American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-5, Issue-8, pp-88-97
www.ajer.org
Research Paper Open Access

Design and Construction of an Indigenous Biogas Plant

C.S. Agu* and J.E. Igwe
Department of Mechanical Engineering, College of Engineering and Engineering Technology, Michael Okpara University of Agriculture, Umudike, Nigeria.

ABSTRACT: *A biogas generating plant which would be affordable and easy to maintain by the local/rural consumers was designed and fabricated with locally available materials. The fabrication was based on the laid down engineering standard and procedures in machine design and fabrication, such as proper design specifications, alignment of parts and strength of materials. Results obtained from the test showed that the plant could generate average volume of 1.58cm^{3}of biogas at average pressure of 1.5bar in a day. Results also revealed that the rate of biogas generation increase with increase in time and for eleven (11) days of the plant's test, the volume of biogas generated increase from 0.0043cm^3 to 5.2510cm^3. From the results, it was observable that the more the pressure in the chamber, the more the volume of biogas generated; thus, at 3.6 bars, it produced maximum volume of 5.3cm^3 of biogas. Finally, from the bill of engineering measurement and evaluation (BEME), the total cost of production was ₦36,320.00 which could be afforded by an average consumer.*

Keywords*: Biogas, plant, fabrication, local materials, average consumers.*

I. INTRODUCTION

The energy demand in our day to day activity have become an outrageous pandemic. Nigeria with its vast population is being faced with the challenge of supplying the energy demand ranging from the industries to citizens; this is because of the vital role that power (energy) has to offer towards the development of the nation. The importance of energy in national development cannot be over emphasized, energy is the hub around which the development and industrialization of any nation revolve. It is a fact that any distortion in energy supply at any point in time results into serious economic and social hardship. The significance of energy of standard of living of mankind and the role it plays in industries for sustainability of production is well known fact [1].There is increasing evidence that current global energy policies, which promote the inefficient use fossil fuels and energy, are environmentally irresponsible and unsustainable since they cause significant environmental degradation at the local regional and global levels. Several studies have shown that by incorporating renewable energy resources into the overall energy mix or unit of nations, any of these negative environmental impacts of energy use could be avoided or minimized. The cost for domestic, commercial and industrial uses in Nigeria has risen astronomically in the past few years following the liberalization and reform of the oil industry and the energy sector as a whole. The cost of energy is now a very significant factor which determines the price paid end users of commodities [2].The injudicious use of primary bio-fuels in most developing countries has caused many problems such as deforestation desertification, erosion and reduced biodiversity.Biomass comprises of biodiesels, solid wastes, landfill and biogas, but we are limiting this study to biogas. Though the case is similar in other nations of the world. This only brought about development of other alternative energy sources, and to the various alternatives, Biogas has started becoming a more formal approach to compensate for the high energy demand especially in Africa. Though its practice can be traced way back in history, it is still undergoing a lot of technological advances for an increased production of the gas.Biogas is an easier, safer and cheaper energy source when compared to solar, hydro, nuclear means of generating energy. Nigeria, though still haven't gone so passionate in the production of biogas, this is because the country is blessed with a lot of mineral resources which includes: petroleum, natural gas, solar, hydro-electric power, wind energy, coal etc. but the still cannot afford to supply power to the citizens especially the rural areas where they are mostly not connected to the national power-grid, so this gives a better reason for providing more alternative energy source, which biogas is one (Brain and Emma, 2009).Biogaswhich is a biomasresource is said to be ideal in deciding alternative sources of energy for rural people in the sense that it is cheap and local in origin and production. It is also an energy source that is useful for multiple purposes: heating, lighting, small scale electric power generation etc. Biogas originates from bacteria in the process of bio-degradation of organic material under anaerobic (without air) conditions. The natural generation of biogas is an important part of the biochemical carbon cycle. Methanogens (methane producing bacteria) are the last link in a chain of micro-organisms which degrade organic material and return the decomposition of products tothe environment. In this process biogas is generated, a source of renewable energy [4].

Any organic matter when subjected to decomposition in the absence of air gives rise to gas which is rich in methane and also contains carbon-dioxide, hydrogen sulphide etc. cattle dung, piggery and poultry droppings can also be used to charge the digester, in addition, agricultural wastes can be fed to the plant. Several different designs of biogas plants have been built but the two most popular are the floating gas holder and the fixed dome digester. There are different operations of biogas plants and they may be classified under two headings: the continuous plant in which the feeding is done every day,and the batch plant in which the feeding in done at intervals.

Each year some 590-880 million tons of methane are released worldwide into the atmosphere through microbial activity. About 90% of the emitted methane derives from biogenic sources, i.e. from the decomposition of biomass. The remainder is of fossil origin (e.g. petrochemical process). In the northern hemisphere, the present tropospheric methane concentration amounts to about 1.65ppm.

Despite the economic values of biogas**.** The practice of using biogas domestically and industrially which has started for many centuries ago all over the world has not been fully utilized in Nigeria especially areas where the raw materials are located.

The objectives of the work are: to prove that alternative energy can be generated from animal wastes and used for several applications; to design and fabricate a biogas system to compensate for the energy supply in the university.tohelp improve agricultural production as the by-product of the biogas being produced serves as a perfect fertilizer and to inculcate a means of making use of the animal dung that lie around the university premises hence adopting an environmental sanitation techniques.

II. MATERIALS AND METHODS

2.1 Design Consideration

The design and fabrication of the biogas had to do with a lot of considerations. This involves: Generation of the gas; Controlling the optimal ambient temperature of the digester; Purifying the gas; Drying the gas; Making the plant mobile.

Hence the introduction of various systems to the digester was implemented, the systems apart from the digester as follows; the heat exchangers, the purifying chambers, and the water collector.

2.1 The Biogas Digester

2.1.1 The Slurry Chamber

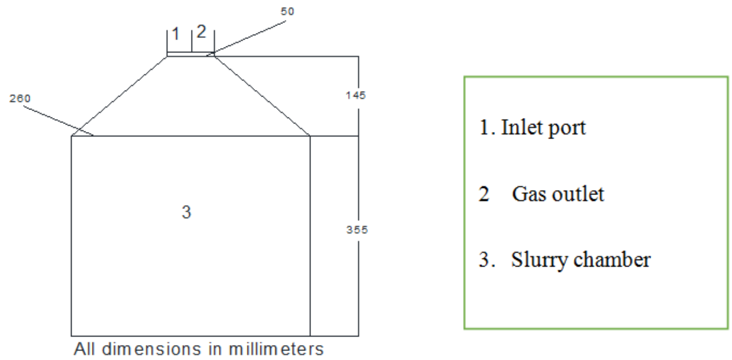


Fig 2.1 The digester configuration

The slurry chamber was made out of a carbon fiber reinforced plastic, thus enabling the feeding and storage of the slurry. The inlet port and the outlet port were situated at the top and bottom of the digester respectively as to ensure continuity of the process in which they are integrated with a ball valve and elbow joints.

Calculating the volume of the digester (slurry chamber) by using

$$\pi r^2 h \qquad (1)$$

Where r = radius and h = height.

This value gives the capacity of the slurry chamber, hence we got three samples: fresh cow dung, poultry waste, and pig dung and mixed it in the ratio of 1:3 in the three different digesters respectively. The mixing was done with hand gloves in a bucket before feeding them into the digesters. We made sure that there were no solid particles contained before introducing them in the digesters. Both the inlet and the outlet valves were locked and made air tight to be left till the retentive time is reached.

2.1.2 The Gas Chamber

The gas chamber serves as a temporary storage of the biogas being evolved. Since the inlet and outlet valves were closed, the gas will be forced to be compressed as a pressure gauge was installed to measure out the volume of the gas evolution through the pressure known.
Calculating the volume of the gas chamber of the digester, we see t

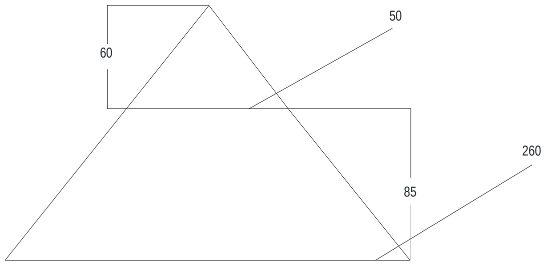


Fig 2.2 volume size of the gas chamber

The gas chamber has a shape of a frustum, so completing it to a cone shape, the volume can be calculated:
Vol of the frustum = Vol of the large cone – Vol of the small cone

$$V = \left(\frac{1}{3}\pi R^2 H - \frac{1}{3}\pi r^2 h\right) \quad \ldots\ldots\ldots\ldots (2)$$

Where R is the large radius of the bottom diameter.
r is the small radius of the top diameter.
H is the height of the large cone.
h is the height of the small cone.

In order to determine the safe pressure that the gas chamber can accommodate using the equation

$$\sigma = \frac{pr}{t} \quad \ldots\ldots\ldots\ldots (3)$$

Where σ - is the yield stress of the plastic chamber.
p - is the safe pressure the chamber can withstand
r - is the radius of the chamber (top and bottom will be considered)
t – is the thickness of the plastic chamber
The yield stress is considered instead of the ultimate stress as due to the fact of the stipulations of the "failure theorem" that a material has failed on exceeding its elastic limit [5].

$$\sigma = p\left(\frac{(R+r)}{2(t)}\right) \quad \ldots\ldots\ldots\ldots (4)$$

In order to ensure proper safety and to avoid strain hardening as it in time changes the structure brittle, a factor of safety of 2 can be taken, hence,

$$\text{Safe, pressure} = \frac{yield\ \ pressure}{factor\ \ of\ safety} \quad \ldots\ldots\ldots\ldots (4)$$

Using the ideal gas equation coupled with the general gas equation (Boyles law as the temperature changes in the digester is negligible).

$$pv = mRt \quad \ldots\ldots\ldots\ldots (5)$$

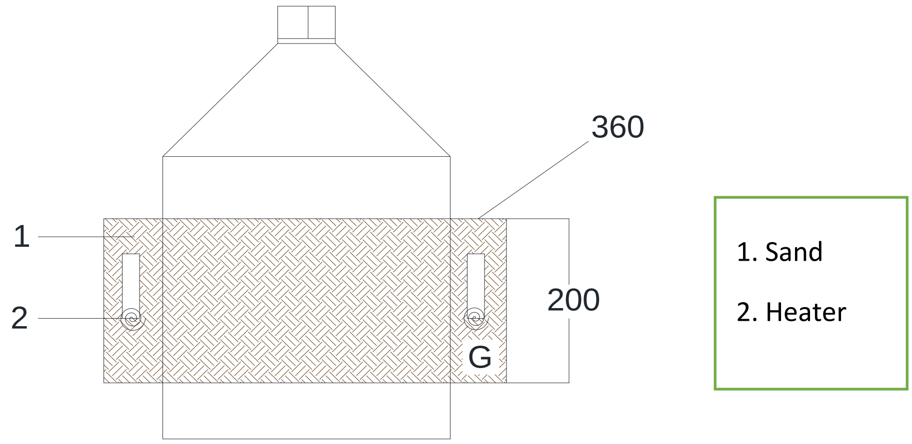
$$\frac{P1}{V1} = \frac{P2}{V2} \quad \ldots\ldots\ldots\ldots (6)$$

Where,
P – is the pressure of the biogas, I and 2 signifying initial and final stages
V – is the volume of the biogas, 1 and 2 signifying initial and final stages
m – is the unit mass of the biogas (assuming methane as the main gas)

2.1.3 The Heat Exchanger

During the design of the digester, it was considered to also install a heat exchanger to the digester. This is to ensure that the optimal temperature in the digester will be achieved at all times. From observation in Umudike, Abia state, the maximum and minimum temperature which occurs during afternoon and midnights are

33 °C and 22 °C respectively in which optimal temperature for the maximum gas production is between (35-40) °C. Hence a heat exchanger with a heat retaining capacity was involved which surround the digester.



All dimensions in millimeters

Fig 2.3 The digester with a heat exchanger.

We used sand as our heat retaining substance since it retains heat and has a thermal conductivity of 0.191Btu/ft°F [6]. We also used a heater so that the heat can be supplied externally through electricity if the heat energy from the sun (radiant energy) is not be used, so that when heat from the heater or from the sun hits the sand. The sand in turn absorbs most of it and retains the heat for some time. We also used clay to insulate the top of the sand surface to ensure that the radiant heat energy from the system is minimized. The heating was to be done on a periodic approach to ensure the heat energy spreads entirely till a uniform temperature matrix is achieved. To calculate the amount of time needed to make the sure that the surface of the digester is at anoptimal temperature, we introduce the energy equivalent theory. Assuming that there is no heat loss through radiation then,Energy dissipated by heater = energy absorbed by the sandConsidering one section of the digester then,

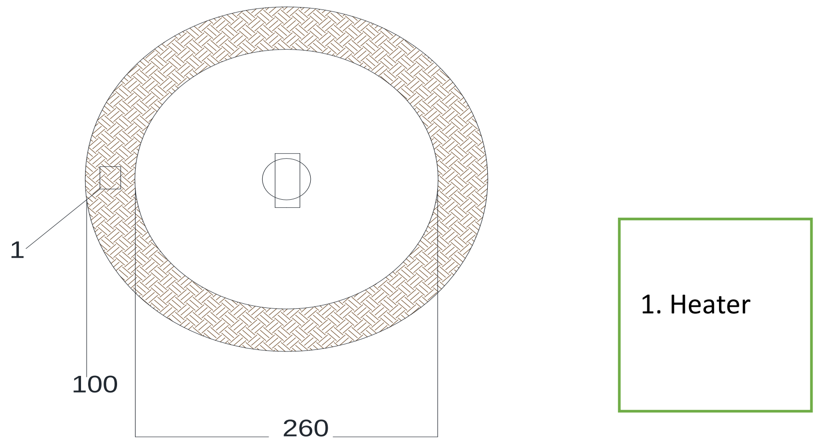


Fig 2.4: the top of the digester

As the heater took 10mm of the outer surface of the heat exchanger, leaving 90mm, the time taken for the digester to attain the optimal temperature (35) using the heater as follows:

Power of the heater: $P = iv$ …………………………………………………….. (8)

Energy dissipated: $Q = ivt$ …………………………………………………….. (9)

Heat conduction to attain the optimal temperature

$$Q = \frac{KA\,(t2 - t1)}{L} \qquad (10)$$

Where Q – is the energy dissipated by the heater
K - -is the thermal conductivity of the sand
A – is the area of the heating coil
L – is the length covered by sand to the digester surface
t_2 – is the optimum temperature to be achieved
t_1 – is the ambient temperature.
t – is the needed time to achieve the optimal temperature.

At 3 minutes of heating we removed the heating source but for effectiveness, we heated it periodically for 2 or 3 with an interval of 1 minute.

2.1.4 The Purifying Chamber.

As we collected the biogas after taken our readings from the pressure gauge, we passed the gas through the purifying chamber to purify the gas by expelling CO_2 and then H_2S. The purifying chamber is of two segments for removing of the above gasses respectively.

The first is the removal of Carbon dioxide $CO_{2.}$ We bubbled the gas through lime water ($CaOH_{(L)}$) as the lime water tend to turn milky after some amount of gas (volume) has been bubbled. The bubbling of the can be done in a laminar flow pattern or turbulent, since the rate of chemical reaction increases with time, we allowed the gas to be first pressurized before feeling it to the purifying chamber. The reaction of the above process is shown:

$CaOH_{(i)} + CO_{2(g)} \rightarrow CaCO_{3(aq)} + H_2O_{(g)}$ ……………………………………………….(11)

From the reaction above it shows that an equal volume of CO_2 is needed to completely react with lime water to make it milky, and since the average amount of CO_2 contained in a volume of biogas is 30%, then it means that there is an averagely production daily of 400 liters of biogas then the amount of lime water needed to will be 120 liters equivalent of the biogas.

The second process of the biogas purification involves the removal of hydrogen sulphide (H_2S) from the biogas. There, we passed the gas through iron fillings, since iron reacts with H_2S. This was achieved by gathering the fillings from grounded/filed iron (chips). The reason is as follows:

Since the surface area of the iron fillings are large, the reaction will be faster, but the effectiveness of this approach was not high enough so we decided to use rusted iron fillings since it reacts well with H_2S. We did this by gathering iron fillings and exposing them to light, air and moisture. This facilitates the internal electrolytic reaction occurring within the iron fillings, hence the moisture acts as the electrolyte and the iron fillings the electrode.

For the anodic reaction, the equation will be;

$$Fe \rightarrow Fe^{2+} + 2e^- \quad ......(12)$$

For the cathodic reaction resulting from basic or oxygenated water (moisture), the reaction will be;

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \quad ......(13)$$

Hence the overall equation for the reaction gives

$$2Fe + 2H_2O + O_2 \rightarrow Fe^{2+} + 4OH^- \rightarrow 2Fe(OH)_2 \quad ......(14)$$

The product further oxidizes to give

$$2Fe(OH)_2 + H_2O + \frac{1}{2}O_2 \rightarrow 2Fe(OH)_3$$ (Myer Kurtz 2002)

The rusted iron fillings then reacts with hydrogen sulphide to give

$$Fe(OH)_3 + 3H_2S \rightarrow Fe_2S_3 + 6H_2O$$
$$Fe(OH)_2 + H_2S \rightarrow FeS + 2H_2O$$

(Habet and Hubertus,1999)

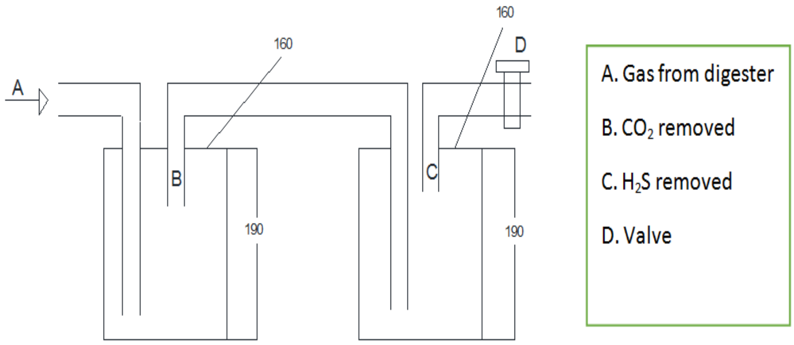


Fig 2.5 – configuration of the purifying chambers

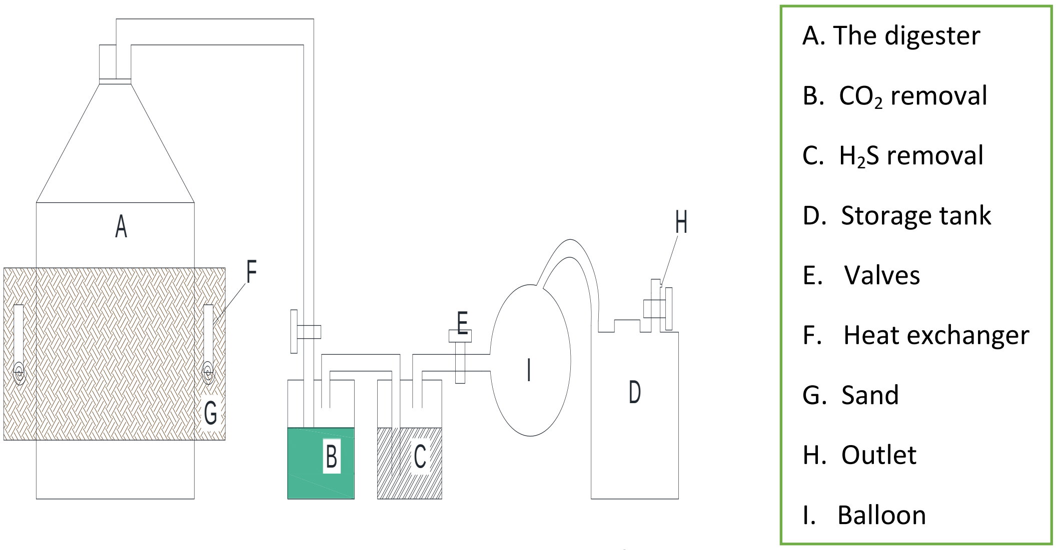


Fig 2.6 the biogas plant configuration

2.2 Fabrication Techniques

2.2.1 Material Selection

The fabrication of the biogas plant was done in a plumber shop at Timber market in which none of the stages required electricity as a source. The parent material used was plastic and its components. The reason for using plastics for this project are as follows;

- Availability of the material
- Easy to machine and correct then there is an error
- A longer life service time
- A high heat conductivity as to help heat up the content is the digester
- An opportunity to make the system mobile.

Though they are also some negative about the use of plastics, which can hinder the progress of the operation. Some of these are:

- Easy to melt
- Sometime, some vital errors might instigate getting a new component altogether.

2.2.2 Manufacturing Processes

The use of several manufacturing process were involved in the fabrication of the plant. This includes cutting, soldering, gumming, etc. the manufacturing procedure for the fabrication work took this sequence;

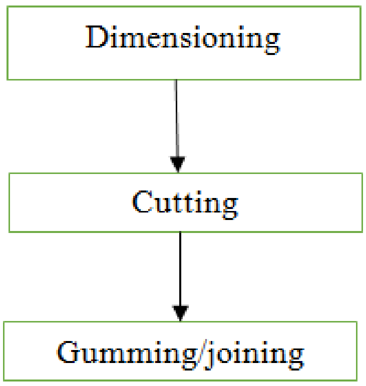


Fig 2.7 – the fabrication sequence

A. Dimensioning: The dimensioning was taken on the purpose of achieving a development of the different sections of the plant.

B. Cutting: Most of the cutting process were achieved using the saw blade machine.

C. Soldering/joining: The joining of the members was achieved using threaded half inch pipes, elbows and the use of gum to join the parts that have no thread in order to make them air-tight.

2.2.3 Operation Techniques

A recommended operation techniques is required, since the system is a gas oriented plant, care has to be taken in operation and requires an experienced technician or an Engineer to maintain and operate the system.

Firstly, when the system has attained the retentive time, it is sure to start producing thee biogas. The pressure gauge connected to the gas chamber can be closed to ensure taking readings to increase in the gas pressure of the gas chamber. When the gas reaches the maximum pressure, it can be released to allow the gas to flow to the next chamber, if the readings are not necessary then, there will be no need to pressurize the gas in the gas chamber. The heater present in the heat exchanger can be alternatively operated with a range of 3-5 minutes to ensure that the optimal temperature will be gotten.

After the gas leaves the chamber, the gas is allowed to flow through the purifying chamber here both carbon dioxide (CO_2) and hydrogen sulphide (H_2S) are expelled from the gas, the gas now moves into the temporary (balloon) chamber. The balloon which has a tipple regulator, one for the inlet into the balloon, the other for the outlet from the balloon, and one which serves as a valve for water droplets. Before the gas leaves the balloon, the gas saturates thereby dropping some water vapour, this was achieved through the phenomenon, "a sudden increase in surface area, brings about condensation.

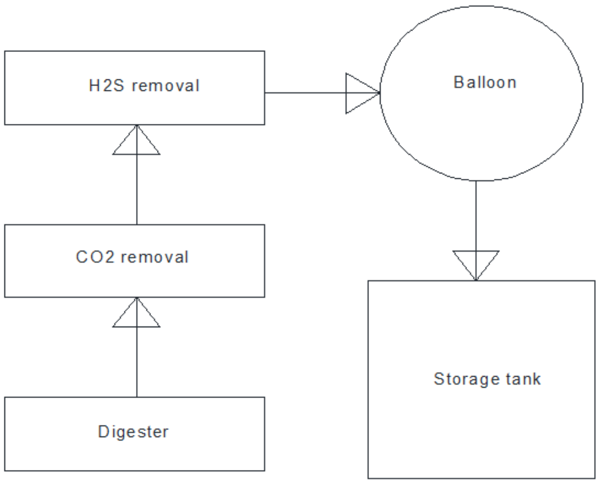


Fig 2.8 – the operational flow chart of the plant

2.2.4 Determination Of Water-Vapour Extracts

The amount of water vapour was achieved by passing the biogas through the balloon. Since the pressure, volume, velocity of the biogas flow is constant, the volume of condensed water vapour will be affected by the temperature and time, but since the time to empty a constant volume of the temporary stored biogas is also constant, then time in this experiment does not affect the volume of the water-vapour attained.

III. RESULTS AND DISCUSSION

3.1 Results

The results of this research work were presented in table 3.1 and 3.2 and figure 3.1 to 3.3

Table 3.1 Volume of biogas produced on daily basis

Time (days)	Pressure (bars)	Volume (cm^3)	Mass (g)	Moles (mol)
10	0.1	0.0043	1.083	0.0414
11	0.2	0.0170	2.167	0.0830
12	0.5	0.1070	5.416	0.2070
13	0.8	0.2740	8.670	0.3310
14	1.0	0.4290	10.83	0.4140
15	1.4	0.8400	15.17	0.5790
16	1.8	1.3890	19.50	0.7450
17	2.2	2.0740	23.83	0.9100
18	2.8	3.3610	30.33	1.1590
19	3.0	3.8580	32.50	1.2410
20	3.5	5.2510	37.91	1.4480
MEAN	1.5	1.58	17.04	0.65

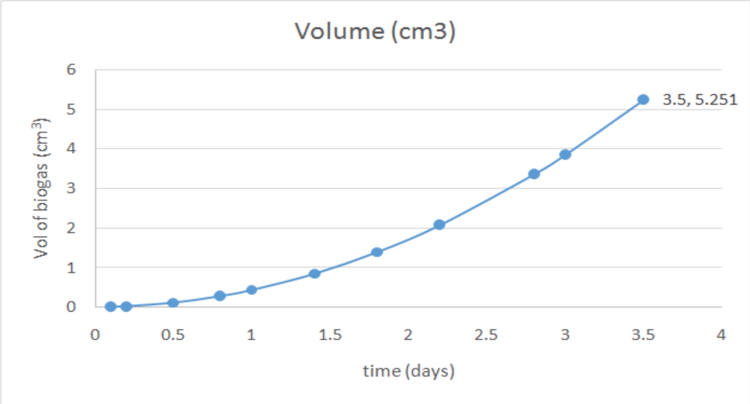


Fig 3.1 – Graph of volume of gas produced over time.

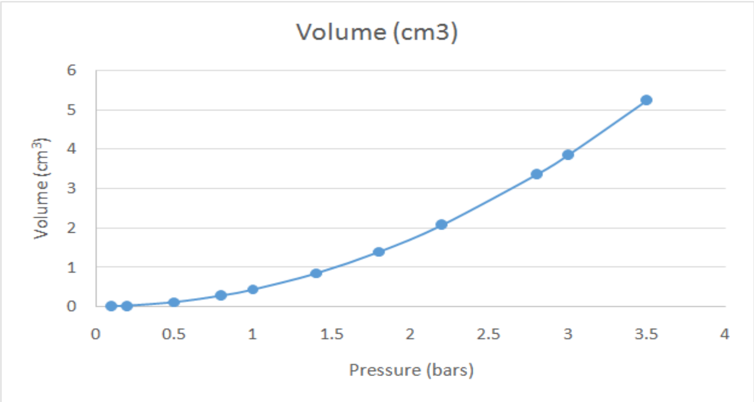


Fig 3.2 – Graph of volume of gas produced against pressure

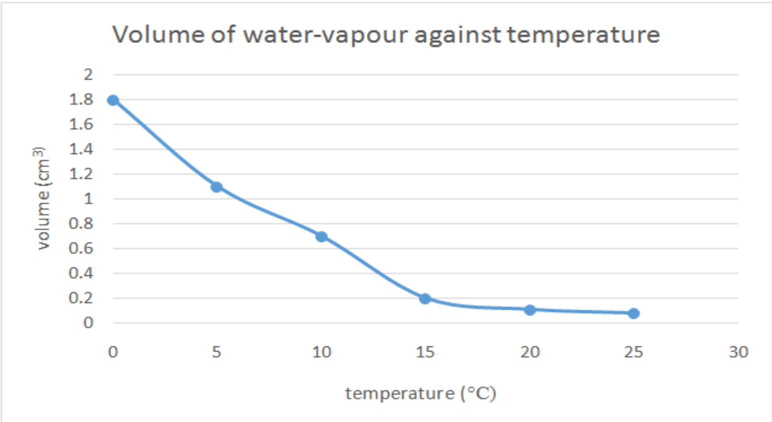


Fig 3.3 – Graph of volume expelled against temperature

Table 3.2 Bill of Quantities

S/N	MATERIAL	LENGTH	QUANTITY	UNIT PRICE	TOTAL PRICE
1	Dispenser bottle		6	1400	8400
2	Half inch pipe	3ft	3	200	600
3	2 inches elbow joint	-	6	80	480
4	Rubber caps	-	12	20	240
5	Ball gauge	-	6	200	1200
6	Half inch T-joint	-	6	40	240
7	Half inch elbow joint	-	6	50	300
8	Half inch threaded joint	-	12	50	600
9	3-liters plastic cans	-	12	200	2400
10	Balloon	-	6	200	1200
11	Hose	3ft	1	300	900
12	Total				16,320

3.2 Discussion

Table 3.1 shows the estimated volume of biogas that will be produced by the plant. For 20 days run of the biogas plant, an average of 5.2510cm^3 of biogas was generated. This is equivalent to 37.91g and i.448mol of biogas produced. Table 1 also revealed that at pressure of 1bar, the volume of biogas generated was 0.429m^3. The graph of volume of gas produced plotted against time in days (figure 3.1) showed that the rate of biogas generated increase with increase in time. This indicates credible performance.

Figure 3.2 showed also that the more the pressure in the gas chamber the more the volume of biogas produced.

From the graph of volume plotted against temperature (figure 3.3) to illustrate the rate of expulsion of water-vapour during the production process. It was observed that the water-vapour expelled is inversely proportional to the temperature. That is to say that at higher temperature, the rate of expulsion of water-vapour becomes very low and that is in agreement with Charlse's law.

Table 3. 2 finally shows the bill of engineering measurement and evaluation. From the results as displayed in the table the total cost of fabricating the biogas plant is ₦36,320.00; and it was constructed with locally available materials which is affordable by local consumers.

IV. CONCLUSION

The harnessing of biogas and usage for domestic, commercial and industrial use as a pure and dried gas can be achieved, which can be injected into the National grid and even stored for future use.It can be seen that biogas is also a cheap, safe, and reliable means of alternative energy source as its raw materials are available in various forms.

Also, the operation technique is very simple, as most of the operations occur gradually and takes less energy. The by-product also is a reliable fertilizer which can be used to aid the production of agricultural products and the soil properties. It also bring a connection between different professions, as the veterinary doctors, Agricultural scientists and Engineers have a role to play in the most-optimizing utilization of the subject case.

V. RECOMMENDATION

At most times, the best design is to make the system continuous and automatic. Some improvements can be made to the individual components of the biogas plant.

1. Presence of a mixing chamber

This chamber should be the mixing place in which both the organic waste andwater are added at their ratios. The mixing should be motorized with an electric motor and a shaft, the shaft should have teeth which will help marsh and smash the solid contents while the rotation will help in the mixing proper. A channel can be made to connect the mixing chamber and the digester. The mixing chamber can be place some distance above the digester to allow gravity introduce the mixed slurry into the digester.

2. Presence of a sensor (thermostat)

At the heat exchanger present in the digester, a sensor (thermostat) should beconnected so that if the temperature of the digester falls some degrees below the optimal temperature you want due to environmental changes or what so ever, the thermostat can start the heating action to keep the temperature of the heat exchanger optimal.

3. Continuous Agitation

To achieve a continuous agitation in the digester, a return mechanism should beimplemented from the outlet gas port of the digester, to return some of the biogas back into the slurry chamber. This helps to agitate (stir) the slurry in the digester.

This method is better when using manual or using an electric motor as no energy/effort id needed to achieve the agitation.

4. Presence of a pressure-relief valve

There can also be an attachment of a pressure relief valve in the gas outlet. This is to measure out a quantity of gas pressure in the gas chamber before it releases the biogas. The aim is to increase the rate of reaction of the gas with other substance, as pressure of a gas increases the rate of chemical reaction.

REFERENCES

[1]. Abdulkareem, A.S. (2003), Refining Biogas Produced from Biomass: An Alternative to Cooking Gas, Chemical Engineering Department, Federal University of Technology, Minna, Niger state, Nigeria.
[2]. Aruh B. and Baul B.S., (1986), Textbook of organic chemistry, 12th edition, McGraw Hill Tokyo, p. 28-32, 1986.
[3]. Brian S. and Emma W., (2009) ACCESS TO SUSTAINABLE ENERGY: What role for institutional oil and gas companies? Focus on Nigeria International Institute for Environmental and Development (IIED) www.iied.org
[4]. Budynas-N. (2006).Shigley'sMechanical Engineering Design, Eighth Edition, McGraw-Hill Prims, United States of Americas.
[5]. Clayton C.and Donald E. (2009), Engineering Fluid Mechanics, John Wiley & Sons, Inc. United States of America.
[6]. Ferdinand, P. B.,Russsell, E. and Johnson, J. R (1992), Mechanics of material 2nd edition by McGraw- Hill Inc, Library of Congress.
[7]. Habets, L. and Hubertus A. (1999), Process for the Removal of hydrogen sulphide (H_2S) From Biogas. www.FreePatentsOnline.com