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EFFECT OF INOCULUM TO SUBSTRATE RATIO ON BIOGAS PRODUCTION FROM DIGESTED GOAT PAUNCH MANURE

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Abstract
In this study goat paunch manure (GPM) was anaerobically digested under mesophilic condition to determine its biogas potential. Inoculum to substrate (I/S) ratios of 1.45, 2.2 and 4.3 were digested in biodigesters labeled R15, R10 and R5 respectively to determine the effect of substrate concentration on biogas production rates and accumulation. Biogas production accumulation was simulated using first order exponential rise and modified Gompertz equations. Results showed that I/S ratio had no significant effect on biogas production rate. Biogas production rate increased to the peak in the order of R10 (0.08856 $Nm^3kg^{-1}VSd^{-1}$), R5 (0.07653 $Nm^3kg^{-1}VSd^{-1}$) and R15 (0.05824 $Nm^3kg^{-1}VSd^{-1}$) on 10^{th}, 9^{th} and 2^{nd} day and decreased to zero on 30^{th}, 29^{th} and 30^{th} day of the digestion period, respectively. Biogas production accumulation increased from 0.44273 to 1.00783 $Nm^3kg^{-1}VS$ with I/S ratio increase. Coefficient of determination (R^2) of the first order exponential rise regression ranged from 0.9602 to 0.9895, while R^2 for modified Gompertz ranged from 0.9983 to 0.9992 showing better simulation of biogas production accumulation.

Keywords: GPM, anaerobic digestion, I/S ratio, biogas production rate and accumulation, simulation

1. Introduction

Goat paunch manure (GPM) is one of the wastes generated from animal slaughter house. The putrescible nature of this manure constitutes a serious environmental problem. Although GPM has been utilized as manure, the cost of handling and transporting this manure to farm is a factor limiting its applicability. Land filling and incineration are not usually practiced in North Eastern Nigeria. The common traditional method for managing this waste is open discharge. This method often leads to land and air pollution on short term basis and underground water contamination on long term basis. Therefore, it is important to find an environmental friendly, efficient and cost effective alternative to manage this waste. Anaerobic digestion of waste materials from agro-processing industries such as animal slaughter house, animal rising and agricultural crops has been utilized not only to manage these wastes but also to generate energy from them.

Anaerobic digestion occurs when organic material is converted biologically in the absence of oxygen to gaseous product called biogas (Angelidaki, 2002). Studies on anaerobic digestion process of several organic residues/wastes have led to the understanding of their inherent conversion potentials and kinetics that resulted to design, development and process control and optimization of biodigesters. Thus, knowledge of biogas potential and conversion kinetics of GPM would be imperative.

Researches to determine biogas potential of several substrates have been conducted for similar purpose. Buswell and Mueller (1952), Baserga (1998) and Raposo *et al.* (2011) proposed empirical relationship that utilizes the elemental or organic chemical compositions of biomass to estimate its theoretical maximum biogas yield. Researchers (Chynoweth *et al.*, 1993; Hansen *et al.*, 2004; Wymyslowski *et al.*, 2010; Feng *et al.*, 2013; Monch-Tegeder *et al.*, 2013; Zhang *et al.*, 2013) have investigated the biochemical methane potential of several substrates and co-substrates using batch method. They determined physicochemical compositions of substrate and developed anaerobic assay for biogas production. The effects of operating parameters on biogas potential have been investigated. Other researchers (Chynoweth *et al.*, 1993; Labatut and Scott, 2008; Feng *et al.*, 2013; Kheiredine *et al.*, 2014) investigated the influence of inoculum to substrate ratio by varying the amount of substrate added to inoculum. The effect of temperature and pH were also investigated (Hashimoto et al., 1981). The optimum pH for anaerobic digestion is between 7 and 8 (Angelidaki, 2002). Studies on modeling of biogas production accumulation and conversion kinetics of several substrates have been conducted (Raghunathan *et al.*, 2008; Yusuf *et al.*, 2011; Adiga *et al.*, 2012; Feng *et al.*, 2013) and results showed that substrates different have different potential and conversion kinetics. The objectives of this study were to evaluate the effect of inoculum to substrate ratio on biogas production of goat paunch manure (GPM) under mesophilic condition (35^{o}C) and to simulate the biogas production accumulation.

2. Materials and Methods

2.1 Sample Collection, Conditioning and Characterization

2.1.1 Inoculum

For the purpose of this study cow dung was used as inoculum. Sample of fresh cow dung, 2 kg, were collected at the Animal Farm, University of Maiduguri, Maiduguri, Nigeria and taken to Agricultural and Environmental Resources Engineering Laboratory of the institution for experiments. In order to adapt the inoculums to mesophilic condition, the cow dung was diluted in distilled water to 10% dry matter (DM) and transferred into a 4 liter glass bottle. The headspace of the 4 liter glass bottle was flushed with a gas mixture of 80% N_2 and 20% CO_2 for 30 seconds and closed with a thick rubber septum which was held tight by a resin. The inoculum solution was then incubated in a water bath at 35±1^{o}C. During incubation, the inoculum solution was degassed completely by allowing gas build-up in the headspace to escape via a valve controlled tube.

2.1.2 Substrate

Exactly 2 kg of fresh GPM was collected at animal slaughter house, Maiduguri. Sample collected was stored over ice and delivered to the laboratory for experiment and analysis. Sub-sample of GPM was collected and diluted to 15%, 10% and 5% (DM) and transferred separately into 2 liter glass bottles and stored at 5^{o}C. The dilution to 15%, 10% and 5% involved dissolving 100 g of GPM respectively with 16 g, 74 g, and 330 g water.

2.1.3 Nutrient medium

A nutrient medium containing the following groups of nutrients and vitamins was prepared:

a. NaCl, $MgCl_2.6H_2O$, $CaCl.2H_2O$
b. $FeCl_2.4H_2O$, $ZnCl_2$, $MnCl_2.4H_2O$, $(NH_4)_6Mo_7O_{24}$
c. Folic acid and riboflavin

Medium nutrient was added to the digester in order to be a source of micronutrients, growth factor vitamins and trace metal necessary for growth of microorganisms and to serve as a pH buffer agent (Angelidaki, 2002). Stock solutions were prepared based on the recommendation of Angelidaki (2002). This involves dissolving certain quantities (g) of the chemicals in group a, b and c separately in one liter of distilled water. Samples of 10, 1 and 1 ml were respectively collected from stock solutions a, b and c, and then added to 988 ml distilled water to obtain a nutrient medium used for the experiment.

2.2 Physicochemical Composition Analysis

Fresh samples of the inoculum and GPM were analyzed for total solids (TS) and volatile solids (VS) contents according to the standard method of American Public Health Association (APHA, 1992). TS was determined by oven drying sample at 95^oC until weight was constant and subsequent oven drying TS for 1 hour at approximately 550^oC to determine proportion of matter lost in the dried sample. To determine the carbohydrate, crude protein, crude fat, crude fiber and ash content, GPM samples were analyzed at Soil Science laboratory, University of Maiduguri.

2.3 Batch Digestion Test

2.3.1 Batch digestion unit

The batch unit consisted of the following equipment:

- A biodigester unit comprises of 250 ml glass bottle and a thick rubber septum with a flexible rubber tube fixed on the rubber septum through an opening.
- A thermostatically controlled water bath with a plastic rack used for agitating and support biodigesters.
- A 100 and 10 ml plastic syringe and gas pressure gauge
- 80% N_2 and 20% CO_2 gas mixture.

2.3.2 Experimental procedure

In the experiment, 60 ml of the degassed inoculum (10% DM) was collected after shaking using 100 ml plastic syringe and transferred into a biodigester unit. Using the 10 ml and 100 ml plastic syringes, 1 ml of nutrient medium and 30 ml of a GPM substrate solution were collected and added to the biodigester unit containing the inoculum. The setup was prepared in 3 biodigesters labeled R15, R10 and R5 to contain inoculum to substrate (I/S) ratio of 1.45, 2.2 and 4.3 respectively, and a control (biodigester containing only inoculum). Biodigesters were flushed with 80% N_2 and 20% CO_2 gas mixture and transferred into water bath preset at 35 ± 1^oC (mesophilic condition). The entire biodigester units were agitated twice a day. Biogas produced was measured using gas pressure gauge twice daily at the initial stage and once daily toward the final stage of the process until no more biogas was produced. After every measurement of biogas accumulation over time biogas was allowed to escape in order to avoid pressure build up that would exceed pressure gauge capacity. This experiment was replicated 3 times and average was reported as biogas production.

2.4 Simulation of Biogas Production Accumulation

The experimental data of biogas production accumulation was simulated using the first order exponential rise and modified Gompertz equations given as equations (1) and (2) respectively

$$B = B_O\,(1 - \exp(-k\times t)) \quad (1)$$

$$B = B_O\times\exp\{-\exp[(R_m\times e/B_O)(L_t - t) + 1]\} \quad (2)$$

where: B is biogas production accumulation ($Nm^3\ kg^{-1}$ VS) at time (day), t is digestion period (days), B_O is maximum biogas production ($Nm^3\ kg^{-1}$ VS), k is first order kinetic constant, R_m is maximum biogas production rate ($Nm^3\ kg^{-1}$ VS d^{-1}), L_t duration (days) of lag phase and e is equal to 2.718282.

2.5 Statistical analysis

Simple descriptive statistical analysis was used to report averages and standard deviations of experimental data. Completely Randomized Design was used to investigate the effect of I/S ratio. ANOVA test was used to verify if there was significant difference on biogas production rate and accumulation. Statistix version 9 software was used to determine equation parameters while Microsoft excel was used to plot graphs.

3. Results and Discussion

3.1 Characteristics of GPM and Inoculum

The physicochemical composition of GPM and inoculum determined are presented in Table 1. The ash content of GPM was 18% which resulted to a relatively higher VS/TS ratio of 82%. This VS/TS ratio indicates that GPM has high organic composition and could be a suitable substrate for anaerobic digestion. The pH level of GPM was within optimum performance of anaerobic digestion process.

Table 1: Physicochemical compositions of SPM and inoculum

	Moisture content (%)	Total solids% (w.b)	Volatile solids% (w.b)	VS/TS ratio	pH	Carbohydrate% (TS)	Crude protein% (TS)	Crude fat% (TS)	Crude fiber% (TS)	Ash% (TS)
GPM	82.6(3.17)	17.2(0.76)	14.1(2.59)	0.82	7.6 (0.18)	38.9 (1.87)	12.1(0.89)	2(0.21)	26 (2.00)	18(0.99)
Inoculum	24.04 (3.13)	75.9(3.51)	67.6 (4.67)	0.89	ND*	ND	ND	ND	ND	ND

- ND means not determined

3.2 Biogas Production Rate and Accumulation

Experimental result showed no biogas produced from controlled biodigester over the digestion period. Figure 1 (a) and (b) presents GPM biogas production rate and accumulation plots respectively. The results showed that it took R15, R10 and R5 biodigesters 30, 29 and 30 days respectively to complete digestion. It can be observed from Figure 1 (a) that the biogas production rates were highly unstable, where R5 biodigester exhibited the maximum instability rate followed by R10 and then R15 biodigesters. This instability could be due to high biomass concentration. The peak (maximum) biogas production rate occurred in the order of R10 (0.08856 $Nm^3\ kg^{-1}\ VS\ d^{-1}$), R5 (0.07653 $Nm^3\ kg^{-1}\ VS\ d^{-1}$) and R15 (0.05824 $Nm^3\ kg^{-1}\ VS\ d^{-1}$), on the 10th, 9th and 2nd day of digestion period, respectively. Total accumulated biogas over digestion period was found to be in the order of 1.00783, 0.84903 and 0.44273 $Nm^3\ kg^{-1}$ VS in R5, R10 and R15 biodigesters respectively ($p=0.0074$). Raghunathan et al., (2008) reported similar biogas production accumulation values (0.382 to 1.1 $Nm^3\ kg^{-1}$ VS). Experimental results showed that 80% of total biogas production yield in R15, R10 and R5 biodigesters had accumulated on the 14th, 17th and 19th day of digestion period respectively.

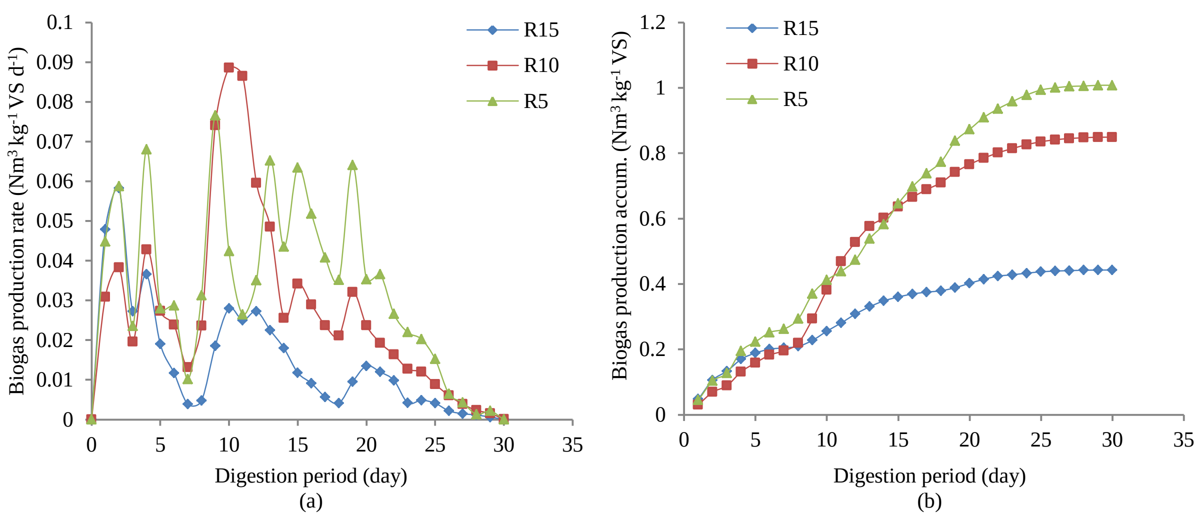

Figure 1: Biogas production rate (a) and accumulation (b) in R15, R10 and R5 biodigesters

3.3 Kinetic Parameters of Biogas Production Accumulation Simulation

First order exponential rise and modified Gompertz regression curves fitted into experimental data of biogas production accumulation in R15, R10 and R5 biodigesters are presented in Figures 2 and 3. Table 2 presents the estimated biogas production accumulation values and kinetic parameters of first order exponential rise and modified Gompertz equations in R15, R10 and R5 biodigesters. It can be seen that first order kinetic constant (k values) decreased as I/S ratio increased. However the estimated biogas production accumulation increased as I/S ratio increased. For modified Gompertz parameters, maximum daily biogas production rates are in the order of 0.0555, 0.0495 and 0.022 $Nm^3\ kg^{-1}\ VS\ d^{-1}$ in R10, R5 and R15 biodigesters respectively. Estimated biogas production accumulation showed increase as I/S ratio increased.

Table 2: Experimental biogas production potential and kinetic parameters of first order kinetic and modified Gompertz equations

		First order kinetic equation				Modified Gompertz equation			
Biodigester	I/S ratio	BPA ($Nm^3kg^{-1}VS$)	Bo ($Nm^3kg^{-1}VS$)	k (d^{-1})	R^2	Bo ($Nm^3kg^{-1}VS$)	Rm ($Nm^3kg^{-1}VSd^{-1}$)	Lt (day)	R^2
R15	1.45	0.1208	0.4941	0.0829	0.9837	0.4705	0.022	-2.5	0.9992
R10	2.2	0.2316	1.455	0.0339	0.9602	0.8857	0.0555	2.9	0.9983
R5	4.3	0.2749	2.3635	0.021	0.9895	1.1706	0.0495	1.6	0.9983

Coefficient of determination (R^2) values of first order exponential rise equation ranged from 0.9602 to 0.9895, while R^2 of modified Gompertz equation ranged from 0.9983 to 0.992 showing slightly better simulation than those of first order exponential rise equation.

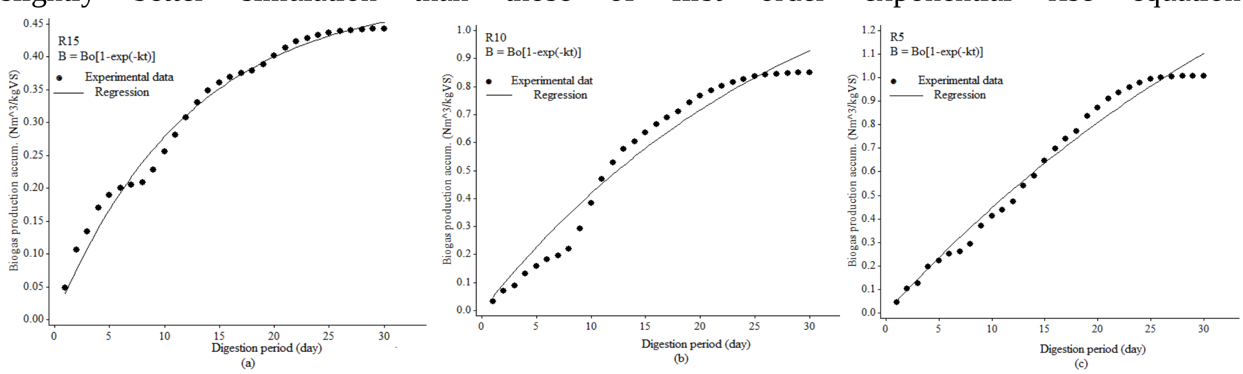

Figure 2: First order kinetic curve fitted into experimental data of biogas production accumulation in R15, R10 and R5 biodigesters

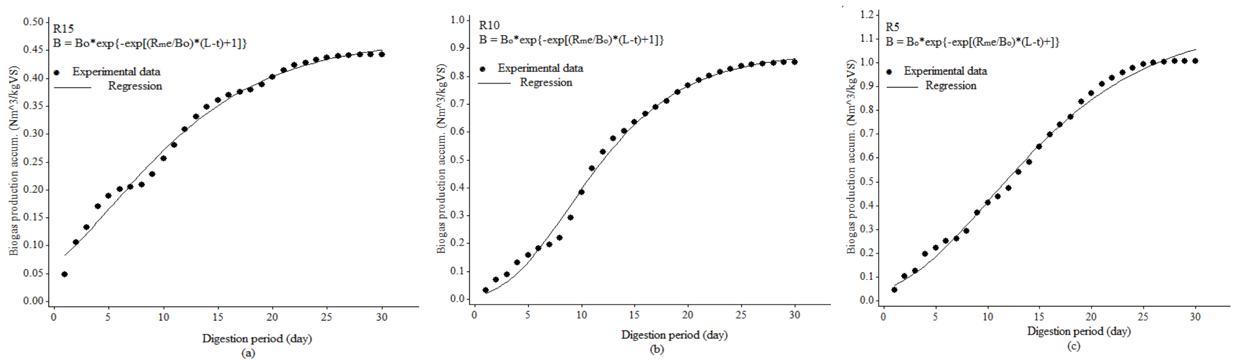

Figure 3: Modified Gompertz curve fitted into experimental data of biogas production accumulation in R15, R10 and R5 biodigesters

4. Conclusion

Biogas production rates of GPM were highly unstable as I/S ratio increased from 1.45 to 4.3 and showed no significant difference at higher I/S ratios. I/S ratio showed significant effect on biogas production accumulation where biogas production accumulation increased from 0.4427 to 1.00783 $Nm^3kg^{-1}VS$ with I/S ratio increase. Modified Gompertz regression of experimental data showed better simulation of biogas production accumulation than first order kinetic regression.

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