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Appraisal of Cumulative Volume of Biogas Produced from Water Hyacinth and Selected Animal Dungs Co-Digestion Mixes

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ABSTRACT

Water Hyancinth (WH) was co-digested with different mix ratios of poultry manure (PM), cow dung (CD) and pig dung (PD). A comparative analysis of the cumulative volume of gas produced from the different co-digestion mixes was carried out. The monitoring of the digestion process was done on a daily basis for a retention period of 40 days. The efficacy of the digestion process as well as the best mix ratio of water hyacinth to the different animal dungs was also evaluated in terms of the volume of gas produced. A rotameter with a capacity of 0.1-1L/Min equipped with a measuring tube was used for the gas flow measurements. From the results obtained the best mix of the PD-aided WH digestion is 3 WH:7 PD while CD - aided WH digestion is 2 WH:8 CD and PM-aided WH digestion is 2 WH: 8 PM. The study also revealed that the PM-aided WH mix produced more biogas compared to the CD-aided and PD-aided WH digestion mix.

Keywords: Co-digested, comparative, cumulative, digestion, biogas.

INTRODUCTION

Water hyacinth (WH) cause ecological and economic problems by impeding navigation and fishing activities, clogging irrigation systems and by creating a chronic shortage of dissolved oxygen harmful to the fauna and the flora (Malik, 2007). Perna and Burrows (2005) noted that the water hyacinth covers on water bodies reduce the gaseous exchanges that take place at the air/water interface and reduce the photosynthetic activity of submerged plants by hindering the penetration of the sun's rays.

Biogas consists primarily of exploitable methane (CH_4) and passive carbon dioxide (CO_2), which are both colourless and odourless. Methane has 20 times more greenhouse gas potential than carbon dioxide, so the capture and burning of methane significantly reduces the greenhouse gas effect (Atkins et al., 2008). Depending on the source of the organic matter and the management of the anaerobic digestion process, small amounts of other gases may be present (Arogo et al., 2009)

Several authors have confirmed the possibility of producing biogas from WH (Katima, 2001; Kivaisi and Mtila, 1997; Patil et al., 2011, Ojo, 2017, Ojo et al., 2018). These studies highlight that WH can produce as much as 20.3 liters of biogas per kg of dry matter.

These researches concluded that aquatic plants generate high-quality biogas. Pachaiyappan et al. (2014) worked on biogas production from water hyacinth blended with cow dung using different combinations and found out that encouraging results were obtained with a combination of 50% water hyacinth and 50% cow dung. Water hyacinth generates biogas that has greater methane content and more soil nutrients than digested dung.

Anaerobic digestion that utilizes manure for biogas production is one of the most promising uses of biomass wastes because it provides a source of energy while simultaneously resolving ecological and agrochemical issues (Budiyono et al., 2010). Animal waste such as cow dung and poultry wastes are familiar feed stooks used in the production of biogas. Several authors have worked on the potential of producing biogas from animal wastes (Itodo and Kucha, 1998; Sadaka and Engler, 2000; Bujoczek et al., 2000; Castrillon et al., 2002; Kivaisi, 2002; Gelegenis et al., 2007, Ojolo et al., 2007, Li et al., 2009; Budiyono et al., 2010; Ofoefule et al., 2010; Yusuf et al., 2011, Nnabuchi et al., 2012). The co-digestion of these familiar feedstocks with less familiar feedstocks, i.e., water hyacinth is imperative.

Co-digestion refers to the anaerobic digestion (AD) of multiple biodegradable substrates (feedstocks) in an AD system. Co-digestion is a technology that is increasingly being applied for simultaneous treatment of different solid and liquid organic wastes (Bouallagui et al., 2009). The general idea is to maximize the production of biogas in an AD plant by adding substrates that produce much more biogas per unit mass than the base substrate. AD is a well establish technology for manure and wastewater treatment and it can produce renewable energy, reduce organic and pathogen content, and create a stable residual waste that can be used as soil fertilizer. However, some manures present problems such as a high solids content or inhibition by toxic compounds released in the process. Co-digestion can not only reduce these problems, but also could improve the overall performance (Zamudio, 2010). Al-Imam et al. (2013) analysed and compared biogas from cow dung, poultry waste and water hyacinth but did not carry out a co-digestion of the different feed stocks. It was observed from that study that biogas production from cow dung, poultry waste and water hyacinth is 0.034 m^3/kg, 0.058 m^3/kg and 0.014 m^3/kg respectively. Adegunloye et al. (2013) investigated the ratio variation of WH on the production of biogas using pig dung. However, the blended water hyacinth and pig dung was only weighed in ratio 1:1 and 1:3.

MATERIALS AND METHODS

Substrates sources

Substrates utilized in this research are water hyacinth (WH), poultry manure (PM), cow dung (CD) and pig dung (PD). WH was harvested from a private pond in Akure, Ondo State, while PM, CD and PD were collected from the animal farm of the Federal University of Technology, Akure. Fresh water hyacinth (leaves, stem and root) on collection was chopped to small sizes of about 2 cm. The feedstocks were appropriately weighed.

31 mix ratios of WH to the PM, CD and PD were evaluated as shown in Table 1.

Table 1. Mix ratios of WH- animal dung aided feed stocks

10WH	9WH:1PD	8WH:2PD	7WH:3PD	6WH:4PD
5WH:5PD	4WH:6PD	3WH:7PD	2WH:8PD	1WH:9PD
10PD	9WH:1CD	8WH:2CD	7WH:3CD	6WH:4CD
5WH:5CD	4WH:6CD	3WH:7CD	2WH:8CD	1WH:9CD
10CD	9WH:1PM	8WH:2PM	7WH:3PM	6WH:4PM
5WH:5PM	4WH:6PM	3WH:7PM	2WH:8PM	1WH:9PM
10PM				

The monitoring of the digestion process was done on a daily basis for a retention period of 40 days. The temperature within the digester was measured using a mercury thermometer calibrated in degree centigrade while the pH was determined using a pH meter. The efficacy of the digestion process as well as the best mix ratio of water hyacinth to the different animal dungs was also evaluated in terms of the volume of gas produced. A rotameter was used to measure the rate of flow of the gas while a manometer was used to measure the pressure of the gas.

A rotameter flowmeter of model LZM-4T with a capacity of 0.1-1L/Min equipped with a measuring tube was used for the gas flow measurements. When the gas from the digester was introduced into the tube, the float was lifted from its initial position at the inlet, allowing the fluid to pass between it and the tube wall. As the float rose, more biogas passed by the float because the tapered tube's diameter was increasing. Ultimately, a point was reached where the flow area was large enough to allow the entire volume of the gas to flow past the float. This position corresponds to a point on the tube's measurement scale and provides an indication of the biogas flow rate.

The equation for the biogas flow rate was calculated using the ideal gas equation which is given in equation 1:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \quad \text{........ (1)}$$

The gas flow rate was calculated from equation 2:

$$V_2 = \frac{P_1V_1T_2}{P_2T_1} \quad \text{........(2)}$$

V_1 = rotameter reading (normal liters per minute)
V_2 = actual flow rate (liters per minute)
P_1=pressure at normal conditions
P_2 = actual pressure
T_1 = air temperature at normal conditions
T_2 = actual temperature of air

The normal conditions used were 0 degrees Celsius (273.15^{o}K) and 1 atmosphere (1.01325 bar)

Data analysis

A multiple regression analysis was carried out to examine the determinants of cumulative volume of gas produced from the three best mixes of the animal dung aided with WH digestion

The regression equation is described by equations 3 and 4

$Y = f(X_1, X_2, X_3, X_4, E)$………(3)

$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + E$ …….(4)

Where Y is the cumulative volume of gas

B_0 is the constant term

B_i's (i=1 to 4) are coefficients of the independent variable

X_1 is the Retention time (days)

X_2 is the Hydrogen ion concentration (μmol/L)

X_3 is the Temperature (^oC)

X_4 is the biogas pressure (bar)

E is the error term

The null hypothesis (H_0) and alternative hypothesis (H_1) of the significance test for correlation were expressed in the following ways for the two-tailed test.

H_0: $\rho = 0$ (the correlation coefficient is 0; there is no association between the determinants of biogas production)

H_1: $\rho \neq 0$ (the correlation coefficient is not 0; a non-zero correlation could exist)

RESULTS AND DISCUSSION

Cumulative biogas yield

The cumulative volume of biogas produced for the different mix ratios is presented in Table 2. The cumulative biogas yield for single-substrate digestion is shown in Figure 1. The results showed that WH single-substrate digestion produced a cumulative gas volume of 32.18 L which corresponds to 5.14 L/kg of WH, PD single-substrate digestion produced a cumulative gas volume of 94.47 L corresponding to 15.1 L/kg of PD. Similarly, CD produced a cumulative gas volume of 126.95 L, corresponding to 20.3 L/kg of CD, while PM produced a cumulative gas volume of 209 L corresponding to 33.58 L/kg of PM.

Figure 2 illustrates the cumulative biogas yield for PD-aided WH digestion. The results revealed a range of 37.54 - 140.32 L for the cumulative volume of biogas produced. 3 WH: 7 PD had the highest cumulative gas volume of 140 L which corresponds to 22.45 L/kg.

Figure 3 portrays the cumulative Biogas yield for CD-aided WH digestion. The results showed a range of 53.18 – 141.72 L with 2 WH: 7 CD recording the highest value corresponding to 22.68 L/kg.

The cumulative biogas yield for PM-aided WH digestion is shown in Figure 4. The results revealed a range of 54.45 – 216.55 L with 2 WH: 8 PM recording the highest value corresponding to 34.65 L/kg.

Table 2. Cumulative volume of biogas produced for the different mix ratios

S/N	Mix ratio	Cumulative Volume of biogas produced (litres)
1	10 WH	32.18
2	9WH: 1PD	37.55
3	8WH: 2PD	54.32
4	7WH: 3PD	64.32
5	6WH: 4PD	78.54
6	5WH: 5PD	102.93
7	4WH: 6PD	117.33
8	3WH: 7PD	140.32
9	2WH: 8PD	124.04
10	1WH: 9PD	119.13
11	10PD	95.47
12	9WH:1CD	53.18
13	8WH:2CD	67.05
14	7WH:3CD	81.04
15	6WH:4CD	89.31
16	5WH:5CD	99.29
17	4WH:6CD	116.38
18	3WH:7CD	128.12
19	2WH:8CD	141.72
20	1WH:9CD	132.78
21	10PM	126.95
22	9WH:1PM	54.46
23	8WH:2PM	70.06
24	7WH:3PM	85.17
25	6WH:4PM	100.64
26	5WH:5PM	117.23
27	4WH:6PM	133.54
28	3WH:7PM	169.54
29	2WH:8PM	216.55
30	1WH:9PM	164.09
31	10PM	209.90

WH: water hyacinth; PM: poultry manure; CD: cow dung; PD: pig dung.

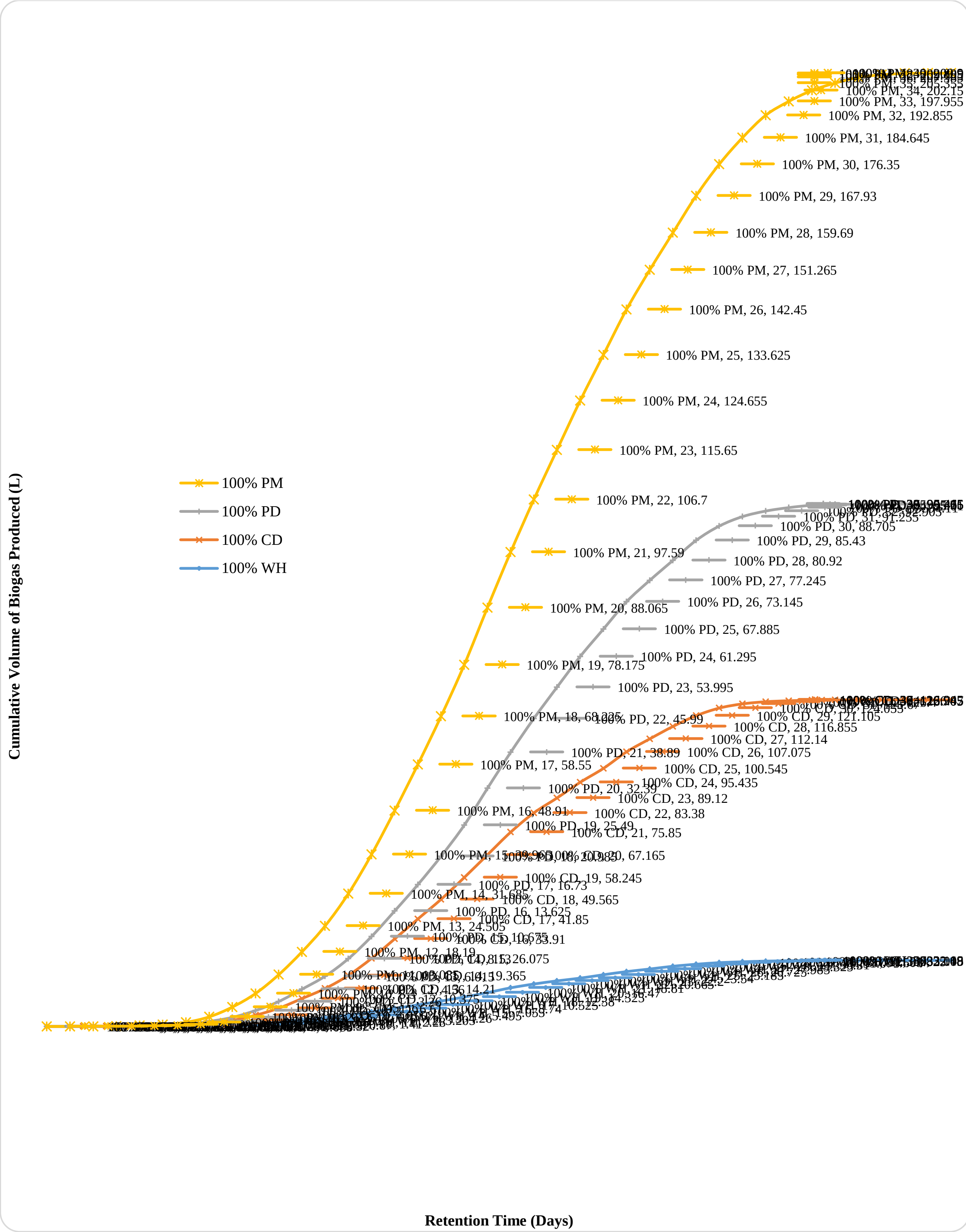

Figure 1. Cumulative biogas yield for single-substrate digestion

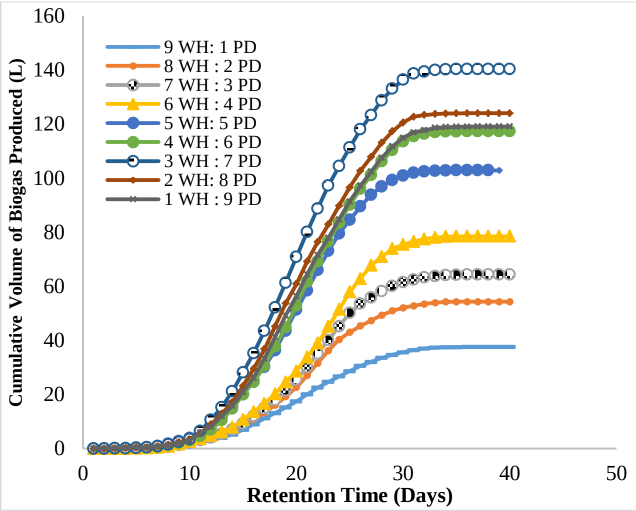

Figure 2. Cumulative biogas yield for PD-aided WH digestion

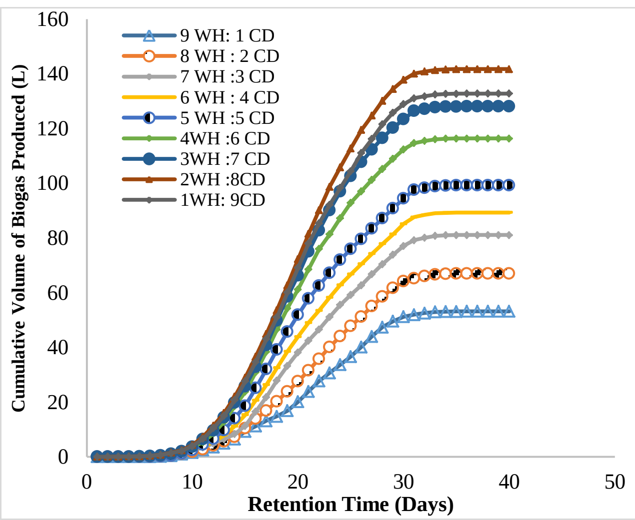

Figure 3. Cumulative Biogas yield for CD-aided WH digestion

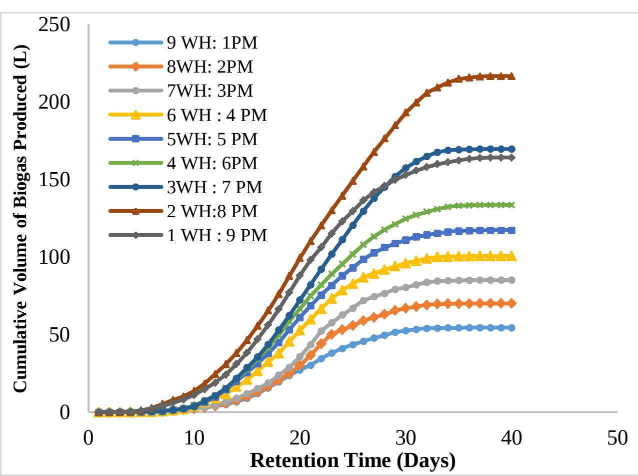

Figure 4. Cumulative Biogas yield for PM-aided WH digestion

Relationship between Independent variables and cumulative volume of gas produced

The relationship between the cumulative volume of gas produced by the three best mixes of animal aided WH digestion and the independent variables were determined using multiple regression and the results are presented in Tables 3, 4 and 5.

Table 3. Estimates of multiple regression analysis for the PD-aided WH digestion

Variables	Coefficient	Std. Error	t_{value}	Sig.
(Constant)	-250.107	81.210	-3.080	0.004
Retention Time (Days)	3.928	.241	16.301	0.0001
Hydrogen Ion Concentration (µmol/L)	160.169	41.790	3.833	0.001
Temperature (°C)	6.715	2.567	2.616	0.013
Biogas Pressure (bar)	1.358	4.301	0.316	0.754

R^2 = 0.956; Adjusted R^2 = 0.950; F_{value} = 188.125; Prob > F = 0.000

From the regression results presented in Table 3, the R^2 value of 0.956 implies that 95.6% of the variations in the cumulative volume of gas produced in the PD-aided WH digestion is accounted for by variations in the four variables put together. This implies that the retention time, hydrogen ion concentration of the substrates, temperature within the digester and pressure of the gas produced were able to explain the behavior of the cumulative gas produced by the mix ratio at 95.6% level of confidence. The adjusted R^2 value further supported the claim with a value of 0.950 or 95.0%. The F value of 188.125 at prob > f of 0.000 shows that the entire regression is significant at less than 1% probability level. On the individual variables, the results show that the retention time, hydrogen ion concentration and temperature are statistically significant at 5% probability level and positively related with the cumulative gas produced. Temperature is one of the main factors affecting performance and stability of anaerobic digestion process (Labatut et al., 2014 and Ziganshi et al., 2013). From the experimental results, at higher temperature decomposition take place quickly and hence, the volume of gas produced increased, ultimately increasing the cumulative volume of gas. On the other hand, the pressure of the gas is positively related to the cumulative volume of the gas produced but not statistically significant. This implies that an increase in the pressure of the gas coming from the digester will lead to a corresponding increase in the cumulative volume of gas produced. The equation for cumulative volume of gas produced by the PD-aided WH digestion can be written as shown in equation 5

$Y = -250.107 + 3.928X_1 + 160.169\ X_2 + 6.175\ X_3 + 1.358\ X_4 + E$ ……………………(5)

Table 4. Estimates of multiple regression analysis for the CD-aided WH digestion

Variables	Coefficient	Std. Error	t_{value}	Sig.
(Constant)	-274.813	37.958	-7.240	0.0001
Retention Time (Days)	3.955	.131	30.160	0.0001
Hydrogen Ion Concentration (μmol/L)	153.143	19.689	7.778	0.0001
Temperature (°C)	7.301	1.232	5.924	0.0001
Biogas Pressure (bar)	4.217	2.877	1.465	0.152

$R^2 = 0.979$; Adjusted $R^2 = 0.977$; $F_{value} = 409.544$; Prob > F = 0.000

Table 4 shows that an R^2 value of 0.979 was observed for the CD-aided WH digestion. This implies that 97.9% of the variations in the cumulative volume of gas produced in the CD-aided WH digestion is accounted for by variations in the four independent variables put together. In other words, the independent variables were sufficient to explain the behavior of the dependent variable at 97.9% level of confidence. This claim is supported by an adjusted R^2 value of 97.7%. The entire regression is significant at less than 1% probability level with a F value of 409.544 at prob > f of 0.000. The results also show that the retention time, hydrogen ion concentration and temperature are statistically significant at 5% probability level and positively related with independent variable. While the pressure of the gas is positively related to the cumulative volume of the gas produced but not statistically significant. The equation for cumulative volume of gas produced by the CD-aided WH digestion can be written as shown in equation 6.

$Y = -274.813 + 3.955X_1 + 153.143X_2 + 7.301\ X_3 + 4.217\ X_4 + E$ ………(6)

An R^2 value of 0.969 was observed for the PM-aided WH digestion as observed in Table 5. This means that 96.9% of the variations in the cumulative volume of gas produced in the PM-aided WH digestion is accounted for by variations in the four variables put together. The independent variables were sufficient to explain the behavior of the dependent variable at level of confidence. This claim is reinforced by an adjusted R^2 value of 96.6%. The whole regression is significant at less than 1% probability level with a F value of 276.488 at prob > f of 0.000. The results also revealed that the retention time and hydrogen ion concentration are statistically significant at 5% probability level and positively related with independent variable. While the temperature within the digester and the pressure of the gas produced is positively related to the cumulative volume of the gas produced but not statistically significant. The equation for cumulative volume of gas produced by the PM-aided WH digestion can be written as shown in equation 7.

$Y = -151.162 + 5.704X_1 + 80.505X_2 + 2.586\ X_3 + 7.445\ X_4 + E$ …………(7)

Table 5. Estimates of multiple regression analysis for the PM-aided WH digestion

Variables	Coefficient	Std. Error	t_{value}	Sig.
(Constant)	-151.162	99.139	-1.525	.136
Retention Time (Days)	5.704	0.307	18.585	0.0001
Hydrogen Ion Concentration (μmol/L)	80.505	20.863	3.859	0.0001
Temperature (°C)	2.586	3.142	0.823	0.416
Biogas Pressure (bar)	7.445	4.089	1.821	0.077

$R^2 = 0.969$; Adjusted $R^2 = 0.966$; $F_{value} = 276.488$; Prob > F = 0.000

CONCLUSION

An appraisal of the cumulative volume of gas produced from different co-digestion mixes of WH and selected animal dungs was done in terms of retention time, hydrogen ion concentration, temperature and biogas pressure. Equations were derived to show the relationship between the cumulative volume of gas produced and the aforementioned variables. At the end of the study, three best mixes of WH to the animal dungs were obtained. From the results obtained the best mix of the PD-aided WH digestion is 3 WH:7 PD with a 140.32 L cumulative volume of biogas produced. For the CD - aided WH digestion, the best mix is 2 WH:8 CD with a cumulative volume of 141.72 L of biogas produced and for the PM-aided WH digestion, the best mix is 2 WH: 8 PM with a cumulative biogas volume of 216.55 L produced. The study revealed that the PM - aided WH mix produced more biogas when compared to the CD and PD aided WH digestion mixes.

DECLARATIONS

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Authors' contribution
OM Ojo performed the experiments, analysed the data obtained and wrote the manuscript. JO Babatola designed the experimental process and revised the manuscript. Both authors read and approved the final manuscript

Conflict of interest
The authors hereby confirm that there is no conflict of interest whatsoever with any third party.

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