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Biogas Production through Anaerobic Co-Digestion of Water Hyacinth and Poultry Manure

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ABSTRACT

In this study, different mix ratios of water hyacinth (WH) to poultry manure (PM) were digested and each experimental run was assessed over a period of 40 days in order to determine the best mix in terms of biogas yield. Water displacement method was used to measure the volume of biogas produced and the data obtained were analyzed using sigma plot non-linear parameter estimation model. 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, while PM single-substrate digestion produced a cumulative gas volume of 209 L corresponding to 33.58 L/kg of PM. For the WH-PM co-digestion, the results revealed a range of 54.45 – 216.55 L with 2WH: 8PM recording the highest value of 34.65 L. 2 WH: 8 PM also had the highest biogas yield of 11.21 L/day and this was observed on the 18th day. The study revealed that the best mix of WH-PM co-digestion is 2 WH: 8 PM.

1. INTRODUCTION

Increase in population has led to unprecedented increase in the demand for energy. United Nations (2013) forecasted that the world population will likely increase by 2.4 billion over the next 38 years, increasing from 7.2 billion in 2013 to 9.6 billion in 2050. Demand for energy is expected to increase by more than 50% by 2025, and as a result, there is an ongoing search to develop sustainable, affordable, environmentally friendly energy from renewable sources (Deublein and Steinhauser, 2008; Khanal, 2008).

At present, the main conventional source of energy in Nigeria is the fossil fuel. Fossil fuels are non-renewable and hence their deposits will eventually be exhausted (Akinola, 2016). Developing countries need to expand access to reliable and modern energy services in order to alleviate poverty and increase productivity, as well as enhance competitiveness and economic growth. Biogas is a cheap and clean renewable form of energy that can be produced sustainably in many countries around the world (Bond and Templeton, 2011; Ben-Iwo *et al*., 2016; Adekoya *et al*., 2018). Biogas production by anaerobic digestion is popular for treating biodegradable wastes because valuable fuel can be produced while destroying the disease - causing pathogens and reducing the volume of disposed waste products (Babatola, 2008). If properly explored, biogas could be harnessed for electricity supply to many Nigerian homes (Ojo, 2017).

Water hyacinth (WH) is considered a deleterious weed in many parts of the world as it grows very fast and diminishes nutrient and oxygen rapidly from water bodies, thereby adversely affecting flora and fauna (Ojo, 2017). 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. With the growing energy crisis supplemented by environmental concerns, biomethanation of WH as a biomass-to-energy generation alternative as become imperative.

Co-digestion of different materials may enhance the anaerobic digestion process due to better carbon and nutrient balance (Mshandete *et al*., 2004; Parawira *et al.,* 2004). According to Mata-Alvarez *et al.* (2000), digestion of more than one substrate in the same digester can establish positive synergism. Co-digestion, which is known as the simultaneous anaerobic digestion of two of more feedstocks in a single digester can be employed for the improvement of biogas yield from anaerobic digesters (Ojo and Babatola, 2020), However, co-digestion does not always give higher biogas yield than digestion of each substrate separately. Some researchers have established the viability of co-digesting WH with other more familiar animal feed stocks (such as poultry manure (PM)) for improved biogas production. Al-Imam *et al.* (2013) analysed and compared biogas from Cow dung (CD), PM and WH but did not carry out a co-digestion of the different feed stocks. It was observed from that study that biogas production from CD, PM and WH was 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 Pig dung (PD) biogas. However, the blended WH and PD was only weighed in ratio 1:1 and 1:3. None of these studies established an optimum mix ratio for efficient biogas production while evaluating some of the parameters that affect biogas production. Thus, this study aims to determine the best mix of WH to be co-digested PM in order to maximize biogas yield.

2. MATERIALS AND METHODS

2.1. Materials

The following materials were used the construction of the digesters utilized in this study:

i. A 25 liters keg which served as the digestion chamber and gas chamber
ii. $\frac{1}{2}$ inches pipes which were used as inlet for the substrates as well as gas outlet.
iii. 1 inches pipe which was used as slurry outlet.
iv. 90^o angle elbows (of sizes $\frac{1}{2}$ inches, 1 inch and 1 $\frac{1}{2}$ inches) which were used for connecting the pipes to each other.
v. Control valves which were used for opening and closing the different inlets and outlets.
vi. Hose which was used for the connection of the gas outlet to the water displacement set up.

The substrates utilized in this study were WH and PM. WH was harvested from a private pond in Akure, Ondo State, while PM was collected from the animal farm of the Federal University of Technology, Akure.

2.2. Methods

A 25 - litre plastic digester was used in this study and the volume of biogas produced was determined using water displacement method as described in Otun *et al.* (2014) and Ojo *et al.* (2016). A black coloured digester was used in order to enhance the operating temperature to the mesophilic temperature range for improved biogas production (Parker *et al.,* 2002). Eleven (11) mix ratios of WH:PM were used in this study: 10: 0, 9: 1, 8: 2, 7: 3, 6: 4, 5: 5, 4: 6, 3: 7, 2: 8, 1:9 and 0: 10. The volume of gas produced was measured daily using water displacement method.

The data obtained were analyzed using Sigma Plot 2010 software for non-linear regression with four parameters. The sigmoid or S - curve obtained is described by Equation 1:

$$y = a[1 - e^{(-bt)}]^c \quad (1)$$

Where: a= ultimate biogas production, b= pseudo-biogas production velocity (rate constant), c= shape factor and t= retention time

Biogas production rate was calculated using Equation 2.

$$G = abe^{-bt}\,(1 - e^{-bt})^{c-1} \quad (2)$$

Optimum (maximum) biogas production rate will be reached when:

$$\frac{d^2y}{dt^2} = abe^{-bt}\,[(c-1)(1-e^{-bt}]^{c-2}.be^{-bt}] + [(1 - e^{-bt})^{c-1}ab\,(-be^{-bt})] = 0 \quad (3)$$

Which simplifies to:

$$acb^2e^{-bt}(c-1)(1-e^{-bt})^{c-2}e^{-bt} = acb^2e^{-bt}(1-e^{-bt})^{c-1}$$

$$(c-1)e^{-bt} = (1-e^{-bt})\ at\ t = t_{max}$$

Where t_{max} is time taken for maximum biogas

$ce^{-bt_{max}} = 1$, which implies that

$$e^{-bt_{max}} = c^{-1}$$

Therefore:

$$-bt_{max} = -lnC$$

$$t_{max} = \frac{(lnC)}{b} \quad (4)$$

At optimum time, when t_{max} (Equation 4) is substituted for *t* in Equation (2), the maximum biogas production rate ($G^1{}_{max}$) is obtained as follows:

$$G^1{}_{max} = abe^{-b(\frac{lnC}{b})}[(1-e^{-b(\frac{lnC}{b})}]^{c-1}$$

$$G^1{}_{max} = abe^{-lnC}[1-e^{-lnC}]^{c-1}$$

$$G^1{}_{max} = -abc[1-c]^{c-1} \quad (5)$$

3. RESULTS AND DISCUSSION

3.1. Ultimate Biogas Production for PM-aided WH Digestion

Figure 1 presents the ultimate biogas produced by the different mixes of the PM-aided WH digestion. Single substrate digestion of WH produced the lowest ultimate biogas of 32.17 L. WH has high water content and hence the solid content is low. Due to the low density of WH in the dry state, there is a tendency that it would flow above the liquid surface and become unavailable for digestion even when they are chopped into very tiny pieces (Ojo, 2017). The results showed that the highest ultimate biogas of 216.07 L was produced by 2 WH: 8 PM and invariably makes it the best PM-aided WH digestion mix. The high volume of biogas produced by this digestion mix agrees with findings of Ahmadu *et al.* (2009).

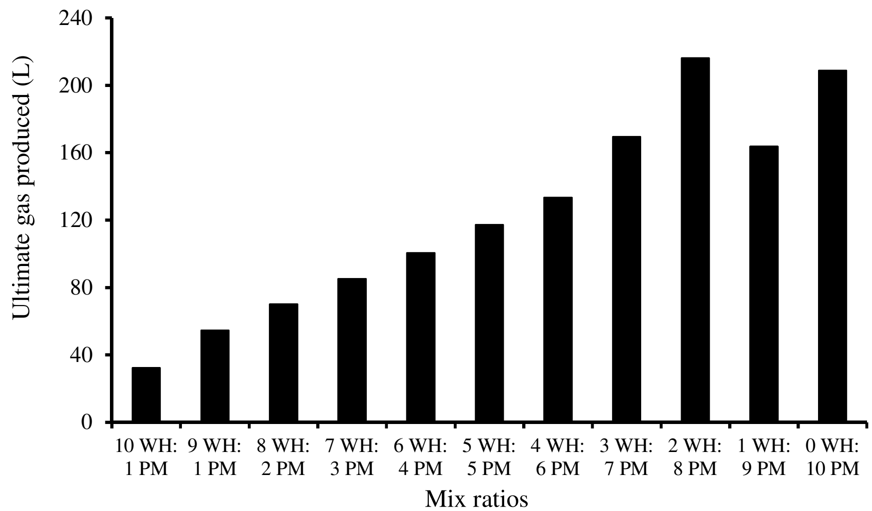

Figure 1: Ultimate biogas production for PM-aided WH digestion

3.2. PM-aided WH Digestion Maximum Biogas Production Rate

Table 1 displays estimation model for the PM - aided WH digestion maximum biogas production rate. Mixes 6 WH: 4 PM, 5 WH: 5 PM, 4 WH: 6 PM and 9 WH: 1 PM recorded their maximum biogas yield on the 17th day. Mix ratio 2 WH: 8 PM had the highest biogas yield of 11.21 L/day and this was observed on the 18th day. The average rate constant for the mixes was 0.16 with a standard deviation of 0.03. From the results obtained, 2 WH: 8 PM was deemed the best digestion mix. Retention time has a significant effect on the digester's performance. This corroborates findings of Ezekoye *et al.* (2011) who observed an increase in biogas production during the first 5 days to 15 days, then a rather constant rate for the next 20 days to 30 days and thereafter an exponential decline.

Table 1: PM-aided WH digestion maximum biogas production rate

Composition (%PM)	a-value	b-value	c-value	t_{max} (days)	Maximum biogas production rate (L/day)
0	34.16	0.16	17.85	17.61	2.12
10	56.92	0.19	30.32	18.10	4.01
20	72.75	0.20	45.70	18.72	5.53
30	88.51	0.20	46.90	18.94	6.69
40	105.00	0.18	24.24	17.53	7.17
50	122.90	0.17	19.93	17.56	7.90
60	141.30	0.16	17.32	17.89	8.53
70	183.50	0.15	18.68	19.08	10.64
80	244.60	0.12	8.779	18.50	11.21
90	173.00	0.15	14.21	17.14	10.21
100	243.80	0.11	8.31	19.60	10.31

4. CONCLUSION

The influence of varying mix ratios of co-digested WH and PM on biogas production was evaluated. Different mix ratios of WH to PM were evaluated and each experimental run was assessed over a period of 40 days. The study revealed that WH is biodegradable and thus it can serve as an important feedstock for biogas production. However, due to its low density in the dry state, when WH is put into digesters, there is a tendency that it would float above the liquid surface and become unavailable for digestion. This affirms why 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 PM. The study further revealed that the best mix of PM-aided WH digestion is 2 WH: 8 PM. Since WH is a ubiquitous cellulosic material particularly in swampy areas, the breakdown of WH can be enhanced in the presence of PM which is also waste in the Agricultural sector.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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