ANAEROBIC CO-DIGESTION OF KITCHEN AND ANIMAL WASTES AT VARYING MIXING RATIOS

ABSTRACT

The treatments of potato:chicken dung (POP:CHD), yam peel:cow dung (YP:CD) and unripe plantain peel:cow dung (PP:CD) wastes by anaerobic co-digestion were studied. A hydraulic retention time (HRT) of 30 days was applied for the digestion process. Biogas production was collected by downward displacement of water. The maximum volume of biogas production from POP:CHD co-digestion was obtained as 5,705 ml at 20% POP:CHD mixing ratio. The maximum volume of biogas production from YP:CD and PP:CD co-digestions were obtained as 1,375 and 1,305 ml at the mixing ratio of 20:80. The parameters analyzed (Ph, temperature, total suspended solids (TSS), carbon oxygen demand (COD), etc.) fell within the prescription limits of WHO (World Health Organization). The kinetics of anaerobic digestion of the wastewater was described by first-order kinetic model. This study showed that biogas can be successfully produced from POP:CHD, YP:CD and PP:CD co-digestions. The slurries obtained can be applied as manure because their improved flow properties would enable the digestate to penetrate faster in the soil.

Keywords: Anaerobic digestion, Potato peel (POP), Chicken dung (CHD), Cow dung (CD), Yam peel (YP), unripe plantain peel (PP), biogas, First-order Kinetic model

1.0 INTRODUCTION

Anaerobic digestion has been widely used for solid waste treatment. It is applied in the production of methane-rich biogas which is a potential source of generating renewable energy (Ali *et al*., 2017). Anaerobic digestion has become a very important area of interest in waste management all over the world. This process of waste treatment is environment-friendly while producing biogas energy and residue that can be used as manure (Nweke *et al*., 2015). The energy generated is advantageous because it is carbon neutral, results in reduced emissions of pollutants, and promotes energy security. The use of renewable energy will result in local job creation and the saving of foreign currency expenditure on the importation of fossil fuels (Roopnarain and Adeleke, 2017).

Although anaerobic digestion is well-known process for treatment, its studies using chicken waste is limited due to economic and environmental concerns. Chicken waste has a high nitrogen content due to its high protein and amino acids content when compared to other farm animals. Hence, it contains low carbon/nitrogen (C/N) ratio and high ammonia value making it a difficult substrate to digest by inhibiting the conversion of organic materials to biogas using this method (Ali *et al*., 2017). It has been proven that C/N ratio is one of the factors affecting biogas production (Song and Zhang, 2015; Wordofa, 2014). An optimum C/N ratio of between 25:1 and 30:1 is required for the digester to carry out its work at full potential (Ali *et al*., 2017; Teghammar, 2013).

Anaerobic co-digestion (ACD) is the anaerobic digestion (AD) process of a combination of different substrates in the anaerobic digestion process (Ozoegwu *et al.*, 2017). Most studies of co-digestion of livestock waste, fruit and vegetable waste, organic fractions of municipal solid waste, anaerobic sludge etc. have given positive results. Results indicated that the biogas and methane volume increased when compared to mono-digestion. Co-digestion of chicken waste with a substrate rich in carbon has been recommended as a method to improve biogas production instead of mono-digestion of chicken dung. Chicken manure is biodegradable and can be employed in anaerobic digestion. This helps to improve the nutrient balance, improve biogas production and dilute the ammonia content without adding water or chemicals which will end up increasing the cost of biogas production. In addition to this, other factors such as temperature, pH, type of substrate, hydraulic retention time (HRT), total solid (TS), volatile solid (VS) contents, mixing and stirring etc. affect biogas production (Ali *et al*., 2017; Wordofa, 2014; Zhai *et al.*, 2015; Huang *et al.*, 2016).

Co-digestion of wastes and cow manure has environmental, technology, and economic benefits when compared with a single substrate processing. This is because mono-digestion of cow dung or food wastes most times led to poor performance and stability due to its insufficiency in essential trace elements of organic waste. Anaerobic mono-digestion of cow dung often resulted in poor performance and stability due to its insufficiency in essential trace elements of organic waste (Tufaner and Avsar, 2016). Also, digesting food waste alone does not release all the biogas yield and inhibition can occur due to nutrient imbalance (Morales-Polo *et al.*, 2018). However, the co-digestion of a different kind of organic waste, especially cow dung resolved any imbalance in pH, alkalinity, macro, and micronutrient elements and increased the biogas production (Tufaner and Avsar, 2016). Other important advantages achieved with co-digestion are improved process stabilization, dilution of inhibitory substances, higher buffer capacity due to higher ammonia from organic wastes, improving moisture content, methane enrichment, and economic feasibility (Morales-Polo *et al.*, 2018). Co-digestion of wastes and cow dung increases the rate of biogas production because it most times achieves the optimum C/N ratio of 20-30 required for improved digestion efficiency (Achinas and Euverink, 2019; Zhang *et al.*, 2013). Co-digestion of substrates can enhance biogas production from 35% to 400% over the mono-digestion of each substrate (Morales-Polo *et al*., 2018).

Sawyerr *et al.* (2017) studied the co-digestion of cow dung and cassava peels (CD:CP) and reported that the CD:CP ratio of 20:80 produced the highest methane yield followed by the ratio of 80:20. Comparable cumulative biogas volume of 1,387 ml was reported from the co-digestion of cow manure and kitchen waste in a one-liter digester with a mixture of 50 g each of both cow dung and kitchen waste in 500 ml of water at 200 gm/L loading rate after ten days HRT in Tasnim *et al*. (2017). Makinde and Odokuma (2015) reported that the mono-digestion of plantain peels produced the least biogas volume when compared to the digestion of yam peels alone and co-digestion of yam peels or plantain peels with cow dung at different mixing ratios. Nweke and Nwabanne (2021) and Nweke *et al*. (2022) observed that the anaerobic digestion of yam peels produced the cumulative biogas volume of 400 ml and 440 ml respectively. Nweke and Nwabanne (2020) reported that the digestion of unripe plantain peels produced the cumulative biogas volume of 285 ml after digestion. However, the co-digestion of yam and unripe plantain peels using cow dung at various mixing ration needs to be investigated.

The aim of this work is to explore the influence of co-digestion of chicken waste and potato peel, the co-digestion of cow dung and yam peels and the co-digestion of cow dung and unripe plantain peels at various mixing ratios in terms of biogas production and to compare them with the biogas yield from their mono-digested states.

2. MATERIALS AND METHODS

2.1. Collection of Materials

The raw materials for this synthesis is potato peal (POP), chicken dung (CHD), unripe plantain peel (PP), Yam peel (YP) and cow dung (CD). The CHD (*Gallus gallus domesticus*) was sourced from a poultry farm at Amawbia, Anambra State while POP (*Solanum tuberosum*), YP (*Dioscorea rotundata*), PP (*Musa sapientun*), were collected from restaurants at the temporary site of Nnamdi Azikiwe University, Awka. CD (*Bos primigenius*), was collected from Kwata slaughterhouse, Awka. Other equipment used were thermometer, volumetric flask, pH meter, measuring cylinder, bio-digester, washing vessels, digital weighing balance, retort stand, digesters, plastic bowls, funnels etc.

2.2. Experimental Procedure

2.2.1 Description and fabrication of a mini-sized bio-digester for domestic use

The biogas digester was made from high density polyethylene (HDPE) plastic of volume 1 litre. It has the following parts; inlet hole (feed entrance) (5cm), outlet hole (3cm) and two gas outlet holes (1cm) drilled at the top of the lid and two extra slurry holes (1.3cm) and drainage hole (1.3cm) drilled at one side of the drum. The digesters were connected using downward displacement method. The schematic diagram of the connection of the different parts of the bio-digester is shown in Fig.1.

2.2.2 Substrate preparation

The preparation here refers to various preparatory steps applied to the raw material before introduction into the bio digester. The steps are discussed below:

2.2.2.1 Mechanical pre-treatment

The peels were sun-dried for 48 hours and ground to 1000 µm sieve size. The sizes of the POP, PP, YP, CHD and CD were reduced by grinding them to 1000 µm sieve size for ease of slurry formation, using a blender.

2.2.2.2 Slurry formation

120 g of the mechanically pretreated POP and CHD were weighed out for each batch of the treatment and then mixed at various mixing ratios with 500 ml of water in a plastic bowl so that the ratio of POP and CHD to water was 1:4. However, 200 g of the mechanically pretreated PP, YP, and CD were mixed at various mixing ratios with 400 ml of water in a plastic bowl so that the ratio of YP or PP with CD to water was 1:4.

2.2.3 Laboratory size bio-digester set up

The bowls were filled to about two-thirds of its volume with water, the cylinder was filled to the brim with water, the measuring cylinder containing water was carefully inverted and placed into the bowl containing water by placing a palm firmly on the open end of the measuring cylinder to avoid spilling the water and to ensure air is not collected above the water when inverted. The measuring cylinder was supported using a retort stand so that it is slightly above the bottom of the bowl tom allow the passage of the hose into the cylinder. This is a water displacement setup for gas collection and volume measurement.

The slurry was introduced into the plastic can using a funnel and a perforated lid was used to cover the can. One end of the hose was carefully passed into the cylinder of the water displacement setup and then the other end into the can through the perforation on the lid. The perforation was sealed with PVC adhesive and tape to ensure that it was airtight. Prior to digestion, CO_2 gas was passed into the digester to replace any air inside. The hose to collect gas was connected to biogas plastic container for gas collection. The amount of gas produced, composition, and the pH and of the substrates was recorded.

Fig. 1: The laboratory setup of anaerobic digestion

2.2.4 Characterization of the Wastes

Proximate analyses consisting of BOD (biological oxygen demand), COD (chemical oxygen demand), pH, temperature and TSS (total suspended solids) was carried out on the different mixtures of the waste slurries as shown in Table 1 for POP and CHD before and after digestion. The result of proximate analysis of PP before digestion can be obtained from Nweke *et al*., (2023). In addition, the result of proximate analysis of YP before digestion can be obtained from Onu *et al*., (2022).

2.2.5 Anaerobic digestion process

The digester was filled with the substrates according to the Table 1 and Table 2. Table 1 showed the various mixing ratios of POP and CHD while Table 2 showed the co-digestion of untreated yam peels (YP) and unripe plantain peels (PP) with cow dung (CD) at various mixing ratios while observing for biogas production. The substrates were mixed at dry weight ratios (Song and Zhang, 2015)**.** The equipment was properly cleaned at the end of each digestion period.

Table 1: Experimental Design for the Co-digestion of POP and CHD

Mixing ratio	Potato peel (POP) (g)	Chicken dung (CHD) (g)	Digester
100% POP	120	0	1st
20% POP, 80% CHD	24	96	2nd
40% POP, 60% CHD	48	72	3rd
60% POP, 40% CHD	72	48	4th
80% POP, 20% CHD	96	24	5th
100% CHD	0	120	6th

Table 2: Experimental Design for the Co-digestion of YP and PP with CD

S/N	Digester	% CD	% Substrate	The gram of dung/substrate in 400ml of distilled water

1	A	0	100	0 g of cow dung, 200 g of substrate
2	B	20	80	20 g of cow dung, 180 g of substrate
3	C	30	70	60 g of cow dung, 140 g of substrate
4	D	40	60	80 g of cow dung, 120 g of substrate
5	E	50	50	100 g of cow dung, 100 g of substrate
6	F	80	20	160 g of cow dung, 40 g of substrate
7	G	90	10	180 g of cow dung, 20 g of substrate
8	H	100	0	200 g of cow dung, 0 g of substrate

2.3 Kinetic evaluation

The first order kinetic model was analyzed using Microsoft Excel (2016 version). The summary of the kinetic model used in the study is shown in Table 3.

Table 3: Summary of Kinetic Models applied in the Co-Digestion of POP:CHD

Kinetic model	Equation	Reference
First Order	$\ln\left(\frac{S_e}{S_o}\right) = -Kt$	(Nweke and Nwabanne, 2020)

3. RESULTS AND DISCUSSION

3.1 Characterization of substrate before Digestion

The physicochemical analysis of the substrate (POP and CHD) before digestion is presented in Table 4. It can be seen that the COD value of CHD was within the range of value of chicken dung obtained in Slobodkina *et al*. (2021) and Zainal *et al*. (2022). The pH was seen to be in line with the value of 7.73 obtained in Rajagopal *et al*. (2021). The value of TSS obtained was higher than the value of 2,900 mg/l obtained in Barros *et al*. (2023) who carried out anaerobic digestion of rumen inoculated crushed poultry manure. The high value obtained in Barros *et al*. (2023) was due to the inoculation of poultry manure with rumen fluid. The value of BOD obtained in 100% CHD was seen to be higher than the value obtained from 100% chicken droplet (15 mg/l) in Saidu *et al*. (2018). The difference in BOD value may have been due to the difference in substrate to water ratio which formed the digester feed. The result of proximate analysis of PP before digestion can be obtained from Nweke *et al*., (2023). In addition, the result of proximate analysis of YP before digestion can be obtained from Onu *et al*., (2022).

Table 4: Characterization of POP and CHD before Digestion

Parameter	**Mixing Ratio (%)**					
	100% POP	**20% POP**	**40% POP**	**60% POP**	**80% POP**	**100% CHD**
pH	6.45	7.13	7.48	7.56	8.14	8.04
Temp (oC)	30.4	28.2	29.2	28.6	28.9	28.4
TSS (mg/l)	37.55	31.05	14.20	28.55	30.65	27.6
COD (mg/l)	104.0	144.0	104.0	77.33	160.0	226.67
BOD (mg/l)	76.80	53.60	126.40	108.40	81.20	129.60

3.2 Effect of Time on Biogas Yield from the substrates

3.2.1 Effect of Time on Biogas Yield of POP:CHD Co-digestion

The plots of the daily and cumulative biogas production volumes of POP:CHD under mesophilic conditions at different mixing ratios are presented in Figs. 2 and 3. The values of biogas volumes can be seen from Tables 6-11. From the figures, it can be seen that at the beginning, the gas production rates of the substrates with mixtures of potato peel and chicken dung were higher compared to 100% POP and 100% CHD. This could have been due to an improved C/N ratio obtained by co-digesting with other substrates through improved nutrients (Achinas and Euverink, 2019; Simeon *et al.*, 2017). More nutrients provide more organic food for the bacteria to decompose and digest. The cumulative gas produced at the mixing ratio of 20% POP:CHD was the highest when compared to other mixing ratios because it contained the highest amount of nutrients (Simeon *et al.*, 2017). However, the methane produced is low for substrates that have 100% CD compared to other digesters because of low C/N ratio (Achinas and Euverink, 2019). The biogas production volume was recorded on the first day which reduced until there was no more gas production. Biogas volume increased between 1-10 days and started decreasing thereafter which is as a result of gradual decrease in biodegradable substrate and microbial concentrations, which is a general trend in anaerobic digestion (Simeon *et al.*, 2017).

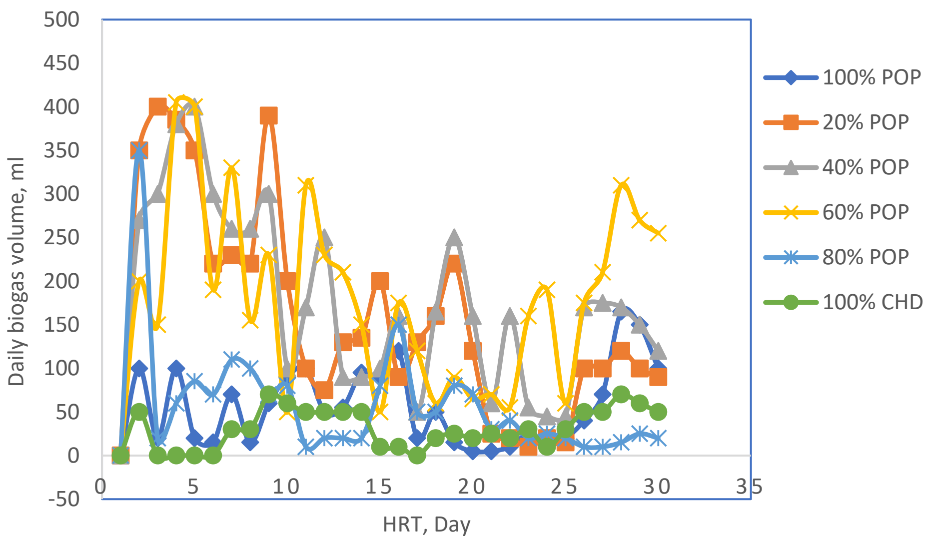

Fig. 2: Variation of daily biogas volume with HRT on POP:CHD co-digestion

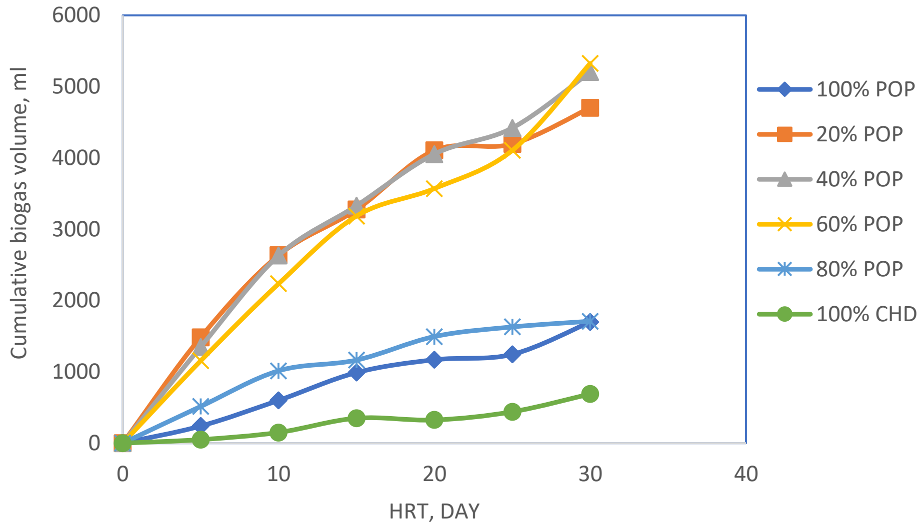

Fig. 3: Variation of cumulative biogas volume with HRT on POP:CHD co-digestion

3.2.2 Effect of Time on Biogas Yield of YP:CD and PP:CD Co-digestion

The results of the daily and cumulative biogas production volumes of YP:CD and PP:CD under mesophilic conditions at different mixing ratios are presented in Figs. 4-7 and Table 12. Biogas production was observed from day 2 for both substrates. The mixing ratios of 20:80 for YP:CD and PP:CD produced the highest cumulative biogas yield of 1,375 ml and 1,305 ml respectively. Sawyerr *et al.* (2017) studied the co-digestion of cow dung and cassava peels (CD:CP) and reported that the CD:CP ratio of 20:80 produced the highest methane yield followed by the ratio of 80:20. Comparable cumulative biogas volume of 1,387 ml was reported from the co-digestion of cow manure and kitchen waste in a one-liter digester with a mixture of 50 g each of both cow dung and kitchen waste in 500 ml of water at 200 gm/L loading rate after ten days HRT in Tasnim *et al.* (2017). Makinde and Odokuma (2015) reported that the mono-digestion of plantain peels produced the least biogas volume when compared to either the mono-digestion of yam peels or the co-digestion of yam peels or plantain peels with cow dung at different mixing ratios. The digestion of YP and PP alone produced the least cumulative biogas volumes. The co-digestion of YP:CD produced higher biogas volumes than PP:CD and may have been due to the high amount of starch and biodegradable organic matter in YP compared to higher amounts of cellulose and lignin in PP which are not easily digestible (Ogunkunle *et al.*, 2018; Makinde and Odokuma, 2015). Makinde and Odokuma (2015) reported that the digestion of yam peels and cow dung produced higher biogas volumes than plantain peels and cow dung. The digestion of CD alone did not produce the highest biogas production. This could have been due to an improved C/N ratio obtained by co-digesting with other substrates (Achinas and Euverink, 2019; Simeon *et al.*, 2017).

The anaerobic digestion of PP:CD showed that optimum biogas production was achieved on the sixth day as also reported by Aiwonegbe *et al.* (2015). After day 7, the daily biogas production reduced in all the digesters as also observed in Sawyerr *et al.* (2017). Observations from Figs. 2 and 3 showed that daily gas productions for YP and PP co-digestions were small both at the beginning and towards the end of digestion. This result is the general trend of gas production in batch mode due to the microbial activities of methanogens responsible for biogas production (Simeon *et al.*, 2017).

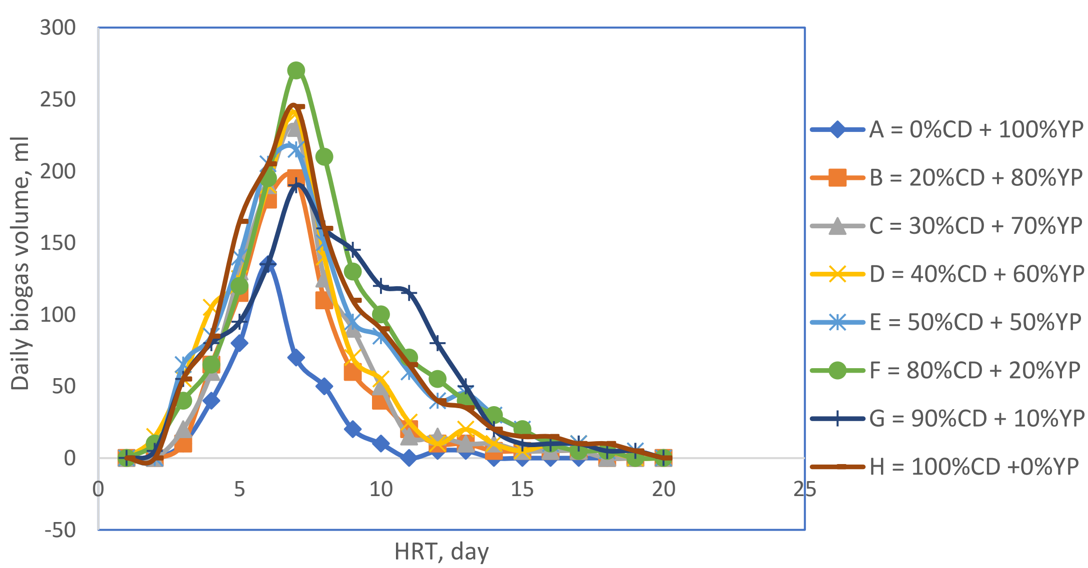

Fig. 4: Variation of daily biogas volume with HRT on YP:CD co-digestion

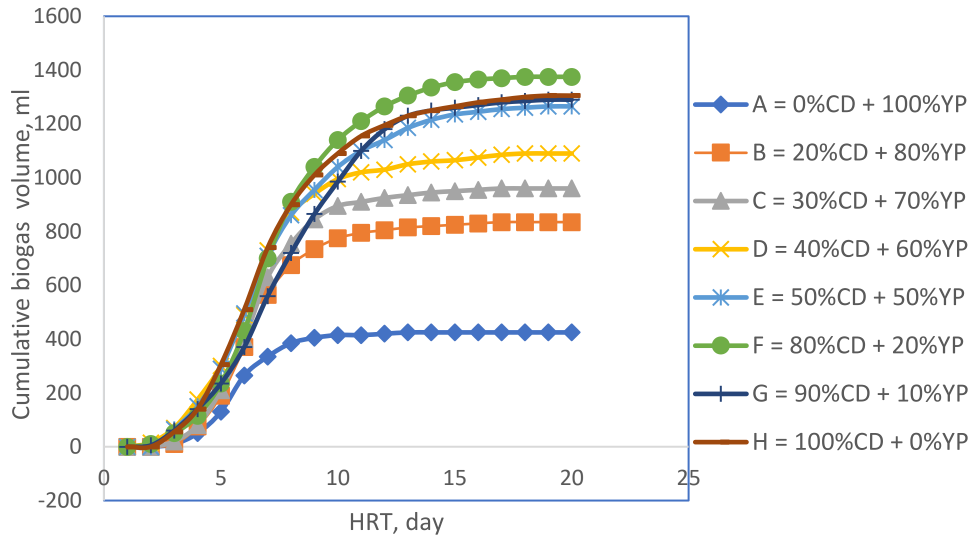

Fig. 5: Variation of cumulative biogas volume with HRT on YP:CD co-digestion

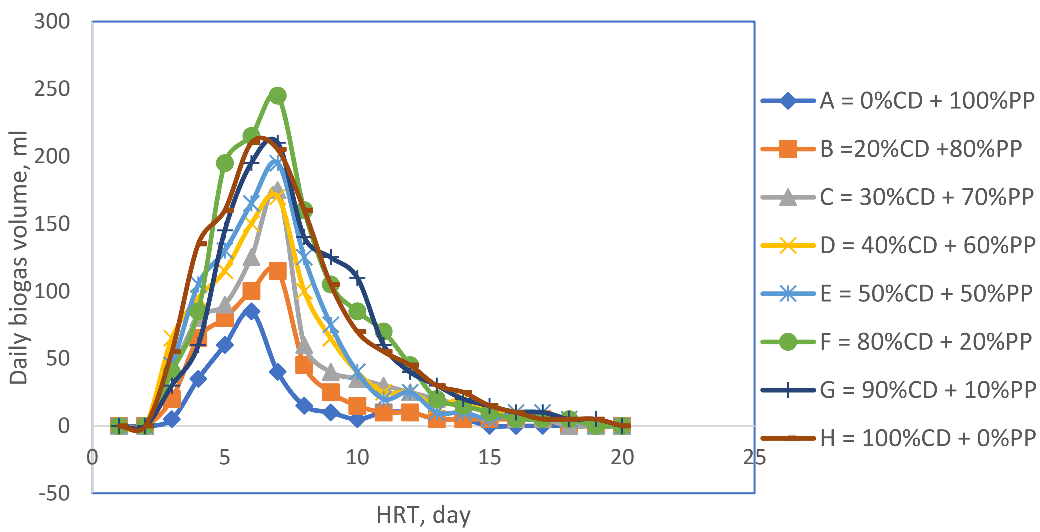

Fig. 6: Variation of daily biogas volume with HRT on PP:CD co-digestion

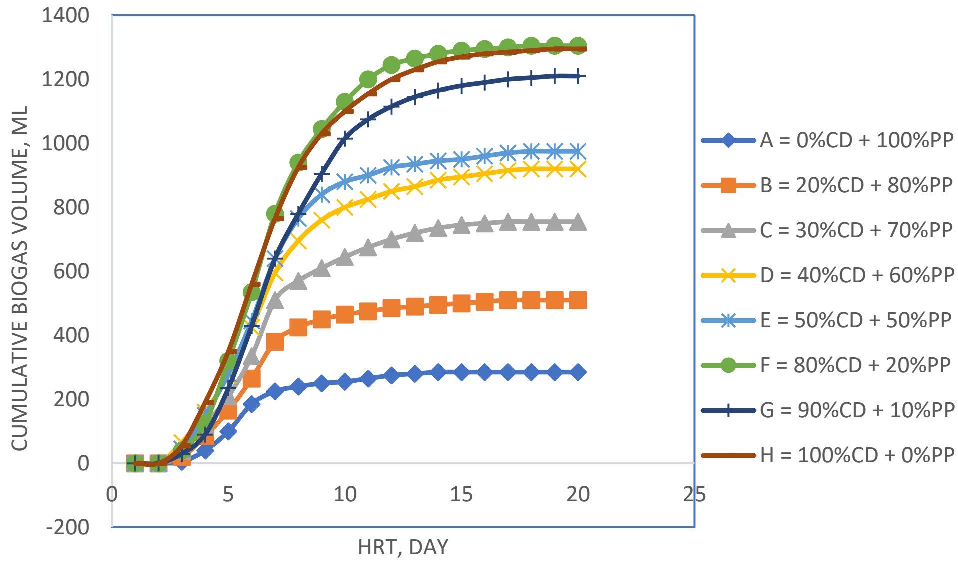

Fig. 7: Variation of cumulative biogas volume with HRT on PP:CD co-digestion

3.3 Kinetic Modeling

Tables 6-11 shows the kinetic data for the POP:CHD digestion at different mixing ratios for a period of 30 days. The COD and TSS reduced with time as also observed in Nweke *et al*. (2015, 2014a, 2014b), Nweke and Nwabanne (2020).

3.3.1 First-order kinetic analysis on POP:CHD

First Order kinetic plot at different mixing ratios are shown in Fig. 8. The linear plots of $-\ln(S_e/S_o)$ versus t gave a correlation coefficient of 0.9929, 0.9899, 0.9715, 0.9770, 0.9964, 0.9554 respectively from 0% CHD to 100% CHD mixing ratios. This confirmed that the kinetics of substrates digestion followed a first order reaction due to their high R^2 values (Jaman *et al*., 2022; Nweke *et al*., 2015). From the figure, reaction constant, K (first order inactivation rate coefficient) was obtained as 0.0145, 0.0053, 0.0102, 0.0168, 0.0123, 0.0107 day^{-1} respectively from 0% CHD to 100% CHD mixing ratios. The values obtained are shown in Table 5. This represents the constant rate at which the microorganisms digested the food available to them before they became inactive (Nweke *et al*., 2014b).

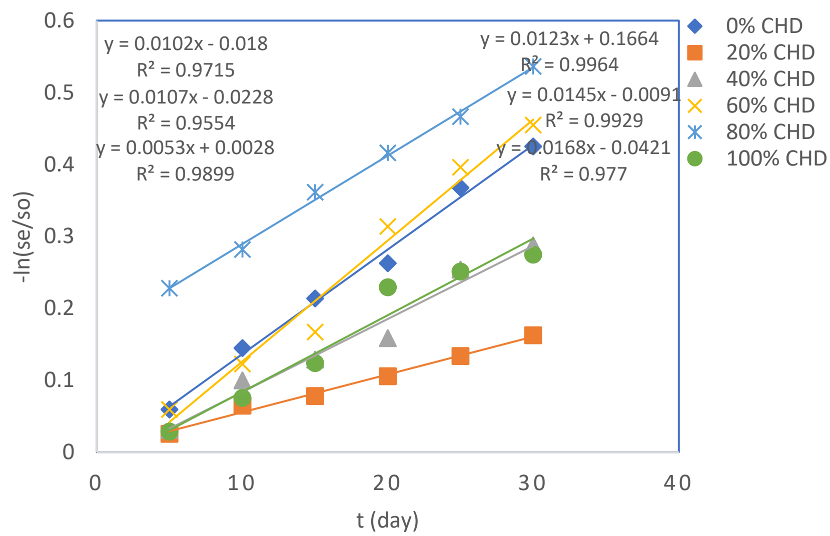

Fig. 8: Plot of First-Order kinetic study on POP:CHD co-digestion

Table 5: Kinetic Constants from the Kinetic Study of POP and CHD Co-Digestion

Constant	**Varying Mixing Ratios**					
	0% CHD	**20% CHD**	**40% CHD**	**60% CHD**	**80% CHD**	**100% CHD**
R^2	0.9929	0.9899	0.9715	0.9770	0.9964	0.9554
K *(day*$^{-1}$*)*	0.0145	0.0053	0.0102	0.0168	0.0123	0.0107

Table 6: Kinetic Data for 100% POP (0% CHD) during Digestion

HRT (day)	**Temp (oC)**	**pH**	**Initial COD (S_o) (mg/l)**	**Effluent COD (S_e) (mg/l)**	**Initial TSS**	**Effluent TSS**	**Ave. TSS (X) (mg/l)**	**Biogas Cum.**

					(X_o) (mg/l)	(X_e) (mg/l)		Vol. (ml)
0	30.40	6.89	104.00	-	37.55	-	-	0
5	30.52	6.90		98.00		28.80	33.175	240
10	30.60	6.98		90.00		14.10	25.825	600
15	30.68	6.93		84.00		11.15	24.35	990
20	31.02	7.05		80.00		24.80	31.175	1170
25	31.14	7.02		72.00		22.25	29.9	1245
30	31.50	7.10		68.00		18.85	28.2	1700

Table 7: Kinetic Data for 20% POP (80% CHD) during Digestion

HRT (day)	**Temp (oC)**	**pH**	**Initial COD (S_o) (mg/l)**	**Effluent COD (S_e) (mg/l)**	**Initial TSS (X_o) (mg/l)**	**Effluent TSS (X_e) (mg/l)**	**Ave. TSS (X) (mg/l)**	**Biogas Cum. Vol. (ml)**
0	32.60	7.40	144.00	-	31.05	-	-	0
5	32.68	7.42		114.67		8.95	28.26	1350
10	32.69	7.48		108.67		38.65	21.43	2635
15	32.80	7.49		100.33		10.50	19.99	3275
20	32.75	7.42		95.00		29.85	17.62	4105
25	33.02	7.50		90.33		30.90	17.00	4195
30	33.08	7.57		84.23		9.75	18.66	5705

Table 8: Kinetic Data for 40% POP (60% CHD) during Digestion

HRT (day)	**Temp (oC)**	**pH**	**Initial COD (S_o) (mg/l)**	**Effluent COD (S_e) (mg/l)**	**Initial TSS (X_o) (mg/l)**	**Effluent TSS (X_e) (mg/l)**	**Ave. TSS (X) (mg/l)**	**Biogas Cum. Vol. (ml)**
0	32.40	7.63	104.00	-	10.85	-	-	0
5	33.48	7.68		98.00		28.80	28.27	270
10	33.52	7.70		92.00		14.10	26.26	1350
15	33.55	7.73		88.00		11.15	21.00	2630
20	33.58	7.75		76.00		24.80	20.00	3330

25	33.68	7.78		70.00		22.25	18.78	4055
30	33.69	7.90		66.00		18.55	19.99	4420

Table 9: Kinetic Data for 60% POP (40% CHD) during Digestion

HRT (day)	Temp (oC)	pH	Initial COD (S_o) (mg/l)	Effluent COD (S_e) (mg/l)	Initial TSS (X_o) (mg/l)	Effluent TSS (X_e) (mg/l)	Ave. TSS (X) (mg/l)	Biogas Cum. Vol. (ml)
0	28.60	7.56	77.33		28.55	-	-	0
5	28.68	7.57		75.00		26.03	28.27	1155
10	29.30	7.59		70.00		23.23	26.26	2235
15	29.45	7.62		68.00		32.64	21.00	3185
20	29.88	7.68		66.00		22.68	20.00	3570
25	30.45	7.72		60.00		12.62	18.78	4105
30	32.30	7.76		58.00		18.32	19.99	5325

Table 10: Kinetic Data for 80% POP (20% CHD) during Digestion

HRT (day)	Temp (oC)	pH	Initial COD (S_o) (mg/l)	Effluent COD (S_e) (mg/l)	Initial TSS (X_o) (mg/l)	Effluent TSS (X_e) (mg/l)	Ave. TSS (X) (mg/l)	Biogas Cum. Vol. (ml)
0	28.90	8.14	160.00		30.65	-	-	0
5	28.98	8.15		156.00		29.20	28.27	515
10	29.40	8.18		150.00		18.27	26.26	1015
15	29.88	8.19		148.00		17.33	21.00	1165
20	30.25	8.21		144.00		20.66	20.00	1495
25	30.68	8.25		140.00		16.22	18.78	1530
30	33.20	8.30		136.00		12.23	19.99	1710

Table 11: Kinetic Data for 0% POP (100% CHD) during Digestion

HRT (day)	Temp (oC)	pH	Initial COD (S_o) (mg/l)	Effluent COD (S_e) (mg/l)	Initial TSS (X_o) (mg/l)	Effluent TSS (X_e) (mg/l)	Ave. TSS (X) (mg/l)	Biogas Cum. Vol. (ml)
0	28.40	8.04	226.67	-	27.60	-	-	0

5	29.01	8.07		220.33		30.64	28.27	50
10	29.88	8.10		210.26		22.36	26.26	150
15	30.20	8.11		200.27		31.22	21.00	320
20	31.04	8.14		180.22		22.33	20.00	350
25	31.68	8.18		176.32		10.22	18.78	440
30	32.70	8.22		172.22		18.20	19.99	690

Table 12: Cumulative Biogas volume of YP:CD and PP:CD Co-digestion

Mixing Ratio	**Cumulative biogas volume (ml)**	
	YP:CD	PP:CD
0% CD	425	285
20% CD	835	510
30% CD	960	755
40% CD	1090	920
50% CD	1265	975
80% CD	1375	1305
90% CD	1290	1210
100% CD	1305	1295

3.4 Characterization of POP:CHD after Digestion

The characterization of POP:CHD after digestion is shown in Table 13. The pH was observed to increase as the percentage of CHD co-digestion increased. However, the values of pH obtained were all within the accepted limit of WHO (Nweke *et al*., 2015). The temperature of the various digesters was observed to be within the accepted WHO temperature limit for disposure. The values obtained for the treated samples as against the untreated samples showed an increment in pH value (more alkaline) after digestion (Nweke *et al*., 2014b). The temperature decreased after digestion for all the digesters. The COD increased for each digester at the end of the treatment. The TSS values reduced for each digester at the end of digestion and is below the world health organization

(WHO) standard (Nweke *et al*., 2015). Further removal of these pollutants and safe disposal of the waste could be obtained if the HRT for digestion is increased.

The proximate analysis carried out on POP:CHD slurry at the end of the experiment is shown in Table 14. The results showed moderate moisture content. The presence of carbon, ash and fiber were also observed in all the digesters. The BOD values increased after digestion. The various slurries in all the digesters were observed to have protein contents confirming the presence of nitrogen in the slurries (Nweke *et al*., 2014a). These results indicated that the slurries can be applied as manure for agriculture. The improved flow properties of the slurries would enable the digestate to penetrate faster in the soil (Rahmat *et al*., 2019).

Table 13: Characterization of POP:CHD after Digestion

Parameter	**Mixing Ratio (%)**						
	0% CHD	**20% CHD**	**40% CHD**	**60% CHD**	**80% CHD**	**100% CHD**	**WHO**
pH	6.89	7.40	7.63	7.76	8.30	8.22	6.0-9.0
Temp (oC)	31.50	32.60	32.40	32.30	33.20	32.70	37.00
TSS (mg/l)	28.80	14.10	11.15	24.80	22.25	18.85	30.00
COD (mg/l)	245.33	181.33	280.00	264.00	218.67	168.00	200.00
BOD (mg/l)	91.60	73.20	48.00	104.00	93.60	121.20	-

Table 14: Proximate Analyses of POP:CHD after Co-Digestion

Parameter	**Mixing Ratio (%)**					
	100% POP	**20% POP**	**40% POP**	**60% POP**	**80% POP**	**100% CHD**
Nitrogen (%)	2.688	3.304	4.256	4.704	3.640	4.928
Carbon (%)	14.55	15.75	14.99	13.89	13.62	12.51

Moisture (%)	16.116	54.30	51.69	75.24	73.38	72.56
Ash (%)	5.23	5.99	6.45	4.57	2.73	5.91
Fibre (%)	6.29	6.71	5.77	7.09	7.10	6.09
Protein (%)	6.30	8.40	9.10	9.80	6.30	5.25
Carbohydrate (%)	18.27	21.66	22.33	1.13	6.29	3.48
Fat (%)	2.52	2.92	4.70	5.20	4.18	4.69

CONCLUSION

The characterization of the substrates showed that they had available nutrients required for anaerobic digestion. The biogas production volume was recorded on the first day which reduced until there was no more gas production. The optimum anaerobic digestion of all the substrates were obtained within the seventh and tenth day of digestion. The cumulative gas produced at the mixing ratio of 20% POP:CHD was the highest when compared to other mixing ratios of POP:CHD by producing 5,705 ml of biogas. The mixing ratio of 20:80 for YP:CD and PP:CD produced the highest cumulative biogas yield of 1,375 ml and 1,305 ml respectively. The anaerobic digestion of the various mixing ratios of POP:CHD was described by first order kinetic model. The proximate analysis obtained from the slurries of various mixing ratios indicated that the values obtained were within the WHO and can be safely applied as agricultural manure.

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