An Evaluation of Sugarcane Bagasse as a Feedstock in a Biological Treatment System for Mine Affected Waters

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Abstract

A passive biological treatment system for sulfate-rich Acid Rock Drainage has been investigated, focussing on using waste biomass such as grass cuttings and sugarcane bagasse to raise the water pH and supply organic carbon as a food source for bioremediation of sulfate by Sulfate Reducing Bacteria. The objectives of this study are to assess the pH change and soluble organics released on contact between sugarcane bagasse and ARD, and if the model treatment process can run only on waste biomass.

Keywords: Sulfate Reducing Bacteria, Bioremediation, Linear flow channel reactor

Introduction

The oxidation of sulfide minerals that occurs during the generation of Acid Rock Drainage (ARD) releases sulfate and the salinity of receiving water systems is often increased. Mine discharge from the Witwatersrand region of South Africa was found to account for 20 % of the salts in the Vaal River, despite effluent water only making up 5% of the total volume of the river system (Durand 2012).

The reduction of sulfite salinity is a priority in a water stressed country like South Africa, where dilution is not a viable option. Traditional active processes are often not feasible for low volume discharges associated with coal mining. Passive treatment options involving biological systems have been developed to remediate acid rock drainage in a less expensive and resource intensive way (Johnson and Hallberg 2005; van Hille and Mooruth 2011).

Sulfate reducing bacteria (SRB) are a group of micro-organisms often found in anaerobic sediments of rivers and dams, and around the root systems of plants found in sulfate-rich environments (Muyzer and Stams 2008). Sulfate reducing bacteria may be assimilatory or dissimilatory, oxidizing organic carbon sources such as volatile fatty acids or sugars, and reducing sulfate at the end of their electron transport chain to sulfide (Muyzer and Stams 2008). When this occurs there is a simultaneous generation of alkalinity, increasing the pH of the system (Harrison et al. 2014).

Sulfide is toxic and has an unpleasant odor so management is important for SRB systems remediation. Biologically catalyzed partial oxidation to elemental sulfur has been identified as a potential way to deal with excess sulfide. The linear flow channel reactor has been used to study the kinetics of simultaneous liquid phase sulfate reduction and partial sulfide oxidation in a biofilm layer, demonstrating the concept while supplementing the feed with acetate or molasses to act as a source of organic carbon (van Hille and Mooruth 2011, Harrison et al. 2014).

Preliminary research suggests that replenishable source of biomass can be broken down by contact with the ARD to supply organic carbon for the downstream biological remediation processes (Ramla and Sheridan 2012). Waste biomass such as grass cuttings, domestic waste and agricultural by-products near to the ARD source are of interest to these studies for economic reasons.

The objective of this work is to initial evaluation sugarcane bagasse, which is the dry, fibrous by-product of sugarcane processing, as a carbon sources for a model bioremediation process based on sulfate reduction and partial oxidation in the context of previous study of this process.Methods

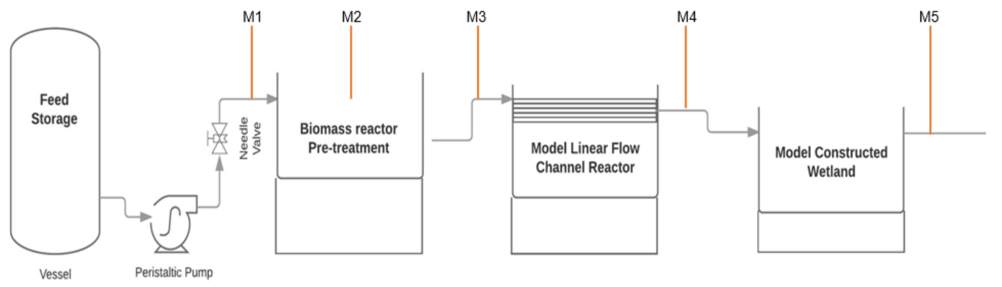

Figure 1 *Layout of the model continuous system with liquid sampling points indicated (M1 to M5)*

The bagasse used in this work was obtained from Illovo Sugar in Eston, South Africa. The ARD used was sourced from active coal mines in the Mpumalanga region of South Africa, and as such varies with time. The typical levels of some components are pH 2.70-2.90, 1800-2400 mg/L Sulfate, 800-1000 mg/L Iron, 200-300 mg/L Magnesium and 300-400 mg/L Manganese.

Batch Experiments

To investigate the effect of bagasse on ARD pH, 15g and 25g of dry bagasse was added to stirred batch vessels initiated with diluted sulfuric acid and coal mine ARD as recorded in Table 1. The objective of this experiment was to measure the pH rise in ARD upon contacting with the biomass.

To mimic possible real-world inputs into the pre-treatment section of the process, various strengths of real ARD were also used in batch vessels with sugarcane bagasse as detailed in Table 2. A commercial cellulase enzyme was added to two duplicated samples.

Continuous Experiments

Figure 1 is an illustration of the layout of the model process used for continuous study and the sampling points referred to in the results section.

The pre-treatment reactor contacts incoming ARD with biomass to raise pH and strip some soluble organic components from the carbon source. This more carbon-rich stream flows into an 8L model Linear Flow Channel Reactor (LFCR) with SRB inoculum and carbon fibre strands to limit microbial washout. After the LFCR, a model constructed wetland is placed to provide further remediation as well as improve clarity and smell of effluent. (i.e. tertiary treatment). The wetland performance is not reported on in this work.

To compare the pH change and rise in

Table 1 *Initial conditions for synthetic ARD batch experiments*

Sample	Type	Initial pH	Volume (mL)
A	Real ARD	2.72	300
S1	Synthetic	2.01	300
S2	Synthetic	2.5	300
S3	Synthetic	3.01	300
S5	Synthetic	4	300
S5	Synthetic	5	300

Table 2 *Initial conditions for coal mine ARD batch experiments*

Sample	Primary liquid	Dilution	Solid
A1	ARD 300ml	None	Bagasse 25g
A2	ARD 250ml	Water 50ml	Bagasse 25g
A3	ARD 200ml	Water 100ml	Bagasse 25g
A4	ARD 150ml	Water 150ml	Bagasse 25g
A5	ARD 250ml	Water 50ml + Cellulase	Bagasse 25g
A6	ARD 150ml	Water 150ml + Cellulase	Bagasse 25g

soluble COD in the pre-treatment reactor phase, two sealed 2L reactors were filled with 200g field grass cuttings and 200g sugarcane bagasse respectively. Both biomass samples were dried in an oven overnight and rinsed to remove fine particles and dust. A peristaltic pump was used to pass ARD through each reactor in a bottom to top flow pattern and the outlet was sampled and stored. For the duration of this experiment the ARD flowrate was approximately 0.8 L/day through each reactor. Oxygen demand (COD) was measured as a proxy for soluble organic carbon released.

To operate the model system, different pre-treatment reactor compartments were packed with 250g of dried roadside grass cuttings followed by 250g of sugarcane bagasse with flow in series. An overflow inlet and bottom outlet flow design was used to minimise short circuiting flow. The system was fed coal mine ARD at 4L/day, setting the LFCR hydraulic retention time at 2 days.

Results and Discussion

Batch Experiments

The pH in the batch reactors treating ARD showed a rapid initial change in pH upon contact with the sugarcane bagasse (fig. 2). Solutions with a pH starting above 3.5 displayed a decrease in pH, stopping in the range of ≈pH 3.8. It is suspected this is due to a limited release of organic acids. Vessels with a higher dry mass of sugarcane bagasse showed a higher initial change and end pH after ≈100 hours of contact time. The rise in pH after 50 hours of run-time is theorised to be due to biological activity. This hypothesis was supported by the smell of hydrogen sulfide and visible biofilm on the liquid surface in samples S3, S4 and S5. This could indicate that some microorganisms, including sulfate reducers, are present on bagasse and are viable in relatively low pH environments.

Coal mine ARD had a similar change in pH on contact with the bagasse, though smaller in magnitude than the synthetic vessels due to higher initial acidity (fig.3). The addition of cellulase enzyme mix had a marked effect on pH comparing samples A3 to A5 and A4 to A6. The pH continuing to rise, and the lowering redox potential could indicate biological activity in samples A4, A5 and A6 even with the higher acidity and dissolved metals of real ARD.

The batch experiments with acid and mine drainage indicated that an observable effect on liquid pH can be seen and biological activity present with the relatively low solid to liquid loading of 25g of sugarcane bagasse. Increasing the solid loading in a continuous system or staging multiple in series to attain the desired pre-treatment pH, and the addition of commercial enzymes to assist with breakdown of the organic matter, are two factors to consider in scaled up experiments.

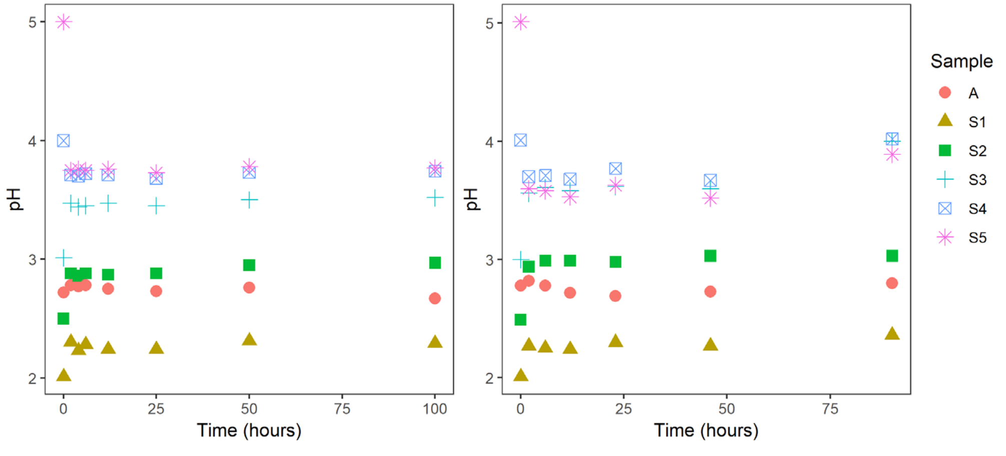

***Figure 2** pH change for dilutions of Sulfuric acid contacted with 15g (left) and 25g (right) of Sugarcane Bagasse*

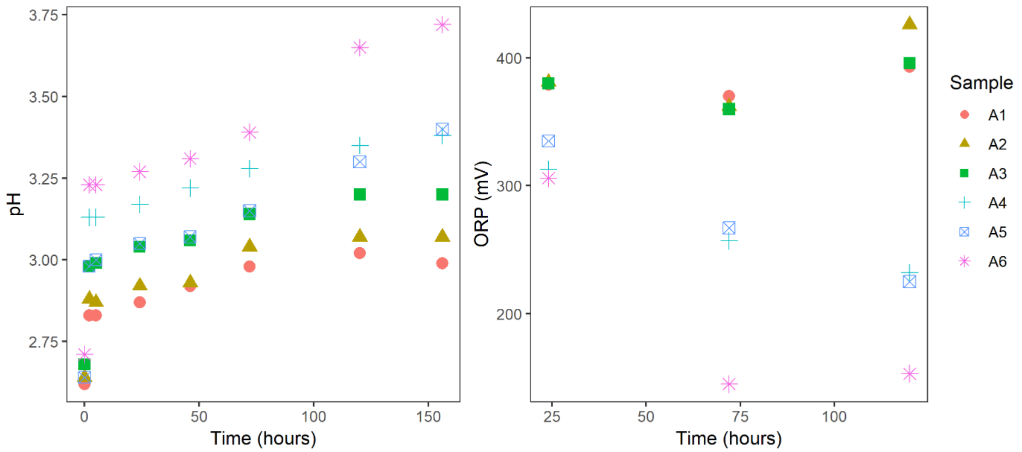

Figure 3 pH change and Redox potential for dilutions of coal mine ARD contacted with 25g of Sugarcane Bagasse

Continuous Experiments

In the continuous pre-treatment experiment, both the outlet pH and oxygen demand were observed to decrease with time (fig 4). The grass cuttings appear to supply more soluble organic material and acid neutralisation than dry bagasse for the duration of the experiment. Investigation into the composition of the outlet organic material is recommended.

Figure 5 shows the change in pH and sulfate concentration with time at the various sampling points in the model continuous system. The pre-treatment reactor (M2 and M3) was filled with ARD before the run was initialised, while the LFCR (M4) had an SRB stock solution and feed comprised of sodium acetate and sodium sulfate. The Constructed Wetland (M5) had a mixture of the runoff from the LFCR and tap water.

The outlets of the two-step pre-treatment reactor (M2 and M3) showed a pH change in excess of 1 pH compared to the ARD feed (M1). The incoming acidity after the pre-treatment step decreased the pH of the LFCR out of the ideal range in which it has been found to operate.

The liquid leaving the LFCR had a lower sulfate concentration than that entering and higher sulfide levels. The sulfate removal and sulfide production were lower than previous experiments using synthetic feedstock where sulfur production was observed (van Hille

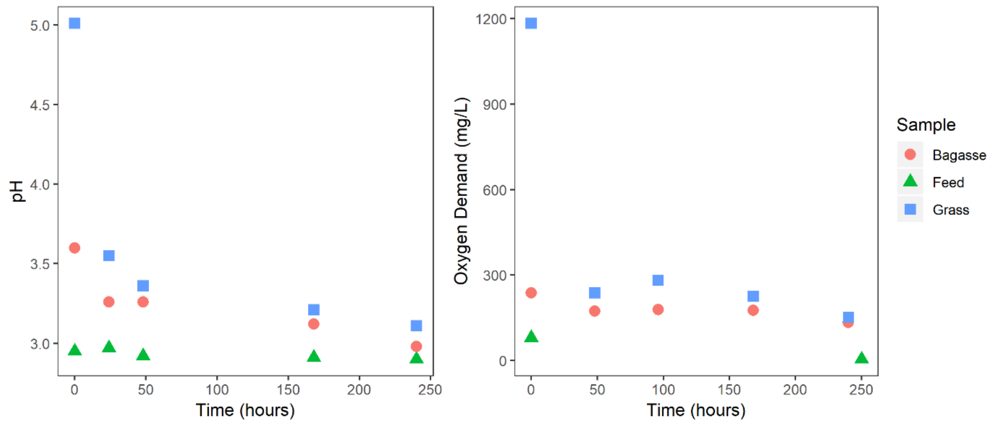

***Figure 4** pH and Chemical Oxygen Demand at the outlet of pre-treatment reactor pairs filled with 200g of Bagasse and Grass respectively, on contact with ARD at a flowrate of 0.8L/day*

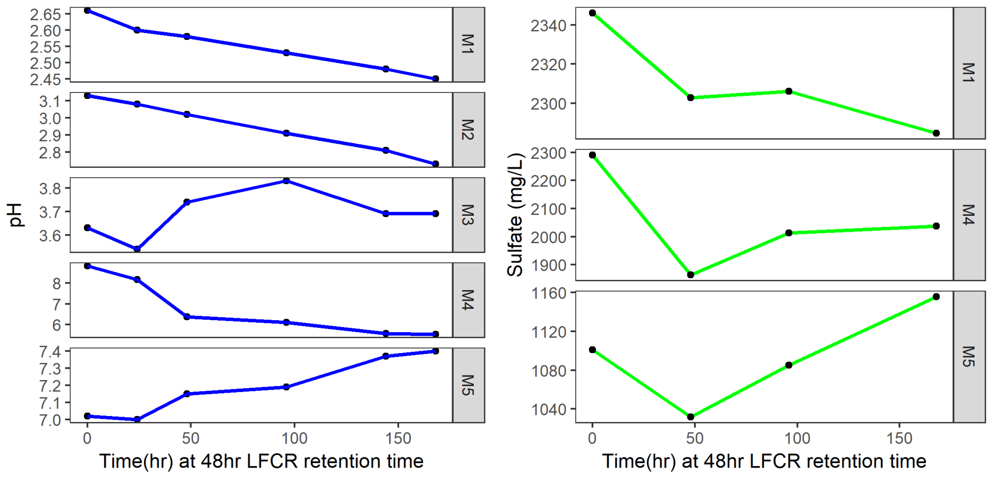

Figure 5 pH and Sulfate concentration for the model continuous flow system as shown in Figure 1 with a 48hr hydraulic retention time

and Mooruth 2011)

Figure 6 illustrates the observed decrease the three highest concentration species of dissolved metals for this ARD throughout the reactor series. The pH in the biomass reactor where most of the metals are removed is too low to directly precipitate manganese. This may be indicative of complexation or adsorption and is an avenue of further study.

Conclusion

This research has shown that it is possible to increase the pH of ARD (albeit minimally) using sugarcane bagasse only and some sulfate reduction can take place at the conditions reached by contacting bagasse with ARD.

Potentially toxic metals may be substantially removed by contacting the ARD with biomass, but the mine water acidity

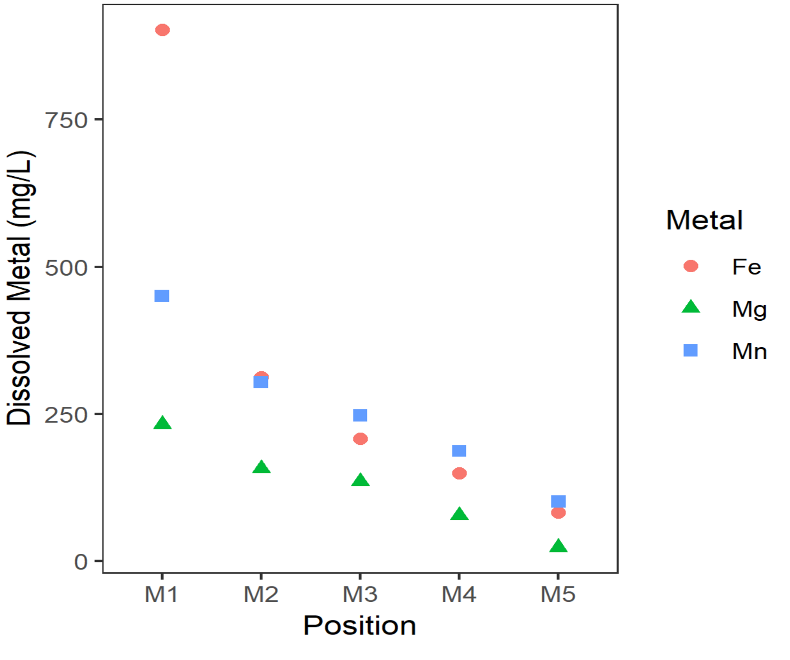

Figure 6 Snapshot of some metal concentrations at 96 hours for the model continuous flow series as laid out in Figure 1 with a 48hr hydraulic retention time relative to the LFCR

remains too high under the configuration conditions tested, decreasing the pH of the bioreactor over time

Current research following from this work is focussing on increasing the solid loading rate and the quantification and characterisation of organic carbon flowing through the model treatment system, with the goal of achieving a higher level of sulfate reduction and partial oxidation of sulfide in the linear flow channel reactor.

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