Bio char Production from Sugar Cane Bagasse and its Application Sugarcane Processing Wastewater Treatment

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Abstract

The sugar producing industry generates tons of bagasse as a waste product. This bagasse has the potential to be converted to bio char. In this study, sugarcane bagasse was converted to bio char at 600 ◦C for 3 hours and a heating rate of 10 ◦C/min using the pyrolysis technology. A bio char yield of 75% was achieved with a surface area of 500 m^2/g and a particle size of <2mm. The bio char was used as an adsorbent media in sugarcane wastewater and the changes in the pH, biological oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (Tot-N), total phosphate (Tot-P) and the total solids (TS) were monitored using standard methods. Application of the bagasse based bio char in sugarcane wastewater treatment resulted in the significant reduction of BOD, COD, Tot-N, Tot-P and TS by 85.1%, 84.8%, 74.8%, 76.5% and 84.7% respectively.

Keywords: Bagasse; bio char applications; physicochemical properties; sugarcane wastewater treatment

1.Introduction

The sugar manufacturing industry is one of the thriving industries in Southern Africa. Despite this industry being one of the major contributors to economic recovery, it also generates a lot of waste in the form of bagasse and wastewater which must be treated before disposal. Sugar is obtained from the various processing stages which include: milling of the sugar cane, the extracted juice preparation and concentration then syrup processing and crystallization. Sugar production being a wet process generates a lot of wastewater as well as bagasse as a by-product. The various key stages in sugar processing are shown in Figure 1.

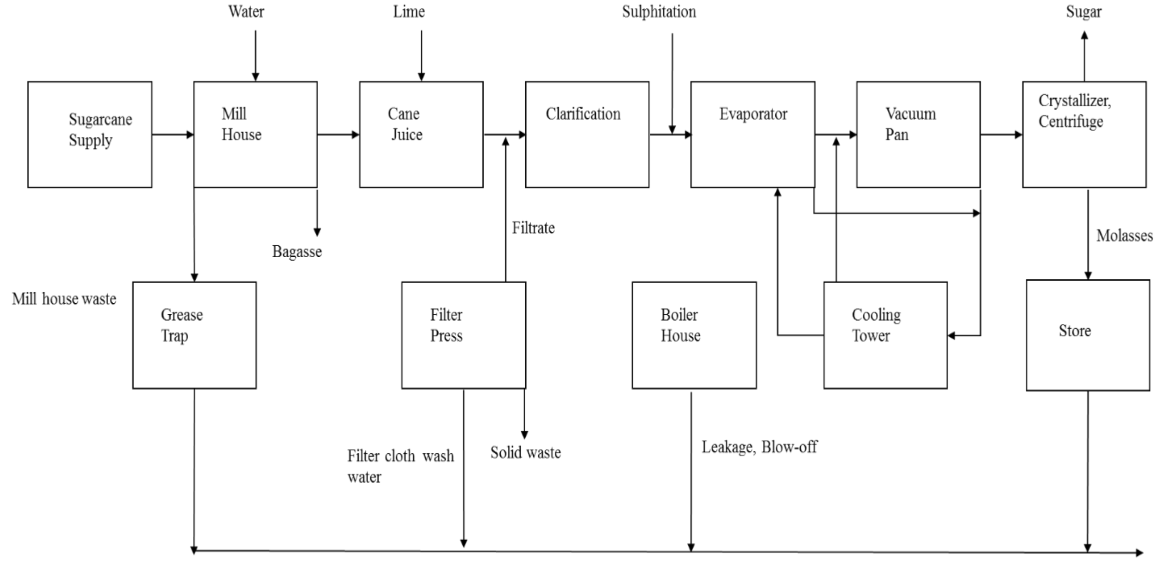


Figure 1. Sugar cane manufacturing process indicating the generation of bagasse and wastewater

The wastewater generated from the sugarcane processing industry is highly contaminated and must therefore be treated before disposal to minimize environmental contamination (APHA, 2005; Brewer et al., 2014). Bagasse is a lignocellulose material that is rich in cellulose, hemicellulose and lignin this bagasse can be converted to bio char a material that can be applied for wastewater treatment as an adsorbent (Chaurasia and Tiwari, 2011; Dalahmeeh et al., 2012). Bagasse from various biomass has been successfully applied as a wastewater treatment media. This study therefore focused on the assessment of the potential to produce bio char from sugar cane bagasse and its usability in sugarcane wastewater treatment. Bi char is regarded as a low cost and environmentally friendly adsorbent used as a bio filter in wastewater treatment (Jeffrey et al., 2011).

2.Materials and methods

Sugarcane bagasse was obtained from a local bio ethanol plant that uses sugar cane as the raw material. The sugarcane bagasse was pyrolysed at 600 ◦C for 3 hours at a heating rate to produce bio char in a 2L lab scale pyrolysis reactor. The bio char yield was also determined by measuring the change in mass of the bagasse sample before and after pyrolysis. The bio char was ground to small particle sizes of 0.8-2.0mm and the particle size was measured through particle size analysis. The surface area of the bio char was determined through the Brunauer, Emmet and Teller (BET) theory whilst the porosity was measured using the pore volume methodology (Knowles et al., 2001).

The bio char produced was used for the treatment of sugary industry wastewater. A 1m by 0.4m vertical column which has 3 different layers comprising of 25 cm top gravel, 70 cm bio char and 25 cm bottom gravel was used as the filtering media for the sugar cane industry wastewater. The bio char particle density was measured using the gravimetric water content and the specific gravity was then calculated in comparison to that of water.

A sample of 500 mL of the wastewater was treated over a 4 run cycle in 48 hours. The sugarcane wastewater was subjected to the bagasse bio char as a filtering media and the changes in the chemical oxygen demand (COD), biological oxygen demand (BOD), total nitrogen (Tot-N), total phosphate (Tot-P) and the pH. The sugarcane wastewater characteristics were measured in accordance to the APHA (2005) standard methods in milligrams per litre (mg/L) except for pH. The pH was measured using a Hanna pH probe HI98196. The efficient removal (RE) of contaminants from the wastewater were measured in accordance to Equation 1:

$$\%RE = \left(\frac{Influent\ concentration\ in - Efluent\ concentration\ out}{Influent\ concentration\ in}\right) * 100 \ldots\ldots(1)$$

The experiments were replicated thrice and the average values obtained were used to determine the trends in the sugarcane wastewater characteristics.

3.Results and discussion

3.1 Bio char characteristics

A highly porous charred bio char was produced after the pyrolysis. The bagasse based bio char had characteristics indicated in Table 1 which made it usable as an adsorbent for sugarcane wastewater treatment. The high surface area (500 m^2/g) and porosity (65-70%) of the bio char makes it usable as an adsorbent in wastewater treatment.

Table 1. Bio char characteristics

Characteristic	Value
Particle size	0.8-2.0 mm
Surface area	500 m^2/g
Porosity	65-70%
Specific density	0.25-0.30
Bio char yield	75%

3.2 Sugarcane industry wastewater characteristics

The characteristics of the sugarcane wastewater that was subjected to treatment using the bio char are indicated in Table 2. The sugarcane wastewater was characterized by high BOD and COD as high as 1167 mg/L and 2809 mg/ L respectively and these have potential to cause eutrophication if disposed in water bodies.

Table 2. Sugarcane wastewater characteristics

Characteristic	Value
pH	8.5±0.1
BOD	1167±15.8
COD	2809.6±7.8
TS	112.3±2.9
Tot-N	50.1±1.7
Tot-P	58.8±1.7

3.3 Effect of bio char on sugarcane wastewater physicochemical characteristics

Effect on BOD

The BOD refers to the amount of oxygen required to oxidise organic material under aerobic conditions. The BOD in the sugarcane wastewater decreased significantly with increase in the treatment time with sugarcane based bio char as indicated in Figure 2. An average of 85.1% in the BOD removal efficiency were observed during the 48-hour period. The BOD removal efficiency was highest up to 24 hours and thereafter the decrease was almost constant. The significant reduction in BOD was attributed to the removal of organic matter from the wastewater due to adsorption on the bio char particles. Dalahmeh et al. (2012) reported a 99% decrease in BOD upon treatment of wastewater with bio char and this was attributed first to the adsorption of the bio contaminants on the bio char followed by the attachment of the bio contaminants on the bio film that would have formed on the bio char surfaces.

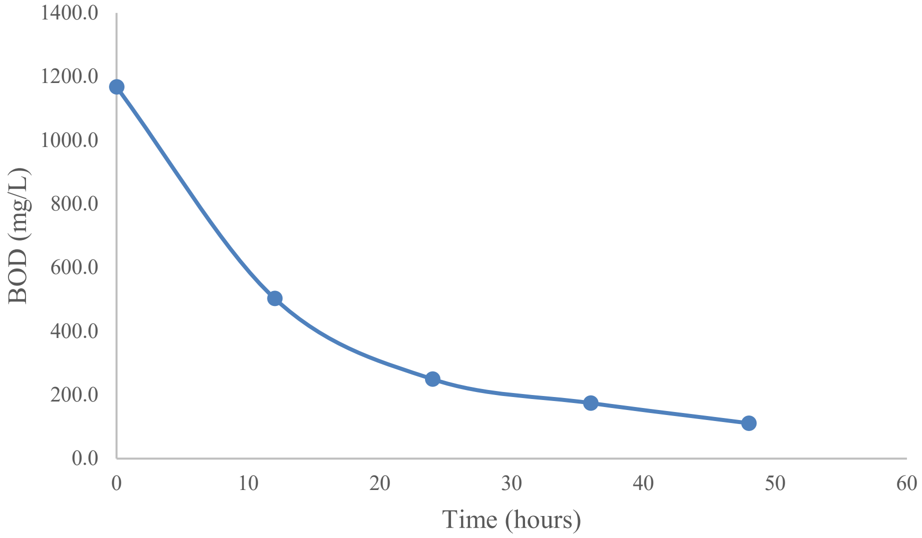


Figure 2: Effect of bio char treatment on BOD

Effect on COD

The COD refers to the amount of oxygen required to chemically oxidize organic matter in the wastewater. The COD in the sugarcane wastewater decreased significantly with increase in the treatment time with the bagasse based bio char (Figure 3). A COD removal efficiency of 84.8% was achieved with the highest removal efficient being observed up to 24 hours of treatment. The changes in the COD were attributed to the removal of both organic and inorganic contaminants in the wastewater as they attached on the bio char particles which acted as a bio filter. Dalahmeh et al. (2012) also reported the same trend in COD when a 94% decrease in COD was observed when bark activated char was used for the treatment of grey wastewater.

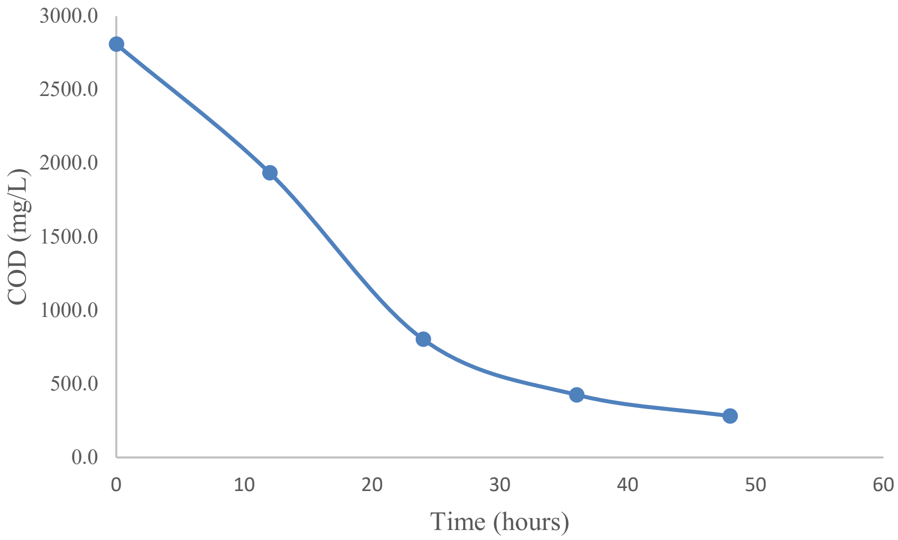


Figure 3: Effect of bio char on COD

Effect on Tot-P

The Tot-P in the sugarcane wastewater significantly decreased with increase in treatment time with the bagasse based bio char as a bio filter media (Figure 4). A 76.5% removal efficiency was observed during the 48-hour treatment period. The same trend in Tot-P reduction was reported by Dalahmeh et al. (2012) with a 78% being observed. This was attributed to the high surface area of the bio char which was 1000 m^2/g which allowed for an efficient adsorption process.

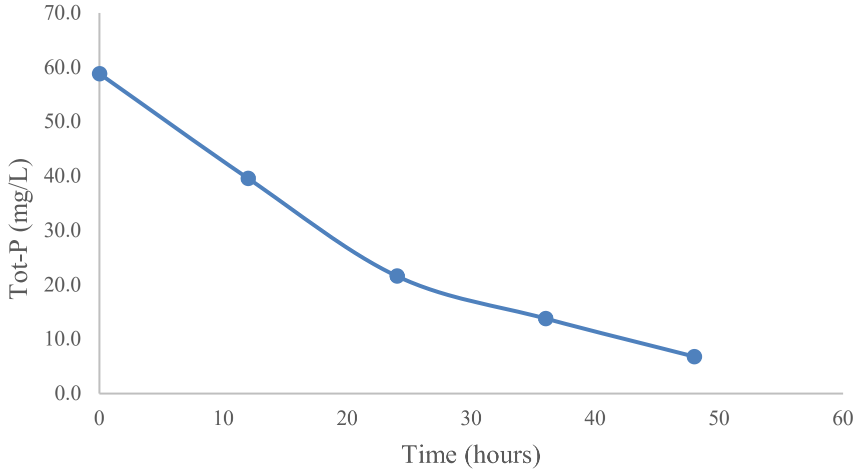


Figure 4: Effect of bio char on Tot-P

Effect on Tot-N

The Tot-N in the sugarcane wastewater decreased significantly with the increase in treatment time with the bagasse based bio char (Figure 5). A total removal efficiency of 74.8% was achieved for the Tot-N removal used the bagasse based bio char. This result observed on Tot-N was in concurrence with what was reported by Dalahmeh et al. (2012) when a 91% decrease was observed for Tot-N and this was attributed to the efficient adsorption process of nitrogen on the bio char from the grey wastewater.

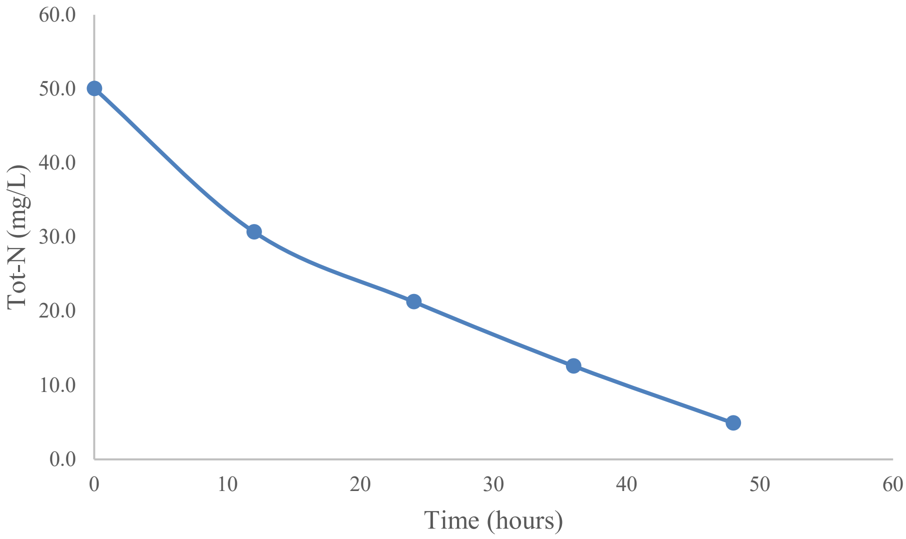


Figure 5: Effect of bio char on Tot-N

Effect on TS

The TS in the sugarcane wastewater decreased significantly with increase in the treatment time with the sugar based bio char as indicated in Fig. 6. The removal efficiency of the TS was 84.7% and this was attributed to the accumulation of the solid pollutants o the bio char through adsorption on the bio char surface.

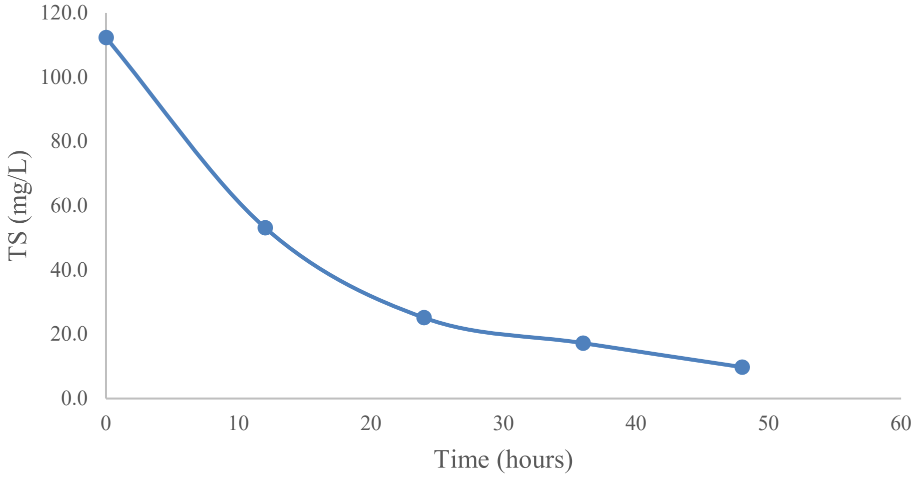
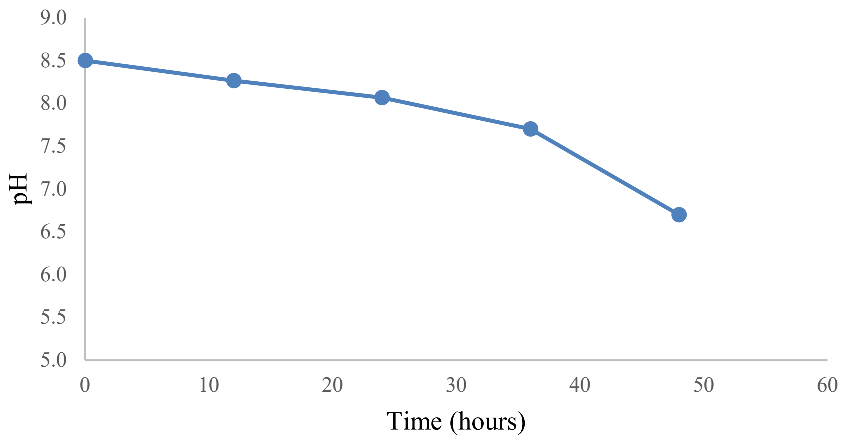


Figure 6: Effect of bio char on TS

Effect on pH

The pH in the sugarcane wastewater decreased with increase in the treatment time with the bagasse based bio char as indicated in Figure 7. The pH changed from 8.5 which was alkaline to neutral pH of 6.5. Previous studies by Dalahmeh et al. (2012) indicated that pH decreased as grey wastewater was treated using bio char as a bio filter with pH values of 7.0-7.9 being observed.



Fiure. 7: Effect of bio char on pH

3.4 Use of bio char in soil amendment

The captured nutrients on the bio char through the process of adsorption allowed the bio char to be rich in nutrients that can then find its end use as a soil amendment material in agriculture (Lemann and Joseph, 2009; Mandu et al; 2011). This specifically refers to the Tot-N and Tot-P adsorbed on the bio char surfaces whose concentration increased by 76.5% and 74.8% respectively. These nutrients had high probability of being passed on for soil amendment by the bio char which was highly porous.

4. Conclusion

Sugarcane bagasse is a good raw material for bio char production. The bio char produced had good porosity and surface area of 500 m^2/g which makes it useful as a bio adsorbent. Application of the bagasse based bio char in sugar cane wastewater treatment resulted in significant decrease in BOD, COD, TS, Tot-P and Tot-N by more than 70%. The bagasse based bio char had good adsorption properties essential in sugar wastewater treatment.

Acknowledgements

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References

APHA, Standard Methods for the Examination of Water and Wastewater. 21st Edition, American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC, 2005.

Brewer, C. E, et al., New approaches to measuring biochar density and porosity, Biomass and Bioenergy; 2014; http://dx.doi.org/10.1016/j.biombioe.2014.03.059.

Chaurasia, N. K., and Tiwari, R. K., Effect of industrial effluent and wastes on physicochemical parameters of river Rapti. Advances in Applied Science Research, vol. 2, pp. 207-211, 2011.

Dalahmeh, S. S., Pell, M., Vinneras, B., Hylander, L. D., Oborn, I., and Jonsson, H (2012) Efficiency of bark, activated charcoal, foam and sand filters in reducing pollutants from greywater. Water Air Soil Pollution, vol. 223, pp. 1–15, 2012.

Jeffery, S., Verheijen, F. G. A., van der Velde, M., and Bastos, A. C. A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. Agriculture Ecosystems Environment, vol. 144, pp. 175–187, 2011 doi:10.1016/j.agee.2011.08.015

Knowles, O .A., Robinson, B. H., Contangelo, A., and Clucas, L. Biochar for Mitigation of Nitrate Leaching from Soil Amended with Biosolids. Science of the Total Environment, vol. 409, pp. 3206-3210, 2011. http://dx.doi.org/10.1016/j.scitotenv.2011.05.011.

Laird, D. A. The Charcoal Vision: A Win–Win–Win Scenario for Simultaneously Producing Bioenergy, Permanently Sequestering Carbon, while Improving Soil and Water Quality. *Agronomy Journal*, vol. 100 (1), pp. 178-181, 2008.

Lemann, J., and Joseph, S., Biochar for environmental management: An Introduction. In Biochar for environmental management: Science and Technology. Lemann J and Joseph S (Eds). Earthscan, London, 2009.

Mandu, B., Gao, W., Ding, P, Pullammanappallil, A. R., Zimmerman, X., Cao, Separation Science and Technology, vol. 46 (12), pp. 1950-1956, 2011.

Biographies

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