Comparative study of biogas production in composite of poultry droppings and lemon grass using pressure computed from strain gage rosette

Adekoya Olaoluwa[1], Akan Williams[1], Ndubuisi Amanda[2], Adebayo Timileyin[3], Henry Boyo[2]

[1]Department of Chemistry, Covenant University, Ota, Ogun State, Nigeria
[2]Department of Physics, Covenant University, Ota, Ogun State, Nigeria
[3]Department of Physics, University of Lagos, Lagos State, Nigeria
E-mail address: olaoluwaadekoya2@gmail.com

Abstract. The advantages of recording micro change in pressure every second inside a biogas production digester using strain gage measurement was well demonstrated in this work. The production of biogas from a composite of Lemon grass and Poultry droppings was carried out by measuring the total gas pressure exerted on the surface of sealed near-cylindrical plastic container used as a digester. The suitability of using a combination of lemon grass and poultry droppings for biogas generation and the determination of an optimal mixing ratio to maximize gas production was studied. The aerobically pre-fermented substrates were mixed in five different ratios labelled 'Digester A-E' respectively to form composite and the formed slurry was digested for 30 days in the five (5) different digesters lagged with fiberglass wool. Pressure values were determined using the principles of 'thin walled cylindrical pressure vessel' computed from the strain gage rosette readings. The results after 30 days show that Digester B with lemon grass had the highest gas production with a pressure of 41.8 kP. Digester C which contained 100% chicken droppings had a pressure of about 11.5 kP, but when mixed with lemon grass inside digester E, in a mixing ratio of 70% to 30% respectively, the pressure of the gas produced increased to 26.5 kP. This is an increase of about 15 kP which is a little over double the amount of gas produced with only chicken droppings. Thus, the result of mixing 30% of lemon grass and 70% of chicken droppings doubled the gas production potential of chicken droppings. Digester A (with 50% lemon grass and 50% chicken droppings) and Digester D (with 70% lemon grass and 30% chicken droppings) had pressures of 17.4 kP and 32.7 kP respectively.
Keywords: biogas production; pressure computed

1. Introduction

Most of organic wastes, such as crop straws, livestock manure, municipal solid wastes and the by-products of food industry, can be used as biogas materials [9]. Study has shown that the methane content of biogas from animal manure substrates could be improved by co-digestion with energy plants [10]. The digestion of organic materials by micro-organisms produces biogas and production of the biogas can be very small in laboratory scale experiments [1].

The level of biogas measured may be used to predict the state of degradation in anaerobic digestion. Unfortunately, several researchers working on biogas in laboratories in most developing countries lack access to sophisticated gas measuring equipment. Accurate measurement of the produced gas pressure could be very difficult task. Most calibrated volume measuring devices may not be sensitive enough to detect micro changes in biogas volume. Direct measurement of the pressure activity inside the digester tells more about biogas formation rather than volume displacement measurement [6].

Pressure measurements and controls are important in digesters because they can influence key processes such as liquid-vapour equilibrium, fluid dynamics and the rate of chemical reaction. A well designed pressure measuring method can be used for comparison of biodegradability caused by microbial activities in biogas production using composite materials [3]. The mechanical Bourdon tube pressure gauge is simple

with excellent sensitivity for higher pressure applications but its slow response to change in pressure and hysteresis makes it unsuitable for low pressure application.

The study was intended to develop the method for measuring biogas produced in a plastic digester, by using strain gage rosette to detect changes in biogas production pressure. Micro changes in biogas production per second, per minute and per hour, on a daily basis could be more informative than volumetric measurement. The study helps to overcome volumetric measurement insensitivity problem at low volume or pressure. A set of three (3) strain gauges (rosette) were attached to the surface of five (5) digesters, to measure strains in different directions, providing precise evaluation of the surface stresses, from which pressure was deduced. The study also aims at measuring the production of biogas using different mixing ratio of chicken droppings and *Cymbopogon citratus* (lemon grass) as feedstock in a plastic bio digester, since co-digestion of both digestible materials may produce different gas quantity in the five (5) digesters.

2. Materials

The biomass used were lemon grass and chicken droppings. The lemon grass was obtained from Covenant University, while the chicken droppings were collected from a poultry farm around Lagos. They were mixed homogenously. Other materials used for the study were the following:

- Five of 20 litre size water dispenser plastic bottle as anaerobic digester.
- Five set of Strain gauge sensor BF350 (3 pieces) and temperature sensor LM 35 (Figures 1, 3).
- Five set of Bridge amplifiers HX711 (3 modules), as shown (in Figures 2, 3).
- Five Arduino microcontroller slave boards for data capturing and transmission enabled with WiFi (Figure 2).
- One Arduino microcontroller master board for data reception and logging to PC, enabled through WiFi.

Figure 1: A set of strain gage sensors assembled at an angle of 45 degrees apart   (LHS) and glued to the plastic digester (RHS)
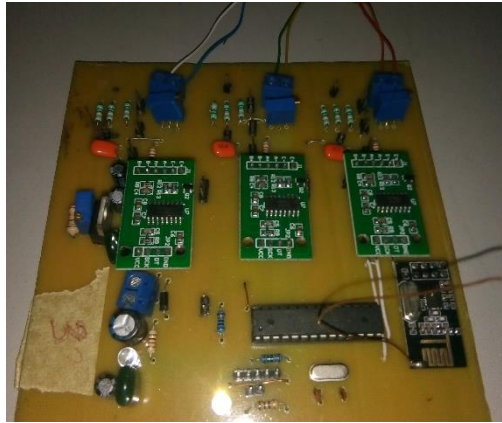
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Figure 2: Strain gage bridge amplifiers on board with ADC, microcontroller and Wifi customized for data logging

Figure 3: Digester plastic before loading it with feedstocks. Attached to the lower side of the plastics are the strain gages which are connected to the data acquisition board placed in front of the digester

3. Method

The design capacity of the anaerobic digesters was chosen due to the required quantity of slurry and the number of days the material would stay in the digesters (retention time). The main structure consisted of a plastic digestion tank, tough enough to bear the weight and pressure of the slurry, and insulated so as to eliminate the effect of ambient temperature perturbations on the activities of the anaerobes. The tank was air tight, wrapped with fibre glass wool as thermal insulator and placed well above the ground level inside a room.

Two (2) feedstocks (chicken droppings and lemon grass) were prepared into five (5) samples with three (3) mixing ratios, and were loaded into the respective digesters as shown in Figure 3 for a period of thirty (30) days during the study. The digesters were clearly labelled viz:

> Digester 1 (A): 50% chicken droppings and 50% lemon grass.
> Digester 2 (B): 100% lemon grass.
> Digester 3 (C): 100% chicken droppings.
> Digester 4 (D): 30% chicken droppings and 70% lemon grass.
> Digester 5 (E): 70% chicken droppings and 30% lemon grass.

Chicken droppings and lemon grass (*Cymbopogon citratus*) were the biomass resources used as feed materials for the study. Lemon grass was crushed and milled. A hammer mill was used for the crushing process before samples were transported to the laboratory for further treatment. Partially decayed butchery house discarded waste was used to seed the digester for all the feedstocks digested.

About 2.4 kg dry weight of the respective pre-fermented wastes was mixed with water to form slurry in the ratio 1:1 by weight and then separately poured into each tank through a funnel. The slurry was permitted to fill half of the digester space, leaving a clear height of half the digester as space for the biogas production. The research was carried out for 30 days in batch fermentation and the following was carried out in the course of the experiment:

- Minute-by-minute measurement of the pressure exerted by the biogas generated till the termination of experiment.
- The daily temperature of the digesters was taken along with the ambient.
- Chemical analysis was carried out on each sample of feedstock before and after digestion.

3.1 Chemical Analysis of Feedstocks

The chemical composition of the substrates both before and after digestion was analyzed using standard methods (APHA, 2012). Parameters analyzed included pH, total solids, moisture content, total nitrogen, ash content, organic carbon, biochemical oxygen demand and chemical oxygen demand (Figure 5).

3.2 Analog to digital count (ADC_count) to Bridge output voltage to Strain value

The bridge output voltage 'e' was scaled from the ADC_count using the fact that, a fixed Bridge excitation voltage 'Vin' (= 3.9V) will result to an ADC count of 224 after it has been amplified with a Voltage gain (=60).

The Gage factor 'Ks' of the strain gage is Ks=2.0, and Strain 'ε', can be determined from the expression

$$\varepsilon = \frac{4}{K_s} * \frac{e}{V_{in}} \tag{1}$$

3.3 Measured Strain to Principal Strain Conversion

The signal from each strain gage is given as ε1, ε2, and ε3 respectively [2][4].
The maximum principal strain is given as,

$$\varepsilon_{max} = \frac{1}{2}\left\{\varepsilon_1 + \varepsilon_3 + \sqrt{2|(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2|}\right\} \tag{2}$$

Minimum principal strain is,

$$\varepsilon_{min} = \frac{1}{2}\left\{\varepsilon_1 + \varepsilon_3 - \sqrt{2|(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2|}\right\} \tag{3}$$

Direction of principal strain from the ε1-axis is given as,

$$\theta = \frac{1}{2}\tan^{-1}\left[\frac{2\varepsilon_2 - \varepsilon_1 - \varepsilon_3}{\varepsilon_1 - \varepsilon_3}\right] \tag{4}$$

3.4 Principal Strain to Principal Stress Conversion

Let 'v' be the Poisson's ratio (=0.3) and 'E' the Young's modulus (=30*106 psi),
Maximum Principal Stress is[7][8],

$$\sigma_{max} = \frac{E}{2(1-v^2)}\left\{(1+v)(\varepsilon_1 + \varepsilon_3) + (1-v) * \sqrt{2|(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2|}\right\} \quad (5)$$

Minimum Principal Stress is,

$$\sigma_{min} = \frac{E}{2(1-v^2)}\left\{(1+v)(\varepsilon_1 + \varepsilon_3) - (1-v) * \sqrt{2|(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2|}\right\} \quad (6)$$

3.5 Stress to Pressure Conversion

For the thin-walled cylindrical digester of thickness 't' (=9.466E-4 meter) and radius 'R' (=12.32E-3 meter), the forces exerted by biogas in the hoop or circumferential direction will result to a pressure 'p', given as

$$p = \frac{t}{R} * \sigma_{max} \quad\quad (7)$$

And the forces exerted by biogas in the longitudinal direction will result to a pressure of

$$p = \frac{2t}{R} * \sigma_{min} \quad\quad (8)$$

The average of both pressures in equation 7 and equation 8 was computed. Although if the bottle is isotropic and have uniform thickness all over, both pressure values will be equal.

4. Results and Discussion

The results after 30 days (Figure 4) shows that Digester B with lemon grass had the highest gas production with a pressure of 41.8 kP. Digester C which contained 100% chicken droppings showed slightly high biogas production with a pressure of about 11.5 kP, but when mixed with lemon grass inside digester E, the biogas pressure increased to 26.5 kP. This is an increase of about 15 kP, which is slightly more than double the amount of gas produced with only chicken droppings. Thus, the result of mixing 30% of lemon grass and 70% of chicken droppings doubled the gas production potential of chicken droppings.

Digester A (with 50% lemon grass and 50% chicken droppings) and Digester D (with 70% lemon grass and 30% chicken droppings) have pressures of 17.4 kP and 32.7 kP respectively. D produced more gas than A because it has higher percentage of lemon grass.

There was a progressive increase in the production of gas within the first fifteen (15) days in all the digesters. Subsequently gas production declined in Digester C (which contained 100% chicken droppings) about the 18th day and in Digester A (with 50% lemon grass and 50% chicken droppings) about the 22nd day indicating low anaerobic activities in both digesters.

Chemical analysis of the digester feedstock before and after digestion is shown in Figure 5 and provided as a reference to describe the chemical state of the feedstock used in this study.

In Figure 6, the temperature fluctuation between maximum and minimum in all five digesters remained within five (5) to ten (10) degrees Celsius and is mesophilic. Higher temperatures above the ambient is an indication of microbial activities in the digester. It is noted that, although Digester B (100% lemon grass) and Digester C (100% chicken droppings) had the same temperature ranges (Figure 6), Digester B produced gas the most (Figure 7) while Digester C produced gas the least.
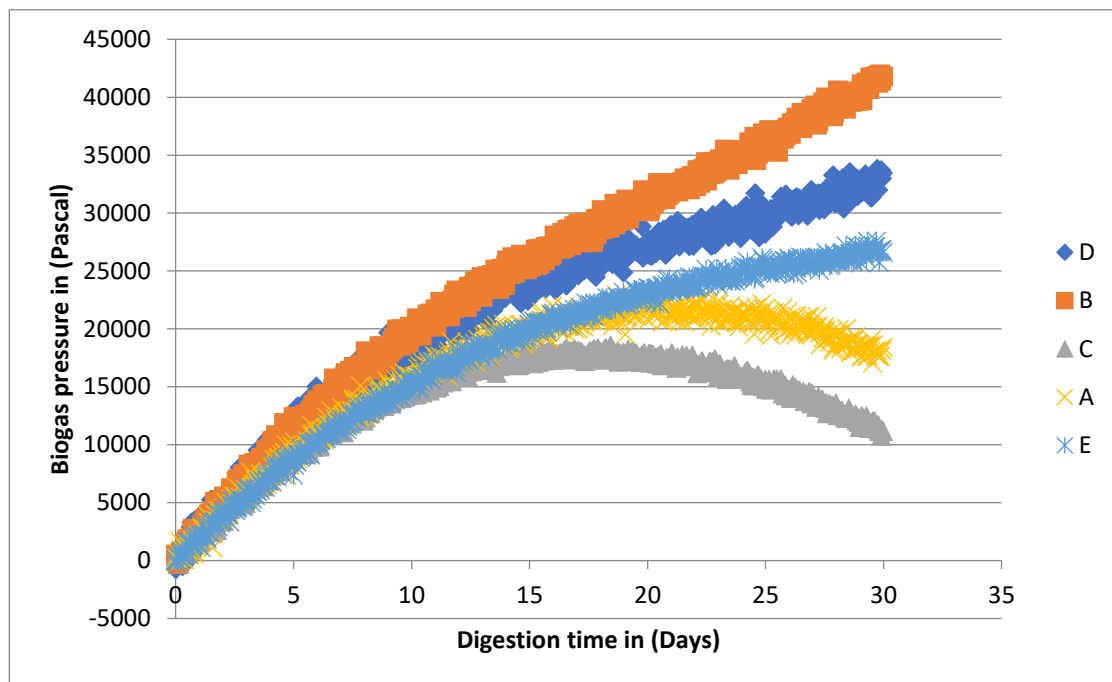
Figure 4: Shows the daily average gas pressure in the five bio-digesters (A-E) computed from strain gage measurements
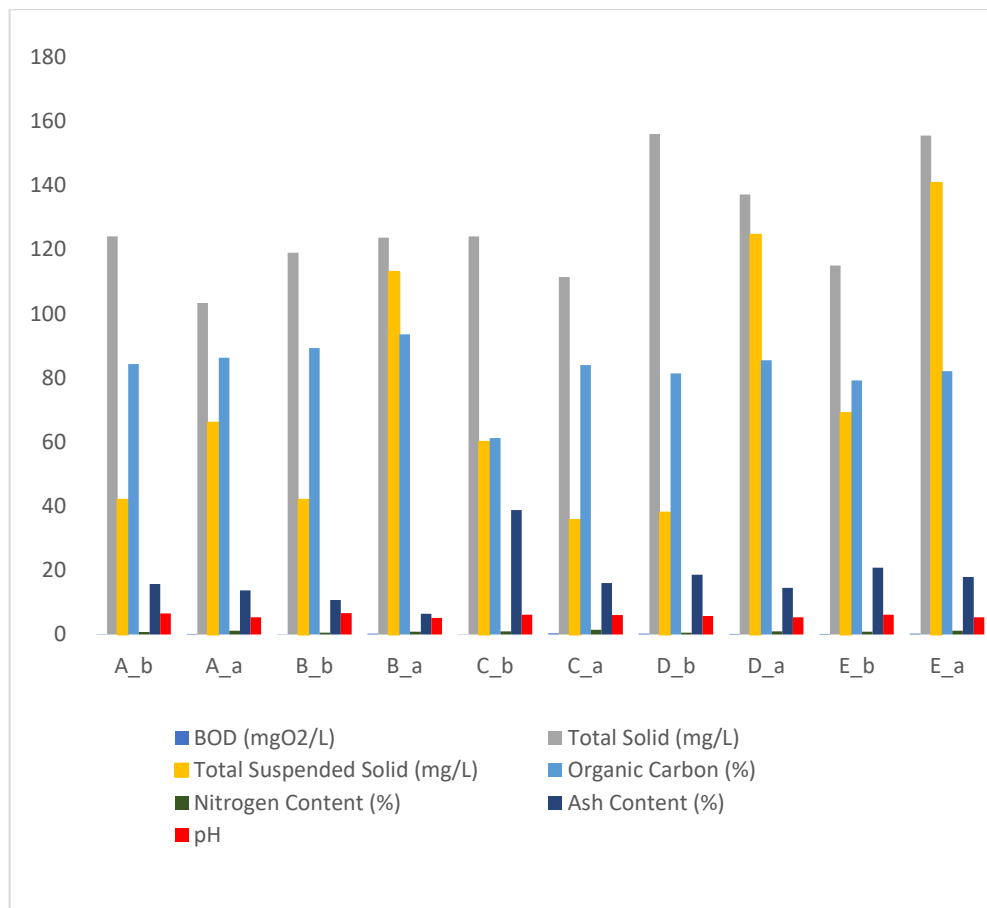

Figure 5: Chemical analysis of the digester feedstock before and after digestion
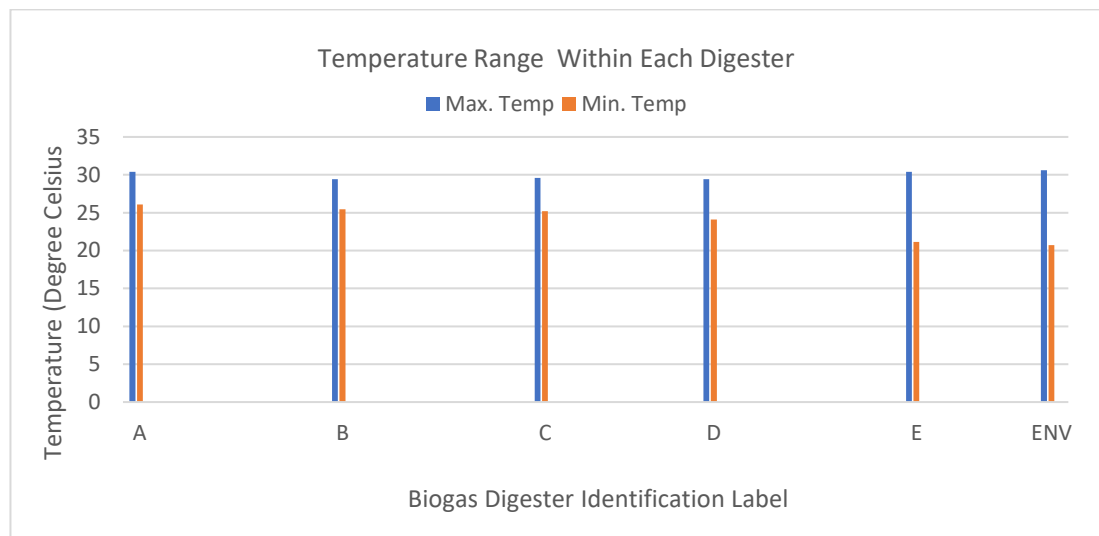
Figure 6: Average temperatures range of the five digesters (A-E) variation and   that of its ambient environment (ENV), showing the effect of insulating the digester with Fibre glass wool

5. Conclusion

The following contributions have been added to the existing knowledge about the anaerobic digestion of biomass for energy generation:

- Although, the downward displacement of water for gas collection has been in use before now, one major challenge faced over the years is its inefficiency for gas volume measurement at very low pressure. The vapor pressure contributed by evaporating surface water may also increase the measurement error at low pressure [5]. Also harvesting from the displacement trough usually end up in wastage of gas and leakages. This research has effectively surmounted this challenge by using a specially designed set of strain gage to measure the strain on the plastic (digester) and strain used to calculate the pressure of biogas in the digester. The strain gage has an advantage of recording micro change in pressure every second. The novel usage of this sensor for biogas production at low pressure improves the sensitivity and measurement accuracies to change in pressure of gas.
- This project has equally demonstrated the possibility and suitability of using a combination of lemon grass and poultry droppings for biogas generation in other to enhance the biogas production potential of chicken waste and also provides an optimal mixing ratio that maximizes gas production. The results will go a long way to reduce the challenge of raw material selection for biogas energy in most home or family size biogas system that can be constructed and installed into every home in Nigeria.

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