DEVELOPMENT OF BIOGAS DIGESTER PLANT

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Abstract-This paper presents the design and fabrication of a 31 litre biogas digester. The work was carried out at the National centre for Energy Research and Development, University of Nigeria Nsukka. The aim is to establish an alternative, green, domesticated, and cost effective source of energy for domestic purposes and also to provide a decentralized energy source that can easily be constructed, operated and maintained using waste from ruminating animals such as cows, poultry, pigs as the raw material for use in the production of the gas. The design of the digester includes the following concept; the basic principles of anaerobic digestion processes, socio-economic status, amount of biogas to be produced. A fixed dome digester type is designed, fabricated and constructed using locally available material, for optimal heat conduction and mass transfer to harness the potential of anaerobic digestion animal waste for the generation of methane gas by the decomposing actions of specific 'domesticated' bacteria on it. The result showed that the digester volume was 31 litres (31382.41cm^3), and inlet and outlet chamber design was 2 litres (2345.22cm^3), the pressure was determined to be 5.72psi (39438N/m^2).

Keywords: design, fabrication, digester, biogas, anaerobic digestion

1. INTRODUCTION

Global depletion of energy supply due to continuous over-utilization is a major problem of the present and future world community. Today's lifestyle is energy demanding, so we need to explore and exploit new sources of energy which are renewable as well as eco-friendly. Energy is generally classified in either renewable or non-renewable. Biogas comes in the category of renewable energy sources. Renewable energy is energy generated from natural resources and can be replenished within a short period of time. The livestock industry is growing day by day concentrated within the urban as well as rural community. The number of livestock for goats and chickens in Malaysia was estimated around 505 and 208 million, respectively; these abundant feaces may release nitrate and ammonia gas causing water pollution, odor pollution and health problems to human beings. The alternative measure to manage this problem is to use these feces as raw materials in biogas production. Biogas consists of a mixture of methane gas, hydrogen gas, carbon dioxide and other gases resulting from decomposition of organic matter by anaerobic bacteria in the absence of oxygen. Biomass is defined as ecologically dried materials from living organisms that present in certain periods for each unit of earth surface (1). Biomass energy is defined as an energy from the plants and raw materials from industrial and municipal waste (White, 1981). The waste from agriculture and animals excrement are among the biomass sources could be converted to energy which are cheaper and renewable energy sources (2)

Biogas technology provides a very attractive route to utilize certain categories of biomass for meeting partial energy needs. Anaerobic digestion (AD) is a technology widely used for treatment of organic/biological waste for biogas production and provides a source of energy while simultaneously resolving ecological and agrochemical issues (3). The anaerobic fermentation of manure for biogas production does not reduce its value as a fertilizer supplement, as available nitrogen and other substances remain in the treated sludge (4).

Anaerobic digestion (AD) is a natural biological decomposition of organic material in a controlled environment in the absence of oxygen. In this deoxidized- zone, bacteria are employed to decompose the proteinaceous and carbonaceous materials producing biogas and sludge (4). Depending on the type of raw material, biogas contains on average 50 -70% methane, 30-40% carbon dioxide, 1-2% nitrogen, 5-10% hydrogen, and trace amounts of hydrogen sulfide and water vapor (5).

One of the burning problems facing the world today is the management of all sources which endangers the existence of human life. Biogas production is a complex biochemical reaction found to take place under the action of delicately pH sensitive microbes mainly bacteria in the presence of little or oxygen (4). Three major groups of bacteria (Hydrolytic, Acidogenesis, Acetogenesis and Methanogenesis) are responsible for breaking down the complex polymers in biomass waste to form biogas at anaerobic conditions (4). Biogas production is slightly slow at the beginning and the end period of observation. This is predicted because biogas production rate in batch condition is directly proportional to specific growth rate of methanogenic bacteria in the bio digester (6).

Ugwuoke et al. (7) investigated the production of biogas from goat dung by anaerobic digestion. The experiment was performed at National Center for Energy Research and Development, University of Nigeria, Nsukka. The atmospheric temperature fluctuates between 27^oC to 30^oC.

Ukpai and Nnabuchi (8) investigated on the comparative study of biogas production from cow dung, cow pea and cassava peeling using 45 litres biogas digester. A 45 Litres capacity metallic prototype biogas plant constructed at the National centre for Energy Research and Development, University of Nigeria, Nsukka was used to investigate the anaerobic digestion in generating biogas from three types of wastes: Cow dung, Cowpea and Cassava peeling

2. MATERIALS AND METHOD

2.1 Total Volume of Frustum

The digester body comprises two cylindrical and a frustum part. Based on the estimated dimensions of the digester the following calculations were made to determine the total volume of the digester. These estimations were made so as to get a volume that will contain the slurry being loaded and make room for gas evolution.

ume of frustum $V_f =$ Volume of big pyramid,V_{bp} – $volume\ of\ small\ Pyramid, V_{sp}$ **(2.1)**

$$ume\ of\ big\ pyramid, V_{bp} = \frac{1}{3} \times A \times H\ (9) \quad (2.2)$$

iere.

: $base\ area\ of big\ pyramid\ in\ cm$

$= height\ of\ big\ pyramid\ in\ cm$

$$ume\ of\ small\ pyramid, V_{sp} = \frac{1}{3} \times A \times h_1 \quad (2.3)$$

ere,

: $base\ area\ of\ small\ pyramid\ in\ cm$

$= height\ of\ small\ pyramid\ in\ cm$

$ploying\ similar\ triangle\ rule:$

$$= \frac{h_1 + h_2}{d_1}$$

$ere\ H = h_1 + h_2$

$$ume\ of\ Small\ cylinder, V_s = \pi r^2 h \quad (2.4)$$

$ere\ r = radius\ of\ small\ cylinder\ in\ cm$

: $height\ of\ small\ cylinder\ in\ cm$

$$ume\ of\ big\ cylinder, V_b = \pi R^2 H \quad (2.5)$$

$ere\ R = Radius\ of\ big\ cylinder\ in\ cm$

$= height\ of\ big\ cylinder\ in\ cm$

Inlet and Outlet Chamber Design

e inlet and outlet chamber has shapes of cylinder and frustum combined.

LET:

Design equation for the inlet chamber is given as $V_i = V_c + V_f$ (2.6)

$where\ V_i = inlet\ volume$ in cm

$V_c = volume\ of\ cylindrical\ part\ in\ cm$

$V_f = volume\ of\ frustum\ part\ in\ cm$

$V_c = Volume\ of\ cylindrical\ part$

$V_c = \pi r^2 h$ (2.7)

Where,

$r = radius\ of\ cylinder\ in\ cm$

$h = height\ of\ cylinder\ in\ cm$

$volume\ of\ frustum, V_f$

$= volume\ of\ big\ pyramid, v_{bp} - volume\ of small\ pyramid, v_{sp}$ (2.8)

The inlet and outlet chamber are of the same direction.

2.3 Design of the Inlet Pressure

Since the inlet pipe is cylindrical in shape, the bursting pressure was calculated using this equation

$P_b = \frac{2S_T t_m}{D_m}$ (10) (2.9)

Where,

$P = bursting\ pressure\ in\ Psi$

$S_T = tensile\ strength\ of\ the\ pipe\ (52Mpa)$

$t_m = minimum\ wall\ thickness\ of\ the\ pipe\ (2.2mm)$

$D_m = mean\ diameter\ (40mm)$

3. DESIGN CALCULATIONS

3.1. Total Volume of the frustum

This can be calculated from equation 2.1

$$Volume\ of\ the\ frustum, V_f = volume\ of\ big\ pyramid, v_{bp} - volume\ of\ small\ pyramid, v_{sp}$$

$$h_2 = \sqrt{(10^2 - 9^2)} = 4.359cm$$

Employing similar triangle rule:

$$\frac{h_1}{15} = \frac{h_1 + h_2}{33}$$

But $h_2 = 4.359cm$

$$33h_1 = 15h_1 + 65.385$$

$$h_1 = \frac{65.385}{18} = 3.6325cm$$

$$H = h_1 + h_2 = 4.359 + 3.6325$$

$$H = 7.9915cm$$

$$Volume\ of\ the\ frustum, V_f = volume\ of\ big\ pyramid, v_{bp} - volume\ of\ small\ pyramid, v_{sp}$$

The volume of big pyramid can be calculated from equation 2.2

$$Volume\ of\ big\ pyramid, v_{bp} = \frac{1}{3} \times base\ area \times height(H)$$

$$v_{bp} = \frac{1}{3} \times \pi R^2 \times H = \frac{1}{3} \times \pi \frac{D^2}{4} \times H$$

$$v_{bp} = \frac{1}{3} \times 3.142 \times \frac{33^2}{4} \times 7.9915$$

$$v_{bp} = 2278.67cm^3$$

The volume of small pyramid can be calculated from equation 2.3

$$volume\ small\ pyramid, v_{sp} = \frac{1}{3} \times base\ area \times height(h_1)$$

$$v_{sp} = \frac{1}{3} \times \pi r^2 \times h_1 = \frac{1}{3} \times \pi \frac{d^2}{4} \times h_1$$

$$v_{sp} = \frac{1}{3} \times 3.142 \times \frac{15^2}{4} \times 3.6325 = 213.47cm^3$$

$$Volume\ of\ the\ frustum, V_f = 2278.67 - 213.47 = 2065.20cm^3$$

The volume of small cylinder can be calculated from equation 2.4

Volume of small cylinder, $\boldsymbol{V_s}$

$$V_s = \pi r^2 h = \frac{\pi d^2 h}{4}$$

$$V_s = \frac{3.142 \times 15^2 \times 11}{4} = 1944.11cm^3$$

The volume of big cylinder can be calculated from equation 2.5

Volume of big cylinder, $\boldsymbol{V_b}$

$$V_b = \pi R^2 H = \frac{\pi D^2 H}{4}$$

$$V_b = \frac{3.142 \times 33^2 \times 32}{4} = 27373.10cm^3$$

$$DIGESTER\ VOLUME = V_f + V_s + V_b$$

$$DIGESTER\ VOLUME = 2065.20 + 1944.11 + 27373.10 = 31382.41cm^3$$

$$\boldsymbol{Digester\ volume} \approx 31litres$$

3.2. Inlet and Outlet Chamber Design

Design equation for the inlet chamber can be calculated using equation 2.6

$V_i = V_c + V_f$

$$h_2 = \sqrt{(7^2 - 5^2)} = 4.899cm$$

Employing similar triangle rule:

$$\frac{h_1}{4} = \frac{h_1 + h_2}{14}$$

But $h_2 = 4.899cm$

$14h_1 = 4h_1 + 19.596$

$$h_1 = \frac{19.596}{10} = 1.9596cm$$

$H = h_1 + h_2 = 1.9596 + 4.899$

$H = 6.8586cm$

$$Volume\ of\ the\ frustum, V_f = volume\ of\ big\ pyramid, v_{bp} - volume\ of\ small\ pyramid, v_{sp}$$

$$Volume\ of\ big\ pyramid, v_{bp} = \frac{1}{3} \times base\ area \times height(H)$$

$$v_{bp} = \frac{1}{3} \times \pi R^2 \times H = \frac{1}{3} \times \pi \frac{D^2}{4} \times H$$

$$v_{bp} = \frac{1}{3} \times 3.142 \times \frac{14^2}{4} \times 6.8586$$

$v_{bp} = 351.98cm^3$

$$volume\ small\ pyramid, v_{sp} = \frac{1}{3} \times base\ area \times height(h_1)$$

$$v_{sp} = \frac{1}{3} \times \pi r^2 \times h = \frac{1}{3} \times \pi \frac{d^2}{4} \times h$$

$$v_{sp} = \frac{1}{3} \times 3.142 \times \frac{4^2}{4} \times 1.9596$$

$$v_{sp} = 8.21cm^3$$

$$Volume\ of\ the\ frustum, V_f = 351.98 - 8.21 = 343.77cm^3$$

3.3 Volume of the Inlet Cylinder

Volume of the inlet cylinder can be calculated using equation 2.7

$$V_c = \pi r^2 h = \frac{\pi d^2 h}{4}$$

$$V_c = \frac{3.142 \times 14^2 \times 13}{4} = 2001.45cm^3$$

$$INLET\ VOLUME, V_i = V_f + V_c$$

$$INLET\ VOLUME, V_i = 343.77 + 2001.45 = 2345.22cm^3$$

$$\boldsymbol{INLET\ VOLUME} \approx 2\ litres$$

The inlet and outlet chamber are of the same dimension hence equal volume.

3.4. Design of the Inlet Pipe Pressure

This equation can be calculated using equation 2.9

$$P_b = \frac{2S_T t_m}{D_m}$$

Hence,

$$P_b = \frac{2 \times 52 \times 2.2}{40} = 5.72Psi$$

3.5. Material Selection and Construction

The materials used for the fabrication of the digester were made up of mild steel sheet and angle iron. This is because of easy workability, durability, availability, cheapness and strength of the mild steel materials. Appropriate gauges and grades of the materials was selected and used for the construction. The dimensions and nature of the materials was as determined in the designed calculation and will last long without failure. The prime mover (Human efforts) for (feeding and turning) selected will provide the required horse power for the maximum load required by the digester. The inner coating with Bitumen substance and the outer finishing (Black body) was meant to make environmental effects manifest. The heat from the sun (ambient) will serve the purpose reliably given the capacity and work load it was subjected to in the design. The construction was carried out using electric arc welding, bolt and nut (11).

4. CONCLUSION

The problem posed by the use of fossil fuels, firewood, burning of dung cake, improper disposal of animal waste forced the dry land farmers to look for alternative sources of energy in the form of biogas and that was addressed by developing an anaerobic digester for co-generation of biogas. The anaerobic digester for biogas production developed was made up of inlet pipe ,the fermentation chamber, the outlet pipe and gas holder. The anaerobic digester was successfully designed, constructed and at the end, preliminary flammability test was conducted and the biogas produced was found to be flammable.

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