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Design of Batch Reactor for Biogas Production from Cassava Wastewater Using Potassium Hydroxide Catalyst

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ABSTRACT
The indiscriminate disposal of cassava wastewater in rural areas of Nigeria without any treatment has been a serious environmental issue. An approach to address this menace is the application of anaerobic digestion technique to cassava wastewater in a batch reactor, resulting in the production of biogas. The design of batch reactor for biogas production from cassava wastewater was investigated. A laboratory scale batch anaerobic digestion experiments were performed using cassava wastewater as substrate and potassium hydroxide (KOH) catalyst under isothermal condition at mesophilic temperature of 35^{0}C. Experimental data obtained for a hydraulic retention time of 30days were subjected to Monod kinetic model to obtain some kinetic parameters. The kinetic parameters obtained are maximum specific growth rate (μ_{max}) of 0.4236 day^{-1}), half velocity constant (K_s) of 2077.9mg/l, microbial yield (Y) of 0.0288mg/mg, endogenous decay constant (K_d) of 0.1367day^{-1}. Design models were developed for batch reactor volume, height, diameter, heat requirement per unit volume of reactor, reactor heat exchanger dimension and capital cost. The design models were simulated over a range of fraction conversion from 0.1 to 0.9 using MATLAB R2015, a computer aided program. The simulation results provided useful information on the dependency of reactor sizes on the extent of fractional conversion and subsequently, the capital cost of the batch reactor.

Keywords: *cassava, wastewater, biogas, anaerobic digestion, batch Reactor*

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I. INTRODUCTION

Cassava (Manihot esculenta, Cranntz) is one the food crops grown in Nigeria and other tropical, Asian and Latin America countries. It is one of the three main root tuber crops cultivated worldwide for its rich starch content, a major source of energy for rural populace (Okunade & Adekalu, 2013). In the Southern part of Nigeria, cassava plays an important economic role among the rural populace where it is cultivated and processed into several products such as garri, fufu and starch, thus providing a source of income for the farmers (Izah et al., 2017). Over the years, there is an increase in the processing of cassava root tubers into durable and stable products such as cassava flour, cassava flake, starch, garri, e.t.c. with less moisture content for domestic and industrial use (Mbongo & Antai, 1994). With increase processing activities of cassava, there is bound to be a lot of waste generation. Environmental problems such as land, water and air pollution became a threat to the ecosystem, arising from the discharge of cassava solid waste and wastewater into the environment without any form of treatment (Izah & Ohimain, 2015). The scale of production and processing techniques determine the amount of cassava wastes generated. The most common technique for processing cassava starts with the removal of peels, fermentation or grating of the root tubers, followed by hydraulic pressing (dewatering). Three sources of cassava wastewater have been identified and they are water for washing cassava tubers after peeling, water from fermentation of cassava root tubers and extraction after grating (Ugwu & Agunwamba, 2012). The industrial processing of cassava root tubers into garri and starch by factories, generate a lot of wastewater which are discharged directly into the environment, leached into the soil, contaminates surface and underground water (Oladele, 2014). In some cases, ditches are dug around cassava processing plant to channel the wastewater into uncovered ponds. The unpleasant odour emanating from the ponds due to the degradation of cassava wastewater is environmentally unfriendly and endangers human health inhabiting the area (Djuma'ali et al., 2011). Report has it, that cassava wastewater is toxic and poisonous due to its acidity and cyanide content which may stripe the

soil bare of its vegetation and renders it unproductive (Izonfuo et al., 2013). In order to manage, control the pollution of the environment and minimize health hazards caused by cassava wastewater and sought an alternative source of energy, biogas production by anaerobic digestion in a batch reactor became a useful technique in addressing the menace of cassava wastewater. The production of biogas from organic materials in a reactor prevents the uncontrolled emission of methane into the atmosphere, thereby reducing global warming (Ahlberg – Allison et al., 2017;)

1.1: Sources of Cassava Wastewater

Cassava wastewater arises from the processing of cassava root tubers into various products like garri, starch, fufu, lafun, cassava flour, chips and flakes. The industrial processing of cassava root tubers is water intensive, large volume of water is required for garri and starch extraction. Seven major stages have been identified in a small scale production of garri from cassava root tubers. This begins with manual peeling of the cassava root tubers, followed by washing, grating, fermentation, dewatering/squeezing, sieving and toasting. Solid and liquid wastes are generated during cassava processing. The solid wastes comprise of cassava peels, cassava pulp and cassava sievate. While the liquid waste is a pale yellow turbid wastewater extracted from the washing, grinding /grating and dewatering of cassava root tubers (Oboh, 2006).The several unit operations in the processing of cassava root tubers in a traditional small-scale into garri is summarized in the flow charts shown in Figure 1.

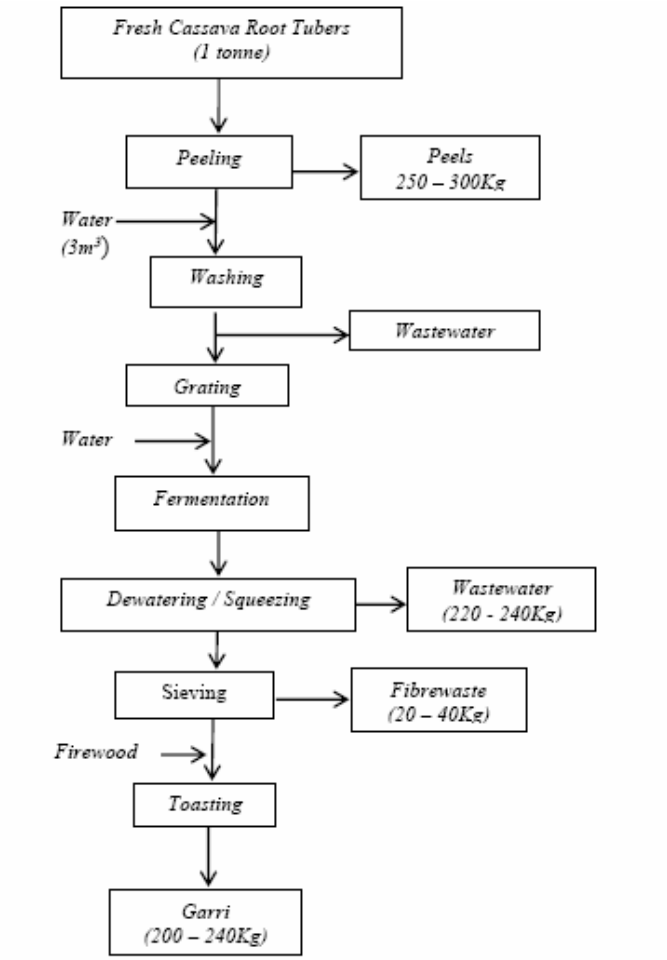

Figure 1: Flowchart for the Production of Garri (FAO, 2013)

1.2: Stages of Anaerobic Digestion

Anaerobic digestion is a biochemical process whereby microorganisms such as bacteria break down organic matter in the absence of oxygen. The anaerobic digestion of cassava wastewater involves four fundamental stages (Yang et al., 2016). These stages are:

- Hydrolysis
- Acidogenesis

- Acetogenesis
- Methanogenesis

Hydrolysis: The hydrolysis of complex organic matter such as carbohydrate, protein, fat and lipids is brought about by extra cellular enzymes. During hydrolysis, water ionizes to release hydrogen ion (H^+) and hydroxyl ion (OH^-). High molecular weight polymer such as carbohydrates, proteins and fats are broken down into smaller molecular weight monomers such as simple sugars, amino acids and fatty acids. These monomers are used by acidogenic bacteria for subsequent action.

$H_2O_{(l)} \leftrightarrow H^+_{(aq)} + OH^-_{(aq)}$ (1)

hydrogen ion hydroxyl ion

$C_{12}H_{22}O_{11} + H_2O \longrightarrow 2C_6H_{12}O_6$ (2)

carbohydrate glucose

Acidogenesis: The second stage of anaerobic digestion is acidogenesis. This is the process whereby acidogenic bacteria convert low molecular weight glucose, amino acid and fatty acid into unstable intermediates such as butyric acid, propionic acid and valeric acid with the release of ammonia and hydrogen sulphide.

$C_6H_{12}O_6 \longrightarrow C_3H_7COOH + 2CO_2 + 2H_2$ (3)

glucose butyric acid

$C_6H_{12}O_6 + 2H_2 \longrightarrow 2C_2H_5COOH + 2H_2O$ (4)

propionic acid

Acetogenesis: The acetogenic bacteria convert the intermediate products (butyric acid, propionic acid and valeric acid) of acidogenesis to acetic acid or ethanol with release of hydrogen and carbon dioxide.

$C_3H_7COOH+2H_2O \longrightarrow 2CH_3COOH + 2H_2$ (5)

acetic acid

$2C_2H_5COOH +2H_2O \longrightarrow 2CH_3COOH + 2CO_2 + 3H_2$ (6)

Methanogenesis: The final stage of anaerobic digestion is methanogenesis. Methane is produced primarily from acetic or ethanoic acid also from hydrogen and carbon dioxide by methanogenic bacteria. Methane production is a slow process and it is generally considered as the rate-limiting step of anaerobic digestion.

$CH_3COOH \longrightarrow CH_4 + CO_2$ (7)

$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$ (8)

methane

The general biochemical equation for anaerobic digestion by bacteria using organic matter as substrate is

Organic matter $+H_2O \xrightarrow{\text{anaerobes}} CH_4 + CO_2 + NH_3 + H_2S$ + New cells + Heat (9)

1.3 Monod Kinetic Model

Organic waste like cassava wastewater inoculated with bacteria could be regarded as a mixed culture for studying anaerobic digestion. The population of the microorganisms feeding on the organic waste could be represented with (X). The rate at which the microorganisms increase is proportion to the initial microbial concentration. Expressing the rate equation as a first–order, gives:

(10)

Where– Microbial growth rate(mg/l/day)

[X] – Microbial concentration (mg/l)

μ – Microbial specific growth rate (day^{-1})

Re-arranging and integrating equation (10) gives:

(11)

Where $[X_0]$ – initial microbial concentration (mg/l)

$[X_t]$ – microbial concentration at time t (mg/l)

Plotting a graph of against (t) gives a straight line with slope equal to and intercept equal to .

Monod identified specific growth rate (μ) of microorganisms as a function of microbial concentration [X] and limiting substrate concentration [Ŝ] (Reynolds and Richards, 1996). An empirical equation relating the specific growth rate and the limiting substrate concentration which is known as Monod equation is expressed in equation (12) below:

(12)

Where μ_{max} – Microbial maximum specific growth rate (mg/l)

[Ŝ] – concentration of limiting substrate

–half velocity constant (mg/l)

Substituting equation (12) into equation (10) gives:

(13)

Equation (13) is the Monod kinetic model.

It was also assumed that the rate at which substrate concentration decreases is proportional to the rate of microbial increase. This assumption is based on, that all the substrates are converted to biomass (Reynolds & Richards, 1996).

(14)

At the stationary phase, the microbial population remains constant, the rate of new cell formation is equal to the rate of death of old cells. In this situation, the substrate is exhausted or there is deficiency in the nutrient. The next phase is the endogenous phase, the microorganisms survive on their own stored energy and consume dead cells. The microorganisms begin to die leading to a decrease in microbial population, expressed by $K_d[X]$.
Where K_d – endogenous decay constant
Relating the decrease in microbial population to the microbial growth rate, equation (13) becomes:

(15)

From equation (11), we have:

(16)

Recalling and linearizing equation (11), we have:

(11)

(17)

Plotting a graph of against will give a straight line with slope equal to and intercept equal to . From the intercept and slope, the values of and half saturation constant (K_s) can be evaluated.

II. MATERIALS AND METHODS

2.1 Materials

The materials used in this studies include a 4litre improvised PVC batch reactor, thermostat water bath, thermometer, digital pH meter, weighing balance, pressure gauge, measuring cylinder, conical flask, pipette, burette, test tubes, NR8082 specie of sweet cassava and potassium hydroxide catalyst.

2.2 Methods

2.2.1 Feed Preparation
The cassava wastewater used for the experiment was obtained from NR8082 specie of sweet cassava from Federal Ministry of Agriculture, Port Harcourt. The cassava tubers were peeled, washed and grated in a cassava milling plant. The grated cassava was packed into knitted polythene bag, followed by hydraulic pressing (dewatering). The wastewater extracted from the grated cassava root tubers constitutes the raw feed for the experiment. The pH of the cassava wastewater was measured immediately and allowed to settle for 24hours by gravity. It was decanted into a 20litre plastic container for experiment at Chemical Analysis Laboratory of Chemical / Petrochemical Engineering Department, Rivers State University, Port Harcourt.
2.2.2 Experiment for Production of Biogas from Anaerobic Digestion of Cassava Wastewater.
A laboratory scale experiment was set up for the biogas production process in a batch reactor under isothermal condition, at a mesophilic temperature of 35^{0}C as shown in Figure 2.

Figure 2: Experimental Set-up for Biogas Production

A 3000ml volume of cassava wastewater weighing 3644g with 5ml of 0.1M aqueous potassium hydroxide catalyst was measured into a 4litre transparent (PVC) batch bio-reactor with a three – holes lid and inoculated with bacterial culture. One of the holes was fitted with mercury-in-glass thermometer and the other holes were fitted with a rubber hose connected to a pressure gauge and gas storage vessel for the biogas produced. The batch bioreactor was made air tight by application of glue and the headspace of the reactor was flushed with nitrogen gas, ensuring the status of anaerobic condition (Abubakar & Ismail, 2012). The pressure gauge had a reference pressure of 720mmHg. The plastic (PVC) batch reactor with its content under anaerobic condition was placed in a thermostat water bath set at a mesophilic temperature of 35^{0}C. The pressure on the gauge was read daily initially after observation of biogas production and at 3days interval. Subsequent readings were made until the pressure drop became insignificant. The volume of biogas produced was estimated from the measured pressure reading using the van der Waal equation (Nelkon & Parker, 1984) expressed as:

(18)

Where P – Absolute pressure (mmHg)
V – Volume of biogas produced (m^3)
n – Numbers of moles of biogas
â& ß - empirical constants
T– Experimental temperature (K)
R – Gas constant (62.364 L mmHg $K^{-1}mol^{-1}$)
Note: Absolute pressure = Gauge pressure+ Atmospheric pressure
The number of moles of biogas produced was obtained from the stoichiometric equation, stated as:

$$C_6H_{10}O_5 + H_2O \xrightarrow{\text{catalyst}} 3CH_4 + 3CO_2 \quad (19)$$

Starch water methane carbon dioxide

2.2.3 Experiment for Determining Cassava Wastewater (Substrate) Concentration
The concentration of cassava wastewater (substrate) was determined relative to the hydrocyanic acid concentration by titration using phenophthalein as indicator. A set of eleven transparent plastic bottles of 350ml capacity were filled with 250ml cassava wastewater and 5ml of 0.1M aqueous potassium hydroxide catalyst. The samples were labeled S_0, S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9 and S_{10}. (Ugwu & Agunwamba, 2012). Sample S_0 was set aside for titration to determine the initial concentration of cassava wastewater, while the remaining ten samples were placed in the thermostat water bath set at a mesophilic temperature of 35^{0}C.

Figure 3: Experimental Set-up for Determining Cassava Wastewater (Substrate) Concentration

The concentration in each reactor was determined at 3days interval by titration with aqueous sodium hydroxide and phenophthalein as indicator. At end point, the phenolphthalein changes from purple to colourless and the volume of cassava wastewater used was read from the burette. The volume of cassava wastewater

(substrate) at end point was used to determine the molar concentration of hydrocyanic acid (Ababio, 2002) using the formula expressed in equation (20)

= (20)

Where M_A – Molarity of acid (M)
M_B – Molarity of base ((M)
V_A – Volume of acid (ml)
V_B – Volume of base (ml)
A – Mole ratio of acid
B – Mole ratio of base
The stoichiometry of the reaction is:

$HCN_{(aq)} + NaOH_{(aq)} \longrightarrow NaCN_{(s)} + H_2O$ (21)

hydrocyanic acid — sodium hydroxide — sodium cyanide — water

2.2.4 Experiment for Determining Microbial Concentration

The cell concentration was determined by serial dilution method using plate count agar (Ben-David & Davidson, 2014). 1ml of bacterial culture was added to a 9ml of cassava wastewater to prepare a 10ml stock. A 5 – fold serial dilution was made with a sterile 1ml pipette.

From the last dilution, a 0.1ml was plated in duplicate unto agar plate, spread with a sterile bent glass rod and incubated for 18 to 24hours at a mesophilic temperature of 35^{0}C.The bacterial colonies were counted and average value used in calculating the colony forming unit per millitre. The formula for calculating the colony forming units per millilitre is:

cfu/ml = (22)

Cell concentration measured in cfu/ml can be converted to mg/l according to the relationship stated by Kim et al. (2012) as follows:

2.04 x 10^{8}cfu/ml = 2.085 mg/ml

III. DEVELOPMENT OF DESIGN EQUATIONS

3.1Design Equation for Batch Reactor Volume

Reactor design begins by writing a material balance with respect to a reactant or product (Levenspiel,1999). Applying the general material balance to cassava wastewater which is the substrate or reactant, we have

Rate of inflow – Rate of outflow – Rate of disappearance = Rate of accumulation (23)

For a batch reactor where no material enters or leaves the reactor during reaction, the first two terms in equation (23) becomes zero.

Rate of disappearance = Rate of accumulation (24)

Rate of disappearance = $(-r_S)V$ (25)

Rate of accumulation = = = (26)

Where N_{so} – Initial number of moles of substrate (mol)
N_{st} – Final number of moles ofsubstrate (mol)
X_A – Fractional conversion

Combining equations (25) and (26), we have

$(-r_S)V = N_{S0}$ (27)

Re-arranging and integrating equation (27) gives

t $=N_{S0}$ (28)

$V = N_{S0}$ (29)

From equation (14), $r_s = r_x$

Then equation (29) becomes:

(30)

Where V_{br} – Volume of batch reactor (m^3)
r_X – Microbial growth rate

Substituting equation (13) into equation (30) gives:

(31)

Equation (31) is simplified as follows:

(32)

In terms of fractional conversion, we have:

(33)

Where – Hydraulic retention time (days)

Equation (33) is the design equation for batch reactor volume.

3.2 Batch Reactor Dimensions and Configuration

Reactor configuration describes the shape of the reactor in relationship with the reactor size parameters. The relationship between the volume of a cylindrical reactor, its length and diameter is stated as follows:

$V_{br} = A_{br} \times H_{br}$ (34)

Where A_{br} – Area of batch reactor (m^2)

H_{br} – Height of batch reactor (m)

But

$A_{br} =$ (35)

(36)

(37)

Substituting equation (33)into equation (37) gives:

(38)

The Height to diameter ratio of a batch reactor is 3:2 (Hysys Operations Guide, 2011) expressed as:

(39)

= (40)

Substituting equation (40) into equation (38) gives:

(41)

Simplifying equation (41), it becomes:

(42)

$^{1/3}$ (43)

From equation (40), the diameter of the batch is given as:

$^{1/3}$ (44)

3.3 Heat Generated per Unit Volume of Batch Reactor

The heat generated per unit volume of batch reactor due to anaerobic digestion of organic waste, from Abowei and Ogoni (1990) is defined by:

(45)

Substituting equation (33) into equation (45) gives:

$^{-1}$ (46)

3.4 Heat Exchanger Dimension for Batch Reactor

The heat transfer from the heating coil to the reactor according to Abowei (1989) is given as:

(47)

Where U – Heat transfer coefficient (J/m^2s^0C)

A – Surface area for heat exchange (m^2)

ΔT – Temperature difference between water and reactor (^0C)

(48)

Substituting equation (46) into equation (48) gives:

$^{-1}$ (49)

The heat transfer surface area is given as:

$A = 2\pi rl_c$ (50)

Where l_c – Length of heating coil (m)

r – Radius of heating coil (m)

Substituting equation (50) into equation (49), gives:

$^{-1}$ (51)

3.5 Cost of Batch Reactor

The capital cost of reactor expressed by Coulson & Richardson (2005) is stated in equation (51) below:

^{f} (52)

Where C_T – Proposed cost of current reactor ($)

C_R – Current cost of already existing reactor at the base year ($)

V_p – Volume of current reactor (m^3)

V_R – Volume of already existing reactor (m^3)

f – index factor

I_P – Cost index of proposed reactor at current year

I_R – Cost index of already existing reactor at the base year

Exchange rate 1US dollar = ₦1500.00 (Nigeria's currency).

For a batch reactor, the capital cost is expressed as:

f (53)

Substituting into equation (33) into equation (53) gives:

(54)

The solution to the integral part of equations (33), (43), (44), (46), (51) and (54) were solved by numerical integration using Simpson's rule. A design algorithm was developed, followed by writing a computer program using MATLAB R2015 and simulated over a range of fractional conversion from 0.1 to o.9.

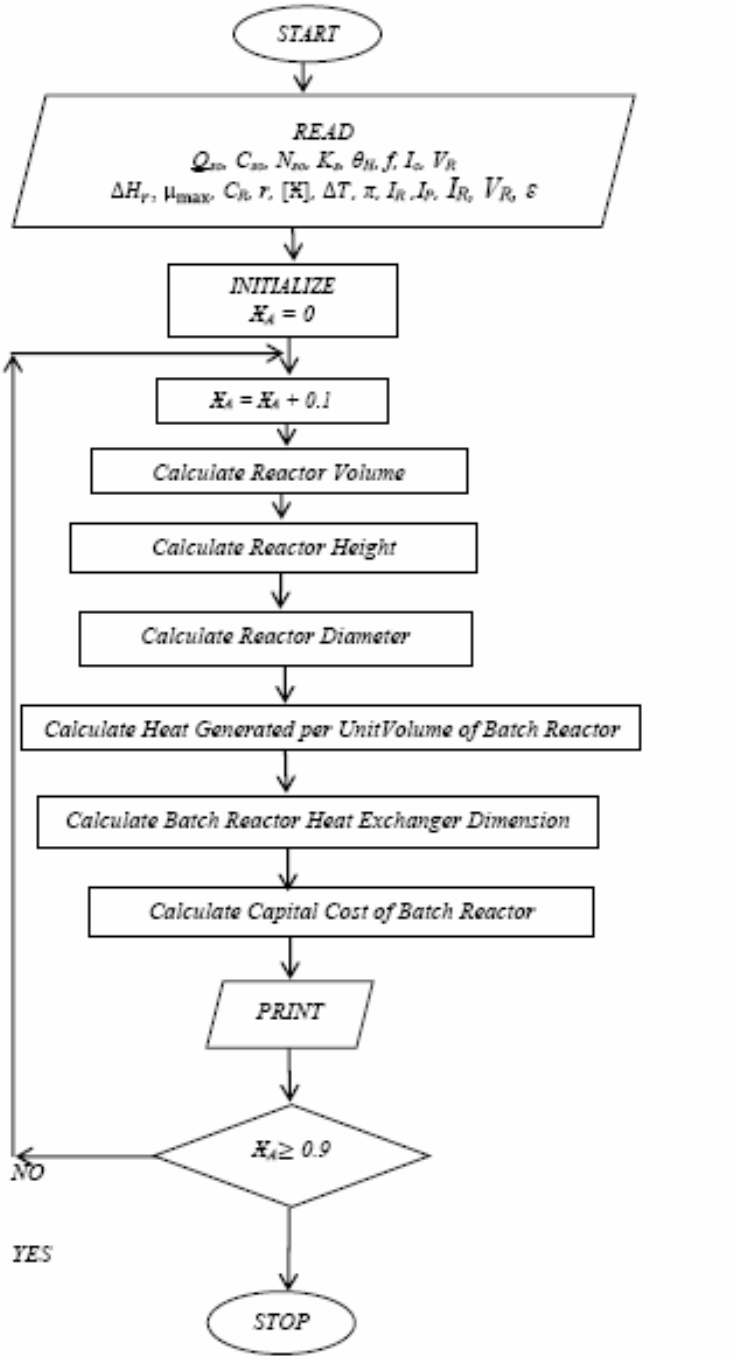

Figure 4: Flowchart for Batch Reactor Design

IV. RESULTS AND DISCUSSION

4.1 Evaluation of Kinetic Parameters

The Monod kinetic model was validated graphically by subjecting the batch experimental data to the appropriate rate equation to obtain the kinetic parameters, shown in Figure 5 below.

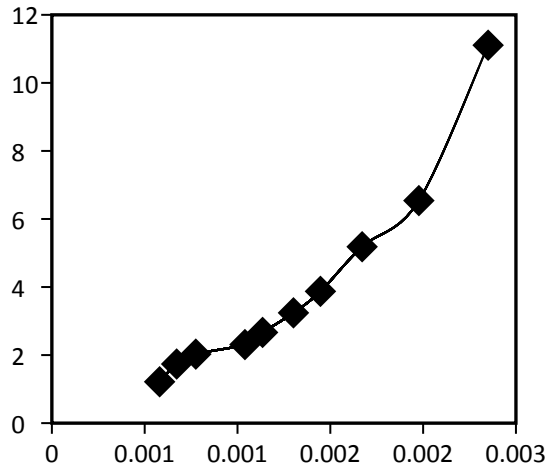

Figure 5: Determination of Microbial Maximum Specific Growth Rate and Half Velocity Constant for Catalytic Anaerobic Digestion

Figure 5 is a variation of with for catalytic anaerobic digestion of cassava wastewater with slope equal to and intercept equal to . The model describing the microbial specific growth rate is expressed in equation (55) with a coefficient of regression: $R^2 = 0.8983$.

$= 4903.4 \quad - 2.3597$ (55)

4.2 Reactor Design and Simulation

The design equations for batch reactor were simulated over a range of fractional conversion (X_A) from 0.1 to 0.9 using MATLAB R2015, a computer aided program. The parameters simulated are batch reactor volume, height, diameter, heat generated per unit volume of reactor, reactor heat exchanger dimension and capital cost of reactor using their appropriate kinetic models.

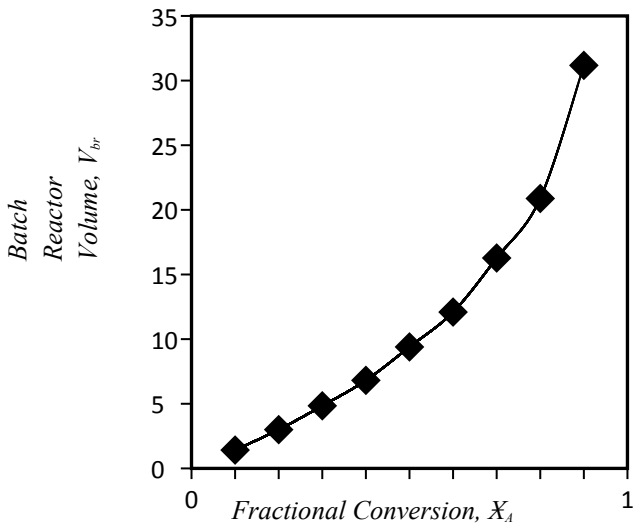

Figure 6: Variation of Batch Reactor Volume against Fractional Conversion

Figure 6 shows the variation of batch reactor volume with fractional conversion for catalytic anaerobic digestion of cassava wastewater. There is an increase in batch reactor volume with increase in fractional conversion, described by equation (56):

$V_{br} = 26.905X_A^{1.349}$ (56)

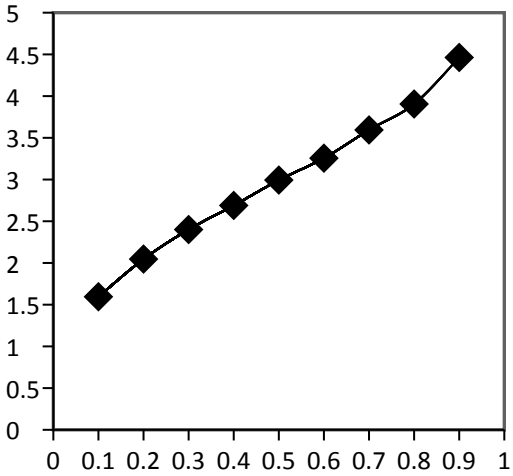

Figure 7: Variation of Batch Reactor Height with Fractional Conversion

Figure 7 shows the variation of batch reactor height with fractional conversion for catalytic anaerobic digestion of cassava wastewater. There is an increase in batch reactor height with increasing fractional conversion, depicted by:

$H_{br} = 3.3338\ X_A + 1.3269$ (57)

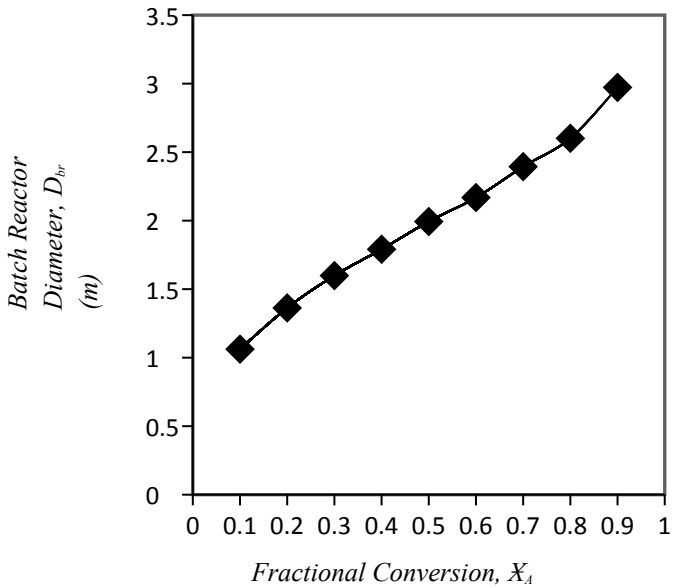

Figure 8: Variation of Batch Reactor Diameter with Fractional Conversion

Figure 8 shows the variation of batch reactor diameter with fractional conversion for catalytic anaerobic digestion of cassava wastewater. There is an increase in batch reactor diameter with increasing fractional conversion, expressed by equation (58) below:

$D_{br} = 2.2203\ X_A + 0.8837$ (58)

Heat Generated per Unit Batch Reactor Volume, q (J/m³)

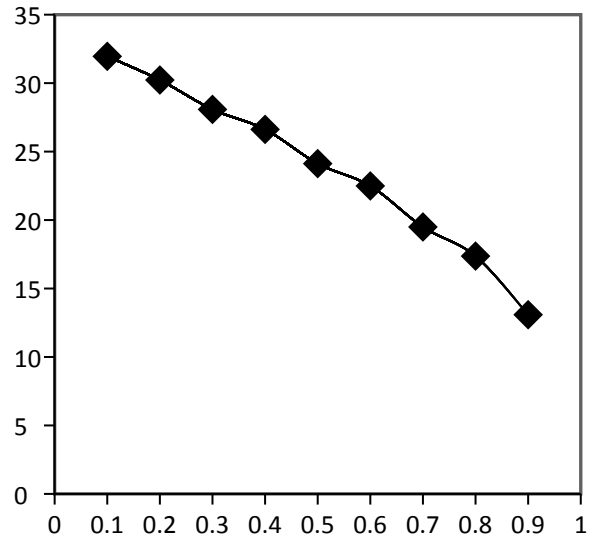

Figure 9: Variation of Heat Generated per Unit Batch Reactor Volume with Fractional Conversion

Figure 9: shows the variation of heat generated per unit batch reactor volume with fractional conversion. There is a decrease in heat generated per unit batch reactor volume with increasing fractional conversion, described by equation (59) below:

$q = -22.56X_A + 34.996$ (59)

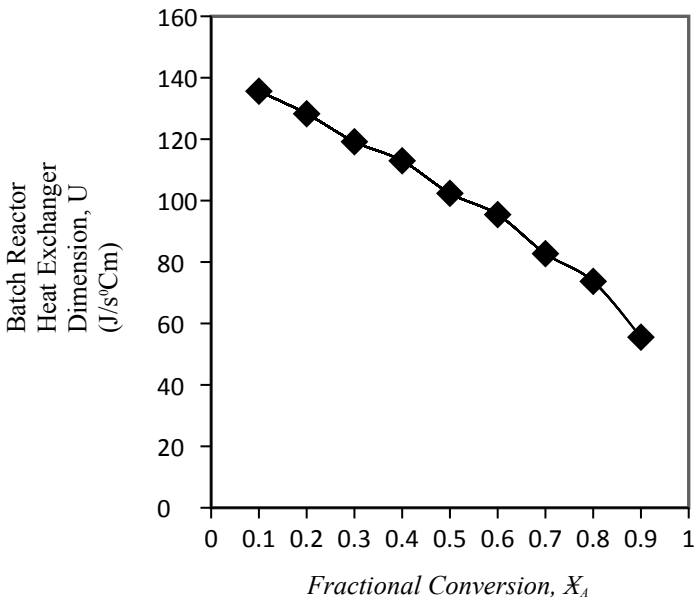

Figure 10: Variation of Batch Reactor Heat Exchanger Dimension with Fractional Conversion

Figure 10 shows the variation of batch reactor heat exchanger dimension with fractional conversion. There is a decrease in batch reactor heat exchanger dimension with increasing fractional conversion expressed by equation (60)

$U = -95.736 X_A + 148.51$ (60)

st of Batch actor CT_{br}(₦) lions

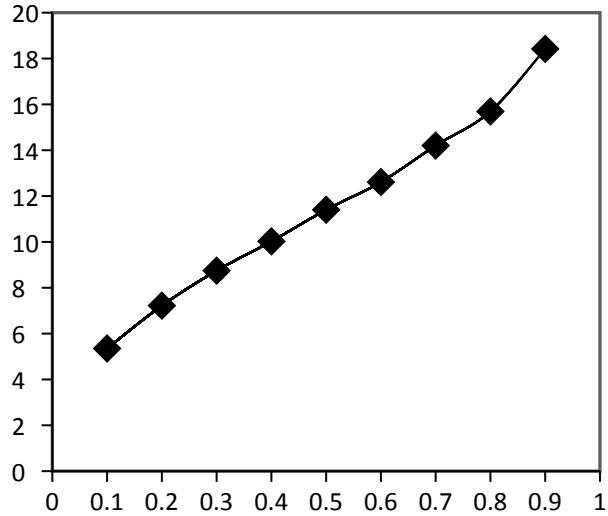

Figure 11: Variation of Cost of Batch Reactor with Fractional

Figure 11 shows the variation of cost of batch reactor with fractional conversion. It depicts an increase in cost of batch reactor with increasing fractional conversion, expressed by equation (61).

$$CT_{br} = 15.198\ X_A + 3.92 \quad (61)$$

V. CONCLUSION

A laboratory scale anaerobic digestion of cassava wastewater for biogas production was performed in a batch reactor. The batch experimental data were subjected to Monod kinetic model and the following were determined; maximum specific growth rate (μ_{max}) of 0.4236 day^{-1}), half velocity constant (K_s) of 2077.9mg/l, microbial yield (Y) of 0.0288mg/mg, endogenous decay constant (K_d) of 0.1367 day^{-1}. The rate constants were used in the development of design models for batch reactor. The model parameters include volume, height, diameter, heat generated per unit volume of reactor, reactor heat exchanger dimension and capital cost of the reactor. A program was written using MATLAB R2015 to solve the model equations and simulated over a range of fractional conversion from 0.1 to 0.9. Simulation results show the dependency of design model parameters on the extent of fractional conversion.

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Table 1: Experimental Results and Process Kinetic Parameters Determination

Sample	θ_H(days)	$[\hat{S}_0]$ (mg/l)	$[\hat{S}_t]$ (mg/l)	$[X_0]$ (mg/l)	$[X_t]$ (mg/l)		$\ln[X_0]$	ln	μ	
S_0	0	2192.4	-	1.584	-	-	0.4599	-	-	-
S_1	3	2192.4	1722.6	1.584	18.70	0.000581	0.4599	2.9285	0.8229	1.2152
S_2	6	2192.4	1487.7	1.584	50.08	0.000672	0.4599	3.9136	0.5756	1.7373
S_3	9	2192.4	1289.8	1.584	134.09	0.000775	0.4599	4.8985	0.4932	2.0276
S_4	12	2192.4	961.5	1.584	286.70	0.001040	0.4599	5.6554	0.4332	2.3084
S_5	15	2192.4	881.0	1.584	439.50	0.001135	0.4599	6.0856	0.3751	2.6659
S_6	18	2192.4	768.4	1.584	408.70	0.001301	0.4599	6.0132	0.3085	3.2415
S_7	21	2192.4	691.2	1.584	358.60	0.001447	0.4599	5.8822	0.2582	3.8730
S_8	24	2192.4	598.3	1.584	162.50	0.001671	0.4599	5.0907	0.1929	5.1840
S_9	27	2192.4	505.8	1.584	98.30	0.001973	0.4599	4.5880	0.1529	6.5402
S_{10}	30	2192.4	425.5	1.584	23.59	0.002350	0.4599	3.1608	0.0900	11.111

Table 2: Simulation Results for Batch Reactor

X_A	V_{br} (m^3)	H_{br}(m)	D_{br}(m)	q(J/m^3)	U(J/s^0Cm)	CT_{br}(₦) Million
0.1	1.4185	1.5950	1.0622	31.354	135.609	5.35188
0.2	2.9990	2.0466	1.3630	30.227	128.272	7.22073
0.3	4.8426	2.4006	1.5988	28.081	119.163	8.74607
0.4	6.8113	2.6894	1.7912	26.620	112.963	10.02470
0.5	9.3957	2.9935	1.9935	24.122	102.363	11.40125
0.6	12.0923	3.2560	2.1684	22.491	95.443	12.61201
0.7	16.2756	3.5944	2.3939	19.495	82.729	14.20358
0.8	20.8789	3.9053	2.6009	17.368	73.703	15.69146
0.9	31.1761	4.4631	2.9724	13.086	55.529	15.69146