CHEMICAL ENGINEERING TRANSACTIONS
VOL. 76, 2019

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Petar S. Varbanov, Timothy G. Walmsley, Jiří J. Klemeš, Panos Seferlis

ISBN 978-88-95608-73-0; **ISSN** 2283-9216

DOI: 10.3303/CET1976246

Effect of Particle Size on Biogas Generation from Sugarcane Bagasse and Corn Silage

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

In this study, the effect of particle size on sugarcane bagasse (SB) and corn silage (CS) with industrial wastewater for biogas production were investigated at a mesophilic temperature of 35 °C. Biogas, a renewable source of energy could serve as an alternative means to replace the use of non-renewables such as coal in South Africa. It has been found that the speed and stability of the anaerobic digestion process depends mainly on the particle size of the input material. Variations in particle sizes for both SB and CS were observed at 2 mm, 1 mm, 0.6 mm and 0.4 mm whiles the hydraulic retention time, the organic loading rate and the pH of the biodigesters were kept constant at 20 d, 0.5 gVS/100 mL and 6.5 - 8.0. 1 L biodigesters controlled in batch mode were used in this study leaving a 200 mL headspace followed by nitrogen purging to create the anaerobic environment. Highest biogas yield of 125 mL/d was observed from CS at a particle size of 0.4 mm. The result showed that smaller particle size distribution favours the biogas production of CS compared to SB.

1. Introduction

As the recognition of energy crops appear on the rise for conversion into renewable forms of energy, the process of anaerobic digestion (AD) cannot be under-estimated. There appears a global concern in the use of non-renewables and so, there is a need to provide an alternative way to solve this problem. Biogas production using the anaerobic digestion process from agricultural waste is a suitable option without the competition for arable land (Kweinor-Tetteh et al., 2018). The introduction and implementation of biogas plants started well over 50 years ago to stabilize sewage sludge at wastewater treatment plants (Fagerström et al., 2018). Now, biogas tests are commonly carried out to determine the possible yield that can be obtained from feedstocks at laboratory scale batch systems (Maile et al., 2016). It thus aids in optimizing the process and establishing the profitability of the AD plants in terms of yield and gas quality in relation to the feedstock under study (Raposo et al., 2011). Though particle size is not considered as a major parameter compared to the pH and temperature of the digester contents, its influence on the biogas yield cannot be overlooked. Several studies have suggested that the efficiency of an AD could be enhanced by reducing the particle size to allow more rapid reaction rates through increased exposure of the surface area of the material to the microbes responsible for the process. The effects of particle size reduction and solubilisation on the overall biogas yield from food waste has also been studied. In that study, the reduction in the particle sizes was found to be dependent on whether the substrate had a higher fibre content and low degradability or with both combination of the substrate to increase the overall biogas production (Hartmann and Ahring, 2005). Smaller particle size has also been found to increase the surface area available to the microorganisms, resulting in an improved nutrient accessibility to bacteria and subsequently, increasing the anaerobic biodegradability (Hajji and Rhachi, 2013). Much attention has been derived from the importance of size reduction in relation to other significant factors such as pH, temperature, carbon nitrogen ratio, volatile fatty acids and pressure. No significant digestion benefit from extensive reduction was reported in a study by Chynoweth et al. (2001). Adding that, smaller particles of the materials under study might be uneconomic due to the energy input required. Mean particle size and the difference between the ranges of particles produced depends on the degree and type of the treatment under consideration. This is an important consideration, however, and it is likely that the preferred particle size distribution may be a compromise between

Paper Received: 13/05/2019; Revised: 07/06/2019; Accepted: 15/06/2019
Please cite this article as: Armah E.K., Chetty M., Deenadayalu N., 2019, Effect of Particle Size on Biogas Generation from Sugarcane Bagasse and Corn Silage, Chemical Engineering Transactions, 76, 1471-1476 DOI:10.3303/CET1976246

promoting the maximum biological activity and maintaining the physical and biochemical stability of biodiesters. According to Maile et al. (2016), different feedstocks have been used for the AD process including sugarcane bagasse, corn silage, water hyacinth, food waste, fruits and vegetables and many more. It is important to notice that the temperature of a bioreactor has a strong effect on the methanogenic consortia of microbes available and the overall kinetic rates (Young, 2012). It is suggested that anaerobes are more active at 35 °C than 55 °C and the latter tend to require higher heat input (Mital, 1997), making 35 °C a suitable temperature set for this study. SB is the residue after sugar mills which is generated from the sugar mill factories (Simo et al., 2016) and is mostly used as fuel in low-efficiency cogeneration systems (Leal et al., 2013). CS is made as a chopped, fermented feed source, primarily from annual crops like corn or wheat. It has been found to be a viable energy crop to increase the yield of biogas production via AD with animal manure by Arici and Koçar (2015). Therefore, the primary objective of this study was to examine the effect of particle size of SB and CS for the anaerobic digestion and also, assessing their suitability and potential as biogas feedstocks.

2. Materials and methods

Sugarcane bagasse and corn silage together with industrial wastewater and activated sludges were fed into each biodigester used in this study. The addition of the industrial wastewater, which is rich in nutrient supplements, was used to replace the use of synthetic feed for the microbes in the activated sludge, contrasting the study reported by Tetteh et al. (2017). Schott bottles, used as biodigesters were purchased by C.C Imelmann (Pty) Ltd, Johannesburg.

2.1 Sample collection and preparation

About 1,000 g of sugarcane bagasse was received from a Local Mill located in Durban, Kwazulu Natal (South Africa). SB was washed, dried, milled and sieved to the particle sizes of interest. It was then stored in plastic bags as a storage medium prior for analysis for the proximate, ultimate analysis and further, for the biogas potential test. Also, about 800 g of corn silage was received in a polyethylene plastic bag from a Rural Agriculture Department, KZN, followed by the proximate analysis, ultimate analysis and particle size distribution. The remaining portion was stored prior for loading into each biodigesters for the biogas potential test. 25 L of industrial wastewater was collected from a sugar wastewater treatment facility in Durban, South Africa. 10 L of activated sludge and 25 L of an inoculum from a primary digester with a digester capacity of 2,000 m^3 in a wastewater treatment plant that treats domestic and industrial effluents was also collected on-site. Thereafter, samples were kept in a cold room operating at a temperature of 4 ºC and characterized in duplicates within 48 h, similar to what was observed in a study by Tetteh et al. (2017).

2.2 Characterization Instrument and Equipment

All characterization procedures were carried out in the Laboratory using an analytical precision balance (Ohaus, Pioneer series, New Jersey, USA), a pH meter (Ohaus Corporation, USA), a convection oven (Thermo fischer scientific, Waltham, Massachusetts, USA), muffle furnace (Nabertherm-Industrieofenbau, Germany), a chemical oxygen demand (COD) reactor (Hach Company, Loveland, COLO, USA), a King test vibratronic (King Tester Corporation, Phoenixville, PA, USA) a thermogravimetric analyzer with a differential scanning calorimeter (TA Instruments, USA, Model: SDT Q600) and a scanning electron microscope (Evo HD 15, Carlzeiss, Germany) coupled with an energy dispersive x-ray analyzer (SEM-EDX) in this study.

2.3 Analytical methods

The proximate analysis classified feedstock in terms of their moisture content, ash content, volatile solids (VS), fixed solids (FS) and total solids (TS) according to the method developed by Sluiter et al. (2008) and are presented in Table 1. TS were determined at 105 °C to constant weight and the VS were measured by the loss in mass on ignition of the dried sample at 550 °C according to APHA (1998). Fixed solids and moisture contents were obtained from results of the VS and TS (APHA, 1998). A muffle furnace was used to carry out the ashing at 600 °C for 4 h until a whitish grey ash was obtained.

Table 1: 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

2.4 Experimental design, material selection and procedure

Duran schott bottles (1,000 mL) each, were used as the biodigesters operating in batch mode. Table 2 depicts the interpretation of each biodigester in relation to SB or CS. 5.1 g and 4.1 g of SB and CS were fed into each biodigesters respectively according to their VS content. Each of SB and CS were separated into their various particle sizes prior to the AD process (Figures 1-2). 150 mL of activated sludge, 400 mL of inoculum and 150 mL of industrial wastewater were added up to each biodigester containing the SB and CS to make up to the 800 mL mark, leaving a 200 mL headspace. 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) as depicted in Figure 3. Each biodigester was contained in a circulating water bath controlled at 35 ± 1°C until the digestion process was complete.
The biogas content was measured by the downward displacement of water over a calibrated measuring cylinder which was recorded daily. To ensure uniformity and to avoid low biogas yield in each biodigester, mixing was ensured regularly.

Table 2: Interpretation of each biodigesters during the anaerobic digestion process

Particle sizes (mm)	Sugarcane bagasse	Corn silage
2	AS	AC
1	BS	BC
0.6	CS	CC
0.4	DS	DC

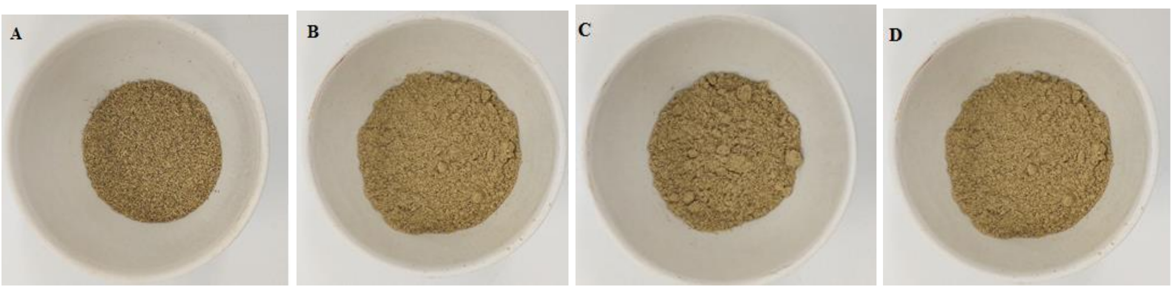

Figure 1: Photographs of the various particle sizes of the corn silage for (A) 2.0 mm, (B) 1.0 mm, (C) 0.6 mm and (D) 0.4 mm

Figure 2: Photographs of the various particle sizes of the sugarcane bagasse for (A) 2.0 mm, (B) 1.0 mm, (C) 0.6 mm and (D) 0.4 mm

Figure 3: Experimental setup of the biogas potential test employed in this study

3. Results and discussion

The trend of the daily biogas production with respect to the retention time (d) for both SB and CS is depicted in Figures 4 - 5. Biogas production commenced within the first 24 h after a short lag phase and was observed to increase significantly for both SB and CS.

3.1 Biogas production from corn silage

Figure 4 shows a gradual rise in the biogas yield from day 1 to 4 of the digestion process with DC reporting a maximum of 300 mL on day 2. BC showed a sharp rise in biogas production of 350 mL on day 10 and gradually declining from day 11 to 14. Afterwards, a total of 42 mL of biogas was reported on the 17th and the 18th day. Maximum biogas yield was observed for DC on day 18 where 446 mL of biogas was produced which could be due to a higher biodegradation performance of the microbial consortium (Simo et al., 2016). The accumulated biogas yield of DC was reported to be 2,500 mL for the entire 20 days, corresponding to an overall maximum biogas yield of 125 mL/d. The trends in the production rate was found in the decreasing order of DC (125 mL/d) > CC (105 mL/d) > BC (45 mL/d) > AC (36 mL/d), with AC reporting a maximum biogas yield of 115 mL on day 4. Highest biogas production from the least particle size has also been found in a similar study by Nalinga (2016).

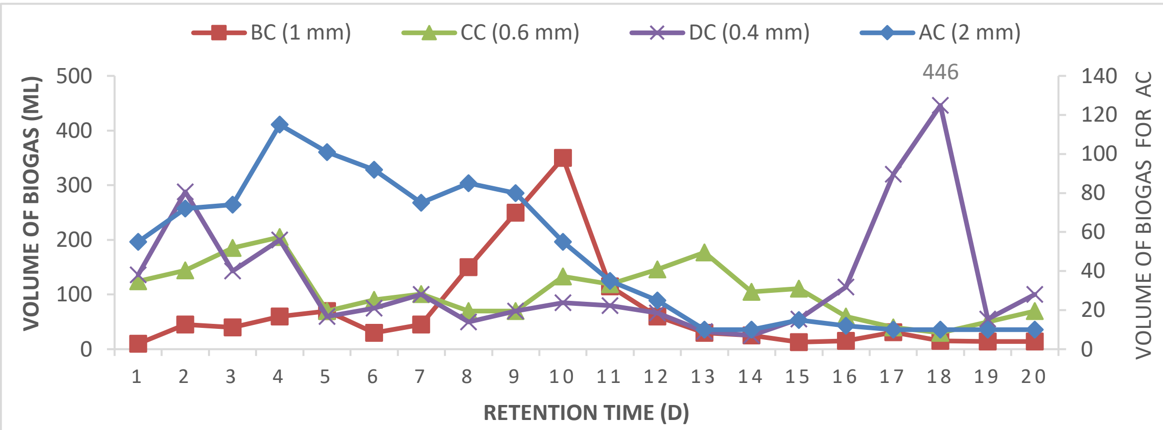

Figure 4: Biogas production from corn silage

3.2 Biogas production from sugarcane bagasse

In Figure 5, it is evidenced that biogas production from all the biodigesters started shortly after the lag phase with production rates increasing steadily in the case of CS on day 7 at a rate of 459 mL but dropped drastically on the 9th day. It could also be observed (Figure 5) that after day 13, all the biodigesters, most especially in the case of CS, no biogas was reported. This could be attributed to insufficient nutrient-enrichers to further enhance the biogas production by microbes leading to a drastically low yield. The trend in the production rate was found in the decreasing order of DS < BS < CS < AS. Increasing trend in the biogas production was observed from day 4 to day 10, evidenced in biodigesters DS, BS and CS. Biogas potential was significantly low in AS which could be due to the larger particle sizes with an accumulated volume of 16.65 mL/day over the entire digestion period as reported in a similar study by Nalinga (2016).

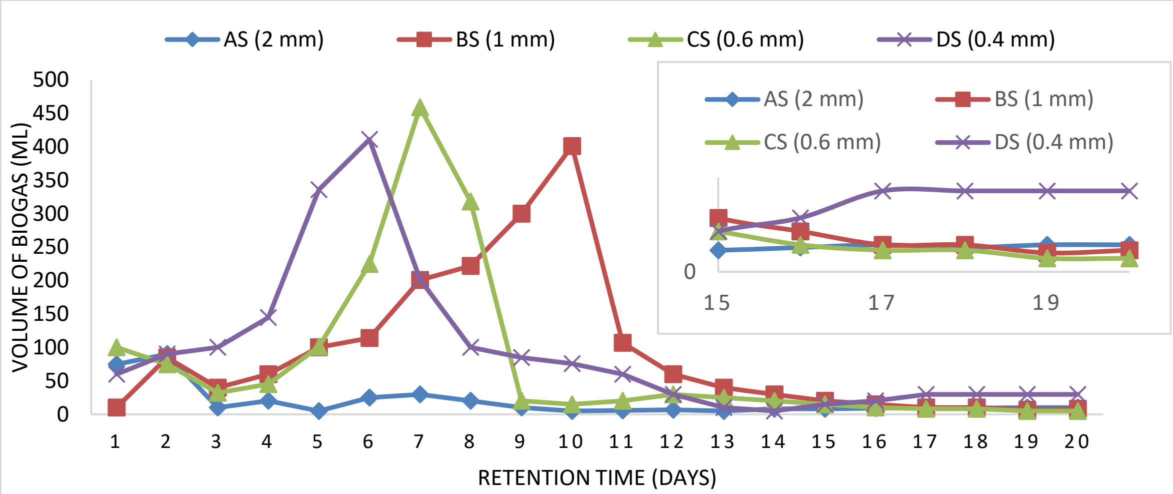

Figure 5: Biogas production from sugarcane bagasse

Biogas plants can be measured by studying and monitoring variation in parameters such as temperature, loading rate, hydraulic retention time and pH. In view of that, any sharp variation in these parameters have been found to adversely affect the biogas production process. The pH of anaerobic biodigesters is an important parameter affecting the growth of microbes during AD. An optimum pH range of 6.0 - 8.5 has been reported by Kougias and Angelidaki (2018), which was monitored in this study without the addition of a pH buffer. In this study, the pH before the AD process was found between the range of 6.2 - 7.0 while that of the pH reported after AD ranged from 6.5 - 8.5 for all the biodigesters (Figure 6). Studies have shown that for pH that exceeds or fall sharply below the optimum range, the AD process declines resulting in sudden decrease in methane production (Kougias and Angelidaki, 2018). This is caused by organic acid accumulations in biodigesters which could be corrected by CO_2 removal. The volatile fatty acids (VFAs) production rate is much higher than the methane production rate resulting in pH levels below the optimum range. This inhibits methanogens because of their higher levels of sensitivity to acidic conditions. In a typical AD process, pH level does not remain constant throughout the process because of the various AD processes especially at the acidogenesis stage due to VFAs production. It was observed in this study that CS or SB could improve the biogas yield and provide a stable plant performance in terms of their pH ranges.

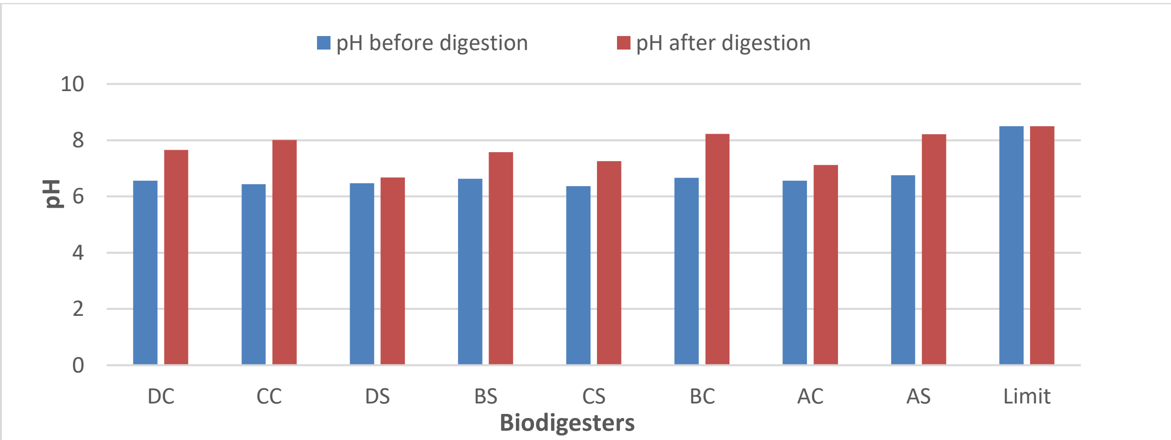

Figure 6: Report of the pH values for all the biodigesters under this study

4. Conclusions

Under the same operating conditions, CS was found to produce higher biogas yield with a smaller particle size as compared to SB. A higher biogas yield of 125 mL/d was observed from CS at a particle size of 0.4 mm for the overall production whiles the lowest biogas production was observed from SB (16.65 mL/d) with a particle size of 2.0 mm. Based on the results of this experiment as well as from that of literature, it could be concluded that the efficiency of biogas production in AD can be significantly improved by using the smallest particle size of the target substrate. Nonetheless, an improvement in the biogas production is found to be related to a good surface area of the feedstock under study for a complete microbial accessibility and biodegradation. Also, mesophilic temperature has been found in our previous study to favour CS than SB which is evidenced in this study as well. The conclusions reached in this study applies to small-scale batch operations, and thus, more investigation is essential to relate these findings to the operation of full-scale continuous digestion processes.

Acknowledgments

This research is funded by the Durban University of Technology under the National Research Foundation with grant number 105817.

References

Ahmad, S.I., Ho, W.S., Hassim, M.H., Elagroudy, S., Bong, C.P.C., 2019, Development of Quantitative Index for Waste to Energy Technology Selection: Safety and Health Parameters, Chemical Engineering Transactions, 72, 43-48.

Arici, Ş., Koçar, G., 2015, The effect of adding maize silage as a co-substrate for anaerobic animal manure digestion, International Journal of Green Energy, 12(5), 453-460.

Chynoweth, D.P., Owens, J.M., Legrand, R., 2001, Renewable methane from anaerobic digestion of biomass. Renewable Energy, 22(1), 1-8.

Fagerström, A., Al Seadi, T., Rasi, S., Briseid, T., 2018, The role of Anaerobic Digestion and Biogas in the Circular Economy. IEA Bioenergy Task 37.

Hajji, A., Rhachi, M., 2013, The influence of particle size on the performance of anaerobic digestion of municipal solid waste, Energy Procedia, 36, 515-520.

Hartmann, H., Ahring, B.K., 2005, Anaerobic digestion of the organic fraction of municipal solid waste: influence of co-digestion with manure, Water Research, 39(8), 1543-1552.

Kweinor-Tetteh, E., Amano, K.O., Asante-Sackey, D., Armah, E.K., 2018, Response surface optimization of biogas potential in co-digestion of *Miscanthus Fuscus* and cow dung, International Journal of Technology, 5, 944-954.

Leal, M.R.L., Galdos, M.V., Scarpare, F.V., Seabra, J.E., Walter, A., Oliveira, C.O., 2013, Sugarcane straw availability, quality, recovery and energy use: a literature review, Biomass and Bioenergy, 53, 11-19.

Maile, I., Muzenda, E., Mbohwa, C., 2016, Biogas production from anaerobic digestion of fruit and vegetable waste from Johannesburg market, International Conference on Biology, Environment and Chemistry, 98, 100-104.

Nalinga, Y., Legonda, I., 2016, The effect of particles size on biogas production, International Journal of Innovative Research in Technology & Sciences, 4 (2), 9-13.

Priya, E.S., Selvan, P.S., 2017, Water hyacinth *(Eichhornia crassipes)*–An efficient and economic adsorbent for textile effluent treatment–A review, Arabian Journal of Chemistry, 10, S3548-S3558.

Rahman, A. Z. A., Amin, N. A.S., 2019, Environmental Sustainability Assessment of Palm Lignocellulosic Biomass Pretreatment Methods, Chemical Engineering Transactions, 72, 13-18.

Raposo, F., Fernández-Cegrí, V., De la Rubia, M., Borja, R., Béline, F., Cavinato, C., Demirer, G., Fernández, B., Fernández-Polanco, M., Frigon, J., 2011, Biochemical methane potential (BMP) of solid organic substrates: evaluation of anaerobic biodegradability using data from an international interlaboratory study, Journal of Chemical Technology and Biotechnology, 86(8), 1088-1098.

Simo, W.S.F., Jong, N.E., Kapseu, C., 2016, Improving Biogas Production of Sugarcane Bagasse by Hydrothermal Pretreatment, Chemical and Biomolecular Engineering, 1(3), 21-25.

Sluiter, A., Hames, B., Hyman, D., Payne, C., Ruiz, R., Scarlata, C., Sluiter, J., Templeton, D. and Wolfe, J., 2008, Determination of Total Solids in Biomass and Total Dissolved Solids in Liquid Process Samples, Laboratory Analytical Procedure, 1-6.

Tetteh, E. K., Amano, K. O. A., Asante-Sackey, D., Armah, E. K., 2017, Biochemical Methane Potential (BMP) of *Miscanthus Fuscus* for Anaerobic Digestion, International Journal of Scientific and Research Publication, 7(12), 434-439.

Young, B., 2012, Enhancement of the Mesophilic Anaerobic Co-Digestion of Municipal Sewage and Scum, Master's Dissertation (Master of Applied Sciences in Environmental Engineering), University of Ottawa, Ottawa, Canada, pp. 19.