Design of Portable High Density Polyethylene (HDPE) Biogas Digester.

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ABSTRACT

A biogas digester using the principle of anaerobic digestion has been developed from low cost materials. Major components of the digester include (i) fermentation chamber, (ii) gas collection unit, (iii) solar collector, and (iv) pressure balancer. The solar collector was made of a metal steel of 4mm thickness. The fermentation chamber was insulated with 40mm thick glass wool. The metal cover which was used as solar collector plate has an area of 2552.09 cm^2. A copper coil of 19.1mm was used as heating element to maintain a steady temperature in the digester chamber. Performance evaluation showed that the digester has an efficiency of 32%.

(Key terms: biogas, anaerobic digestion, digester, solar, temperature)

INTRODUCTION

The demand for research studies on the topic of bio-methanization is on the rise in this present century; the consequences of prospects associated with energy generation from renewable and non-renewable sources. Petroleum which is the main source of energy in Nigeria, is a non-renewable energy resource, and some investigation has shown that it will become a scarce commodity over the years (due to envisage tremendous production shortages). The immediate result is that the prices of the petroleum based resources are continuously increasing, causing hardship to the majority of the global population (85% of which are mainly found in the rural areas).

Also the consistent use of fossil fuels is now frowned upon due to high carbon content their contributions to the greenhouse gases produced globally [1].

At present, environmental friendly energy is being encouraged to reduce the effect of the greenhouse gases, ozone layer depletion and other environmental hazards [2]. It has therefore become necessary to find other sources of energy for the good of future generations and to reduce energy cost in the world today.Other sources of energy are hydro-electric power, coal, wind, and nuclear- fission; (Nigeria proposes to embark upon the last) [3].

Biogas technology was originally used as a means of reducing the amount of organic matter which must be treated, while little emphasis was made on the gas so produced. Recently, the anaerobic process has moved from mere waste stabilization to the level of gas production [4]. In today's energy demanding life style, need for exploring and exploiting new sources of energy which are renewable as well as eco-friendly is a must.

In rural areas of developing countries, various cellulosic biomass (cattle dung, agricultural residues, etc.) are available in plenty which have a very good potential to cater to the energy demand, especially in the domestic sector [5]. In India alone, there are an estimated over 250 million cattle and if one third of the dung produced annually from these is available for production of biogas, more than 12 million biogas plants can be installed (Kashyap et al., 2003)[6].

Biogas technology offers a very attractive route to utilize certain categories of biomass for meeting partial energy needs. In fact proper functioning of a biogas system can provide multiple benefits to the users and the community resulting in resource conservation and environmental protection.

Biogas is a product of anaerobic degradation of organic substrates, which is one of the oldest processes used for the treatment of industrial wastes and stabilization of sludges. Since it is carried out by a consortium of microorganisms and depends on various factors like pH, temperature, HRT, C/N ratio, etc., it is a relatively slow process. Lack of process stability, low loading rates, slow recovery after failure and specific requirements for waste composition are some of the other limitations associated with it (Van der Berg and Kennedy, 1983)[7].

Anaerobic fermentation being a slow process, a large HRT of 30–50 days is used in conventional biogas plants. This leads to a large volume of the digester and hence high cost of the system. The decrease in gas generation during the winter season has been reported, which poses a serious problem in the practical application of this technology.

Kalia and Singh (1996) found that biogas production reduced from around 1700 l/day in May–July to around 99l/d in January– February. All of this has resulted in restricted popularization of biogas technology in rural areas [8]. Thus there is a need to improve the overall efficiency of anaerobic digestion process in the biogas plants. This could be done by several methods such as optimizing the various operational parameters, satisfying the nutritional requirements of microbes (Lettinga et al., 1980) [9], using different biological and chemical additives and by manipulating the feed pro- portions (Sanders and Bloodgood, 1965) [10].

Recirculation of digested slurry (washed out microbes) back into the reactor and modification in the design of existing biogas plants are some of the other ways to improve the gas production in biogas plants. Recently, efforts have been made to either reduce the HRT or enhance biogas production for the same HRT by incorporating fixed film matrices in the reactors, which help to retain microbes in the reactors. Recently ultrasonification of wastewater has been found to enhance the removal of COD by almost 10% (McDermott et al., 2001) [11].

Process and Mechanism of Biomethanation

The anaerobic biological conversion of organic matter occurs in three steps. The first step involves the enzyme- mediated transformation of insoluble organic material and higher molecular mass compounds such as lipids, polysaccharides, proteins, fats, nucleic acids, etc., into soluble organic materials, i.e. to compounds suitable for the use as source of energy and cell carbon such as monosaccharides, amino acids and other simple organic compounds [12]. This step is called the hydrolysis and is carried out by strict anaerobes such as *Bactericides*, *Clostridia* and facultative bacteria such as *Streptococci*, etc.

In the second step, acidogenesis, another group of microorganisms ferments the break-down products to acetic acid, hydrogen, carbon dioxide and other lower weight simple volatile organic acids like propionic acid and butyric acid which are in turn converted to acetic acid.

In the third step, these acetic acid, hydrogen and carbon dioxide are converted into a mixture of methane and carbon dioxide by the methanogenic bacteria (acetate utilizers like *Methanosarcina spp*.and *Methanothrix spp*. and hydrogen and formate utilizing species like *Methanobacterium*, *Methanococcus*, etc.).

Techniques for Enhancing Biogas Production

Different methods used to enhance biogas production can be classified into the following categories:

(i) Use of additives

(ii) Recycling of slurry and slurry filtrate

(iii) Variation in operational parameters like temperature, hydraulic retention time (HRT) and particle size of the substrate

(iv) Use of fixed film/biofilters

Use of Additives

Some attempts have been made in the past to increase gas production by stimulating the microbial activity using various biological and chemical additives under different operating conditions. Bio logical additives include different plants, weeds (Gunaseelan, 1987)[13], crop residues, microbial cultures, etc., which are available naturally in the surroundings. As such, generally these are of less significance in terms of their use in the habitat, however if used as additives in biogas plant could improve its performance significantly. The suitability of an additive is expected to be strongly dependent on the type of substrate.

Green Biomass

Powdered leaves of some plants and legumes (like *Gulmohar*, *Leucacena leucocephala*, *Acacia auriculiformis*, *Dalbergia sisoo,* and *Eucalyptus tereticonius*) have been found to stimulate biogas production between 18% and 40% (SPOBD, China, 1979) [14]. Increase in biogas production due to certain additives appears to be due to adsorption of the substrate on the surface of the additives. This can lead to high-localized substrate concentration and a more favorable environment for growth of microbes. The additives also help to maintain favorable conditions for rapid gas production in the reactor, such as pH, inhibition/promotion of acetogenesis and methanogenesis for the best yield, etc.

Alkali treated (1% NaOH for 7 days) plant residues (lantana, wheat straw, apple leaf litter and peach leaf litter) when used as a supplement to cattle dung resulted in almost twofold increase in biogas and CH4 production (Dar and Tandon, 1987) [15]. Partially decomposed ageratum produced 43% and *Euphorbia tirucalli* L. produced 14% more gas as compared to pure cattle dung (Kalia and Kanwar, 1989) [16].

Trujillo et al. (1993) [17] found that the addition of the tomato-plant wastes to the rabbit wastes in proportion higher than 40% improved the methane production. Crop residues like maize stalks, rice straw, cotton stalks, wheat straw and water hyacinth each enriched with partially digested cattle dung enhanced gas production in the range of 10 80% (El Shinnawi et al., 1989)[18].

Babu et al.(1994) [19] observed improvement in biomethanation of mango processing wastes by several folds by the addition of extracts of seeds of Nirmali, common bean, black gram, guar and guargum at the rate of 1500 ppm. Mixture of Pistia stratiotes and cowdung (1:1) gave a biogas yield of 0.62 $m^3/(m^3$ day) (CH4 ¼76.8%, HRT¼15 days) (Zennaki et al., 1998) [20].

Recently Sharma (2002) observed an increase of 40–80% in biogas production on addition of 1% onion storage waste (OSW) to cattle dung in a 400-l floating drum biogas reactor.

Microbial Strains

Strains of some bacteria and fungi have also been found to enhance gas production by stimulating the activity of particular enzymes. Cellul olytic strains of bacteria like *Actinomycetes* and mixed consortia have been found to improve biogas production in the range of 8.4–44% from cattle dung (Tirumale and Nand, 1994) [21]. All the strains exhibited a range of activity of all the enzymes involved in cellulose degradation, viz. C1 enzyme, exglucanase, endoglucanase, bglucosidase. It seemed that endoglucanase activity was of central importance for the hydrolysis of cellulose.

Geeta et al. (1994)[22] found that sugarcane bagasse pretreated with *Phanerochaete chrysosporium* for 3 weeks under ambient temperature conditions produced higher gas with cattle excreta. Dohanyos et al. (1997) [23] examined the use of cell lysate as a stimulating agent in anaerobicm degradation of municipal raw sludge, excess activated sludge and their mixture.

The effect of lysate is caused by the still remaining activity of released enzymes and by the stimulating properties of other compounds that are present inside the cells. The improvement of CH_4 yield from thickened activated sludge ranged from 8.1% to 86.4% while in case of a mixture of thickened activated sludge and primary sludge it was found to vary from 0% to 24%.

DESIGN CONCEPT

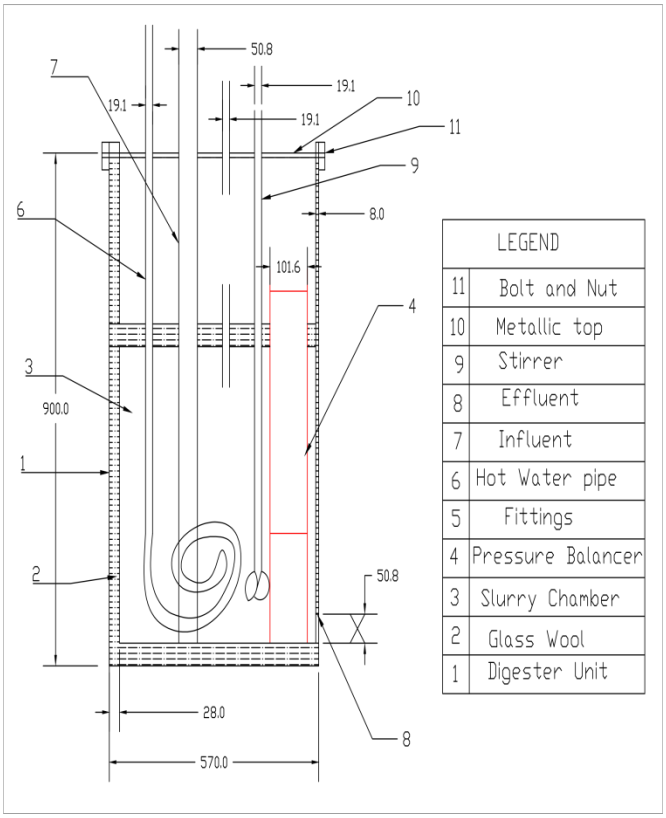

Figure 1: Schematic diagram of a Portable High Density Polyethylene Digester.

OPERATION PRINCIPLE (PRINCIPLE OF ANAEROBIC DIGESTION)

Biogas is produced when organic matter is degraded in the absence of oxygen. This anaerobic decomposition (or anaerobic digestion) process occur naturally in wet lands, lake bottoms, and deep in lagoons and landfills. Anaerobic decomposition can also be artificially made by decomposition of organic matter occur in absence of oxygen.

The process is the achievement of four groups of microorganisms' combined action: primary fermenting bacteria, secondary fermenting bacteria and two types of archae [24].The anaerobic decomposition of organic matters will finally turn into biogas (methane and carbon dioxide), typically divided into three steps. Firstly (hydrolysis), substrate is hydrolyzed to smaller units by primary fermenting bacteria [25]. Then acidogenesis and acetogenesis, the formed soluble oligomers and monomers are converted into acetic acid, hydrogen and carbon dioxide by primary fermenting bacteria and secondary fermenting bacteria. The last step (methanogenesis), acetic acid, hydrogen and carbon dioxide are converted into biogas by the archae [26]. For the optimal work of the decomposition process, the dependence of these three steps should work equally well and providing the next step with the substrate as required. For example, if hydrolysis is inhibited, the substrate to the second and third step will be limited and there is a reduction in methane production as a result [27].

DESIGN ANALYSIS

Assumptions

Volume of the digester V=23Litres

Radius of the digester, r =285mm

Ambient temperature, Ta=25°C

MEASURED PARAMETERS

Thermal conductivity of the water tube= 386W/mk.

Thermal conductivity of glass wool=29W/mk.

HEIGHT OF DIGESTER CHAMBER HOUSING.

Volume of overall container= volume of cylinder.

Volume of cylinder=$\pi r^2 H$.

But, (r=D/2;$r^2 = \frac{D^2}{4} = \pi \frac{D^2}{4} H.$

Using, V= $\pi r^2 H$.

Radius = (28.50cm=285mm).

Diameter (57.0cm=570mm).

Volume of the digestion housing=22.9688litres.

But 1 litre 1000 cm^3.

22.9688litres=229688.055 cm^3.

229688.055 cm^3=3.142x28.5^{2}H.

229688.055=2552.095H

H=$\frac{229688.055}{2552.095}$=90cm=900mm.

HEIGHT OF THE FERMENTATION CHAMBER.

Volume of the slurry chamber=2/3 Volume of the Digester assembly.

Volume of the slurry chamber=15.3litres.

But 1 litres =1000 cm^3.

15.3litres=153000 cm^3.

Volume of the cylinder=$\pi r^2 h$.

But (r=D/2;$r^2 = \frac{D^2}{4}, v = \pi \frac{D^2}{4} h.$)

Volume of the cylinder= $\pi \frac{D^2}{4} h.$

Radius =28.50cm=285mm;

D=2r=2x285=570mm=57cm.

But 153000= $\pi \frac{D^2}{3x4} hx2.$

153000=3.142x$\frac{57^2 xh}{4}$.

612000=10208.36h.

h=
$\frac{612000}{10208.36} = 59.95cm \simeq 600mm.$

Area of Collector =$\pi r^2 = 3.142x28.5^2$
= 2442.09 cm^3

INSULATION THICKNESS

Using Fourier's law of heat conduction, insulation thickness of the fermentation chamber is calculated as follows [9] (Rajput, 2002):

For cylindrical vessels, heat loss per unit time, $Q_l = 2\times l\ (t_f - t_a) / [\ \ln (r_2 / r_1\ ) / k + 1 / h_0\ r_2]$ (Okafor,2013)

Where t_f and t_a are final and ambient temperatures of the slurry and r_2 and r_1 are radii of outer and inner cylinders respectively; h_0 is the convective heat transfer coefficient of outer cylinder; k is the thermal conductivity of insulating material.

Heat gain by slurry, $Q = mc_p\ (t_f - t_i\ )$

Where m is mass of slurry; t_i is initial temperature of slurry; and c_p is the specific heat capacity of slurry at constant pressure.

But Heat Loss by fermentation chamber = Heat Gain by slurry; $2\times l\ (t_f - t_a) / [\ \ln (r_2 / r_1\ ) / k + 1 / h_0\ r_2] = Mc_p\ (t_f - t_i\ )$

Substituting values; h_o = 0.96 W/m^2K

Critical radius of insulation, $r_c = k / h_o = r_2$ [11](Rajput, 2002)

r_c= 0.025 / 0.96 = 0.026m; thus, chosen thickness of insulation = 40mm.

PERFORMANCE EVALUATION

Measured Quantities Include

T_p = Temperature of absorber plate, 100°C

T_1 = Slurry inlet temperature, °C

T_a = Ambient temperature, °C

T_2 = Slurry outlet temperature,° C

G = Insolation, 430 W/m^2.

Estimated Quantities

Temperature rise of water, $\Delta T = T_2 - T_1$

Heat gain by water, Q_u = MCpΔ T
Efficiency of the collector, **(%)** = 100 x $(T_2 - T_1) / T_{p[12]}$

Table 1shows the result of the performance test.

Table 1: Results of Evaluation Test.

D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
T_a	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
T_1	31	34	28	27	33	32	28	31	27	25	30	32	34	30	32	34	28	31	30	29
T_2	42	45	38	41	49	39	37	35	43	41	40	45	38	44	47	37	34	32	39	41
V	0.8	1.0	1.2	2.1	2.8	3.2	3.4	3.7	4.3	4.5	4.8	5.1	4.9	5.2	5.5	5.7	5.8	6.3	6.1	6
P_H	6.0	-	-	-	-	-	8.6	-	-	-	-	-	7.2	-	-	-	-	-	-	6

Dung Used: Pig dung

Mass of the dung: 21.19kg

Mass of slurry: 31.98kg.

In testing this digester, a lot of consideration was made with regard to the material type, availability and quantity of gas estimated to be produced or generated.

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