buller Gorge	125	$15.63
Waipuna, Upper Grey Valley	165	$20.65
Sherry River Quarry, Sherry River Valley, Tasman	195	$24.38
Ngarua, Golden Bay, Tasman	279	$34.88

Methods

Limestone used as a neutralent for water treatment systems needs to have a high level of reactivity, (a result of internal porosity, particle size, and available surface area for reactions to occur). Coarse particles can be prone to being coated with precipitates which renders them somewhat ineffective and coarser products will also generally require more mixing energy, longer reaction times and, in some instances, may not be fully available for reaction within the constraints of the treatment system.

Reagents should also exhibit flocculation\settling characteristics that result in improved clarity of the resultant supernatent; marbles and highly crystalline limestones are generally unsuitable.

Alkaline reagent preparation

The test alkaline reagents were dried in an laboratory oven at 110^o C for 24 hours, crushed in a ring mill for ~2 minutes, passed through 106 µm and 38 µm 200mm diameter sieves to obtain the sized 38 – 106 µm fraction. Prior to use the reagents were again oven dried at 110^{o}C for 24 hours (to remove any moisture) before being prepared into a 5 wt% slurry. All dosing work was undertaken using a 5 wt% slurry as this allowed accurate and reliable control of dose rates.

Sample preparation

Approximately 1500 L of untreated Mangatini Stream water, which is impacted by AMD, was collected on 20 October 2011. The sample was obtained from the Mangatini Stream at a location just upstream of the limestone dosing point. The sampling pump was positioned to ensure the samples were consistent and representative of the flow and, in particular, to ensure no additional TSS were not introduced by disturbance of the stream bed. The sample was collected in 20 L plastic containers which were sealed without air voids and transported for testwork. The Mangatini Stream is characterised by a pH of ~ 2.6, acidity to pH 5.5 of 680 mg\L $CaCO_3$ equivalent, and dissolved iron and aluminium concentrations of 37 mg\L and 104 mg\L respectively.

Alkaline regent dose rate evaluation

Evaluation of alkaline reagent dose rates was undertaken by obtaining a representative 500 mL sub-sample of Mangatini Stream water. The sample was mixed using a magnetic stirrer while two independent lab grade EDT RH357 pH meters logged the pH every 10 seconds. A 1 L sample of freshly prepared alkaline reagent slurry was kept well mixed. All alkaline reagents were dosed using a 0.1-1 µL Eppendorf Research calibrated air displacement pipette (this was calibrated on a balance accurate to 0.001 mL). The pipette was used to titrate slurry to the mixed Mangatini Stream sample at an exact rate of 0.5 mL of slurry every five minutes. At 5 wt% solids this equated to 0.03 mg of limestone every five minutes.Surface area and pore size distribution analysis

The BET method was used to analyse the five point surface area plus poresize distribution (40 points adsoption, 40 points desorbtion) of all 12 test reagents

Results and Discussion

The primary treatment objectives\targets prior to discharge of Mangatini catchment runoff beyond the mine boundary are to increase the pH to 5.5. At this pH, dissolved aluminium and iron has precipitated and is captured via sedimentation, as well as a significant proportion of the entrained suspended solids (including the precipitated aluminium and iron sludge). There is also a determination to ensure the discharge from site has an acceptable clarity.

Alkaline reagent dose rates

For clarity, the ***12*** reagents have been considered to fall into one of three categories, these are:

1. Limestone ($CaCO_3$) which has been obtained from local quarries and crushed to a desirable and practical particle size,
2. Limestone manufactured as fine limestone from external suppliers (Victory Lime and Transform Minerals), and
3. Calcium oxide and calcium hydroxide.

Figure 1 illustrates the dose rates required for each alkaline reagent to increase the pH from 2.6 to pH 5.5.

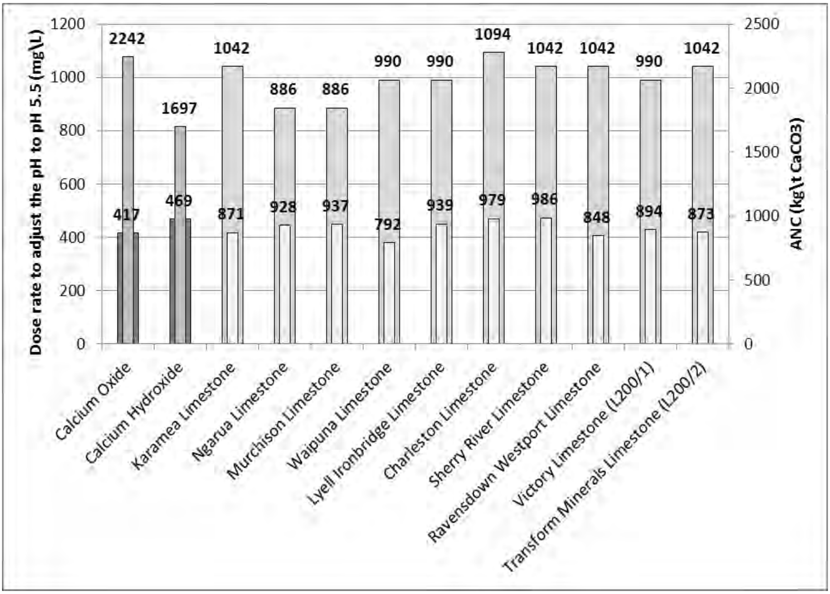

Figure 1 *Required alkaline reagent dose rate to increase the pH from pH 2.6 to 5.5 and Acid Neutralising Capacity (kg\t $CaCO_3$ equivalent). Note: With reference to Figure 1, the corresponding acidity to pH 5.5 was 680 mg/L as CaCO3.*

Supernatant properties

Adjustment of the pH ($\geq$ 5.5) can be achieved with any of the 12 alkaline reagents tested. Therefore the key differentiating performance indicator for each reagent is its ability to produce a discharge (supernatant) with a low suspended solids concentration and an acceptable level of clarity. A summary of the supernatant characteristics for all 12 alkaline reagents is illustrated in Table 3

Solids flocculation and settling characteristics

This research has demonstrated that the two categories of reagents (limestone versus calcium oxide and calcium hydroxide) produce quite distinctive and somewhat different flocculation and sedimentation outcomes.

The use of limestone to treat Mangatini catchment runoff will produce very fine dispersed particles (floc[1] formation isn't apparent). These very fine and dispersed particles take significantly longer to settle.

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[1] A floc is a group of suspended particles which have joined together to form a larger particle with sufficient mass to settle readily from solution.

The use of either calcium oxide or calcium hydroxide results in the production of large bulky gelatinous hydroxide flocs. When other suspended solids are present they will readily combine with these hydroxide flocs. The hydroxide flocs rapidly gather size and mass as they move and settle through the water column. As they do this they pick up remaining fine dispersed particles (a process known as sweep floc enmeshment). The result is generally a rapidly settling sludge interface with the rapid production of a high-clarity supernatant (Table 3).

Surface area analysis

The results of this method of analysis are presented, in conjunction with all other tested parameters (dose rate, TSS, Turbidity and Clarity), in Table 3 below.

Conclusions

Use of calcium oxide and calcium hydroxide is recommended, dependent upon further work to elucidate issues associated with sludge bulking.

Six of the 10 limestone reagents tested are also recommended based upon their performance in laboratory trials (Table 3). It is also suggested that four of the 10 limestone-based reagents be avoided as they are less likely to achieve the treatment objectives (especially under site conditions).

Additional results obtained from this research clearly demonstrate the potential benefits of dual reagent use. The addition of limestone slurry to the water being treated resulted in the production of fine dispersed particles, typical of limestone use. The subsequent addition of the calcium hydroxide rapidly resulted in the production of large 'bulky flocs'.

Table 3 *Summary of required alkaline reagent dose rate to increase the pH from pH 2.6 to pH 5.5, key performance properties following treatment with the 12 alkaline reagents, surface area and poresize distribution and suggested ranking of all reagents.*

Alkaline reagent	Supernatant properties (after 24 hours sedimentation)			Total Surface Area ($m^{2/}g$)	Suggested ranking	Suggested ranking	Surface Area Ranking
	TSS (mg\L)	Turbidity (NTU)	Clarity (cm)				
Calcium Oxide	≤ 15	≤ 15	70	5.70E-06	AA	1	9
Calcium Hydroxide	≤ 15	≤ 15	70	9.26E-01	AA	1	1
Karamea Limestone	≤ 25	≤ 25	55	4.35E-01	BB	2	2
Ngarua Limestone	≤ 25	≤ 25	50	3.70E-01	BB	2	4
Murchison Limestone	≤ 15	≤ 15	35	1.56E-01	AD	3	8
Waipuna Limestone	≤ 15	≤ 25	50	1.74E-01	AB	1	7
Lyell Ironbridge Limestone	≤ 15	≤ 15	40	4.13E-01	AC	3	3
Charleston Limestone	≤ 15	≤ 15	60	1.92E-01	AA	1	5
Sherry River Limestone	≤ 15	≤ 15	55	1.83E-01	AB	1	6
Ravensdown Westport Limestone	≤ 15	≤ 15	45	4.35E-01	AC	3	2
Victory Limestone (L200/1)	≤ 15	≤ 15	55	4.13E-01	AB	1	3
Transform Minerals Limestone (L200/2)	≤ 15	≤ 15	45	1.83E-01	AC	3	6
Limestone + Calcium Hydroxide (dual reagent)	≤ 15	≤ 15	70	5.41E-01	AA	1	8 & 1

Type of alkaline reagent		TSS and NTU		Clarity		
▓	Calcium oxide (Burnt Lime) or Calcium hydroxide	≤ 15	A (Excellent)	≥ 60	A (Excellent)	1 = Recommended
░	Limestone	≤ 25	B (Very good)	50-59	B (Very good)	2 = Suitable for use
				40-49	C (Poor-Good)	3 = Avoid this product
				≤ 39	D (Poor)	

On a cost per tonne of acid neutralised, health, safety and handling basis, UFL and hydrated lime are still the preferred products for neutralisation of acidity at Stockton, when compared to other alternative such as Sodium Hydroxide (Refer Table 4). Based on a preliminary assessment, fine limestone processed by a crushing plant (operated by Solid Energy) provides the lowest cost per tonne of acid neutralised.

Table 4 *Neutralisation costs per tonne of acid neutralised for dosing the Mangatini Stream.*

Product	**Delivered Cost per tonne + Opex costs**	**Reactivity\ Efficiency**	**ANC per tonne of $Ca(OH)_2$ (kg/t)**	**Cost per tonne of Acid Neutralised**
Fine Limestone (Current LDP)	$216.95	~40%	1000	$542.38
Fine Limestone (MG15 LDP)	$202.56	~55%	1000	$368.29
Fine Limestone (SENZ Operated Crushing Plant + MG15 LDP)	$133.78	~55%	1000	$243.24
Hydrated Lime	$458.80[2]	≥93%	1256	$365.43
Burnt Lime	$351.84[3]	≥93%	1660	$212.54
Sodium Hydroxide (50% w/v liquid)	$671.00[4]	~99%	2502	$562.93

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