Use of small-scale passive systems for treatment of acid mine drainage

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Abstract

The general goal of passive acid mine drainage (AMD) treatment is to reduce levels of acidity and metals to acceptable levels. Most treatment systems use either an oxidizing or a reducing strategy. In oxidizing systems, alkalinity is added along with dissolved oxygen; in reducing systems, dissolved oxygen is removed (if present) and then alkalinity is added. It is recommended that small-scale field trials be conducted as part of the methodology of selecting the best remediation strategy at AMD sites. Following successful field trials at the Sullivan Mine AMD, the Pike River Coal Company (PRCC) has shown foresight by using the same system to treat AMD generated as a result of taking a bulk sample of coal at the Pike River coal field. The system reduced acidity by 100%, iron by 99%, aluminium by 96%, nickel by 95%, manganese by 51%, and zinc by 99%. The success of this field trial suggests that a system using a reducing strategy may be appropriate for the Pike River Adit AMD site.

Keywords: *acid mine drainage (AMD), acid rock drainage (ARD), Pike River, Sullivan Mine, passive systems, vertical flow wetlands, successive alkalinity producing systems (SAPS), water treatment.*

Introduction

Acid mine drainage (AMD) is an environmental problem that can be associated with coal mining in New Zealand (Alarcon, 1997; de Joux, 2003; James, 2003; Black et al., 2005, Trumm et al., 2005). AMD has been documented at both active and abandoned mines, both opencast and underground in various areas throughout New Zealand. However, most AMD occurs on the West Coast of the South Island, and it is estimated that 125 km of waterways are affected by AMD on the West Coast alone (James, 2003).

Research has been completed on the source, magnitude, and effects of AMD on the ecosystem in New Zealand (Lindsay et al., 2003; Bradley 2003; Brown et al., 2003; Hughes et al., 2004; Black et al., 2005), but few attempts have been made to remediate AMD in New Zealand. In this paper, we discuss strategies to treat AMD and present the results of a pilot treatment system at the Pike River Coal Field.

Remediation strategies

AMD is generated by oxidation of sulphides present in coal and surrounding lithologies, which results in the dominant contaminant, iron, being present in two oxidation states, ferrous iron (Fe^{2+}) and ferric iron (Fe^{3+}, Singer and Stumm, 1970; Caruccio et al., 1981). To remove iron from AMD, this oxidation process can be encouraged to continue so that all ferrous iron is oxidized to ferric iron, and once the pH has been increased sufficiently, iron is precipitated out of the AMD as ferric hydroxide ($Fe(OH)_3$). Alternatively, the process can be reversed, so that oxidized iron is reduced and precipitates as FeS_2 and FeS (Rose and Cravotta, 1998; Sexstone et al., 1999; Skousen et al., 2000). We refer to these two strategies as the oxidizing and reducing remediation strategies, respectively (Trumm et al., 2005).

During treatment by the oxidizing remediation strategy, alkalinity is added by limestone dissolution, and dissolved oxygen (DO) is added by aerating the AMD. Typical remedial systems that employ the oxidizing strategy are open limestone channels (OLCs) and diversion wells (Anonymous, 2001). During treatment by the reducing remediation strategy, DO is stripped from the AMD using a system that creates an anaerobic environment, and alkalinity is added by limestone dissolution. After pH is raised, any remaining iron not already removed as sulphides precipitate as metal hydroxides upon aeration. Typical remediation systems that employ a reducing strategy are anaerobic wetlands (Anonymous, 2001), vertical flow wetlands (VFWs; Zipper, 2001), and if the AMD is already low in DO, anoxic limestone drains (ALDs; Hedin and Watzlaf, 1994). Selection between oxidizing and reducing strategies is typically based on the water chemistry, flow rates, surface topography, and available land area.

Methods

Exploration in the Pike River Coal Field began in the 1940s when coal was discovered in the Pike River (Wellman, 1949). Exploration intensified in the 1980s and 1990s by the Pike River Coal Company and in the late 1980s a small adit was excavated into an outcrop of the coal in the Paparoa Range. Subsequently, a small stream of AMD began flowing out of the adit.

A small-scale VFW was constructed at the Pike River adit site using a plastic tub 1.3m long by 0.56m wide. Fifteen cm of limestone gravel at the base was covered by 13 cm of spent mushroom compost. AMD entered the system through a PVC pipe placed on top of the VFW and the flow rate was regulated with a valve. Treated water exited the system through a perforated PVC pipe buried in the limestone layer and connected to an external PVC pipe with the outlet near the level of the top of the tub. This method of discharge ensured that a sufficient head of water was always above the compost layer for the VFW to remain anaerobic.

The system operated for a period of 151 days. During the trial, DO, ferrous iron concentration, pH, conductivity, temperature and flow rate were measured on a monthly basis. Samples were collected from the untreated AMD and the outlet to the system on a monthly basis and laboratory-analyzed for acidity and dissolved iron, aluminium, manganese, nickel, calcium, and sulphate.

Results

Compared to the chemistry of the Sullivan Mine AMD, the Pike River Adit AMD contains much lower acidity, slightly higher pH, and most significantly, much lower aluminium (Table 1). It is possible that these differences are due to different source rock lithologies. At the Sullivan Mine, the source of the iron and sulphate in the AMD is mostly mudstones that form the roof lithology over a significant portion of the Mine and the aluminium is suspected as originating from feldspars within the sandstone units which are interbedded with the coal (Trumm et al., 2005). At the Pike River adit, the walls, floor and ceiling of the adit are still located within the coal. It is likely that the source of the AMD is from oxidation of sulphides within the coal and the AMD flows out of the adit without contacting surrounding lithologies which could be a source of other elements such as aluminium. The flow rate from the adit was relatively consistent at about 8 L/m throughout the trial.

Following the successful trial of the VFW at the Sullivan Mine, the Pike River Coal Company decided to treat the drainage from the Pike River adit using the same system. Results from the field trial show that the concentration of DO was lowered by the VFW and that the percent of

Table 1: Analytical results for water samples collected from Sullivan Mine AMD and the Pike River Adit AMD.

Parameter*	Sullivan Mine AMD	Pike River AMD
pH	2.9	3.2
Acidity (mg/L)	214	113
Dissolved oxygen (mg/L	10	9
Aluminium (mg/L)	14	1.6
Iron (mg/L)	47	34
Manganese (mg/L)	0.51	0.35
Nickel (mg/L)	0.13	0.12
Zinc (mg/L)	0.72	1.1
Percent of iron as Fe^{3+}	96%	93%

* - Analytical Methods
Acidity: Hot acidiy procedure, APHA 2310B (modified) 20th ed. 1998
Samples filtered using method APHA 3030B
Aluminium, Iron, Manganese, Nickel, Zinc: ICP-MS, APHA 3125B
Ferrous iron concentration: Portable Merck Photometer SQ 300

iron in the ferric state was less in treated water compared to the AMD, indicating that reducing conditions were present in the VFW (Fig. 1A, 1B). The pH in treated AMD remained neutral throughout the duration of the trial (Fig. 1C). Residence time of the AMD in the VFW averaged about 23 hours through the duration of the trial (Fig. 1D). Similar to the Sullivan Mine AMD trial, concentrations of iron and aluminium were significantly lowered by the VFW, and all contaminants, with the exception of manganese after two months, were removed (Fig. 2A, 2B, 2C). By day 58 the system was reducing the levels of acidity by 100%, iron by 99%, aluminium by 96%, nickel by 95%, manganese by 51%, and zinc by 99%.

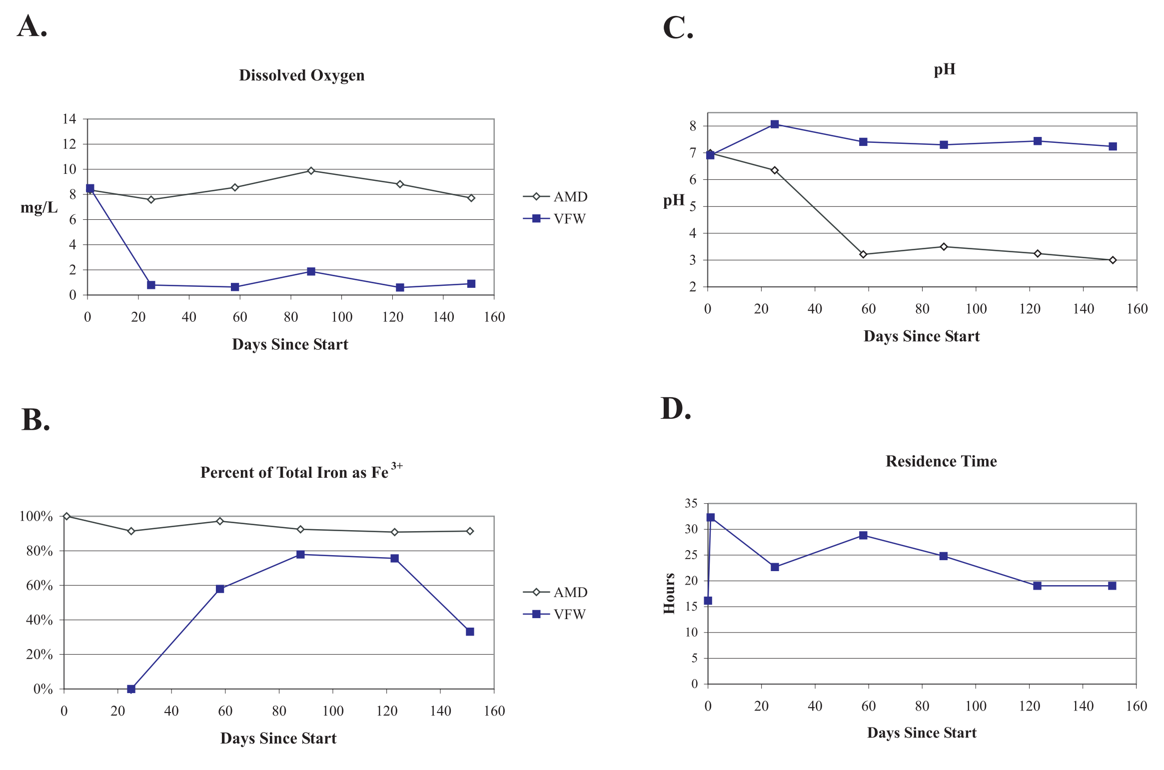

Figure 1. Field paramters measured from VFW at Pike River adit. (A) dissolved oxygen (B) percent of iron in ferric state (Fe3+) (C) pH (D) residence time.

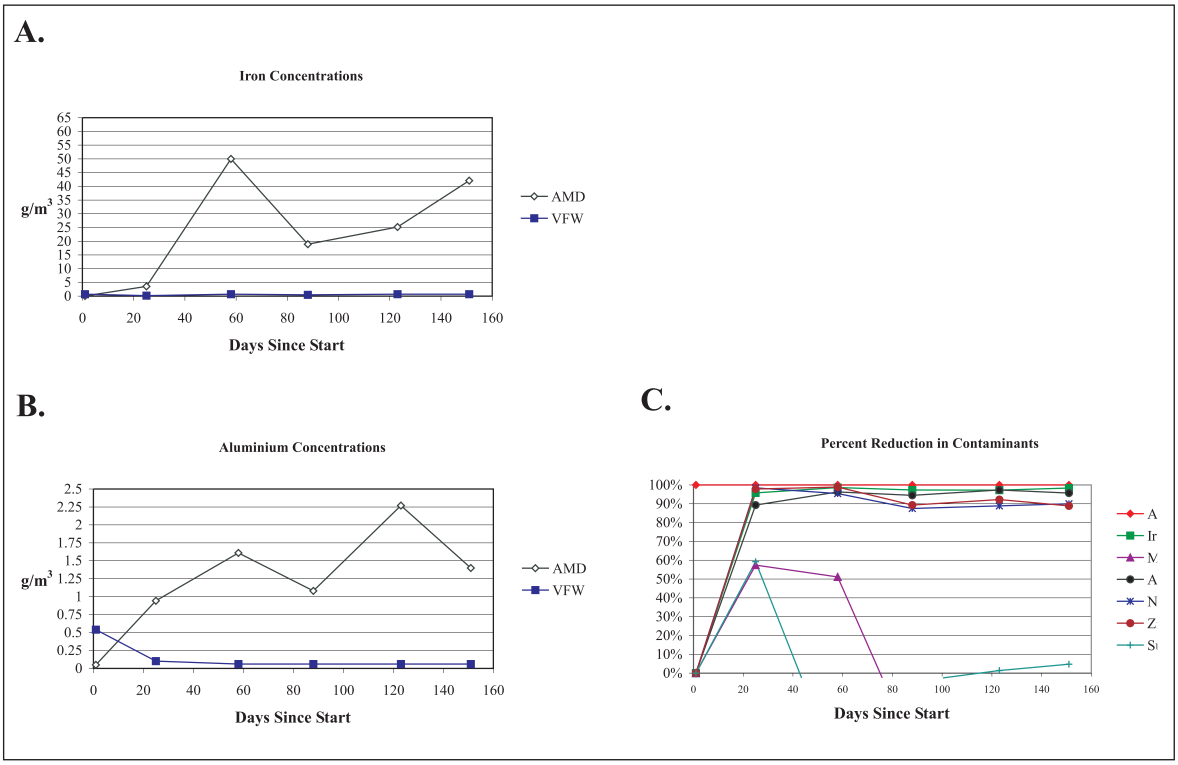

Figure 2. Analytical results from VFW at Pike River adit. (A) iron concentrations (B) aluminium concentrations (C) percent resultion of acidity and metal concentrations.

Discussion and conclusions

A VFW utilizing a reducing strategy was effective at restoring pH to neutrality and removing dissolved metals at the Pike River Adit AMD site. These results are comparable to the successful trials using a VFW at the Sullivan Mine AMD site (Trumm et al. 2003; Trumm et al. 2005), and to the successful laboratory experiment using a limestone-based treatment system to treat the Blackball Mine AMD (Trumm and Gordon, 2004).

Selection of large-scale passive AMD treatment systems should be based on AMD chemistry, flow rates, available land area, surface topography, and the results of small-scale field trials and laboratory experiments. For the Pike River Adit AMD, with the exception of very low levels of aluminium and lower acidity, the chemistry is similar to the Sullivan Mine AMD. The flow rate is very low (only 1/250th that of the Sullivan Mine AMD) and surface area in the vicinity of the AMD is limited, with only the floor of the adit and a small area outside suitable for any treatment system. Similar to the Sullivan Mine AMD, high DO levels suggest using an oxidizing strategy, however flow rates, available land area and a successful field trial suggest using a reducing strategy. The PRCC will install a full-scale treatment system at the Pike River Adit to treat any ongoing AMD at the site.

It is suggested that field trials should continue be used in New Zealand to test the effectiveness of different treatment strategies to reduce the level of contaminants at AMD sites. The results of these trials, in conjunction with an evaluation of AMD chemistry, flow rates, available land area, and surface topography will be useful when designing full-scale remediation systems.

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