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Design, Development and Evaluation of Slaughterhouse Anaerobic Digestion Plant Model

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ABSTRACT: *While extensive researches have been and are being carried out on biogas production from cow dung from abattoirs, the need to design, develop and evaluate a biogas plant specifically for the treatment of abattoir waste, production of biogas and compost materials has not received the attention of researchers. It was for this reason that this was explored in this study. An abattoir biogas plant model comprising of a 2.5 m3 equalization tank, 2.5m3 digester, 0.7m3 gasholder and 2.5 m3 digestate collection tank as well other appurtenances was developed and evaluated. The Modified gompertz model was used to describe the cumulative production. The total biogas produced was 0.61m^3 while the maximum biogas potential was 0.771m^3. The maximum biogas production was 0.037 m^3/day while the lag phase was 10.53 days implying that it took the microorganisms more than 10 days to acclimatize and begin active digestion for biogas production. The parameters obtained would provide useful information for the eventual development of the prototype abattoir biogas plant.*

Keywords: *Abattoir waste, anaerobic digester, Biofertilizer, Biogas, Compost*

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I. INTRODUCTION

The inadequacy of energy has been recognized over the years to be a major factor limiting economic growth, restricting socio-economic activities and adversely affecting the quality of life in developing economies [1]. This buttresses the fact that energy is a major necessity for the existence of humans [2]. There has been a consistent and progressive exploration by various nations of the world for safer and cleaner sources of fuel that will be an alternative to the current fuels of fossil origin which have been identified to have negative impact on humans and the eco-system [3]. This paradigm shift becomes imperative as the high cost of the current sources and its attendant contribution to climate change have become unthinkable.

There is a consensus among stakeholders that adequate exploration and exploitation of alternative and renewable energy will be a step in the right direction towards the attainment of the Sustainable Development Goals [4,5]. The challenge however is not the awareness of the possibilities of meeting the global energy needs with this alternative and renewable energy but the optimization of the processes that can lead to their easy implementation. One of this is the design of the anaerobic digesters; an airtight reactor that allows the conversion of biomass to biogas (predominantly methane and digestate with great biofertilizer potentials. Previous researches have also been able to establish the capability of the biogas reactors to significantly reduce the microbial load of the substrates especially animal waste which makes the digestate safer biofertilizers compared to the undigested dung [6].

Extensive researches on biogas production from cow dung often obtained from abattoirs have been carried out by various researchers especially in developing economies such as Nigeria [1,2,7-10]. This notwithstanding, the design and evaluation of an anaerobic digestion plant model specifically for an abattoir capable of being replicated in others seem to be non-existent. While exploration for other treatment options are being made for different municipality, it is imperative that an attempt be made at considering biogas reactor which will not only serve as a waste management option for the abattoir but a source of energy for households and biofertilizer for farmers. It is for this reason that this study was carried out to design, develop and evaluate an anaerobic digestion plant model for the treatment of abattoir waste as well the production of biogas and biofertilizer.

II. MATERIALS AND METHODS

2.1 Design of anaerobic digestion system

The design of the anaerobic digester body, equalization tank, the gas collection systems comprising of the gasholder, water jacket, guide frame and gas pipe, and liquid fertilizer (digestate) collection tank are presented in Tables 1 – 4, respectively. The Design calculations of all the components were done using Microsoft Office Excel® 2007. The design was carried out for one cattle as a model for the evaluation of its biogas and biofertilizer potentials so as to provide basis for its replication depending on the number of cattle slaughtered per day in the respective slaughterhouse.

Table 1: *Design of Digester Body*

Input	Calculation	Result
No of cows =1 Av. Mass of paunch/cow =34kg/day W_p=34kg/day Ts=16% of Paunch Mass TS=5.44kg/day TS=7.5% of Substrates Mass, Q (Momoh et al. (2013) Q = 72.53kg Q = 72.53kg HRT = 30 days Take density of slurry = 1000 kg/m^3 V_o =90% V_T V_o = 2.2m^3 V_T = 2.5m^3 Take height = 4 x radius r_d = 0.23m	Total Mass of paunch (W_p) =1x34kg Total solids (TS)=16% of Paunch weight TS = 0.16 x 34kg=5.44kg Q = TS/0.075 = 5.44/0.075=72.53333kg Mass of water, Mw = 72.53-34 = 38.53kg Operating Volume of digester, V_o =Q x HRT V_o =72.53 x 30/1000kg/m^3 = 2.1759m^3 Total Volume, V_T = V_o/0.09 = 2.44444m^3 Total Vol., V_T=пr^2_d h_d radius, r_d = [(V_T/п)$^{1/3}$]/4 = 0.231670136m Diameter, d_d = 2 x 0.23 = 0.46m Height, h_d = 4 x 0.23 = 0.92m	M_p=34kg TS = 5.44kg Q = 72.53kg Mw =38.53kg V_o = 2.2m^3 V_T = 2.5m^3 Take r_d = 0.23m Take d_d = 0.50m Take h_d = 1.0m

Table 2: *Design of Equalization Tank*

Input	Calculation	Result
V_o = 2.2m^3 Give 10% allowance for mixing V_e =2.5m^3 Take height = radius r_e = 0.93m	Volume of equalization tank, V_e = V_o + (0.1xV_o) = 2.2 +(0.1 x 2.2) = 2.42m^3 V_e=пr^2_e h_e radius, r_e = [(V_e/п)$^{1/3}$] = 0.926680545m Diameter, d_e = 2 x 0.93 = 1.86m Height, h_e = 1 x 0.93 = 0.93m	Take V_e = 2.5m^3 Take r_e = 0.93m Take d_e =1.9m Take h_e = 1.0m

Table 3: *Design of Gas collection system*

Input	Calculation	Result
	Design of Gas Holder	
volume of gas /kg of cow dung/day =0.000616m^3 V_g =0.62832m^3 Give 10% allowance V_{gh} =0.7m^3 Take height = 4 x radius r_{gh} = 0.15m	Total Volume gas, V_g=0.000616*30x34=0.62832m^3 Total Vol of gasholder, V_{gh}=V_g+(0.1*V_g) V_{gh}=0.62832 + (0.1 x 0.62832)=0.691152 V_{gh}=пr$^2_{gh}$ h_{gh} radius, r_{gh} = [(V_{gh}/п)$^{1/3}$]/4 = 0.15156176m Diameter, d_{gh} = 2 x 0.15 = 0.30m Height, h_{gh} = 4 x 0.15 = 0.60m	V_g =0.62832m^3 Take V_{gh} =0.7m^3 Take r_{gh} = 0.15m Take d_{gh} =0.30m Take h_{gh} = 0.60m
	Design of Water Jacket	

d_{gh} =0.30m	Diameter of water jacket, $d_j = d_{gh} + 2c$ where c = clearance on both sides Take c = 2cm Therefore, $d_j = 0.3 + 2 \times 0.01 = 0.32$m Diameter of water jacket, $d_j = d_{gh} = 0.60$m	Take d_j =0.32m Take h_j = 0.60m
	Design of Guide frame	
allowance, a = 0.01m L_f = 0.59m d = 0.1m	Length of guide frame, $L_f = h_{gh}$-a = 0.6-0.01 = 0.59m Maximum displacement, $d_{max} = L_f$-d = 0.59 - 0.1 = 0.49m	L_f = 0.59m d_{max} = 0.49m
	Design of Gas Pipe	
volume of gas /kg of cow dung/day =0.000616m^3 Daily gas prod = 0.021m^3 Take pipe length, L= 2m Gas prod/minute = 1.46E-05m^3	Total Volume gas/day =0.000616*x34=0.0.020944m^3 Gas production/minute (g_m) = 0.021/(24*60) = 1.4833E-05m^3 Pipe diameter, $d_{pipe} = (gm/(\pi L)^{1/2}$	Daily gas prod = 0.021m^3 Gas prod/minute = 1.46E-05m^3 d_{pipe} = 0.012m d_{pipe} = 0.63 inches Take d_{pipe} = 1.0 inch

***Table 4:** Design of Digestate Collection Tank*

Input	Calculation	Result
$V_o = 2.2m^3$	Volume of collection tank, $V_c = V_o + (0.1xV_o)$ = 2.2 +(0.1 x 2.2) = 2.42m^3	Take $V_c = 2.5m^3$
Give 10% allowance for mixing		
V_c =2.5m^3	$V_c = \pi r^2_c h_c$	
Take height = 1.5 x radius	radius, $r_c = [(V_c/\pi)^{1/3}]/1.5 = 0.61778703$m	Take r_c = 0.62m
r_c = 0.62m	Diameter, d_c = 2 x 0.62 = 1.24m	Take d_c =1.25m
	Height, h_e = 1.5 x 0.62 = 0.93m	Take h_e = 1.0m

The fabrication of the digester, gas collection system, equalization tank and digestate (liquid fertilizer) collection tank was carried out at the mechanical workshop of the Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaria using locally available materials. Galvanized steel was used as building material for all components because of its strength and durability in acidic or basic environment. Five different holes were bored on the lid of the digester for insertion of temperature and pH probes using threaded steel adapters and rubber stoppers to avoid gas leakage. The cylindrical shape was adopted to enhance better mixing. A flow diagram of the anaerobic digestion system is presented in Fig. 1.

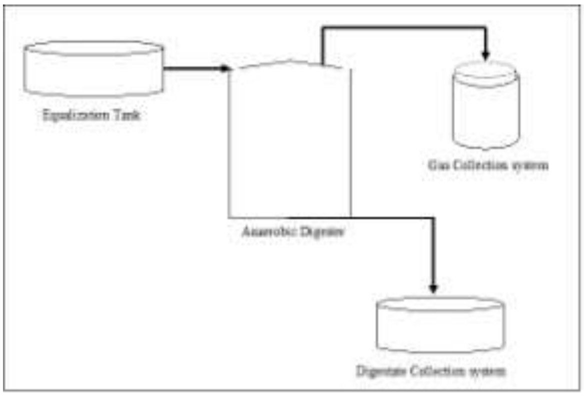

Fig. 1: Process diagram of the Slaughter house Anaerobic Digestion System

2.2 Sample Collection and Experimental Procedure

The abattoir biogas plant model developed was used to digest cattle paunch of a cow slaughter at the Zaria abattoir. The complete paunch evacuated from the rumen of the cow were collected in sacks and transported to the research ground in the Department of Water Resources and Environmental Engineering, Ahmadu Bello University, Zaria. All organic materials were immediately sorted and removed. In accordance with the design specifications, the paunch was mixed with water (1/1 by weight) in the equalization tank to form slurry. After thorough mixing for near homogeneity, the slurry was fed into the digester to fill 80% of its volume leaving 20% for gas production. All they valves were open before feeding the digester with the slurry to prevent negative pressure build up. A batch anaerobic digestion was carried out for a retention period of 30 days under mesophilic conditions. The choice of the mesophilic digestion over the thermophilic one was informed by its tolerance for most nitrogen fixing and phosphate-solubilizing microorganisms [4]. A sample of the biogas produced was collected and taken for analysis using gas chromatography at Landmark University, Umu Aran, Nigeria.

In other to obtain parameters such as lag phase and maximum biogas obtainable that will be useful for design and process optimization of the eventual prototype abattoir biogas plant, the modified Gompertz model (eqn. 1) was used to describe the cumulative biogas production.

$$Y(t) = A\exp\left[-\exp\left(\frac{\mu \times e}{A}(\lambda - t) + 1\right)\right] \qquad (1)$$

Where *Y(t)* is the cumulative of biogas produced (m^3) at any time (t), *A* is biogas production potential (m^3), μ is the maximum biogas production rate (m^3/day), λ *is* the lag phase period (days), which is the minimum time taken to produce biogas or time taken for bacteria to acclimatize to the environment, *t* is cumulative time for biogas production (days) and *e* is mathematical constant (2.718282) [11,12]

The method of determination of the constants A, μ and λ have been described previously in Alfa *et al*. [13].

III. RESULTS AND DISCUSSIONS

The result of the modified Gompertz model description of the biogas production potentials from the cattle paunch digested using the developed plant model is shown in Table 5.

Table 5: Results of the Modeling of the Cumulative Biogas Production with the Modified Gompertz Model

Total Volume of Biogas Produced (m^3)	Biogas Production Potential A (m^3)	Maximum Biogas production rate μ (m^3/day)	Lag phase □ (days)	Sum of Square Error (SSE)	Coefficient of Determination (R^2)	Methane content (%)
0.61028	0.771	0.037	10.525	0.003	0.908	62.98

The total volume of biogas produced over the retention period of 30 days was 0.6108 m^3 while the biogas production potential as estimated by the modified gompertz model is 0.771. This means that at the time the experiment was truncated, there was still about 0.1602 m^3 of biogas yet to be produced. The results on Table 5 also shows that the maximum biogas production rate was 0.037 per day implying that a total of 20.84 active digestion days (0.771/0.037) are required to exploit the full potential of the cattle paunch for biogas production. Although the retention time was 30 days, the lag phase of 10.53 days obtained shows that the active digestion took place for only 19.47 (30-10.53) days implying that an additional 1.37 days on the retention period would lead to full exploitation of the biogas potentials. The coefficient of determination of 0.908 obtained validates the reliability of this result. Meanwhile, the methane content of the biogas produced was 62.98 % which makes it comparable to previous studies [3,4].

Another implication of the biogas potential of 0.771 m^3 estimated by the model is that the 7m^3 volume of gasholder may not be sufficient at full potential. A redesign of the gasholder is therefore necessary using the maximum biogas potential rather than the total volume produced.

IV. CONCLUSIONS

An abattoir biogas plant model comprising of a 2.5 m^3 equalization tank, 2.5m^3 digester, 0.7m^3 gasholder and 2.5 m^3 digestate collection tank as well other appurtenances was developed and tested. The model with the modified gompertz model helped to estimate the maximum biogas potential at 0.771 m^3. It took the microorganisms more than 10 days to acclimatize and begin active digestion for biogas production. These parameters provide useful information for the eventual development of the prototype abattoir biogas plant. Finally, the design of gas collection system should be done using the maximum biogas potential rather that the total biogas produce as this can lead to the estimation of lesser volume.

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