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# Design and Construction of an 'Improved' Anaerobic Digester

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**Abstract:**
The shortage and inadequate energy demand in meeting essential domestic needs has consistently lead to increasing incidences of exposure and risk to fuel wood pollution among vulnerable populations particularly women and children residence in rural communities in Nigeria. Taking into account innumerable and abundant biomass energy sources in Nigeria that can be converted into usable and safe energy; biogas technology has proven to be one of the best technological options that can be exploited in meeting Nigeria energy crisis and demand. The low cost of this technology (relative to others) and its huge potentials/benefit form the basis of this research. This paper therefore focuses on the design and construction of 'an improved' anaerobic biodigester using fresh cow dung as fed. The volume of the digester composed of 110kg of fresh cow dung and 220kg of clean water at a temperature 43℃. Slurry fed into the digester was prepared by thoroughly mixing fresh cow dung with water in a ratio of 1:2 by mass. After a retention time of thirty four (34) days, the biogas generation rate was 0.215lit/hr. The biogas produced gave characteristics blue flame during combustion test indicating very high percentage of Methane.

**Keywords:** Biogas Technology, Biomass, Energy, Biodigester, Anaerobic

## I. INTRODUCTION

### Background of the Study:

The problem of energy in many developing countries like Nigeria has not changed in the last 20 – 30 years and millions of people still lack enough energy inputs to sustain economic development (Stout and Best, 2001). The sudden and unexpected fall in the price of crude oil in the world market over the past three years till date has being having devastating socio-economic effect on mono product (specifically crude oil) dependent economies like Nigeria. This calls for an urgent need to prioritize diversification of the energy sector of Nigeria's economy through optimal and effective use of available and abundance 'energy based raw materials/resources' such as animal waste, biomass and renewable resources. Furthermore, underutilization of large quantity, readily available and 'gasifiable' animal waste produced annually in Nigeria (Jekayinfa and Omisakin, 2005) may also increase incidences of exposure/risk to fuel wood pollution among vulnerable populations particularly rural dwellers in Nigeria. In fact the World Energy Council as well as Food and Agricultural Organization of the United Nation strongly recommend that government should promote renewable and sustainable technologies that will adequately and substantially address energy crisis and its' associated socio-economic effects peculiar to their respective countries.

### Statement of the Problem:

Generally, waste generations are inevitable in domestic, agricultural and industrial operation. Taking into cognizant the environmental and hazardous health implication of these wastes; there has been increasing call and trend towards achieving cleaner production (in which higher percentage of raw materials are converted to product) or conversion of the waste generated to alternative economic uses. Biological gasification of waste or biomass (Biogas technology) is one of the effective and affordable technologies of alleviating environmental-health consequences of waste by converting them to useable energy (biogas). Biogas technology is used to mitigate the problem of waste. It employs anaerobic digestion of waste to produce methane rich gas known as biogas. Nigeria, an agrarian country produces large quantity of agricultural residues and waste annually which can play a significant role in meeting her energy demand (Oladeji, et al, 2009. But the implied potentials of these agricultural wastes (cow dung, poultry dung, pig dung e.t.c.) and feed stock are yet to be fully tapped specifically in converting them to energy using biogas technology. Pioneer biogas plants in Nigeria are 10$m^3$ biogas plant constructed in 1995 by the Sokoto energy research Center (SERC) in Sokoto and the 18$m^3$biogas constructed in 1996 at Ojokoro Ife and Lagos by the federal institute of Industrial Research Oshodi (FIIRO) Lagos (Zuru et.al., 1998).

Abubakar and Ismail (2012) carried out an investigation on biogas production potential of cow dung using a laboratory scale of 10L bio-digester. It was found that cow dung stands a promising feedstock for biogas production. Ukpai and Nnabuch (2012) have also reported significant volume of methane gas produced from cow dung using anaerobic digestion. Okoro Igwe et. al., 2013, has also reported that biogas generated from cow dung using bio-digester is capable of producing energy requirement of a household for continuous cooking. Over the years, research carried out on Biogas technology in the department of Mechanical Engineering, Bayero University Kano has produces little or no result due to some identifiable constraints. The lack or insufficient biogas production in past researches in the Department may be due to improper design of the biogas digester. Some of the identifiable limitations are improper air tightening of the digester, biogas pressure were not considered, no bio-digester lagging and no basis for choosing the volume of the digester. Thus, the need for this research.

## II. AIM AND OBJECTIVE OF THE STUDY

### Aim
To design, construct and test an improved bio-digester.

### Objective
To produce biogas sufficient to cook for a family of four (4) for one day.

## SCOPE AND LIMITATION OF THE STUDY

### Scope
This study covered design, construction and testing of an improved (anaerobic) bio-digester suitable for a family of four using cow dung.

### Limitation
Analysis and purification of the biogas generated is not considered in this research work.

## EXPERIMENTATION

### Daily Energy Requirement per Head
The daily energy required per head was obtained by conducting a preliminary experiment which involved cooking 500 g of beans using kerosene stove. The aim of this experiment was to determine the mass of water evaporated ($M_{ev}$) during the cooking experiment so as to obtain the latent energy component of the energy equation given in equation (i) below.

### Experimental Materials
500 g of black eyed-pea beans, 1.39 liters of clean water, Stop watch, Stove, Cooking pan, weighing balance, Thermometer and 0.25 litres of kerosene.

### Properties of water
$Cp = 4.2$ kJ/kgK
Boiling point of water $T_{bp} = 100$ ℃
Mean room temperature $T_R = 29$ ℃ (experimental)
Density of water $\rho_w = 1000$ kg/m$^3$

### Properties of beans (black-eyed-peas beans)
Mass of beans cooked $M_B = 500$ g
Cp of beans = 1.84 kJ/kgK
Time required to cook 500g of beans = 51 minutes (experimental)

## III. SYSTEM DESIGN

### Design of the Biogas Digester
The feedstock used for this project is fresh cow dung as it is the ideal substrate for digesters due to its low acidity (Karanja and Kiruiro, 2003).The fresh cow dung was obtained from Riga Fulani at Danbare village in Kumbotso LGA, Kano State, Nigeria.

### Retention Time (R.T)
For a fresh cow dung R.T between 20-90 days (Chengdu Biogas Research Institute China, 1992).

### Volume of Biogas Required to cook 500 g of Beans
To obtain the volume of biogas required to cook 500 g of beans for a family of four (4), the following energy equation is used. Energy E required to cook 500 g of beans may be given below:

$E = M_w C_{pw} (T_{bp} - T_R) + M_B C_{PB} (T_B - T_R) + M_{ev} L_{ev}$ ………………… (i)

Where: $M_w$ = Mass of water required to cook 500 g of beans=1.39 kg; $Cp_w$ = Specific heat capacity of water = 4.2 kJ/kgK; $T_{bp}$ = Boiling point of water = 100℃;$T_R$ = Room temperature = 29℃; $M_B$ = Mass of beans cooked = 500 g; $Cp_B$ = Specific heat capacity of beans = 1.84 kJ/kgK; $T_B$ = Temperature of which 500g of beans was cooked = 97℃; Mev = Mass of water that vaporized after 500 g of bean cooked = 866.67 g; Lev = Latent heat of vaporization of water = 2260 kJ/kg.
From equation (i) we have
$E = 1.39\times4.2(100-29) + 0.5\times1.84(97-29) + 0.867\times2260$
$= 2436.48$ kJ
The efficiency of a kerosene stove is 35 – 50 % (Centre for Energy Studies, Nepal, 2001).
For this design 40 % was chosen, the actual total energy required is therefore given by:
$E_a = E/\eta$ή = 6091.2 kJ
For a biogas containing 50 – 60 % of methane the energy content for 55 % methane of biogas is 21600000 J/m$^3$ (Jan and Felix, 2010).
The volume of biogas required to cook 500 g of beans
$V = E_a/(E_C)$ ………………………………… (ii)
Where: $E_a$ = total energy from kerosene stove; $E_C$ = Energy content of biogas having 55 % methane content
From equation (ii) above,
$V = \frac{6091.2}{21600000} = 0.282$ m$^3$
This is the volume of biogas required to cook 500 g of beans, by mass it is equal to 341g of biogas. This volume is stored in 15% of the digester volume as a common practice in sizing digester volume (Chengdu Biogas Research Institute China, 1992).

The digester volume ($V_D$) = $1.15 \times V$
From the calculated volume above, we have
$V_D = 1.15\times0.282$
$V_D = 0.325$ m$^3$
The volume of biogas expected per day can be calculated from the expression below:

$V_E = Y \times V_D$………………………………… (iii)
Where: $V_E$= volume of biogas expected per day; Y=yield of biogas per meter cube of cow dung; $V_D$=digester volume.
The yield of biogas for cow dung is 0.2m$^3$/m$^3$ day (Rai, 2004)
$V_E = 0.2m^3/m^3 day \times 0.325$ m$^3$
$= 0.065$ m$^3$/day
The volume of biogas $V_B$ expected after the first 10 days of the retention time during the digestion period.
$V_B = V_E \times 10 \text{ days} = 0.065m^3/day \times 10\ days = 0.65$m$^3$

### Determination of Digester Parameters
The digester volume consists of three basic elements which are biogas collecting element, biomass holding element, biomass flush out element as shown in figure (i)

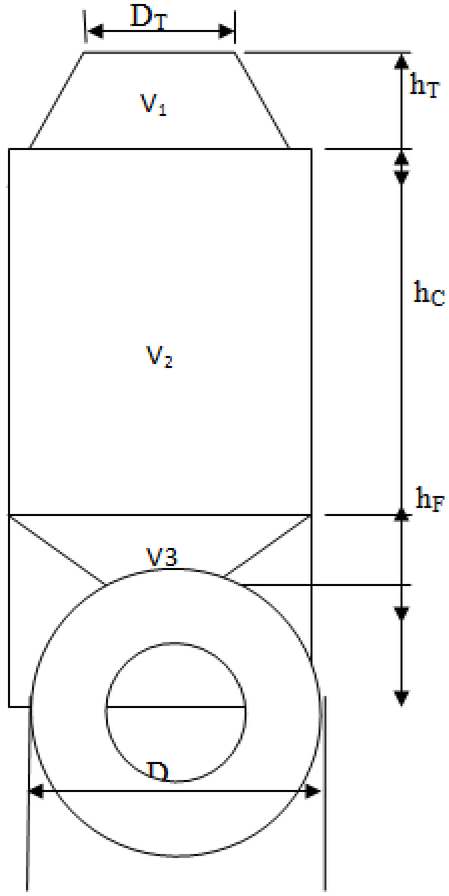


**Figure.1. Digester Elements**

For this design, the following percentages by the digester volume are distributed to the elements that made up the digester volume.

i. Biogas collecting element (V1) 15% of digester volume

ii. Biomass holding element (V2) 82% of the digester volume

iii. Biomass flush out element (V3) 3% of the digester volume

**Biomass Holding Element**

The design for the digester cylinder involves the determination of the diameter from volume of cylinder.

If the height of the digester h=1000 mm

$V_2 = \frac{\pi D^2}{4} h$………………………….. (iv)

Where: $V_2 = 0.2665\ m^3$

From equation (4), $D_d = 0.6$ m = 600 mm

**Biogas Collecting Element**

The design for the truncated top cone of the digester involves the determination of the height of the element, which may be expressed as

$V_1 = ((\pi R^2)/3)\ h$……………………………………… (v)

Where: R= radius of the cone (300 mm); h=height of the cone; $V_1 = 0.04875\ m^3$ (since the biogas collecting element $V_1$ is 15 % of digester volume).

Substituting these values of R and $V_1$ into equation (5), we get h=500 mm

If the top of this element is truncated at a point where the diameter is $D_d$ = 200 mm to allow for stirrer seat. Truncating using similar triangle theorem, we have the truncated height of the cone

$h_T$ = 330 mm

By this truncation, the digester volume is reduced by 0.00712 $m^3$, to account for this loss in the biomass holding element

$1/3\, \pi r^2 h = \frac{1}{4} \pi D^2 h_1$……………………………… (vi)

$1/3 \times \pi \times 0.1^2 \times 0.17 = \frac{1}{4} \times \pi \times 0.6^2 \times h_1$

.: $h_1$ = 0.0063 m

The total height of biomass holding element

$h_C = h + h_1$………………………………………..(vii)

= 1.0+0.0063

= 1.006

.: $h_C$ = 1006mm

**Biomass Flush out Element**

The slurry after digestion is corrosive to the digester walls if not properly expelled or flushed out from the digester. For this reason the lower part of the digester will be coned to allow for easy flush out of the digested slurry.

To obtain the perpendicular height of the lower cone 3% of the digester volume will be taken as the volume of flush out element.

$V_3 = 0.00966 m^3$

$0.00966 = \frac{\pi R^2}{3} h_f$…………………………………….. (viii)

$h_F$ = 0.102m

= 100mm

**Design For the Inlet and Outlet Pipes**

**Design for the Feeding Pipe**

The main function of feeding pipe is to convey the slurry to the digester after proper mixing. In this design, the slurry is fed at a velocity of 0.05m/s and the maximum volume of slurry in the digester is attained in 5 minutes. Flow rate of the slurry Q ($m^3$/s) may be expressed as:

$Q = V_D/t$……………………….(ix)

Where: $V_D$ = volume of slurry in digester; t = time to fill the digester to the maximum height of slurry.

$Q = \frac{0.85 \times 0.325}{5 \times 60} = 0.000921\ m^3/s$

From Q = AV

$Q = \frac{\pi d^2}{4} \times v$……………………………………….. (x)

Where: v = velocity of the slurry into the digester; d = diameter of the feeding pipe

$0.000921 = \frac{\pi d^2 \times 0.05}{4}$

d = 0.152 m=150mm

**Design for the Biomass Outlet Pipe**

The main function of the biomass outlet pipe is to expel already digested biomass from the digester cylinder by gravity. After the biogas is collected from the slurry, the final product becomes more viscous than when it was admitted into the digester. For this, the velocity of flow will be lower than when it was admitted into the digester. If the velocity of the digested slurry is 0.025m/s since it has a higher viscosity, the time to fill the digester with slurry and the time to expel the slurry are equal.

Mathematically, $Q = \frac{0.85 \times 0.322}{5 \times 60} = 9.21 \times 10^{-4}\ m^3/s$

$9.21 \times 10^{-4} = \frac{\pi D^2 \times 0.025}{4}$

D = 0.216 m= 0.2 m (approximate)

D = 200 mm

**Design for the Gas Outlet Valve**

The design for the gas outlet valve will be based on the pressure of the biogas at the collecting chamber of the digester. The valve will open for flow of gas from the digester to the gas storage cylinder when the pressure of the biogas generated is the same as the pressure of the biogas required to cook the 500g of beans. To account for the value of this pressure we use the percentage composition of biogas has shown below:

**Table.1. Percentage Composition Of Biogas**

| Constituent | % by volume | Molecular Mass (Kg/Kmol) |
|---|---|---|
| Methane ($CH_4$) | 55 – 65 | 16 |
| Carbon dioxide ($CO_2$) | 30 – 35 | 44 |
| Hydrogen sulphide ($H_2S$) | 0 – 3 | 2 |
| Hydrogen ($H_2$) | 0 – 1 | 18 |
| Water vapor ($H_20$) | 1 – 5 | 34 |

(Source: Guyana Energy Agency)

Using Dalton's law of partial pressure, total pressure ($P_T$) = $\sum P_i$

$P_T = P_{CH4} + P_{CO2} + P_{H2S} + P_{H2} + P_{H20}$....................................... (xi)

$P = \frac{mR\bar{T}}{MiV}$................................ (xii)

V = Volume of biogas required to cook 500g of bean = $0.282m^3$

$\bar{R}$ = General gas constant = 8.3145kJ/kgkmol K

$M_i$ = Mass of the constituent, this will be the product of mass of biogas and the percentage by volume.

Mass of biogas ($m$) = $\rho_B$ X V

$= \frac{1.21\text{kg x } 0.282\,\text{m}^3}{m^3}$

= 0.341kg

At Mesophillic temperature, T = 35 + 273 = 308K

The partial pressures of the constituents of the biogas are computed below:

$P_{CH4} = \frac{0.56\times0.341\times8.3145\times308}{16\times0.282} = 108.38$ kN/m$^2$

$P_{CO2} = \frac{0.35\times0.341\times8.3145\times308}{44\times0.282} = 24.63$kN/m$^2$

$P_{H2} = \frac{0.01\times0.341\times8.3145\times308}{2\times0.282} = 15.48$ kN/m$^2$

$P_{H2O} = \frac{0.05\times0.341\times8.3145\times308}{18\times0.282} = 8.60$ kN/m$^2$

$P_{H2S} = \frac{0.03\times0.341\times8.3145\times308}{34\times0.282} = 2.73$ kN/m$^2$

From equation (11) above

$P_T$ = 108.38+24.63+15.48+8.6+2.73

= 159.82kN/m$^2$= 159820N/m$^2$

$P_T$ = 1.6 bar

The valve that will be selected for this design will allow the flow of the biogas to the storage tank when its pressure reaches 1.60 bars. From the pressure of the valve an appropriate diameter of the storage tank inlet hose will be selected.

**Design for Stirrer**

The slurry in the digester settles into layers which reduce the biogas production rate if left undisturbed for some hours due to this stirrers are provided.

The design for stirring rod involves the determination of its length and a suitable diameter. Mathematically, the length of the stirrer rod is given by:

$L_S=h_T+h_C+h_E$.......................................... (xiii)

Where: $L_S$= Length $L_s$ of the stirring rod; $h_T$= Truncated height of top cone; $h_C$= cylinder height; $h_E$ = height the rod above the truncated top cone.

For this design, L will be 200 mm to enable the digester to be stirrered from the ground level without constructing any base for the that Purpose. Substituting, we have;

$L_S$ = 330+1006+200 = 1536 mm

An appropriate 25mm diameter stainless rod was selected based on the induced stress.

**Design for Stirrer Handle**

The design of the stirrer handle involves the determination of the digester radius

The length of the stirrer handle L = R = 300 mm

**Design for Stirrer Arms**

For the stirrer arms not to sweep the cylinder wall of the digester, an appropriate clearance is provided. For this design, a clearance of 50mm will be chosen. Therefore the radius of the stirrer arm is 250mm

**Design Consideration of the Stirrer Bushings**

To stirrer the content of the digester effectively, two brass bushings are mounted at the lower and top part of the digester. The internal diameters of these bushings are equal to the outer diameter of the stirring rod.

**Design selection of Rubber Seals**

To make all the joints in the digester to be air tight, appropriate seals are selected for this joint. The two seals at the top of the truncated cone are selected base on the internal diameter of the stirrer rod.

**Design for digester stand**

This involves the determination of the height of the stand from ground level, the number of stand to support the digester and its slurry content. For this design, a suitable height of 460mm will be chosen, this will be mounted 90$^{\circ}$ round the circumference of the lower part of the digester cylinder.

**Design for Flange Joint**

For the joints to be fluid tight, the relation $P_i$ = 2840d will be used to estimate the nominal diameter of the bolts d (mm) knowing the initial tension ($P_i$) (Khurmi and Gupta, 2005).

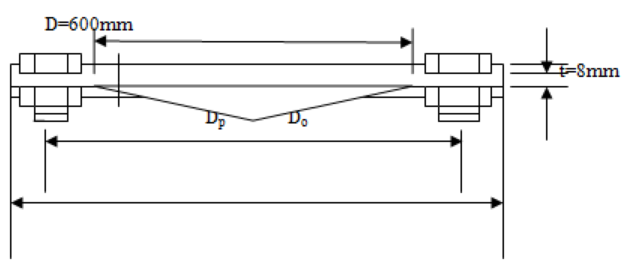


**Figure.2. Flange Assembly**

To obtain $P_i$ the analysis below is carried on the content (mass of slurry) of the digester and the force exerted on the slurry due to the pressure of the biogas.

For the ratio of biomass (cow dung) to water to be 1:3

The mass $M_S$ of slurry in the digester from the biomass to water ratio may be expressed thus:

$M_S=\frac{1}{4}V_2\rho_S+\frac{3}{4}V_2\rho_w$........................................ (xiv)

Where: $V_2$= digester volume; $\rho_S$=density of slurry; $\rho_w$=density of water

Substituting these values into equation (xiv) we have

$M_s=\frac{1}{4} \times 0.85 \times 0.322\, m^3 \times 1600\, \frac{kg}{m^3} + \frac{3}{4} \times 0.85 \times 0322\, m^3 \times 1000\, kg/m^3$

= 109.49 + 205.275

$M_s$ = 314.755 kg

The force due to Ms on the joint

$F_s = M_s g$........................................................ (xv)

= 314.755 × 9.81

= 3087.75N

The force due to the pressure of the biogas exerted on the slurry

$F_p = P \times A$ …………………………………………………………… (xvi)

P= pressure of biogas.

A= area of the digester

$F_P = P \times \frac{\pi D^2}{4}$

$= 1.6 \times 10^5 \times \frac{\pi \times (0.6)^2}{4}$

$F_P$ = 45238.934N

$P_i = F_p + F_s$ …………………………………………………………… (xvii)

= 45238.934+3087.75

= 48326.684N

$P_i$ =2840d

$d_i$ = 17.016mm

The nominal diameter of the bolt is 18mm i.e. M18

Number of bolts required to achieve the fluid-tight joint for the above nominal diameter of stress area 192mm$^2$, knowing that permissible stress in the bolts is 33mpa (Khurmi and Gupta 2005) is given by:

$48326.68 = 192 \times 33 \times n$

n = 8 bolts

For this design 12bolts will be used for safety purpose.

From figure 2 above, the relation below can be generated.

$D_p = D + 2t + 3d_i$ ………………………………………………… (xviii)

$Do = D_p + 3d_i$

Where: D =diameter of digester = 600 mm; t = thickness of digester wall = 2.5 mm; $d_i$ = diameter of the bolts hole = 19 mm

$D_p = 600 + 2 \times 2.5 + 3 \times 19 = 662$ mm

$Do = D_p + 3d_i = 662 + 3 \times 19 = 719$ mm

The width of the flange = 57mm

**Design for Insulation Thickness**

Figure 3 shows the schematic of the heat transfer mechanism from which the analysis below is made.

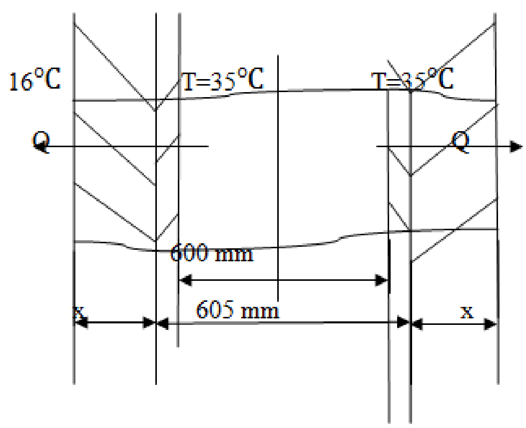


**Figure.3. Sectional Section of the Lagged Digester**

Mass of slurry in the digester = $M_S$

Mass of biomass in slurry = $M_B$

Mass of water slurry = $M_W$

$M_S = M_B + M_w$------------------------------------- (xix)

If the biomass to water ratio in the slurry = 1:3

Density of fresh cow dung 1.2 – 1.6g/cm$^3$ (Sobel,1966)

Density of water 1g/cm3

$M_S = P_B V_B + P_W V_W$

$= 1600 \times {}^{1}/_{4} \times {}^{85}/_{100} \times 0.322 + 1000 \times {}^{3}/_{4} \times {}^{85}/_{100} \times 0.322$

= 109.48 + 205.275

$M_S$= 314.755kg

Specific heat capacity of the slurry Cp = 4.05kJ/kg K (Manfred et al, 2007).

Mean Ambient lower temperature of Kano state, within November to March $T_A$ = 16$^0$C (Kano state meteorological centre).

The temperature of the slurry Ts will be maintained at mesophillic level of 35$^0$C.

Heat loss by slurry $Q = M_S Cp (T_S – T_A)$ ------------------ (xx)

$= 314.755 \times 4.05 \times 10^3 \times (35 – 16)$

= 24220397.25J

Heat loss by the slurry per day $Q = \frac{24220397.25}{24 \times 60 \times 60}$ = 280.33W

From Fourier's

$Q = \frac{2\pi LK\ (T_s - T_m)}{ln R_2/R_1}$…………………… (xxi)

Where: Q=heat flow rate; L=height of the cylinder; k=thermal conductivity; $T_S$=slurry temperature; $T_m$=mean ambient temperature; $R_2$=external radius of the cylinder;$R_1$=internal radius of cylinder

For stainless steel thermal conductivity k = 16 W/m K

From equation (21) the temperature may be obtained by substitution as shown below

$280.33 = \frac{2\pi \times 16 \times 1.006 (35 - T)}{L_n \frac{0.3025}{0.3}}$

$2.326/(2\pi \times 16) = 35 – T$

T = 34.988$^0$C this will be the temperature of the outer surface of the digester wall.

To select appropriate lagging material that will maintain the slurry temperature at mesophillic level of 35$^o$C. The insulating material selected is fibre glass due to its effectiveness, availability in the market and its flexibility to be formed into the required shape. The thermal conductivity k = 0.04W/mK

The thickness of the insulation, x was calculated by:

$Q = \frac{2\ \pi\ K \times 1.006\ (T_s - T_A)}{L_n R_2/0.3025} = 280.33$

$$ln \frac{R}{0.30125} = \frac{2\ \pi\ \ \times 0.04\ (34.988 - 16)}{280.33}$$

R = 0.3064m

x= 0.3064 – 0.30125

$x = 5.15 \times 10^{-3} m$

x = 5.5 mm= 6 mm (Approximate)

The thickness of the insulation is 6 mm

**Design of Storage Tank**

Since the biogas generation is intermittent, the volume required to cook for this family is obtained in every 12 hours. The volume of the storage tank $V_S$ = biogas expected per day$\times$0.5 day

$V_S = 0.065 \times 0.5 = 0.0325$ m$^3$

The design of the storage tank involves the determination of the diameter of the storage tank from the volume of a cylinder. In this design, the height of storage tank will be $h_S$ = 400 mm

$V = \frac{\pi D^2 h}{4}$

$0.032 = \frac{\pi D^2 \times 0.4}{4}$

$D_S = 0.32$ m. Say 300mm

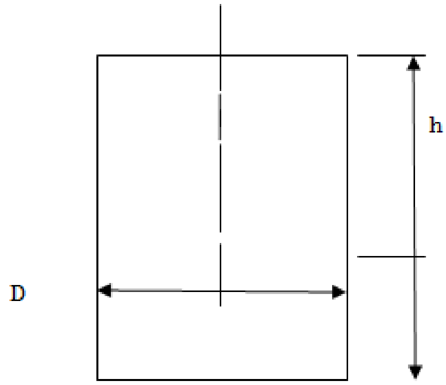


**Figure.4. Storage Tank**

## IV. EXPERIMENTAL SETUP

### Preparation of Digester Slurry

The volume of the digester composed of 110kg of fresh cow dung and 220kg of clean water at a temperature 43℃. Slurry fed into the digester was prepared by thoroughly mixing fresh cow dung with water raised to a temperature of 43℃ in a ratio of 1:2 by mass.

### Cost Analysis and Specification

The table below shows the materials which the digester is made of, with their specification.

**Table.2. Estimated Cost Of The Digester**

| S/N | MATERIALS DESCRIPTION | QUANTITY OF MATERIALS | SPECIFICATION OF MATERIALS | UNIT COST (₦) | AMOUNT (₦) |
|---|---|---|---|---|---|
| 1 | Stainless-steel plate | 2 sheets | 8ftx4ft and 2.5mm thick | 48000 | 96000 |
| 2 | Mild steel plate | 1 sheet | 8ftx4ft and 8mm thick | 32000 | 32000 |
| 3 | Pipe | 1 | 25mm,5.2ftlong | 6000 | 6000 |
| 4 | Valves | 2 | 4" W.O.G | 15000 | 30000 |
| 5 | Bourdon gauge | 1 | 6bar | 5000 | 5000 |
| 6 | Rubber seals | 2 | Double acting | 400 | 800 |
| 7 | Fiber glass | | | 4180 | 4180 |
| 8 | Stainless steel flat bar | 1 | 4.92ft | 4000 | 4000 |
| 9 | u-channel (mild steel) | 1 | 8.2ft | 3000 | 3000 |
| 10 | Tube | 1 | 22 | 1000 | 1000 |
| 11 | Workmanship | | | | 37000 |
| 12 | Cow dung | 110kg | Fresh | | 3500 |
| 13 | Others | | | | 50000 |
| | | | | **Total** | **270,780** |

### Procedures during the Fabrication of the Digester

**The following procedure were observed during the construction of the digester**

- Materials procurement
- Marking out of the stainless steel and the mild steel sheets.
- Rolling of the biogas collecting cone, biomass holding cylinder, biomass flush out cone. All these were done according to the design parameter hence the end parts were welded together.
- Turning of an 8mm thick mild steel into a flange and drilling of 12 bolts holes across the circumferential width of the flange
- Joining the flange to the lower part of the biomass holding cylinder and the top of biomass flush out element by welding.
- Joining of the biogas collecting element with the biomass holding cylinder by welding.
- Constructing the biomass stirring bars and fastening them to the stirrer pipe with a lock bolt.
- Construction of the bio-digester stand with a mild steel u-channel
- The construction of the biomass inlet and outlet unit and mounting of the valves.

## V. RESULTS AND ANALYSIS/DISCUSSION

### Experimental Results

The following experiments was carried out after the digester loaded with cow dung

### Temperature behavior

The constructed bio-digester lagged with fiber glass was observed to have a temperature lower than the ambient temperature twelve (12) days after the slurry was fed into the digester at a temperature of 43°C, this necessitated the monitoring of the temperature behavior of the slurry in the digester which was obtained from the digester wall. The results are tabulated below.

**Table.3. Ambient And Digester Wall Temperature**

| DAY | AVERAGE TEMPERATURE OF DIGESTER ( $^{O}C$) | | | | AMBIENT TEMPERATURE $^{O}C$ | | | |
|---|---|---|---|---|---|---|---|---|
| | M | A | E | Average | M | A | E | Average |
| 1 | 24.2 | 33.9 | 29 | 29.03 | 19.8 | 36 | 28 | 27.94 |
| 2 | 26.33 | 36 | 30 | 30.5 | 21 | 43 | 29 | 31 |
| 3 | 26.33 | 30.5 | 28.33 | 28.31 | 23.5 | 35 | 27 | 28.5 |
| 4 | 25.83 | 31.21 | 29 | 28.68 | 23 | 37 | 28 | 29.33 |
| 5 | 26 | 31.33 | 29 | 28.75 | 21 | 36 | 28 | 28.33 |
| 6 | 26.83 | 31 | 29 | 28.94 | 25 | 35 | 28 | 29.33 |
| 7 | 26.83 | 31 | 29 | 28.94 | 24.5 | 35 | 28 | 29.11 |

Where: M=Morning,
A=Afternoon
E=Evening

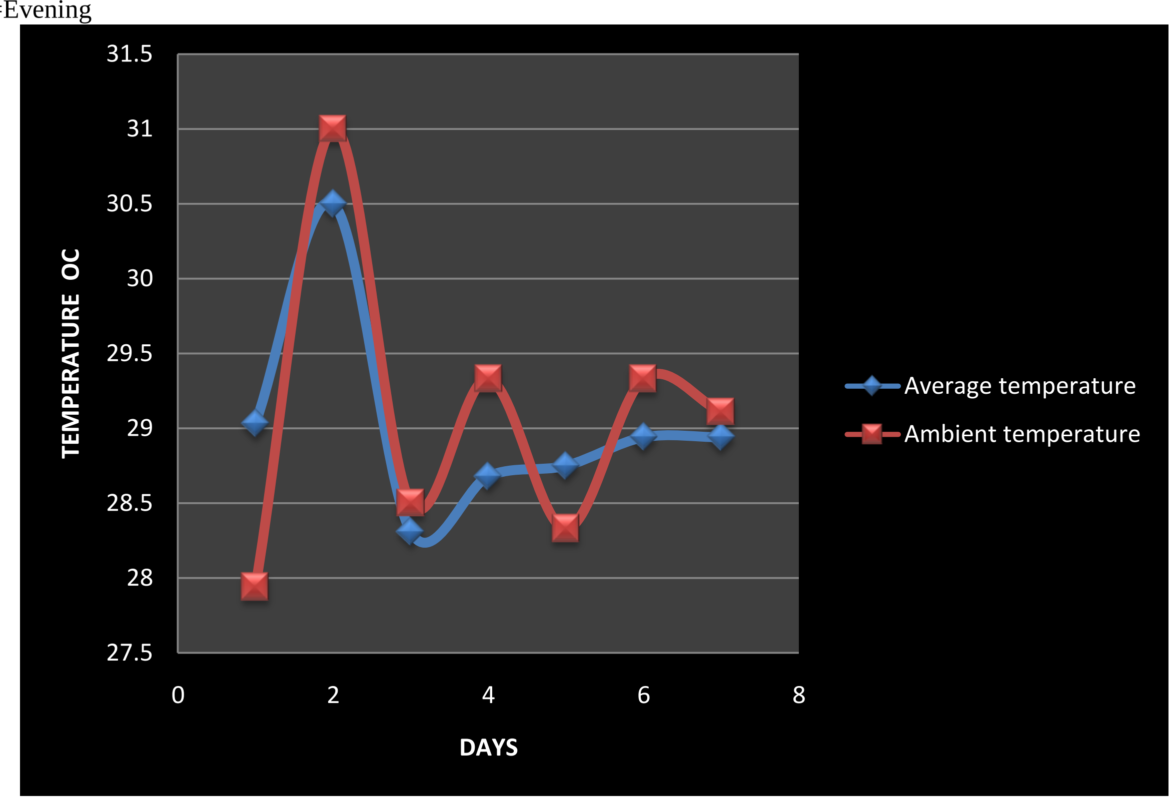


**Figure.5. Fluctuation Of Digester Temperature**

Plotting these values in table 3 against number of days resulted into the graph in Fig. v. It was observed that the temperature of the digester before the retention time, is on the average lower than the ambient temperature by a range of 2-3$^{o}$C for both morning and evening. This implies that the methanogenic bacteria were growing in population during this period. When the retention time elapsed, the temperature of the digester was observed to be greater than the ambient temperature particularly in the morning and evening, an indication that the methanogenic process has increased hence biogas production has begun.

**Biogas production rate**

During the retention time the biogas production was obtained by measuring the volume of the biogas produced in every twenty four (24) hours. This analysis was carried out after the first production of the biogas was expelled from the digester due to large amount of air present. Twenty four (24) hours after the expulsion, the following results were obtained.

**Table.4. Volume of Biogas Generated (With a Production Rate Of 0.215litres/Hour)**

| S/N | Time collection after first production was expelled from the digester (hours) | Volume of biogas collected (Litres) | Accumulated volume (Litres) |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 2 | 24 | 3.5 | 3.5 |
| 3 | 48 | 5.0 | 8.5 |
| 4 | 72 | 7.0 | 15.5 |

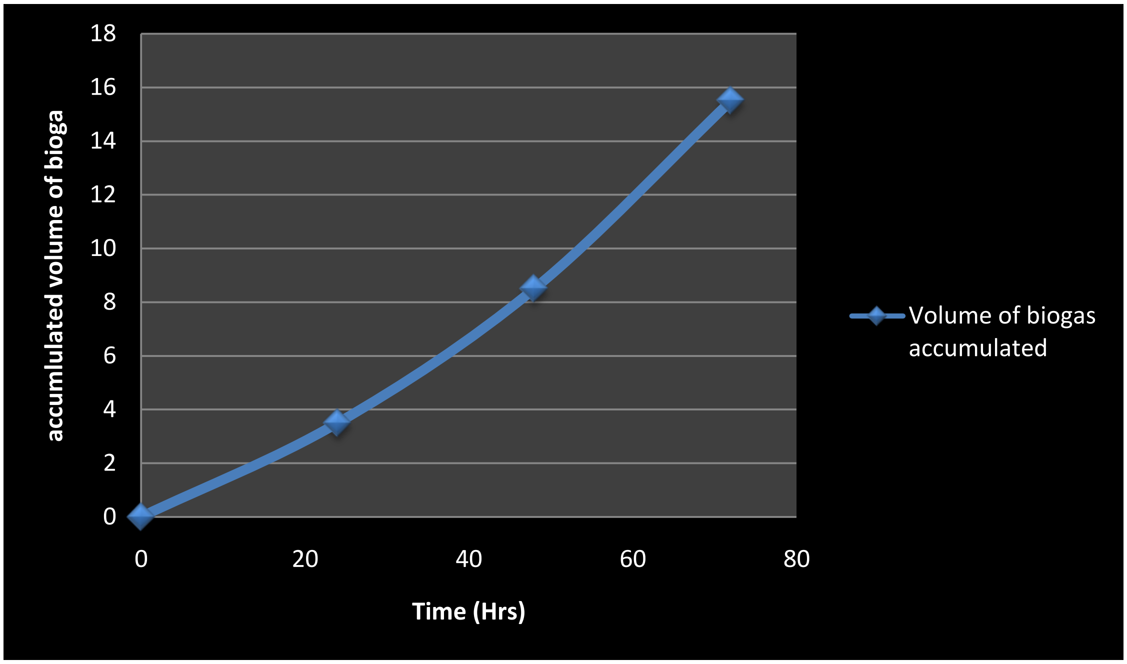


**Figure.6. Volume of biogas accumulated against time (hrs)**

**Combustion Test**

The combustion test carried out on the generated biogas for different days revealed that the methane content in the biogas improved on daily bases. A week after the first sample of the biogas was generated it was observed that it burnt satisfactory with a blue flame. Data obtained are as shown in Table. (v) below.

**Table.5. Combustion results**

| **No of days after the slurry was loaded into the digester** | **Volume of biogas combusted (Litres)** | **Remark** |
|---|---|---|
| 34 | 1.0 | Supported combustion |
| 35 | 2.5 | Slightly combusted |
| 36 | 3.5 | Improved combustion |
| 37 | 6.5 | Combustion satisfactory |

**Bubble Test**

This was carried out to achieve a partial cleaning of the generated biogas in a measuring cylinder.

## VI. CONCLUSION

A bio-digester was designed, constructed and tested. The biogas generation rate was 0.215litre/hr after a retention time of thirty four (34) days. Although the combustion of the initial biogas generated was unsatisfactory during combustion test probably due to large amount of incombustible gases, subsequent biogas generated was combusted for 10mintues to boil 1 litre of clean water. The biogas generated from this research was not analyzed due to time constrain but gives a characteristic blue flame of methane during combustion suggesting a high percentage of methane in the composition.

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**Recommendations for Further Research**

Further research in this field and or related fields should:

i) Vary the biomass fed (using different types) into the digester so as to make relative comparison with respect to volume of biogas generated between or among the feds.

ii) During construction of the biodigester, it is strongly advice that the stirrer handle be placed on the biomass holding element and not the biogas collecting element. This will to a very significant extent reduces leakages.

iii) Due to wearing effect on the internal diameter of the seal resulting from continuous usage; it is strongly advice to replace the seal periodically.

iv) Design and construct a gas collecting chamber with a specialized burner might result to effective combustion of biogas generated.

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