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DESIGN AND CONSTRUCTION OF A METALLIC BIO-DIGESTER FOR THE PRODUCTION OF BIOGAS FROM COW DUNG

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ABSTRACT
Biogas production has contributed greatly as an alternative source of fuel power to solving various developing nations' problems including high dependency on petroleum products. This gives a clear objective why its production is seriously needed, as it plays a significant role in destroying and converting municipal and agricultural wastes into a useful fuel which can be used in homes and on farms for lighting, heating and moving equipment by supplying the fuel power needed This work focused on design and construction of a metallic bio-digester for the production of biogas. Cow dung was mixed with water in ratio 1:2 of particulate mass. The experiment was carried out in a metallic digester under mesophilic temperature. The average retention time for the experiment was 30days. The average internal temperature of the biogas digester was 32.3°C. The total volume of biogas produced was 5.208m^3. The concentrations of methane and carbondioxide in the biogas produced were found to be 59% and 40% respectively. The developed metallic bio-digester has been found to be appropriate for the production of biogas from cow dung at mesophilic temperature.

Keywords: Digester, Cow dung, anaerobic digestion, hydraulic retention time, Biogas.

Introduction

Solid wastes generation rates have become a major concern worldwide and different issues about their disposal are still arising. Solid wastes have an average composition, on a weight basis, of 45% of yard wastes, 26% of food wastes, 13% of waste plastics, 12% of waste papers, 3% of waste textiles and 1% of waste metals whereby the vegetable and agricultural wastes account for more than 50% of the waste stream (Sadugh *et al.,* 2009). These can be converted to biogas *via* anaerobic digestion (Kashyap *et al.,* 2003).

Biogas is a term used to represent a mixture of different gases produced as a result of the action of anaerobic microorganisms on domestic and agricultural wastes (Ezeonu *et al*., 2005). Anaerobic digestion is the consequence of a series of metabolic interactions among various groups of microorganisms. It occurs in four stages, hydrolysis/liquefaction, acidogenesis, acetogenesis and methanogenesis (Kangle *et al.,* 2012**).** It usually contains 50% and above methane and other gases in relatively low proportions, namely; Carbondioxide (CO_2), Hydrogen (H_2), Nitrogen (N_2) and Oxygen (0_2) (Kalia *et al*., 2000). The mixture of the gases is combustible if the methane content is more than 50% (Agunwamba, 2001). Anaerobic digestion comprises of decomposition of organic material in the absence of free oxygen resulting to production of methane, carbondioxide, ammonia and traces of other gases and organic acids of low molecular weight (Lopes *et al.,* 2004).

There are a lot of digester types ranging from continuously stirred tank reactors (CSTR), plastic digesters, drums, etc. in use for biogas production. But, despite the increasing production and installation of biogas digester plants, there are some serious limitations that have not allowed biogas technology to make any real impact on the total energy scenario. They include:

- defects in construction of digester
- microbiological failure

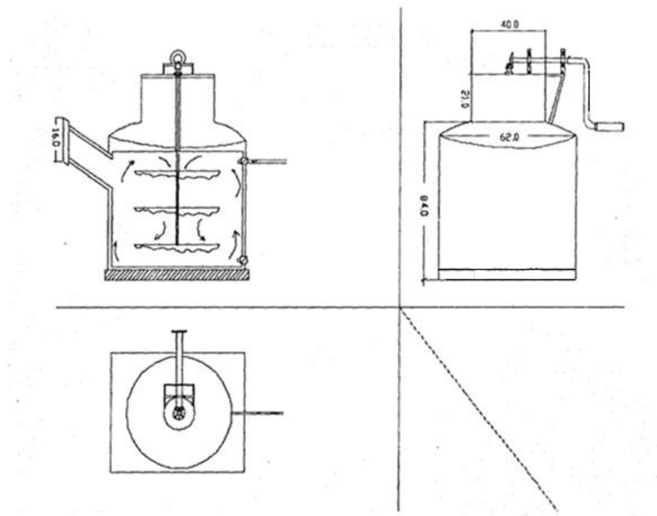
Materials and Methods

Plant Design Description

The biogas plant that was constructed consisted of a vertical cylindrical drum made of stainless steel. It has the following parts: inlet pipe (feed entrance), slurry outlet, gas outlet, stirrer (Manual), cover and the tank for digestion process. Figures 1 and 2 show the orthographic and isometric views of the designed bio-digester respectively.

Materials

The materials used for the design are; stainless steel, iron rods, steel pipes, tap key, rollers, bolts and nuts, bearing, rubber nut, gasket, hose and paint (Black)



ALL DIMENSIONS IN CM

Figure 1: Orthographic view of the digester

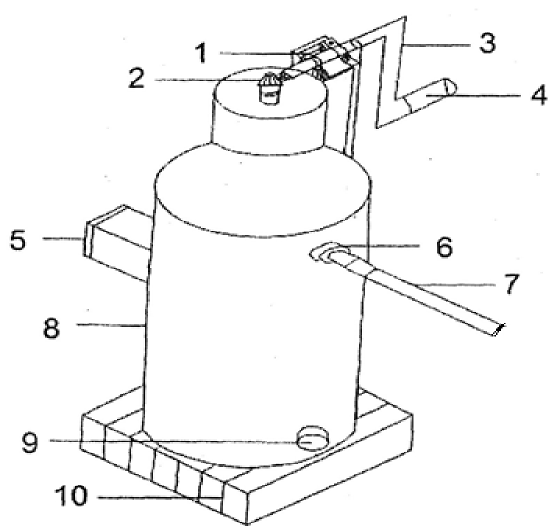


Figure 2: Isometric view of the digester

MATERIAL PARTS LIST

S/N	DESCRIPTION	QUANTITY	S/N	DESCRIPTION	QUANTITY
5	Feed inlet	1	10	Wooden stand	2
4	Stirrer handle	1	9	Slurry outlet	1
3	Stirrer	1	8	Digester body	1
2	Bevel gear	2	7	Rubber hose	2 yards
1	Angle iron	2	6	Gas outlet	1

Design Assumptions

The following assumptions were made in the course of the plant design:

- The height of the upper cylindrical part is 21cm
- The height of the trapezoidal base of the upper part is 5cm.
- Height of the lower cylindrical tank is 79cm.
- Length of shaft equals height of digester, but 10cm length of it is projected out of the tank to allow for fitting of the crank.
- The digester was designed to accommodate an average of $0.5m^3$ of slurry.
- Stainless steel (Yield stress, Y_s=200N/mm^2) was used as material for constructing the biogas plant and the shaft due to its corrosion-resistant property.
- The average continuous human power 0.75kW (4.5kJ/min), was used to design the shaft since the machine will be manually agitated (Suggs *et al.*, 1979).
- Number of crank turns, N = 40rpm as practically stated by Williams (1972).

Detailed Design Calculations

- **Capacity of the Biogas Digester**

The digester consists of the upper part and the lower part. The upper part is designed to have a cylindrical shape with a trapezoidal base while the lower part takes the form of a perfect cylinder

Diagram

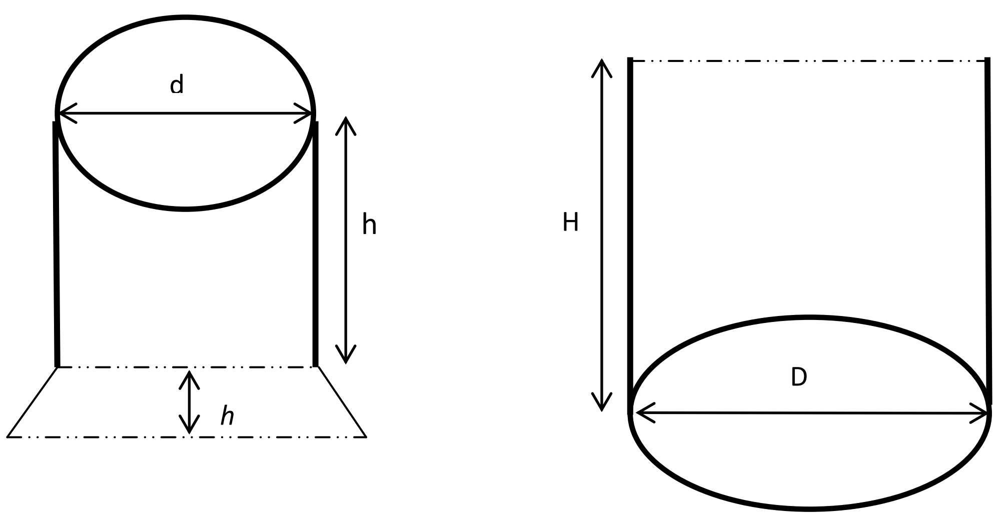


Figure 2.1: Upper part and lower part of the biogas digester

Design Calculations

- Volume of Digester, V_D = volume of upper part + volume of lower part

$V_D = V_U + V_L$

V_D = Volume of digester

V_U = Volume of upper part,

V_L = Volume of lower part.

- Volume of upper part = volume of the cylindrical part + volume of the trapezoidal base
- Volume of the upper cylindrical part, $V_U = \pi r^2 h$

Diameter, d = 40cm (0.4m)

Radius, r = 20cm (0.2m)

Height, h = 21cm (0.21m)

$$Volume, V_U = 3.142 \times 0.2^2 \times 0.21$$

$$V_U = 0.026m^3$$

- Volume of the trapezoidal base, V_t = Area of trapezoid * height

Upper length, a = 40cm (0.4m)

Base length, b = 62cm (0.62m)

Height, h = 5cm (0.005m)

$$V_t = \frac{1}{2}(a+b) \times h \times h$$

$$V_t = \frac{1}{2}(0.4 + 0.62) \times 0.05 \times 0.05$$

$$V_t = \frac{1}{2}(1.02) \times 0.0025$$
$$V_t = 0.51 \times 0.0025$$
$$V_t = 0.00127m^3$$

- Total volume of upper part is = (0.026 + 0.00127) m^3 = 0.02727 m^3
- Volume of lower part = $\pi r^2 h$

Diameter, D = 62cm (0.62m)
Radius, *r* = 3 1cm (0.3 1m)
Height, *h* = 84cm (0.84m)

$$Volume, V_L = 3.142 \times 0.31^2 \times 0.79$$
$$V_L = 0.238m^3$$

- Total Volume of Digester = ($V_U + V_L$)

= (0.02727 + 0.238) m^3
= 0.265m^3

- The Total Height of Digester, H_D

H_D = H + h
H = height of upper part of the digester
h = height of lower part of the digester
H_D = 21 + 5 + 79
= 105cm (1.05m)

- Length of shaft, L_s

L_s = 105cm (1.05m)
Length of shaft inside the digester = 95cm (0.95m)
Length outside the digester = 10cm (0.1m)

Maximum Allowable Stress

The maximum allowable stress can be calculated from the formula; S_s=0.27Ys, as given by Eggling *et al*., (1979). Y_s is the ultimate yield stress for steel.

S_s = 0.27Ys
S_s = 0.27 x 200
S_s = 54MPa
S_s = 54N/mm^2

Diameter of Shaft, d

$$d = \sqrt[3]{\frac{5.1T}{S_s}}$$

(Eggling *et al.*, 1979)

T = torque transmitted through the shaft

$$T = \frac{9.55 \times 10^6 P}{N}$$
$$P = 0.75KW$$
$$N = 40rpm$$
$$T = \frac{9.55 \times 10^6 \times 0.75}{40}$$

T = 179062.5 *Nmm*

$$d = \sqrt[3]{\frac{5.1 \times 179062.5}{54}}$$
$$d = \sqrt[3]{16911.46}$$

d = 25.67 *mm*

Plate 1 shows the pictorial view of the designed and constructed bio-digester for the production of biogas.

Methodology (Material Preparation)

The dung from cattle was obtained from the abattoir called "Attenda" in Ogbomoso North Local Government area. The sample of this substrate was taken to the laboratory for analysis. The following were determined; ash content, volatile acidity, dry matter, moisture content, pH, nitrogen, phosphorus, potassium and carbon using standard methods.

The inlet pipe was closed and the valve and the screw pipe on the gas outlet and slurry outlet respectively were closed. Airtightness was ensured through a careful examination before charging the digester, cow dung-water mixture of about five gallons (0.02m^3) in ratio 1:2 was made first to undergo aerobic fermentation in an air-tight rubber container (Ukpai and Nnabuchi, 2012). This procedure is called 'chemical pretreatment.' Sodium hydroxide (NaOH) was added to the mixture to remove any presence of lignincellulotic material that may resist anaerobic decomposition of cow dung easily. Sodium hydroxide, which is a strong alkali, also prevents too much acidification that may build up in the mixture. Iron filings were also added to the pretreatment to facilitate the growth of methanogenic bacteria which feeds on acids and breaks down the substrate. The mixture was left for seven days.

The mixture was then added to newly-prepared cow dung-water mixture to initiate and speed up the digestion process. The newly prepared substrate was 0.143m^3 in volume, which makes a total of 0.163m^3 of substrate fed into the digester altogether. The whole set up was run for a period of four weeks (30days). The pH of the fresh cow dung was 7.3. The pH and temperatures were monitored during the experiment. The gas produced was collected using an improvised gas bag (tire tube).

Results and Discussion

Biogas production

Table 1 shows the results of the chemical analysis carried out on the fresh cow dung before and after digestion. The volume of biogas produced was 5.208m^3. The biogas produced was found to compose of 59% of methane (CH_4), 40% of carbondioxide (CO_2), 0.08% Hydrogen Sulphide (H_2S) and 0.003% of water vapour (Table 2). The average internal and external temperatures were 32.3 and 38.8^oC

respectively indicating that the experiment was carried out at mesophilic temperature (Table 3). The pH increased gradually until it became 8.2 after digestion which showed the breaking of volatile fatty acids by the methanogenic bacteria to produce neutral slurry.

Biogas Collection

The tire tube fitted to the gas outlet point was seen increasing gradually indication that biogas production was already taking place. Such was the way the gas produced was collected with tubes and stored in a cool dry place.

Table 1: Results of Chemical Analysis of Fresh Cow Dung

Components	Analysis before digestion (%)	Analysis after digestion (%)
Ash content	3.40	2.14
Volatile acidity	3.140	3.846
Dry matter	86.40	94.0
Moisture content	13.6	5.12
pH	7.3	8.2
Nitrogen	3.42	2.33
Phosphorus	0.74	0.81
Potassium	2.38	2.47
Carbon	4.75	5.42
Organic matter	8.17	9.60

Table 2: Percentages of the Components of Biogas

Component	% Composition
Methane (CH_4)	59.0
Carbondioxide (CO_2)	40.0
Hydrogen Sulphide (H_2S)	0.08
Water Vapour	0.003

Table 3: Average Temperature Readings during Biogas Production

HRT	Temperature (°C)	
Weeks	Internal	External
1st	33	38
2nd	34	39
3rd	33.5	40
4th	32.5	38
Average	32.3	38.8

HRT= Hydraulic Retention Time

Testing of biogas

The biogas produced was tested in a gas burner. A flexible hose which protruded from the outlet of the tube to the bottom mouth of the burner carrying the biogas to the burner as soon as the knob of the burner was released open. The flame of biogas burnt sparsely but strong enough to cook if produced in large volumes. The sparsely burning flame was as a result of carbon dioxide present in the gas. The gas burnt with a bright yellowish flame when the knob of the burner was completely open and also showed bluish flame when the knob was slightly closed to release lesser gas (Plate 2). Biogas burning rate was compared with other fuel. Biogas burning rate was compared with other fuels. Table 4 shows the results of the boiling of 1005cm^3 (0.001005m^3) of water in an aluminium pot using biogas, kerosene and natural gas.

Plate 1: Digester after construction

Boiling of water using biogas took a higher duration when compared to kerosene and natural gas. This can be attributed to the presence of carbon dioxide in the biogas. Nijaguna (2006) reported that the presence of carbon dioxide in biogas reduces the flame temperature and speed of biogas in utilization devices and there is a need for its removal. This can be done using a water scrubber or dissolving the biogas in organic liquid reagents like MEA (Monoethanolamine), DE (Diethanolamine) and TEA (Triethanolamine) all of which have high capacity for physically absorbing carbon dioxide (CO_2) (Nijaguna, 2006).

Plate 2: Biogas testing with a burner

Table 4: Time Variations of Biogas Testing with other Fuels (Kerosene and Domestic Gas)

Fuel	Duration of Boiling
Biogas	15 minutes 21 seconds
Kerosene	8 minutes 12 seconds
Gas	7 minutes 5 seconds

Conclusions

It can be concluded that biogas production took place after a minimum retention time of four weeks from microbial digestion of cow dung in an anaerobic condition. A biogas digester that is air-proof is a necessary design for this. It can be stated that pretreatment of cow dung for partial digestion before charging fully the digester speeds up the anaerobic digestion process. Biogas production under a mesophilic temperature (between 20 and 45 °C) is possible while using an air-tight biogas digester.

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