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Research Article

Design and Fabrication of a Plastic Biogas Digester for the Production of Biogas from Cow Dung

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Biogas digester dimensions and materials of construction are important factors of consideration during the design and fabrication phase. The aim of this study is to provide a detailed analysis of the design and fabrication of a 2.15 m^3 pilot plastic biogas digester for biogas generation. To establish this, a design equation covering the volume of the digester, inlet and outlet chambers, and digester cover plate were developed considering the shape of the digester. The digestion chamber of the biogas digester under study was fabricated using high-density polyethylene (HDPE) plastic, while the inlet and outlet chambers were constructed with bricks/cement. The study was motivated due to some limitations such as leakage associated with previous designs. In the present study, a ventilation test was conducted after the fabrication to ensure the digester is leak free. Results obtained showed a total volumetric methane gas yield of 2.18 m^3 (54.50%) and carbon dioxide yield of 1.77 m^3 (44.25%) making up a total biogas yield of 4.00 m^3. In addition, the percentage concentration of methane and carbon dioxide were found to be 60% and 30%, respectively. The developed plastic biogas digester has been found to be appropriate for biogas production using cow dung as substrate.

1. Introduction

For future energy security and improvement in the use natural resources, the depletion of conventional energy resources such as fossil fuel can be solved by the use of renewable energy sources. In the midst of numerous renewable energy sources and their production means is the sustainable generation of biogas through anaerobic digestion technology [1]. Anaerobic digestion is a microbial process whereby organic carbon are converted by subsequent oxidation and reductions to its most oxidized state (CO_2) and reduced form (CH_4). It is a biological route that is catalyzed by the activities of microorganism in the absence of oxygen [2]. Biogas is a gaseous fuel obtained from waste fermentation, which is of interest in producing energy for electricity, cooking, heating, and biofuels for vehicles [3, 4]. The production of biogas from waste fermentation offer some additional benefits, namely, reduction in pathogens, foul odor, and methane emission from landfill sites where these wastes are ordinarily disposed. Anaerobic digestion of organic waste in digesters occurs in four stages, namely, hydrolysis, acidogenesis, acetogenesis, and methanogenesis in a system called biogas digester [5]. These four stages results in production of biogas comprising of methane (55–70%) and carbon dioxide (30–45%) with traces of other gases such as hydrogen sulphide, hydrogen, and nitrogen [3]. Interestingly, biogas is considered a low carbon fuel source, which is of interest to rural communities in meeting their energy need for cooking.

Biogas digesters are mostly designed and constructed using bricks, cement, metals, and reinforced concrete, while in some cases, the dome of the gas holder is made up of fiberglass. These biogas digesters encounter some challenges such as leakages at the edges of the brick structure after a short period of operation. There are some few biogas digester designs that utilize reinforced plastic; however, some of the reinforced plastic of the biogas digester deteriorates and creates holes due to the effect of ultraviolet (UV) radiations. Furthermore, the effect of corrosion that mostly occurs in biogas digesters built from metals results in their failure. In addition to the limitations aforementioned, the construction of the biogas digester using bricks or cement block is quite expensive due to high labor cost and materials. To overcome these weaknesses and challenges associated with the various materials mentioned, an alternative construction material was investigated in this study. Therefore, to minimize the high cost of construction of these previous designs, a more cost-effective design is proposed. Thus, the study employed a high-density polyethylene (HDPE) plastic to fabricate the digestion chamber and bricks/cement for the construction of inlet and outlet chambers. The choice of a plastic for the study is based on it being noncorrosive, a good insulator, cost-effective, and easy to maintain. The uniqueness of the present study stem from the use of composite materials (bricks/cement and plastic). Another factor that made the present study different from previous design is the subjection to the ventilation test to ensure leak free, which will result to more biogas yield and production. The introduction and use of this technology involving composite materials will help to generate biogas for research purposes and serve as a perfect fertilizer used in the university farm; all these motivated the need for this study. Therefore, the study fills this knowledge gaps existing in biogas digester designs, hence making it easier to consider a composite material for biogas digester design. The aim of the study was to design and fabricate a biogas digester using high-density polyethylene (HDPE) as an alternative material of construction/fabrication. The detailed knowledge of the design equations and the nature of material used in the construction of the biogas digester will be helpful to the energy engineer, researcher, and academic contributions to the development of biogas technology. Hence, the objective of the study is to formulate a design equation used for the construction of the biogas digester and to carry out a ventilation test to certify the digester a leak free one, which is not usually common in previous studies.

2. Studies on Designs and Fabrication/Construction of the Biogas Digester

This section presents the design equations used to determine the volume of the digesters from various authors and the material used for the fabrication and construction. The volume of the digester was taken as the response parameter because it determines the rate of the biogas yield. Agu and Igwe [6] conducted a study on the design and construction of an indigenous biogas plant from plastic with the aim of generating alternative energy from animal wastes. The equation considered in their study includes the volume of the slurry chamber and the volume of the gas chamber. The volume of the digester chamber (slurry chamber) was calculated using

$$V = \prod r^2 h. \tag{1}$$

The gas chamber has a shape of frustum from which a cone-like shape was obtained. Hence, the volume of the frustum was obtained from the volume of a large cone and a small cone. Mathematically, this is given as

$$V = \left(\frac{1}{3}\prod R^2 H - \frac{1}{3}\prod r^2 h\right). \tag{2}$$

The study resulted in a biogas yield of 0.0000053 m^3 considering a 20 days retention time. However, the volume of the biogas digester was not reported in the study. Bello and Alamu [7] designed and constructed a metal biogas digester aimed to provide solution towards exploration and development of biogas in rural communities. The volume of the digester chamber (Vdc) was determined using

$$\prod r_1{}^2 h_1 + \frac{1}{3}\prod r_1{}^2 h_2 + \prod r_2{}^2 h_3. \tag{3}$$

While the volume of the gas chamber (V_{gs}) was calculated using

$$\prod r^2 h_1 + \frac{1}{3}\prod r^2 h^2. \tag{4}$$

The digester volume was reported to be 0.048 m^3 with a biogas yield of 0.035 m^3. Another study designed and fabricated a low-cost plastic rectangular-shaped digester, fed with poultry and pig manure. Mathematically, the digester chamber volume was determined using

$$V_d = L \times B \times H. \tag{5}$$

From equation (5), the volume of the digester chamber and gas storage chamber were found to be 0.6 m^3 and 0.4 m^3, respectively. This gives the total volume of the biogas digester to be 1 m^3. This digester gave a biogas yield of 6.66 m^3 for 30 days retention time [8]. In Jekayinfa et al.' [9] study, the total volume of the digester presented in equations (6) and (7) was obtained from a combination of upper cylindrical volume and lower cylindrical volume of the digester.

$$V_d = Vu + VL, \tag{6}$$

$$V_d = \prod r^2 h + \prod r^2 h. \tag{7}$$

This gave a total biogas digester volume of 0.265 m^3. Nwankwo et al [10] designed and fabricated a household plastic biogas digester. The total volume of the digester was determined using

$$\begin{aligned} V = {} & V_c\,(\text{volume of gas collecting chamber} \leq 25\%V) \\ & + V_f\,(\text{volume of fermentation chamber} \leq 25\%V). \end{aligned} \tag{8}$$

This resulted in a total volume of 3.6 m^3 with a biogas yield capacity range of 0.50–0.60 m^3/day using cow dung. In the study by Mukumba et al. [11], a surface cylindrical biogas digester was designed and constructed to generate biogas through anaerobic codigestion of donkey manure and vegetable waste. The total volume of the digester was calculated using

$$V = V_{\mathrm{GA}} + V_{\mathrm{GB}} + V_{\mathrm{GC}} + V_{\mathrm{GD}}, \tag{9}$$

where volume of gas collecting chamber $= V_{\mathrm{GA}}$. Volume of gas storage chamber $= V_{\mathrm{GB}}$. Volume of fermentation chamber $= V_{\mathrm{GC}}$. Volume of the sludge layer $= V_{\mathrm{GD}}$. [11]

A total digester volume of $1\,\mathrm{m}^3$ was obtained from equation (9), and this generated approximately $12.98\,\mathrm{m}^3$ biogas in 30 days. Having considered the previous design and fabrication/construction of the biogas digester from selected authors, Table 1 summarizes the results of the previous designs.

3. Materials and Methods

3.1. The Context of the Study. The biogas digester was installed at the Solar Watt Park of the Institute of Technology Research Centre, University of Fort Hare Alice, South Africa. The geographical coordinates of the University are as follows: latitude 32°47′24.48″ South and longitude 26°46′35.02″ East. However, the exact geographical coordinates of the study site are as follows: latitude 32°47′1.28″ South and longitude 26°51′15.10″ East with an elevation of 1905 feet, as shown in Figure 1. The average temperature range of the site during summer season (November–March) is from 25°C to 30°C and winter season (May–August) is from 10°C to 15°C. The study site experiences an annual rainfall of 713 mm. The digester was installed for the purpose of research, which serves as a pilot study for rural community engagement. Due to availability of cow dung in the University farm, the digester was fed with cow dung.

Figure 1 shows the geographical location of the study site.

3.2. Description and Fabrication of the Biogas Digester System. The biogas digester of the present study was made from a high-density polyethylene (HDPE) plastic. It has the following parts: the inlet chamber (feed entrance), outlet chamber (removal of digested waste), and the gas storage chamber. The inlet and outlet chambers were built with bricks and cement mortar, which were made locally out of a mixture of cement and sand. The inlet chamber was connected to the digester chamber via an inlet pipe made of Ø 110 cm PVC pipe, inclined at an angle of 28° to the vertical, while the outlet chamber was connected using a 300 cm PVC pipe. The dimensions of the inlet chamber were 895 mm and 985 mm for the height and width, respectively, while that of the outlet chamber were 1290 mm for the height and 1430 mm for the width. The fabricated biogas digester was installed underground and above-ground as shown in Figure 2. A four equal-sided plain wood was used as cover for the inlet and outlet chambers to prevent impurities from entering the chambers. The digester cover was made of the same HDPE plastic material that could withstand harsh environmental conditions and still maintain anaerobic condition. The slurry and gas temperature were monitored using a K-type thermocouple inserted into the digester through the cover of the digester.

3.3. Material Preparation. The cow dung was collected from University of Fort Hare Diary Farm, and some samples of it were subjected to laboratory analysis. The following physiochemical characteristics were determined prior to the cow dung being fed to the digester: total solids, volatile solids, chemical oxygen demand, calorific value, and pH. Table 2 presents the physiochemical characteristics of the cow dung used in the study. Prior to the digestion process, the slurry was obtained by diluting solid waste (cow dung) with water at a ratio of 1 : 1 (waste/water) to ensure that the percentage of the total solids was less than 10%. The biogas digester was fed with 200 L of slurry on the first day and subsequently with 50 L every three days. After the first day of feeding, the gas valve was left open for 72 hours to allow expulsion of any air [13].

3.4. Experimental Procedure and Measurement

3.4.1. Volume of the Digester. The volume of the designed and fabricated biogas digester is $2.15\,\mathrm{m}^3$ size. Total digester volume took into consideration digester neck volume (V_n) where the digester cover was fixed, gas storage volume (V_{gh}), and the slurry or fermentation chamber volume (V_{fc}). For the fabrication of the biodigester, the design calculation of the digester neck, gas storage section, and slurry chamber were considered. After the fabrication of the digester chamber, the actual digester volume was determined by measuring the dimension of other components using the builder's meter. Figure 3 shows the schematic design calculation of the volume of the biogas digester.

The three shapes used in describing the different compartments of the biogas digester include the cylindrical shape that formed the neck, the spherical shape (for gas storage), and the frustum shape of the slurry chamber. The volume of each of these shapes contributed to the total volume of the biogas digester.

The following parameters were used in the calculation:

No. of sides = 12 sides
Length of each side of the bottom stage = 0.36 m
Length of each side of the top stage = 0.39 m
Apothem length of the bottom and top stage = 0.65 m
Height of the digester = 1.70 m
Height of the hemispherical part = 0.73 m

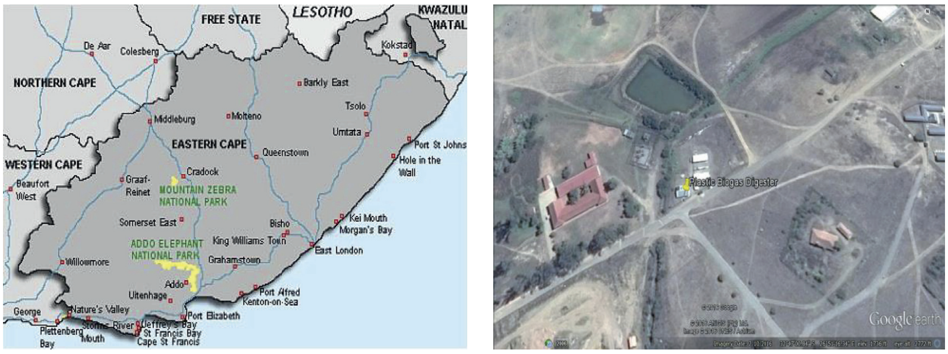
First, considering the biogas digester neck, the volume is determined as

$$V = \pi r^2 h, \tag{10}$$

where $r = 0.15$ m, the radius of the neck of the bio digester, and $h = 0.12$ m, the height of the cylindrical shape. Therefore,

Table 1: Summary of previous design of biogas digesters with their gas yield.

Type of material	Volume of digester (m^3)	Feed stock used	Biogas yield (m^3)	References
Plastic	—	Cow dung + poultry waste + pig dung	0.0000053	Agu and Igwe [6]
Metal	0.048	Cow dung + buffalo dung	0.035	Bello and Alamu [7]
Plastic	0.03	Cow dung	0.18	Jyothilakshmi and Prakash [12]
Plastic	1	Poultry + pig manure	6.66	Anaswara [8]
Metal	0.265	Cow dung	5.20	Jekayinfa et al. [9]
Plastic	3.6	Cow dung	0.50–0.60	Nwankwo et al. [10]
Brick/cement	1	Donkey manure + vegetable waste	12.98	Mukumba et al. [11]
Plastic	2.15	Cow dung	4.00	Present study



(a) (b)

Figure 1: Map showing the Eastern Cape Province of South Africa, and besides, it is the exact location of the study site.

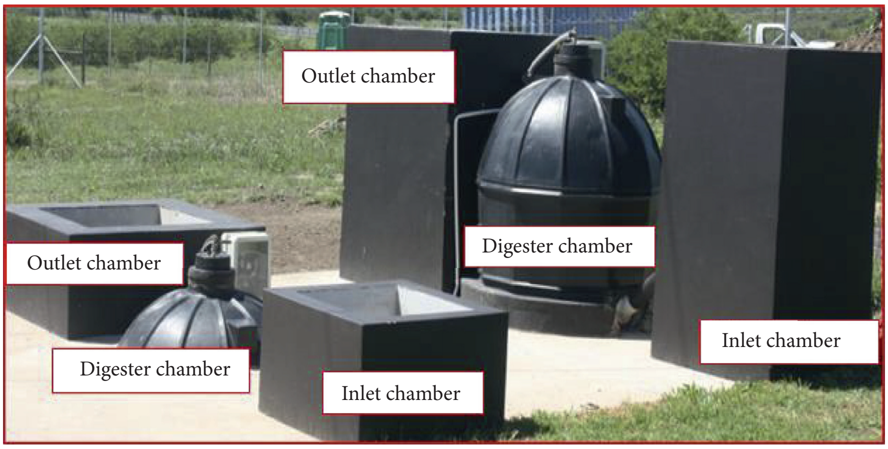


Figure 2: The designed installed biogas digester [13].

Table 2: Properties of fresh cow dung used in the study [13].

Properties of cow dung	Values	Test method used
pH	7.83 at 30°C	Hydrogen-electrode method
Total solids (TS) g/L	130 800	ALPHA 2005 method
Volatile solids (VS) g/L	110 476	ALPHA 2005 method
Chemical oxygen demand (COD) g/L	42 583	Calorimetric method
Calorific value MJ/g	27.00	Direct method

the volume of the neck (V_n) of the digester neck was obtained to be 0.01 m^3.

Second, for the gas storage section, the volume of the hemisphere = $2/3\,(\pi r^3)$

Here, the radius (r) of the hemisphere is 0.67 m. Therefore, the volume of the hemisphere is $(2/3)\pi(0.67)^3 = 0.64\ m^3$. Hence, the volume of gas storage (V_{gs}) is 0.64 m^3.

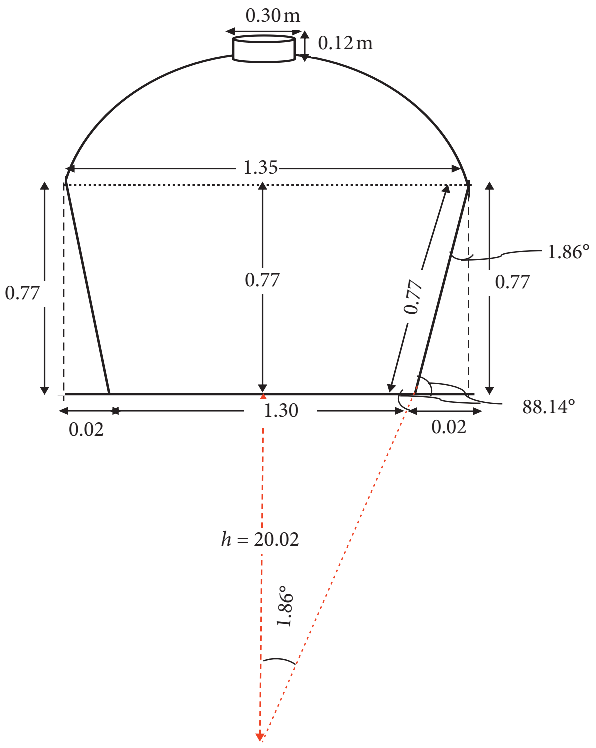


FIGURE 3: The design calculation of the volume of the biogas digester (all measurements are in meters).

Finally, the volume of the slurry or fermentation chamber is calculated from the volume of the frustum, which is equal to the volume of the large pyramid-volume of the small pyramid. The volume of pyramid (either large or small) is calculated as

$$\frac{1}{3}\times \text{area of base} \times \text{height}, \tag{11}$$

where h is known as the apothem length.

Hence, the volume of the large pyramid $= (1/3) \times [12 \times (1/2)(0.39) \times 0.67] \times 20.79 = 10.86\,\text{m}^3$.

And the volume of the small pyramid $= (1/3) \times [12 \times (1/2)(0.36) \times 0.65] \times 20.02 = 9.37\,\text{m}^3$.

This results in a frustum volume of $1.49\,\text{m}^3$, which represents the volume of the slurry chamber (V_{sc}).

Therefore, the total volume of the fabricated biogas digester was found to be $2.15\,\text{m}^3$ derived from equation (13).

$$(V_D) = V_n + V_{gs} + V_{sc}. \tag{12}$$

The volume of the digester chamber was chosen on the basis that the design is a small family size digester that could be used to meet family cooking need, since the study is a pilot study for installation of biogas digester in rural communities. Other criteria considered in the choice of volume include the availability of feed stock and retention time. The angle employed in the design was to avoid building a rectangular shape of 90° that may result in clogging or dead zone. This in turn might cause a reduction in biogas production. Hence, the digester chamber was built in an inclined angle of 88.14°. This will enable the smooth downward flow of slurry from the inlet chamber. A continuous feeding mode was employed in the digester. Although the volume of the biogas digester ($2.15\,\text{m}^3$) falls within the batch operation, however, a continuous feeding was preferred because of the adequate metabolism associated with it. Moreover, the bacteria growth rate are also more in continuous compared to batch feeding [14], which helps during the production of biogas. The schematic layout of the designed biogas digester is shown in Figure 4.

3.4.2. Inlet and Outlet Chambers Volume. The geometric configuration of the inlet and outlet chambers of the constructed biogas digester is a rectangular prism. Inlet and outlet chambers of the biogas digester were built a little above the fabricated digester to create pressure for enhanced biogas production.

The volume of the inlet chamber $= L \times W \times H = 0.75 \times 0.68 \times 0.81 = 0.41\,\text{m}^3$.

The volume of the outlet chamber $= L \times W \times H = 0.96 \times 0.96 \times 1.78 = 1.64\,\text{m}^3$.

Figure 5 shows the calculated volume of the inlet and outlet chambers of the biogas digester and the pressure exerted on the inlet and outlet chambers.

3.4.3. Inlet and Outlet Chambers Design Calculation in Terms of Pressure. The schematic view of the biogas digester in Figure 5 illustrates the calculation of the pressure exerted by the inlet and outlet chambers.

Assumption 1. The forces in input and output chamber are equal.

Keys:

V_{inlet} = volume of the inlet chamber
V_{outlet} = volume of the outlet chamber
V_{sc} = volume of the slurry chamber
V_n = volume of the neck of the digester
V_{gs} = volume of the gas storage
P_{inlet} = pressure in the inlet tank
P_{outlet} = pressure in the outlet tank

Pressure defined as the force per unit area is mathematically given as

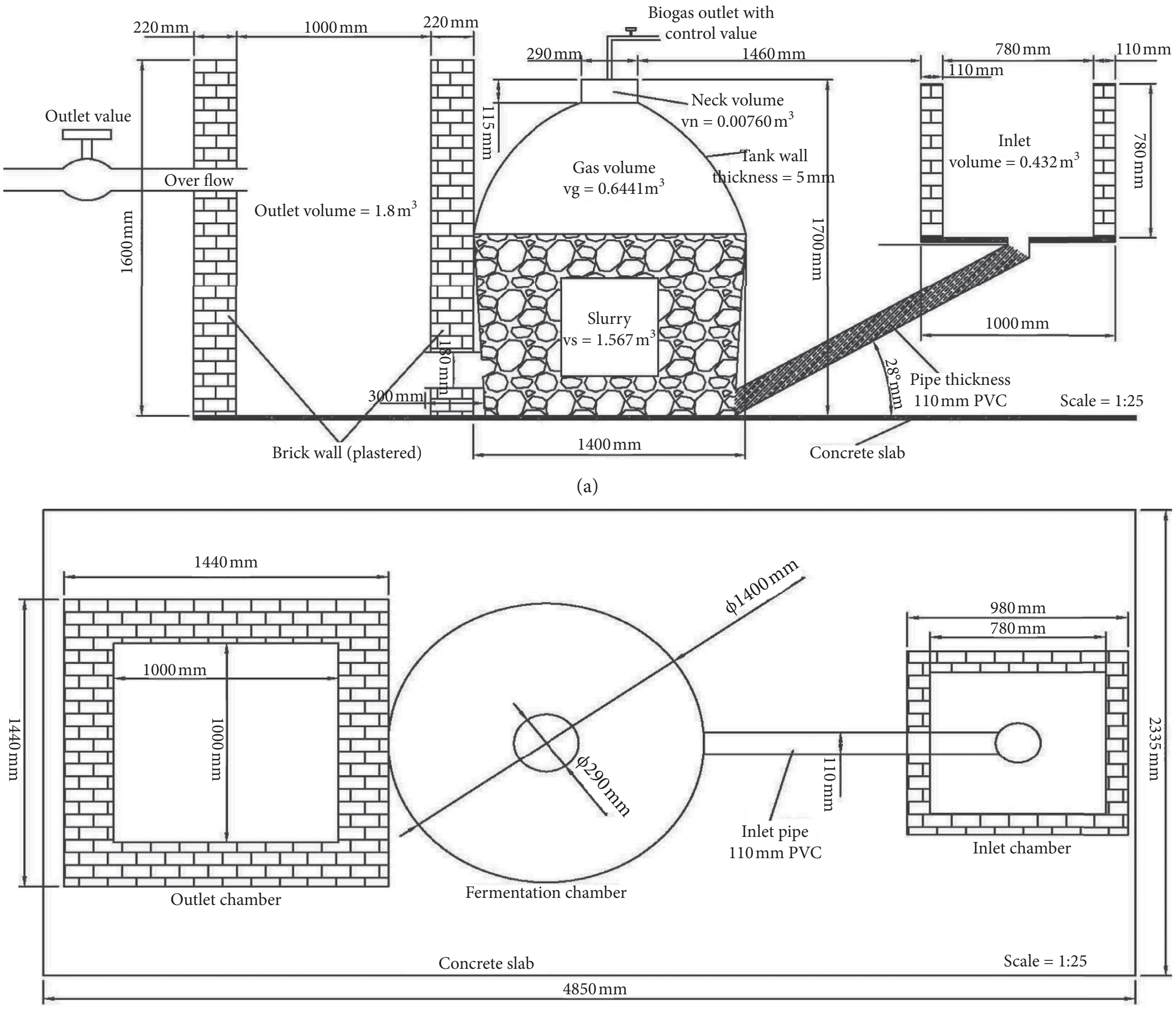
$$\vec{P} = \frac{\vec{F}}{A}. \tag{13}$$

Hence, the pressure in the outlet tank is given by

$$\vec{P}_{\text{outlet}} = \frac{\vec{F}}{A_{\text{outlet}}}. \tag{14}$$

While the pressure in the inlet tank is given by

$$\vec{P}_{\text{inlet}} = \frac{\vec{F}}{A_{\text{inlet}}}. \tag{15}$$



(a)

(b)

Figure 4: Schematic layout of the designed biogas digester system showing the front and above view. (a) View of the fabricated digester from front. (b) View of the fabricated digester from above.

The inlet chamber with an angle of 28° to the digester chamber acts on a resultant force F^1 with a mass (Mg) of the downward movement of the slurry to the digester chamber.

Introducing Cos θ as the angle,

$$\vec{P}_{\text{inlet}} = \frac{\vec{F}\,\text{Cos}\,\theta}{A_{\text{inlet}}}. \tag{16}$$

Making F the subject of the formula gives

$$\vec{F} = \frac{\vec{P}_{\text{inlet}} A_{\text{inlet}}}{\text{Cos}\,\theta}. \tag{17}$$

From equation (17),

$$\vec{F} = \frac{\vec{P}_{\text{outlet}}}{A_{\text{outlet}}}. \tag{18}$$

Substituting equation (18) into equation (16) gives

$$\vec{P}_{\text{inlet}} = \left(\frac{\text{Cos}\,\theta}{A_{\text{inlet}} \times A_{\text{outlet}}}\right)\vec{P}_{\text{outlet}}. \tag{19}$$

The inlet pipe is of circular diameter; therefore, the area of a circle is πr^2. Where $r = 55$ mm.

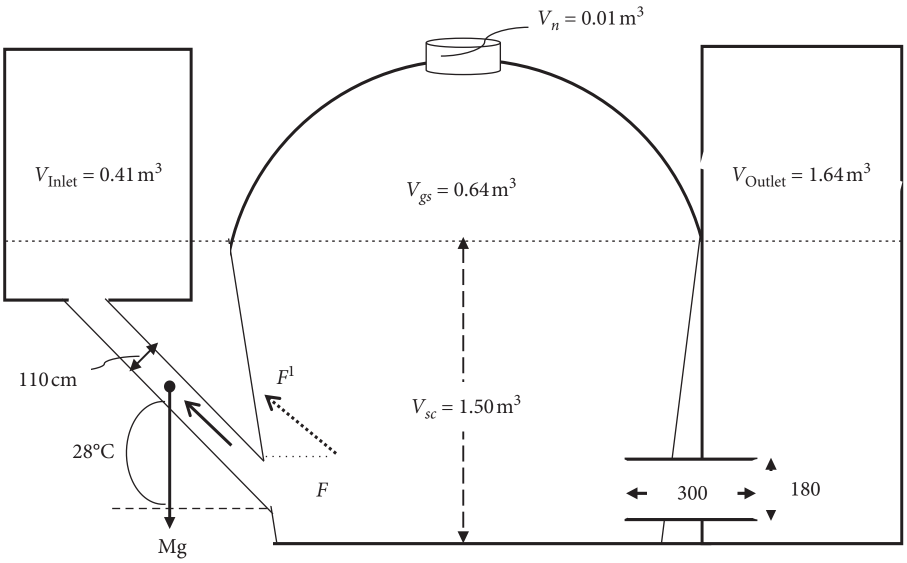


FIGURE 5: Inlet and outlet chambers based on the pressure.

The area of the outlet (A_{outlet}) = length x breadth. Where the length was 300 mm, and the breadth was 180 mm.

Substituting these values,

$$\begin{aligned}\vec{P}_{\text{inlet}} &= \left(\frac{0.8830}{3025\pi \times 300 \times 180}\right)\vec{P}_{\text{outlet}},\\ \vec{P}_{\text{inlet}} &= \left(\frac{0.8830}{513179160}\right)\vec{P}_{\text{outlet}},\end{aligned} \tag{20}$$

$P_{\text{inlet}} = 1.720 \times 10^{-9}$ (which is less than 1). Therefore, $P_{\text{inlet}} < A_{\text{outlet}}$

From the above calculation, assuming all forces are equal, the *F* component in the inlet chamber will be less than the *F* component in the outlet chamber. This indicates that the pressure in the outlet chamber will be greater than that of the inlet chamber. Hence, as gas was produced at the top of the biogas digester, pressure was exerted in the outlet chamber. This is why the volume of the outlet chamber is greater than the inlet chamber.

3.4.4. Digester Cover Plate Design. The digester cover plate was made from the same material (HDPE) used for fabrication of the digester. The placing of gas storage over the slurry unit or digester chamber can induce stress on the cover plate. Thus, the cover plate was firmly sealed to the digester using a heat gun. In addition, the bottom lid plate was clamped in order to resist any force exerted by the gas pressure. The cover plate assisted in ensuring that there was no gas leakage. The diameter of the cover plate was 120 mm, and the neck of the plate was 30 mm with a thickness of 0.5 mm.

3.4.5. Pipe Design. Factors considered during selection of the appropriate plastic material for inlet and overflow pipes are as follows:

Material type and size
Thermal expansion and temperature effect
Maintenance ease and installation
Safety, in terms of the design factor, and
Adequate support

The inlet pipe is cylindrical in shape, and the bursting pressure was calculated using the following equation:

$$P_b = \frac{2 \times S_T \times t_m}{D_m}, \tag{21}$$

where P_b is the bursting pressure in psi. S_T is the tensile strength of the pipe (52 Mpa). t_m is the minimum wall thickness of the pipe (2.2 mm). D_m is the mean diameter (110 mm)

Using equation (21) and substituting the values, the calculated bursting pressure (which is the difference between the internal and external pressure) is given as $P_b = 2.08$ psi.

3.4.6. Gas Valve Design. The gas valve is of similar size as the gas outlet pipe; however, this scenario does not always hold. Usually, the valve size is determined by the valve orifice and shape of the valve plug. The flow rate and expected pressure drop across the valve were factors considered in sizing the gas valve. Some other parameters considered in determining the size of the gas valve were dependent on the gas and flow regime. This includes gas flow, laminar or turbulent flow, incompressible or compressible flow, nonideal gas effect, and limit on outlet velocity to prevent shock waves and noise. The type of gas valve used was the ball valve.

Considering the pressure drop expected across the gas valve to the flow rate of the gas and the size of the gas valve, the Bernoulli equation was applied.

$$E = \frac{(P_1 - P_2)}{\rho}. \tag{22}$$

Introducing the frictional loss term, the Bernoulli equation is expressed as

$$E = K\frac{V_{o^2}}{2gc}, \tag{23}$$

where K is an experimentally determined factor, which is the frictional loss factor of the gas valve. Combining equations (22) and (23) will result in

$$V_0 = \left(\frac{2gc\left(P_{1-}P_2\right)}{K_\rho}\right)^{(1/2)}. \tag{24}$$

Dividing equation (24) by A_o and let $\rho = \rho w \eta$, where η is the specific gravity of the slurry.

Let the gas valve coefficient Cv be defined as

$$\mathrm{Cv} = 7.48\,(12)\,(60)\,A_o\left(\frac{2gc}{K\rho w}\right)^{(1/2)}, \tag{25}$$

$$Q = \mathrm{Cv}\left(\frac{\left(P_1 - P_2\right)}{\eta}\right)^{(1/2)}, \tag{26}$$

where equation (26) represents the gas valve equation.

3.5. Ventilation Test of the Biogas Digester. The ventilation test was conducted to ensure that the designed and fabricated biogas digesters were leak free. Hence, the underground and above-ground digesters were tested for leaks under high pressure. This was performed by filling the biogas digesters with CO_2 to levels close to 100% CO_2 content. The CO_2 gas pumped into the dome was measured using the CO_2 gas sensor. Under high pressure, it is most likely that existing leakages might be enhanced or new ones might even form. This condition is detrimental for potential biogas capture. Carbon dioxide gas was released into the biogas digesters at a specific rate. But a precaution was taken to ascertain that the dome maintained a closed system, to avoid the carbon dioxide leakages within or outside. Figure 6 shows the experimental setup for the ventilation test.

4. Results and Discussion

4.1. Material Preparation. Table 2 shows the results obtained from the determination of selected physiochemical properties of the cow dung used in the study.

The pH influences the activity of microorganism in destroying organic matter into biogas, whereas the total solids are useful in determining the organic loading rate of the biodigester and to predict when maintenance is needed. Volatile solid is used in estimating the quantity of the substrate that has the potential to produce methane, while the chemical oxygen demand provides information on how much energy is contained in the sample. The calorific value determines the heat of combustion or calorific value of any solid or liquid.

4.2. Digester Volume. Table 3 shows the values obtained from the calculation of various components of the designed biogas digester and the gas yield. The effective designed calculated volume of the digester was 2.15 m^3. The 2.15 m^3 biogas digester produced a biogas yield of 4.00 m^3.

A digester volume of 2.15 m^3 obtained in this study is a typical digester volume capable of providing the energy cooking need of a family of four. With a biogas yield capacity of 4.00 m^3, a total energy of 4 kW/h can be obtained.

4.3. Biogas Production. The designed and fabricated 2.15 m^3 biogas digester was installed above-ground and underground. Biogas yield was made possible by the action of anaerobic bacteria in the presence of moisture and in the absence of oxygen. The performance of the biogas digester in terms of biogas yield was measured over the 18 days retention period and are presented in Figure 7. The biogas digesters were fed with cow dung manure at a mixing ratio of 1 : 1 for slurry and water.

From Figure 7, it is observed that biogas production was initiated from day 1; however, the methane yield was low about 0.05 m^3 in both above-ground and underground digesters. This is due to the lag phase of microbial growth, particularly the methane-producing microorganism. However, carbon dioxide (CO_2) gas exceeded methane (CH_4) gas from day 1 to day 5 in Figure 7 by approximately 0.05 m^3. The higher yield of CO_2 is attributed to the activities of acid-producing bacteria that convert fatty acids, amino acids, and simple sugar into acetic acid, hydrogen, and carbon dioxide [15, 16]. With the production of methane and carbon dioxide from day 1 as observed, it is evident that hydrolysis, acidogenesis, and methanogenesis process were initiated from day 1 but with lesser activities of the methane-forming bacteria. The production of methane gas from day 1 further proved that the three stages of anaerobic digestion were occurring simultaneously within the biogas digester as highlighted in Kangle et al. [17] and Prasad et al. [15, 18, 19]. The increase in the methane yield recorded in the biogas digester is associated to the presence of readily biodegradable organic matter in the cow dung and presence of the methanogens. In addition, the high methane yield is evident that the methanogenesis process of the anaerobic digestion is attaining its optimum stage indicating the full activities of the methane formers. A total volumetric yield of 2.18 m^3 (54.50%) and 1.77 m^3 (44.25%) were obtained for methane and carbon dioxide, respectively, from the biogas digester. Therefore, the total volume of biogas produced was 4.0 m^3. The optimum methane and carbon dioxide volume of the digester is 60.0% and 30.0% as shown in Table 4.

From Table 4, it is evident that the methane and carbon dioxide percentage composition of the digester was 60.0% and 30.0%, respectively. A methane composition of 67.9% and carbon dioxide composition of 27.2% recorded in a study exceeded that of the present study by 7.9% and 2.8% for the digester [20]. The discrepancy in values can be because of the longer retention time and temperature difference. However, various authors reported different values for biogas composition. Mukumba et al. [21] reported a methane composition of 40.0%–60.0%, carbon dioxide composition of 30.0%–45.0%, and 9.0% for the composition of other gases using cow dung. Oliveira and Doelle [22] reported an average methane composition of 73.0%, while

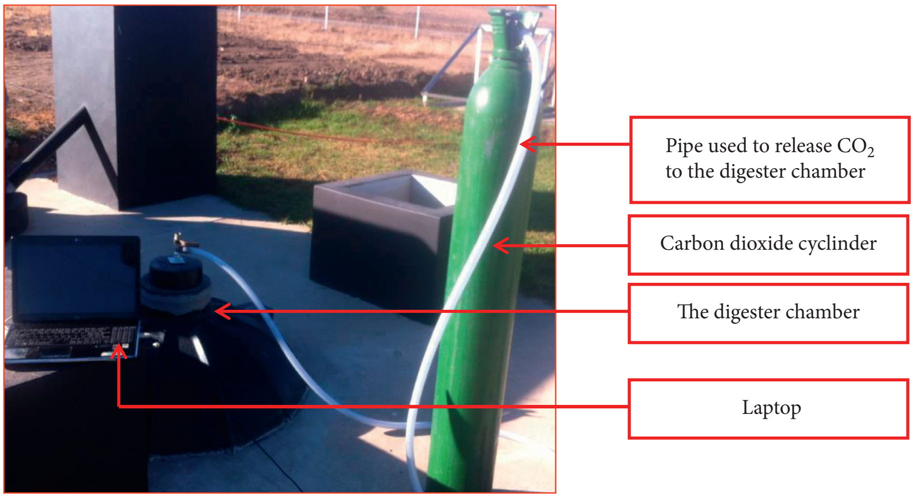


Figure 6: Experimental setup for the ventilation test.

Table 3: Determination of biogas digester components and gas yield.

Digester volume (m^3)	Inlet chamber (m^3)	Outlet chamber (m^3)	Gas yield (m^3)
2.15	0.41	1.64	4.00

Uncertainty on gas yield reported as ± 0.05 m^3.

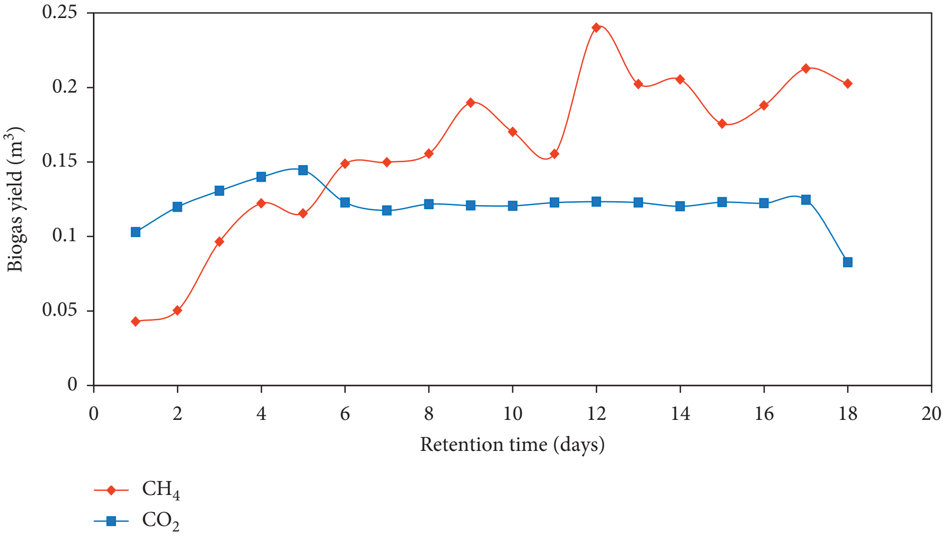


Figure 7: Biogas yield profile against time for the biogas digester [13].

carbon dioxide and other gases accounted for 27.0% using food waste. Furthermore, in a study conducted by Anaswara [8], optimum methane and carbon dioxide composition of 66.0% and 34.0% were recorded on the 23rd day of the experiment. The results in Table 4 is within the range of methane content of 50.0%–60.0% reported for donkey dung substrate for a retention time of 30 days [21]. Therefore, the biogas composition of the present study agrees with values reported in literatures for methane (50.0%–70.0%) and carbon dioxide content (30.0%–40.0%).

4.4. Ventilation Test. The biogas digester began with the fresh air reading of around 22% CO_2 in the atmosphere as shown in Figure 8.

In the first fifty minutes, the CO_2 was increased in steps of 20% in both digesters, and the flow was stabilized afterward to prevent the supply pipe from freezing. After the stabilization of the gas flow at 60 minutes, the gas level was monitored to determine if there is decay in CO_2 concentration. The gas concentration remained constant indicating that the digester chamber was airtight.

Table 4: Optimum biogas composition for the biogas digester.

Gas components	Percentage composition (%)
Methane	60.0
Carbon dioxide	30.0
Hydrogen sulphide, hydrogen, and other gases	10.0

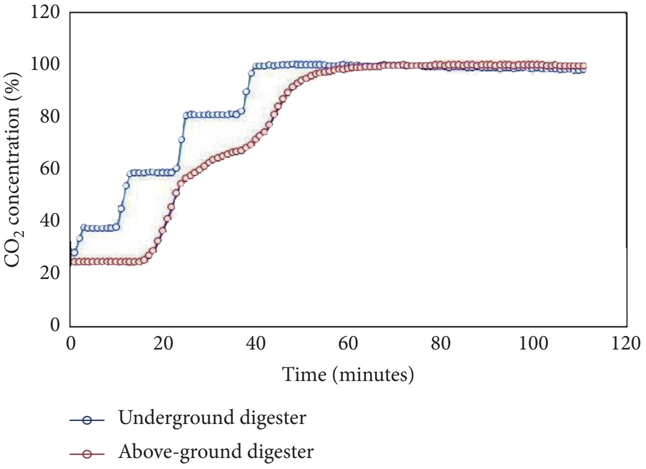


Figure 8: CO_2 concentration in the underground and above-ground digesters showing the stable level for almost an hour under high pressure.

5. Conclusion

The study has successfully designed and fabricated a 2.15 m^3 HDPE biogas digester fed with cow dung. A total volumetric gas yield of 2.18 m^3 (54.50%) and 1.77 m^3 (44.25%) were obtained for methane and carbon dioxide, respectively, thus giving a total biogas yield of 4.00 m^3. Methane gas dominated the biogas composition indicating a high flammability tendency of the produced gas. This is further supported by the calorific value of 27 MJ/g recorded for the substrate. The ventilation test confirmed that the designed and fabricated biogas digester was leak free. Therefore, the study concludes that the use of a HDPE in the fabrication of the digester chamber offers a huge benefit of providing a leak free digester and reduction in the overall cost of installing a digester.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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