Technical note

Development of a Linear Flow Channel Reactor for sulphur removal in acid mine wastewater treatment operations

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ABSTRACT

Where sulphate removal is targeted in the biological treatment of acid mine drainage wastewaters, a step additional to sulphate reduction is required to prevent the complete oxidation of sulphide back to sulphate. This linearisation of the biological sulphur cycle has presented a technological bottleneck, particularly in passive treatment operations. We report an investigation of sulphur production in floating sulphur biofilms as a means for addressing this problem. These 50 µm to 500 µm structures may be seen to form on the surface of sulphidic, organic waters and in which sulphide is partly oxidised to S_o and polysulphide. A Linear Flow Channel Reactor was developed in which the formation of the floating sulphur biofilm could be optimised and studied under controlled conditions. In this study the sulphide feed was sourced from a lignocellulose packed bed reactor treating a synthetic acid mine water (2 000 mg·ℓ$^{-1}$ Na_2SO_4 solution) and the Liner Flow Channel Reactors (surface area 1.1 m^2 and 2.2 m^2) were operated in a controlled environment chamber. The floating sulphur biofilm was harvested by settling to the bottom of the reactor where it remained largely unreacted until removed. It was shown that up to 88% of sulphide in the feed stream may be removed in this way and that this was achieved mainly by oxidation of sulphide to sulphur (including a polysulphide fraction). A mass balance accounting for the process showed that up to 66% of total sulphur species entering the system were recovered as S_o. Oxidation of sulphide to thiosulphate and sulphate was not found to be significant. A fraction of fine particulate sulphur is released into the stream on harvesting of the biofilm which does not readily settle in the reactor and may thus be lost to the mass balance account. The effects of temperature, loading rate and reactor surface area were investigated in optimising the performance of the reactor. Scale-up application studies in the use of the Linear Flow Channel Reactor in an acid mine drainage passive treatment environment have been undertaken in field studies.

Keywords: floating sulphur biofilms, acid mine drainage, AMD passive treatment, linear flow channel reactor, sulphur biotechnology

INTRODUCTION

Environmental impacts of acid mine drainage (AMD) on public water systems may be widespread and South Africa presents a paradigm case where, following over a century of intensive gold and coal mining operations, water-scarce Witwatersrand and Mpumalanga areas are now under threat (McCarthy, 2011). Both large-volume and diffuse flows require treatment and biological processes offer potential advantages of low cost and low operational input requirements, particularly where applied in passive treatment operations (Molwantwa et al., 2009). The long-term nature of the problem also needs to be considered and, with certain Roman mine workings in Britain and Europe reportedly still actively generating AMD some 2000 years later (Field, 2003), the extended time frames over which the problem will require treatment needs to be taken into account. The sustainability of treatment operations over the long time periods anticipated also favours biological process options (Rose, 2005).

Biological treatment involves the manipulation of the biological sulphur cycle at one or more of its stages of operation, with the reduction of sulphate to sulphide by sulphate-reducing prokaryote (SRP) populations and providing the first unit operation in the process. Apart from neutralisation and metal removal functions, which may be effected at this stage, it is also necessary to remove sulphur from the stream in one of its reduced forms in order to prevent its complete oxidation back to sulphate. However, linearisation of the biological sulphur cycle has presented a technology bottleneck, particularly in the development of passive treatment operations, and a variety of processes have been considered for the effective removal of sulphur (Molwantwa et al., 2009).

Here we report a bioprocess development study on sulphur removal from AMD which is based on its formation in floating sulphur biofilms (FSB). These structures, which are 50 µm to 500 µm thick, form on the surface of sulphidic, organic waters (Fig. 1A), and our initial observation and investigation of FSB structures were reported for tannery wastewater evaporation ponds (Rose et al., 1996; Dunn, 1998). FSB have been shown to be true biofilms in both structural and functional features (Gilfillan 2000; Rein 2002; Bowker, 2002; Rose et al., 2002; Molwantwa et al., 2007). Molwantwa (2008) demonstrated the presence of well-differentiated aerobic, anoxic and anaerobic functional zones within these biofilms in which redox conditions are poised over a narrow range around –150 mV and thereby enable sulphur formation in the polysulphide and orthorhombic S_o forms (Fig. 2). Where conditions are maintained that allow the biofilm to thicken, it will finally break away from the surface and settle at the bottom of a reactor vessel, where it remains largely unreacted until removed.

Preliminary studies on the use of the FSB system for sulphur removal in Integrated Managed Passive Treatment

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