RESEARCH

Vol. 16, 2019

ISSN 2319–7757 EISSN 2319–7765

Indian Journal of Engineering

Predictive modeling of Biogas production from the degradation of Cow Rumen

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Article History
Received: 21 August 2018
Accepted: 06 October 2018
Published: January 2019

Citation
Ekine Hamilton Onengiyeofori, Akpa JG, Ehirim EO, Ukpaka CP. Predictive modeling of Biogas production from the degradation of Cow Rumen. *Indian Journal of Engineering*, 2019, 16, 1-14

ABSTRACT

This research work was carried to examine the rate of production of biogas through anaerobic digestion of fresh Cow rumen obtained from slaughter house in Woji, Trans-Amadi, Port Harcourt. The Kinetics of the biogas produced upon the influence of biodegradation was studied using kinetic model linear, power, growth rate decay, non-elementary rate models to establish the model that best predicts the amount of biogas obtained from the experimental obtained parameters. The total solid, volatile solid, ash content and pH was evaluated upon the influence of the biomass. Also, the temperature and pressure build-up during the anaerobic digestion process were recorded weekly. The results of the analysis showed that is, volatile solid, ash content were 0.924g/g, 0.734g/g and 0.1414g/g, while the P^H value before and after the analysis were 7.45 and 7.26 as well as fluctuation in temperature between 30^0C and 34.5^0C was observed. The results revealed that the range of temperature recorded showed that biogas production was favored by the process as well as indicating mesophilic temperature. Whereas the pressure increased non-linearly as time was increased, indicating the effect of biogas accumulation. However, investigation on the kinetics showed biogas production can be studied by any of the models, but the most effective is the growth rate decay model with regression value R^2 of 0.9901. Finally, the research demonstrates the significance of biogas production from the degradation of cow rumen.

Key words: Predictive, modeling, biogas, production, degradation, cow rumen

1. INTRODUCTION

Energy need and its application increases annually in both developed and developing countries as it is one of the sources of economic growth. Energy could be obtained from renewable and non-renewable sources. The global energy supply comes majorly from the non-renewable sources which constitutes environmental challenges. These challenges has provoked continuous search of sources of generating energy with less or no health and environmental problems to man and other living organisms. Fortunately, several researches conducted on renewable energy sources as an alternative to conventional energy sources have been successful as it was able to address the challenges non-renewable sources posed to man and its environment.

Renewable energy can be classified as energy sources from solar power, wind power, hydroelectricity, biomass and biofuels. About 18 percent of global energy consumed in 2006 was generated from renewable sources, and out of this percentage, 13% comes from traditional biomass, while hydropower provided about 3% (Oyeleke *et al*., 2003 and Rabah *et al*., 2010).

The generation of gases as source of energy from wastes has proven useful and less problematic to the environment and theses gases are called biogas. Biogas is a gas produced from animal and plant's wastes through fermentation process under certain conditions. Biogas was defined by Hamawand *et al*. (2014) as a renewable and sustainable source of energy, having similar characteristics with coal seam gas. Biogas can be produced through the digestion of biomass from animal wastes, kitchen wastes, municipal wastes or agricultural wastes. When biogas is produced from the decomposition of biological materials in the absence of oxygen, it is known as anaerobic digestion (Garba and Atiku, 1992), while the decomposition of waste biological materials in the presence of oxygen is termed as aerobic digestion (Cassidy *et al*., 2008). The production of biogas by the anaerobic process has been most widely used and it is carried out in a vessel called digester, which serve as a reactor.

According to Bruni *et al*. (2010), the production of biogas from anaerobic digesters has attracted keen interest to many developed and developing countries due to the decline of fossil-fuel resources. Also, the use of anaerobic digester has been found to be very useful process in wastewater treatment plant, although, it is a complicated chemical and biological processes (Hamawand and Baillie, 2015). For a large scale production, the start-up for anaerobic digester may take two to four months, while a further two to four months may be expended to analyse the efficiency of the process (Khanal, 2008). Apart from the time involved in the start-up and analysis, monitoring the performance of anaerobic digester involves enormous set of data for its measurement over time. Again, the process of substrate digestion that led to biogas production depends on feed composition and the fermentation products of the waste (Vikrant and Shekhar, 2013).

The production of biogas from renewable resources is gaining more attention globally, and despite the divide of opinions on this technology, the role of biogas in the domestic and agricultural purposes is of great importance, as have been reported in Asian Countries as sources of energy used for cooking and crop drying (Meena and Vijay, 2010). Rabahet *et al*. (2010) has stated though, on theoretical perspective, that Nigeria can produce about 6.8 million cubic of biogas daily, which in terms of energy is equivalent to about 3.9 million liters of petroleum. The availability of local raw material in most developing countries can be a driving factor to rural development as biogas plant can be built utilizing the materials that is easily accessible (Baki, 2004).

The management of wastes generated from slaughterhouse located almost in all market places especially, in the city of Port Harcourt is becoming a great challenge as the wastes are dumped indiscriminately, constituting lot of nuisance due to the stench it generates. This environmental effect has the potential of causing epidemic diseases and many more others undesirable issues. However, these problems seemed to be on the increase as population growth and uncontrolled municipal waste disposal continue to be on the rise. Bodkhe and Vaidya (2012) stated that organic waste materials contain adequate quantity of nutrients essential for the growth and metabolism of anaerobic bacteria in biogas production. Port Harcourt city generates huge amount of animal waste daily, therefore it became necessary to develop appropriate mechanism to utilize these wastes especially from abattoir waste in the production of biogas for energy usage which will also minimize the accumulation and indiscriminate disposal of slaughterhouse wastes in the city and importantly, serve as a means of wealth creation. However, the study of the decomposition pattern of waste is necessary to be established while producing biogas especially, the kinetics. This is fundamental as to monitor the progress and more importantly, predict the amount of biogas obtained at any time in a bio-digester.

The aim of this research is to establish the kinetics of biogas production from anaerobic digestion process as a sustainable technology for the production of biogas. In realizing the stated aim, the following objectives were followed to accomplish this research setup and conduct a laboratory scale experiment for the production of biogas from cow internal waste.

2. MATERIALS AND METHODS

The materials and method used in line with stated objectives are stated and discussed in this chapter. Various kinetic rate models for evaluation of biogas kinetics were studied. Also, the batch reactor was used to validate the performance of the rate models. The materials and apparatus used for the experiment include: cow rumen, distilled water, bio-digester (batch reactor), pressure gauge, pH meter, thermostat, stirrer, gas cylinder, GC-MS chromatography, hand glove, Bunsen burner, mask, weighing balance, flexible hose and clip.

Experimental Procedure

The procedures involved in the production of the biogas were collection and preparation of the biomass, biogas production and analysis of biogas produced.

Collection and Preparation of the Cow Rumen

The cow rumen was bought at Woji slaughterhouse and immediately transported to Chemical/Petrochemical engineering laboratory. The cow rumen was immediately prepared for analysis upon arrival. The cow rumen was cut into slices to facilitate decomposition. Thereafter, the sliced sample was weighed.

Physiochemical Analysis of Cow Rumen

The physiochemical analysis of the cow rumen was performed according to AOAC (1990) methods. However, the total solids (TS), volatile solids (VS) and ash content would only be determined.

Estimation of Total Solids

A representative sample of the cow rumen weighing 100g was weighed and transferred into a predetermined weighed empty dried crucible. The crucible with its content was heated in an oven at temperature range of 103° C to 105° C. Thereafter, it was removed and cooled in desiccator to remove moisture content. The total solid (TS) content was then calculated using the formula:

$$TS = \frac{Weight\,of\;Dried\,Sample}{Weight\,of\;Wet\,Sample} \tag{1}$$

Estimation of Volatile Solids

The dried solid sample obtained from total solid analysis was further heated to temperature between 500°C and 550ºC in a furnace. The crucible with the ash content was removed, cooled and weighed again. The volatile solid (VS) content was then calculated using the formula:

$$VS = \frac{Wetght\,of\;Ash\,Content}{Weight\,of\;Dried\,Sample} \tag{2}$$

Biogas Production Procedure

The reactor was checked for leakage by pumping air into it via vacuum pump. After which, it was cleaned and the sliced sample weighing 21100g (21.2kg) was transferred into a bucket, where distilled water measuring 7000ml (7 litres) was added to add the fermentation process. The water-biomass mixture was transferred slowly into the bioreactor with capacity of 20 litres. In the bioreactor, the mixture was stirred manually with the aid of a stirrer for uniform distribution of water in the reactor. The bioreactor was fitted with pressure gauge to record the pressure exerted by the biogas produced during the decomposition process, while the daily temperature was recorded by a thermometer incorporated with the reactor. Silica gel column was attached with the reactor to absorb moisture content in the gas before escaping to the gas collection cylinder. Increase in pressure is an indication that there was gas build-up. Also, the pH of the mixture was taken at the first week and at the last week of the analysis since the experiment was performed in batch operation. The pH was measured by mixing 1gram samples with distilled water using pH meter (ECFC7252101 BE).

Figure 1 Experimental Set up for Biogas production

Gas Collection

A cylinder was also attached to collect the escaped gas from the bioreactor via a flexible hose of about 12.7mm (1/2 inch) in diameter. The cylinder was placed on a weighing balance to record the initial weight. The weighing was repeated every week to determine the amount of biogas that was trapped in the cylinder. Upon completion of the experiment, the content (biogas) of the cylinder was taken for analysis using gas chromatography (GC) to determine the composition of the gas components and percentages. The biogas analysis was performed by Rofnel Energy Services Ltd, Rukpokwu, Port Harcourt. The GC machine was switched on and thereafter, the carrier gas (helium) was opened which flows into the machine.

Biogas Test

The method applied by Adiotomre and Ukrakpor, (2015) was used to test the biogas produced. Because the cylinder was designed with burner head and valve, the test was conducted directly after disconnecting the flexible hose connected between the bioreactor and the gas cylinder. The gas burner was screwed to the burner head and lighted on by match stick.

Kinetic Model

To enhance proper evaluation and understanding of the biogas production rate from the cow rumen (biomass), the obtained experimental data were fitted into four empirical rate models. The rate equations investigated include the linear, power, the growth rate decay (GRD) and non-elementary rate (NER) models.

Linear Model

The linear model investigated in this work for the rate of biogas gas production was expressed in terms of the biomass concentration given in equation (4) as follows.

$$-r_s = r_b = kC_s \tag{4}$$

Where, $r_b =$ Biomass depletion rate (g/ml.day), $r_b =$ Biogas production rate (g/ml.day), $C_s =$ Biomass concentration (g/ml) and $k =$ Specific rate constant (day^{-1})

The value of the specific rate constant was determined by plotting the rate of biogas production against the instantaneous concentration of the biogas. The slope of this graph represents the specific rate constant.

Power Model

The power model investigated in this work for the rate of biogas gas production is expressed as given in equation (5), we have

$$-r_s = r_b = kC_s^n \tag{5}$$

Where, $r_b =$ Biogas production rate (g/ml.day), $C =$ Biogas concentration (g/ml), $k =$ Specific rate constant ((g/ml)$^{1-n}$.day) and $n =$ Constant representing the order of the bio-reaction (-)

Growth Rate Decay Model

The growth rate decay model investigated in this work for the rate of biogas gas production is expressed as follows.

$$-r_s = r_b = \frac{kC_s}{M + C_s} \tag{6}$$

Where, $r_b =$ Biogas production rate (g/ml.day), $C_s =$ Biogas concentration (g/ml), $k =$ Maximum rate specific rate constant (g/ml.day) and $M =$ Constant (g/ml)

Non-Elementary Rate Model

The non-elementary rate model investigated in this work for the rate of biogas gas production is expressed as follows.

$$-r_s = r_b = \frac{k_1 C_s - k_2}{C_s} \tag{7}$$

Where, $r_b =$ Biogas production rate (g/ml.day), $C_s =$ Biogas concentration (g/ml), $k_1 =$ Specific rate constant (g/ml.day) and $k_2 =$ Constant ((g/ml)^2.day)

Application of the Rate Equations to Batch Reactor

The effectiveness of the above rate equations was investigated by applying the various rate equations in batch reactor. The resulting equation was utilized to predict the amount, or yield of the biogas produced with time. However, the model equation for batch reactor was obtained from the mass continuity equation as follows.

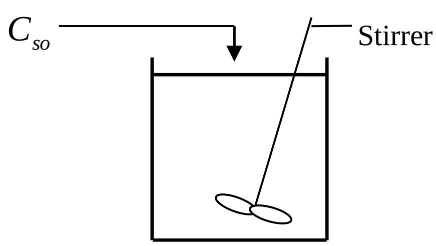

Figure 2 Batch Reactor

Where, $C_{so} =$ Initial concentration of biomass (g/ml), $C_s =$ Instantaneous concentration of biomass (g/ml) and $C_b =$ Biogas concentration (g/ml)

$$\begin{pmatrix}\text{Rate of}\\ \text{mass flow}\\ \text{into reactor}\end{pmatrix} = \begin{pmatrix}\text{Rate of}\\ \text{mass out}\\ \text{from reactor}\end{pmatrix} + \begin{pmatrix}\text{Rate of}\\ \text{biomass}\\ \text{depletion}\end{pmatrix} + \begin{pmatrix}\text{Rate of mass}\\ \text{accumulation}\\ \text{within reactor}\end{pmatrix} \tag{8}$$

From equation (8) we obtained as follows:

$$\text{Inflow of mass into reactor} = F_o C_{so} \tag{9}$$

Outflow of mass from reactor $= FC_s$ (10)

Rate of biomass depletion $= -r_s V$ (11)

Rate of accumulation $= -\frac{dm_b}{dt}$ (12)

Substituting equations (9) through (12) into (8) yields

$$F_o C_{so} = FC_s - r_b V - \frac{dm_b}{dt} \quad (13)$$

Since in batch reactor, there is no flow of mass, the inflow and outflow terms of the reactor are reduced to zero. Thus equation (13) becomes:

$$-\frac{dm_b}{dt} = -r_s V \quad (14)$$

Manipulating equation (14) as follows we have:

$$-\frac{d(\frac{m_b}{V})}{t} = -\frac{dC_s}{t} \quad (15)$$

The ratio of mass to volume can be written as the mass concentration, thus, equation (14) becomes:

$$-\frac{dC_s}{t} = -r_s \quad (16)$$

Equation (3.16) is the model equation for batch reactor.

Where, F_o = Outlet volumetric flow rate (ml/day), F = Inlet volumetric flow rate (ml/day), V = Volume of reactor (ml), m_s = Mass of biomass (g), t = Time of biogas production (day)

Substituting the rate term of the various models into equation (16), we obtained the respective model equations.

Application of the Linear Model

The substitution of the linear model into the batch equation yields:

$$-\frac{dC_s}{t} = kC_s \quad (17)$$

Integration of equation (17) by separation of variable method yields

$$-\int_{C_{SO}}^{C_S} \frac{dC_s}{C_s} = k\int_0^t t \tag{18}$$

$$-\ln\left(\frac{C_s}{C_{so}}\right) = kt \tag{19}$$

$$\ln C_s = \ln C_{so} - kt \tag{20}$$

A plot of $\ln C_s$ versus t gives the slope of the graph as the specific rate constant. However, to predict the concentration of biomass depleted over time in the batch reactor, the exponentiation of equation (20) is taken to give as follows.

$$C_s = C_{so}\exp(-kt) \tag{21}$$

Power Model

Similarly the linear model, the power was substituted into the batch model equation (3.16) as follows.

$$-\frac{dC_s}{t} = kC_s^n \tag{22}$$

Taking the logarithm of both sides of equation (22) gives

$$-\ln\left(\frac{dC_s}{t}\right) = \ln k + n\ln C_s \tag{23}$$

A plot of $-\ln\left(\frac{dC_s}{t}\right)$ versus $\ln C_s$ gives the slope of the graph of n, while the intercept represent the logarithm of the specific rate constant. Again, to predict the concentration of the biomass in the batch reactor over time, equation (22) is solved by integrating using the separation of variable method as follows.

$$-\int_{C_{So}}^{C_S} \frac{dC_s}{C_s^n} = k\int_0^t dt \tag{24}$$

After simplification, we have:

$$\frac{C_{so}^{1-n} - C_s^{1-n}}{1-n} = kt \tag{25}$$

Or

$$C_s^{1-n} = C_{so}^{1-n} - (1-n)kt \tag{26}$$

Multiplying the powers of both sides by $\frac{1}{1-n}$, we have

$$C_s = \left[C_{so}^{1-n} - (1-n)kt\right]^{\frac{1}{1-n}} \quad (27)$$

Equation (27) is the predictive equation for concentration of biomass remaining in the batch reactor over time.

Application of the Growth Rate Decay Model

Substituting the growth rate decay model of equation (6) into equation (16) gives as follows.

$$-r_s = -\frac{dC}{dt} = \frac{kC_s}{M + C_s} \quad (28)$$

However, one of the simplest ways of obtaining the constants in equation (28) is by inverting both sides of equation (28) as follows.

$$\frac{1}{-r_s} = \frac{M}{k}\left(\frac{1}{C_s}\right) + \frac{1}{k} \quad (29)$$

A plot of $\frac{1}{-r_s}$ versus $\frac{1}{C_s}$ gives the slope of the graph of $\frac{M}{k}$, while the intercept represent $\frac{1}{k}$. However, to predict the concentration of the biomass in the batch reactor over time, equation (28) was solved by numerical integration using the Runge-Kutta method as follows.

$$C_s(j+1) = C_s(j) + \left[k_1 + 2(k_2 + k_3) + k_4\right]/6 \quad (30)$$

Where, $k_1 = hf\left(t(j), C_s(j)\right)$ (31)

$$k_2 = hf\left(t(j) + \frac{1}{2}h, C_s(j) + \frac{1}{2}k_1\right) \quad (32)$$

$$k_3 = hf\left(t(j) + \frac{1}{2}h, C_s(j) + \frac{1}{2}k_2\right) \quad (33)$$

$$k_4 = hf\left(t(j) + h, C_s(j) + k_3\right) \quad (34)$$

$h =$ Step size

The computation of the Runge-Kutta algorithm was implemented in MATLAB program.

Application of the Non-Elementary Rate Model

Again, to apply the non-elementary rate model to the batch and utilizing it for prediction of the biomass concentration over time in the batch reactor, the rate equation described by the power model was substituted into the batch equation (16) as follows.

$$-r_s = -\frac{dC}{t} = \frac{k_1 C_s - k_2}{C_s} \quad (35)$$

Further simplification of equation (35) is yield as follows.

$$\frac{1}{-r_s} = k_1 - \frac{k_2}{C_s} \quad (36)$$

A plot of $\frac{1}{-r_s}$ versus $\frac{1}{C_s}$ gives the slope of the graph of k_2, while the intercept is k_1. However, to predict the concentration of the biomass in the batch reactor over time, equation (35) was solved by numerical integration using the Runge-Kutta method. The method of solution is the same as the algorithm stated in equation (30) through equation (34).

Determination of Biogas Production Rate

The rate of biogas production was determined using the numerical method expressed in Fogler (2005).

$$\left(\frac{dC_s}{dt}\right)_{t_0} = \frac{-3C_{so} + 4C_{s(1)} - C_{s(2)}}{2\Delta t} \quad (37)$$

$$\left(\frac{dC_s}{dt}\right)_{t_i} = \frac{C_{s(i+1)} - C_{s(i-1)}}{2\Delta t} \quad (38)$$

$$\left(\frac{dC_s}{dt}\right)_{t_n} = \frac{C_{s(n-2)} - 4C_{s(n-1)} + 3C_{s(n)}}{2\Delta t} \quad (39)$$

Equation (37) was used to calculate the rate at time zero; equation (38) was used to calculate all intermediate rates at any time, while equation (39) was used to calculate the rate at the last time. The experimental data was used for the calculation as demonstrated in Appendix A.

Determination of Biogas Concentration and Yield

The concentration of biogas produced at any time was calculated using the mathematical relation:

$$C_{biog} = C_{so} - C_s \quad (40)$$

C_{biog} = Biogas concentration (g/ml)

Similarly, the biogas yield can be obtained as follows.

$$Y = \frac{C_{so} - C_s}{C_{so}} = \frac{C_{biog}}{C_{so}} \quad (41)$$

Determination of the Deviation between Measured and Predicted Parameters

The deviation between the experimental and predicted values of biomass and biogas concentrations as well as the biogas yield was determined using the expression stated in equation (42).

$$d = \frac{\sum_{i=1}^{n} X_{\exp t.} - \sum_{i=1}^{n} X_{pred.}}{\sum_{i=1}^{n} X_{\exp t.}} \quad (42)$$

Where, $\sum_{i=1}^{n} X_{\exp t.}$ = Sum of all the values obtained at any time from the experiment, $\sum_{i=1}^{n} X_{pred}$ = Sum of all the values obtained at any time from the model. The deviation was calculated in Appendix B.

3. RESULTS AND DISCUSSION

Results of the kinetic investigation on the production of biogas from cow rumen (biomass) performed experimentally were presented in this chapter. The performance of the investigated kinetics was also compared. The gas burned with blue flame which was initially small, but increased in intensity with no presence of soot. Further test was carried out by placing a test tube filled with 50ml of water, which boils after a few minute, indicating that there was increase in temperature and hence the heat of water.

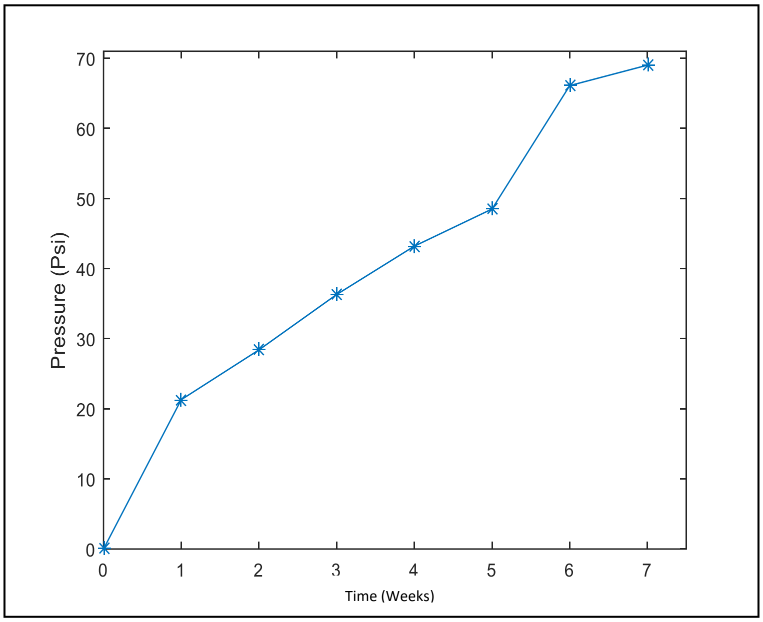

Figure 3 Variation of Pressure with Time

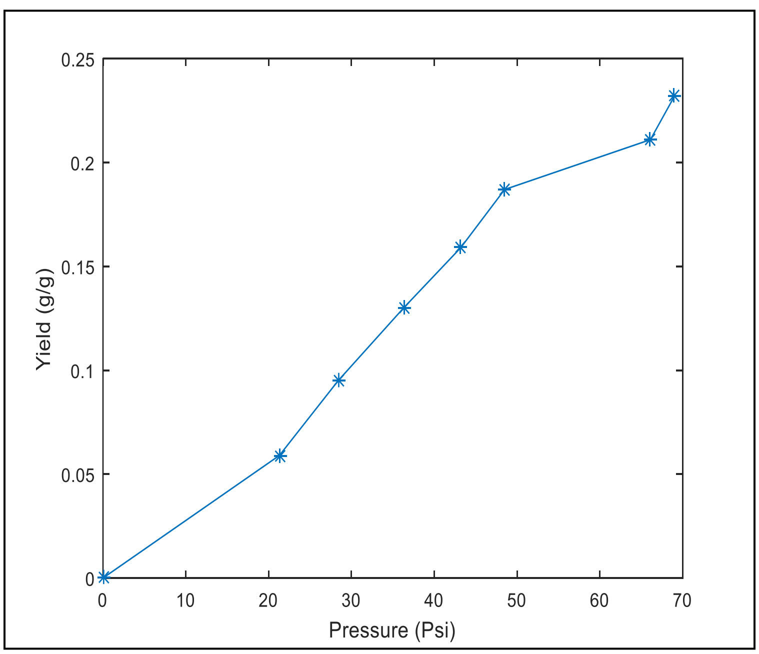

Figure 4 Pressure Variation with Biogas Yield

The change in pressure exerted by the biogas against time is shown in Figure 3 and thus, pressure increases as time was increased in a non-linear profile. Between the 6^{th} and 7^{th} week, there was low increase in pressure, which is an indication that the yield of biogas was approaching it optimum limit. Adiotomre and Ukrakpor (2015) stated that the sudden slow in pressure increased was as a result of declined in bacterial activities. However, the increase in pressure build-up shows that there was production of biogas from the cow Rumen.

Again, the yield of biogas as pressure increases was shown in figure 4 and the yield of biogas increases as the pressure exerted by the gas produced in the reactor increases. This implies that yield of biogas in the bioreactor is directly proportional to pressure build-up in the reactor.

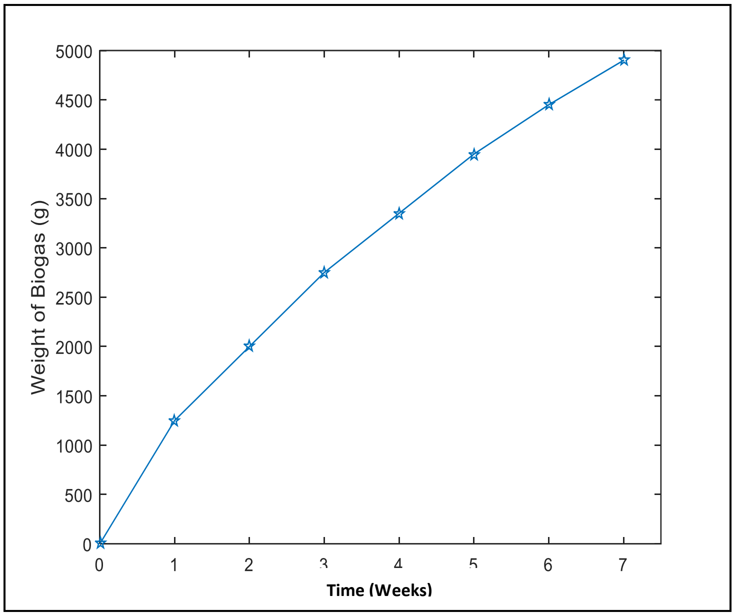

Figure 5 Variation Biogas Weight with Time

The weight of biogas measured between zero time and 7 weeks is shown in Figure 5; therefore the weight of biogas obtained increases as the time of fermentation of the cow rumen (biomass) was increased. At the end of the experiment, the weight of biogas measured was 4900g.

Determination of Biogas Production Kinetics

To effectively utilise the formulated rate equations, the constants were first determined. Importantly, the constants may change depending on several factors such as environment, process conditions and mechanism of operation. However, the constant coefficients in the respective rate equations were determined with the use of Microsoft Excel spread sheet, where the experimental results were fitted to the corresponding model equation develop, which was demonstrated in Figures 6 to 9.

Linear Model Coefficient

The specific rate constant in equation (4) was determined using the equation in Figure 6 and the detail calculation was carried out. Hence, from the calculations, the specific rate constant was obtained as $0.0367 day^{-1}$. Therefore, the rate of biogas production with the linear model can be expressed as a function of the substrate (biomass) concentrate $r_{biog} = 0.0367 C_s$.

Power Model Coefficients

Again, like the linear model, the specific rate constant and the order of reaction in the power model were determined using the equation in Figure 7. The detail calculation performed in Appendix B showed that the specific rate constant, k is 0.000419 $(ml/g)^{-3.5}.day$, while the order of the bio-reaction, n is approximately equal to 4.5. Therefore, the rate of biogas production with the power model can be expressed as a function of the substrate concentrate $r_{biog} = 4.1944 \times 10^{-4} C_s^{4.5}$.

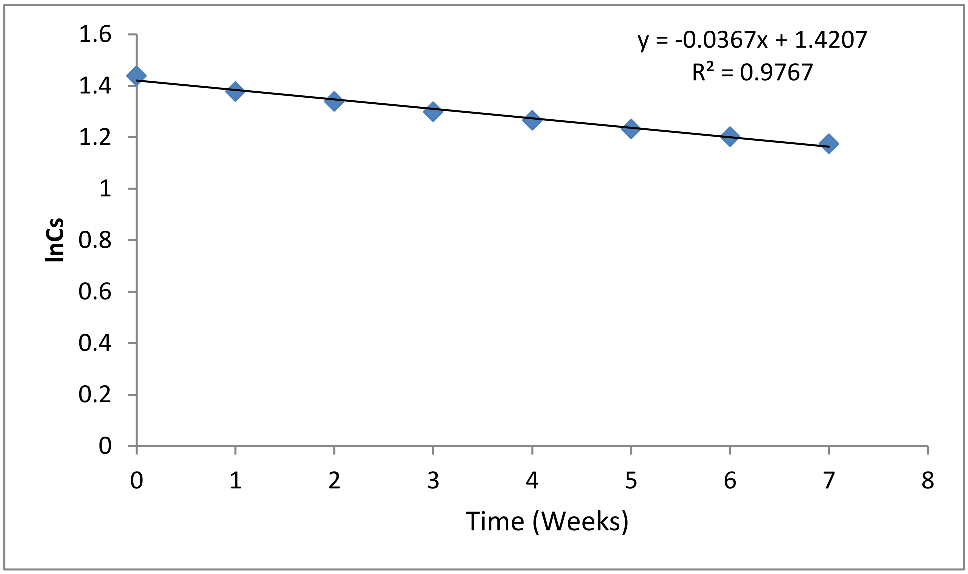

Figure 6 Plot for Determination of Coefficient in Linear Model

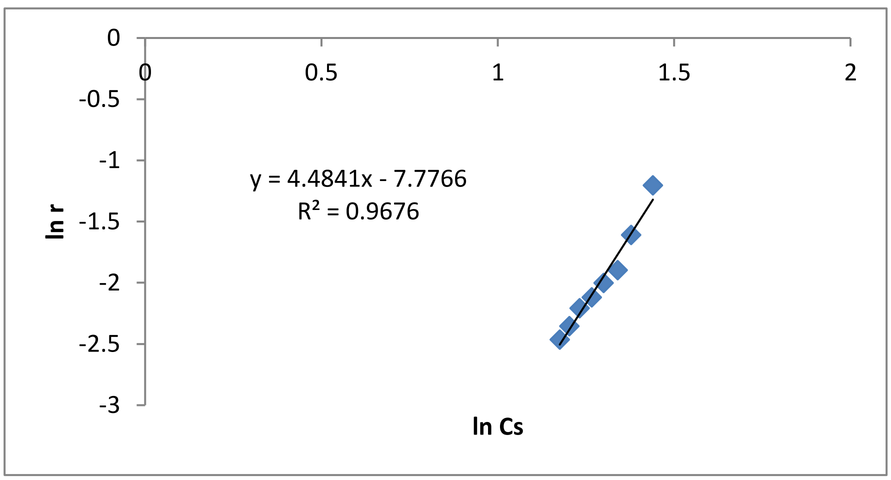

Figure 7 Plot for Determination of Coefficients in Power Model

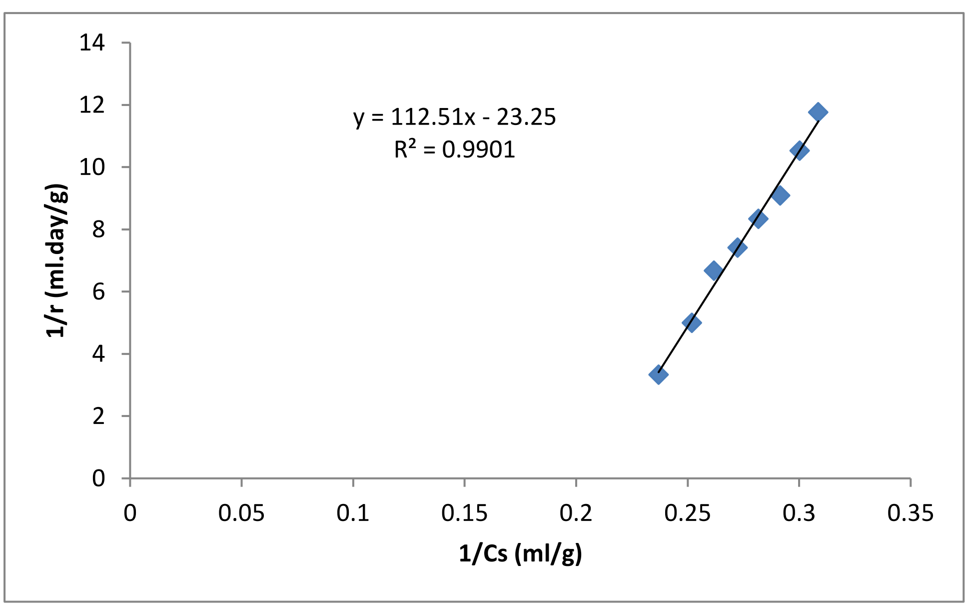

Figure 8 Plot for Determination of Coefficients in GRD Model

GRD Model Coefficients

The maximum specific rate constant, *k* and the constant, *M* in the growth rate decay model were determined using the equation in Figure 8. The calculations performed showed that the maximum specific rate constant, *k* is -0.043g/mlday, while the constant, *M* is approximately equal to 4.838g/ml. Therefore, the rate of biogas production with the growth rate decay (GRD) model in terms of the substrate concentrate can be expressed as $r_{biog} = -\frac{0.043C_s}{4.838 + C_s}$.

NER Model Coefficients

Finally, the specific rate constant, k_1 and the second constant k_2 in the non-elementary rate model were determined using the equation in Figure 9. Again, form the calculations performed in the research work, we have that the specific rate constant, k_1 is 0.88g/ml.day, while the second constant k_2 is 2.650(g/ml)^2.day. Therefore, the rate of biogas production with the non-elementary rate (NER) model expressed as a function of the substrate concentrate can be written as: $r_{biog} = \frac{0.88C_s - 2.6503}{C_s}$.

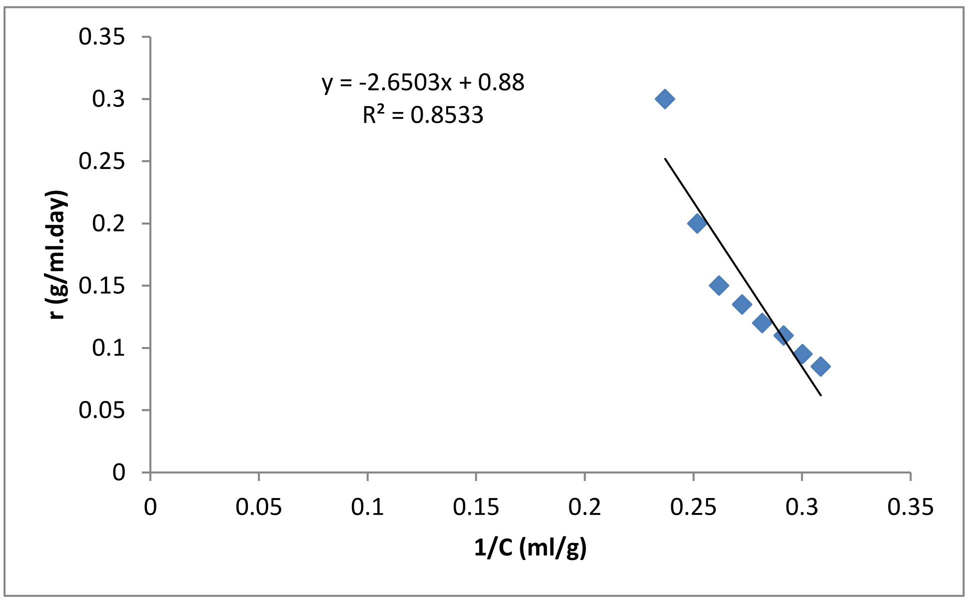

Figure 9 Plot for Determination of Coefficients in NER Model

4. CONCLUSION

The production of biogas from fresh cow rumen was investigated in this study under mesophilic temperature between 30.10ºC to 34.70ºC. The week laboratory measurement of the collected biogas revealed increase in concentration and hence, the yield of biogas from the cow rumen, which would be significance in energy generation if properly harnessed. Also, there was increase in the system pressure as the amount of biogas increases, which was an indication that more concentration of the biogas are being produced as the cow rumen ferments in the reactor thereby, releasing the molecules of the gases and therefore, increasing their mean kinetic energy and hence, the system pressure. The physiochemical parameters analysis on the cow rumen revealed that the pH, total solid, volatile solid, ash content and moisture content agreed with values reported in previous work.

Further analysis on the biogas produced revealed that methane has the highest proportion (68.14%), followed by carbon dioxide (27.71%), while nitrogen, hydrogen and hydrogen sulphide occupied the remaining percentages. This high methane percentage is an indication that the gas is combustible and has the potential to provide alternative energy for small scale utilization especially, for cooking and electricity supply in homes.

On the other hand, the investigation of the biogas kinetics revealed that biogas production can be interpreted by different kinetics. However, the level of the accuracy will equally differ. In this study, four different rate models were investigated: linear, power, GRD and NER models. The GRD model predicted the biogas more accurately, followed by the power model and then the NER model, while the linear model recorded the least accurate prediction. Despite the variation in the prediction, we observed that any of the rate models can be applied to batch reactor for biogas analysis. This was validated by the small deviations obtained especially, in the power, GRD and NER.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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