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Biomethane Potential of Agricultural Biomass with Industrial Wastewater for Biogas Production

Edward K. Armah[a,*], Maggie Chetty[a], Nirmala Deenadayalu[b]

[a]Department of Chemical Engineering, Faculty of Engineering and The Built Environment, Durban University of Technology, Durban, 4001, South Africa
[b]Department of Chemistry, Faculty of Applied Sciences, Durban University of Technology, Durban, 4001, South Africa
edwardkarmah@gmail.com

The aim of this present study is to determine the biogas potential of sugarcane bagasse and corn silage. Sugarcane bagasse (SB) and corn silage (CS) are feedstocks that could be used to produce renewable sources of energy such as biogas, serving as an alternative energy source. There have been several drawbacks in the past decades on anaerobic monodigestion such as reactor failure and process instability. Also, there has not been any studies on the use of industrial wastewater with SB or CS for biogas production, hence, providing the novelty in this study. A working pH range of 6.0 to 8.5 was observed in this study without the addition of a buffering medium. A feedstock loading of 1.5 gVS/100 mL solution was used with SB or CS controlled over a digestion period of 35 days for both 35 °C and 25 °C. The proximate and the ultimate analysis were carried out by the gravimetric method and the use of the scanning electron microscope (SEM) coupled with the energy dispersive x-ray (EDX) analyzer, respectively. The thermogravimetric analyzer (TGA) and the differential scanning calorimeter (DSC) were used to evaluate the changes in masses (gain or loss) for both CS and SB over a temperature range as a function of time. A higher biogas yield of 1.2 L/d was observed at 35 °C by the anaerobic co-digestion (AcoD) of CS with industrial wastewater with a methane yield of 79 % at a working temperature of 35 °C. The result of the study showed that the AcoD of CS or SB is promising and could contribute significantly on the yield of biogas production.

1. Introduction

The increase in the emission of greenhouse gases coupled with the over-reliance on the use of non-renewable forms of energy has inspired researchers in the past decades to search for an alternative means of sustainable energy (Ahmad et al., 2019). South Africa, like most other counties in the world, rely largely on coal for energy production such as electricity generation. This is a non-renewable source of energy and thus, a need to seek for an alternative means of energy that is affordable and cheap according to the United Nations Sustainable Development goal (7th goal) for 2050. The anaerobic digestion (AD) process to produce biogas from agricultural biomass is, therefore, the surest way. The monodigestion of energy crops still struggle to meet the reduction targets concerned with the drawbacks in the AD process such as reactor failure and process instability as compared to anaerobic co-digestion (AcoD) (Fagerström et al., 2018). The AcoD of sugarcane bagasse (SB) or corn silage (CS) with industrial wastewater for biogas production in South Africa has not been done. Recent studies have been focused on the use animal manure with agricultural residues and also, inhibitors involved during the AD process. There is larger volumes of SB and CS produced in South Africa annually and specifically Durban, KwaZulu Natal Province where this study was carried out. This present study was carried out to provide a novel study towards the AcoD of SB or CS with industrial wastewater for biomethane production. These energy crops have been found to be potential feedstocks for bioenergy production without the competition for arable land. Industrial wastewater is to provide the necessary nutrients required by the microbes present in the activated sludges to cause the biodegradation without the use of synthetic feed, thereby reducing operational cost. Temperature variation causes process imbalances relating to the buildup of volatile fatty acids (VFAs), leading to a decrease in biogas production in most biodigesters (Kougias, 2018). It has been found that anaerobes are more active at 35 °C than 55 °C and the latter tend to require higher heat input (Mital, 1997). In

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this regard, a thermophilic temperature of 55 °C was not considered in this study. It is observed that the temperature of a bioreactor has a strong effect on the methanogenic consortia of microbes available (Speece et al., 2006) and the overall kinetic rates as the overall digestion time could be much longer (Young, 2012). In this study, temperatures at both 25 °C and 35 °C were considered in determining the biomethane potentials of these feedstocks.

2. Materials and methods

The identification of the activated sludge, feedstocks and industrial wastewater in this study were collected within the city of Durban in the KwaZulu-Natal (KZN) Province of South Africa.

2.1 Sample collection and preparation

Sugarcane bagasse was collected from a local mill in Durban in the eThekwini Municipality, KZN after washing and milling. To increase the surface area between the biomass and the inoculum during the digestion process, the SB was sieved to an appreciable size on dry weight basis. Corn silage was sourced from an Agriculture Research Institute in Durban, South Africa, milled into a 1 mm particle size prior to analysis. Other substrates used were anaerobic digested sludge and inoculum collected from a digester plant located at a municipal WWTP. Duran schott bottles (1,000 mL) each (represented as A1, A2, B and C, with contents detailed in section 3.2 lines 3-6) were used as the biodigesters or reactors, operating in batch mode with an organic loading rate made up to the 800 mL mark according to the experimental design in Table 1. Nitrogen gas was purged in each biodigester to create the anaerobic environment within the system with silicone tubes connected from each biodigester to an inverted measuring cylinder for the measurement of the biogas potential in milliliters (mL). Each biodigester was contained in a circulating water bath controlled at a specific temperature of interest (25 °C or 35 °C) until the digestion process was complete as biogas potential is measured daily.

2.2 Analytical methods

The proximate analysis classified feedstock in terms of their moisture content, ash content, volatile solids, fixed solids and total solids according to the method developed by Sluiter et al. (2008) as presented in Table 1. The ultimate analysis classified feedstocks in terms of the content of carbon, oxygen, silicon, iron and other trace elements as shown in Table 3 using the SEM-EDX.

2.3 Experimental design and procedure

Table 1. Experimental design for the substrate mixture

Parameters	Activated sludge (mL)	Inoculum (mL)	Sugar wastewater (mL)	Organic loading rate (gVS/100 mL)
A1 (control 1)	400	400	-	-
A2 (control 2)	200	400	200	-
B	150	400	200	9.4
C	150	400	150	11.5

3. Results and discussion

This section describes the data obtained on the characterization of both SB and CS. Following, was the experiment of the biogas potential test for both SB and CS controlled at 25 °C and 35 °C.

3.1 Characterization of sugarcane bagasse and corn silage

Volatile solids are the part of the organic matter that undergoes biodegradation to yield biogas (Patil et al., 2014). Reported proximate values were found to be similar to what was reported by Simo et al. (2016). The volatile solids of CS were found to be higher than that of SB which was evidenced at higher temperatures of 35 °C and 55 °C, giving an indication that higher biogas yield is influenced by higher volatile solids. The results showed a good biogas potential as a significant biodegradable fraction existing in the feedstocks. The scanning electron microscope operated at 12 keV with magnification of 50 µm was used to study the morphology of untreated SB and CS before the AD process was carried out (Figure 1). Samples were sputter coated with gold before imaging to prevent charging on the surface of the specimen as well. In the thermogravimetry and differential scanning analysis of both untreated SB and CS, it was observed that three major steps were involved in each process which was due to the removal of moisture when the sample was heated (Figure 2). Exothermic peaks observed could also be attributed to charring.

Table 2: Proximate analysis results of sugarcane bagasse and corn silage

Parameters	Sugarcane bagasse (% weight)	Corn silage (% weight)
Total solids	94.2	93.0
Volatile solids	78.0	96.0
Moisture content	5.9	7.0
Fixed solids	22.0	4.1
Ash content	9.9	3.5

Table 3: Ultimate analysis results of sugarcane bagasse and corn silage

Elements	Sugarcane bagasse (% W)	Corn silage (% W)
Carbon	27.07	27.02
Oxygen	72.43	72.33
Silicon	0.14	0.04
Iron	0.10	0.01
Others	<0.10	<0.10

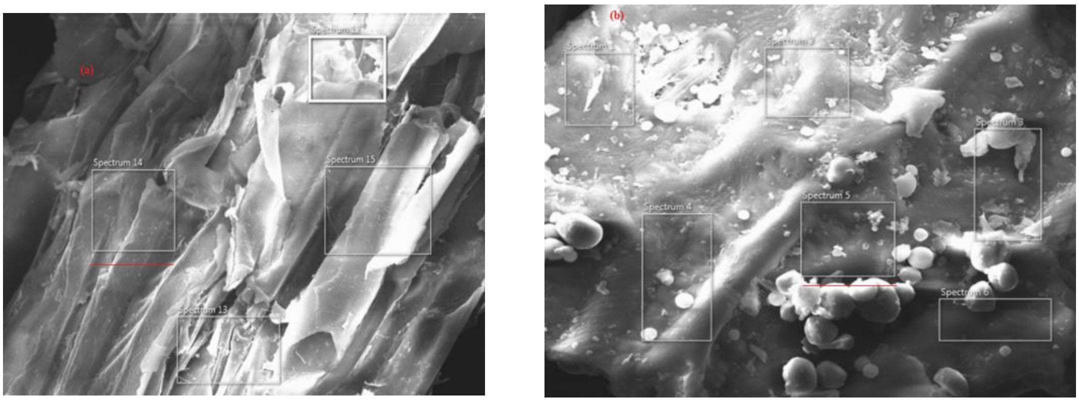

Figure 1: Electronically microscopic view of (a) sugarcane bagasse (left) (b) corn silage (right)

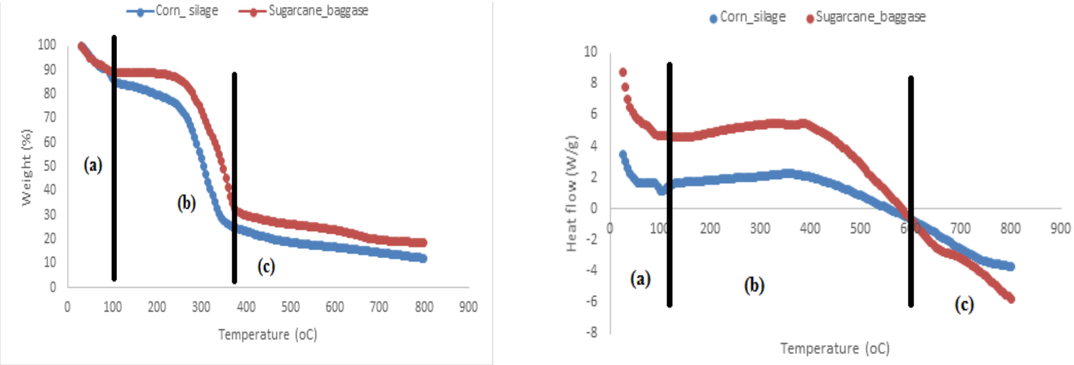

Figure 2: TGA thermograms of an untreated sugarcane bagasse and corn silage (left). Illustrations on plots denotes (a) dehydration step, (b) decomposition step and (c) stabilization step. DSC thermograms of an untreated sugarcane bagasse and corn silage (right). Illustrations on plots denotes (a) degradation step, (b) transition step and (c) stabilization step.

3.2 The Biogas potential test

A schematic diagram of the experimental unit is shown in figure 3. It consists of a temperature-controlled circulating water baths maintained at both 25 °C and 35 °C to hold each biodigester connected to glass tubes for the biogas collection. Biodigester A1 contained an inoculum and activated sludge only; A2, contained an inoculum with activated sludge and sugar wastewater; B, comprised of an inoculum, activated sludge, sugar wastewater and corn silage and C, contained an inoculum, activated sludge, sugar wastewater and sugarcane bagasse.

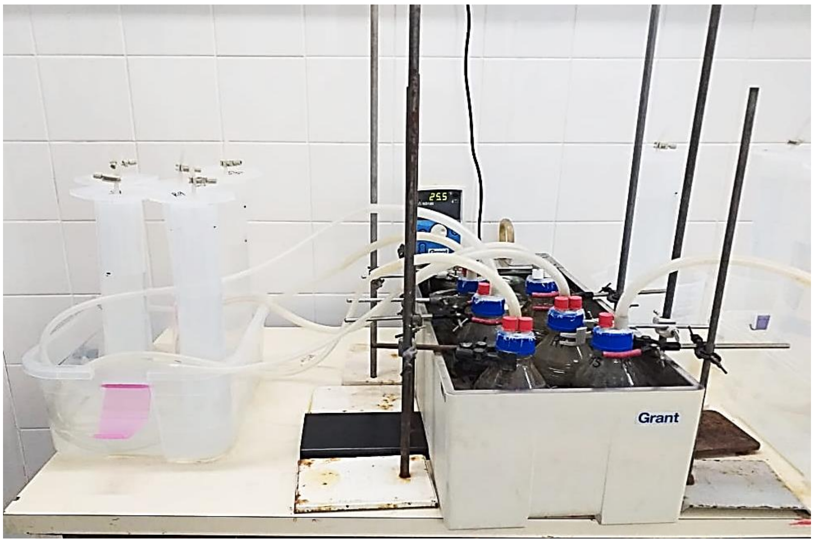

Figure 3: The setup of the biomethane potential test employed in this study

3.2.1 Biogas production at 25 °C

In the operation of biodigesters at 25 °C, biogas production was relatively slow at the start of the experiment and was observed to increase on day 9 for both biodigesters A2 and C (Figure 4). Biogas production of biodigesters A1 and B were observed to increase slightly until day 5 where both were found to produce at a constant rate until digestion was completed (Figure 4). Production rates on day 29 (663 mL) and day 30 (665 mL) were observed to be almost the same for both C and A2, but afterwards, A2 produced biogas at a constant rate on day 30 until digestion was complete. A sharp rise in biogas potential on day 34 of biodigester C could be attributed to maximal hydrolytic activity of the ferment which in turn could have caused rapid carbon dioxide production.

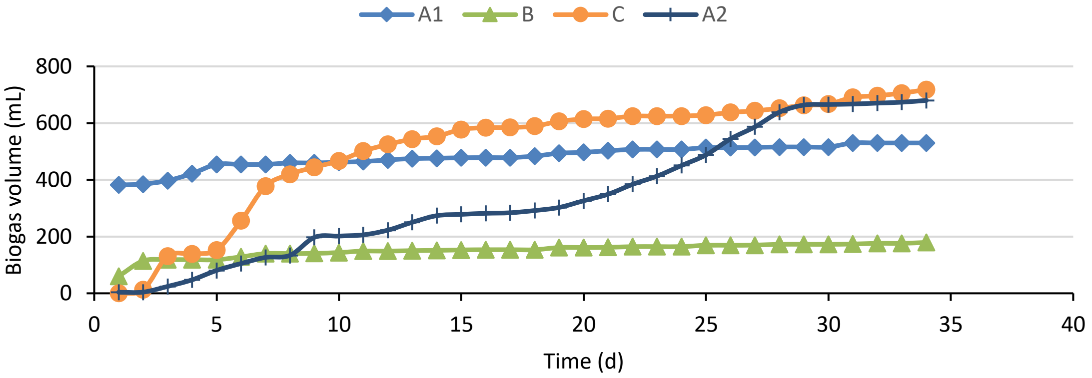

Figure 4: Cumulative biogas potential at 25°C

3.2.2 Biogas production at 35°C

In the operation of biodigesters at 35 °C, biogas production was relatively slow at the start for biodigesters C, B and A1. In the case of A2, there was a prolonged increase in the biogas production after day 1 to day 19 when a sharp rise was noticed. Thereafter, the biogas production was observed at a constant rate until the digestion was complete. Under this temperature, there was a lag phase on day 1 for all biodigesters as observed in a similar study by Simo et al. (2016). There was also a sharp rise in the biogas production between days 19 and 20 in biodigester B which could be due to a higher biodegradation performance of the microbial consortium. It was evidenced that, the AcoD with CS or SB could improve the biogas yield and provide a stable plant performance (Figure 5).

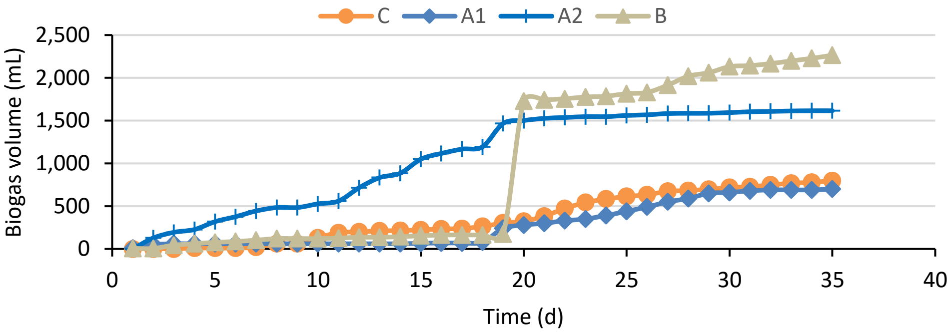

Figure 5: Cumulative biogas potential at 35 °C

According to Terboven et al. (2017), high temperatures favour the biogas potential in most anaerobic biodigesters. This is evident as higher biogas yield was observed in biodigester B (Figure 6) at 35 °C (2264.4 mL). Even though the highest biogas yield was reported by biodigester B at 35 °C, its potential of biogas at 25 °C was reported to be the lesser, an indication that biogas production by CS is favoured under high temperatures. Considering the biogas potential of biodigester C, the temperature variations at both temperatures were slightly different, even though the higher yield was favoured under 35 °C (Figure 6). The differences in the biogas yield was higher in biodigester A1 (169.9 mL) at both temperatures as compared to that of biodigester C (71.1 mL). A larger difference in biogas yield of 935 mL was observed by biodigester A2 between the two temperatures, favouring biogas production at 35 °C. The difference in biogas yield for the two temperatures are as follows: B>A2>A1>C.

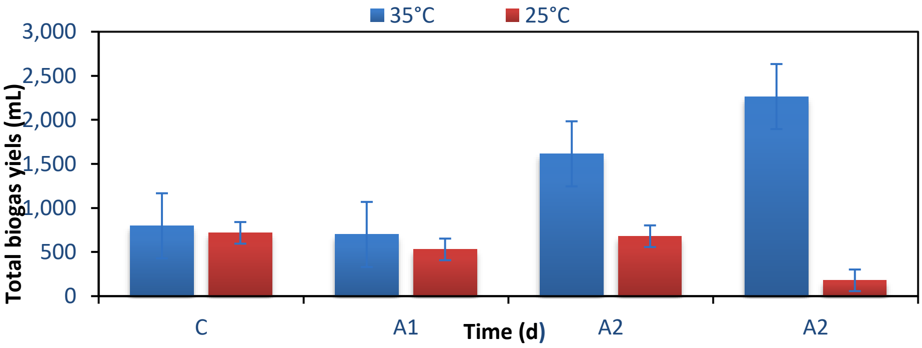

Figure 6: Overall biogas yield at 25 °C and 35 °C

4. Conclusions

In this study, SB and CS were observed to be potential feedstocks for biogas production to ease the dependency on fossil fuel, a non-renewable source of energy. Results from this study show that AcoD of CS at 55 °C obtained the highest biogas yield of 1.12 L/d at a lower retention period of 15 days, gaining an overall methane yield of 79 %. SB was also observed to yield higher biogas at 25 °C, an indication that low temperatures favour the biogas yield in SB compared to CS. In this regard, it could be deduced that temperature variation in anaerobic biodigesters play a significant role in the overall biogas potential. However, the AcoD of SB and CS were found to be viable, promising and could serve as an alternative energy source over anaerobic monodigestion in terms of operational cost and biogas yield. It is important, however, to engage energy researchers to consider the need for the usage of these feedstocks for clean and affordable energy as contained in the SDGs.

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