PPLICATION OF THE LINEAR FLOW CHANNEL REACTOR (LFCR) FOR THE REMOVAL OF SULPHIDE FROM SEMI-TREATED ACID MINE DRAINAGE (AMD)

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ABSTRACT

Biological treatment of mine waters has been the subject of increasing interest, especially in the provision of technological options that are sustainable over the long-term. These, however, are the subject of a number of constraints including, importantly, the capability to remove reduced sulphates from the treated stream and thus linearize the removal of sulphur compounds from the system. The removal of sulphide from acid mine drainage (AMD) treated effluent particularly in passive treatment has been a subject of interest at Golder Associates Africa (GAA). The results of these studies indicated that biological sulphide oxidation has potential for the removal of sulphide from passive AMD treatment systems (Molwantwa *et al.*, 2007) such as integrated managed passive (IMPI) treatment systems. As an output of these studies, the linear flow channel reactor (LFCR) was developed and operated under controlled conditions.

In the LFCR, the oxidation of sulphide to elemental sulphur is achieved *via* the application of a sulphide oxidizing prokaryote (SOP) consortium in the form of a floating biofilm. The reactor will be operated in such a way that oxidation back to sulphate is limited and near-complete removal of sulphide from the feed water is achieved. The LFCR reactor consists of a channel separated into compartments by under/over baffles which serve to retain the sulphur biofilm within each compartment. This enables sequential harvesting of different compartments while biofilm growth and sulphur recovery continues in the others. The reactor is operated such that the final compartment is clean and free of a sulphur biofilm, thereby ensuring that all recoverable sulphide has been oxidised to sulphur. Channel compartments will be harvested one at a time so that there are always sufficient sections of the reactor that have an active oxidising biofilm to remove the sulphide.

Laboratory scale results have indicated that the LFCR removed 65% of the influent sulphide, 56% of which was subsequently recovered as sulphur (Molwantwa, 2008). A pilot scale LFCR for removal of sulphide from the passive IMPI treatment system has been included as part of the demonstration passive plant built at BHP Billiton Energy Coal South Africa's Middelburg mine. This paper will discuss the application of the LFCR as a pilot scale component of an IMPI treatment process.

1. INTRODUCTION

Passive mine water treatment systems "rely on the use of naturally available energy sources such as microbial metabolic energy, photosynthesis, chemical energy and natural topographical gradients to regulate flow and require regular but infrequent maintenance" (Pulles *et al.*, 2004). This implies that a means of treating mine drainage should be developed that is self-sustaining over the long term and only requires infrequent but regular maintenance for optimal operation.

It is generally accpeted that mining will generate polluted drainage which is considered a long-term problem that will not be resolved easily. Thus the search for a method for effective and sustainable treatment is ongoing. The characteristics of mine drainage differ from case to case, however in the South African coal mining industry the greatest issue is high sulphate loads generated as a result of the chemical and biological oxidation of sulphides (pyrite and other) associated with the coal. Sulphur cycle bacteria have long been considered an effective low-cost solution for sulphate removal from contaminated mine drainage since sulphate reducing prokaryotes in particular, are able to reduce sulphate load, neutralize pH and reduce metal loads. One of the consequences of sulphate reduction is the production of a sulphide-rich effluent. This sulphide can be re-oxidised to sulphate via biological and chemical pathways, thus reversing the removal. To ensure sulphide oxidation is prevented, the effluent must undergo further treatment in order to linearize the sulphur cycle and effectively remove sulphur compounds from the water.

BHP Billiton Energy Coal South Africa's Middelburg Mine in Mpumalanga, South Africa has commissioned the construction of a passive water treatment demonstration scale plant capable of treating the sulphate-rich waters generated as a result of their coal mining activities (Figure 1). This plant combines the patented degrading packed bed reactor technology for sulphate reduction with an experimental unit capable of oxidizing sulphide to elemental sulphur, the linear flow channel reactor (LFCR).

The development of the LFCR is the result of a number of years of research into sulphide oxidation from semi-treated mine drainage. The initial studies were carried out jointly between Golder Associates Africa (GAA) and the Environmental Biotechnology Research Unit (EBRU) at Rhodes University as part of an passive treatment project sponsored by the Innovation Fund. The results of these studies indicated that biological sulphide oxidation had potential for the removal of sulphide in passive AMD treatment systems (Molwantwa, 2008) such as the integrated managed passive (IMPI) treatment system (Pulles *et al*., 2003). This resulted in the award of Water Research Commission (WRC) funding during 2002 for the development and refinement of the floating sulphur biofilm reactor (Molwantwa *et al*., 2004). Subsequently, a three year project funded by the WRC was carried out at EBRU with GAA forming part of the steering committee. This study focused on fundamental investigations of the molecular microbial ecology and structural, functional as well as chemical characteristics of the floating sulphur biofilm reactor under a controlled environment (Molwantwa, 2008). Results of this study have accounted for 65% sulphide removal, 56% of which was recovered as elemental sulphur.

2. MIDDELBURG MINE PASSIVE WATER TREATMENT PILOT PLANT

The plant is based on the IMPI system concept, the core of which is the degrading packed bed reactor (DPBR). This unit has been built at full operational scale and can treat 200 m^3/day. The core function of the DPBR is the reduction of sulphate to sulphide. This is achieved through the cultivation of a consortium of sulphate-reducing prokaryotes (SRP) within an anaerobic environment. The redox conditions created within this anaerobic environment enable the SRP to utilize the lignocellulose packing material as a carbon source, while using the sulphate as a terminal electron acceptor in cellular respiration. The final effluent from such a reactor would have an increased pH and elevated sulphide levels.

The function of the linear flow channel reactor (LFCR) is to remove sulphides from the DPBR effluent in the form of elemental sulphur, thereby linearizing the sulphur cycle and enabling almost complete removal of sulphur compounds from the water. This removal is achieved through the activity of sulphide oxidising prokaryotes, which form a biofilm on the surface of the sulphide-rich water. This unit, and all of those downstream of it, have been built at an experimental scale only, and are capable of treating a 20 m^3/day stream which is diverted from the DPBR. The remaining effluent emanating from the DPBR is returned to the return water dam.

The effluent from the LFCR is then passed through a series of downstream treatment steps. The first is a secondary sulphate reducing reactor (SSRR), similar in operation to the DPBR. The SSRR will remove any sulphate resulting from the reoxidation of sulphide, and any residual volatile fatty acids originaring from the DPBR will also be consumed. The second step in the polishing process is an oxidation cascade. Some chemical sulphide oxidation may take place in this step due to the presence of high oxygen levels. However, the main function of the oxidation cascade is for manganese, ammonia and residual chemical oxygen demand (COD) removal. The final polishing step is an aerobic wetland which will serve as a final sink for COD and nutrients.

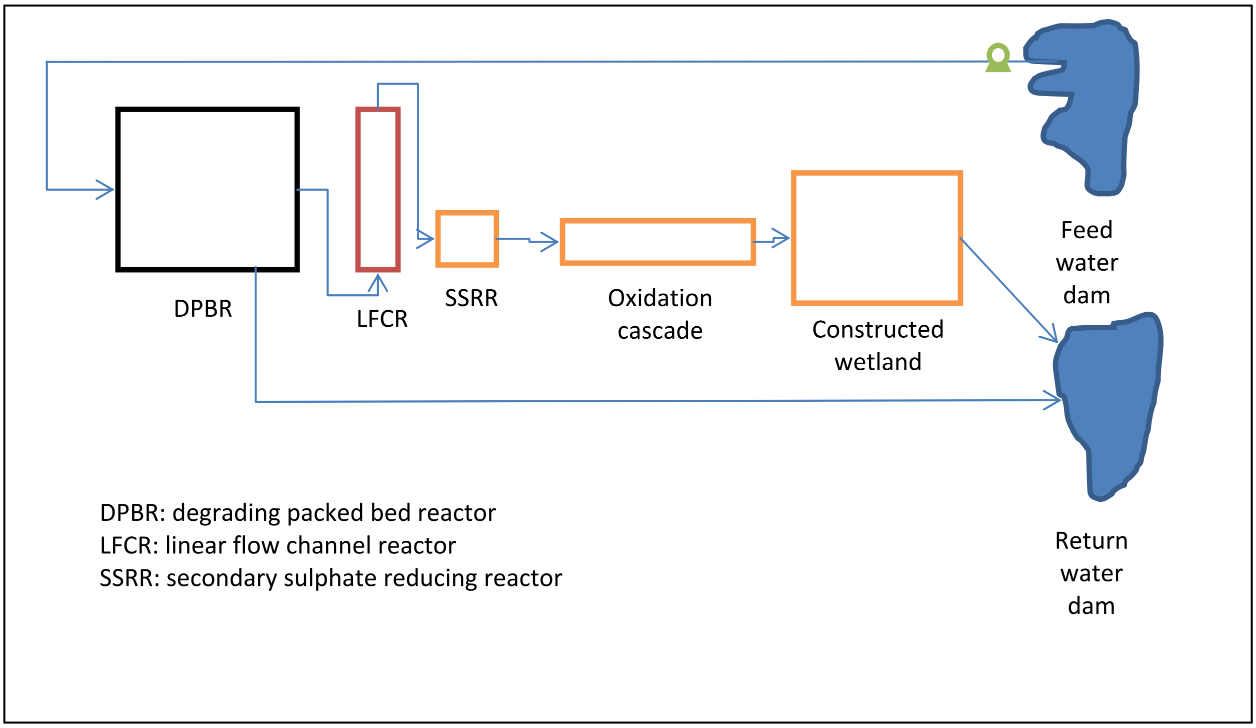

Figure 1. Simplified schematic of the Middleburg Mine IMPI water treatment plant.

The water quality of the feed water dam along with the predicted quality at key points in the process is indicated in Table 1.

Table 1. Feed water quality and predicted water quality at key process points.

Parameter	Unit	Feed water dam	DPBR out	BSOR out	SSRR out
Total Alkalinity	mg/l	110	500	700	1000
pH	-	7.7	8	8.4	8.5
SO_4	mg/l	1978	1000	1200	400
S^{2-}	mg/l	-	300	40	250
COD	mg/l	-	600	400	400
NH_3	mg/l	0.8	20	20	30

3. THE LINEAR FLOW CHANNEL REACTOR

Sulphide Oxidation Microbiology

Under anaerobic conditions sulphur compounds such as sulphate, sulphite and organic sulphur compounds present in wastewater are reduced by bacterial activity to sulphide. The biological oxidation of sulphide with oxygen is significantly faster than the chemical non-catalyzed oxidation of sulphide with oxygen (Buisman *et al*., 1989), making a biologically mediated oxidation process particularly attractive. Autotrophic bacteria are capable of oxidizing sulphide at high rates, which has lead to the development of biotechnological processes for sulphide removal from effluent streams. Of particular advantage from an environmental perspective is the recovery of sulphur, thereby preventing eutrophication of receiving waters through the discharge of sulphate-containing wastewaters. The advantages of a such a biotechnological process include low sludge production (both biological and chemical), low energy consumption, absence of a catalyst/oxidant other than air, low sulphate discharge, and the possibility of producing sulphur of a quality that can be reused (Buisman *et al*., 1989).

Microbial processes operate at ambient temperatures and at atmospheric pressure, thus eliminating the costs involved in heat and pressure generation, such as those for chemical treatment processes. The LFCR makes use of sulphide oxidizing prokaryotes capable of converting sulphide to elemental sulphur.

The functionality of the LFCR is based on the cultivation of a biofilm comprising sulphide oxidising prokaryotes at the air/water interface. An integrated descriptive model for the various processes that occur within the biofilm is illustrated in Figure 2 (Molwantwa, 2008). These processes occur against decreasing O_2 and redox potential gradients and sulphide migrating upwards into the biofilm. Aerobic heterotrophic bacteria establish at the air/liquid interface and, in consuming oxygen diffusing into the strongly anaerobic system, establish steep dissolved oxygen and redox gradients at the surface. Below this layer, extracellular polysaccharide producers generate a copious slime layer, which constitutes the matrix of the biofilm. Within the correctly poised redox window, both biological (black dots) and inorganic (yellow diamonds) sulphur formation occurs and gives rise to large sulphur granules which characterize the biofilm.

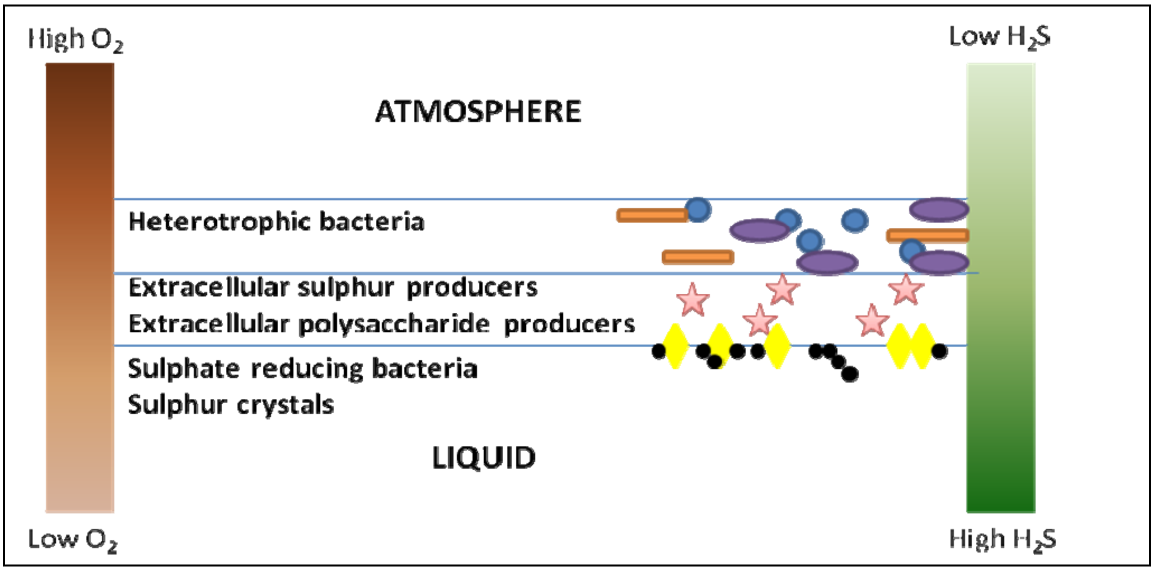

Figure 2. A descriptive model integrating the processes occurring within the SOP biofilm during sulphide oxidation (Molwantwa, 2008).

Sulphide Oxidation Application

A schematic of the pilot-scale LFCR is shown in Figure 3. The reactor consists of eight parallel channels that operate as individual LFCRs. Each channel is further divided into eight compartments by a series of under/over baffles (blue dashed lines). These baffles retain the biofilm within each compartment, which allows for harvesting of individual compartments while allowing biofilm growth and sulphur conversion to continue in the others. The reactor is operated in such a way that the final compartment is clean and free of a sulphur biofilm, thereby ensuring that all recoverable sulphide has been oxidised to sulphur. The biofilm is harvested by briefly spraying the water surface with a fine spray. This is achieved by means of fine fog or mist spray nozzles suspended over the individual channels from wire supports. The spray must break the surface tension enough to drop the accumulated sulphur, without destroying the biofilm. Channel compartments will be harvested one at a time so that there are always sufficient sections of the reactor that have an active oxidising biofilm to ensure sulphide removal continues.

A degree of flexibility has been designed into the LFCR so that the results of experiments completed at a laboratory scale can be implemented at pilot scale. Parameters that can be modified to optimise the system include water level depth, flow rate and harvesting methodology such as duration of harvest and extent of inter-harvest period.

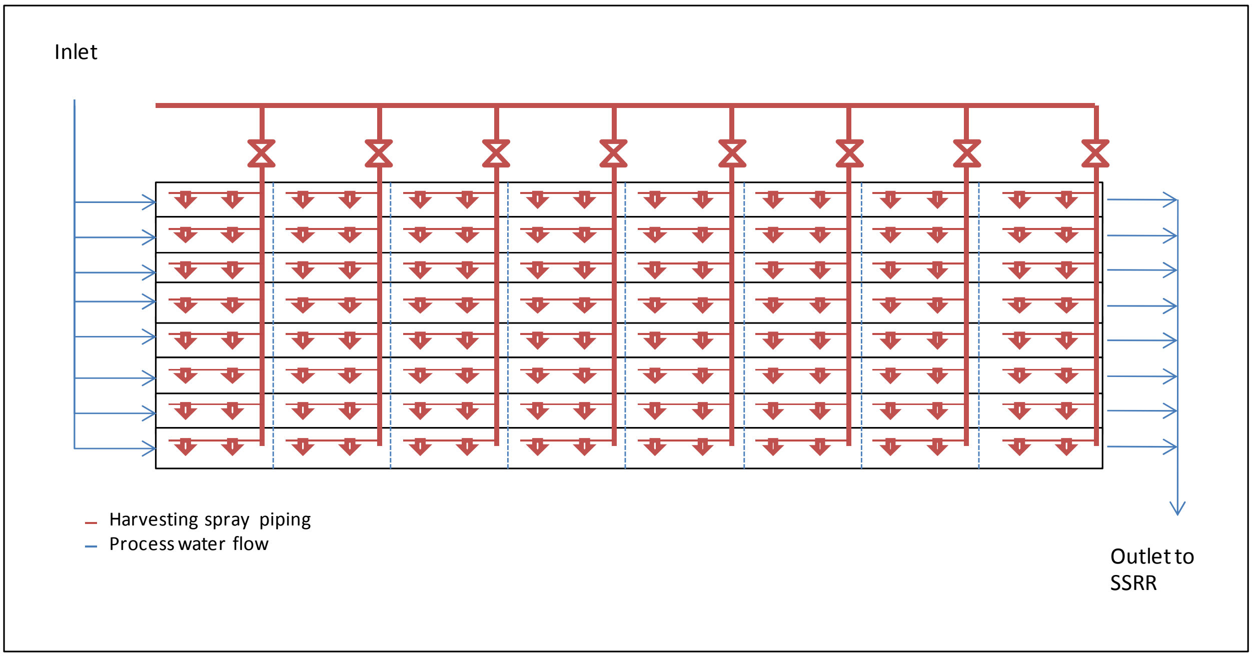

Figure 3. Schematic representation of the linear flow channel reactor (LFCR).

4. ANTICIPATED OUTCOMES

Construction of the plant was completed in early July 2009, and the commissioning phase began in late July. For the duration of the plant operation (commissioning phase included), the plant will be sampled every two weeks. As with all bioreactors, it is anticipated that the DPBR will require at least three full retention times before steady-state operation can be expected. Thus collection of steady-state results is expected to begin towards the end of September 2009. At this stage, reliable results will begin to be generated by the LFCR and the other units downstream of the LFCR.

A second project funded by the Water Research Commission is closely aligned to the development of the LFCR. This project involves the experimental manipulation of a laboratory-scale LFCR, specifically to develop the operational guidelines for a larger-scale unit such as the one included in the passive treatment plant. Operating parameters that can be adjusted on the laboratory-scale LFRC include water depth and flow rate, and the harvesting apparatus (including spray strength, spray duration and inter-harvest period). Preliminary observations indicate the development of the sulphide oxidizing biofilm in the form of elemental sulphur particles although this is subject to confirmation by chemical analysis.

5. REFERENCES

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