Development of the floating sulphur biofilm reactor for sulphide oxidation in biological water treatment systems

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Abstract

The formation of floating sulphur biofilm was observed in the microbial ecology studies of tannery ponds undertaken by the Environmental Biotechnology Group at Rhodes University. This was related to the steep Redox gradients established at the air/water interface of anaerobic, organically loaded and actively sulphate reducing systems. This study investigated the potential for applying these observations in developing a floating sulphur biofilm reactor for the removal of sulphide from sulphide-rich effluents produced in wastewater treatment systems. This was carried out in five sequential experimental phases. Where original studies had been undertaken using sulphide-rich water derived from sewage sludge as the carbon source, the successful establishment of a floating sulphur biofilm from effluent of lignocellulose-derived wastewaters had been shown.

The effect of influent sulphide concentrations, flow rate and reactor dimensions on the sulphur biofilm formation were investigated for the optimisation of elemental sulphur recovery and sulphide removal efficiency. Polysulphide formation was enhanced by inserting a silicone tube rack and resulted in increased elemental sulphur recovery. Sulphide removal efficiency of 65% and a sulphur recovery of 85% were obtained at the end of the investigation while inter-harvest recovery period of the biofilm was reduced from an initial 4-5 days to 6-12 hours.

Introduction

Biological sulphur cycle in the treatment of high sulphate wastewaters relies on the activity of sulphate reducing bacteria (SRB), which, in the presence of organic compounds such as carbon and an electron donor source, will reduce the sulphate to sulphide (Jorgensen, 1982; Gilfillan, 2000; Bowker, 2002; Rein, 2002; Pulles Howard and de Lange Inc., 2002; Molwantwa et al., 2003; Dunn, 1998; Rose, 2002). However, sulphide is a toxic by-product, which can be removed from the treated wastewater either as a metal sulphide or in its oxidised form as elemental sulphur removed as a suspended solid.

Biological oxidation of sulphide in natural environments has been noted without the chemical parameters and bacterial populations present in these natural systems being well documented (Jorgensen, 1982; Gilfillan, 2000; Bowker, 2002). Although the formation of elemental sulphur in floating sulphur biofilm which form under various conditions in nature has been noted, little work has been carried out on the potential biotechnological applications of such systems (Gilfillan, 2000; Bowker, 2002; Rein, 2002). The development of a reliable technology for sulphur recovery under heterotrophic conditions would increase the choice of possible carbon sources and especially waste carbon sources for biotechnological sulphate reduction (Rein, 2002; Rose, 2002). A process that can produce large amounts of elemental sulphur from sulphide under heterotrophic conditions would contribute significantly to the development of an integrated biological sulphate removal process to treat the large volumes of AMD that are predicted to occur in South Africa (Pulles Howard and de Lange Inc., 2002; Molwantwa et al., 2003; Rose, 2002).

In an attempt to develop a biotechnological sulphide oxidising process, the Environmental Biotechnology Group (EBG) studied the chemical parameters of abiotic and biotic sulphide classical flask experiments (Bowker, 2002; Rein, 2002). The results of these studies suggested that the presence of an organic carbon source and a heterotrophic bacterial population were able to decrease oxygen concentrations thereby favouring biological sulphide oxidation and the subsequent formation of elemental sulphur a product (Bowker, 2002; Rein, 2002). Results of these studies also suggested that the overall oxygen supply rate was a key parameter in determining the major product of microbial sulphide oxidation under heterotrophic conditions (Rein, 2002). After the observation of a sulphur biofilm forming on the surface of tannery ponds in Wellington (Dunn, 1998), further research was done on the fundamental microbiology and structure of the sulphur biofilm (Gilfillan, 2000; Bowker, 2002).

A major fundamental research effort on biological sulphide oxidation mechanisms and processes has been undertaken by the EBG with input from Pulles Howard and de Lange Inc. (PHD). This project was funded by the Department of Arts Culture Science and Technology (DACST), and has resulted in the development of a basic sulphide oxidation technology that would serve to remove sulphides formed during the biological reduction of sulphate from wastewater (Rein, 2002; Pulles Howard and de Lange Inc., 2002). A sulphide oxidising bioreactor (SOBR) was developed for the operation of the process.

Objectives

The objectives of the project were:

- Evaluate and refine a previously developed sulphide oxidation process that can be incorporated into both passive and active sulphate removal technologies.

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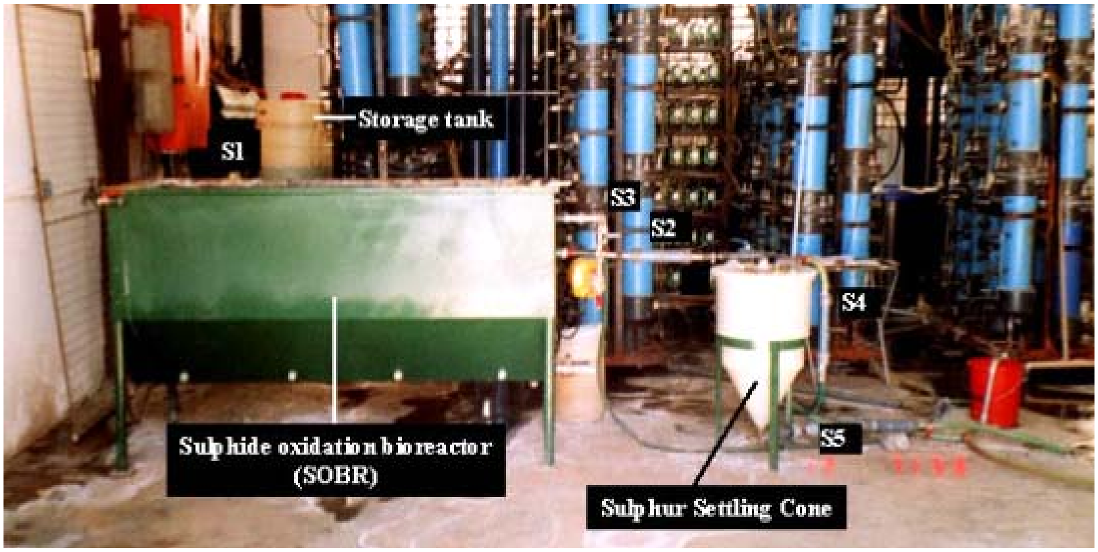

Figure 1
Sulphide oxidation biofilm reactor as initially set up in the laboratory showing sampling ports S1 to S5

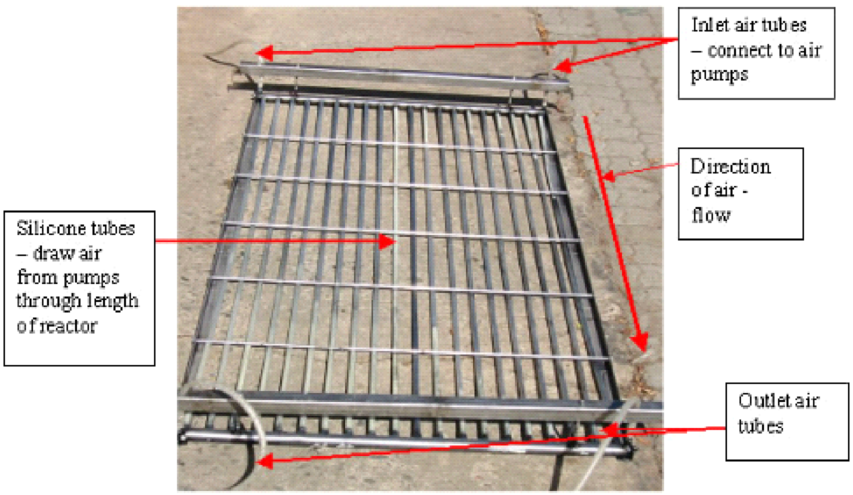

Figure 2
Silicone tube rack fitted to enhance polysulphide formation in the reactor

- Develop operational guidelines for such a process for both passive and active applications.

Methodology

Reactor development

Based on the objectives, five sequential experimental phases were formulated to investigate the potential of the SOBR system and its development as an independent bioprocess, which may be incorporated as a unit operation in the Rhodes BioSURE Process® and Integrated Managed PassIve (IMPI) treatment systems for biodesalination treatment of acid mine drainage (AMD) wastewaters.

Sampling and analyses

Three sets of samples were collected at each sampling point for analysis and the results are presented as the mean of triplicate samples. The analyses carried out were sulphide (*Standard Methods*,1998), sulphate (*Standard Methods*,1998), sulphur (Mockel, 1984), alkalinity (*Standard Methods*,1998), chemical oxygen demand (COD) (*Standard Methods*,1998), redox potential and pH.

Figure 3
Automated SOBR

Experimental protocol

A 1 m^3 SOBR was constructed in Grahamstown and was commissioned at the PHD laboratories in Johannesburg (Fig. 1).

Initially, the reactor was fed with effluent from a lignocellulose-fed Passive Systems experiment but it proved necessary to establish a separate dedicated sulphide production unit.

Previous studies (Rein, 2002) had shown that the formation of polysulphide in the presence of sulphur particles produced by sulphide oxidising bacteria such as *Thiobacillus* and *Ectothiorhodosprira* spp. was a rate-limiting step in the production of elemental sulphur (Bowker, 2002; Rein, 2002). It had been shown that biofilms containing these organisms could be successfully estab-

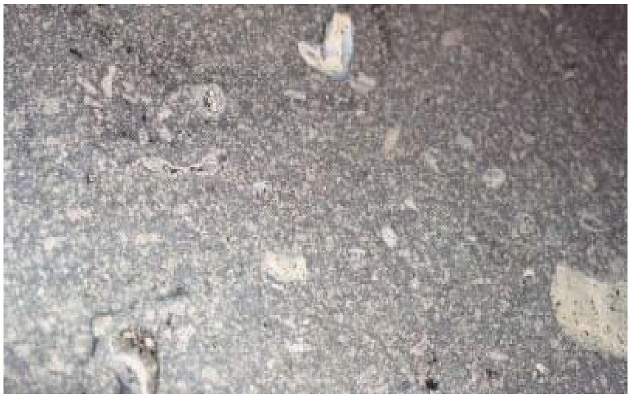

Figure 4
Speckled incomplete biofilm form

Figure 5
Complete flexible biofilm form

Figure 6
Complete brittle biofilm form

lished on air-fed silicone tubes. A silicone tube rack (Fig. 2), was constructed and inserted 20-30 mm below the water surface. Air was pumped through the silicone tubes in order to allow oxygen diffusion into the SOBR.

Harversting procedures were automated by installing EL-O Matic actuator valves to the Harvest and Effluent Ports (Fig. 3). This enabled accurate control of the harvesting process and also the length of the sulphur biofilm recovery period. Once steady state conditions had been established, a sulphur species mass balance was derived.

Results and discussion

After a period of adaptation, the biofilm formed successfully.

There were variances in biofilm form which are important for operating the system:
- Speckled and incomplete biofilm (Fig. 4)
- Complete flexible (Fig. 5)
- Complete brittle biofilm (Fig. 6).

Which, have important implications for sulphide oxidation and sulphur harvesting.

After fully optimising the system the following was established:
- Percentage sulphide removal 65%
- Percentage sulphur recovery 85%.

Conclusions

- Observations of sulphur biofilm formation were successfully duplicated in these studies.
- It was shown that sulphide generated in lignocellulose-based AMD treatment technologies such as the Rhodes BioSURE® process and IMPI can be successfully removed from these wastewater streams in the form of elemental sulphur.
- Further studies on the mechanisms of biofilm formation and scale-up of the SOBR are currently underway.

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References

BOWKER ML (2002) The Biology and Molecular Ecology of Floating Sulphur Biofilms. M.Sc. Thesis, Rhodes University.

DUNN K (1998) The Biotechnology of High Rate Algal Ponding Systems in the Treatment of Saline Tannery Wastewaters. Ph.D. Thesis, Rhodes University.

GILFILLAN J (2000) The Structure and Microbiology of Floating Sulphide-oxidising Biofilms. M.Sc. Thesis, Rhodes University.

JORGENSEN BB (1982) Ecology of the bacteria of the sulphur cycle with special reference to anoxic-oxic interface environments. *Philosophical Transcripts of the Royal Society of London* **298** 543-561.

MOCKEL HJ (1984) Retention of sulphur and sulphur organics in reversed phase liquid chromatography. *Journal of Chromatography*. **317** 589-614.

MOLWANTWA JB, ROSE PD, COETSER SE, HEATH R and PULLES W (2003), Development of the Floating Sulphur Biofilm Reactor for Sulphide oxidation in biological mine water treatment systems. Interim report to the Water Research Commission. Project K5/1349.

PULLES HOWARD AND DE LANGE INC. (2002) Development of Low-Maintenance Self-Sustaining Biological (Passive) Systems for the Treatment of Contaminated Mine and Industrial Effluents. Final report to the DACST Innovation Fund, Project 32130.

REIN NB (2002) Biological Sulphide Oxidation in Heterotrophic Environments. M.Sc. Thesis, Rhodes University.

ROSE PD (2002) Salinity, Sanitation and Sustainability: A study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa. Water Research Commission Report K5/1078.

STANDARD METHODS (1998) *Standard Methods for the Examination of Water and Wastewater* (20th edn.). APHA.