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PERFORMANCE EVALUATION OF PARTIAL MIXING ANAEROBIC DIGESTER

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ABSTRACT

All fermentation reactions are autocatalytic in nature. In autocatylic reactions, the products act as a catalyst. Fermentation reactions are carried out in the reactors, during this reaction it generate methane gas or biogas. In the exiting biogas plants gas production per m^3 of volume is less and Hydraulic Retention Time is more than 60 days and additional power required for circulation of slurry in the digester. The exiting biogas plants are constructed based on either mixed flow or Plug flow model where the self circulating biogas plant designed based on mixed flow followed by plug flow reactor. It gives a better performance than either mixed or plug flow reactors, because of partial mixing. The autocatalytic reaction requires partial pumbing for fast reaction, which need the source of power. The fermentation process takes nearly 60 days to complete, it is a very slow reaction. For self-mixing, the density difference is to be maintained in the reactor. The difference in density can either be created by pumping or by bubbling biogas through the reactor, requiring additional power. The increase in microbe concentration could be achieved by immobilizing microbes on carriers. The immobilized bacteria in the central column increase the biogas production rate and hence the lower density is maintained than the outside column. An increase in concentration in some section of the digester could lead to more generation of gas. The bubbling gas reduces the bulk density considerably causing hydrostatic pressure difference in density is responsible for the circulation of slurry in the digester. In order to achieve this, a tube of diameter roughly to one third of the diameter and volume equal to 10.7% of total volume is fitted at the centre of digester. It is filled with washed and broken burnt bricks. The bricks act as an adsorbent, immobilizing microbes. In addition, the bricks acting as bio filters increase the gas generation by 60%. Two digesters having an effective volume of 200 litres- One digester is constructed with central tube filled with biofilters and another digester constructed without central tube. 3.5 Kg of cow dung with 3.5 liters of water is added daily. On steady state condition, this recycle reactor has yielded nearly 60% increases in gas generation compare with conventional model, proving our assumption namely “Self circulation by density difference or a partial mixing digester would perform well”.

Keywords: digester, gas generation, autocatalytic reaction, immobilizing microbes.

INTRODUCTION

The escalating costs of fossil fuels and the decreasing availability of renewable resources of fuel have forced many developing countries to consider the use of renewable energy technologies for example solar, wind, and biomass technologies such as biogas, power alcohol and gasifiers (Rai. G.D, 1996) of these techniques, biogas is the one of the lowest financial inputs per Kwh of output. Biogas was first discovered by Alessandro Volta in 1776 and Humphrey Davy was the first to pronounce of combustible gas methane in the farmyard manure in as early as 1880. The technology of scientifically harnessing this gas from any biodegradable material (organic matter) under artificially created conditions is known as biogas technology. Biogas technology can alleviate many technical problems for example deforestation, rural energy shortages, low agricultural productivity and poor public health. Biogas can be produced by fermenting organic materials in absence of air with the help of bacteria to break down materials to intermediates such as alcohols and fatty acids and finally to methane and carbon dioxide. This process is called as anaerobic fermentation. Biogas has also been known as swamp gas, sewer gas, fuel gas, marsh gas, wet gas and in India more commonly known as gobar gas Rai. G.D, (1996).

Biogas can be produced from dairy cow wastes, poultry litter, sheep and goat droppings, crop-residues of various plants, sugarcane trash, bagasse, rice husk, rice bran, tobacco wastes and seed, cotton dust from textile mills, tea waste, fruit and vegetable wastes, marine algae, seaweeds Rai. G.D, (1996). Biogas consists of 60-65% methane, 35-40% carbon dioxide and traces of hydrogen sulphides and ammonia. Biogas is a clean burning fuel and finds its application as an efficient fuel for lighting, cooking, and engines. Biogas process digests animal manures and night soil; it has the potential to considerably reduce plant, animal and human pathogens. The process is autocatalytic and the mixing can be brought about by pumping, which needs the source of power. Fermentation process is a slow reaction and the mixing can be done at a slower rate. The increase in microbe concentration could be achieved by immobilizing microbes on carriers. Due to increased microbial concentration, the biogas production is at a higher rate. Increased gas production bubbles through in the central column, which creates a density difference between the central column and the reactor. The density is at a lower rater in the central tube. The recycle reactor gives an increase of 60% biogas production is achieved because of immobilization Bello-Mendoza, R., Sharratt, P.N., (1998).

Mechanism of the reaction

Because of the higher concentration of substrate than the bacteria concentration in the early stages, the effect of concentration of the substrates on the rate will be more pronounced then the bacteria concentration. However the bacteria concentration also builds up as the reaction proceeds. The continuous depletion of substrate concentration leads to a lowering of the reaction rate (or gas production), while the continuous increase in bacteria concentration leads to an increase in the reaction rate. Therefore, up to a concentration point, the resultant rate will slow an increasing trend Casey, T.J. (1986). Beyond this point, the resultant rate falls steadily, as the effect of depletion in concentration of substrate begins to out weigh the effect of increase in bacteria concentration. Therefore, the concentration of the substrate versus the resultant rate of gas production (or reduction rate) takes a maximum rate value at a particular conversion. This behaviour corresponds to an autocatalytic reaction (Figure-1) Octave levenspiel, (1999).

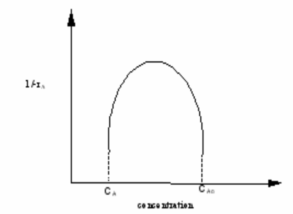

Figure1.Rate concentration curve for Autocatalytic reaction

Reactors

The classification of reactors is based upon mixing of fluid in the reactor. If the fluid is completely mixed, it is known as mixed reactor. If not, it is a plug of flow reactor (zero mixed). The time required for any conversion may be obtained from the plot of (1/r) versus C_A. The time required in plug flow reactor is obtained from the area below the curve (Figure-5). In the plug flow reactor, the rate would have an average value intermediate between the high initial and low final rate. The time required for any conversion in a mixed flow reactor, is given by the area of the rectangle (Figure-4). Since the conversion of inlet slurry drops a value existing inside the digester, the rate of reaction is always lower. Hence the time required is greater than in a plug flow reactor. On the other hand, if the reaction is carried out in a mixed reactor, upto a conversion, C_{Ao} and then carried out in plug flow reactor, upto a final conversion C_A, the overall time required in this combined reactor will be less than that is required for either a mixed reactor or a plug flow reactor (Fig. 6). Thus, it is evident that a combined reactor assembly requires less time and hence a less volume for a given gas production rate El-Halwagi M., (1984).

Biogas Reactor

Depending upon the mode of storage of gas, the biogas generators are differentiated. There are two types of biogas generators namely (1) Floating dome type, and (2) Fixed dome type, which is commonly used Rai. G.D, (1996). The important features of these are discussed as follows:

Floating Dome type

In this type, the biogas generated is collected on a floating drum and the fresh and spent slurry move as slugs from the bottom to the top without much mixing with each other (Figure-2). The overall performance of this digester corresponds to that of the plug flow digester and the time required for any conversion may be obtained as discussed earlier.

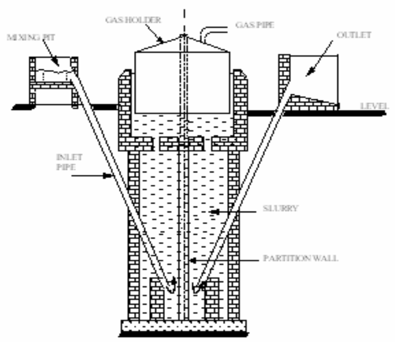

Figure 2.Floating Dome Type Biogas Plant

Fixed Dome type

In this type, the gas is stored due to the displacement of slurry. The generated gas pushes away the slurry sideways. When the gas is consumed, the displaced slurry enters back into the digester pumping out the gas. Because of this movement of slurry, a certain degree of mixing of slurries of different ages is achieved. Thus the performance of this digester approaches that of a mixed digester Rai. G.D, (1996).

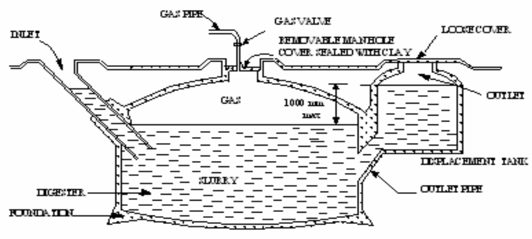

Figure 3.Fixed Dome Type biogas plant

It has observed that a mixed digester followed by a plug flow digester requires less volume for any gas production, the fixed dome digester followed by floating dome digester is expected to give better performance than either fixed dome digester or a floating dome digester Rai. G.D, (1996).

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Autocatalytic reactions

In an autocatalytic reaction, however, the rate of reaction is slower at the start because little product is present, it increases to a maximum as product is formed and then drops to a low value as reactant is consumed. In autocatalytic reactions, the mixed flow is highly efficient at low conversions and the plug flow is better for high conversions.

Mixed flow reactor

When a reactor is perfectly mixed, all solutes and suspended matter in the reactor are equally distributed throughout the reactor. A stirred tank reactor is often assumed to be perfectly mixed. This is assumption is used in the concentration of a component leaving the reactor is equal to the concentration in the reactor. In practice, the larger the reactor, more it will deviate away from perfect plug flow Octave levenspiel, (1999).

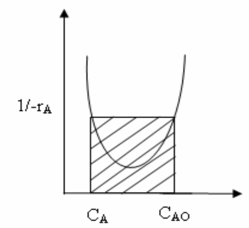

Figure 4.Typical rate concentration curve for mixed flow reactor

Plug flow reactor

In contrast to a perfectly mixed reactor, there is no mixing in a perfect plug flow reactor. Plug flow bioreactors normally have a long length to diameter ratio (like a long pipe). Substrates enter the reactor at one end and leave at the other. In between the microbial population in the reactor reacts them on. Because there is no mixing in the reactor, there will be a “concentration profile” with the concentration of substrate decreasing as it flow along the reactor. This is in contrast to a perfectly mixed reactor in which the concentration of substrate will be uniform across the reactor. Packed bed reactors used for immobilized cell culture and immobilized enzyme reactions have plug flow characteristics. How far a reactor deviates from perfect plug flow depends on the type of packing used, the feed flow rate, the reactor diameter, the reactor length and changes in viscosity and density along the reactor. The necessary condition for plug flow is for the residence time in the reactor to be the same away from perfect flow. The shaded area gives the residence time of reactor Octave levenspiel, (1999).

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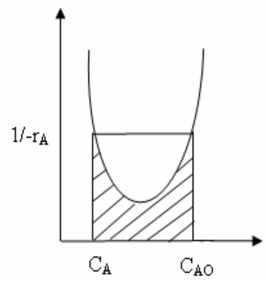

Figure 5.Typical Concentration curve for Plug flow reactor

Advantages of mixed flow followed by plug flow reactor

Initially, the species are mixed in the reactor, which gives perfect mixing. Then the plug flow pattern is applied to the system. Mixed flow reactor has longer residence time, whereas plug flow has lesser residence time. Hence when this combination is adopted, the reactor can be achieved with lesser residence time and improved efficiency than that of mixed or plug flow Octave levenspiel, (1999). The shaded area gives the residence time of the reactor. This is the best setup, which can be adopted for getting maximum efficiency with residence time Ghaly, A.E., Ben-Hassan, R.M., (1989).

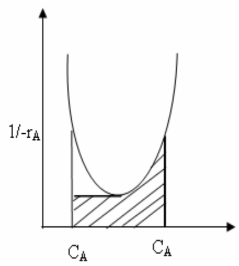

Figure.6.Typical Concentration curve for mixed flow followed by Plug flow.

MATERIALS AND METHODS

Experimental setup

Increase in microbe concentration could be achieved by immobilizing microbes on carriers. The carrier employed to immobilize microbes should be

- Highly porous
- Non biodegradable
- Mechanically stable
- Cheaper and freely available

Broken bricks of about 5.5cm satisfying all the above criteria were selected as a carrier. Broken bricks were soaked in water until all air bubbles cease. Then they were immersed in cow dung (TS = 10%) for 40 days under anaerobic condition. During this period, the microbes were expected to be immobilized and stabilized. After this period, the broken bricks were used as carriers in the experiment. The digester consists of a cylindrical drum of diameter D = 57.3cm, height H = 90cm for holding 168 litres of cow dung slurry (TS = 10%). Provisions are made to admit fresh slurry at the top and to discharge the spent slurry at the other side end of the digester. The central tube in the digester was filled with 20 litres of bio filters (10%) prepared as mentioned earlier. The tube has triangular slots at the bottom (Height H = 7.62cm) to provide slow mixing of the cow dung slurry in the digester. The discharge tube is kept at one side that has rectangular slot bottom (Height H = 3.81cm). The gas which is discharging collected in the tubes and the collected gas is measured daily using Wet gas meter. The digester was charged with 7 liters of cow dung slurry daily (TS = 10%) at the feed inlet. At the discharge end, the spent slurry of 7 liters was discharged daily. The collected gas was measured daily using wet gas meter. The reading was taken continuously for 90 days both self circulating model and conventional model. The working model for the Partial Mixing or self circulating biogas plant is shown in Figure-8 and the conventional model shown in Figure-7.

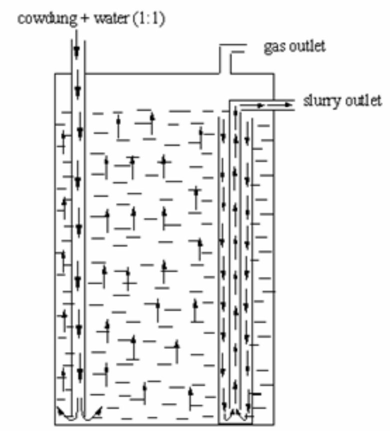

Figure.7.Conventional Biogas Plant Model

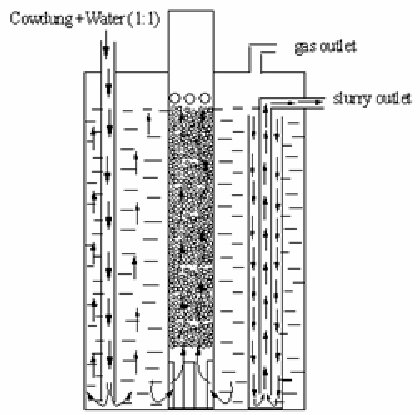

Figure: 8. Partial Mixing Digester

Anaerobic fermentation takes nearly 60 days to complete and it is a very slow reaction. For better mixing, the density difference is to be maintained. The difference in density can be created either by partial pumping or bubbling biogas in the central column where the density is maintained low. The immobilization gives an improved efficiency of gas production Lee, S.R. *et al.*, (1995).

Percentage of immobilized bricks in the central column

In the given digester, the volume of the central tube column contains 10% of the original volume of the digester. The percentage volume of central tube occupied volume is calculated by using the formulae given below

$$\% \text{ of immobilized bricks} = \frac{\text{Volume of the central tube}}{\text{Volume of the digester}}$$

The volume of the digester and the central tube was $0.2321 m^3$ and $0.0225 m^3$, respectively. The percentage of immobilized bricks was calculated to be 10.7%.

RESULTS AND DISCUSSION

The process adopted in this equipment is autocatalytic the immobilized bacterial column provided in the central column increases the microbial content. The increased gas production in the central column creates a difference in density and the density and the density difference helps in better mixing. Ghosh, S., (1997) the mixing process adopted here eliminates the requirement of power. There is an increase of 60 percent gas production is achieved in self-circulating plant than conventional model and the hydraulic retention time is only 40 days where in conventional model HRT is 60 days. Temperature is usually maintained at 35 ºC but different temperature can be used provided to no variation is allowed. Hence a constant temperature is essential for high yield Ghosh, S., (1997).

The fermentation process that has taken place is a slow reaction and it requires 60 days for the process to be completed. Hence only slow mixing is required, that can be done either by pumping or bubbling of biogas through the column, which needs the source of power. The immobilization column provided in the centre of the digester increases the population of microbes in that column, which increases the biogas production rate. Hence a density difference is created between the central column and the digester. This density difference helps in self-mixing of the slurry. For the same digester size, in the autocatalytic reaction, the volume of gas produced is more when compared with conventional digester Kontandt, H.G., Roediger, A.G., (1977). The population density of attached growth bacteria is always higher and more effective. The bacteria increase in its population and favour the gas production to a higher rate. Since the bacterial population increase in its number at a higher rate and the gas produced is more, the digester size can be reduced for the same volume of gas production in conventional digesters. The cow dung and water is mixed with equal proportion and fed to the digester daily about 7 litres by connecting the wet gas meter readings are taken continuously for 90 days and plot the graph between gas productions versus Time as shown in the Figures 9, 10, 11. Maximum biogas production requires daily loading of the digester. Desired capacity and life of a plant affects the cost and complexity of a biogas system. Size of biogas plant digester is controlled by number of factors like number, size and type of animals providing feed, slurry dilution and reaction time. The most easily controllable factor is reaction time. Longer the reaction time, larger size of the digester. High flow rates in a reactor are possible in combination with high biocatalyst retention.

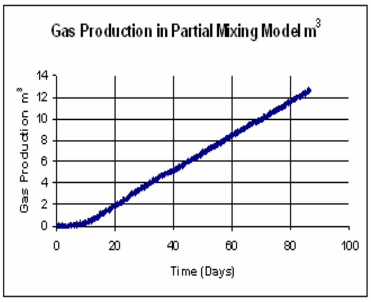

Figure.9.Partial Mixing Digester with Microbial Growth continuous operation Cumulative value up to 90 days

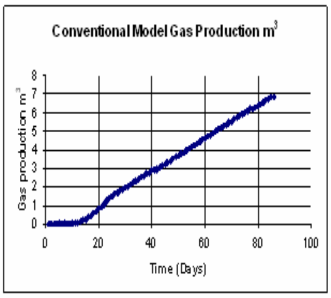

Figure.10.Conventional Model gas production Continuous operation – Cumulative value up to 90 days

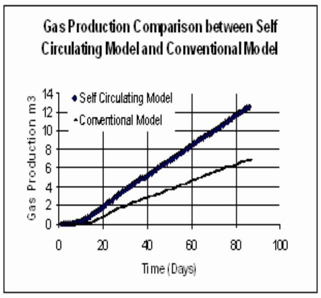

Figure.11.Gas production increases 60% in self-circulating biogas plant (cumulative value)

CONCLUSIONS

The immobilized bacteria increase the microbe concentration in the brick and the biogas production is increased in the central column. Self-mixing is done in the digester by density difference in the solid and gas generation leads to more bubbles formation within the digester. Compare with the conventional model the recycle generator gives an increase of nearly 60% biogas production is achieved and the cost of the self circulating model is three times less than the exiting model. This is newly invented model for anaerobic digestion of any animal manure or municipal solid waste. Microbial growth within the digester is directly proportional to the amount of gas generation. The microbial growth in the self circulating model is more than the existing model because of immobilizations and also the gas generation rate is 1.7 times more than the conventional model. The volume of digester to the volume of gas produced is 1.33 for self circulating model and 2.33 for conventional model, once the V_d/V_g ratio is nearer to 1 these types of digesters are having higher efficiency. In future these type of plants are increases the overall conversion efficiency by adopting the same immobilization technique. This model tested only by a family type biogas plant having a capacity of 200 litres. We have tested using the same technique for $2m^3$, $15m^3$ capacity biogas plants and achieved more gas generation than existing model. In future the same technology is useful for industry related waste recycling processes or dairy waste.

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