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Design, Development and Performance Evaluation of an Anaerobic Plant

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ABSTRACT: *The need for safe and cost effective alternative energy source is a major challenge facing developing economies globally. This study explored the design, development and performance evaluation of a cost effective anaerobic plant using locally available materials. The digester was fabricated at Amalgamated Tin Mining of Nigeria workshop using locally available materials such as mild steel, galvanize and copper pipes. The digester was used to digest cow dung mixed with water in the ratio of 1/1 by weight for a retention period of 12 days. Fifty (50kg) of cow dung of white Fulani cows that fed on the open field grasses in some part of Northern Nigeria were collected. The qualitative analysis of the biogas produced showed that the biogas contained 85.331% methane, 0.014% air, 0.013% carbon mono oxide, 1.596% Nitrogen and 13.011% carbon dioxide.*

Keywords: Anaerobic digestion, Biogas, Digester, Fulani Cow, Methane content

I. INTRODUCTION

Globally, energy is a major necessity for the existence of humans. Over the years, nations of the world have been exploring the need for safer and cleaner sources of fuel that will be an alternative to the current fuels of fossil origin (Alfa *et al.*, 2014). This shift becomes necessary as a result of the high cost of the current source and its attendant contribution to climate change. More so, there is a consensus of opinions that attaining the Sustainable Development Goals (SDGs) will require an adequate exploration of alternative and renewable energy source (Owamah *et al.*, 2014). Furthermore, a report by MIT (2010) noted that the environmental impacts of the current energy sources (environmental pollution) and the inadequate infrastructure to support new energy trends place serious burden on the developing world which in turn impacts the whole world at large. From the forgoing, there is an urgent need especially in developing economies to explore and exploit reliable, cost effective energy service which is key to improving the quality of life in both rural and urban regions of human settlement. This will not only help to provide energy for electricity and heating but will also affect other aspects of human endeavour such as but not limited to water, sanitation and health (MIT, 2010)

One of the technologies that have the capability of meeting this energy need is the anaerobic digestion for the production of Biogas (Alfa *et al.*, 2013a). This refers to the biodegradation of organic matters by anaerobic bacteria in the absence of oxygen (Alfa *et al.*, 2013). The process yields biogas principally composed of methane and carbon dioxide and digestate which be used as biofertilizers (Alfa *et al.*, 2013b).

Notwithstanding the fact that anaerobic digestion has been widely recognized as a source of alternative, renewable and reliable energy for developing economies, the design of cost effective rectors for optimum performance in developing economies remain a major challenge. That is the reason why this study explored the design and construction of a simple cost effective biodigester using locally available materials.

II. MATERIALS AND METHODS

The design theory of anaerobic digester adopted in this study was a combination of the design theories described previously by Aribasala and Omotosho (2009) and the Training Manual of the Biogas Training Center (2008) of Renewable Energy and Environmental Network (REEIN) Chengdu, Sichuam-China (2008) with slight modification. The design comprise of a simple digester with four chambers (Figure 1). It is made up of the Fermentation Chamber, Gas storage chamber, Gas collection chamber and Sludge layer. The theory assumes that the size of a digester depends on the quantity of waste to be digested, the quantity of water needed for dilution and the Hydraulic Retention time (HRT). The total Volume of digester according to Aribasala and Omotosho (2009) is given by equation 1.

$$V_T = V_c + V_{gs} + V_f + V_s \qquad (1)$$

Where:

V_c = Volume of gas collection chamber
V_{gs} = Volume of gas storage chamber
V_f = Volume of Fermentation Chamber
V_s = Volume of Sludge layer

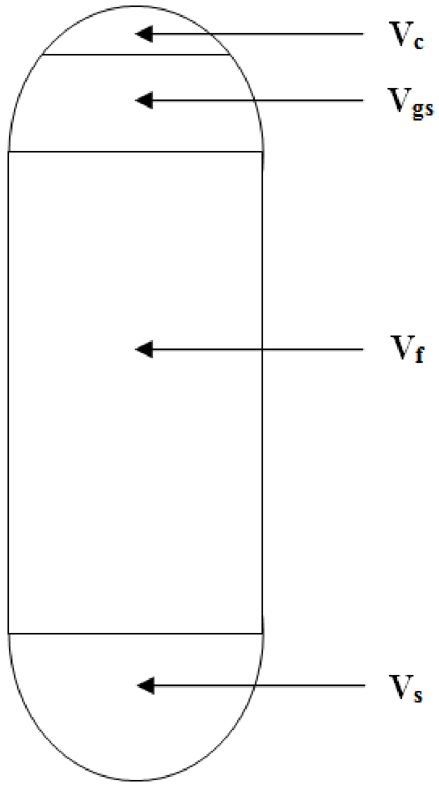

Fig 1: Cross Section of a Biodigester

The design of the anaerobic digestion chamber, the Sludge layer and the gas collection and storage system are presented on Tables 1 – 3

Table 1: Design of Digestion Chamber

Input	Calculations	Result
	Determination of Digester Chamber Volume	
No. of cows = 2	Dung discharge/cow/day = 10kg (BTC, 2008) Total Discharge/day $T_d = 2 \times 10kg = 20kg/day$	T_d = 20kg/day
T_d =20kg/day	Total solid (TS) of Fresh dung = 16% of dung Thus, $TS = 0.16 \times 20kg/day = 3.2kg/day$	TS = 3.2kg/day
TS = 3.2kg/day	TS = 8% of Total Influent Thus, Total Influent, $Q = 3.2/0.08 = 40kg/day$	Q = 40 kg/day
Q = 40kg/day **T_d =20kg/day**	Required water, $Q_w = 40 - 20 = 20kg/day$	Q_w = 20 kg/day
Q = 40kg/day **HRT =12days**	Working Digester volume, $V_w = V_{gs} + V_f = Q \times HRT$ Where V_{gs} = Volume of gas storage, V_f = Volume of fermentation Chamber and HRT = Hydraulic Retention Time. Thus, $V_w = \frac{40kg/day \times 12days}{1000kg/m^3} = 0.480m^3$	$V_w = 0.480m^3$
$V_w = 0.480m^3$	Working Digester Volume, V_w = 80% of operational Digester Volume V_o Thus, Total digester Vol., $V_o = 0.480/0.8 = 0.6m^3$	$V_o = 0.6\ m^3$
	Determination of Digester Chamber Diameter	

V_o = 0.6m^3	Digester Diameter, $D = 1.307V^{1/3}$ $D = 1.307 \times 0.6^{1/3} = 1.1024m$	Take D = 1.2m
	Determination of Digester Sludge Volume	
D = 1.2m	Sludge Volume, $V_{ds} = 0.3142D^3$ $V_{ds} = 0.3142 \times 1.2^3 = 0.542938m^3$	Take V_{ds}=0.55m^3
	Determination of Digester Sludge Height	
V_{ds} = 0.55m^3 **D = 1.2m**	Sludge Height (obtained from Volume of cylinder), $H = \frac{4V_s}{\pi D^2}$ $H = \frac{4 \times 0.55}{\pi \times 1.2^2} = 0.486307m$	Take H = 0.5m

Table 2: Design of Sludge Layer

Input	Calculations	Result
	Design of Sludge Layer Volume	
V_o = 0.6m^3	Volume of Sludge layer V_s = 15% of operating Volume V_o Thus, $V_s = 0.15 \times 0.6 = 0.09m^3$	V_s = 0.09 m^3
D = 1.2m	Height of Sludge layer $h_s = D/8$ Thus, $F_s = 1.2/8 = 0.15m$	hs =0.15 m
D = 1.2m	Radius of Sludge layer, $R_s = 1.0625D$ Thus, $R_s = 1.0625 \times 1.2 = 1.275m$	R_s = 1.3 m

Table 3: Design of Gas Collection and Gas Storage Chambers

Input	Calculations	Result
	Design of Gas collection Chamber	
V_o = 0.6m^3	Volume of gas collection chamber V_c = 5% of operating Volume V_o Thus, $V_c = 0.05 \times 0.6 = 0.03m^3$	V_c = 0.03 m^3
D = 1.2m	Height of Sludge layer $h_c = D/5$ Thus, $h_c = 1.2/5 = 0.24m$	h_c =0.24 m
D = 1.2m	Radius of Sludge layer, $R_c = 0.725D$ Thus, $R_c = 0.725 \times 1.2 = 0.87m$	R_c = 0.9 m
	Design of Gas Storage Chamber	
V_w = 0.48m^3 **V_s = 0.09m^3** **K = 0.4**	Volume of gas storage chamber, $V_{gs} = 0.5(V_w + V_s)K$ Where $V_w = V_{gs} + V_f$ = 0.48m^3, V_s = 0.09 m^3 K = gas production rate per m3 digester volume per day Thus, $V_{gs} = 0.5 \times (0.48 + 0.09) \times 0.4 = 0.114$	V_c = 0.12 m^3

The fabrication of the digester was done at the Amalgamated Tin Mining of Nigeria workshop using locally available materials such as mild steel, galvanize and copper pipes. Standard arc welding procedures were carefully followed in the fabrication. The fabricated digester is shown in plate 1-3.

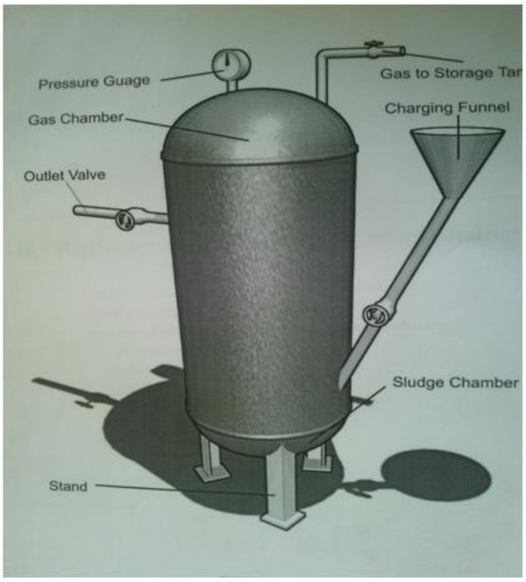

Plate 1: Fabricated Anaerobic Digester

Plate 2: Explosive view of digester

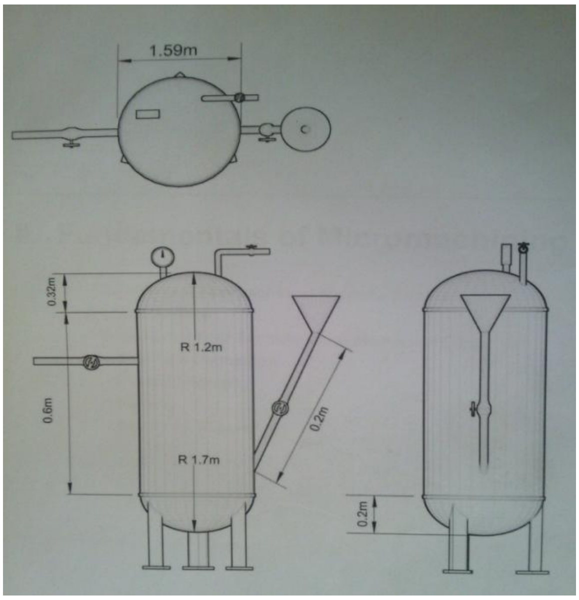

Plate 3: Schematic diagram of digester

2.2 Experiment Procedure

The fabricated biogas plant was used to digest cow dung from Fulani cows obtained from the Jos city Abattoir. The cow dung was collected in sacks from the abattoir and transported to the experimental ground where all inorganic materials were sorted and removed. As mentioned in the design procedure, the cow dung was mixed with water in the ratio 1/1 by weight to form slurry. The slurry was fed into the digester to fill 80% of its volume leaving 20% for gas production. With all the appurtenances fixed as shown in Plate 1, the digestion of the cow dung was done for a retention period of 12 days. On completion of the retention period the biogas produced was collected for qualitative Analysis at the Kaduna Refinery and Petrochemicals (KRPC) limited Laboratory.

2.3. Method of Biogas Analysis

The biogas qualitative analysis was carried out using the 263 – 50 gas chromatograph and Δ2500 chromato–integrator at the laboratory of KRPC according to the standard procedure described previously in Owamah *et al.* (2013). The chromatograph was connected to the chromate – integrator and a vacuum pump was use to extract air out of the chromatograph. The gas sample was introduce into the chromatograph and changed for a period of 13 minutes.

III. RESULTS AND DISCUSSION

The results of the qualitative analysis of the biogas produced from the Fulani cow dung using the digester fabricated in this study are presented in Table 1.

Table 1: Results of the Analysis of Biogas Produced from Fulani Cow dung

S/N	Retention time (mins)	Area (mm^2)	Height (mm)	Moles %	Factor	BC
1.	0.260	1500	69	0.048	1.000	BV
2.	0.610	446	34	0.013	1.000	VB
3.	1.513	2829635	205996	85.331	1.000	BB
4.	4.790	52935	3134	1.596	1.000	BB
5.	11.340	41450	10469	13.011	1.000	BB
Total	-	3316054	219702	100.000	-	-

The results indicate the presence of air (oxygen and nitrogen). The results show that the biogas produced from in this study is composed of 85.331% methane, 0.014% air, 0.013% carbon mono oxide, 1.596% Nitrogen and 13.011% carbon dioxide (Figure 2).

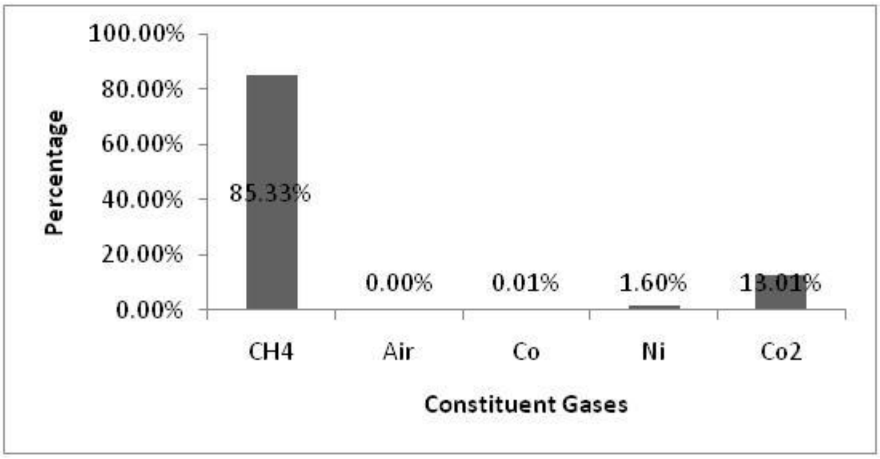

Figure 2.0 Percentage of Component gas in the Biogas produced

The high methane content obtained in this present study agrees with the results of previous studies of Ojolo *et al.* (2012), Owamah *et al.* (2014), Alfa *et al.* (2013a) and Alfa *et al.* (2014). More so, the low CO_2 content shows that minimal scrubbing is required although, for the gas to be used on an industrial scale, an adequate and cost effective method of CO_2 scrubbing should be explored and developed.

IV. CONCLUSION

The design of a simple and cost effective Biodigester of 0.6 m3 capacity was achieved in this study. The fabrication of the plant was carried out using locally available materials. The analysis of the biogas showed that the biogas from the Fulani cow could produce biogas with sufficient methane content (85.33%) sufficient to meet the energy needs in developing economies. Finally, since energy remains a global challenge especially to the third world countries and the abundance of arable land for grazing of the local cows, government should encourage the mass production of plants by way of loan scheme for the production of the plants so that those in the rural areas who have more access to the local cows can convert such to cooking and lighting gas.

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