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Co-Digestion of Water Hyacinth and Poultry Manure for Improved Biogas yield

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Abstract: *The best mix of Water hyacinth (WH) to be co-digested with Poultry manure (PM) in order to maximize biogas yield in terms of quantity was determined in this study. Eleven (11) mix ratios of WH: PM were evaluated. 25 litre laboratory size digesters were used for the experiments. The overall assessment of the best mix ratios was measured in terms of the gas flow rate. The results revealed that biogas production started between 2nd and 6th day for all the mixes. The highest gas produced was observed between 17th and 19th day for all samples. Biogas production stopped between 34th and 39th day for all samples. WH: PM ratio of 2:8 gave the highest biogas yield of 11.62 L on the 19th day, starting gas production on the 2nd day and stopping on the 39th day. The results revealed a cumulative biogas yield which ranged from 54.45 to 216.55 L with 2 WH: 8 PM recording the highest value corresponding to 34.65 L/kg. The 3rd order polynomial curve for the different mixes of the PM aided biogas production rate had a significant* R^2 *value of 0.9678 with 2 WH: 8 PM being the best PM-aided WH digestion mix. . From the results obtained, 2 WH: 8 PM is the best PM-aided WH digestion mix in terms of daily biogas production, cumulative volume of gas produced and maximum biogas production rate.*

Keywords: *Best mix, Water hyacinth, Poultry manure, Biogas, Production*

INTRODUCTION

Energy consumption in Nigeria has been increasing on a relatively high rate. According to [1], on a global scale, the Nigerian energy industry is probably one of the most inefficient in meeting the needs of its customers. This is most evident in the persistent uncertainty in the markets for electricity and petroleum products, especially kerosene and diesel. Energy utilization in Nigeria has increased progressively over the last decades as a result of increase in population and technological advancement. 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 [2].

Water hyacinth (WH) is considered as a noxious weed in many parts of the world as it grows very fast and depletes nutrient and oxygen rapidly from water bodies, thereby adversely affecting flora and fauna. There have been cases of complete blockage of waterways by water hyacinth making water transportation, fishing, navigation and recreation extremely difficult. [3] reported that under favorable conditions, WH can achieve a growth rate of 17.5 metric tons per hectare per day. A considerable number of studies have been conducted to investigate anaerobic digestion of WH as feedstock for digestions processes [4, 5, 6, 7]. 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 [8]. In the absence of appropriate disposal methods, animal dungs can cause diverse environmental and health problems such as odour, greenhouse gas emission and water contamination. Interestingly, anaerobic fermentation of manure for biogas production does not reduce its value as fertilizer supplement as nutrients remain in the treated sludge.

Combining animal with plant wastes catalyzes the biogas production with consequent increased yield [9, 10] Organic waste can become a channel for wealth creation if they are harnessed as feed materials for the production of biogas as well as biofertilizers that would be produced from the digestate. With the growing energy crisis supplemented by environmental concerns, biomethanation of WH as a biomass-to-energy generation alternative has become imperative. Knowing the best mix of substrates as well as the time at which maximum biogas is produced will help in selecting the best substrates during co-digestion and when to re-load the digester. Varying the mix ratios of different feed stocks during co-digestion will help to know the best mix ratio to adopt in order to ensure maximum biogas production since co-digestion does not necessarily mean increased methane production. The aim of this study is to determine the best mix of WH to be co-digested with PM in other to maximize biogas yield in terms of quantity.

METHODOLOGY

2.1 Materials and Methods

Substrates utilized in this research are WH and PM. WH was cultivated and harvested from a private pond in Aule, Akure, Ondo State, while PM was collected from the poultry of the Federal University of Technology, Akure. Plate 1 shows the pond at the point of harvest of WH. 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. These mix ratios were selected using fractional factorial design. A fractional design is a design in which experiments are conducted on only a selected fraction of all possible runs.

25 litre laboratory size digesters were used for the experiments. The digesters were designed as specified in [11]. The experimental set-up is as shown in Plate 2. The pH of the substrates and temperature within the digester was measured daily for a retention period of 40 days using a pH meter and thermometer respectively. The overall assessment of the best mix ratios was measured in terms of the gas flow rate. 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: Pond at the point of harvest of WH

Plate 2: Experimental set-up

2.2 Mathematical Models

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

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

Where: y is biogas yield
a is ultimate biogas production
b is pseudo-biogas production velocity (rate constant)
c is shape factor
t is retention time

Biogas production rate is given by:

$$G^1 = \frac{dy}{dt} = a\,(1 - e^{-bt})^{c-1}.be^{-bt}$$

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

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

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

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,

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

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

The maximum biogas production rate ($G^1{}_{max}$) is given by:

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

3. RESULTS AND DISCUSSIONS

3.1 pH and Hydrogen ion concentration of Substrate

The pH values observed are a measure of the hydrogen concentration of the slurry. 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 values observed for the pH evidently describes the three main stages (hydrolysis, acidogenesis/acetogenesis and methanogenesis) that clearly defines any Anaerobic Digestion (AD) process [12]. The hydrogen ion concentration was derived from the pH using equation 6.

$$pH = -log_{10}[H^+] \quad \ldots(6)$$

Figure 1 shows the variation in hydrogen ion concentration with time for the 2:8 mix ratio of WH: PM. It was observed that the cumulative value of hydrogen ion concentration for the mix ratio 2:8 of WH: PM digestion is much higher than that of the other co-digestion substrates. This explains why the volume of biogas produced from the 2:8 co-digestion mix outweighs the volume of biogas produced from co-digestion of other mixes. The findings support that of [13].

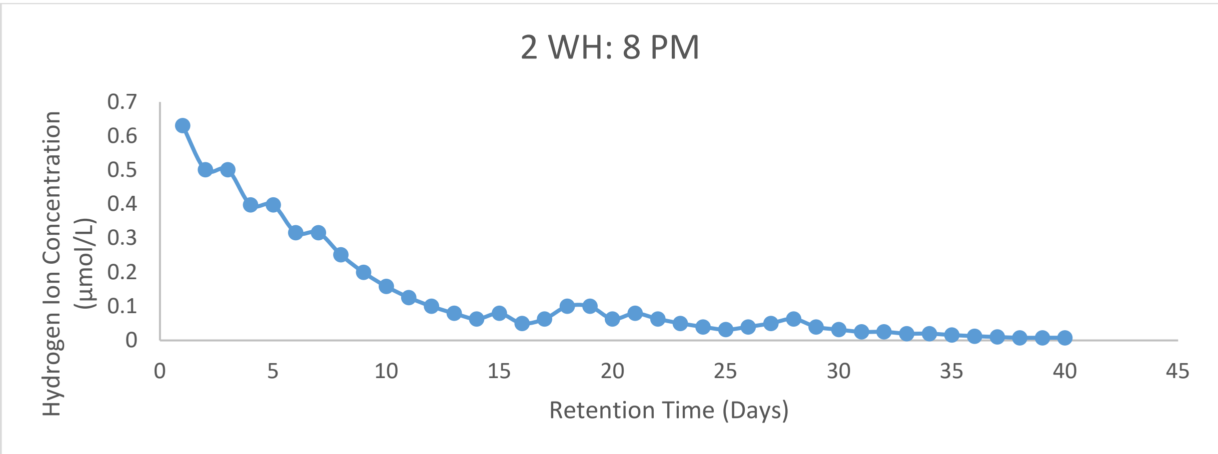

Figure 1: Hydrogen ion concentration for 2 WH: 8 PM digestion

3.2 Temperature within the Digester

The temperature ranged from 28.2 to 31.8 ºC for the PM-aided WH digestion. Figure 2 shows the temperature variations with time for the 2: 8 co-digestion mix of WH: PM. The graph shows that the digestion process occurred within the mesophilic temperature range, which is ideal for AD as this temperature range adequately supports microbial activities within the digester [14]. The variations in the temperature values was due to the weather conditions during the experiment. Since the temperature values remain within the mesophilic range, the activities of methanogens were enhanced, encouraging the production of methane rich biogas. However, a close study of the temperature values reveals that the volume of gas produced slightly increased with increase in temperature.

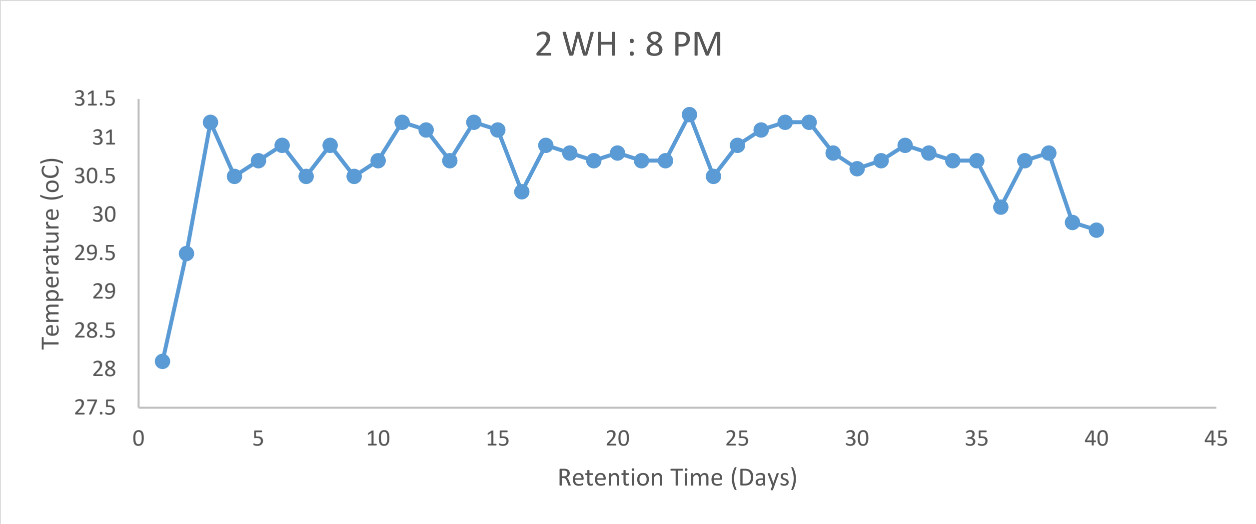

Figure 2: Temperature variation for 2 WH: 8 PM digestion.

3.3 Daily Biogas Production

For WH single-substrate digestion, biogas production started on the 7th day and stopped on the 36th day recording its highest value of 2.6 L on the 21st day. For the PM single-substrate digestion, gas production started on the 3rd day and stopped on the 39th day, recording its highest value on the 19th day. Evaluating biogas yield for PM - aided WH digestion, mix 2 WH: 8 PM recorded the highest daily biogas yield of 11.62 L on the 19th day, starting gas production on the 2nd day and stopping on the 39th day. The daily gas production curves for the different mixes followed a similar trend confirming that all anaerobic digestion processes follow a similar pattern, starting with hydrolysis and ending with methanogenesis. The results revealed that biogas production started between the 2nd and 6th day for all the mixes. The highest gas produced was observed between the 17th and 19th day for all the samples. Biogas production stopped between the 34th and 39th day for all the samples. As may be seen from the sigmoid curves obtained, biogas evolution with time follows a uni-modal/Gaussian distribution. The anterior and posterior ends is characterized by modest tailing. The delay in biogas production is indicative of WH conditioning due to dissolution characterized by the onset of hydrolytic enzymes that facilitate the breakdown of complex large macromolecules in the feedstocks [15, 16]. The tailing at the posterior end is consistent with the slowdown in methanogens reaction as the concentration of methanogenic organisms decreased in the medium. The results obtained shows that anaerobic digestion can be seen as a four stage process namely hydrolysis, acidogenesis, acetogenesis and methanogenesis [17].

3.4 Cumulative biogas production

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 produced a cumulative gas volume of 209 L/kg corresponding to 33.58 L/kg of PM. The cumulative biogas yield for PM-aided WH digestion is shown in Figure 3. 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.

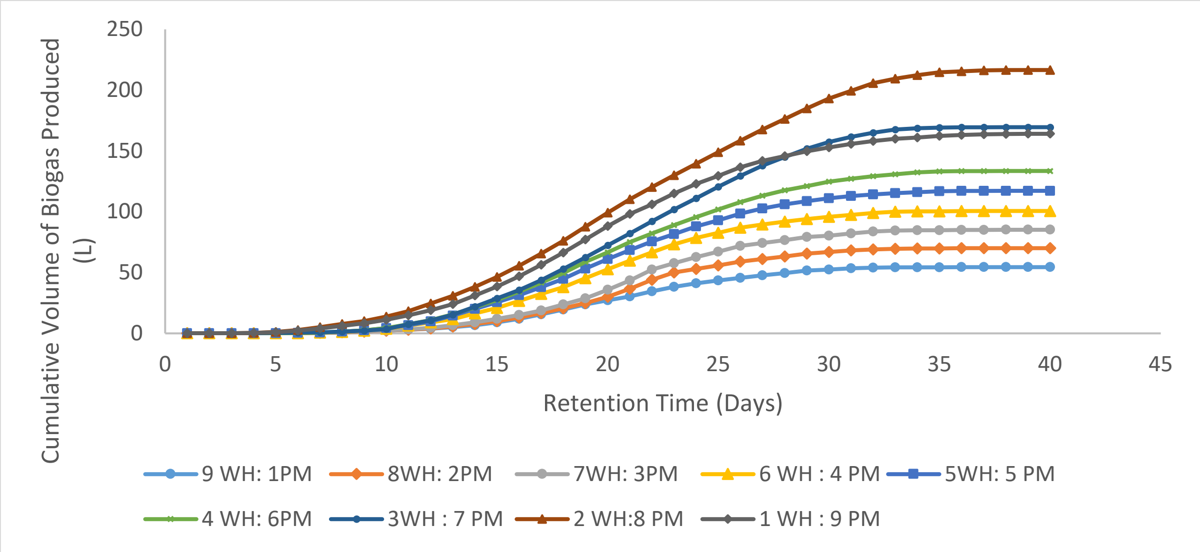

Figure 3: Cumulative biogas yield for PM - aided WH digestion

3.5 Maximum biogas production rate for PM-aided WH digestion

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. The 3rd order polynomial curve for the different mixes of the PM aided biogas production rate is shown in Figure 4. The curve has a significant R^2 value of 0.9678. From the results obtained, 2 WH: 8 PM is the best PM-aided WH digestion mix.

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

Mix ratio (WH: PM)	a-value	b-value	c-value	tmax (days)	Maximum biogas production rate (L/day)
10: 0	34.16	0.16	17.85	17.61	2.12
9: 1	56.92	0.19	30.32	18.10	4.01
8: 2	72.75	0.20	45.70	18.72	5.53
7: 3	88.51	0.20	46.90	18.94	6.69
6: 4	105.00	0.18	24.24	17.53	7.18
5: 5	122.90	0.17	19.93	17.56	7.90
4: 6	141.30	0.16	17.32	17.89	8.53
3: 7	183.50	0.15	18.68	19.08	10.64
2: 8	244.60	0.12	8.78	18.50	11.21
1:9	173.00	0.16	14.21	17.14	10.21
0: 10	243.80	0.11	8.31	19.60	10.31

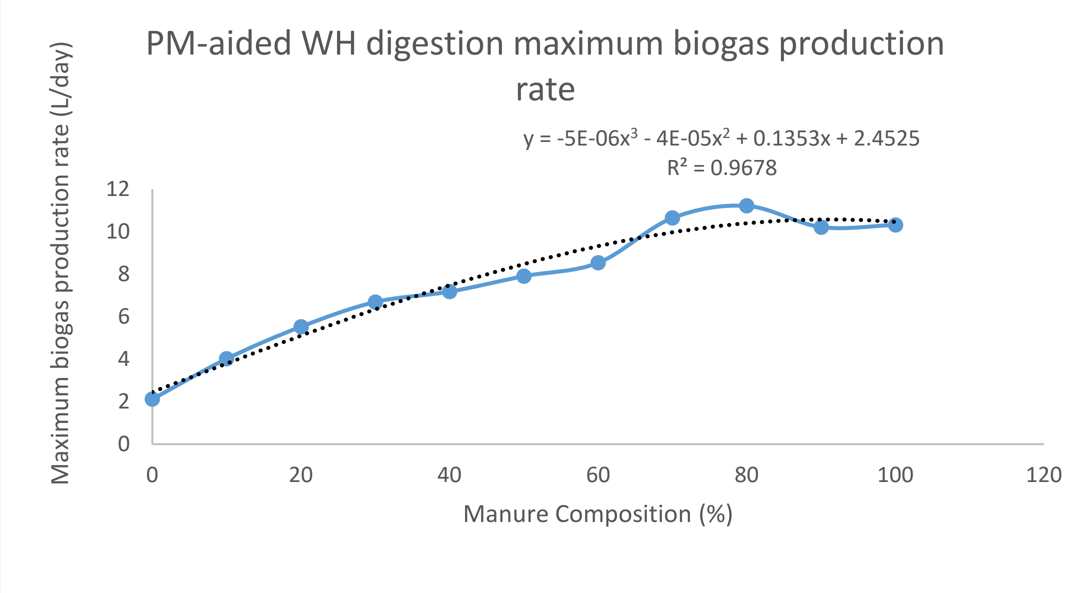

Figure 4: Maximum biogas production rate for PM-aided WH digestion

CONCLUSIONS

The pH of the substrates and temperature within the digester were ideal for biogas production. Daily gas production yields greatly improved in the co-digestion runs. The daily biogas production curves followed a similar pattern characterized by model tailing at the anterior and posterior ends. The results obtained for the cumulative volume of gas produced revealed a range of 54.45 – 216.55 L with 2 WH: 8 PM recording the highest value corresponding to 34.65 L/kg. Mix ratio 2 WH: 8 PM had the highest biogas yield of 11.21 L/day and this was observed on the 18th day with a 3rd order polynomial curve significant R^2 value of 0.9678. From the results obtained, 2 WH: 8 PM is the best PM-aided WH digestion mix in terms of daily biogas production, cumulative volume of gas produced and maximum biogas production rate.

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