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Evaluation of biogas production and pressure from composite of poultry droppings and lemon grass using strain gage rosette

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Abstract. The study explored the production of biogas from a composite of Lemon grass and Poultry droppings by studying the total gas pressure exerted on a sealed near-cylindrical plastic container used as a digester. The composite pre-fermented substrates were mixed with water and the formed slurry was digested for a month. The temperature was kept relatively constant by lagging the digester with fiberglass wool. The exerted stress on the digester by the produced biogas was determined using a tri-axial quarter-bridge strain gage rectangular rosette, carefully fixed to the external surface of the plastic digester. Subsequently, the total pressure exerted on the wall of the digester container was determined. The daily gas production potential in form of computed pressure is presented. Results showed a maximum gas pressure of 31,200 pascal above atmosphere produced from the composite over the period of four weeks. The research demonstrated that pressure changes at relatively constant volume can be used to monitor gas production.

1. Introduction

Biogas energy production is a clean energy technology. Pollution caused by animal manure especially in developing countries can be recycled and reduced. 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. Advanced research and accuracies of data may be limited especially where gas volumes are to be measured conventionally [5]. Small perturbation factors such as micro changes in temperature and pressure may affect measurements of biogas yield. Most calibrated volume measuring devices may not be sensitive enough to detect micro changes in biogas volume.

1.1. Bubbles and pressure in biogas

Bubbles are formed from within the slurry when microbes digest it. Whenever we see bubbles rising in the slurry, we literally say gas is being formed. The formation of bubbles require very high internal pressure. From the fundamental principles of bubbles formation in biogas production, more bubbles implies more gas accumulation and hence more pressure in the digester. That may suggest to us that direct measurement of the pressure activity inside the digester tells more about biogas formation rather than volume displacement measurement [6]. Gas will always occupy any available space or volume. For an ideal gas it is specified as 22.4 liters at STP and serves as a reference to convert gas pressure to volume.The formation of the bubbles is due to excess pressure ‘p_{excess}’ inside it as described by the Laplace's law.

$$p_{excess} = {}^{2S}/_{r} \qquad (1)$$

S = surface tension, r = bubble radius. Let ‘ρ’ be the density of the medium and ‘g’ gravity, then (Bubble external pressure) = (static pressure of liquid at bubble height h) + (pressure in the digester)

$$p_{ext} = h\rho g + p_{digester} \qquad (2)$$

Bubble is formed within the slurry when, the Internal Pressure of bubble ‘p_{int}’ equals Excess pressure ‘p_{excess}’ plus External pressure of bubble ‘p_{ext}’

$$p_{int} = {}^{2S}/_{r} + p_{ext} \qquad (3)$$

New bubbles are formed with extremely high internal pressure because they will have a smaller radius ‘r’ making 2S/r very large.

1.2. Reasons to measure pressure

Pressure measurements and controls is important in digesters because it 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.

1.3. Research aims

The study here is intended to, develop the method for measuring total biogas in a plastic digester; by using strain gage rosette to detect changes in biogas production pressure. A set of three (3) strain gauges (rosette) were attached to the surface of the digester, to measure strains in different directions, providing precise evaluation of the surface stresses, from which pressure is deduced.

The study described helps to overcome volumetric measurement insensitivity problem at low volume or pressure. It may not be as simple as volumetric measurement but it could be more informative regarding to micro changes in biogas production per second per minute per hour on a daily bases.The study also aims at measuring the production of biogas, using a mixture of chicken droppings and *Cymbopogoncitratus* (lemon grass) as feedstock in a plastic bio digester, since co-digestion of both digestible material produced high gas quantity from the digester.Calibration of the designed automated meter is easy but not discussed here and can give more precise measurement of micro changes in biogas production.

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:

- A twenty (20) litre size water dispenser plastic bottle as anaerobic digester.
- Strain gauge sensorBF350 (3 pieces) (Figure 1) and temperature sensor LM 35 (2 pieces).
- Bridge amplifiers HX711 (3 modules), as shown in Figure 2.
- Arduino microcontroller for data logging to PC, enabled through WiFi (Figure 2).
- Tyre tubes with valve used to cap the digester and Fibre glass wool for insulation (Figure 3).

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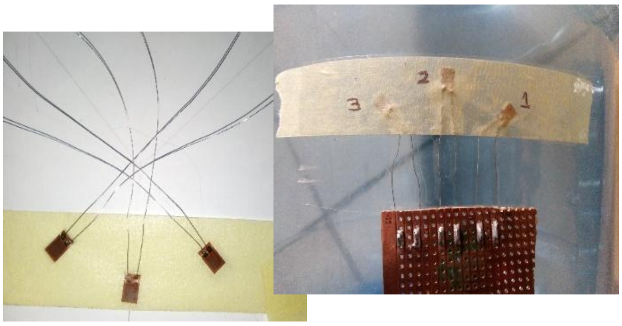

Figure 1: A set of strain gage sensors assembled at an angle of 45 degrees apart (LHS) and glued to the plastic digester (RHS)

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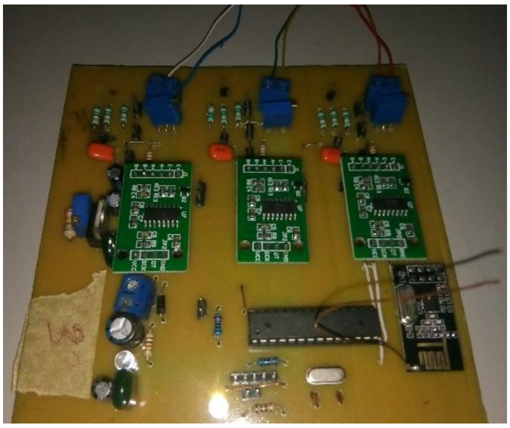

Figure 2: Strain gage bridge amplifiers on board with ADC, microcontroller and Wifi customised for datalogging.

Figure 3: (LHS) Digester plastic before loading it with feedstocks. Attached to the lower side are the strain gages and temperature sensors which are connected to the data acquisition board. (RHS) Insulated digesters capped with tyre tube during data acquisition.

The digester structure primarily is a plastic almost cylindrical bottle strong enough to withstand weight and gas pressure of the slurry. The tank was loaded with the feedstocks (70% chicken droppings and 30% lemon grass). The slurry was allowed to fill about half of the digester space leaving half height of the digester as space for the producedbiogas. The digester was sealed air tight, wrapped with fibre glass wool as thermal insulator and left for thirty (30) days to digest while measurements were taken (Figure 3).The experiment was carried out at the laboratory of Covenant University Centre for Research and Innovative Development.

3. Method

Affixed with glue to the digester are a set of three strain gage sensors whose resistance varies with applied force and also converts pressure into a change in electrical resistance which can then be measured. Each strain gage signal from the BF350 sensor is connected in a Wheatstone bridge configuration, amplified (x60) and the bridge voltage is finally converted from analog to digital signal using a 24-bit ADC converter on a BF711 moduleon-board [7], [8]. The digital signals are collated in an Arduino microcontroller and sent to PC using a Wifi module. Two (2) temperature sensors type LM35 data signals were also processed in the same microcontroller and sent to PC. The data retrieved from PC is shown in a spreadsheet format (Table 1).

3.1. 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 2^{24} 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

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

3.2. 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,

$$\varepsilon_{max} = \frac{1}{2}\left\{\varepsilon_1 + \varepsilon_3 + \sqrt{2|(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2|}\right\} \tag{5}$$

Minimum principal strain is,

$$\varepsilon_{min} = \frac{1}{2}\left\{\varepsilon_1 + \varepsilon_3 - \sqrt{2|(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2|}\right\} \tag{6}$$

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

$$\theta = \frac{1}{2}\tan^{-1}\left[\frac{2\varepsilon_2 - \varepsilon_1 - \varepsilon_3}{\varepsilon_1 - \varepsilon_3}\right] \tag{7}$$

3.3. Principal Strain to Principal Stress Conversion

Let 'v' be the Poisson's ratio (=0.3) and 'E' the Young's modulus (=30*10^6psi),

Maximum Principal Stress is,

$$\sigma_{max} = \frac{E}{2(1-v^2)}\left\{(1+v)(\varepsilon_1 + \varepsilon_3) + (1-v) * \sqrt{2|(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2|}\right\} \tag{8}$$

Minimum Principal Stress is,

$$\sigma_{min} = \frac{E}{2(1-v^2)}\left\{(1+v)(\varepsilon_1 + \varepsilon_3) - (1-v) * \sqrt{2|(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2|}\right\} \tag{9}$$

3.4. Stress to Pressure Conversion

For the thin-walled cylindrical digester of thickness‘t’(=9.466E-4meter) 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

$$p = \frac{t}{R} * \sigma_{max} \tag{10}$$

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

$$p = \frac{2t}{R} * \sigma_{min} \tag{11}$$

The average of both pressures in equation 10 and equation 11 was used. Although if the bottle is isotropic and have uniform thickness all over, both pressure values will be equal.

4. Results and Discussion

4.1. Results

There was a progressive increase in the production of biogas within the period of thirty (30) days(Figure 4). A third degree cubic curve fits the data set with a correlation coefficient of 0.9885 and an equation $p = 1.2932t^3 - 90.748t^2 + 2655.3t - 16.864$
(12)

Where ‘p’ denotes the pressure in Pascal and ‘d’ is the day number starting from the first day of digestion as day 1 onward.

Physical observation of the graph in figure 4 reveals; a steep rise in gas production from day 1 to 11, followed with a slower steady rise in gas production between days 19 to 30. There was a slowdown in gas production between 12 and day 17.

Mathematically, equation 12 can be shown to be ‘non-stationary point of inflection and rising’.

The first derivative of equation 12 gives ‘p'’

$$p' = 3.8796t^2 - 181.496t + 2655.3 \tag{13}$$

Itssecond derivative gives ‘p''’

$$p'' = 7.3592t - 1811.496 \tag{14}$$

The 2ndderivative is zero (p''=0)at t=24.66 days which indicates the day of minimum gas production. The 1st derivative (Figure 5)gives the rate of gas productionthe day (t=24.66)as p'=538.88 Pascal/day. The gas pressure on day t=24.66 was p=29,669 Pascal.

From the temperature profile graph (Figure 6), the digester temperature consistently stayed above its ambient temperature.Cubic polynomialswere fitted to show the relationship between the ambient temperature ‘$T_{\_ambient}$’ and that of the digester ‘$T_{\_digester}$’. The fitted trend lines showed a smooth divergence in temperatures overthe period of digestion. It signifies that bacterial activities are increasingly active during the period of gas production and most likely uncompleted. Equation 15 and equation 16 are the derived from the fitted function. The correlation of fit for the digester function is $R_{\_digester}{}^2$ (= 0.7827) and that of the ambient temperature function is $R_{\_ambient}{}^2$ (= 0.4405).

$$R_{\_digester}{}^2 = 0.7827 \text{ and } T_{\_digester} = 0.0017t^3 - 0.0713t^2 + 0.8743t + 26.131 \tag{15}$$

$$R_{\_ambient}{}^2 = 0.4405 \text{ and } T_{\_ambient} = 0.0013t^3 - 0.0534t^2 + 0.6429t + 26.015 \tag{16}$$

$R_{digester}{}^2$ (=0.7827) being greater than $R_{ambient}{}^2$ (=0.4405) indicates less temperature perturbations in the digester which is the effect of insulating the digester with Fibre glass wool.Both temperatures attained their peak on the eight day (30.0°C and 29.3 °C).

Both the digester temperatures and ambient temperatures fluctuate in a correlated pattern except that the amplitude of fluctuations of the digester is less than that of the ambient.

Table 1: A sample spreadsheet format of the data retrieved from the data-logger showing the tables of strain gage and temperature measurements every second.

Day	Hr	Min	Sec	ADC_1	ADC_2	ADC_3	T_digester	T_ambient
24/04/2018	19	21	30	1583114	1974904	1928112	26.43	25.22
24/04/2018	19	22	30	1580761	1975889	1927975	26.43	25.22
24/04/2018	19	23	30	1577929	1975203	1926529	26.43	25.22
24/04/2018	19	24	30	1576531	1975770	1926375	26.43	25.22
24/04/2018	19	25	31	1573728	1974779	1925197	26.43	25.22
24/04/2018	19	26	31	1573409	1975276	1925430	26.43	25.22
24/04/2018	19	27	31	1569824	1974253	1924486	26.43	25.22
24/04/2018	19	28	31	1568387	1974584	1924726	26.43	25.22
24/04/2018	19	29	31	1567205	1973470	1923760	26.43	25.22
24/04/2018	19	30	32	1566577	1973756	1924140	26.43	25.22
24/04/2018	19	31	32	1565398	1972676	1923145	26.43	25.22
24/04/2018	19	32	32	1564705	1973110	1923605	26.43	25.22

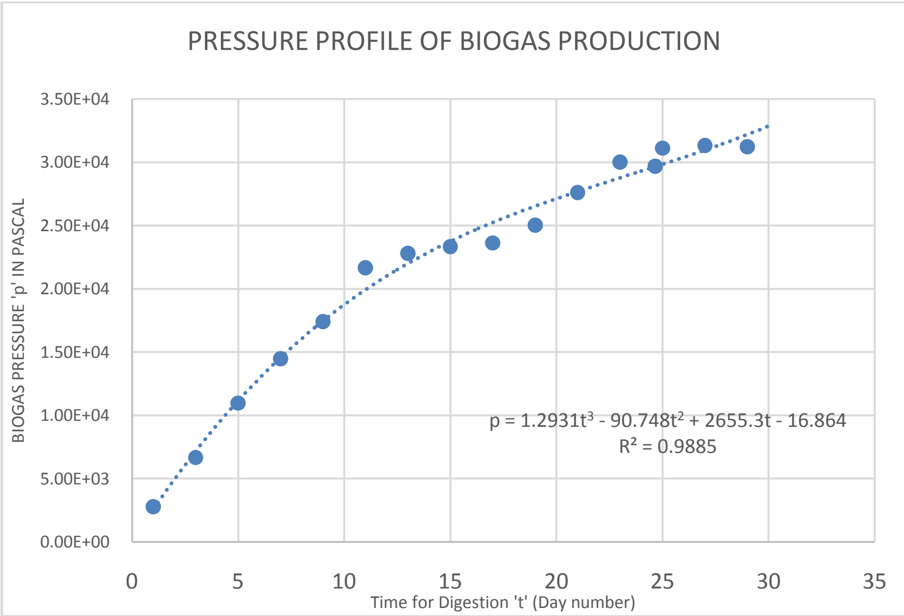

Figure 4: Shows the daily average gas pressure in the bio-digester computed from strain gage measurements.

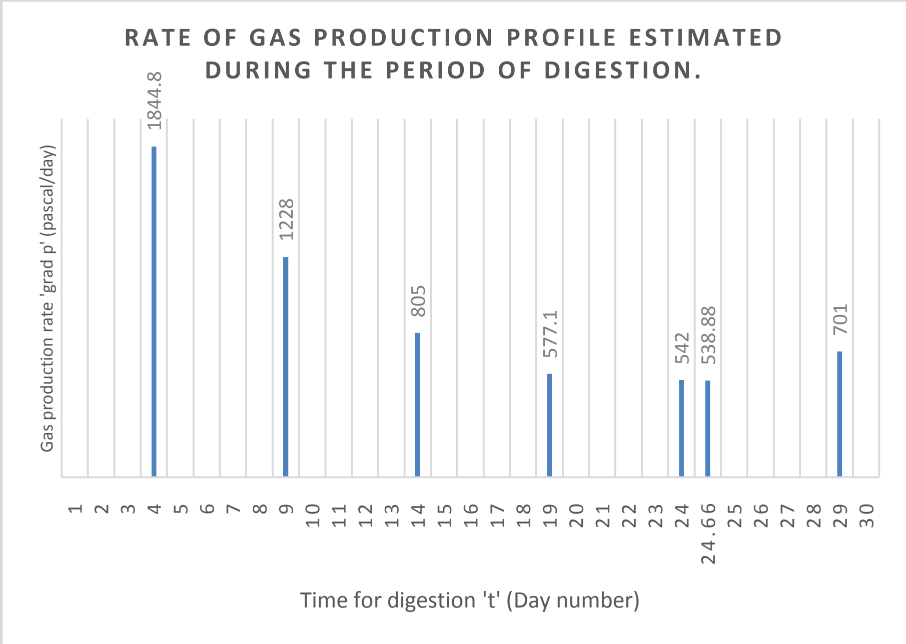

Figure 5: Shows the daily average gas pressure in the bio-digester computed from the pressure derivatives.

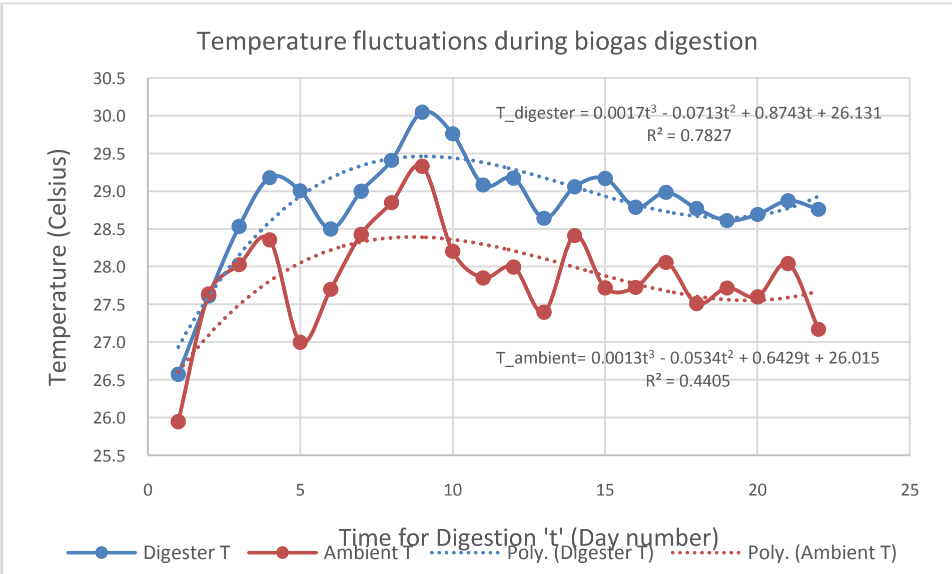

Figure 6: Temperature variations of the digester and that of its ambient showing the effect of insulating the digester with Fibre glass wool.

4.2. Discussion

Production of biogas from the composite of Lemon grass and Poultry droppings was studied using pressure computed from strain gage measurements of stress on the walls of the digester. The digestion for a period of one month inside a twenty litre plastic digester produced gas up to a pressure of 31.2 kP.

The sensitivity of using strain gage with instrumentation for measurement of biogas production especially at low gas volume or pressure was established by the perfect correlation of the data set within day 0 to day 10 of Figure 5. The biogas production pressure-profile of Figure 5 also showed three (3) distinct phases of biogas production corresponding to; aerobic digestion (days 1-11), end of aerobic to start of anaerobic digestion (days 12-17), and thirdly the anaerobic digestion (days 19 onward). As shown in Table 1, frequent changes in strain (hence pressure changes) are accurately captured every second because of the sensitivity of this method rather than conventional volume measurement. The temperature profile also could be used to predict the progress of the digestion if well insulated and compared with that of the ambient environment.

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