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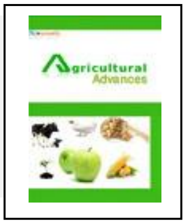

Original article

Kinetics of biogas production from jackfruit wastes co-digested with cow paunch in batch mode

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ABSTRACT

Application of appropriate mathematical models is one of the strategies in solving the stability problems often exhibited by anaerobic digestion process. Kinetics of batch anaerobic digestion of jackfruit waste co-digested with cow paunch for biogas production was studied for 30 days hydraulic retention time (HRT). Data from cumulative biogas yield obtained during the experimental stages was fitted to C-NIKBRAN mathematical model based on first order reaction which adequately predicted the kinetic behavior of the substrate's anaerobic biodegradability. The validity of the applied model was also verified through application of the regression model (ReG) (Least Square Method using Excel Version 2003) in predicting the trend of the experimental results. Comparative analysis of Figs. 7-10 show very close alignment of curves which precisely translated into significantly similar trend of data point's distribution for experimental (ExD), derived model (MoD) and regression model-predicted (ReG) results of cumulative biogas yield. Also, critical analysis of data obtained from experiment and derived model show low deviations on the part of the model-predicted values relative to values obtained from the experiment. Correction factor was introduced to bring the model-predicted cumulative biogas yield to those of the corresponding experimental values. Deviational analysis from strongly indicates that cumulative biogas yield was most reliable based on the associated admissible deviation of the model-predicted cumulative biogas yield from the corresponding experimental values); 9.2% within the pH range. The values of cumulative biogas yield within the highlighted deviation indicates over 90% confidence level for the applied model and over 0.9 effective dependency coefficients (EDC) of cumulative biogas yield on pH, chemical oxygen demand (COD), total viable count (TVC) and total dissolved solids (TDS). Also, deviation of model-predicted cumulative biogas yield from corresponding experimental results indicates a maximum deviation of 7.17%. This translated into over 92% operational confidence for the derived model as well as over 0.92 effective dependency coefficients (EDC) of cumulative biogas yield on pH, chemical oxygen demand, total viable count, and total dissolved solids.

1. Introduction

Energy is vital in all human activities. Presently, about 86 percent of the world's energy supply comes from fossil fuels, about 12 percent are provided by hydroelectric and nuclear power alternative sources of energy contribute close to 2 percent (Mayer, 2001). However, recent rise in oil and natural gas prices may have driven the current economy towards alternative energy sources (Ojolo et al., 2007; Chukwuma et al., 2012). Furthermore, fossil fuels as energy source are not renewable energy sources. Fossil fuels deposits are continuously depleting. Bio-fuel which is an alternative and cheap source of renewable energy can be made available to rural areas of the country (Achebe et al., 2012). Biofuels can be defined as fuels produced from biomass for either transportation or combustion purposes (Angeldaki et al., 1993).

Biogas, a gas produced through anaerobic digestion process is composed of approximately 50-60% methane, 40-50% carbon dioxide, water vapour, nitrogen, sulfur, and other trace compounds, is a cheap alternative energy (Nwabanne et al., 2012). It is produced from renewable sources and it plays important role in the domestic and agricultural life of many countries of the world especially in Asia, America, and Europe where it is used for cooking, heating, transportation, and as soil fertilizer (Ofoefule et al., 2010; Umeghalu et al., 2012; Chukwuma, 2012). Biogas generation takes place in an oxygen-free environment. It uses anaerobic bacteria that live only in the absence of oxygen to break down complex organic compounds in fairly well defined stages in a process known as anaerobic digestion (AD). The effluent at the end of digestion can be used for growing crop as fertilizer (Ojolo et al., 2007). Anaerobic digestion process occur in three stages; observing that in the first stage (hydrolysis process), the bacteria break down the biodegradables (fats, carbohydrates, and proteins) to soluble compounds; in the second stage of the process, the acetogens convert the soluble compounds to organic acids while in the third stage, the methanogens convert the organic acids to methane and carbon dioxide and the other products of the process (Ojolo et al., 2007).

Anaerobic digestion systems are rather complex processes that unfortunately often suffer from instability. Such instability is usually witnessed as a drop in the methane production rate, a drop in the pH, a rise in the volatile fatty acid (VFA) concentration, causing digester failure (Lyberatos and Skiadas 1999). It is caused by (a) feed overload, (b) feed under load, (c) entry of an inhibitor, or (d) inadequate temperature control. The usual remedy, is a rapid increase in the HRT (hydraulic retention time), and when this fails, the digester has to be primed with sludge from a "healthy" digester. This, however, may be quite costly, in view of the fact that anaerobic digestion is a very slow process. Kinetic models for anaerobic digestion can be used to describe the relationship among the principal state variables and explain the behavior of anaerobic processes quantitatively. The anaerobic digestion process is carried out by a delicately balanced population of various bacteria. These bacteria can be very sensitive to changes in their environment. Lyberatos and Skiadas (1999), Chukwuma et al., (2012) reported that temperature, pH, substrate composition, carbon/nitrogen ratio (C/N), ammonia concentration, volatile fatty acids (VFA), digester configuration are some of the vital factors that influence anaerobic process.

Jackfruit (Artocarpus heterophyllu lam) is a large fruit of a milky-juice tree, of Moraceae family. The edible, pulpy part represents the parianth. Jackfruit is the largest edible fruit in the world (Naik, 1949 and Sturrock, 1959). It was believed to have originated in the forests of the Western Ghats (India), where it still grows in the wild, as well as in the evergreen forests of Assam and Myanmar. It is cultivated throughout Bangladesh, Burma, India, Indonesia, and Malaysia.

Jackfruit has been reported to contain high levels of protein, starch, calcium, and thiamine (Brukill, 1997). The juicy pulp of the ripe fruit is eaten fresh as a dessert. The bulbs (excluding the seeds) are rich in sugar, fairly well in carotene and also contain vitamin C (Bhatia et al., 1955). Jackfruit is also rich in nutrients such as sodium, potassium, iron, vitamin B6, calcium, zinc, and many other nutrients. Jackfruit can lower blood pressure, cure fever and diarrhea. According to Bobbio et al. (1977), jackfruit is also known to be beneficial to fighting asthma, ulcers, indigestion, tension, nervousness and constipation. It can slow down aging and cell degeneration. Jams, beverages, candies, conserves and dehydrated forms are other industrial uses for which the jackfruit can be utilized. At present, jackfruit is mainly grown for its ornamental values in Nigeria. The consumption of its seeds is still not popular and is regarded as waste or as feed for domestic animals. The starch of the crop is found to be high in sugar yield which will translate to high ethanol yields. However, much attention has not been paid to the crop by researchers leading to its underdevelopment as a potential feedstock for biofuel production. Biogas production from jackfruit may increase due to the vast area of land and abundant labour available for growing the crop in Nigeria. More so, the crop is not widely consumed therefore would not compete largely with human or animal food.

2. Materials and methods

2.1. Sources of materials

Ripe jackfruits were purchased from Eke Ojoto Market in Idemili South Local Government Area of Anambra State of Nigeria. Fresh cow paunch (CP) was obtained from Umeba Slaughter House at Umuoji, while poultry droppings were collected fresh from F. C. Muonwem Poultry Farm Limited, Uke in Idemili North Local Government Area of Anambra State, Nigeria. Four plastic bottles of 1liter volume were used as micro-digesters for the study. Also 2 plastic containers of 20 liter volume each were used for partial decomposition of the substrates.

2.2. Preparation of waste samples

The main experimental apparatus consists of micro-digester fitted at the top with cork, which was perforated for the insertion of hose pipe used to connect the micro-digester to the 1 litre measuring cylinder for measurement of the daily biogas production. Biogas formed was measured by liquid displacement method (Pound et al., 1981). Other materials used were water trough, biogas burner locally fabricated for checking gas flammability. All the wastes (jackfruit and cow paunch) were allowed to degrade for a period of 20 days. This was followed by soaking them in water for ten days to allow for partial decomposition of the wastes by aerobic microbes. Chukwuma et al. (2012) reported that partial decomposition of substrates aids faster digestion of the waste by anaerobic micro-organisms. Large sized mesh screen was then used to strain the waste from water while the water was used for the charging of the wastes.

2.3. Charging of the micro-digester

150g of pure waste of jackfruit (PWJ) + 150g of cow paunch (CP) were weighed, mixed thoroughly and put into the micro-digester + 600g of water and stirred thoroughly. This gave water to waste ratio of 2:1. The micro-digester was stirred thoroughly on daily basis to ensure intimate contact of the waste with micro-organisms responsible for converting the wastes to biogas. Daily biogas production was measured by downward displacement of the water in the trough by the gas produced and recorded as the difference between the initial reading at the beginning of each day and the final reading at the end of the same day. pH of the waste slurries were monitored daily for a period of 5 days to ensure stability of the slurries. Ambient and slurry temperatures were monitored daily all through the 30 days hydraulic retention time (HRT.

3. Results and discussions

Figure 2 shows the effect of time on pH. Result shows that pH value decreases with increase in hydraulic retention time (HRT).This may be explained by the fact that as anaerobic digestion is taking place, pH decreases due to the action of acetogenic methanogens break down sulphur containing organic and inorganic compounds to form fatty acids (Garba and Atiku, 1992). According to Oyeleke et al. (2003), some micro-organisms evolve later in the process while others die mid-way through the process. Methanogens need a pH range between 6.5 and 7.8 whereas the acid-producing bacteria have optimum value between 5 and 6. In this study, pH range in lie within the optimal value as posited by Verma (2002). Also, Shellford's law states that "the occurrence of any organism in any environment is determined not only by availability of nutrients but also by availability of other physiochemical factors." Hence, as the medium tends to become acidic, non-acid tolerance organisms are replaced by acid tolerant organisms. . pH stability in this study can be accounted for by the high level of protein content and other micro-molecule present in the residue which has some buffer effect (Dinamarca et al., 2003).

Figure 4: presents the relationship between –ln(Se/So) with time. The plot depicts the exponential growth of the organisms as the nutrient is utilized. The graph is linear with regression coefficient $R^2 = 0.984$ confirming that the kinetics of the substrates anaerobic biodegradation followed a first order reaction.

Figures 5: shows the plot of I/U against I/Se for the substrate's degradation. The plot is linear with Ks/K and I/K as slope and intercept respectively and regression coefficient $R^2 = 0.910$. Where, Ks is the half-velocity constant (mg/l), K is maximum rate of substrate utilization. From the graphs, it could be seen that the digesting microbes require more hydraulic retention time to regenerate and hence inoculation for better performance. This is in line with Nwabanne et al. (2012) who also made the same observation in their study of the kinetics of anaerobic digestion of palm oil effluent. The specific rate of substrate utilization is related to mean cell residence time and can be represented with the formula:

$$I/\theta = YU - Kd \qquad \text{……………………………(1)}$$

Where:

Y = biomass yield/microbial growth yield (mg/mg).
Kd = endogenous decay coefficient.
Θ = mean cell resilence time (day-1)
U = specific rate of substrate utilization

Figure 5: shows variations of net specific growth rate of micro-organisms and hydraulic retention time. The net specific growths of the micro-organisms tend to decrease with increase in time. This is explainable with the fact that the micro-organisms that fed on the nutrients reduce by dying off as the available nutrients reduce with time.

Figures 6: Shows the effect of time on total dissolved solids. Result shows that total dissolved solids decrease with increase in time. This may be explained by the fact that anaerobic digestion is progressing whereby as the degradable organic matters are being decomposed and biogas is being generated the total suspended solids gradually decrease and biodegradable nutrient concentration decreases.

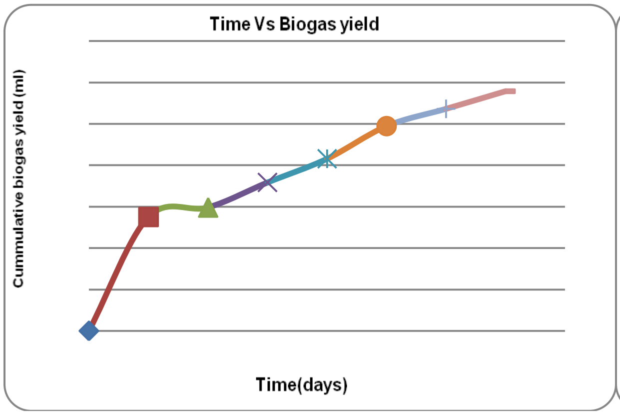

Fig. 1. Plot of cumulative biogas yield against time.

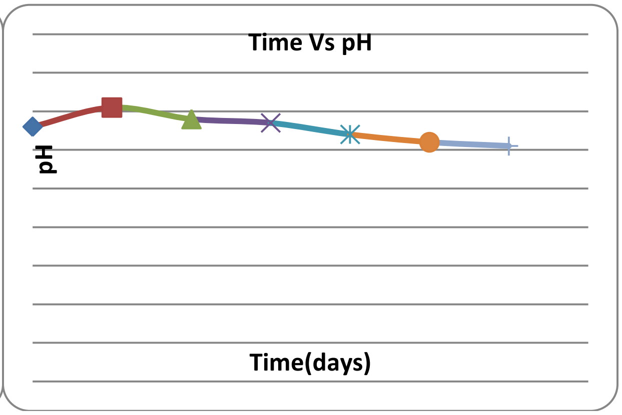

Fig. 2. Plot showing effect of time on pH.

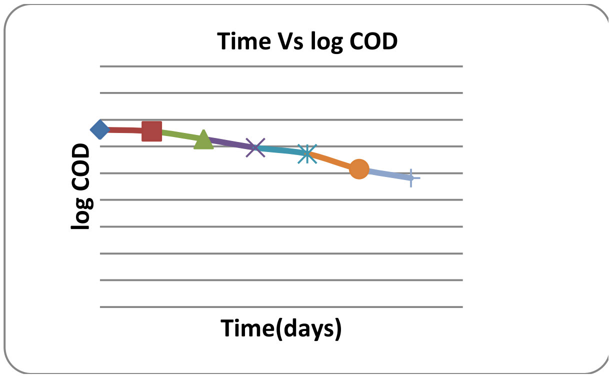

Fig. 3. Plot showing effect of time on COD.

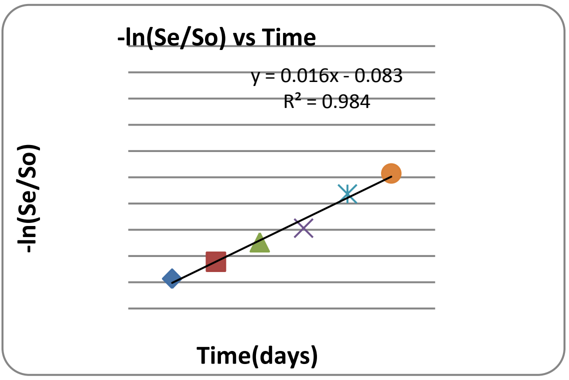

Fig. 4. Graph of -ln(Se/So) vs time.

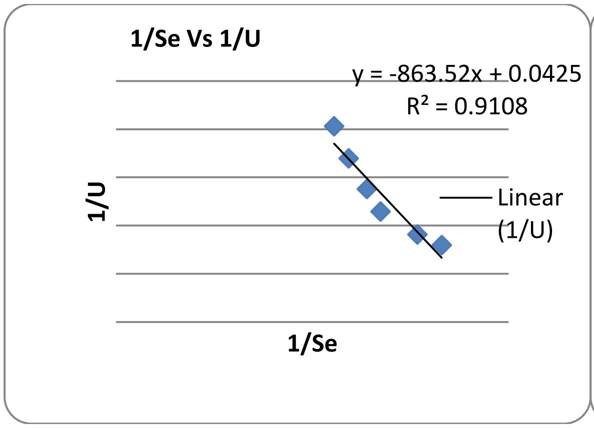

Fig. 5. Graph of 1/Se vs 1/U.

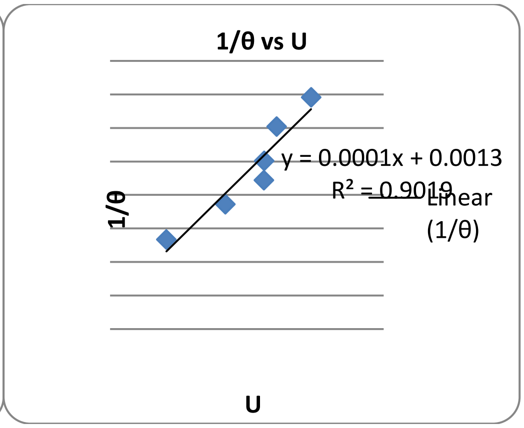

Fig. 6. Graph of 1/θ vs U.

3.1. Model predicted results

Graphs of correlation between cumulative biogas yield and pH, COD, TDS, TVC for pure waste of jackfruit co-digested with cow paunch

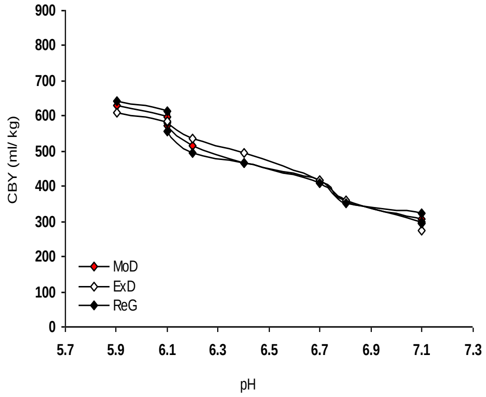

Fig. 7. Graph of cumulative biogas yield against pH.

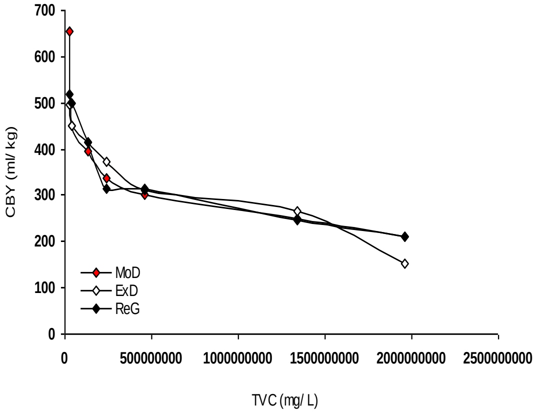

Fig. 8. Graph of cumulative biogas yield against TVC

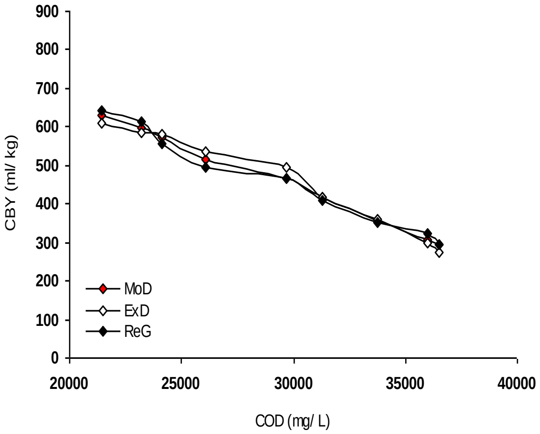

Fig. 9. Graph of cumulative biogas yield against COD.

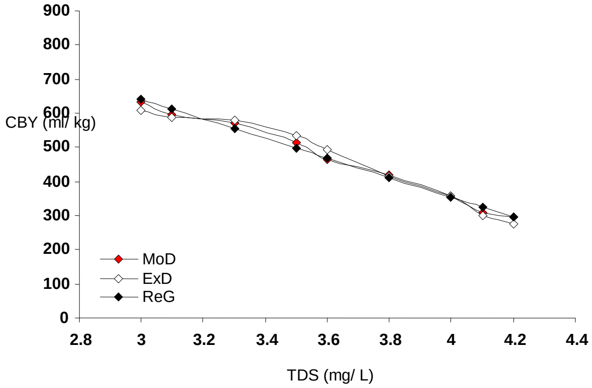

Fig. 10. Graph of cumulative biogas yield against TDS.

3.2. Validation of model

Statistical analysis

The derived model was validated by carrying out a statistical analysis

a) Comparison with standard model, regression model and deviational analysis

1) Correlation

The correlation coefficient between cumulative biogas yield (CBY) and pH, chemical oxygen demand (COD), total viable count (TVC) and total dissolved solids (TDS) were evaluated from the results of the derived model, experiment and regression model considering the coefficient of determination R2 accompanying Figs. 7-10. The evaluation was done using the equation.

$$R = \sqrt{R2} \qquad (1)$$

The evaluated correlations are shown in Table 1. These evaluated results indicate that the derived model predictions are significantly reliable and hence valid considering its proximate agreement with results from actual experiment and regression model. Table 1: shows result of comparison of derived model with standard model of pure waste of jackfruit.

Table 1
Comparison of derived model with standard model.

PWJ-CP		
	pH	
ExD	MoD	ReG
0.9947	0.9892	0.9752
COD		
0.9788	0.9949	1.0000
TVC		
0.9159	0.8786	0.8510
TSS		
0.9875	0.9979	0.9901

The validity of the derived model was also verified through application of the regression model (ReG) (Least Square Method using Excel version 2003) in predicting the trend of the experimental results.

Comparative analysis of Figs.7-10 show very close alignment of curves which precisely translated into significantly similar trend of data point's distribution for experimental (ExD), derived model (MoD) and regression model-predicted (ReG) results of cumulative biogas yield.

b) Deviational analysis

The deviation Dv, of model-predicted cumulative biogas yield from the corresponding experimental result was given by

$$Dv = \left(\frac{MoD - \xi\ ExD}{\xi\ ExD} \right) \times 100 \qquad (2)$$

Where: ξExD and ξMoD are cumulative biogas yield obtained from experiment and derived model respectively.

Critical analysis of data obtained from experiment and derived model show low deviations on the part of the model-predicted values relative to values obtained from the experiment. This was attributed to the fact that the surface properties of the substrates (pure cocoyam and jack fruit co-digested with cow paunch) as well as the physico-chemical interactions between the substrates and the degrading microbes which played vital roles during the digestion process were not considered during the model formulation. This necessitated the introduction of correction factor, to bring the model-predicted cumulative biogas yield to those of the corresponding experimental values.

Table 2

Deviation of model-predicted cumulative biogas yield and correction factor for pure waste of jackfruit co-digested with cow paunch (PWJ-CP).

CBY ExD	CBY MoD	Dv (%)	Cf (%)
275.13	294.85	+7.17	- 7.17
298.25	307.98	+3.26	- 3.26
358.64	357.89	- 0.21	+ 0.21
415.71	417.19	+ 0.36	- 0.36
494.60	465.28	- 5.93	+ 5.93
536.14	514.42	- 4.05	+ 4.05
578.90	571.64	- 1.25	+ 1.25
586.64	596.05	+1.60	- 1.60
610.20	631.83	+3.54	- 3.54

Deviational analysis from Table 2 strongly indicates that cumulative biogas yield (from pure cocoyam digestion) was most reliable at pH values between 7.4 and 8 based on the associated admissible deviation (of the model-predicted cumulative biogas yield from the corresponding experimental values); 9.2% within the pH range. The values of cumulative biogas yield within the highlighted deviation indicates over 90% confidence level for the derived model and over 0.9 effective dependency coefficients (EDC) of cumulative biogas yield on pH, COD, TVC and TDS. Comparative analysis of Tables 1 and 4 shows that cumulative biogas yield at pH values below 7.4 and above 8 are unreliable. This is because at these extreme pH values, the deviation values were over 30%, making the associated cumulative biogas yield (CBY) unacceptable and unrealistic.

Table 2 shows deviation of model-predicted cumulative biogas yield from corresponding experimental results. The table indicates a maximum deviation; 7.17%. This translated into over 92% operational confidence for the derived model as well as over 0.92 effective dependency coefficients (EDC) of cumulative biogas yield on pH, COD, TVC and TDS.

Thus, the model being able to fit the experimental data set with the goodness of fit (R2) only could be attributed to the deviations in the bacterial activities in the initial and final stages of anaerobic digestion process.

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