Production of bioenergy from rice-melon husk co-digested with cow dung as inoculant

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Abstract: Anaerobic digestion of energy crops, residues, and wastes is of increasing interest in order to reduce the greenhouse gas emissions and to facilitate a sustainable development of energy. Production of bioenergy provides a versatile carrier of renewable energy, as methane can be used for replacement of fossil fuels in both heat and power generation. Biogas was produced from co-digestion of rice husk (RH), melon husk, (MH) and cow dung (CD) for 200 days at different rice-melon husk (RH:MH) ratios. Fixed quantity of cow dung slurry was added to each treatment as inoculant to seed the digesters. A mixture-process variable design was used to formulate biogas production from different biomaterials. Concentration of NaOH was varied from 8 to 9% while total solids were also varied within a range of 8% to10%. Initial properties of RH, MH and CD were determined. Melon husk was found to be the densest with total solids (96.9%), followed by rice husk (91.8%) then cow dung (16%). In terms of volatile solids, cow dung and melon husk have values close to each other (96.4% and 89.5% respectively), rice husk recorded lower value (79.2%). RH:MH (100:0) recorded the highest biogas yield (606.933 mL kg^{-1}) while RH:MH (0:100) recorded the least biogas yield (376.533 mL kg^{-1}). Biodegradation and maximum biogas yield models based on first-order kinetics were fitted to the experimental biogas yields to predict maximum biogas yields from each treatment. The high R^2 values showed that the biodegradation model and the maximum biogas yield model predicted the maximum yields adequately. Biogas yield from RH:MH (0:100) was the best described and predicted by the biodegradation model while biogas yield from RH:MH (100:0) was best described by the maximum yield model.

Keywords: rice husk, melon husk, agro-residue, biodegradation model, co-digestion, biogas yield

Citation: Mohammed, I. S., M. Aliyu, N. A. Abdullahi, and I. A. Alhaji. 2020. Production of bioenergy from rice-melon co-digested with cow dung as inoculant Agricultural Engineering International: CIGR Journal, 22 (1):108-117.

1 Introduction

Large quantity of fossil-fuel is utilized to produce energy in Nigeria which is not only a financial problem for the country but also surges universal anthropogenic emissions of greenhouse gases. Renewable energy system includes; biomass, geothermal, wind and solar, gives attractive projections because they are cheap and unlimited (Mohammed et al., 2018). Biomass is made up of an extensive variation of agricultural residue, is originated in huge amount and it is the main supplier to renewable energy which occupied approximately 10% of the whole energy (Antizar-ladislao and Turrion-Gomez, 2008). In developing countries, huge extents of lignocellulosic biomass such as other form of agricultural residue which

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Received date: 2017-11-21 **Accepted date:** 2019-11-12

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includes molasses, green leaves, plant stover, fruit seeds, fruit shells, nut shells, straws, melon husk and rice husk are produced yearly but are vastly underutilized (Demirbas, 2001). Consequently, agricultural biomass is proliferating in sub-urban and rural area which contributes to environmental pollution (Arvanitoyannis et al., 2007).

In Nigeria, it is estimated that about 227,500 tons of animal wastes is formed daily. Hence, 0.03 m^3 of biogas is form from 1 kg of animal wastes then, Nigeria can produce biogas of about 6.8 million m^3 per day. In addition to these, municipal solid waste of 20 kg per capita is projected to be generating in the country yearly (Akinbam et al., 1996). As industrialization and urbanization increases, the municipal solid waste produced will continue to increase yearly (Midilli and Dincer, 2006). Anaerobic digestion (AD) of biodegradable wastes and agricultural biomass is broadly utilize as the best treatments option because it produces CO_2 and methane rich biogas which is suitable for energy production. Single anaerobic digestion of highly biodegradable organic substrate could result in process failure in the absence of proper external nutrients addition and buffering agent for pH adjustment (Demirel and Scherer, 2008). This problem could be overcome by adding another waste as co-substrates which may eliminate alkali addition for pH control and the need of any external nutrients (Bouallagui et al., 2009). This process of digesting multiple substrates is known as co-digestion. Researcher interest in co-digestion technique as increase in literature few years back. Literature as reported a number of studies that improved biogas yield as a result of co-digestion of organic waste which include; meat, fruit and vegetable wastes (Garcia-Peña et al., 2011), kitchen waste and cattle manure (Li et al., 2014), chicken manure, kitchen waste and corn stover (Li et al., 2013), landscape and food waste (Drennan and DiStefano, 2014), food waste and rice husk (Maliha et al., 2015), rice husk and cow dung (Okeh et al. 2013) etc.

Local milling of rice and melon is one of the major practices in Niger state, Nigeria. 1 ton of rice is processed to generated 240 kg of husks (Hosseinnia et al., 2007). Hence, rice and melon husks constitute the main environmental nuisances as they formed the municipal solid wastes heap in the areas where they are disposed. This disposed husks during milling are burnt in the field. As a result of these, many countries have imposed new regulation to restricts field burning practice (Mansaray et al., 1999). Then, dispose technique and to use agricultural residues such as rice straw, melon and rice husks have shifted towards the universal “waste to wealth” agenda (Okeh et al., 2013).

Therefore, the aim of this present study was to evaluate the use of rice-melon husk in biogas production using anaerobic digestion. In addition, biodegradation and maximum biogas yield models based on first-order kinetics were fitted to the biogas yield data to describe the process response and estimate the maximum yield attainable, respectively for co-digested substrates at room temperature in batch reactors.

2 Materials and methods

Cow dung was collected from dairy farm in Federal University of Technology, Minna, Niger State. Rice husk and melon husk were collected from local mills in Kure market in Minna, Niger State. Digestion was done in Bosso, Minna, Niger state, Nigeria.

2.1 Analytical procedure

The samples were analyzed for total solids (TS) content, volatile solids (VS) content, pH, total carbon (TC) content, Total Nitrogen (TN) and Carbon-Nitrogen (C/N) ratio. TS content was carried out by oven drying at 105°C for 24 h; volatile solids content by ashing of TS at 550°C for 5 h; total nitrogen by regular-Kjeldahl method; (Bremner, 1996); pH (using a digital pH meter). The TC content was estimated from the ash content according to the formula (Adanikin et al., 2017):

$$TC(\%) = \frac{100 - ASH(\%)}{1.8} \qquad (1)$$

2.2 Experimental set-up

The experimental set up of the digestion comprises of digesters, water (displacement) tanks, water collectors, and gas collectors. Two experimental set-ups were made. The digesters, water tanks and water collectors were adopted using 20-liter, 12-liter and 8-liter plastic containers respectively, balloons were used for gas collection. Inlet valves were provided for feeding of each digester. Drain valves were also provided on each digester for collection of samples for pH and removal of slurry. A thermometer was fitted to each digester for temperature measurement. Boiling rings were inserted inside the digesters to provide heat necessary for digestion and thermostats were attached for temperature control. A stirrer was put inside to agitate the mixture to prevent bubble formation and ensure intimate contact between the microbes and the substrates in the digesters. 8 mm rubber hoses were used to connect each digester to the water tank and from the water tank to the water collector. Figure 1 shows the schematic diagram of the set-up. The gas produced in the digester passes through the hose to the displacement tank where the gas displaces water and a hose takes the displaced water from the displacement tank to the water collector, which fitted airtight in the displacement tank and was inserted up to the bottom of the displacement tank. Another hose takes the gas to the gas collector after measurement. Digestion was done at thermophilic temperature range (35°C). During the experiment, the volume of the produced gas was measured with the use of water displacement method (Salam et al., 2011). At the time of experiments, the set ups were fully gas tightened to prevent gas leakage.

2.3 Biomaterial preparation

The rice husk and melon husk samples were cut to < 6mm sieve size (Zennaki et al., 1996) and mixed at different RH:MH ratios as shown in Table 1. Mixtures were adjusted to appropriate TS content with potable water (WHO’s drinking water standards). The cow dung was diluted to 8% TS as recommended by Zennaki et al. (1996),and screened using a 6mm plastic mesh to remove gross solids. Each digester was filled to 75% capacity with cow dung (as inoculant to seed the digesters) and the biomaterials. Equation 2 was used to determine the amount of water to be added to the mixture.

$$C_1V_1=C_2V_2 \tag{2}$$

Where:

C_1 = Initial concentration (kg m^{-3})

C_2 = Final concentration (kg m^{-3})

V_1 = Initial volume (m^3)

V_2 = Final volume (m^3).

2.4 Pretreatment of biomaterials

The pretreatment was done by soaking samples of rice husk and melon husk (1kg) into solution of NaOH. The NaOH solution was prepared by dissolving the designated amount of NaOH with portable water (WHO’s drinking water standards). The NaOH solution was added to the designated concentration of rice husk and melon husk and stirred until it reaches a homogenous state. The mixtures were stored in a closed container at room temperature for 24 hours as done by Avicenna et al. (2015). The samples were then sun-dried for 2 hours.

2.5 Mixture-process variable design

Mixture design was used to formulate biogas production from rice husk and melon husk. Process variables involved in production of biogas play an important role in the final quantity of the biogas. TS and NaOH concentration were the process variables used in this design. Even with the biomaterial (rice husk and melon husk), different total solids and NaOH concentration can produce different results. Interaction between composition variables and process factors can be shown by experiments that combine mixture components with process factors.

In this work, a (2, 2) simplex lattice mixture design was used for a mixture with two components (rice husk and melon husk) with cow dung being constant. Together with the center point, it has a total of five runs or five different combinations. A two-level factorial design was selected for the two process variables. It has a total of six combinations for these two variables. If the five different mixtures are made under each of the six-process variable combination, then the experiment has nineteen runs, control being the twentieth. This is shown in Table 2.

The (2, 2) simplex design with center point has five combinations given in Table 1. The two process variables (Total solids and NaOH concentration) which were also studied at two values (the low and high values) each are shown in Table 3. Combining the simplex design and the factorial design together, we get the nineteen runs shown in Table 3. The twentieth run being the control, which is the production of biogas with cow dung only.

2.6 Kinetics of the biogas yield

The volatile solids biodegradation model to describe and estimate biogas yield by co-digesting rice husk and melon husk in digesters was based on first-order kinetics. First-order kinetic equation can provide an empirical approach to studying the biodegradability of organic materials by observing changes in volatile solids during decomposition. The study assumed that:

a. There was a correlation between volatile solids biodegradation and biogas yield at any time.

b. Certain quantity of volatile solids in the substrates was assumed to be unwilling to biodegrade within the retention time allowed (although this was at variance to the assumption by previous researchers (Linke, 2006; Mahnert and Linke, 2009; Yusuf and Ify, 2011). Hence, the model was modified to reflect remnant volatile solids; and

c. There was no lag time before the beginning of volatile solids biodegradation (since biogas production started within 24 hours of digestion).

The substrate removal rate is given by:

$$rc = -\frac{dc_t}{dt} = 0 at 0 \le t \le t_L \tag{3}$$

$$rc = \frac{dc_t}{dt} = -k(C_t - C_e) at\ t_L \le t \tag{4}$$

Where:

C_t=Volatile solids concentration in the substrates at any time;

$t_{L=}$ Lag time before volatile solids begins to degrade (d);

k = Volatile solids biodegradation rate constant based on the quantity of volatile solids in substrate (d^{-1}) and;

C_e=Remnant volatile solids concentration after retention time.

By integrating Equation 4, the volatile solids biodegradation model is given by:

$$C_t = (C_o - C_e)e^{-k(t-t_L)} + C_e at\ t_L \le t \tag{5}$$

Where:

C_o = Volatile solids concentration in the substrates at the beginning of the experiment.

However, since lag time was assumed to be zero, Equation 5 becomes:

$$C_t = (C_o - C_e)e^{-k(t-t_L)} + C_e at\ o \le t \tag{6}$$

Equation 6 was then log-transformed to linearize it as:

$$ln[\frac{(C_t - C_e)}{C_o - C_e}] = -kt \tag{7}$$

The original biogas yield data was then transformed using the left side of Equation 7 to generate a new data set on Y:

$$Y = -kt \tag{8}$$

Equation 8 was calibrated with the experimental cumulative biogas yield data of each treatment to obtain the kinetic constant (k). Maximum biogas yield for each treatment was estimated using the relationship (Yusuf and Ify, 2011):

$$Y_t = Y_m(1 - e^{-kt}) \tag{9}$$

$$Y_m = \frac{Y_t}{(1 - e^{-kt})} \tag{10}$$

Where:

Y_t and Y_m are biogas yield at any time and maximum biogas yield, respectively.

The half-life of first-order kinetic model is given by:

$$t_{1/2} = \frac{ln(2)}{k} = \frac{0.693}{k} \tag{11}$$

The goodness of fit of the model was evaluated using the R-squared (R^2) statistic and Standard Deviation.

R^2 was calculated from the variance statistics that are reported for the regression, using the equation (Adanikin et al., 2017):

$$R^2 = \frac{SS_{Regression}}{SS_{Total}} \tag{12}$$

A value of R^2 close to unity indicates a good fit whereas a value close to zero indicates a poor fit. Standard deviation is the average deviation of the residuals (observed minus estimated values for a given data point) from zero. T-test was used to evaluate the observed and estimated data based on the deviation, with the null hypothesis that the overall mean of the residuals did not differ significantly from zero at $p \leq 0.05$. If the resulting p-value of the test is greater than 0.05, it implies that the estimated values closely approximate the observed values.

Table 1 (2, 2) Simplex design levels

Standard order	Rice Husk	Melon Husk
1	1	0
2	0.25	0.75
3	0.5	0.5
4	0.75	0.25
5	0	1

Table 2 Mixture-process design matrix for conduct of experiment

Run	Rice Husk	Melon Husk	Total Solids (%)	NaOH (%)
1	1.000	0.000	10.000	9.000
2	1.000	0.000	8.000	9.000
3	0.250	0.750	9.500	8.250
4	0.000	1.000	8.000	8.000
5	0.000	1.000	10.000	8.000
6	0.750	0.250	9.000	8.500
7	0.000	1.000	8.000	8.000
8	1.000	0.000	8.000	8.000
9	1.000	0.000	9.500	8.250
10	0.000	1.000	8.000	9.000
11	0.500	0.500	10.000	9.000
12	0.000	1.000	10.000	8.000
13	0.000	1.000	9.000	8.500
14	0.000	1.000	8.000	9.000
15	0.500	0.500	10.000	8.000
16	0.500	0.500	8.000	9.000
17	0.250	0.750	8.500	8.250
18	0.500	0.500	10.000	9.000
19	1.000	0.000	8.000	9.000
Control:	Cow Dung 1.000			

Table 3 Process variables levels

Total Solids	NaOH
+10	-8
-8	-8
+10	-8
-8	+9
+10	+9
-8	+9

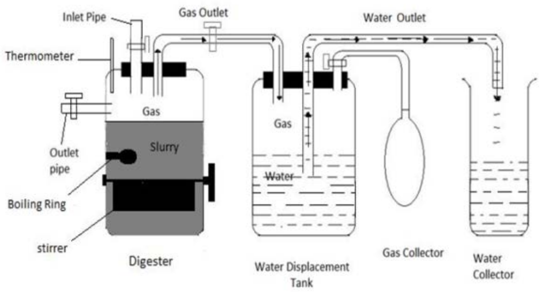

Figure 1 Schematic diagram of the set-up

3 Results and discussion

3.1 Initial properties of biomaterials mixture

The properties of the biomaterials (cow dung, rice husk and melon husk) used in this study are shown in Table 4. Among the biomaterials, melon husk was the densest in terms of total solid content followed by rice husk while cow dung has the lowest. Melon husk and rice husk can be seen to have close values of total solids. There was variation in the volatile solids content of the three biomaterials; while cow dung and melon husk have values close to each other, rice husk recorded lower value. The initial C/N ratios of the individual biomaterials were above the optimal range of 16:1 - 20:1 reported for anaerobic digestion (Alvarez et al., 2010). This may be due to the high nitrogen content of the biomaterials.

Table 4 Initial properties of the biomaterials

Treatments	PH	TS (%)	VS (%)	TC (%)	TN (%)	C/N ratio
Individual Materials						
CD	7.50	16.00	96.40	53.60	1.05	51.04
RH	Nd	91.8	79.20	44.00	0.65	67.69
MH	Nd	96.9	89.50	49.70	0.42	118.33
Mixtures (CD+biomaterials)						
RH:MH (100:0)	6.67	61.48	81.00	45.00	1.24	36.29
RH:MH (75:25)	6.52	62.40	82.60	45.90	1.218	37.68
RH:MH (50:50)	6.48	63.01	85.70	47.61	1.213	39.25
RH:MH (25:75)	6.84	63.62	87.50	48.61	1.206	40.31
RH:MH (0:100)	7.01	64.45	90.18	50.10	1.201	41.72

Note: TS: Total Solids; VS: Volatile Solids; TC: Total Carbon; TN: Total Nitrogen; CD: Cow Dung; RH: Rice Husk; MH: Melon Husk; Nd: Not determined. (*: 1:1 w/v sample: water.)

3.2 Biogas yield of the mixture

The biogas yield of the different mix ratio is shown in Table 5.

Table 5 Biogas yields of biomaterial mixture

Run	Rice Husk (%)	Melon Husk (%)	Total Solids (%)	NaOH (%)	Biogas Yield (mL kg^{-1})
1	1.000	0.000	10.000	9.000	534.933
2	1.000	0.000	8.000	9.000	567.333
3	0.250	0.750	9.500	8.250	468.000
4	0.000	1.000	8.000	8.000	476.067
5	0.000	1.000	10.000	8.000	414.333
6	0.750	0.250	9.000	8.500	463.600
7	0.000	1.000	8.000	8.000	376.533
8	1.000	0.000	8.000	8.000	560.800
9	1.000	0.000	9.500	8.250	606.933
10	0.000	1.000	8.000	9.000	488.733
11	0.500	0.500	10.000	9.000	427.000
12	0.000	1.000	10.000	8.000	588.200
13	0.000	1.000	9.000	8.500	545.133
14	0.000	1.000	8.000	9.000	566.400
15	0.500	0.500	10.000	8.000	568.667
16	0.500	0.500	8.000	9.000	492.200
17	0.250	0.750	8.500	8.250	581.333
18	0.500	0.500	10.000	9.000	555.000
19	1.000	0.000	8.000	9.000	592.000
	Control:	Cow Dung (%)			
20		1.000			553.000

The biogas yield from cow dung treatment was subtracted from the yields of every treatment. It was observed that co-digestion did not have significant effect on the yield. RH:MH (100:0) with total solids of 9.5% and NaOH concentration of 8.25% recorded the highest yield while RH:MH (0:100) with total solids of 9.5% and 8.5% concentration of NaOH recorded the least biogas yield. The insignificant lower yield may be attributed to lower temperature recorded during the test run. Regardless of the initial C/N ratios of the treatments, biogas production started within 24 hours of digestion. The early production could be due to the high volatile solids content in the starting mixtures (Table 4) or possibly a synergetic effect due to the complementary characteristics of the biomaterials mixed (Comino et al., 2012. Two treatments had days of non-production, RH:MH (75:25) and RH:MH (0:100) runs. There was a single day of non-production for the RH:MH (75:25) run (29.2^{o}C), while, two days were recorded for RH:MH (0:100) run (31.8^{o}C and 33.5^{o}C), which may be also due to low temperature recorded. The varying biogas yield may be attributed to the differences in the degree of biodigestibility of the biomaterials (Odeyemi, 1982).

The fluctuations observed in the volume of biogas produced may also be attributed to the change in metabolism of the bacteria in response to the fluctuations in the temperature and pH of the digestion medium. (Alfa et al., 2014) The higher and faster biogas generation in the control (Cow Dung only) could be attributed to the faster rate of decomposition of animal intestinal wastes which have already undergone a form of digestion in the digestive system of the cows. Therefore, the action of bacteria on this category of waste is fast relative to the rice husk and melon husk which contains fibrous tissues like lignin, suberin, cutin etc. which may not have been completely degraded during the pre-fermentation stage prior to anaerobic digestion. (Alfa et al., 2014).

3.3 Modelling result

Table 6 shows the summary of modeling results on the yields from the mixtures. The rates of biodegradation varied slightly among the treatments. The rate constants (k) varied between 1.6174 and 2.1313, with RH:MH (75:25) having the least (indicating least biodegradation rate) and RH:MH (25:75) had the highest biodegradation rate. The k values found in this study were not close to 0.047–0.052 observed by O'sullivan et al. (2010) during anaerobic digestion of water weeds. No correlation was established between k and biogas yield. The same trend was observed in the study by Mahnert and Linke (2009). The estimated biogas yields followed a first-order kinetic reaction (Figure 2). The goodness of fit test showed high R^2 values indicating that the biogas yield obtained can be explained adequately by the biodegradation model. The biodegradation model had the best fit on RH:MH (0:100) as indicated by the highest R^2. The t-test analysis showed that the estimated yields closely approximate the observed yields in all the treatments. This can be attributed to the low residual values during digestion (Figure 2). The low residual values gotten were better than that of the study of (Adanikin et al., 2017). The time at which half of the yield was produced, $t_{1/2}$, which was a function of k, varied linearly with k. The maximum biogas yields (Y_m) and the corresponding R^2 values showed that the maximum biogas yield model can adequately be used to predict Y_m from anaerobic digestion. RH:MH (100:0) was the best described by the maximum biogas yield model.

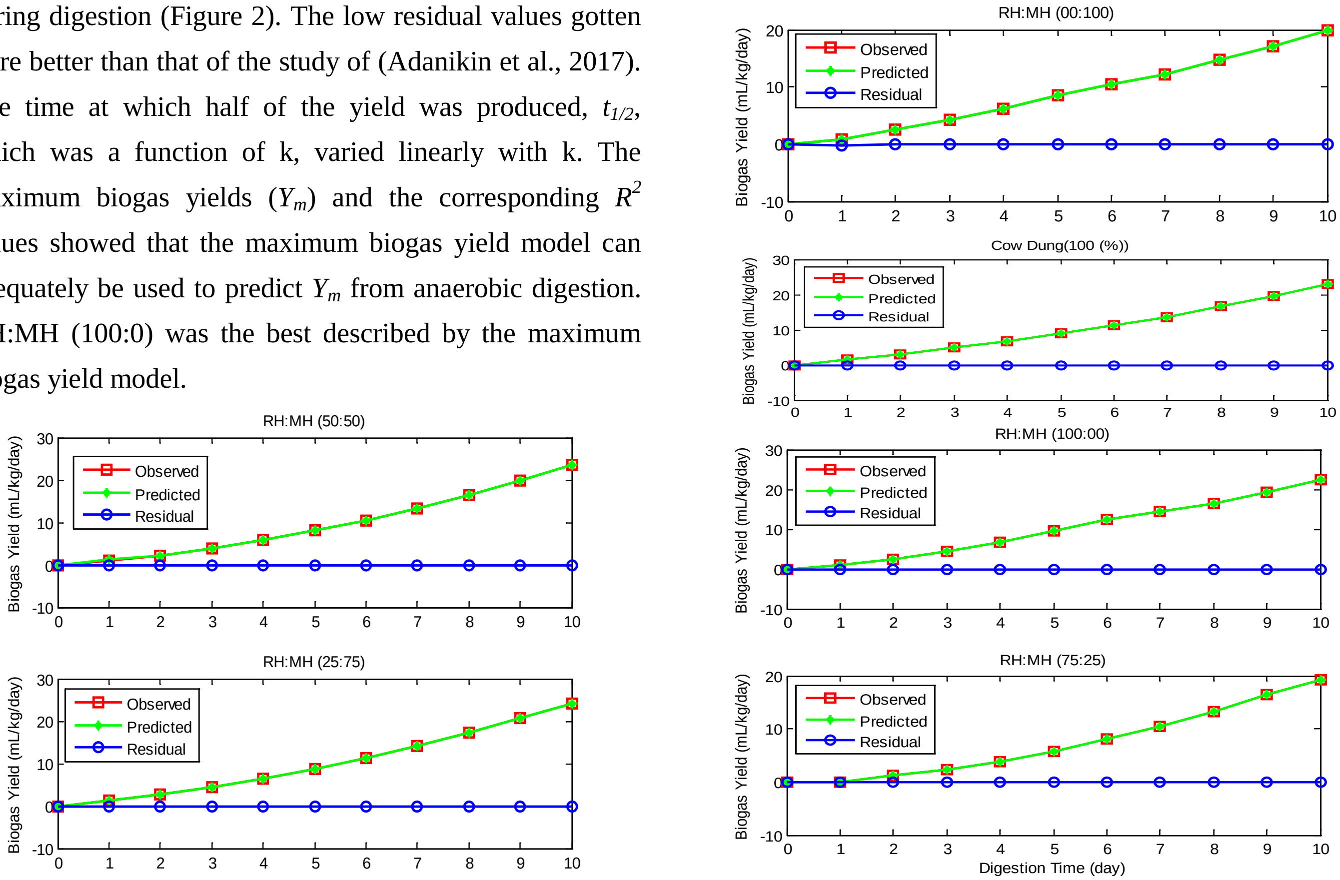

Figure 2 Profiles of observed and predicted (estimated) cumulative biogas yield

Table 6 Summary of modelling results

Treatment	Degradation Model						Maximum biogas yield (ym) model		
	k	R^2	R_r	R_{SD}	t-test (p value)	$T_{1/2}$	estimated Y_m	R^2	Est./obs.%
RH:MH (100:0)	2.0706	0.9716	0.01805	0.039103	<0.0001	0.334686	22.2890 (22.2889)	0.9957	0.999996
RH:MH (75:25)	1.6174	0.8960	0.00802	0.073921	<0.0001	0.428465	19.3167 (19.3167)	0.9732	1.000000
RH:MH (50:50)	2.0305	0.9288	0.02083	0.047601	<0.0001	0.341295	23.6944 (23.6944)	0.9739	1.000000
RH:MH (25:75)	2.1313	0.9486	0.02059	0.047386	<0.0001	0.325154	24.2222 (24.2222)	0.9816	1.000000
RH:MH (0:100)	1.8313	0.9749	0.02355	0.045778	<0.0001	0.37842	19.8361 (19.8361)	0.9955	1.000000

3.4 Effects of temperature and pH of the substrates on biogas yield

3.4.1 Effects of temperature of the substrates on the biogas yield

Temperature was recorded daily. From Figure 3, it can be observed that the range of the daily ambient and substrate temperatures during digestion (23.3℃ – 28.9℃ and 34.9℃ – 40.1℃, respectively) indicated that the anaerobes that caused the decomposition operated within the thermophilic temperature range of 35℃ and above considered optimal for the support of biological reaction rates (Tchobanoglous et al., 2003). It was observed that the digester temperature fluctuated between 34.9℃ and 40.1℃ (Figure 3). The consistent fluctuations observed in the daily substrate temperatures can be related to the activities of the anaerobic microorganisms during digestion.(Alfa et al., 2014).

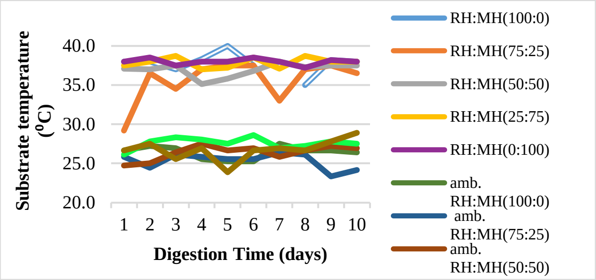

Figure 3 Variation of ambient and substrate temperatures during digestion

3.4.2 Effects of pH of the substrates on biogas yield

pH was measured every two days. The initial pH of the treatments (Table 4) fell within the range of 6–8 considered suitable for bacteria involved in anaerobic digestion (Adanikin et al., 2017; Abubakar and Ismail, 2012). The pH during digestion ranged between 6.43 and 7.53 (Figure 4). The control (cow dung only) decreased in the early days of digestion and then increased throughout the rest of digestion period. The decrease in pH implied the production of volatile fatty acids (Cuzin et al., 1992). After the whole experiment, pH values were observed to increase slightly which is consistent with work of (Shoeb et al., 2000).

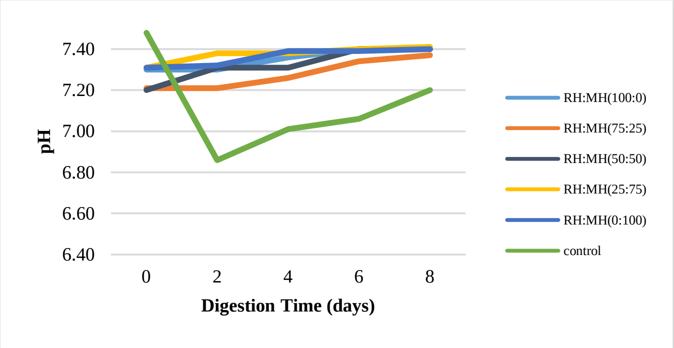

Figure 4 Variation of pH as function of digestion time

3.5 Effects of processing parameters and component proportion on biogas yield

3.5.1 Effects of processing parameters on biogas yield

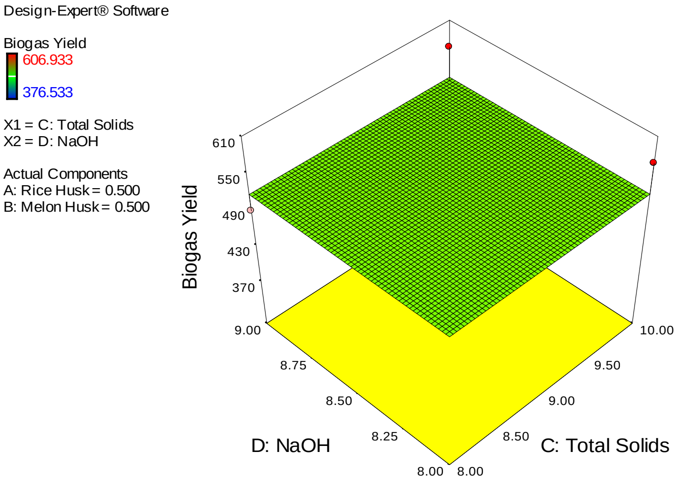

Figure 5 Three-dimensional surface plot between NaOH concentration and total solids against biogas yield

The 3-dimensional surface plot shows interaction between the NaOH concentration and total solids with no significant effect on the biogas yield (Figure 5). From the figure, it can be seen that there was constant biogas yield at different concentration of NaOH (8% - 9%). This disputes the study of Avicenna et al. (2015), who concluded that increase in the concentration of NaOH increases biogas yield. It can also be seen that with varying total solids (8% - 10%), the biogas yield remained the same, i.e. constant. At increasing NaOH concentration and total solids, there is no effect on the maximum biogas yield.

3.5.2 Effects of component proportion on biogas yield

The component proportion (RH:MH) and total solids in relation with biogas yield can be shown in the 3D surface plot in Figure 6. The surface plot shows the interaction between the component proportions and total solids with significant effect on the production of biogas. The biogas yield was highest at RH:MH (100:0) and lowest at RH:MH (0:100). The change in total solids has no effect on the biogas yield as it increases from 8% to 10%. This suggests that component proportion has a significant effect on biogas yield, which is consistent with the study of (Parawira et al., 2004)

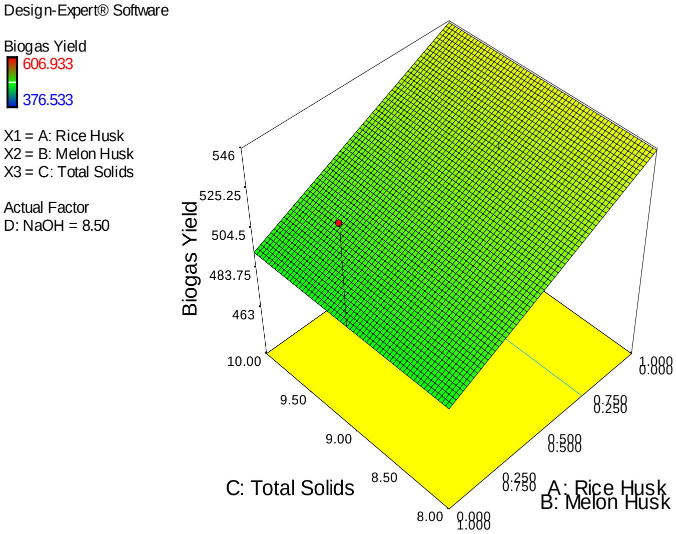

Figure 6 Three-dimensional surface plot between total solids and component proportion against biogas yield

3.6 Process variable optimization of the biogas yield

The optimum result of the biogas yield is shown in Table 7. The predicted response was obtained by using a point prediction node (under optimization node in the mixture-process design module). The rice husk, melon husk, total solid and NaOH concentration were fixed in the range of 1-0, 1-0, 8%-9% and 8%-9%. Based on this constraint the software decided the following optimum condition. Rice husk of 100%, melon husk of 0%, total solid of 9.5%, NaOH concentration of 8.25% and yield of 606.933 mL kg^{-1}. the optimum biogas yield was characterized for methane (CH_4), carbon dioxide (CO_2) and carbon monoxide (CO) concentration.

Table 7 Optimization results for biogas yield

parameters	Optimum operating conditions
Rice husk	100 %
Melon husk	0 %
Total solid	8.25 %
NaOH Conc	9.5 %
Gas Composition	**% Proportion**
CH_4	70
CO	5
CO_2	5
Other Gases	20

4 Conclusion

The results obtained from the experimental data set shows that RH:MH (100:0) produced more biogas than the rest of the co-digested biomaterials but the difference was insignificant. The goodness of fit test showed high R^2 values indicating that the biogas yield obtained can be explained adequately by the biodegradation model. The biodegradation model had the best fit on RH:MH (0:100) as indicated by the highest R^2 value. The R^2 values and percentages of predicted maximum yield/observed maximum yield showed that the maximum biogas yield model predicted the maximum yield adequately. Biogas yield from RH:MH (100:0) was best described by the maximum yield model. The maximum biogas yield was characterized for methane, carbon (iv) oxide and carbon (ii) oxide to be 70%, 5% and 5% respectively. Temperature has a significant effect on the yield of biogas which was seen from the results.

References

Abubakar, B. S. U., and N. Ismail. 2012. Anaerobic digestion of Cow dung for biogas production. *ARPN Journal of Engineering and Applied Science*, 7(2): 169-172

Adanikin, B. A., G. A. Ogunwande, and O. O. Adesanwo. 2017. Evaluation and kinetics of biogas yield from morning glory (Ipomoea aquatic) co-digested with water hyacinth (Eichhorniacrassipes). *Ecological Engineering*, 98(4): 98-104.

Akinbami, J. F. K., I. O. Akinwumi, and A. T. Salami. 1996. Implications of environmental degradation in Nigeria. *Natural Resources Forum*, 20(4):319-31

Antizar-Ladislao, B., and J. L. Turrion-Gomez. Second-generation biofuels and local bioenergy systems. 2008. *Biofuels Bioproducts & Biorefining*, 2(5): 455-469

Alfa, I. M., S. O. Dahunsi, O. T. Iorhemen, C. C. Okafor, and S. A. Ajayi. 2014. Comparative evaluation of biogas production from poultry droppings, cow dung and Lemon grass. *Bioresource Technology*, 1572, 270-277.

Alvarez, J. A., L. Otero, and J. M. Lema. 2010. A methodology for optimizing feed composition for anaerobic co-digestion of agro-industrial wastes. *Bioresources Technology*, 101(4): 1153-1158.

Arvanitoyannis, I. S., A. Kassaveti, and S. Stefanatos. Current and potential uses of thermally treated olive oil waste. 2007. *International Journal of Food Science and Technology*, 42(7): 852-867.

Avicenna, M. Mela, S. I. Ihsan, and R. H. Setyobudi. 2015. Process improvement of biogas production from anaerobic co-digestion of cow sung and corn husk. *Procedia Chemistry*, 14: 91–100.

Bremner, J. M. 1996. Nitrogen-total. In *Methods of Soil Analysis*, ed. D. L. Sparks, part 3, 1085-1122. Madison, WI: SSSA Inc., ASA Inc.

Bouallagui, H., H. Lahdheb, E. B. Romdan, B. Rachdi, and M. Hamdi. 2009. Improvement of fruit and vegetable waste anaerobic digestion performance and stability with co-substrates addition. *Journal of Environment Management*, 90(5): 1844-1849.

Comino, E., Riggio, V.A. and Rosso, M., 2012. Biogas production by anaerobic co-digestion of cattle slurry and cheese whey. *Bioresource technology*, 114, pp.46-53.

Cuzin, N., J. L. Farinet, C. Segretain, and M. Labat. 1992. Methanogenic fermentation ofcassava peel using a pilot plug flow digester. *Bioresource Technology*, 41(3): 259-264.

Demirbas, A. 2001. Biomass resource facilities and biomass conversion processing for fuels and chemicals. *Energy Conversion and Management*, 42(11): 1357-1378.

Demirel, B., and P. Scherer. 2008. Production of methane from sugar beet silage without manure addition by a single-stage anaerobic digestion process. *Biomass Bioenergy*, 32(3): 203-209.

Drennan, M. F., and T. D. DiStefano. 2014. High solids co-digestion of food and landscape waste and the potential for ammonia toxicity. *Waste Manage*, 34(7): 1289-1298.

Garcia-Peña, E., P. Parameswaran, D. Kang, M. Canul-Chan, and R. Krajmalnik-Brown. 2011. Anaerobic digestion and co-digestion processes of vegetable and fruit residues: process and microbial ecology. *Bioresource Technology*, 102(20): 9447–9455.

Hosseinnia, A., M. S. Hashtroudi, and M. Banifatemi. 2007. Surfactant removal. *Water and Wastewater Asia*, 102(3): 52-55.

Li, Y., Zhang, R., Liu, X., Chen, C., Xiao, X., Feng, L., He, Y., Liu, G., 2013. Evaluating methane production from anaerobic mono-and co-digestion of kitchen waste, corn stover, and chicken manure. *Energy Fuels*, 27 (4), 2085–2091.

Li, H., X. Guo, F. Cao, and Y. Wang. 2014. Process evolution of dry anaerobic co-digestion of cattle manure with kitchen waste. *Chemical and Biochemical Engineering Quarterly*, 28(1): 161-166.

Linke, B. 2006. Kinetic study of thermophilic anaerobic digestion of solid wastes from potato processing. *Biomass Bioenergy*, 30(10): 892-896.

Mahnert, P., and B. Linke. 2009. Kinetic study of biogas production from energy crops and animal waste slurry: effect of organic loading rate and reactor size. *Environmental Technology*, 30(1): 93-99.

Maliha, J. Z., Y. Sohail, R. H. Muhammad, and N. M. Riffat. 2015. High-solids anaerobic co digestion of food waste and rice husk at different organic loading rates. *International Biodeterioration and Biodegradation*, 102(5): 149-153.

Mansaray, K. G., A. E. Ghaly, A. M. Al-Taweel, F. Hamdullahpur, and V. I. Ugursal. 1999. Air gasification of rice husk in a dual distributor type fluidized bed gasifier. *Biomass and Bioenergy*, 17(4): 315-332.

Mohammed, I. S., A. Mohammed, M. D. Solomon, B. A. Audu, and K. Y. Baba. 2018. Synthesis and optimization process of ethylene glycol-based biolubricant from palm kernel oil (PKO). *Journal of Renewable Energy and Environment*, 5(2): 1-9.

Midilli, A., I. Dincer, and M. Ay. 2006. Green energy strategies for sustainable development. *Energy Policy*, 34(18): 3623-3633.

Okeh, C. O., O. O. Chukwudi, and J. C. O. Frederick. 2013. Biogas production from rice husks generated from various rice mills in Ebonyi State, Nigeria. *Renewable Energy*, 62(2): 204-208.

O'sullivan, C., B. Rounsefell, A. Grinham, W. Clarke, and J. Udy. 2010. Anaerobic digestion of harvested aquatic weeds: water hyacinth (Eichhornia crassipes), cabomba (Cabomba Caroliniana) and salvinia (Salvinia molesta). *Ecological Engineering*, 36(10): 1459-1468.

Odeyemi, O. 1982. Relative Biogas Generation from Animal Manures in Nigeria. Saskatchewan, Canada: University of Regina.

Parawira, W., M. Murto, R. Zvauya, and B. Mattiasson. 2004. Anaerobic batch digestion of solid potato waste alone and in combination with sugar beet leaves. *Renew Energy*, 29(11): 1811-1823.

Salam, B., S. Biswas, and T. K. Das. 2011. Biogas from thermophilic anaerobic digestion of cow dung (RE-003). In *Intl. Conf. on Mechanical Engineering (ICME 2011)*, 256 -264. Dhaka, Bangladesh, 3 June.

Shoeb, F., and J. H. Singh. 2000. Kinetic of biogas evolved from water hyacinth. In *2nd International Symposium on New Technologies for Environmental Monitoring and Agro-Application*, 06-114. Turkey, 16 July.

Tchobanoglous, G., F. L. Burton, and H. D. Stensel. 2003. *Waste-water Engineering: Treatment and Reuse*. 4th ed. New Delhi: Tata McGraw-Hill Publishing Company Limited.

Yusuf, M. O. L., and N. L. Ify. 2011. The effect of waste paper on the kinetics of biogas yield from the co-digestion of cow dung and water hyacinth. *Biomass Bioenergy*, 35(3): 1345-1351.

Zennaki, B. Z., A. Zadi, H. Lamini, M. Aubinear, and M. Boulif. 1996. Methane fermentation of cattle manure: effects of HRT, temperature & substrate concentration. *Tropicultural*, 14(4): 134-140.