Design and Development of Floating Type Biogas Digester for Power Generation

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***Abstract*— The world is very keen to produce the first generation biofuels (ethanol and biodiesel) for replacement of petroleum fuels. However, the second generation biofuels are also considered for the same purpose as they can be produced from various organic substances that are not convertible by the fermentation and transesterification which are the processes used to produce first generation biofuels. Biogas produced by the anaerobic digestion from various organic substances offers low cost and low emissions than any other secondary fuels. This paper provides a short review on the biogas production. And also the paper describes the design and development of a floating type biogas digester.**

***Keywords*— Anaerobic digestion, biogas digester, floating type, gaseous fuel**

I. Introduction

Due to less existence of fossil fuel resources and increasing fuel prices, the demand on alternative fuel sources increases day by day. Biofuels are alternative fuels, made from renewable sources and bio wastes, having environmental benefit. The use of biofuels in automobiles and heating applications is increasing. Biogas is generated from organic substances by anaerobic digestion with the help of microorganisms. Biogas technology offers a very attractive route to utilize certain categories of biomass for meeting partial energy need in villages and rural areas for heating, cooking and low load power application. A brief on the research works done in the production of biogas is given in the subsequent sections.

A. Mechanism of anaerobic digestion

Anaerobic digestion is a biological process in which biodegradable organic matters are decomposed by bacteria forming gaseous byproducts. The gaseous byproduct consists of methane (CH_4), carbon dioxide (CO_2), and tresses of other gases [1]. The anaerobic digestion process is considered to be a minimum of two stage biological reaction, involving at least two different groups of microorganisms, one is acid forming bacteria (saprophytic) and the other is methane forming bacteria. The acid phase is generally considered to include the conversion of complex organic compounds into simpler organic compounds and finally into the organic acids i.e. acetic acid by acid forming bacteria [2], [3], [4]. It is a multi-stage process which can be divided in to four phases: hydrolysis, acidogenesis, dehydrogenation/ acetogenesis, and methanation [5], [6], [7]. The first phase is namely as single stage unmixed, second phase is two stage mixed primary, the third phase is anaerobic contact process with sludge recycle and the fourth phase is anaerobic filter with methane formation. The first two processes are generally used for digestion of solid wastes and waste water sludge and the other two process are for the formation of acetic acid, CO_2, and methane (CH_4) [5]. During this process, the organic compounds are hydrolysed into smaller components like sugars, amino acids, alcohols and long chain fatty acids so both solubilisation of particulate matter and biological decomposition of organic polymers to monomers or dimers take place [8]. Several mechanical, thermal, chemical and biological pretreatment methods have been considered to improve the performance by easy accessible of intermolecular matters to anaerobic microbacteria. The stability of process and the rate of gas production depend upon the organic feed rates [6]. CH_4 and CO_2 are the principal gas produced during the process of digestion. Small amounts of hydrogen sulphide is also produced which can be characterised by the order of the digester gas [9]. The optimized methane gas produced is dependent on the rate of optimized decomposition.

B. Operating parameters

Factors such as heat, pH balance, carbon/nitrogen ratio, retention time and feedstock input rate to the digester affect the rate of decomposition and amount of gas production. Bacteria have a limited range of temperature in which they are best active. Mesophilic and thermophilic are the two types of anaerobic bacteria most commonly found in the digesters. The mesophilic bacteria have the optimum output at a temperature of 25^{o}C-40^{o}C and the thermophilic bacteria survives best at 50^{o}C-65^{o}C [10], [12]. The suitable pH level for anaerobic digestion is between the ranges of 5.5-8.5 [11], [13]. It is necessary to maintain proper composition of the feedstock for efficient operation of biogas plant so that the C/N ratio in feed remains within the desired range. In general, microorganisms utilize the carbon 25-30 times faster than nitrogen. Therefore to meet this requirement, microbes need a 20-30:1 ratio of C to N [14]. A high C/N ratio is an indication of rapid consumption of nitrogen by methanogens and results in lower gas production. On the other hand, a lower C/N ratio causes ammonia accumulation and pH values exceeding 8.5, which is toxic to methanogenic bacteria. Optimum C/N ratios of the digester materials can be achieved by mixing material of high and low C/N ratios, such as organic solid waste mixed with sewage or animal manure [15]. The retention time is determined by the average time taken for organic materials to get digest completely, as measured by the chemical and biological oxygen demand (COD and BOD) for existing effluent [12].

C. Digester material, production rate and C/N ratio

The material used for making biogas plant was of PVC (Poly Venial Chloride) water tank of capacity 1500 litres as the digester and 1000 litres as gas holder. The other accessories are some pipe fittings, pressure gauge, gas regulator, ball valve and feedstock pulpier.

Total solid contained in a certain amount of materials is usually used as the material unit to indicate the biogas production rate of the materials. Most favourable total solid (TS) value desired is 8%. The total solid content of some common solid and liquid digestible materials in rural areas are given in Table I.

TABLE I
TOTAL SOLID CONTENT OF SOME COMMON SOLID AND LIQUID DIGESTIBLE MATERIALS

Materials	Dry matter content (%)	Water content (%)
Dry rice straw	83	17
Dry wheat straw	82	18
Corn stalks	80	20
Green grass	24	76
Humanexcrement	20	80
Pig excrement	18	82
Cattle excrement	17	83
Human urine	0.4	99.6
Pig urine	0.4	99.6
Cattle urine	0.6	99.4

At mesophilic condition the bacteria have the optimum output at a temperature of 25^{o}C-40^{o}C and in thermophilic bacteria survives best at 50^{o}C-65^{o}C. Table II shows biogas produced from some common digestible materials at different temperatures [16]. The pH value for anaerobic digestion is in the range of 5.5-8.5.

TABLE II
BIOGAS PRODUCED FROM SOME COMMON DIGESTIBLE MATERIALS AT DIFFERENT TEMPERATURES

Materials	Biogas produced at 35 ^{o}C (m^3/kg)	Biogas produced at 8^{o}C ~ 25 ^{o}C (m^3/kg)
Pig manure	0.45	0.25 ~ 0.30
Cattle dung	0.30	0.20 ~ 0.25
Human wastes	0.43	0.25 ~ 0.30
Rice straw	0.40	0.20 ~ 0.25
Wheat straw	0.45	0.20 ~ 0.25
Green grass	0.44	0.20 ~ 0.25

During anaerobic digestion microorganisms utilize carbon 25-30 times faster than nitrogen. High C/N ratio indicates low biogas production. Similarly low C/N ratio indicates accumulation of ammonia that increases the pH level of the digested slurry more than 8.5. Thus, to meet this requirement, microbes need 20-30:1 ratio of C to N [16]. Table III shows the carbon nitrogen ratios of some common digestible materials.

TABLE III
CARBON- NITROGEN RATIOS OF DIGESTIBLE MATERIALS (APPROX.)

Materials	Carbon content of materials (%)	Nitrogen content of materials (%)	C/N ratio
Dry wheat straw	46	0.53	87:1
Dry rice straw	42	0.53	67:1
Corn stalks	40	0.75	53:1
Fallen leaves	41	1.00	41:1
Soybean stalks	41	1.30	32:1
Wild grass	14	0.54	27:1
Peanut stems and leaves	11	0.59	19:1
Fresh sheep droppings	16	0.55	29:1
Fresh cattle dung	7.3	0.29	25:1
Fresh horse droppings	10	0.42	24:1
Fresh pig manure	7.8	0.60	13:1
Fresh human wastes	2.5	0.85	29:1

D. Hydraulic retention time (HRT)

There are two ways in which anaerobic digestion carried out that are (i) batch process (ii) continuous process. In the batch process, the substrate is put in the reactor at the beginning of the degradation period and sealed for the duration of digestion. All of the reaction stages occur more or less consecutively and therefore the biogas production follows a bell curve. Retention time ranges from 30-60 days and only about 1/3 of the tank volume is used for active digestion. If anaerobic digestion is to complete with other MSW (Municipal Solid Waste) disposal options, the retention time must be lower than the current standard of 20 days [12]. For mesophilic digestion where temperature varies from 25 ^oC to 40 ^oC the HRT is greater than 20 days. Table IV shows biogas production rate and methane yield of some digestible materials.

Typical reactions during anaerobic digestion are given below [12].

$$\underset{\text{(organic compound)}}{C_6H_{12}O_6} \rightarrow \underset{\text{(ethanol)}}{2C_2H_5OH} + \underset{\text{(carbon dioxide)}}{2CO_2}$$

$$\underset{\text{(ethanol)}}{2C_2H_5OH} + \underset{\text{(carbon dioxide)}}{CO_2} \rightarrow \underset{\text{(methane)}}{CH_4} + \underset{\text{(acetic acid)}}{2CH_3COOH}$$

$$\underset{\text{(acetic acid)}}{CH3COOH} \rightarrow \underset{\text{(methane)}}{CH_4} + \underset{\text{(carbon dioxide)}}{CO_2}$$

$$\underset{\text{(carbon dioxide)}}{CO_2} + \underset{\text{(hydrogen)}}{4H_2} \rightarrow \underset{\text{(methane)}}{CH_4} + \underset{\text{(water)}}{2H_2O}$$

TABLE IV
RATE OF BIOGAS PRODUCTION AND METHANE YIELD FOR SOME DIGESTIBLE MATERIALS

Feed stocks	Yield of biogas (m^3/kg TS)	Methane content (%)
Animal barnyard manure	0.260 ~ 0.280	50 ~ 60
Pig manure	0.561	45 ~ 68
Horse droppings	0.200 ~ 0.300	55 ~ 65
Green grass	0.630	70
Flax straw	0.359	55
Wheat straw	0.432	59
Leaves	0.210 ~ 0.294	58
Sludge	0.640	50
Brewery liquid waste	0.300 ~ 0.600	58
Carbohydrate	0.750	49
Lipid	1.440	72
Protein	0.980	50

Two categories of biogas plant were studied. The first one was farm based plant and the other was community based, or cooperative plants. The farm based plants were located on farms. Some were solely operated by the farm owner, while others involved partnerships between two or three farm owners. Others were located at the farm site, but were owned and operated by companies separate from the farm. The community and cooperative plants were located in large commercial sites which collect manure from as many as farms, digesting it, and then returning it to the farms to be applied as landfills [18].

The present work is aimed to develop a floating type digester that will be useful to generate 6-7 m^3 of biogas from organic feed stock.

II. BIOGAS DIGESTERS

Common biogas plant types can be differentiated according to methods of substrate feed, gas collecting method, material used for construction, horizontal or vertical position, underground and above ground digester location and according to additional equipment used. These plant types again can be broadly classified as (i) batch type plant

(ii) continuous type plant and (iii) movable drum type plant.

A. Batch type plant

Batch type biogas plants are appropriate where daily supplies of raw materials are difficult to be obtained. A batch loaded digester is filled up to maximum capacity level and given sufficient retention time in the digester. After completion of digestion, the residue is emptied and filled again. There are certain problems encountered with batch type plants, that are

- Uneven gas production
- For continuous supply more plants are required in series
- Occupation of more space
- Larger volume of digester so initial cost is high
- Needs addition of digested slurry each time to start the process

B. Continuous type biogas plant

In this type of plant, the gas supply is continuous and the digester is feed with biomass feed stock regularly. Continuous biogas plants can be single stage, double stage or multiple stages. Digestion of waste materials in a single chamber or digester is called single stage process, in two chambers or digester is called multi stage process. In double stage process, acidogenic and methanogenic stage are physically separated into two chambers. Thus, the first stage of acid production is carriedout in a separate chamber and only diluted acids are fed into the second chamber where biomethanation takes place. In single stage, acidogenic and methanogenic stage are carried out in the same chamber without barrier. These plants are economic, simple and easy to operate. However, the two stage biogas plants are costlier, difficult in operation and maintenance but, they produce more gas. Continuous process offers two distinct merits and that are

- Retention period is less
- Small digestion chambers are required

C. Movable drum type plant

The conventional movable drum type comprises a masonry digester with an inlet on one side for feeding slurry and an outlet on the other side for removing digested slurry. The gas collects in a PVC gasholder which is inverted over the slurry and moves up and down depending upon accumulation and discharge of gas. The gasholder and digester are anticorrosive. This plant maintains constant pressure. This type is also referred as floating type digester. The digester offers constant gas pressure with high rate of gas production and high methane yield. These digesters require less retention period and small digestion chamber.

The proposed work is based on movable drum or floating drum type plant because, it has more benefits than other types. Fig. 1 shows the fabricated floating type biogas digester.

Fig.1 Floating type biogas plant photo layout

III. Geometrical Dimension Calculation of Floating Dome Type Digester

A. Digester volume calculation

Before going for the fabrication, the volume of digester that produces gas and height of digester is being calculated as below

Total volume of digester (V) includes volume of gas collecting chamber (V_c), volume of gas storage chamber (V_{gs}), Volume of digestion chamber (V_d) and volume of sludge layer (V_s).

Mathematically $V = V_c+V_{gs}+V_d+V_s$

For best design development some following mentioned assumptions are to be considered such as

$V_c \leq 5\%V$
$V_s \leq 15\%V$
$V_{gs} + V_d = 80\%\ V$
$V_{gs} = 0.5(V_{gs} + V_f + V_s)\ Gr$
Where G_r = Gas production rate per m^3 of digester volume/day.

B. Digester height calculation

If D = Diameter of digester tank in (cm)
$(V_c + V_{gs}) = 0.0827\ D^3$
$V_d = 0.3142\ D^3$
And $V_s = 0.05011\ D^3$
$H_1 = D/5$
$H_4 = D/8$
Where, H_1 = Height of gas collecting chamber in centimetre.
H_4 = Height of sludge layer in centimetre.
H_2 = Height of gas storage chamber in centimetre (varies accordingly as the storage chamber floats and dips inside the slurry due to generation of biogas)
H_3 = Height of digestion chamber in centimetre (can be calculated from digestion volume (V_d) and diameter of tank (D)) as shown in Fig. 2.

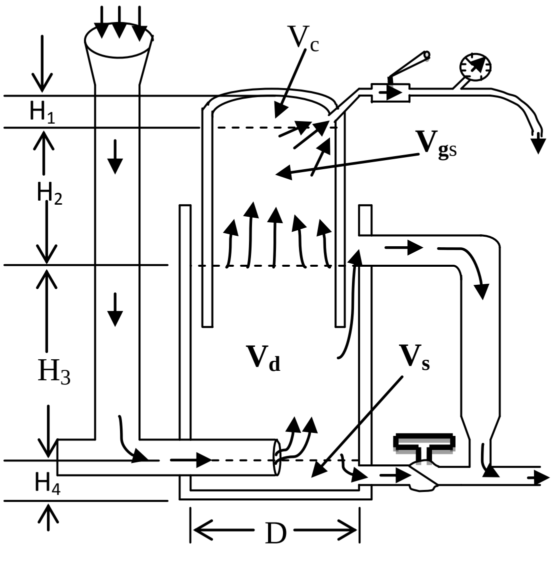

Fig. 2 showing geometrical parameters of biogas plant

Based on the data available and calculations, two PVC tanks of volumetric capacity of 1500 litres as digester and another of 1000 litres as gas holder were taken. The upper portion of both the tank is being cut in such a way that, the smaller tank can easily enter inversely into the larger tank. Larger tank act as digester, which holds the feed stocks and water mixed slurry, that are to be digested. The smaller tank floats inside larger tank, acting as a biogas storage holder. The digester tank is connected to two circular pipes. One is connected at the bottom of the digester through which water and feed stocks are being fed and the other pipe is connected at the top of digester tank acting as the drainage for digested slurry. Fig. 3 shows the layout of floating dome type anaerobic digester.

The feed stocks that are fed to the digester must be pulped properly to a suitable range of particle size 1.4-2.0 mm [17]. Hence the methane yield will go to optimum. Once the digester is filled by feed stock it will have to keep for 5 to 7 days then the plant will start producing biogas. During digestion process time to time the pH of the slurry is to be checked which limits to a maximum range of 8.5 for the best performance of the plant.

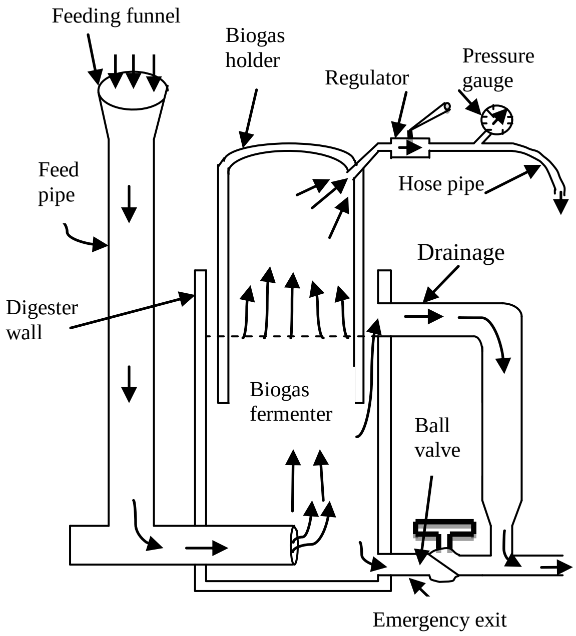

Fig. 3 Biogas plant layout sketch

The plant is able to digest any type of degradable organic materials and produces biogas having highest methane (CH_4) yield of 50-70 %, carbon dioxide (CO_2) 30-40 %, hydrogen (H) 5-10%, nitrogen (N) 1-2 %, hydrogen sulphide(H_2S) (traces) and water vapour 0.3%. This biogas is 20% lighter than air and having ignition temperature in the range of 650 ^oC to 750 ^oC. It is a colourless gas burns with clear blue flame similar to that of LPG. The calorific value of biogas is 20 Mega Joules per cubic metre (MJ)/m^3 and burns with 60 % efficiency in a conventional biogas stove. This biogas can be a useful substitute for firewood, agricultural residues, dung, petrol, diesel and electricity depending on the nature of the task and local supply conditions and constraints. The anaerobic digesters also act as a waste disposal system.

IV. CONCLUSION

A short review on the production of biogas is discussed in this paper considering the various types of digester design, total solid content, C/N ratio, and methane yield for different feed stocks. Further a floating type digester was designed and fabricated for producing the biogas for generation of power. The biogas system developed is economical and simple to operate.

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