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DESIGN, CONSTRUCTION AND TESTING OF A BIOGAS REACTOR FOR PRODUCTION OF BIOGAS USING CASSAVA PEEL AND COW DUNG AS BIOMASS

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Abstract

Cassava peel and cow dung have constituted to global warming worldwide because it constitutes heaps of agro-wastes that contributes immensely to greenhouse gas (GHG) emission. Their contributions to environmental hazards are enormous due to high production of methane gas while degrading. A methane gas can be used for domestic and industrial application if produced and refined in a biogas reactor. A biogas reactor of capacity 0.29 m^3 was designed and constructed to produce biogas (methane) using dried cassava peel and cow dung biomass as substrate. The simplicity of the design aids easy loading and unloading, air tightness and operated at mesophilic temperature of 32°C and pH of 6.80. The machine consists of agitator for mixing the biomass to prevent the formation of scum, inlet pipes, valves, gas outlet, and stand, crank and pressure gauge. All components were made of galvanized steel except valves outlet and inlet pipes which was made of galvanized aluminum pipe. The criteria considered in the design of the biogas reactor included air tightness of the whole unit, mesophilic temperature, pH, nature of substrate, and substrate retention period. The biogas reactor was tested with 24 kg of dried cassava peel co-mixed with 48 kg of pasty cow dung in ratio 1:2. Daily gas yield was determined; gas pressure in the biogas reactor was measured by pressure gauge, while the ambient temperature was measured using hand held mercury-in-glass thermometer. Results show that biogas was produced after 24 days retention period at average substrate temperature and pH of 32°C and 6.80 respectively. The reactor was designed to accommodate 0.145m^3 of substrate equivalent to half of the reactor volume. The reactor has a total production cost of ₦31,360 with all materials being available locally.

Keywords: Biogas reactor, cassava peel, cow dung, mesophilic temperature, pH, biogas

1 Introduction

Agricultural wastes and municipal wastes such as cassava peels and cow dung are major challenges in both developed and underdeveloped nations as revealed by past research findings, including Slims and Wolf (1994) and Macias-Corral et al. (2008). Their effect on natural resources such as surface and ground waters, soil and crops, as well as human health is enormous as they constitute to environmental hazards, leading to global warming and causing environmental diseases thereby resulting in high mortality rate among populace (Sarmah, 2009). Agricultural wastes can be used as fuel or fuel precursor for power generation in place of fossil fuel when treated in an anaerobic digestion medium (Olaniyan *et al.*, 2014). Meanwhile, the depletion of fossil fuel has called for alternative means of power generation that use renewable sources of energy such as solar, wind, biomass and various form of ocean energy. Subsequently, high natural gas prices has called for the development of high efficient, high reliable energy source for immediate and intermediate load application. However, there is an encouragement of new technology that is capable of generating power from renewable energy source which do not release Sulphur Oxide (SO_2), Nitrogen Oxides (NO_2), particulate matter, and trace element emission while exhibiting high efficiencies (Stoddard, 2005). One of such technology is a biogas reactor.

A biogas reactor is a machine used for the production of biogas which is a by-product of anaerobic decomposition of organic matter in an anaerobic condition. A biogas reactor is also known as biogas plant or an anaerobic digestion unit. The biogas can be used in small family units for cooking, heating and in larger institutions for heating or power generation. Biogas reactors are used to convert ‘waste’ material such as animal manure, excreta, sewage sludge and kitchen wastes to biogas while the effluent slurry can be used as fertilizer by biotransformation processes. Chongrak (1989) evaluated the environmental requirement of biogas reactor for the production of biogas. He considered two ranges of temperature in methane production; mesophilic (25-40°C); thermophilic (50-65°C) temperature range. It was revealed that the rate of gas (methane) production increases as the temperature increases, but there is a distinct break in the rise around 45°C as this temperature favours both the mesopholic and thermophilic bacteria.

Diak, *et al.,*(2012) used batch bioreactors and continuous-flow bioreactors designed and operated as septic tanks to study the effect of enzymatic treatments on the hydrolysis and digestion rates in primary sludge. The differences in digestion rates with or without enzymes were determined by measuring total solids, soluble solids, volatile solids, and protein, carbohydrate, ammonia and volatile acid concentrations in the sludge and effluent samples. Results showed that there was no significant improvement in enzyme-treated bioreactors compared with those without enzyme treatment. The performance of a potential centralized anaerobic digester for the production of biogas energy by using five types of municipal food wastes as feedstock was evaluated by Chen *et al.,*(2010). The wastes used in the evaluation were obtained from a soup processing plant, a fish farm, a cafeteria, a grease tap collection service anda commercial kitchen. Results showed that it was imperative to use NaOH or other appropriate chemicals to control pH of a single-stage anaerobic digestion plant for the treatment of food wastes. Wantanee (2009) carried out comparative analysis of physical and chemical composition of fresh and dried cassava tubers in his biogas production from cassava tubers co-mixed with various concentration of nitrogen sources (urea) and seed culture using a single state digester of 5-L working volume. It was observed that the fresh tuber has the average contents of 65% of moisture, 18% starch, 17% of total carbon, 0.20% of total nitrogen and 35% of total solid. The dried cassava tuber has 18.65%

of moisture, 56% of total carbon, and 0.46% of total nitrogen and 81.35% of total solid. The result shows that the reaction of 1.00% (w/v) total solid and 0.004% (w/v) urea (carbon-to-nitrogen ratio of 20:1) gave a gas yield of 1.95L/day having a maximum methane content of 67.925% at 10^{th} day retention time. These results revealed that at a scale up of the single state digester to 50 L working volume, 1 kg of dried cassava tuber (18.65% of moisture) could be biologically converted to 443 L of biogas containing 242 L of methane which could be calculated to energy volume of 9765 kJ.

International livestock research institute reported that approximately 98% of Nigeria's cassava peels annually are wasted due to constraints associated with drying and concerns about safety of use, particularly hydrocyanide and mycotoxins-related food poisoning. Due to variations in weather conditions, sun-drying of cassava peels in the open for 2-3 days is practically impossible during the rainy season. Consequently, peels are left to rot in heaps or set on fire polluting the nearby air, soil and groundwater and wasting a potential energy resource (ILRI, 2015).

Cassava peels and animal waste, especially cow dung has been a major environmental hazards. Conversely, nowadays, wastes generally are not a subject of concern but an asset if they are well explored. Hence, dried cassava peel and cow dung can be used for biogas production which can further be used for cooking, lighting, and power generation. The effluent slurry produce can be used as soil nutrient reclamation. Therefore, the objectives of this study is to design, construct and test a biogas reactor for the production of biogas from dried cassava peels co-mixed with cow dung.

2 Design of Machine Elements

2.1 Design Considerations and Assumptions

The criteria considered in the design of the reactor included air tightness of the system, substrate retention period, mesophilic and thermophilic temperature, nature and combination of the substrate used and the size of the reactor tank. Other considerations included the desire to make the reactor tank of galvanized steel to ensure good quality of the gas produced. The assumptions made in the design process included: the height of shaft is made equal to the height of the reactor tank plus 5 cm to allow fitting of the crank, the mass and volume of the spikes were considered negligible compared with the mass and volume of the reactor tank and substrate.

2.2 Description of Machine and Its Working Principles

An overview of the anaerobic biogas reactor is shown in Figure 1. The major components of the reactor are biomass holding container, the cover, the agitator (spike shaft) and gas collector. Other components included inorganic collector, inlet and outlet valve for introduction of slurry and collection of digested slurry respectively. An agitator is built inside the reactor to avoid coagulation of slurry and to aid uniform temperature profile inside the reactor. The shaft of the reactor was design in such a way that it will be driven by hand through the use of crank. The reactor was designed to accommodate 0.145m^3 of substrate equivalent to half of the reactor volume and a total production cost of ₦31,360 with all materials being available locally.

Figure 1: Model of the Reactor

The reactor tank is a cylindrical tank of 570 mm diameter and 930 mm height. To form a tank of this specification, a standard 1 mm thick galvanized steel sheet was cut using a chisel and hammer to have a length of 1790 mm and breadth of 930 mm. The plate was rolled using a plate roller, forming a cylindrical tank of open end then tacked together using an arc welding machine at the breadth ends. The base cover of the reactor, 560 mm in diameter was also cut using a chisel and hammer from the 1 mm thick galvanized sheet. The circle was marked using a wooden divider, rolled to form a frustum by marking and cutting a circle of 400 mm radius and 50^0 from the centre of the plate using hammer, chisel and wooden divider and then tacked at the end using an arc welding.

The agitator shaft was made from a mild steel rod which was machine to 15 mm diameter and 1540 mm length on the lathe with a facing steel tool. A 40 mm diameter stainless steel plate was cut into three piece of length 500 mm and welded to the agitator shaft in alternative arrangement to form the spikes. The inlet pipe was made from 15 mm long, 50 mm diameter galvanized pipes and a 50 mm inner diameter aluminum valve. The two pipes were threaded at both ends on a lathe machine. Sealing tape was rolled on the two-threaded pipes before tightened with a pipe wrench into the valve, and then one plane end of one of the pipes was arc welded to the tank along a hole made at the top end of the tank. For the outlet pipe, the same material and procedure were used. The triangular stand was made from 45 mm x 45 mm galvanized steel angle iron which was cut to three legs piece of 300 mm long each. A square steel of 420 mm x 500mm were welded to the edges of the reactor cylinder and to the triangular stand to aid adequate support. However, the crank was made by welding 3 mild steel of diameter 15 mm together forming L-shape. A bevel gear 120^0 to each other was welded to the top of the crank setting the shaft into motion. All the various components were joined together by welding and assembled. Putty was also used to fill the few openings to ensure tightness.

2.3 Design of the Biogas Reactor Tank

The following criteria were used as design guide in designing the reactor: average human power of 0.1 hp (0.0749 kW); rotational speed of the agitator = 30 rpm; D = lower diameter of the frustum = 56 cm; d = upper diameter of the frustum = 18 cm; height of the cover cylinder (H_{cyc}) is 11 cm; height of frustum cover (h_f) = 25 cm and radius of the cylinder cover (r) = 8.4 cm; upper (D_b) and lower (d_b) diameter of the reactor frustum are 4.9 cm and 56 cm respectively. Height of the reactor bottom frustum (h) = 20 cm

2.4 Radius of the Biogas Reactor Tank

The reactor was designed with a total capacity of 0.29 m^3 the radius of curvature of the cylindrical tank is 28.50 cm. The expression for volume of the cylindrical tank is given in eq. (2) while the height of the tank was determined using the expression in eq. (2) below as:

$$V = \pi R^2 h. \qquad (1)$$

$$h = \frac{V}{\pi R^2} \qquad (2)$$

where, R is the radius of curvature of the cylindrical tank and V is the volume of the tank, h is the height of the tank. Substituting V= 0.29 m^3 and R = 28.50 cm into eq. (2) gives h as112 cm. Therefore radius of 30 cm and height of 115 cm was selected for the design of the reactor tank to gives enough clearance between the substrates and the base tank.

2.5 Design of the Biogas Reactor Shaft

The reactor shaft was designed primarily to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading conditions. The shaft is usually subjected to torsion, bending due to rotary motion during the mixing process. Therefore, the diameter of the agitator shaft was determined from the expression below as:

$$\tau = \frac{16T}{\pi d^3} \qquad (3)$$ (Hall *et al*., 1987)

According to Erik *et al*. (2004), for a line shaft carrying pullets, the torque on the shaft is given by the expression in eq. (3) as:

$$T = \frac{9.55 \times 10^6 P}{N} \qquad (4)$$

And according to Erik et al., (2004), the diameter of the shaft was determined a modified form of eq. (3):

$$d = \sqrt[3]{\frac{5.1T}{\tau}} \qquad (5)$$

where, τ is the torsional stress, T is torque on the shaft, P is the power input, N is the rotational speed of the shaft, and d is the diameter of the shaft.

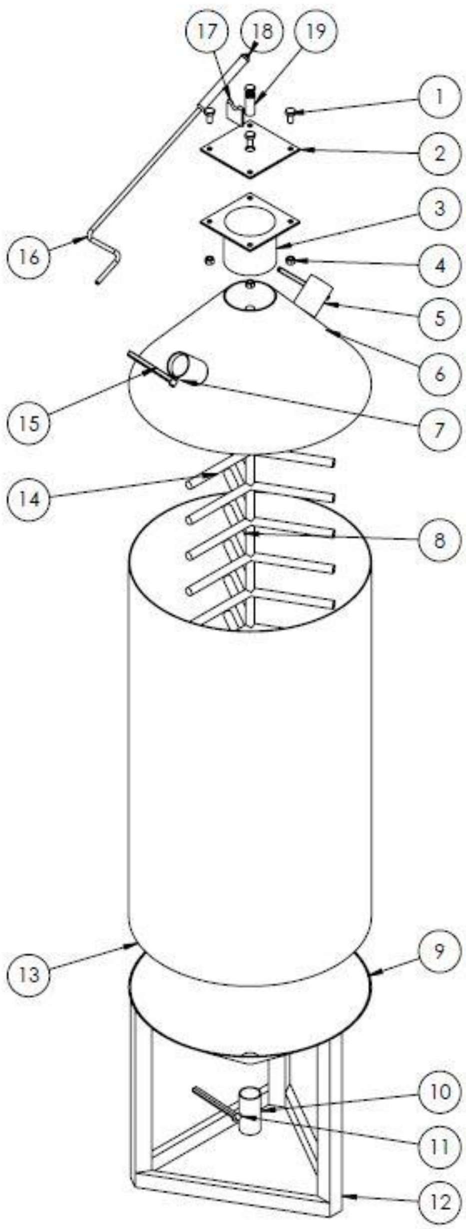
Substituting P = 0.1 hp = 0.0749 kW and N = 30 rpm in eq. (4) gave T= 23843.17 Nmm or 23.843 Nm. Given a yield stress of 200 MPa from stress table, allowable stress τ is given as

$$\tau = 0.27\, \gamma_s s \qquad (6)$$

Therefore τ = 54 N/mm^2, hence from eq. (5), d = 13.11mm. Hence, a mild steel rod of 15 mm was selected for the agitator shaft.

3 Materials Selection and Fabrication

The list of materials selected for construction is as shown in Table 1 while Figures 1-3 show the engineering drawings of the biogas reactor. The reactor was fabricated at the machining and fabrication workshop of the Department of Agricultural and Biosystems Engineering, University of Ilorin, Nigeria.



ITEM NO.	PART NUMBER	QTY.
1	B18.2.3.3M - Heavy hex screw, M12 x 1.75 x 25 --25C	4
2	REACTOR FLAT PLATE COVER	1
3	REACTOR COVER CYLINDER	1
4	B18.2.4.1M - Hex nut, Style 1, M12 x 1.75 -- D-N	4
5	PRESSURE GAUGE PIPE	1
6	REACTOR FRUSTUM COVER	1
7	INLET	1
8	SHAFT	
9	REACTOR FRUSTUM BOTTOM	
10	OUTLET PIPE	1
11	VALVE 2	1
12	FRAME	1
13	REACTOR CYLINDER	1
14	AGITATOR SPIKE	1
15	VALVE 1	2
16	STIRRER ROD	1
17	STIRER HOLDER	1
18	GEAR	2
19	SHAFT HOLDER	1

Figure 2: Exploded view of the Reactor

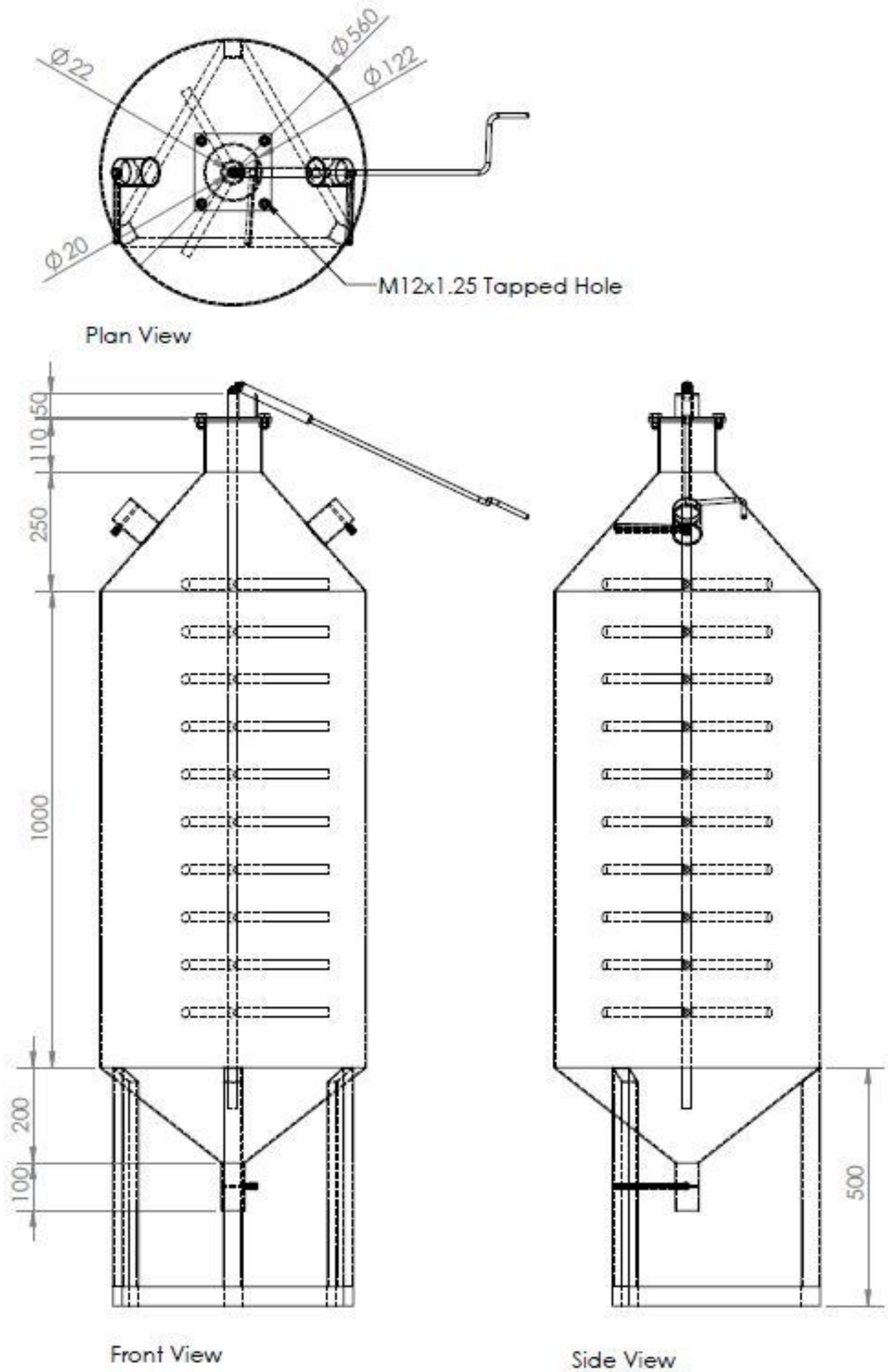


Figure 3: Orthographic Views of the Reactor

Table 1: Construction Materials and their Specifications

Material	Quantity	Specification	Unit Cost (₦)	Amount (₦)
Galvanized steel plate	2	8'x 4'	4,500	9,000
Rectangular plate	1	25 x 25 x 200 mm	1000	1,000
Rectangular plate	2	45 x 45 x 1500 mm	1,200	2,400
Gas valve	1	3/4"	750	750
Gate valve	2	1 1/2 "	900	1,800
Bolt and nut	34	32 (13 x1)	20	640
		2 (14 x1)	30	60
Hollow pipe	1	ϕ 50 x 500 mm	400	400
Shaft	1	ϕ 15 x 1400	1000	1,000
	3	ϕ 15 x 150	100	300
Rod	1	ϕ 10 x 1700 mm	600	600
Pressure guage	1	0-100 bars	2500	2,500
Tarpaulin	3 yards	3mm x 1200 mm	400 per yard	1,200
Bearing	1	ϕ 15 mm	120	120
	1	ϕ 12 mm	150	150
Electrode	1 ½	-	-	1,800
Bevel gear	2	ϕ 15 mm	500	1,000
Putty	-	-	-	500
Hose	3 yards	-	200	600
Clip	2	-	20	40
Filling rod	-	-	1000	1000
Painting	1 tin	Finishing paint	500	500
Miscellaneous				4000
Total				**31,360**

4 Performance Evaluation

4.1 Materials and Methods used for Testing

Fresh cassava peel was collected from local gari processor within Ilorin metropolis, dried under sun for five days prior to the start of the experiment to remove moisture content majorly cyanogenic fluids which may slow down biogas production. Also, cow dung was obtained from barn cage in Ipata Market, Ilorin, Kwara State in Northern Nigeria. To prepare the feedstock, 48 kg of the cow dung was diluted with water to form slurry. The dried cassava peel was soaked in water for three hours to absorb water in order to create a conducive environment for the reaction of methanogenic bacteria bringing about biogas production. However, the substrates slurry (24 kg of cassava peel and 48 kg of cow dung) was co-mixed in the ratio of 1:2 and the solid particles in the manure were removed. $0.145m^3$ of the mixed substrates was transferred into the bio-reactor, and then the bio-reactor was sealed with a rubber cork. The mixed slurry was digested for 20 days in which the daily temperature and gas measurements were measured using hand held mercury-in-glass thermometer and pressure gauge meter respectively. Temperature readings were taken in replicate of 4 hours interval per day and average temperature was computed. The pH of the digested slurry was taken on the tenth day using a digital pH meter.

4.2 Results and Discussion

The summary of the average temperature of the reactor for ten days is shown in Table 2. The temperature ranges from 27-34^{0}C. The temperature fluctuation could be as a result of the activities of some methanogenic bacteria present inside the reactor that eventually leads to biogas production. The reactor was able to keep the temperature within mesophilic range (20-45^{0}C). However, the pH of the slurry on the seventh day of loading was 6.94 which show that the medium is favourable for biogas production. Though according to Chongrak (1989), the optimum medium for biogas production is 7.00-7.2 but methanogenic bacteria performs well at an optimum pH range of 6.6 to 7.6 (Olaniyan *et al*., 2014).

Similarly, the summary of the average temperature of the reactor for eleventh days through twentieth days of loading is shown in Table 3. The temperature ranges from 29-35^{0}C. This shows that the activities of the methanogenic bacteria raised the temperature of the reactor and is proportional to the days of loading. This agreed with the findings of Batista *et al*., (2012) who estimated the specific grow rate of microorganisms from the measurement of biogas concentrations.

Table 2: Average Temperature of the Reactor the 1st – 10thDay

Day	**T_1(^{0}C)**	**T_2(^{0}C)**	**T_3(^{0}C)**	**T(^{0}C)**
1			31	31
2	30	32	34	32
3	31	32	33	32
4	25	26	30	27
5	27	28	29	28
6	31	31	31	31
7	29	32	32	31
8	28	31	31	30
9	29	31	30	30
10	29	31	33	31

Table 3: Average Temperature of the Reactor for the 11th – 20th Day ofLoading.

Day	**T_1(^{0}C)**	**T_2(^{0}C)**	**T_3(^{0}C)**	**T(^{0}C)**
11	28	30	32	30
12	29	33	34	32
13	29	31	33	31
14	29	33	34	32
15	27	32	34	31
16	29	33	34	32
17	29	32	35	32
18	29	33	34	32
19	31	35	33	33
20	32	35	35	34

5 Conclusion

A biogas reactor of capacity 0.29 m^3 was design and fabricated to produce methane gas using cassava peels and cow dung as substrates. The results reported in this work show that temperature and pH play a vital role in anaerobic digestion of cassava peels co-mixed with cow dung. The biogas production rate was found to be increasing with temperature. However, beyond the mesophilic range, biogas production decreases. The optimum yield was obtained at average substrate temperature and pH of 32^0C and 6.80 respectively. This was attributed to the rapid growth of bacteria required to breakdown organic matter for maximum production of biogas and for the reactor stability. The optimal retention time of anaerobic digestion of cassava peels co-mixed with cow dung was found to be 24 days regardless of the effect of temperature and pH of the reactor. It can also be mentioned that cassava peels has high TS which makes it suitable for anaerobic digestion. This work provide a potential mean of eradicating wastes such as cassava peels and cow dung thereby checking environmental hazards and global warming caused by these wastes. However, the biogas produced can further be process to aid high pressure gas that can be used for cooking, lightening, powering machine.

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