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Characterization of Sugar Effluent from a Sugar Milling Industry in the Kwazulu-Natal Province of South Africa for Biogas Production

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Sugar industry is one the biggest contributors to the environmental pollution in the modern world. The effects are specifically felt by the aquatic environment which in turn affects the human beings as they depend (partially and otherwise) on the aquatic creatures such as fish for food resource. Also, water demands are growing continually as human population increases although the supply of water is diminishing. The disposal of the effluent from industries to water streams becomes detrimental as it does not only disturb the aquatic life but also the water quality that is used for domestic and agricultural purposes. Effluent discharging industries include thermal power plants, paper mills, oil refineries, sugar mills etc. The composition of this effluent is total suspended solids, chemical oxygen demand, biological oxygen demand, heavy metals and sometimes the total dissolved solids. Treatment and reuse of industrial effluent (wastewater) then becomes a necessary step to meeting the environmental strain. One way of effectively solving the crisis of industrial wastewater is through treating while making additional useful products such as biogas and electricity. The aim of the present paper is to do a thorough analysis of the effluent from sugar milling industry for production of biogas and electricity through anaerobic digestion.

1. Introduction

Sugar industry is one of the big contributors to the economy of South Africa and elsewhere in the globe. In the 2018/19 season is one of the leading sugar producing countries in Africa producing between 750 and 2500 m3 of sugar effluent a day (Ndobeni, 2017). Moreover, South Africa alone produced about 2.2 million tons of sugar which generates a direct income of around 14 billion South African Rands. The industry offers direct employment to approximately 85 000 people in its production and process section while also providing the country with indirect job security (350 000) to many other support industries such as food, chemical, transport and fertiliser industries (SASA, 2021). This same industry contributes largely to environmental pollution with its waste and discharges (Ansari, 2006). The pollution is due to the fibrous waste that remains after the extraction of the sugar producing juice (bagasse, pressmud, pulp), mollases and huge quantities of effluent waste matter (Mashoko et al., 2010). The solid waste is discarded openly on land causing the quality of land to deteriorate whereas the liquid effluent is usually discharged into rivers and oceans untreated or partially treated causing negative impacts to the environment, human and animal life (Gondudey et al., 2020). Nevertheless, waste from sugar processing industry has been found to have a revitalisation power and a solution to the challenges of energy faced by many countries (Farzad et al., 2017).

Since sugar is produced from two sources i.e. sugarcane and sugar beet, effluent from both sources is useable in energy production processes (Chauhan et al., 2011). In a study conducted by Özkan et al. (2012) an investigation of the photo fermentative hydrogen production from thermophilic dark fermentative effluent of sugar beet thick juice was done in a solar fed-batch panel photobioreactor. Also, Chojnacka et al. (2015) gave noteworthy facts regarding a methane producing microbial community which process acidic effluent from sugar beet molasses fermentation.

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This is achieved when the separation of the hydrogen yielding and the methane yielding steps is done under controlled conditions. A recent study focused on investigating the enhancement of biogas production through the electrokinetic assisted anaerobic digestion of spent mushroom with sugar mill wastewater where the reactor performance was optimized through the use of response surface method and artificial neural network tools (Kumar et al., 2021).
Sugar industry wastewater contains high pollutants loads due to the presence organic (chemical oxygen demand and total dissolved solids) and inorganic materials (Gondudey et al., 2020). Due to the large quantities of polluted sugar industry effluent several treatment methods have been established, these include membrane separation (Bogliolo et al., 1997), coagulation and electrochemical (Asaithambi and Matheswaran, 2016), microbial (Yetis et al., 2000), anaerobic biological treatments (Atashi et al., 2010) etc. Table 1 is a representation of these different treatment methods according to their classes. Each of these treatment methods has its advantages such as being cost effective and ease of operation and disadvantages such as high costs of installation and operation for others. The scope of the present study is based however on the biological treatment of sugar industry wastewater using microorganisms via anaerobic digestion. Also, this method of treatment offers added benefits specifically energy generation in the form biogas and hydrogen.

Table 1: Wastewater treatment methods

Method	Detail
Biological	use of activated sludge: anaerbic conditions, oxygen conditions
Mechanical	centrifugation crystalization drawl filtration sedimentation separation
Physicochemical	coagulation and flocculation electrocoagulation ozonation sorption membrane use

2. Materials and experimental details

Wastewater samples were collected from the endpoint of the process plant. This is a composite sample which carries the final drain wastewater of all the sections and going outside the process plant. Physical analysis was done on site, while chemical analysis was done in the laboratory not far from the collection site (about 10.2 km). Samples had to be preserved by keeping the sample container in the cold room at 4 °C before analysis was done. Physicochemical parameters such as colour, odour, pH, temperature, COD, TS and VS were analysed by standard analytical methods as explained in the next section.

3. Results and discussions

All measurements were done in triplicates to check reproducibility

Physicochemical properties of sugar wastewater:

3.1 Colour

Colour is a qualitative feature that is used to evaluate the condition of wastewater. This characteristic is a crucial factor for aquatic life for making food from sun-rays where the photosynthesis activity is reduced due to the dark coloration. The colour of untreated effluent from sugarcane industry has been reported as dark brown while the treated effluent was whitish (Kolhe et al., 2009). Other authors have reported sugar effluent colour to be black

(Samuel and Muthukkaruppan, 2011), brown (Saranraj and Stella, 2012) etc. In the present study, the colour of the wastewater was recorded as dark grey.

3.2 Odour

Food industry wastewater have unpleasant odours which is usually produced by gases formed by anaerobic decomposition of organic matter. One of the most common compounds that give odour is hydrogen sulfide which smells like rotten eggs (Metcalf, 2003). Determination of odour has been found an important aspect of analysis for proper operation of wastewater treatment facilities. Generally, sugar wastewater has a fermented smell and even for the sugar wastewater used in this research it was the same (Sahu and Chaudhari, 2015).

3.3 Temperature

Temperature affects chemical and biological reactions that occur in water, so it is an important parameter. It is greatly dependant on the season, time and sampling. Industry wastewater generally has high temperatures which then causes adverse effects when discharged to land. Temperatures between 31 ℃ and 41 ℃ have been reported for other sugar industry wastewater with treated effluent having the lowest range (Kolhe et al., 2009). The wastewater temperature was read as 24.8 ℃ in this study, this is within the accepted discharge range (Sahu and Chaudhari, 2015).

3.4 pH

pH is a biotic factor which helps in serving as a pollution index. This parameter influences the rate of biological reaction and how several microorganisms survive. pH measurements were carried out to determine the degree of acidity or alkalinity of the wastewater. This was done to ascertain the pH range is at the required standard for both discharge and anaerobic digestion process to be carried out or corrected if not. The pH range for discharge according to South Africa and Department of Water Affairs is 5 – 9.5 while pH range of 5.5 – 8.5 has been reported to favour anaerobic digestion process (Adedeji and Chetty, 2020). The pH of the effluent as shown in Table 2 was noted to be 4.8. This effluent pH result showed that the sample was more acidic in nature, due to its lowest p H value. Therefore, when conducting the biogas production reactions, wastewater pH has to be corrected to be within 5 to 9 pH range.

3.5 Chemical Oxygen Demand (COD)

COD gives an indicative measurement of the oxygen amount that can be consumed by reactions in a measured solution. It indicates the contents of reducing substances in water, which are organic, nitrite, sulfide, ferrous salts, etc., where the organic is dominant. COD is generally expressed in mass of oxygen consumed over measured volume of solution. This analysis relies on the principle that; approximately all organic compounds can be completely oxidized to carbon dioxide with a strong oxidizing agent in acidic conditions. COD is used to check the toxic level of the wastewater as well as the biological resistant substances. In the current experiment COD was used to measure organic pollutants load and the results are shown in Table 2.
Physicochemical properties of sugar wastewater differ according to the stage of the production process and the resultant quality of effluent varies as per chemicals utilized in the production phases (Fito et al., 2019). Previous studies have reported COD to be in the ranges of 1100.3-2148.9 mg/L (Fito et al., 2019), 1360-2000 mg/L (Kolhe et al., 2009) and 2000-8000 mg/L (Macarie and Le Mer, 2006) with values that can be lower than 317 mg/L at times (Saini and Pant, 2014). The COD value obtained from the current study therefore compares well with the hitherto reported findings. High COD content of sugar wastewater has unfavorable effects on the environment, aquatic biota and plants just like other industrial waters, thus proper management of this type of water must be done.

3.6 Total Solids (TS)

This was measured as the residue left after evaporation of a sample and subsequent drying till constant weight is achieved. The defined temperature once evaporation of sample is complete is 105 ℃ according to (APHA, 2005). A measurement of 4 mL of the wastewater in preheated crucibles of known weight. The crucible and the wastewater samples would then be placed in the oven for 90 minutes at 105 ℃. The crucible with the residue was then weighed. The value of the total solid was calculated using the Equation 1 with the results tabled in Table 2.

$$Total\ Solids\ (\frac{mg}{L}) = \frac{(A - B) \times 1000}{C} \tag{1}$$

Where:
A = weight of crucible + residue (mg)
B = weight of crucible (mg)
C = sample volume in mL

TS analysis is among the other physicochemical properties that need to be checked for both the treated and untreated sugar wastewater besides COD. Kolhe et al. (2009) reported that TS for untreated effluent was between 3000 and 2015 mg/L for two consecutive months while other studies observed values between 870 and 4485 mg/L (Khan et al., 2003, Kumar et al., 2001, Maruthi and Rao, 2000). TS value obtained from this study exceed the values reported in literature which clearly shows this water might need further treatment before it can be used for the proposed biogas production.

3.7 Volatile Solids (VS)

This is the term used to ascertain the weight loss on ignition in a furnace at 550 ℃ for 30 minutes according to (APHA 2005). Determination of VS is needed prior and after digestion process since some calculation of the biogas produced are based on the VS as well as organic loading rate determination and %VS reduction.
VS for each sample was determined by igniting the crucible and residue obtained after TS in a muffle furnace for 30 minutes at 550 ℃. The value of the volatile suspended solid was calculated using the Equation 2 below. VS results are provided in Table 2.

$$Volatile\ Solids\ (\frac{mg}{L}) = \frac{(B - D) \times 1000}{C} \tag{2}$$

Where:
B = weight of residue and crucible in mg from Total solids test
D = weight of residue and crucible in mg after ignition

VS found in this research is higher than other sugar wastewater reported in the past but far less than the value for sewage sludge (Adedeji and Chetty, 2021).

Table 2: Wastewater characteristics

pH	4.8
COD	5200 mg/L
TS	47500 mg/L
VS	15000 mg/L
VS/TS ratio (%)	31.6

4. Conclusions

A local sugar wastewater characterization was done as part of the preliminary studies. This was done to assess the viability of the used wastewater from the end point of the sugar milling plant which is inclusive of every kind of waste used in the sugar making process. This type of wastewater showed a COD of 5200 mg/L which is beyond the accepted disposal ranges of South Africa. Also, pH measurements are lower than the biogas production working pH of 5.5- 8.5. VS/TS ratio was found to be low (less than 40 %) indicating that this type of water might not be biodegradable. Characterization experiments of wastewater from other parts of the process plant are being carried out to further investigate which one will be more suitable for biogas production leading to the desired results as the current data cannot be used further for biogas production. All in all, the data obtained from this study was able to clearly show that not all sugar wastewater is viable for energy recovery. Therefore, there is still room for other treatment options for this type of wastewater besides biogas production process.

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