Relationship between Different Anaerobic Digestion Parameters in a Pig-dung Aided Water Hyacinth Digestion Process

Ochuko M. Ojo, Josiah O. Babatola, and Taiwo O. Olabanji

***Abstract* — This study is aimed at assessing the relationship between different anaerobic digestion parameters (biogas quality, retention time, pH, temperature, biogas pressure, volume of biogas produced and cumulative volume of gas produced) in a Pig-dung (PD) aided Water Hyacinth (WH) digestion process in order to maximize biogas yield in terms of quantity and quality. 25 - litre capacity plastic prototype digesters were used in the study and eleven (11) mix ratios of PD and WH were prepared namely: 10 WH: 0 PD, 9 WH: 2 PD, 8 WH: 2 PD, 7 WH: 3 PD, 6 WH: 4 PD, 5 WH: 5 PD, 4 WH: 6 PD, 3 WH: 7 PD, 2 WH: 8 PD, 1 WH: 9 PD and 0 WH: 10 PD. The digestion process was evaluated for a retention period of 40 days. A bivariate Pearson correlation analysis was carried out to examine the relationship between the quality of gas produced and other variables. The results revealed that daily gas production yields greatly improved in the co-digestion runs with mix 3 WH: 7 PD recording the highest maximum daily yield of 9.5 L with a cumulative gas volume of 140 L. For this mix, the methane content of the gas produced increased from 5.8% on day 4 to 69.2% on day 20. The least quantity and quality of gas was produced by mix 10 WH: 0 PD with a maximum daily yield 2.34 L and a cumulative gas yield of 32.18 L. The digestion of all the mixes occurred within a mesophilic temperature range of 28.2 to 31.4 0C and an increase in temperature within the digestion resulted in an increase in the quality of gas produced. The gas pressure ranged from 1 bar to 3.324 bars with an increase in gas pressure leading to a corresponding increase in volume of gas produced. 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 results revealed a very strong, positive and significant association between the quality of the biogas produced and other digestion parameters.**

***Keywords* — Anaerobic digestion, biogas quality, correlation analysis, relationship.**

I. Introduction

The main conventional source of energy in Nigeria today is fossil fuel [1]. Unfortunately, fossil fuels are non-renewable and eventually, their deposits will be exhausted [2]. Biogas is a renewable energy that can be exploited to meet the ever-increasing energy demands of man (especially in developing countries like Nigeria) without depleting the environment [3].

Water hyacinth (WH) are very problematic plants that cover water bodies, hindering the penetration of the sun's rays and thereby reducing the photosynthetic processes of submerged plants [4], [5]. WH cause severe environmental and economic problems by impeding navigation and fishing activities, as well as clogging irrigation channels [6]. The conditions that allow WH to thrive cannot be easily controlled hence it is difficult to eradicate this noxious plant [7]. Several studies have attempted to utilize this problematic plant for the production of biogas [1], [5], [8]–[13]. Animal dungs contain nutrients which are detrimental to public health, but which can be used as biomass for fuel generation [14]. Pigs produce a huge amount of dungs that could be harmful to the environment if not properly managed [15]. Manure nutrients (total nitrogen and total phosphorus) found in Pig dung (PD) are considered the main source of environmental pollution [16]. In Nigeria and sub-Saharan Africa in general, pig production has increased in great measure as a result of increase in the animal protein needs of the people caused by rapid increase in population [17]. There is a continuous need to properly harness these two constituents of environmental pollution.

Co-digestion may be referred to as the anaerobic digestion (AD) of multiple biodegradable substrates (feedstocks) in an AD system [6]. The ultimate goal of co-digestion is to improve the biogas yield from an AD process. Several parameters are used the evaluate the effectiveness of an AD process they include biogas quality, retention time, hydrogen ion concentration, temperature, biogas pressure, volume of biogas produced and cumulative volume of gas produced. The aim of this study is to assess the relationship between different anaerobic digestion in order to maximize biogas yield in terms of quantity and quality.

II. Methodology

A. Digestion Process

25-litre capacity plastic prototype digesters, with a thickness of 2 mm, height of 400 mm and width of 320 mm were used in the study. The substrates used in this research are WH and PD. Fresh WH were harvested from a private pond in Akure, Ondo State, while PD were collected from the animal farm of the Federal University of Technology, Akure. WH were chopped into small sizes ranging from 1 cm to 2 cm. Both feedstocks were appropriately weighed. Eleven (11) co-digestion mix ratios of WH to PD were evaluated as follows: 10 WH: 0 PD, 9 WH: 2 PD, 8 WH: 2 PD, 7 WH: 3 PD, 6 WH: 4 PD, 5 WH: 5 PD. 4 WH: 6 PD, 3 WH:7 PD, 2 WH: 8 PD, 1 WH: 9 PD, 0 WH: 10 PD.

The digestion process was evaluated for a retention period of 40 days. The temperature within the digester was measured

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using a mercury thermometer calibrated in degree centigrade while the pH was determined using a pH meter.

The hydrogen ion concentration was derived from the pH using equation 1.

$$pH = -log_{10}[H^+] \quad (1)$$

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 while a manometer was used to measure the pressure of the gas. The quality of the gas produced was determined using a locally fabricated potassium hydroxide (KOH) solution biogas quality determination apparatus as specified by [18].

B. Data Analysis

A bivariate Pearson correlation analysis was carried out to examine the relationship between the quality of gas and the other variables.

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)

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

III. Results and Discussion

A. Daily and Cumulative Gas Production

Daily gas production yields greatly improved in the co-digestion runs. For the PD - aided WH digestion, mix 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 day. The least daily yield of gas was produced by mix 10 WH: 0 PD with a maximum daily yield 2.34 L. The results also revealed that WH single-substrate digestion produced a cumulative gas volume of 32.18 L while PD single-substrate digestion produced a cumulative gas volume of 94.47 L.

B. Correlation between Gas Quality and Retention Time

The association between the gas quality and retention time for the different mixes was not statistically significant. The results revealed a negative and weak association between the quality of gas produced and the retention time for the PD–aided mix as shown in Fig. 1. This is due to the fact that the quality of the gas produced by the evaluated mixes followed a unimodal path increasing from the beginning of the digestion process to a peak and then decreasing gradually till the end of the retention time. This behavior resulted from the batch feeding method employed in this research described by [19].

C. Correlation between the Gas Quality and the pH and Hydrogen Ion Concentration

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 results revealed a weak and negative association between the gas quality and the hydrogen ion concentration of the different mix substrates as shown in Fig. 2. However, the association was not statistically significant for the PD-aided WH digestion. This may be due to the microbial composition of the mix substrates. The PD mix recorded very high microbial count before and after digestion.

D. Correlation between Biogas Quality and Temperature

The digestion of all the mixes occurred within a mesophilic temperature range of 28.2 to 31.4 °C and an increase in temperature within the digestion resulted in an increase in the quality of gas produced. The mesophilic temperature range is ideal for AD as this temperature range adequately supports microbial activities within the digester [11], [20]. The correlation between temperature and biogas quality was statistically significant at 1% which means that the temperature within the digester clearly affects the quality of the gas produced with up to 99 % confidence level. Fig. 3 shows that the association between the temperature and gas quality was positive implying that an increase in temperature within the digestion leads to an increase in the quality of gas produced.

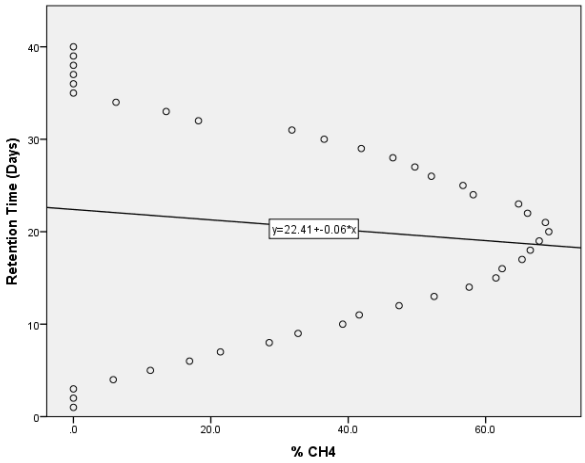

Fig. 1. Association between biogas quality (%CH_4) and retention time for PD - aided WH digestion.

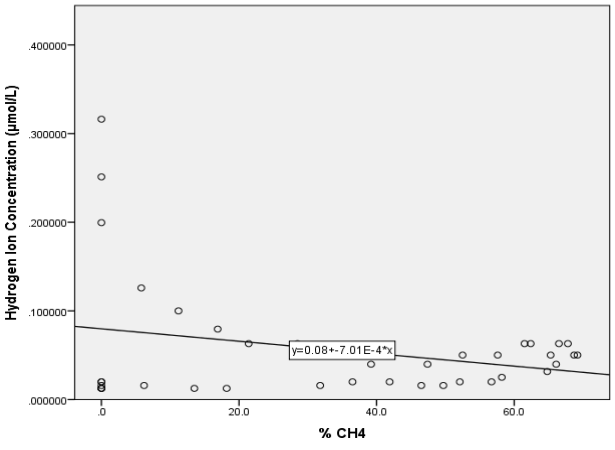

Fig. 2. Association between biogas quality (%CH_4) and Hydrogen ion concentration for PD-aided WH digestion.

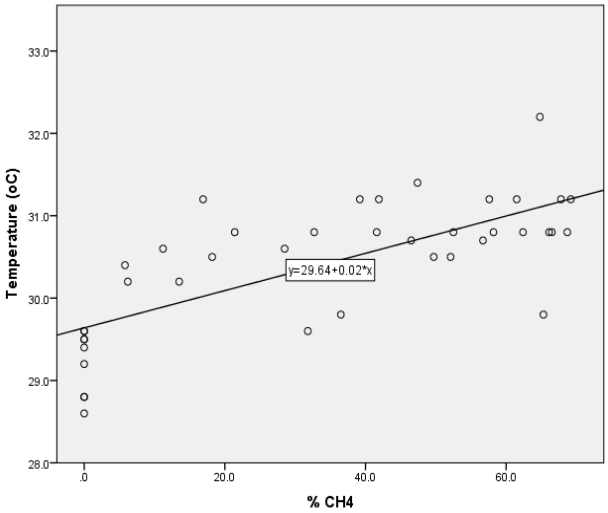

Fig. 3. Association between biogas quality (%CH_4) and Temperature for PD - aided WH digestion.

E. Correlation between Biogas Quality (%CH_4) and Gas Pressure

The gas pressure ranged from 1 bar to 3.324 bars with an increase in gas pressure leading to a corresponding increase in volume of gas produced. A strong and positive association between the pressure of the produced gas and its quality was observed for the different mixes of PD aided WH digestion, as shown in Fig. 4. The association was significant at 1%. This implies that the more the pressure of the gas, the more the quality of the gas would be.

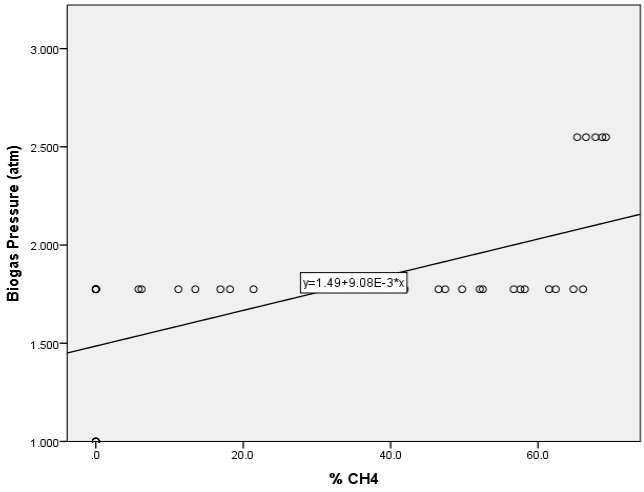

Fig. 4. Association between biogas quality (%CH_4) and Biogas Pressure for PD -aided WH digestion.

F. Correlation between Biogas Quality (%CH_4) and Daily Gas Volume

The results revealed a very strong and positive association between the daily volume and quality of the gas produced by PD-aided WH digestion mixes as shown in Fig. 5. The association was statistically significant at 1%. This implies that an increase in the volume of gas produced leads to a corresponding increase in the quality of the gas.

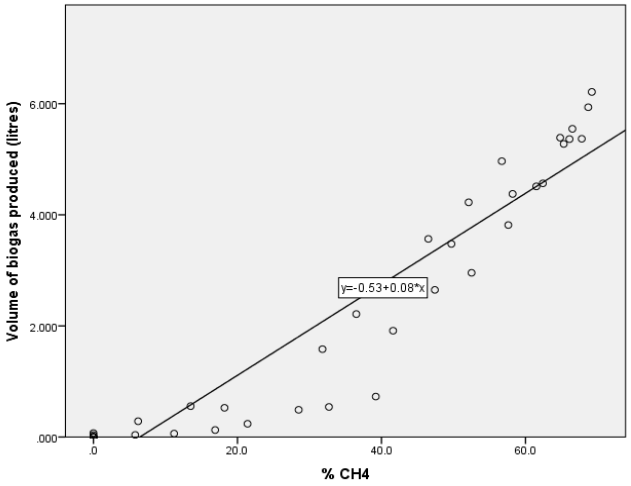

Fig. 5. Association between biogas quality (%CH_4) and Volume of gas produced for PD-aided WH digestion.

G. Correlation between Biogas Quality (%CH_4) and Cumulative Gas Volume

The results revealed that WH single-substrate digestion produced a cumulative gas volume of 32.18 L while PD single-substrate digestion produced a cumulative gas volume of 94.47 L. This could be linked to the nature of organics present in the two substrates [21]. Mix 3 WH: 7 PD recorded the cumulative gas volume of 140 L. For this mix, the methane content of the gas produced increased from 5.8% on day 4 to 69.2% on day 20. The least cumulative volume of gas was produced by mix 10 WH: 0 PD with a cumulative gas yield of 32.18 L. The results revealed that the relationship between the gas quality and the cumulative gas produced for the different mixes was not statistically significant as shown in Fig. 6. This is due to the fact that the digestion was a batch-fed process with the cumulative volume of gas reaching its ultimate value at the end of the 40-days retention time.

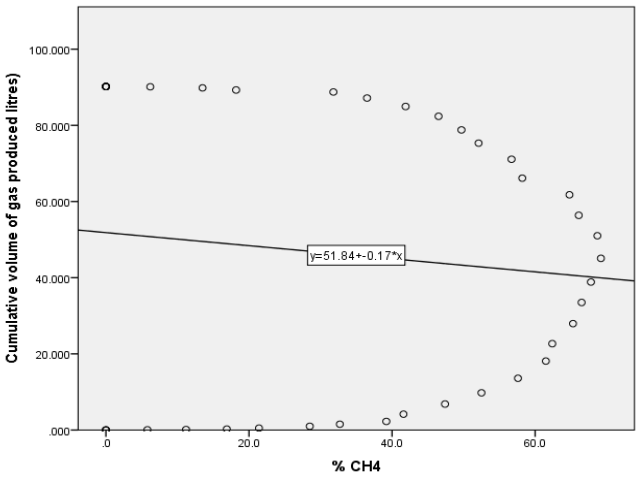

Fig. 6. Association between biogas quality (%CH_4) and cumulative volume of gas produced for PD - aided WH digestion.

IV. Conclusion

This study has affirmed that there exist a very strong, positive and significant association between the quantity and quality of biogas produced and other digestion parameters. The yield of biogas from anerobic co-digestion of different feedstocks can be enhanced if the digestion parameters are closely monitored.

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CONFLICT OF INTEREST

The authors declare that they do not have any conflict of interest.

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