Comparison of diversion well substrates for the treatment of acid mine drainage Bellvue Mine, West Coast, New Zealand

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Abstract

Bellvue Mine, an abandoned coal mine north of Greymouth, West Coast, is discharging AMD into Cannel Creek, resulting in low pH conditions and high dissolved metal concentrations. A diversion well is a form of passive treatment of AMD. This research aimed to test the efficiency of a diversion well using mussel shells in treating AMD at Bellvue, in comparison to the more traditional diversion well using limestone. Results indicate that limestone is more effective at improving water chemistry. Greater increases in the pH level of treated water and greater decreases in dissolved metal concentrations were achieved using the limestone substrate.

Keywords: Acid mine drainage, Bellvue Mine, diversion well, mussel shells, semi-passive treatment

Introduction

A long history of coal mining on New Zealand's West Coast has resulted in the production of acid mine drainage, having a negative effect on the quality of fresh water streams. Bellvue, an abandoned coal mine north of Greymouth, is discharging acidic run-off into Cannel Creek. Past studies have shown sections of the creek, downstream of the mine site, have pH levels as low as 3.55 (Trumm and Cavanagh, 2006). Acidic discharge is also causing high dissolved metal concentrations (West, 2014). As a result, stream water quality is poor, leading to low ecosystem health and a loss of aquatic biodiversity.

Bellvue Mine is approximately 12 km north of Greymouth, West Coast, situated on Cannel Creek (fig. 1). Bellvue Mine operated over several decades beginning in 1927 until production ceased in 1970. The mine was opened as an extension to the larger James Mine, further northwest of Bellvue, along the same Brunner Coal seam. Extraction of coal has exposed minerals, specifically pyrite, allowing the formation of AMD, which flows into the nearby Cannel Creek. Bellvue Mine adit is located at the top of a 50 m cascade. Contaminated water pools at the mine adit as the mine entrance has collapsed over time, damming water behind it. Acid mine drainage flows down the cascade, over a flat, non-vegetated area and into Cannel Creek.

Figure 1 Red square indicating location of Bellvue Mine site, West Coast, New Zealand (adapted from Google Maps (2017) and Land Information New Zealand (2016)).

Passive treatment of AMD is a favourable method of treating contaminated waters at sites similar to Bellvue. These treatment systems are low maintenance, low cost and take advantage of the naturally occurring processes at the given site. Limestone diversion wells are a common form of passive treatment of acid mine drainage. Basic design and system function of a diversion well is described by Arnold (1991) and Schmidt and Sharpe (2002). A typical well consists of a circular casing, often sunk into the ground at a shallow level alongside a stream. Water is forced into the well by having an elevation difference that creates hydraulic head. This often involves damming water upstream. The water is flushed into the centre of the well through a pipe and exits the pipe near the bottom of the well. The water then flows upwards, fluidizing the limestone substrate. Calcium carbonate reacts with the contaminated water to raise the pH and increase alkalinity, thus allowing for the removal of metal contaminants. Treated water is then piped from the well back into the stream (fig.2) (Arnold, 1991; Schmidt and Sharpe, 2002). A diversion well is usually 2/3 full of limestone, which needs to consist of greater than 85% of calcium carbonate for optimal results (Schmidt and Sharpe, 2002). This form of passive treatment is effective in that it treats AMD quickly, without long residence time, and it does not require large amounts of space to install and is of low cost. However, regular maintenance is required to replace limestone and to clear any vegetation debris that can block the well intake (Arnold, 1991; Schmidt and Sharpe, 2002).

This research aimed to determine the efficiency of a diversion well using mussel shells for the treatment of AMD at Bellvue, in comparison to the more traditional diversion well using limestone.

Methods

The system setup consisted of an 800 × 400 mm well (110L blue barrel), linked to two intermediate bulk containers (IBC's: fig 3). Acidic water was siphoned from pooled mine waters using three pre-existing 25 mm alkathene pipes, to a 50 mm PVC pipe, which fed vertically to the bottom of the well. This inlet pipe rested on the base of the well and was perforated with 10 mm holes, equalling the cross-sectional area of the pipe. This increased the velocity of the water flowing into the well, increasing the ability for grains to fluidize towards the outer edges of the well. From the well, IBC 1 was connected down gradient using a 50 mm PVC pipe, and another 50 mm PVC pipe connected IBC 2 to IBC1. This set up allowed siphoned acidic water to flow down into the bottom of the well, up through the substrate, out of the well and through the connected IBCs, exiting the system through a 50 mm hole in IBC 2, which allowed treated water to flow back into Cannel Creek. The use of the IBC's was to increase residence time of water flowing through the system.

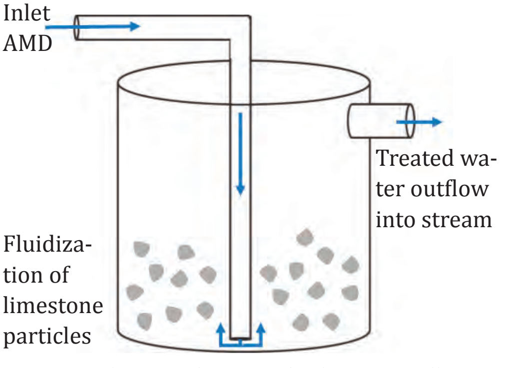

***Figure 2** Schematic diagram of a diversion well.*

Figure 3 *Diversion well setup at Bellvue Mine site. Inlet AMD enters the well where fluidization of substrate occurs. Treated water then flows through each IBC, where further dissolution of substrate and neutralisation reactions occur. Treated water then flows into Cannel Creek.*

The residence time of water in the system was measured by simply timing how long it took the whole system to fill with water, with the diversion well containing substrate. On average, the system took 10 minutes 3 seconds to fill. Initial sampling took place as soon as water started flowing out of the IBC 2 outlet, back into Cannel Creek, that is 10 minutes, 3 seconds after the valves were turned on allowing water flow through the system. The 15-minute sampling then took place 15 minutes following the initial sample, and so on. Flow rates were taken throughout the experiments using a bucket and stop watch method. Average flow rates of water flowing out of IBC 2 was 2.4 L/second, the same as for inflowing water.

Limestone and mussel shells were tested individually as diversion well substrates. The limestone used was 0-5 mm aggregate and was sourced at size from Springfield Lime Company Ltd. The mussel shells were sourced whole, as a waste product, from United Fisheries, and were crushed using a garden mulcher to and sieved to 0-4.5 mm. Sixty litres of substrate was used in the well during each test, equating to just over half the well volume.

Each test consisted of running the system and collecting data over several hours to observe changes in water quality and chemistry over time. Inlet and outlet samples were collected for total and dissolved Al, Fe, Mn, Ni and Zn and sulphate analysis, for each time interval. The sample time intervals were: at the start (inlet and outlet), 15 minutes, 30 minutes, 1 hour and 18 hours (outlet only). This was repeated four times for limestone treatment and three times for the mussel shell treatment. Water samples were sent to Hills Laboratories for chemical analysis. Previous analysis of acidic drainage at Bellvue indicated elevated levels of Al, Fe, Mn, Ni and Zn. These metals were therefore, chosen for analysis in this project. The pH level, electric conductivity and dissolved oxygen levels for each sample were measured using a YSI probe.

Results

Initially, dissolved metal concentrations rapidly decrease for both substrates compared to the inlet AMD (tables 1 and 2). The pH levels rapidly increase, allowing metals to precipitate. However, over time, improvements in water chemistry and quality decrease. This is likely a result of all the finer substrate material having already been consumed in early stages of diversion well operation, and only the larger grains remain, which take longer to break down and dissolve. Also, precipitated iron hydroxides start to coat the remaining substrate after 18 hours, reducing further dissolution.

The limestone shows greater decreases in dissolved metal concentrations and greater increases in pH levels compared to that of the mussel shells, indicating the limestone is a more favourable diversion well substrate (fig. 4, 5 and 5). Limestone is a much softer, brittle material than the shells. Therefore, it is likely easier to break up and dissolve in the system compared to the shells, resulting in more effective treatment.

Table 1. *Average dissolved metal concentrations for treatment using limestone*

Metal	Inlet AMD	Initial	15 min	30 min	1 hr	18 hr
Al	37	0.55	23.7	31.3	36	31
Fe	54.2	15	53	33.3	29.5	32.5
Mn	0.71	0.78	0.89	0.73	0.71	0.62
Ni	0.12	0.12	0.14	0.12	0.12	0.11
Zn	0.31	0.24	0.335	0.29	0.30	0.26

Table 2. *Average dissolved **metal concentrations for treatment using mussel shells***

Metal	Inlet AMD	Initial	15 min	30 min	1 hr	18 hr
Al	37	26.3	36.5	35	36.3	39.7
Fe	54.2	41.1	75.5	64.3	67.7	73.7
Mn	0.71	0.73	0.82	0.74	0.73	0.72
Ni	0.12	0.12	0.136	0.124	0.126	0.127
Zn	0.31	0.29	0.34	0.31	0.31	0.323

Table 3. *Average water **quality parameters for treatment using limestone***

	Inlet AMD	Initial	15 min	30 min	1 hr	18 hr
pH level	2.7	5.9	3.3	3.2	3.1	2.8
Sulphate (g/m3)	717.1	1008	800	685	697.7	600
DO (%)	42.3	52.8	55.1	45.9	41.9	58.2
EC (µs/cm)	1472	934	1047	911	889	1068

Table 4. *Average water **quality parameters for treatment using mussel shells***

	Inlet AMD	Initial	15 min	30 min	1 hr	18 hr
pH level	2.7	3.8	3.1	3.0	2.9	2.8
Sulphate (g/m3)	717.1	746.7	780	750	756.7	770
DO (%)	42.3	46.7	48.7	39.4	35.5	54.8
EC (µs/cm)	1472	1412	2030	1550	1603	1793

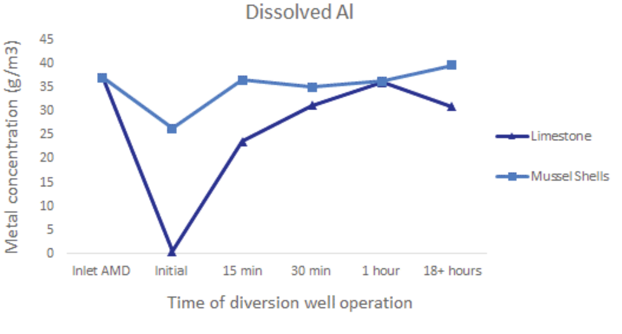

Figure 4 *Graph showing comparison of dissolved Al concentration for limestone and mussel shell treatment. Limestone shows greater decrease in concentrations, indicating it is more effective at treating AMD in a diversion well compared to the mussel shells.*

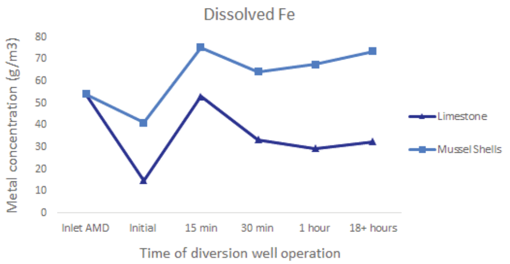

Figure 5 *Graph showing comparison of dissolved Fe concentration for limestone and mussel shell treatment.*

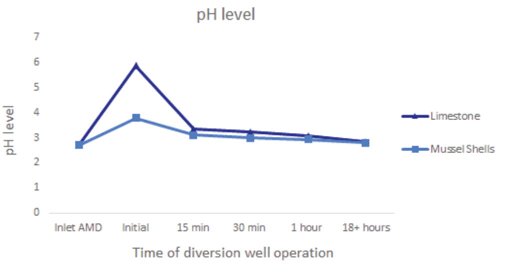

Figure 6 *Graph showing comparison of pH levels for limestone and mussel shell treatment.*

Conclusions

The efficiency of limestone as a diversion well substrate was compared to that of mussel shells in a diversion well setup at Bellvue Mine. Comparing the water chemistry and quality for treated waters showed that limestone is a more effective diversion well substrate. Greater decreases in dissolved metal contaminants and greater increases in pH levels were seen using the limestone substrate compared to the shells. This system set up was unable to achieve effective long-term function. Having a larger well and thus more substrate is necessary for future semi-passive treatment at Bellvue.

Acknowledgements

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