Regression Analysis of Biogas Production from the Co-Digestion of Water Hyacinth and Pig Dung

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Abstract— The aim of this study is to determine the best mix of water hyacinth (WH) to be co-digested with pig dung (PD) in order to maximize biogas production in terms of quantity. 11 mix ratios of WH to PD were evaluated and each experimental run was assessed over a period of 40 days. The data obtained were analyzed using regression analysis and non-linear parameter estimation model. From the results obtained, 3 WH: 7 PD co-digestion mix recorded the highest daily yield of 9.5 L of biogas on the 20th day, starting its gas production on the 3rd day and ending on the 34th day. The results also showed that WH single-substrate digestion produced a cumulative biogas volume of 32.18 L which corresponds to 5.14 L/kg of WH and PD single-substrate digestion produced a cumulative gas volume of 94.47 L corresponding to 15.1 L/kg of PD. 3 WH: 7 PD had the highest cumulative gas volume of 140 L which corresponds to 22.45 L/kg. Similarly, the highest maximum biogas production rate of 9.874057 L/day was observed for the 3 WH: 7 PD co-digestion mix and this was recorded on the 17th day of digestion. From the results obtained the best mix of the PD-aided WH digestion is 3 WH: 7 PD.

Keywords— Biogas, Co-digestion, Cumulative, Pig Dung, Water Hyacinth

1 INTRODUCTION

Energy consumption in Nigeria has been increasing on a relatively high rate. According to Iwayemi (2008), on a global scale, the Nigerian energy industry is probably one of the most inefficient in meeting the needs of its customers. In addition, the ever increasing prices of petroleum products globally, has made kerosene, which is the most commonly used fuel for cooking and lighting, unaffordable to many, especially the rural dwellers (Ahmadu, 2009).

Water hyacinth (WH) has invaded freshwater systems in over 50 countries on five continents and it is especially pervasive throughout Southeast Asia, the Southeastern United States, Central and Western Africa, and Central America (Brendonck et al., 2003). There have been cases of complete blockage of waterways by WH making water transportation, fishing, navigation and recreation extremely difficult. Shoeb and Singh (2002) reported that under favorable conditions WH can achieve a growth rate of 17.5 metric tons per hectare per day.

Animal dungs contain high concentrations of pathogens which need to be effectively managed in order to minimize environmental pollution and public health risks. In addition, with the enormous animal population in Nigeria, millions of tonnes of dungs are released daily and these emit a lot of methane gas (which is 320 times more harmful to human health than carbon dioxide) when exposed to the atmosphere (Thakur, 2006). Biogas is produced from different substrates which give varying quantities and quality of the gas. However the time required to produce the maximum amount of gas is usually not known. In biogas production, the advantages of co-digestion of different feed stocks include better digestibility, enhanced biogas production/methane yield arising from availability of additional nutrients, as well as a more efficient utilization of equipment and cost sharing (Parawira and Mshandete, 2009).

Knowing the best mix of substrates as well as the time at which maximum methane is produced will help in selecting the best substrates during co-digestion and when to re-load the digester. Although some researchers have established the viability of co-digesting water hyacinth with other more familiar feed stocks such as Pig Dung (PD) (Adegunloye et al., 2013, Al-Iman et al., 2013) for improved biogas production, none of them have established an optimum mix ratio for efficient biogas production while evaluating some of the parameters that affect biogas production. The aim of this research is to determine the best mix of water hyacinth to be co-digested with PD in order to maximize biogas yield in terms of quantity while evaluating the time at which maximum gas is produced.

2 METHODOLOGY

25- litre laboratory size plastic digesters were used in this study. Eleven (11) mix ratios of WH to PD (10 : 0, 9 : 1, 8 :2, 7 :3, 6 : 4, 5 : 5, 4 : 6, 3 : 7, 2 : 8, 1 : 9, 0 : 10) were evaluated. 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 WH to PD was also evaluated in terms of the volume of gas produced. The performance efficiency of the reactor as well as the overall assessment of the best mix ratios obtained were measured in terms of the gas flow rate, gas pressure and gas quality. A rotameter flowmeter of model LZM-4T with a capacity of 0.1-1 L/min equipped with a measuring tube was used to measure the rate of flow of the gas while a manometer was used to measure the pressure of the gas. Plate 1 shows the experimental set up of the experiments.

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Plate 1: Experimental set-up

A multiple regression analysis was carried out to examine the determinants of cumulative volume of gas produced from the different mixes of the PD - aided WH digestion. The regression equation is described by equations 1 and 2

$$Y = f(X_1, X_2, X_3, X_4, E) \quad (1)$$

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + E \quad (2)$$

Where Y is the cumulative volume of gas

B_0 is the constant term

$B_1 – B_4$ 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

Nonlinear parameter estimation using Sigma 10 plot was used to determine the maximum biogas production rate. Biogas production rate is given by equation 3.

$$G^1 = abe^{-bt}(1 - e^{-bt})^{c-1} \quad (3)$$

The maximum biogas production rate was obtained using equation 4. The results obtained are presented in tables and graphs.

$$G^1{}_{max} = -abc[1 - c]^{c-1} \quad (4)$$

Where a is ultimate biogas production

b is pseudo-biogas production velocity (rate constant)

c is shape factor

t is retention time

3 RESULTS AND DISCUSSIONS

3.1 pH OF SUBSTRATE

The pH of the substrates ranged from 6.1 to 8.4 with the values low at the start of the digestion process and gradually increasing to its maximum at the end of the digestion process. The pH values observed are a measure of the hydrogen concentration of the substrate. The substrate's pH is an important parameter affecting the growth of microbes during anaerobic digestion (Yadvika et al., 2004). The values observed for the pH evidently describes the three main stages (hydrolysis, acidogenesis/acetogenesis and methanogenesis) that clearly defines any Anaerobic Digestion process (Li et al., 2011).

3.2 TEMPERATURE WITHIN THE DIGESTER

The temperature ranged from 28.6 to 32.2 °C for the PD - aided WH digestion. This shows that the digestion process occurred within the mesophilic temperature range, which is ideal for Anaerobic Digestion as this temperature range adequately supports microbial activities within the digester (Wang et al., 2009). The temperature at which digestion occurs can significantly affect the biogas production in terms of the conversion, kinetics, stability and consequently the methane yield. The result does not show any significant variation, this is probably because the digesters were not lagged. The variations in the temperature values were due to the weather conditions. Since the temperature values remain within the mesophilic range, the activities of methanogens was enhanced, encouraging the production of methane rich biogas. Nonetheless, a close study of the temperature values reveals that the volume of gas produced slightly increased with increase in temperature.

3.3 DAILY/CUMULATIVE VOLUME OF GAS PRODUCED

The daily biogas yield for PD - aided WH digestion revealed that 3 WH: 7 PD recorded the highest daily yield of 9.5 L on the 20th day, starting its gas production on the 3rd day and ending on the 34th. Figure 1 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.

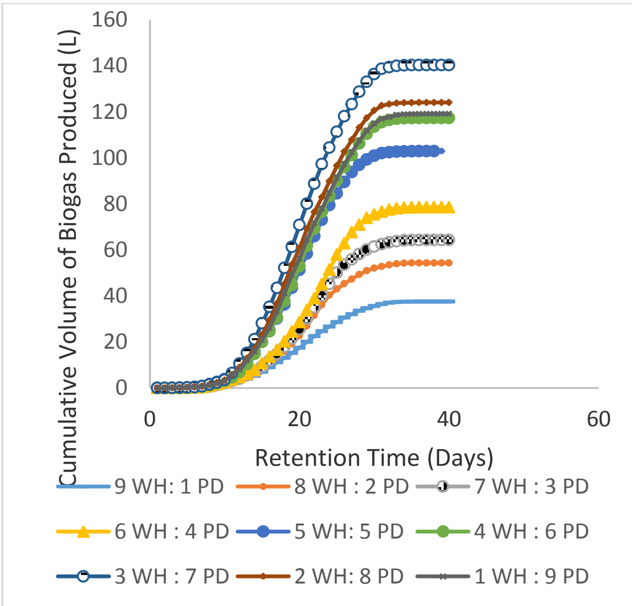

Fig. 1: Cumulative biogas yield for PD - aided WH digestion

3.4 MAXIMUM BIOGAS PRODUCTION RATE

Table 1 depicts the estimation model for the PD - aided WH digestion maximum biogas production rate. An average rate constant of value of 0.178464 was recorded with a standard deviation of 0.008784. Mix ratio 3 WH: 7 PD recorded the highest maximum biogas production rate of 9.874057 L/day and this was recorded on the 17th day. From the results obtained the best mix of the PD - aided WH digestion in terms of maximum biogas production rate is 3 WH: 7 PD.

Table 1. PD-aided WH digestion maximum biogas production rate

Composition (%PD)	a-value	b-value	c-value	t_{max} (days)	Maximum biogas production rate (L/day)
0	34.16	0.1637	17.85	17.6054	2.116757
10	40.04	0.1636	19.9	18.28068	2.472193
20	57.23	0.1878	34.36	18.8333	4.012424
30	68.03	0.187	36.28	19.20463	4.745573
40	83.95	0.1839	36.97	19.63081	5.757517
50	108.8	0.1865	34.46	18.98016	7.574894
60	124.2	0.1791	28.19	18.64303	8.331408
70	147.8	0.1778	23.98	17.86963	9.874057
80	131.1	0.1751	23.85	18.11413	8.626389
90	126.2	0.1736	24.3	18.37832	8.229546
100	101.4	0.185	42.29	20.24081	6.983785

3.5 Relationship between Independent Variables and Cumulative Volume of Gas Produced

The relationship between the cumulative volumes of gas produced and the independent variables which were determined using multiple regression are presented in Tables 2.

Table 2. Estimates of multiple regression analysis for the PD - aided WH digestion

Variables	Coefficient	Std. Error	tvalue	Sig.
(Constant)	-250.107	81.210	-3.080	.004
Retention Time (Days)	3.928	.241	16.301	.000
Hydrogen Ion Concentration (μmol/L)	160.169	41.790	3.833	.001
Temperature (oC)	6.715	2.567	2.616	.013
Biogas Pressure (bar)	1.358	4.301	.316	.754

$R^2 = 0.956$, Adjusted $R^2 = 0.956$, Fvalue = 188.125, Prob > F = 0.000

From the regression results presented in Table 2, the R2 value of 0.956 implies that 95.6% of the variations in the cumulative volume of gas produced 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 R2 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. 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 but this is not sufficient to describe the behavior of the digestion process. The equation for cumulative volume of gas produced by the PD - aided WH digestion can be written as shown in equation 5 (Ojo, 2017). .

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

4 Conclusion and Recommendations

The results affirmed that the cumulative volume of biogas produced from the single substrate digestion of WH is quite low compared to that obtained from the single substrate digestion of PD. This is due to the fact WH has low density in the dry state, such that when they are put into digesters, there is a tendency that they would float above the liquid surface and become unavailable for digestion. From the results obtained the best mix of the PD-aided WH digestion is 3 WH:7 PD. It is recommended that the conversion of WH to bio energy should be encouraged in order to meet the ever - increasing demand for energy. In addition, the synergistic effect of co-digesting animal manures with WH should be harnessed in order to create transformational change that would produce high value renewable energy.

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