The use of a passive treatment system for the mitigation of acid mine drainage at the Williams Brothers Mine (California): pilot-scale study

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ARTICLE INFO

ABSTRACT

A pilot-scale study was undertaken to assess the feasibility of using a passive treatment system to mitigate the acid mine drainage at the abandoned Williams Brothers Mine site, a remote site located in Sierra National Forest (California). The advantages of implementing passive treatment systems in remote or abandoned mine sites are their low energy and maintenance requirements compared to conventional systems. A pilot-scale system was designed and implemented at the site, which consisted of: (1) an aeration rock channel to facilitate oxidation of ferrous iron to ferric iron; (2) a sedimentation tank to collect iron oxyhydroxide precipitates that could lead to the clogging of the system; (3) a peat biofilter for the removal of dissolved iron and copper; (4) a sulphate-reducing bacteria reactor for the generation of alkalinity and consequent pH increase, and the removal of dissolved nickel, zinc, and residual dissolved iron and copper; and, (5) a re-aeration limestone channel to add alkalinity prior to effluent discharge into the natural receiving environment. The pilot-scale system was monitored over a 17-month period (500 days from July 2007 to November 2008) and performance was determined by monitoring the pH, sulphate and dissolved metal concentrations of the influent acid mine drainage and the effluents from the peat biofilter and sulphate reducing bacteria reactor. A decrease in sulphate concentration was noted in the sulphate reducing bacteria reactor, suggesting sulphate reducing bacteria activity and alkalinity generation. The effluent pH from the system increased from as low as 4.5 to above 6.0, but remained below water quality objectives for the San Joaquin River Basin. Dissolved copper, nickel and zinc removal to below water quality objectives was noted in the peat biofilter to below water quality objectives. Dissolved iron and manganese removal was also observed in the sulphate reducing bacteria reactor. The feasibility of employing this system as a sustainable low cost and low maintenance treatment alternative at the Williams Brothers abandoned mine site to ensure that drainage effluent will meet water quality objectives showed promise. However, long-term monitoring would be required to demonstrate and ensure their long-term effectiveness.

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1. Introduction

Passive treatment systems are considered to be low energy environmentally sustainable wastewater treatment systems. They have low operational and maintenance requirements, as well as demand very little technical expertise in their operation. Passive treatment systems utilize the chemical, biological and physical removal processes that often occur naturally in the environment to improve water quality (Ackil and Koldas, 2006). They are particularly well suited to drainage from mine waste such as tailings and waste rock at rural, remote, or at abandoned industrial sites, where the installation and maintenance of an active water treatment system would require access, disturb the local environment and be more costly. The drainage from sulfide-bearing mine waste is often acidic and high in sulphate due to the oxidation of iron sulfides such as pyrite (Cohen, 2006). The dissolved concentration of other elements such as zinc, copper and arsenic may be elevated if primary

minerals contained in tailings are leached (Lottermoser, 2010), in drainage ranging from acidic to circumneutral (Nordstrom, 2011). Acid mine drainage is potentially toxic to many species in the aquatic environment and is generally considered one the most environmentally damaging aspects of metal mining should untreated drainage be released (Cohen, 2006). Martins et al. (2010) reported on the production of circumneutral irrigation quality water resulting from the bioremediation of acid mine drainage (AMD) in a system consisting of a settler fed with AMD and treated water recycle and a sulphate reducing biological reactor fed with clarified settler effluent.

The feasibility of using passive treatment systems to mitigate AMD is dependent on the ability of a particular system to produce alkalinity, in order to increase the pH, as well as its ability to remove dissolved metals from solution (Kalin et al., 2006). A number of pilot-scale passive treatment systems have been implemented in order to test their performance under field conditions. In general, the design and performance of these systems have been noted to be variable in the generation of alkalinity and the removal of dissolved metals, specifically Fe and Mn. Many of the documented pilot-scale passive treatment systems include the use of sulphate reducing bacteria (SRB) reactors as part of their treatment configuration (Neculita et al., 2007). These systems have been reported to efficiently remove dissolved metals, such as Cd, Cu, Ni and Zn, from solution via the precipitation of metal sulphides (Clyde et al., 2010). In general, bacterial sulphate reduction conditions are established within the bioreactors with a labile organic matter source (e.g. spent mushroom compost) serving as a readily degradable source of carbon (Garcia et al., 2001). The formation of insoluble metal sulfides through biologically mediated reactions has been identified as the most significant metal removal mechanism. Alkalinity generation in SRB reactors can be attributed to both bacterial sulphate reduction and limestone dissolution (Neculita and Zagury, 2008). Other studies demonstrated that the addition of peat in passive treatment systems could enhance the removal of metals significantly due to the high sorption capacity of the peat substrate (Eger, 1994). However, the removal of Fe and Mn has been observed to be variable between systems depending on the temperature and metal loading to the system (Champagne et al., 2008).

Pilot-scale anaerobic reactor systems were developed to treat metal contaminated drainage in an underground coal mine by Dvorak et al. (1992) and Nairn and Mercer (2000), who noted the removal of Fe from a bioreactor system in the form of iron sulphides. In contrast, Zaluski et al. (2003) reported Fe removal for only the initial 8 months of their study and this removal was attributed to sorption reactions onto the organic substrate materials. After the sorption period, Fe concentrations in the effluent were higher than those of the influent AMD. This was considered to be a result of Fe^{3+} precipitates, such as Fe oxyhydroxides, which had formed prior to the bioreactor and had entered the bioreactor system in this oxidation state. As such, Fe^{3+} underwent reduction to Fe^{2+} and was released into the aqueous solution, increasing effluent concentrations. Similar observations were reported by Whitehead et al. (2005), where Fe oxyhydroxides from aerobic settling ponds prior to the SRB reactors were introducing Fe^{3+} into the bioreactor, and effluent Fe concentrations from the bioreactor were higher than those of the influent. The poor removal of Fe in these systems may be a result of a lack of SRB growth or more elevated concentrations of other metal ions. Jong and Parry (2003) noted that iron sulphide formation is dependent on the amount of hydrogen sulphide (H_2S) and other metal ions in solution. As other metals, such as Cu, Ni and Zn, form sulphides more favourably than Fe, a lack of H_2S in solution would result in a low iron sulphide formation, and consequently low amounts Fe removal. During the study by Zaluski et al. (2003), the total concentration of other

metals in solution were much higher than the concentration of Fe and were much higher than in the studies conducted by Dvorak et al. (1992) and Nairn and Mercer (2000). This would explain the low Fe removal as other metal sulphides precipitated more readily than Fe. In the study by Whitehead et al. (2005) the low Fe removal initially observed in their three systems was attributed to a low SRB growth. However, after a ten month shut-down period of one of the systems, the effluent Fe concentrations were below detection limits, while the other systems continued to have high effluent Fe concentrations. The increased removal of Fe after the shut-down period correlated with an increase in SRB populations.

Efficient Mn removal was noted in SRB reactors by Dvorak et al. (1992), Nairn and Mercer (2000), Champagne et al. (2005, 2008), while Zaluski et al. (2003), Whitehead et al. (2005) and Clyde et al. (2010) reported low removal of Mn. Zaluski et al. (2003) noted Mn removal only during the initial stages of their study, when Mn was sorbed onto the substrate material. Whitehead et al. (2005) and Clyde et al. (2010) observed low removals of Mn from SRB reactors over the entire course of their study. Jong and Parry (2003) reported that Mn removal via SRB reactors only occurs when the concentration of Mn is much greater than the total concentration of other metals in solution. This explanation was further corroborated by a study performed by Nairn and Mercer (2000), where removal of Mn in their system, which consisted of two SRB reactors followed by settling ponds, connected in series, occurred in the second SRB reactor, after the removal of Fe and other metals. These two studies may also provide some insights regarding the low Mn removal noted by Zaluski et al. (2003) and Whitehead et al. (2005). However, in the study by Dvorak et al. (1992) the removal of Mn was attributed to Mn carbonate formation rather than Mn sulphide precipitation, using geochemical modelling Martins et al. (2010).

In each of these studies, near-neutral pH values were reported, with the exception of a study by Whitehead et al. (2005), where each of the three systems tested had effluent pH values that rarely exceeded 5.5. However, after a shut-down period of one of the systems, the effluent pH from the SRB reactor of that system increased and was consistently between 6 and 7, while the effluent pH from the other two systems remained at approximately 5.5. This was attributed to an increase in SRB population in the bioreactor. The shut-down period of the one system appeared to have a conditioning effect on the bioreactor, allowing for increased SRB growth.

Another important passive treatment system that has been reported involved the application of a peat/limestone system to treat AMD (Eger et al., 1997). The system consisted of three ponds containing a peat substrate with limestone berms between the ponds. It was reported that the system was capable of increasing the pH of AMD to neutral values, while removing Cu and Ni from the influent AMD.

In order to investigate the applicability of using a passive treatment system at the Williams Brothers Mine site in California, bench-scale and pilot-scale studies were undertaken. Based on the results of the bench-scale system (Clyde et al., 2010), a pilot-scale passive treatment system was designed, implemented and monitored for a 16-month period at the Williams Brothers Mine site. The results of the investigation indicated that each system component tested at the bench-scale was capable of mitigating certain AMD constituents. The peat biofilter primarily retained Fe and Cu, while the SRB reactors removed Cu, Ni and Zn from solution. The SRB-ALD and SRB reactor systems were also efficient at increasing the pH to approximately 6.5 (SD 0.2). As such, a combination of these treatment systems was utilized for the pilot-scale passive treatment system at the Williams Brothers Mine.

The aim of the pilot-scale system investigation was to test the effectiveness and robustness of a passive treatment system in