Characteristics of products from anaerobic digestion of cassava waste for biogas production

Abstract

This paper examines the characteristics of products from anaerobic digestion of cassava waste with and without starter culture. The anaerobic digestion experiment was conducted using a 20Litre anaerobic digester at mesophilic temperature for 41day hydraulic retention time. In addition to experimental yields, maximum theoretical biogas yield and biomethane potential were estimated using Buswell and Neave model, while the Hashimoto model was used to determine the kinetic parameters. Digestate specie distribution was assessed using elemental analysis. The result of study showed biogas yields of 0.1-0.25$m^3/kgVS_{added}$ for digester1 (D1), and 0.1-2.5$m^3/kgVS_{added}$ for digester2 (D2), with average yield ~0.2 and 1.0$m^3/kgVS_{added}$ for respective digesters. About 0.8$m^3/kgVS_{added}$ was estimated maximum theoretical biogas yield, and 1.32$m^3/kgVS_{added}$ for CH_4. The percentage of CH_4 in produced biogas was approximately 60%. The correlation coefficient (R^2) was 0.91 (D1) and 0.96 (D2), while 0.06 (D1) and 0.32 (D2) was obtained for the decay constant (k). The elemental composition of the digestates substantially reduce when compared with that of initial feedstock. About 40–68%C, 36.57%H_2, 21.4–28.6%S and up to 94%N was distributed to biogas phase, the remnant in the digestate.

Keywords: Agricultural waste, Anaerobic digestion, Biogas, Biomass–Bioenergy, Cassava waste

1. Introduction

With dwindling fossil fuel sources and growing concerns about climate change, effective waste disposal techniques and pollution control, pursuing an alternative and renewable source of energy has become important.

Interestingly, most of these developing tropical countries are highly dependent on agriculture, of which cassava is one of the major food crop, especially in Africa (Kemausuor *et al*., 2015). Approximately 60% of cassava product are used for human consumption, and also for animal and extraction of starch (Pandey *et al*., 2000; Veiga *et al*., 2016). In 2012, cassava product was reported to account for about 260MT globally. However, during processing of cassava from harvesting stage to finished products, large quantities of polluting organic wastes (peel and wastewater) are generated and discharged into the environment. Due to limited supply of energy from the national electric grid to the locals in these countries, they are highly dependent on wood and charcoal as form of energy for processing of the harvested cassava. Apparently, such activities leads to deforestation, erosion, loss of biodiversity and pollution effects such as release of particulate and smoke irritation to eyes and difficulties in breathing (Duku *et al*., 2011).

Cassava waste could be of great interest as it contains highly exploitable energy, availability, and have a relatively low market price incentive for cassava roots (Pattiya, 2011). On dry basis, cassava peel contains 2.20% lignin, 18.47% cellulose, 6% hemicellulose (Tovar *et al*., 2015). Therefore, organic waste from large areas of cassava field could be a source of renewable energy, and if the investment is economically viable, surplus amount of energy can be sold to improve profits. In last decade, worldwide cassava production had increased by 30% (FAO, 2012), thus bolstering the potentials of producing energy with cassava waste (Veiga *et al*., 2016). Cassava waste has been reported as one of most promising agricultural waste for biogas production (Thomsen *et al*., (2014).

As a result, there have been increasing research on developing technologies for conversion of the unutilized cassava waste to produce energy required for either drying and or mechanical press unit) during processing of cassava. Anaerobic digestion is one of the techniques for the conversion of organic waste materials. The biodegradation of organic matter through anaerobic digestion is a well-known natural process which is performed by specific microorganisms that transform degraded organic matter to produce biogas, and stabilized semi solid residue usually referred to as digestate (Roati *et al*., 2012). Biogas is an eco–friendly alternative source of energy, and contains 50–70% (v/v) methane (CH_4), 30–40% (v/v) carbon dioxide (CO_2) and trace amounts of hydrogen sulphide (H_2S) and ammonia (NH_3) (Kemausuor *et al*., 2015; Manilal *et al*., 1990). The digestate contains essential nutrients for plant growth, hence could be applied as biofertiliser.

A review of the scientific literature showed limited study on anaerobic digestion of cassava waste for biogas production. The few scientific studies were mostly on the feasibility of CH_4 production, either using cassava waste as a single substrate or co-digested with other organic waste. Aso *et al*., (2019) investigated anaerobic digestion of cassava peel using a batch mode anaerobic digester. They reported biogas yield including percentages of methane and mass balance for processing of cassava peel. However, the study performed individual AD of separated cassava peel of periderm and cortex. It is envisaged additional cost and time would be incurred for separation. Pattiya (2011) investigation was on the characteristics of cassava residues (stalk and rhizome) using proximate and ultimate analysis. Thomsen *et al*., (2014) investigated theoretical analysis of biomethane production using the Boswells' formula and the stoichiometry of chemical oxygen demand for varieties of agricultural waste including cassava peel.

In 1992, Cuzin *et al*. investigated methane potential of cassava peels using a plug flow anaerobic digester. They reported 85% of theoretical of biogas yield and estimated amount of energy for drying unit. Other research studies were on biomethane production from codigestion of cassava peel with other organic waste (Asikong *et al*., 2012; Ezekoye *et a*l., 2011; Oparaku *et al*., 2013). This aforementioned studies have demonstrated the feasibility of producing biogas from cassava waste. However, there are limited data on methanogenic pressure build-up inside digesters and elemental species distribution during anaerobic digestion. Also, there is limited data on the maximum methane yield achievable from AD of cassava waste (Ahou *et al*., 2019) Therefore, the focus of this study is to address the knowledge gap.

2. Materials and method

Cassava peel used for this study was collected from local farm in Oleh (5.4589°N, 6.2031°E) Delta State, Nigeria. Anaerobic digestion experiment were conducted using 20L fabricated digester. The digester had three openings at the top. One of the openings was used an inlet for addition of substrate, the second functioned as an outlet for gas collection, while the third was fitted with pressure gauge. A schematic view of the anaerobic digester parts and its assembly is shown in Figure 1.

Starter culture was prepared using 3kg of cow dung and 9L of water, forming a slurry. The slurry was fed into the digester, sealed, and allowed to stand for 14day HRT. After allowed stand time, the digester was opened to obtain the effluent (wastewater), which was filtered in order to remove particles. The filtrate obtained was used as starter culture.

2.1.Anaerobic digestion procedure

Two digesters were used for the anaerobic digestion experiment. One of the digester (D_1) was loaded with 2kg of cassava peel (3mm), 3L water and 3L starter culture, while the second digester (D_2) was fed with 2kg of cassava peel and 6L of water.

The anaerobic digestion experiment was conducted over 41days hydraulic retention time (HRT). The digesters were agitated by manual shaking for about 2minutes daily during the entire HRT (Labatut *et al*., 2011). This is in order to facilitate contact between bacteria and substrates, to avoid accumulation of toxic substances, fatty acids, and to enhance digestion (Eboibi *et al.*, 2015). The daily biogas production was collected on a two-day interval basis using water displacement method. After completion of predefined HRT, the digestion was stopped and the digestate were removed.

=

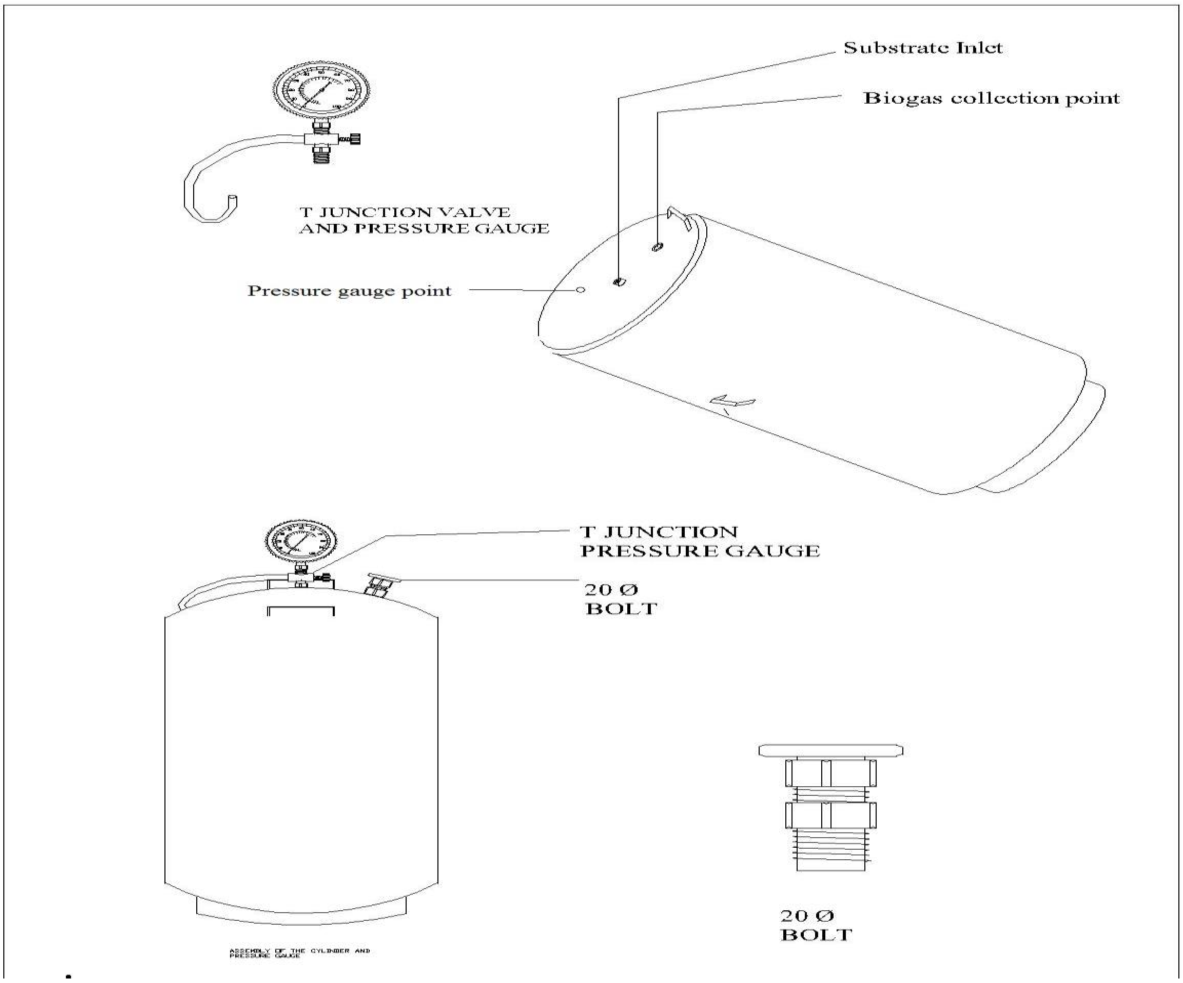

Figure 1: Schematic view of anaerobic digester.

2.2. Analysis

The proximate analysis were determined by methods as explained in previous studies (Aso *et al*., 2019; Polematidis *et al*., 2008).

The composition of elemental carbon (C), hydrogen (H), nitrogen (N), and sulfur (S) of cassava peel, and the anaerobic digestates were determined in accordance to the ASTM-D-5239 method using VarioEL III Elemental Analyser system, GmBH. The oxygen (O) content was obtained by difference (100% - sum (CHNS)).

The higher heating values (HHV, MJ/kg) were determined by substituting the CHNSO data into a unified correlation equation (Eq. (1)) proposed by Channiwala and Parikh, (2012)

$$HHV\ \left(\frac{MJ}{kg}\right) = 0.3491C + 1.1783H + 0.1005S - 0.1034O - 0.151N - 0.0211A \qquad 1$$

where: C, H, N, S, and O represents the mass of carbon, hydrogen, nitrogen, Sulphur, and oxygen on a dry weight basis.

Buswell and Neave, (1930) proposed formula (Eq. 3), developed from stoichiometric balance between the amount of organic matter (expressed as $C_aH_bO_cN_b$) to be biodegraded and the gaseous product resulting from its anaerobic biodegradation was applied to estimate methane yield.

$$C_aH_bO_cN_b + \left(a - \frac{b}{4} - \frac{c}{2} + \frac{3d}{4}\right) H_2O \rightarrow \left(\frac{4a+b-2c-3d}{8}\right) CH_4 + \left(\frac{4a-b-2c-3d}{8}\right) CO_2 + d^* NH_3 \quad 2$$

The maximum theoretical biogas and methane yields (also known as the biochemical methane potential) were estimated using Eq. (3) and Eq. (4), respectively, which was obtained from the general balance of Eq. (2) (Roati *et al*., 2012).

$$Biogas\ (\frac{m^3}{kgVS}) = \frac{22.415a}{12a+b+16c+14d} \quad 3$$

$$CH_4\ (\frac{m^3}{kgVS}) = (\frac{\frac{4a+b-2c-3d}{8}}{12a+b+16c+14d})22.415 \quad 4$$

The percentage of methane production was obtained using Eq. (5) (Roati *et al*., 2012)

$$CH_4\% = \frac{CH_4\ (\frac{m^3}{kgVS})}{Biogas\ (\frac{m^3}{kgVS})} \quad 5$$

The kinetics of the methane yield was determined using a first order kinetic equation (Eq. 6) proposed by (Hashimoto, 1989).

$$B = B_o(1 - exp^{(-kt)}) \quad 6$$

where B, B_o, k, t, represents the cumulative methane yield, maximum methane yield, first order decay constant, and hydraulic retention time, respectively.

3.0. Results and discussion

3.1. Feedstock analysis

The proximate and elemental composition of the feedstock (cassava peel) is presented in Table 1. The cassava peel has a moisture content of 6.4%, 89.5% volatile solids, and about 3.2% ash content. Also, it comprises of 54.33% carbon, 6.84% hydrogen, 0.90% nitrogen, ~0.1% sulfur content and 37.83% oxygen content, with HHV of 22.92MJ/kg. As shown in Table 1, the elemental and proximate data within the range of previous research investigations. The carbon content was found to be more than 42.91 to 44.6% carbon content reported by Veiga *et al*., (2016) but close to 51.59% reported by Pattiya, (2011). The hydrogen content of 6.52% to 6.69%, 0.8% to1.27% nitrogen and 0.1-0.2 % sulfur are very well with the range of respective element found in the present study.

Moreover, there was a marginal difference between the oxygen content of present study to those of previous report, which corresponded with little variation in the HHVs of 22.92MJ/kg of present study. HHV of 21.46MJ/kg was reported by Pattiya, (2011), while Tovar *et al*., (2015) reported 12.78MJ/kg. About 16.59-23.67MJ/kg HHV was reported by Veiga *et al*., (2016). The difference in this HHV could be due to the differences in oxygen content, as the higher the oxygen content the lower the HHV, vice-versa. The volatile solids of 77.77% and 85% to 87% were found close to 89.5% of present study. Also, the ash (3.2%) and moisture (6.4%) contents and were in within range of those reported in scientific literature, as shown in Table 1.

Table 1 Properties of cassava waste

Analysis	Present study	Pattiya, (2011)	Tovar *et al*., (2015)	Veiga *et al*., (2016)
	Proximate analysis			
Moisture content	6.4	8.31%	NR	9.55 to 9.73
Ash	3.2	4. 05%	NR	2.13 to 3.3
VS	89.5	77.77	NR	85 to 87
	Elemental analysis			
C	54.33	51.59	39.96	42.91 to 44.6
H	6.84	6.69	3.98	6.52 to 6.58
N	0.90	1.27	0.26	0.8 to 1 01
S	0.1	<0.1	0.12	<0.2
O	37.83	40.45	55.68^	48. 08 to 49.97
HHV, MJ/kg	22.92	21.46*	12.78*	16.59 to 23.67

^Estimated by difference. *Estimated with Channiwala and Parikh, (2012) unified correlation equation

3.2. Biogas yield and pressure build-up

The biogas yield obtained from AD of cassava peel with (Digester 1) and without starter culture (Digester 2) is shown in Figure 2. As shown in Figure 2, there was a wide difference in yield of biogas, despite observing the digestion under same condition except with and without starter culture. Biogas yield from Digster2 was between 0.1 and 2.52m^3/kgVS$_{added}$ with the maximum yield (2.52m^3/kgVS$_{added}$) obtained at 17day HRT, the minimum (0.025m^3/kgVS$_{added}$) at 41day HRT. For D_1, biogas yield was in the range of 0.1-0.35m^3/kgVS$_{added}$, with the maximum yield of 0.327m^3/kgVS$_{added}$ at 23day HRT, and minimum of 0.08m^3/kgVS$_{added}$ at 15day HRT. The trend in yield depict microorganisms growth phase comprising of lag phase, stationary to dead phase as reported in previous study (Eboibi *et al.*, 2015). During AD, there is increase growth of syntropic bacteria such as Syntrophomonas and Syntrohorhabdus, which are capable to degrade large range of different types of organics (Usman *et al.*, 2020). The average yield for D1 and D2 were ~0.2m^3/kgVS$_{added}$ and 1.0m^3/kgVS$_{added}$, respectively. The variation in biogas yields for D1 and D2 suggest the starter culture led to inhibitory influence, thereby reducing the biodegradability in D1 compared to D2. Rapid acidification due to high biodegradable sugars and low nitrogen content and release of cyanide has been reported to cause early inhibitory effects and toxic to methanogenic bacteria during anaerobic digestion of cassava peel (Ahuo *et al.*, 2019; Cuzin *et al.*, 1990).

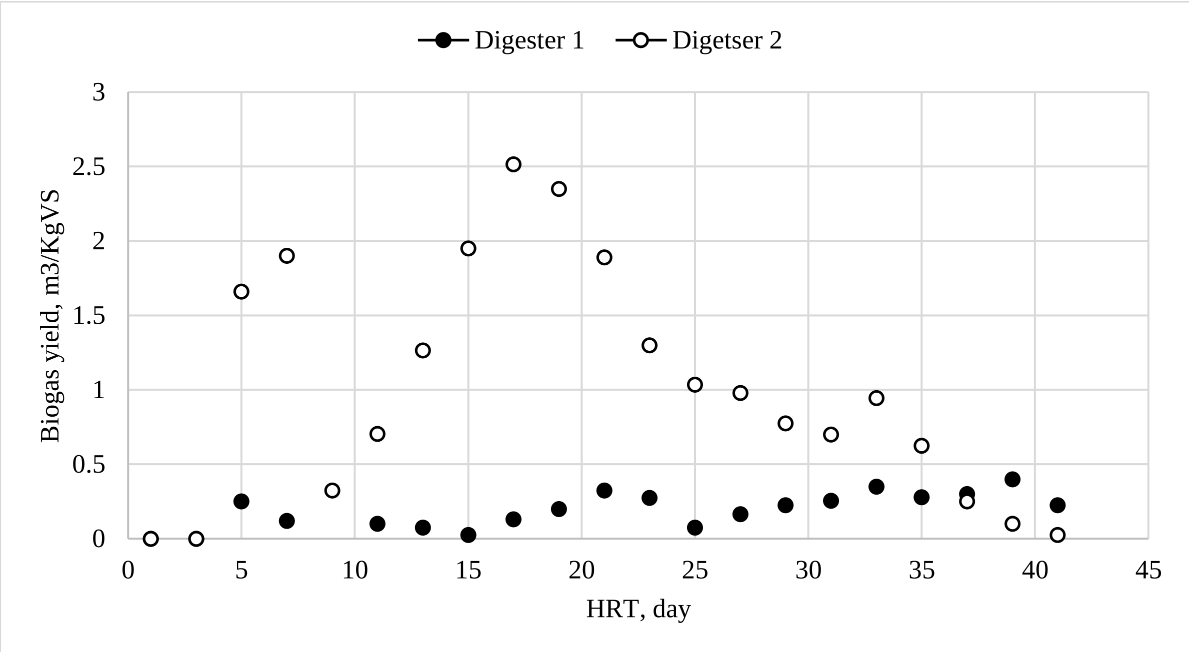

Figure 2: Biogas yield from anaerobic digestion of cassava peel.

Furthermore, the pressure build up inside the digesters are presented in Figure 3. As illustrated in the figure, pressure build-up in D1 was lower when compared to that of D2. This differences in pressure corresponded with biogas yields as mentioned earlier. Due to perceived inhibitory effects the methanogenic *Archaebacteria* could also have been supressed, reducing biological pressure production. About 0.08-0.7Psi and 0.08-3.7Psi pressure build-up was observed for D1 and D2, respectively. The maximum pressure was obtained at 17day HRT for D2, while it was at 23day HRT for D1, which also tallied with the HRT observed for maximum yields in biogas. Also, the pressure build-up inside both digesters were of similar trend as observed for biogas yields. This finding therefore suggests pressure build-up inside digesters could be a function of biogas yield.

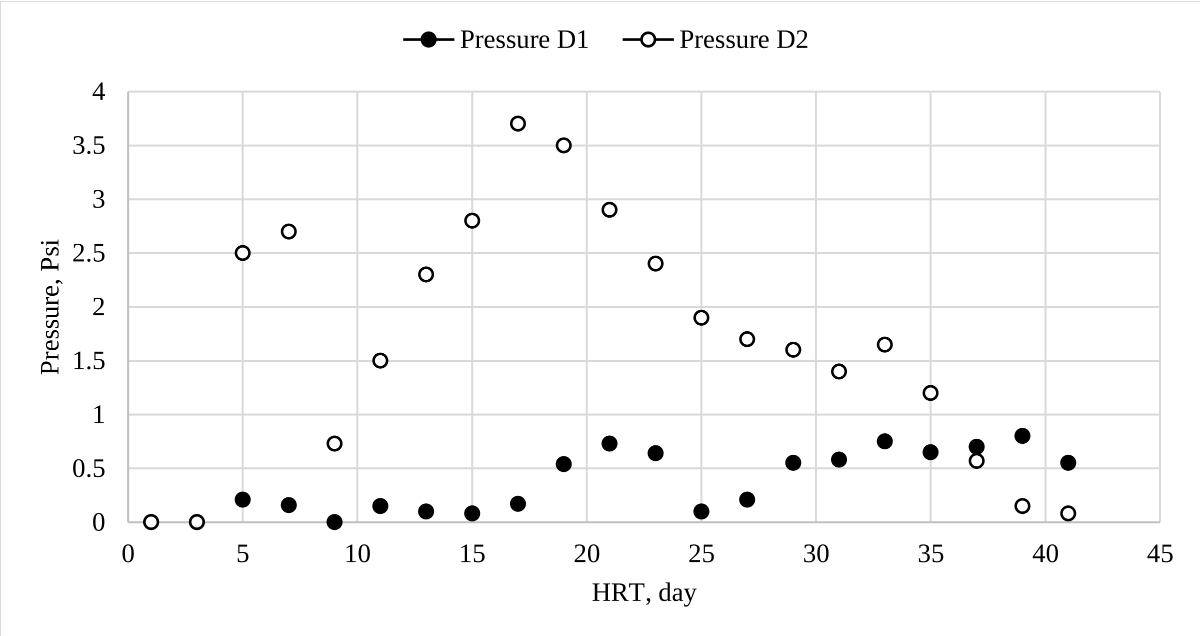

Figure 3: Pressure build-up from anaerobic digestion of cassava peel

Based on the biogas and biochemical methane potential analysis, the maximum methane (CH_4) yield from anaerobic digestion of cassava peel was 60%, which is in agreement and within the range of previous reports on anaerobic digestion of cassava waste. Earlier, Aso *et al*., (2019) reported 54% as mean CH_4 yield from the biogasification of cassava residue, while 58%, 57% and 59%CH_4 was obtained by Ahou *et al*., (2019), Cuzin *et al*., (1990) and Manilal *et al*., (1990), respectively, for anaerobic digestion of cassava waste.

This study has shown that anaerobic digestion of cassava waste produces biogas containing up to 60% CH_4, which is an important energetic potential. This could be of value in improving the economies of farmers involved in cassava processing. Moreover, the amount of methane could be improved up to 90%, reducing the CO_2 content, with the use of pressurised batch reactor (Lemmer *et al*., 2017; Lindeboom *et al*., 2011).

The biomethane methane potential for AD of cassava peel was found to be 0.8$m^3/kgVS_{added}$, while maximum theoretical yield in biogas yield was 1.32$m^3/kgVS_{added}$. In 2012, Roati *et al*. reported 0.72-1.61$m^3/kgVS_{added}$ biogas potential with 0.42-0.56%CH_4 for processing cassava wastewater The theoretical biogas yield of 1.32$m^3/kgVS_{added}$ was found to be within the range of previous studies but higher, but close, when compared to the average experimental biogas yield of ~1.0$m^3/kgVS_{added}$. This variation was expected as the Buswell's formula has been previously shown to overestimate yields, which could be majorly due to unaccounted microbial maintenance and biodegradability of substrate. Nevertheless, the application of stoichiometric method and biodegradability data was able to give reasonable estimation of specific methane yields (Labatut *et al*., 2011).

3.3. Kinetic parameters

The cumulative methane yields is presented in Figure 4. As shown in Figure 4, the correlation coefficient (R^2) was ~0.91 for D1 and 0.96 for D2, while the first order decay constant (k) were 0.06 for D1 and 0.36 for D2. There are limited information on the kinetics parameter of cassava peel, however, the obtained data in present was compared with related organic waste. The obtained R^2 and k values were found in good agreement with previously reported data on AD of organic waste, as shown in Table 2. Labatut *et al*. (2011) reported R^2 of 0.93 using Buswells' formula and 091 for McCartys model. Fleck *et al*., (2017) obtained R^2 of 0.94 and 0.80 for anaerobic digestion of cassava process wastewater. Li *et al*., (2013) reported R^2 of 0.980 and 0.964, and k of 0.15 and 0.09, respectively for rice straw and wheat straw.

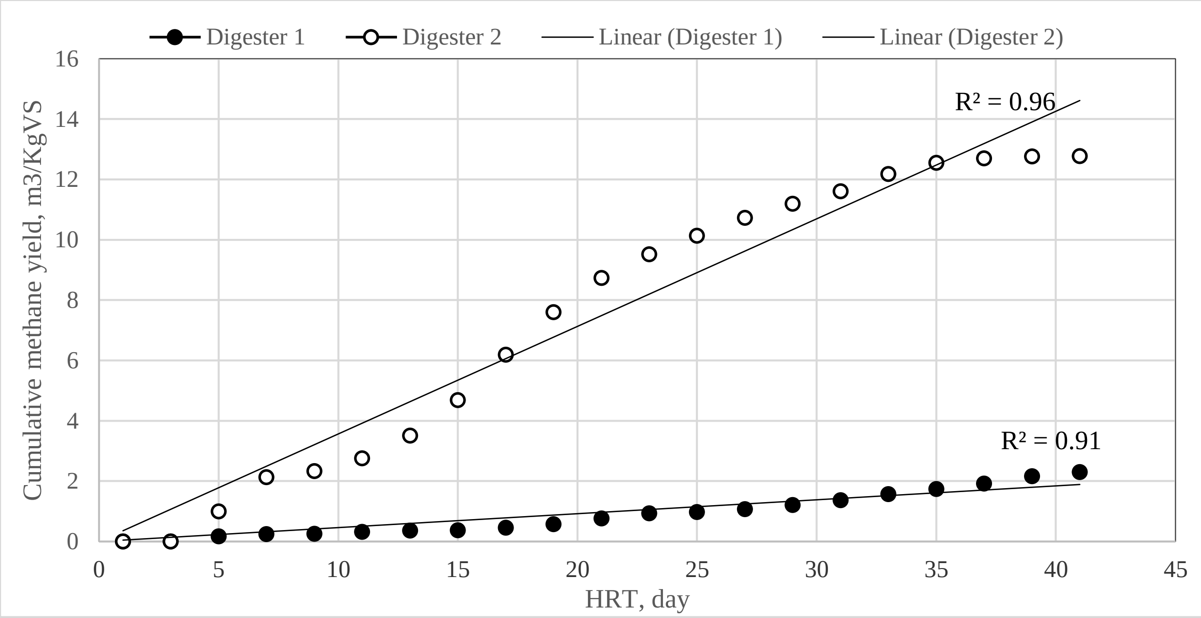

Figure 4: Cumulative methane yield from anaerobic digestion of cassava peel

Table 2: kinetic parameters for anaerobic digestion of cassava peel

Organic waste	R^2		k		Reference
	D1	D2	D1	D2	
Cassava peel	0.91	0.96	0.06	0.36	Present study
Food waste	0.86-0.99		0.056-0.364		Browne and Murphy, (2013)
Cassava wastewater	0.94, 0.80		NR		Fleck *et al*., (2017)
Organic substrates	0.91, 0.93		NR		Labatut *et al*., (2011)
Rice straw	0.980		0.15		Li *et al*., (2013)
Wheat straw	0.964		0.09		Li *et al*., (2013)

3.4. Elemental composition of digestates

The elemental composition (CHNSO) of the digestates obtained from D1 and D2 and compared with that of feedstock is presented in Figure 5. Figure 5 showed that the carbon content reduced from 54.33%w/w (initial feedstock) to 32.78%w/w and 17.31%w/w for D1 and D2 digestates, respectively. These element are essential in microbial growth during anaerobic digestion, which led to substantial loss of about 94% N in both digesters, and 36.5%, and 70.1% hydrogen, 21.4% and 28.6% sulfur for D1 and D2, respectively. Apparently, the oxygen content would reduce, due to biodegradability of the substrates, which had substantial impact on the digestate HHVs. The HHV of digestate reduced from 22.9MJ/kg to 10.1MJ/kg for D1 and 2.3 MJ/kg for D2, which accounted for 56.10% (for D1) and 89.80% (for D2) usage by the substrate. This finding reaffirms the better performance of digester 2 during anaerobic digestion. This study has provided additional information improving the database for anaerobic digestion conversion efficiency of cassava waste, which could be useful in the design and applications for biogas production.

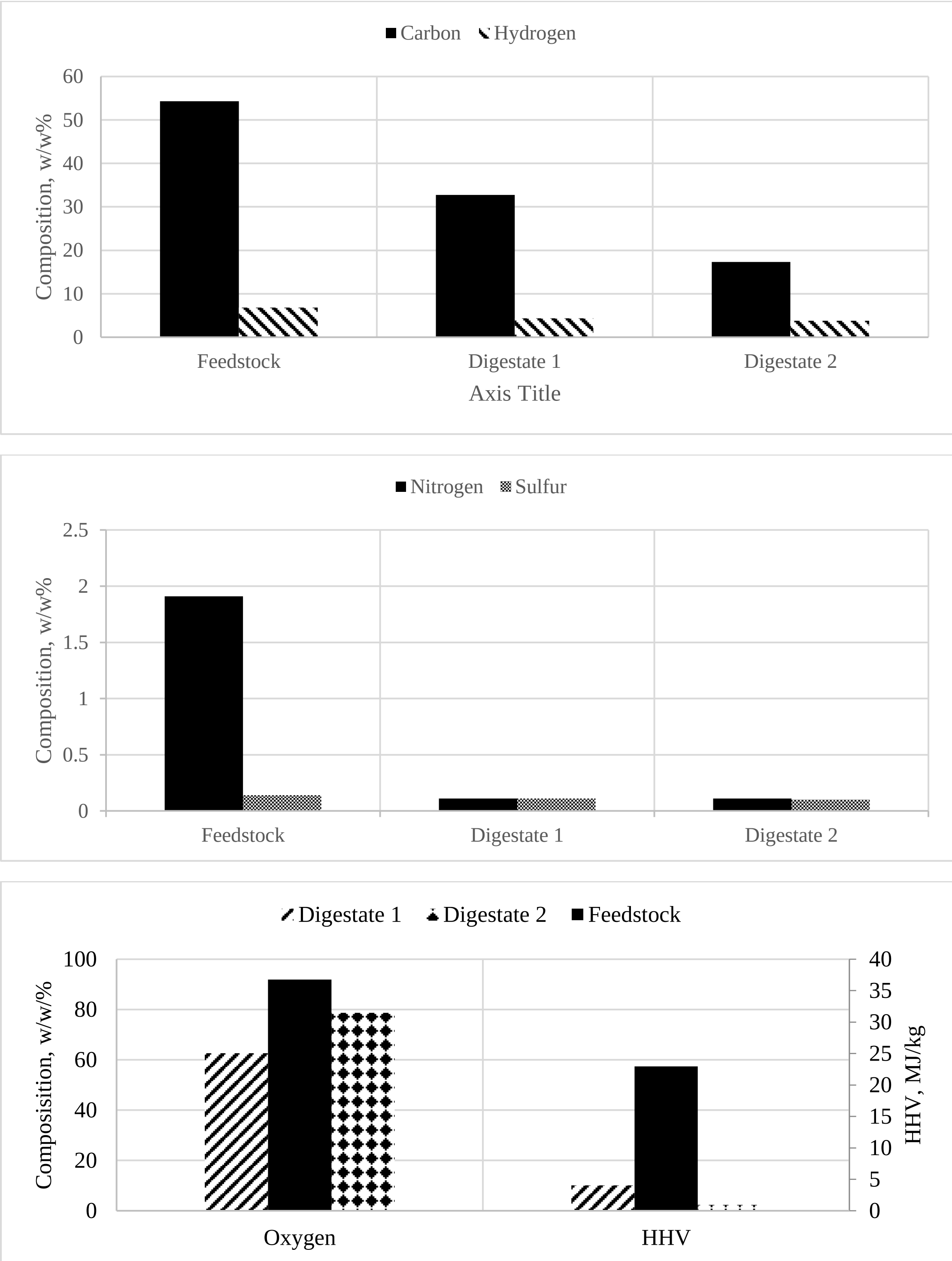

Figure 5: Elemental composition of digestate from anaerobic digestion of cassava peel

Conclusion

Characteristics of product from anaerobic digestion of cassava waste was evaluated in this study. Experimental yields and theoretical estimates were also compared. The study showed the feasibility of producing biogas from cassava waste, with substantial impact of starter culture on products yield and properties. An average biogas yield of 0.2 and 1.0m^3/kgVS$_{added}$ was produced, while 1.32 m^3/kgVS$_{added}$ was estimated maximum theoretical yield, with 60%CH_4 content. Further studies on influence of starter culture at different ratios on AD is necessary. The elemental composition of the digestates were found to substantially reduce when compared with that of initial feedstock. About 40–68%C, 36.57%H_2, 21.4–28.6%S and up to 94%N was distributed to biogas phase, the remnant in the digestate.

References

Ahou YS, Jean-Romain Bautista Angeli J-RB, Awad S, Baba-Moussa L, Andre Y (2019) Lab-scale anaerobic digestion of cassava peels: A first step of energy recovery from cassava waste and water hyacinth. Environmental Technology, DOI: 10.1080/09593330.2019.1670266

Aso SN, Pullammanappallil PC, Teixeira AA, Welta BA (2019) Biogasification of cassava residue for on-site biofuel generation for food production with potential cost minimization, health and environmental safety dividends. Environmental Progress & Sustainable Energy, DOI 10.1002/ep.

Asikong BE, Epoke J, Agbo BE, Antai EE, Eja ME (2013). Potentials of biogas generation from mixture of three substrates, water hyacinth, cassava peels and cow dung- Wh+Cp+Cd, Chemical and Process Engineering Research, 17, 2. 28.

Browne JD, Murphy JD (2013) Assessment of the resource associated with biomethane from food waste. Applied Energy 104, 170–177

Buswell AM, Neave SL (1930) Laboratory studies of sludge digestion. Department of Registration and Education, 1-85.

Channiwala SA, Parikh PP (2012) A unified correlation for estimating HHV of solid, liquid, and gaseous fuels. Fuel, 81:1051–1063.

Cuzin N, Farinet JL, Segretain C, Labat M (1992) Methanogenic fermentation of cassava peel using a pilot plug flow digester. Bioresource Technology, 41, 259-264

Duku MH, Gu S, Hagan EB. (2011). A comprehensive review of biomass resources and biofuels potential in Ghana, Renewable and Sustainable Energy Reviews, 15, 404–415.

Eboibi BE, Lewis DM, Ashman PJ, Chinnasamy S. (2015) Influence of process conditions on pretreatment of microalgae for protein extraction and production of biocrude during hydrothermal liquefaction of pretreated *Tetraselmis* sp. RSC Adv., 5, 20193 –20207.

Ezekoye VA, Ezekoye BA, Offor PO (2011). Effect of retention time on biogas production from poultry droppings and cassava peels, Nigerian Journal of Biotechnology, 22, 53–59.

FAO-Food Agriculture Organisation of the United Nations, FAO Statistical Database, 1990-2011, 2012.

Fleck L, Tavares MHF, Eyng E, Andrade MAM, Frare LM (2017) Optimization of anaerobic treatment of cassava processing wastewater. Eng. Agríc., Jaboticabal, 37, 574-590.

Hashimoto AG (1989) Effect of inoculum substrate ratio on methane yield and production rate from straw. Biological Wastes 28, 247-255.

Kemausuor F, Addo A, Darkwah L (2015) Technical and Socioeconomic Potential of Biogas from Cassava Waste in Ghana. Biotechnology Research International, http://dx.doi.org/10.1155/2015/828576.

Li Y, Zhang R, Liu G, Chen C, He Y, Liu X (2013) Comparison of methane production potential biodegradability, and kinetics of different organic substrates. Bioresource Technology, 149, 565–569.

Labatut RA, Angenent, LT, Scott NR (2011) Biochemical methane potential and biodegradability of complex organic substrates. Bioresource Technology, 102, 2255–2264.

Lemmer A, Merkle W, Baer K, Graf F (2017) Effects of high-pressure anaerobic digestion up to 30 bar on pH-value, production kinetics and specific methane yield. Energy, 138, 659-667.

Lindeboom, REF, Fermoso FG, Weijma J, Zagt K, van Lier JB (2011) Autogenerative high pressure digestion: anaerobic digestion and biogas upgrading in a single step reactor system. Water Science & Technology 64, 3, 647-653.

Manilal VB, Narayanan CS, Balagopalan C (1990) Anaerobic digestion of cassava starch factory effluent. World Journal of Microbiology and Biotechnology 6, 149-154.

Oparaku NF, Ofomatah AC, Okoroigwe EC (2013). Biodigestion of cassava peels blended with pig dung for methane generation, African Journal of Biotechnology, 12, 5956–5961.

Pandey A, Soccol CR, Nigam P, Soccol VT, Vandenberghe LPS, Mohan R (2000) Biotechnological potential of agro-industrial residues. II: cassava bagasse. Bioresource Technology, 74, 81–87.

Pattiya A Thermochemical Characterization of Agricultural Wastes from Thai Cassava Plantations (2011). Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 33:8, 691-701.

Polematidis I, Koppar A, Pullammanappallil P, Seaborn S. (2008). Biogasification of sugarbeet processing by-products, Sugar Industry/Zuckerindustrie, 133, 323–329.

Roati C, Fiore S, Ruffino B, Marchese F, Novarino D, Zanetti MC (2012) Preliminary Evaluation of the Potential Biogas Production of Food-Processing Industrial Wastes. American Journal of Environmental Sciences, 8, 3, 291-296.

Thomsen ST, Kadar Z, Schmidt JE (2014) Compositional analysis and projected biofuel potentials from common West African agricultural residue. Biomass and Bioenergy, 63, 210-217.

Tovar CT, Ortiz AV, Jaraba LEG (2015) Kinetics of Adsorption in Mercury Removal Using Cassava (*Manhiot esculenta*) and Lemon (Citrus limonum) Wastes Modified with Citric Acid. Ing. Unv., 19, 283-298.

Usman M, Shi Z, Ren S, Ngo HH, Luo G, Zhang S (2020) Hydrochar promoted anaerobic digestion of hydrothermal liquefaction wastewater: Focusing on the organic degradation and microbial community. Chemical Engineering Journal (2020),doi: https://doi.org/10.1016/j.cej.2020.125766.

Veiga JPS, Valle TL, Feltran JC, Bizzo WA (2016) Characterization and productivity of cassava waste and its use as an energy source. Renewable Energy, 93, 691-699.