RESEARCH ARTICLE OPEN ACCESS

Design of a Biogas Generator

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Abstract
The world is facing an energy crisis due to depletion of fossil fuels. Therefore the need to search for renewable alternative energy is a major concern for stakeholders around the world. Biogas is a combination of gases produced during anaerobic decomposition of organic material of plant origin. This study's main objective was to design a biogas generator which utilizes animal waste to generate biogas for use in Murang'a University College. Cow dung gas is 55-65% methane, 30-35% carbon dioxide, with some hydrogen, nitrogen and other traces. Its heating value is around 600 Btu/ft^3. The daily energy required for both lighting and cooking was calculated and the volume of biogas required from animal waste was determined. From this a cylindrical shaped digester with a spherical gas holding top was selected having the dimensions for both the cylinder and sphere arrived at mathematically. As this paper will show, the digester was found to be 5 metres in diameter, with the top dome for holding the gas equivalent to be 3.7 metres high.
Keywords: Biogas, animal waste, anaerobic, aerobic, organic fertilizer

I. Introduction

As the demand for the world's fuel increases, their prices rise. Thus interest is now rightly focused on the development of renewable energy sources. Renewable sources of energy often offer the most potential energy conservation and development options for the future. The use of these energy sources can meet considerable energy demands for our institutions and villages across the country. Amongst the renewable sources of energy, biomass is the most promising. Biomass refers to the different forms of organic matter including crop residues, agro-industrial by products, urban and municipal wastes, animal dung. This may be transformed by physical, chemical and biological processes to bio-fuels. In chemical form biomass is stored solar energy and can be converted into solid, liquid and gaseous energy. A detailed study of energy demands in Kenya indicates that firewood, charcoal and crop residues accounts for more than 75% of the total energy consumed. This implies that the forest cover is being depleted at a faster rate than are efforts at growing trees. Electrical power cannot also be relied on not only because of the cost implication, but also because of the very unpredictable weather patterns largely attributed to global warming [1,2].

1.1 Statement of the Problem

Electricity is very important in our day to day life; however, electrical power is very expensive for rural Kenyans. Thus a lot of money is spent annually on electricity bills. In Murang'a University College (MUC), water heaters and electrical cookers were removed to try to save on cost. MUC now depends on firewood for cooking. Electricity is used for lighting and for running machines in the mechanical workshop. Firewood is not a good option as the forest cover is reducing at an alarming rate. In view of the above, an alternative source of power is urgently required. MUC has a number of cows plus a lot of food waste from the kitchen. This would be a good source of raw material for a biogas generator. The unit would supply the much needed energy for cooking, lighting and any other use that could require heating.

1.2 Objectives of the study

The main objective of this study was to design a biogas generator unit suitable for MUC. The design of the digester was for meeting the energy requirements of the institution.

1.3 Significance of the Study

In the exploitation of alternative energy, biogas holds the greatest promise as a cheap source of energy because it is renewable, simple to generate and convenient to use. MUC has a herd of cows used for milk production, and pigs for meat. At present, the waste from these animals is not used.

II. Materials and Methods

2.1 Materials

Cow dung gas is made up of 55-65% methane, 30-35% carbon dioxide, with some hydrogen, nitrogen and other traces. Its heating value is around 600 Btu/ft^3. Biogas yield can be enhanced by filtering it through lime water to remove carbon dioxide, iron filing to absorb corrosive hydrogen sulphide and calcium chloride to extract water vapour after the other two processes [3]. Cow dung slurry is composed of 1.8-2.4% nitrogen (N_2) 1.0-1.2% phosphorus (P_2O_5), 0.6-0.8% potassium (K_2O) and 50-75% organic humus. About one cubic foot of gas may be generated from one pound of cow manure at around 28^o C, an adequate amount to cook a day's meal for 4 - 6 people. About 1.7 m^3 of biogas equals one litre of gasoline. The manure produced by one cow in one year can be converted to methane which is the equivalent of over 200 litres of gasoline [4].

The Biogas Production System

A biogas production system consists of the following features:

a) **Substrate inlet**

This consists of a receptacle for the raw fresh organic waste and pipe of at least 10 cm diameter leading to the digester. The connection between the inlet pipe and the digester must be air tight.

b) **Digester**

This is the reservoir of organic wastes in which the substrate is acted on by anaerobic micro organisms to produce biogas.

c) **Gas Storage /Reservoir**

Depending on the proposed design, this may be simply an empty but enclosed space above the slurry in the digester, an inverted floating drum whose diameter is just slightly smaller than that of the cylindrical digester or an air tight polythene tube with an inlet –outlet outfit.

d) **Gas Burner**

This may be a special lighting lamp or a modified burner for cooking.

e) **Exhaust outlet**

This consists of a pipe of similar size to the inlet pipe connected to the digester at a slightly lower level than the inlet pipe to facilitate outflow of exhausted slurry.

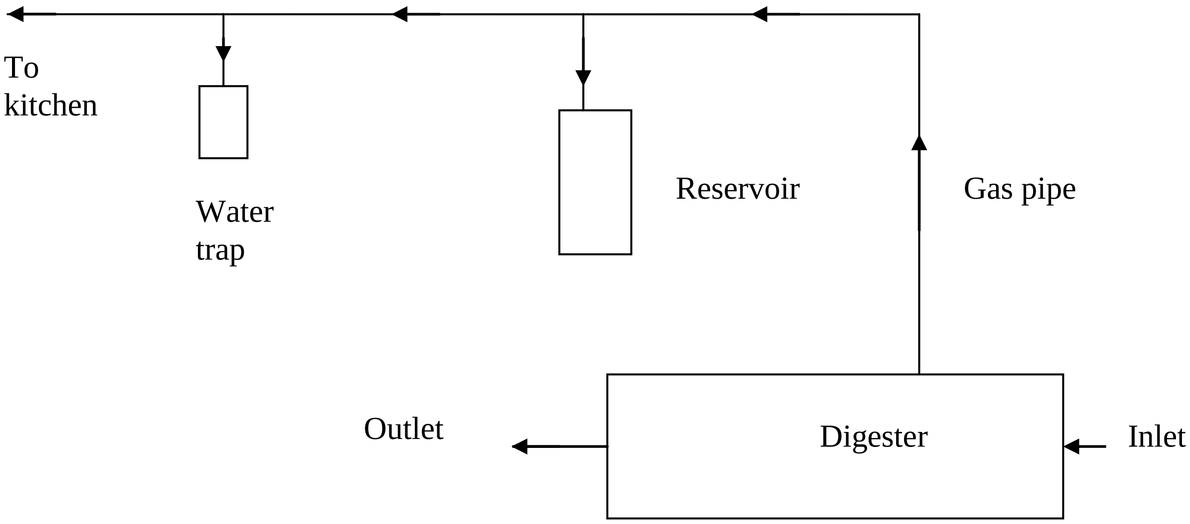

Fig.1: Biogas Production System

2.2 Methods

Biogas can be obtained from any organic material after anaerobic fermentation by three main phases. The fermentation of organic wastes under anaerobic conditions to produce biogas occurs in the following three stages:-

1. **First Stage**

Complex organic compounds are attacked by hydrolytic and fermentative bacteria, which secrete enzymes and ferment hydrolyzed compounds into acetate and hydrogen .A small amount of the carbon converted will end up as volatile fatty acids, primarily propionic and butyric acids.

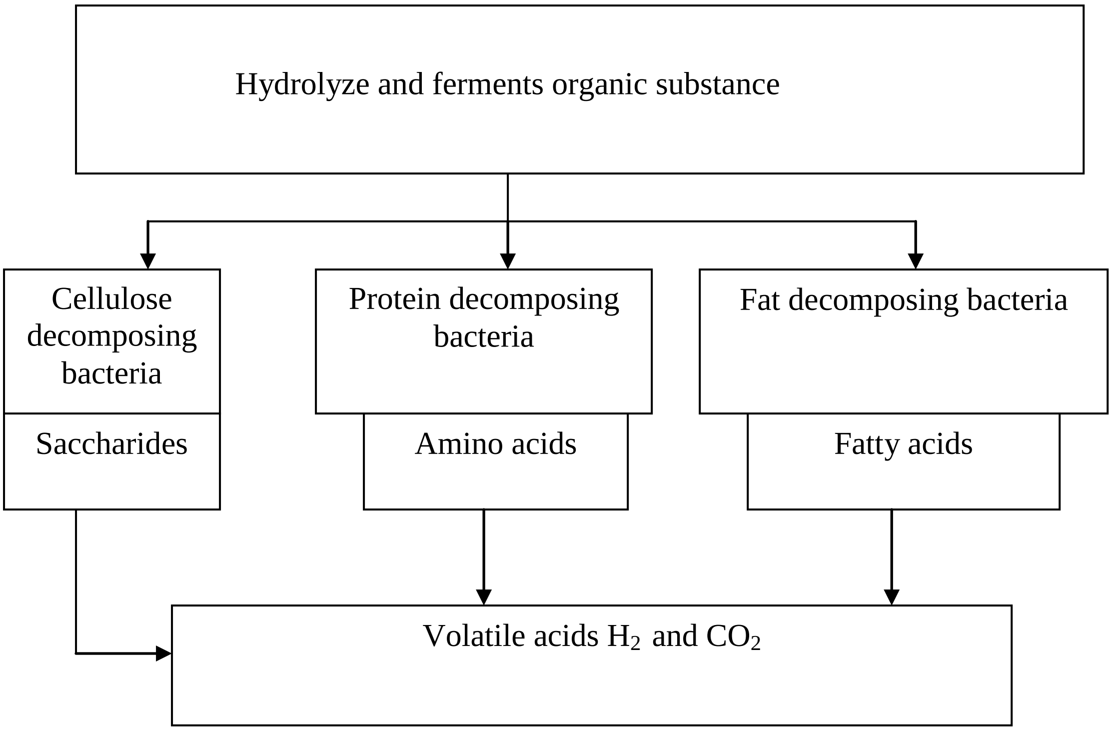

Fig. 2: Fermentative Bacteria

2. **Second Stage**

The hydrogen- producing acetogenic bacteria continue decomposing by converting the volatile fatty acids into acetate and hydrogen producing acetogenic bacteria.

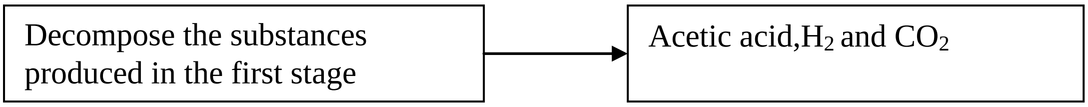

Fig.3: Decomposition of Fatty Acids

3**. Third Stage**

Methane –producing bacteria convert the hydrogen and acetate into methane .There is a certain amount of specialization in that different bacteria act on different substrates .In order for these bacteria to work properly and achieve the desired end products, the following conditions have to be well balanced .

- The dilution of the substrate i.e. amount of water to dilute the animal waste.
- The optimum temperature which should be 35^0C
- Type of substrate (due to their suitable carbon to Nitrogen (C: N) ratio and total solid content cattle, pig and poultry manures are recommended).
- Rate of feeding the digester (overfeeding can lead to accumulation of volatile fatty acids).

2.2.1 Design and Construction of Biogas Plants

2.2.1.1 Design of Generator (Based on Methane Production Rate)

In designing the digester two terms must be taken into consideration

- ✓ Type of digester that will be used
- ✓ The purpose or performance goal

The size of the digester is based on;

a) Size based on health criteria
If the primary purpose is for health i.e. reduction of the possible transmission of the diseases then temperature and retention time are very important criteria.

b) Size based on production of soil conditioner
If the purpose of the system is to produce primarily a soil conditioner, then the breakdown, stabilization, and storage of the organism and nutrients will govern the system.

c) Size based on energy.

If the production of energy is the most important objective, the gas production should be optimized then the primary variables that affect production of the gas are:

- ✓ Biodegradability of the materials
- ✓ Concentration of the feed.
- ✓ Kinetic constants.
- ✓ Retention time.

Temperature has a professional effect on the digestion since the kinetic constants are affected by changes in temperature.

2.2.1.2 Design Based on End User Requirement

The design involves the following parameters:

1. Input parameters
   - ✓ Water availability.
   - ✓ Daily availability of raw materials.
   - ✓ Financial inputs.
   - ✓ Climate of the region and its geographical location.
   - ✓ Appropriate space availability.
2. Output parameter:
   - ✓ End use energy requirement(kWh) and useful power requirements(kW) of thermal and material energy
   - ✓ Requirement of biogas or methane (in energy units or m^3 per day)
3. Design parameter
   - ✓ Optimum temperature range and heating.
   - ✓ Retention period.
   - ✓ C/N ratio of feed.
   - ✓ PH of slurry.
   - ✓ Feed of water ratio (V_f/V_w).
   - ✓ Percent of total solid in feed (T_S %).
   - ✓ Percent of volatile solids in feed (V_S %).
   - ✓ Fraction of the methane in gas (F_{CH_4})
   - ✓ Gas yield (m^3/m^3 of digester/day).
   - ✓ Ultimate gas yield (m^3/m^3 of digester/total retention time).

2.3 Design Approach.

If Y = Biogas yield (m^3 of biogas / m^3/m^3 of digester/day).

Y_{min} = minimum yield in the year ($m^3$of the biogas / m^3/m^3 of digester/year)

Y_{max}= maximum yield in the year ($m^3$of the biogas / m^3/m^3 of digester/year)

Y_g methane yield ($m^3$of methane/year / m^3 of digester/year)

Then, $Y_g = Y \times F_{CH_4}$

The total methane yield from a reactor of volume V_r per day is $Y_{tg}= Y_g.V_g$

The total energy content generated per day, $E_{tg} = Y_{tg} . C_f$

Where, V_r= volume of the reactor (m^3), C_f = calorific value of CH_4

If E_{ti} = the energy consumption of a devices '*i*' per hour (e.g. lighting tubes, burner etc).

T_{ti} = the operating time of the device '*i*' per day

Then, Total energy content generated per day, $E_{tg}= \sum E_{ti} T_{ti} +E_{tt}$

where, E_{tt}=unutilized energy per day (Kj/day)

If E_{oti} is the useful energy of the energy point device and η_{ti} is the overall efficiency of the end point device'i'

$$E_{tg} = \sum \frac{E_{oti}T_{ti}}{\eta_{ti}} + E_{tt}$$

The procedure for determining the digester volume V_r is

a) Based on the useful energy output of the end point device, E_{oti}
   - The operating time of the device per day; T_{ti}
   - The overall efficiency η_{ti} of the end point device energy per day may be suitably assumed.

b) From E_{tg} and Y_{tg} , the volume V_r can be determined.

c) Based on the Y_{min} and Y_{max}, V_{rmin} and V_{rmax} can be calculated.

d) Based on Y_{min} and Y_{max} , E_u can be computed.

$$E_u = \frac{Y_{\max} - Y_{\min}}{2} - Y_{\min}$$

Digester Volume $V_r = V_s + V_g + V_x$

where, V_s= volume of the slurry space or digester Volume in m^3, if V_x tends to zero, then

$V_r = V_s + V_g$, $V_s = t_r I_d$,

Where, t_r= residence time, days. I_d=influent charge or slurry per day,m3/day.

The fraction of the feed f_f (m^3 of V_s/ m^3) of slurry input is

$$f_g = \frac{V_f}{(V_w + V_f)}$$

$$\frac{1}{f_f} = \left(\frac{V_w + V_f}{V_f}\right)$$

But V_w/V_f = water Ts feed ratio, thus

$$f_f = \frac{1}{1 + WF}$$

where W_F is the water to feed ratio, $V_f = I_d f_f$ =volume flow rate of pure feed (m^3/day)

III. Results and Discussions

The numbers of classrooms were 40. With each classroom having a florescent tube of 36W and an average lighting time of 10hrs,

Power required = (10×40×9×36W)/1000= **129.6kWhr**

The workshops and laboratories with the number of tubes they contain are listed below.

Workshop and Laboratory Number of tubes

- Mechanical training w/s 50

- Electrical training w/s 40
- Electrical lab 30
- Woodwork w/s 40
- Masonry w/s 10
- Plumbing w/s 20
- Automotive w/s 20
- Mechanical production w/s 30
- Chemistry lab 10
- Biology 10
- Dressmaking w/s 10
- Food &Beverage restaurants 20
- Food & Beverage kitchen 20
- Total number of tubes 210 tubes.

With an average lighting time of 10hrs,

Power required = (210×36×10)/ 1000 = **75.6 kWhr**

Data for the main kitchen was listed as shown below.

- Dining hall 12
- Kitchen +store +offices 20

Total number of tubes 32

With an average lighting time of 20hrs,

Power required = (32×36×20) ÷1000 = **23.03kWhr**

Other utilities were listed as shown below:

- Administration block 45
- Main hall 20
- T.V room 8
- Main stores 8
- Toilets 8
- Cyber cafe 8

Total number of tubes 95 tubes

With an average lighting time of 10hrs,

Power required = (95×36×9×10)÷1000 = **34.2 kWhr**

Security lighting required 50 tubes with each tube consuming 150 Watts and an average lighting time of 12 hrs,

Power required = (50×150×12)÷1000 = 90 **kWhr**

The student halls of residence data was listed as follows:

- Block A 21
- Block B 23
- Block C 20
- Gal sheet 10
- Extension 10
- Canteen 6
- Milimani (A+B) 25

Total number of tubes 115

With an average lighting time of 10hrs,

Power required = (10×115×36)÷1000 = **44.4kWhr**

The total power required for lighting daily,

= 129.6+75.6+23.04+34.2+90+41.4= **393.84kWhr.**

Approximately 400kWhr

1kWhr = 3.6×10^6 joules, therefore the daily energy requirement

= 400 ×3.6×10^6 = 1.44×10^9/day

Assumption:

Production of Biogas /kg of fresh dung =$0.06m^3$ or a retention of 30 days.

Calorific value of the biogas produced = $20MJ/m^3$

Thus, the daily Biogas flow rate = daily energy requirement /calorific value of fuel.

= (1.44×10) ÷ (20×10^6)

= $72m^3$/day

The institution's kitchen uses 150 kg of wood per day.

Biogas equivalent = 0.18 m^3/kg of wood

Amount of biogas required = 0.18 m^3×150

= **27 m^3 Biogas per day**

Therefore, the total amount of biogas required daily =72+27= **99 m^3/day**

The Quantity of cattle dung required = gas production per day/gas per kg of fresh dung

= 99/0.06

= 1650kg of dung per day

Average dung collection /adult animal/day = 10kg

Total number of cattle required = total dung/dung per animal

=1650/10

= **165 heads of cattle**

DIGESTER DIMENSION CALCULATIONS

Cow dung water mix ratio=1:1

Mass of slurry per day = mass of cow dung + mass of water

= 1650×2

= 3300kg

Density of the slurry = 1000kg/m3with solid Concentrations of 8-10%

Volume of slurry = mass of the slurry/density of the slurry

= 3300/1090

= 3.027 m^3

= 3 m^3

Let the retention time (assumed) to be 30 days

Digester volume = Volume of dairy charge × retention time = 3×30 = 90 m^3

This is the minimum working volume. The actual volume should be 10% more to provide some empty space at the top for proper disengagement of the gas

Actual digester volume = 90×1.1 = 99 m^3

A cylinder shape for the digester was chosen.

The height (H) to diameter (D) ratio was taken as entity for any large capacity plant time

Thus H/D = 1 of the digester

Digester volume, $99 = \frac{\pi}{4} D^3$

Therefore the height was taken as = 5 m

Let the digester be dome shaped at the top to hold the required daily gas,

Then,

$$V_d = \frac{\pi}{6} d_h \left[3\left(\frac{D}{2}\right)^2 + d_h{}^2 \right]$$

where, V_d = daily gas volume required, D_h = Dome height and D = Diameter of the cylinder part of the digester

Therefore,

$$99 = \frac{\pi}{6} d_h \left[3\left(\frac{5}{2}\right)^2 + d_h{}^2 \right]$$

By the trial and error, the digester dome height, D_h = **3.7m**

IV. Conclusions

Based on the findings of this study, the following conclusion can be drawn:

- The biogas digester is the best option to save cost on power.
- It will provide sufficient energy for both cooking and lighting.
- Any excess gas generated should be sold to the neighbourhood.
- Organic fertilizers can be made from the slurry generated after the biogas production process. This can also be sold to generate income for MUC.

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