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A review study on anaerobic digesters with an Insight to biogas production

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ABSTRACT: *In India we provide the fuel for industry, household mainly from fossil fuel in the form of Petrol, Diesel, LPG, Natural gas, Coal. Since the source for the fossil fuel is fast depleting and at the same time, creating some actual problem related to availability, high cost and atmospheric pollution, so research are extended to search an alternative source of non-conventional energy named as Biogas. Biogas is produced by anaerobic digestion of the organic waste material, which typically consists of methane, with a significant proportion of carbon dioxide, and smaller quantities of other gases such as nitrogen and hydrogen. The calorific value of biogas varies from 4800-6900 Kcal/m^3. Different types of feed material are 1. Manure (Cow Dung) 2. Sugar Cane Baggase 3. Cotton dust 4. Weed 5. Night soil 6. Poultry Bird 7. Cowdung and Cotton stalk 8. Cow dung and weeds.*
Biogas is used for cooking, lighting, motive power and industrial uses.
The biological anaerobic degradation of green house residues, which can be divided into four steps

1. *Hydrolysis 2. Acedogenesis 3. Acetotgenesis 4. Methanogenesis*

The factors influencing the biogas production are 1. Nutrients 2. Solid concentration 4. Temperature 5. Retention time 5. pH 6. Mixing 7. Effect of Hydrogen Sulphides 8. Effect of carbon-di-oxide concentration 9. Scum formation 10. Thickness of insulation.
Types of reactor are
1. Plug flow digester,
2. Complete mix digester,
3. Covered lagoon digester,
4. Fixed film digester.
Design of plug flow digester: Digester volume= 15.277 m^3 Biogas produced= 4.0075m^3/day
Complete mix digesters, are unsuitable for high efficiency and rapid rate conversion of solid or semi solid substrates. Plug flow digester are suitable for the digestion of solid and concentrated semisolid feeds which are by far the largest biomass and waste resources available for simultaneous stabilization and energy production.

Keywords: *fossil fuel, non conventional energy, anaerobic digestion, plug flow digester, complete mix digester.*

I. INTRODUCTION

Biogas originates from bacteria in the process of bio-degradation of organic material under anaerobic (without air) conditions. The natural generation of biogas is an important part of the biogeochemical carbon cycle. Methanogens (methane producing bacteria) are the last link in a chain of micro-organisms which degrade organic material and return the decomposition products to the environment. In this process biogas is generated, a source of renewable energy. A 1000 cubic feet of processed Biogas is equivalent to 600 cubic feet of natural gas, 6.4 gallons of butane, 5.2 gallons of gasoline or 4.6 gallons of diesel oil.[1,5].

Each year some 590-880 million tons of methane are released worldwide into the atmosphere through microbial activity. About 90% of the emitted methane derives from biogenic sources, i.e. from the decomposition of biomass. It is known from the study that from 1 ton of waste produces 260kgs of biogas from which we can light a house for 14 hours. The world is producing several million tons of waste every day, if we utilize the waste to produce biogas and intern electricity the energy crisis in the world can be eliminated.

The article addresses the effect of using different bacteria inoculums at identical technical settings on the anaerobic digestion process for treatment of semi solid organic waste from the local market, to produce biogas, as well as to reduce their pollution potential.[1]. This paper also strives to address the technical and biological viewpoints in depth and highlights a few environmental and financial issues, in relation with the various type of digester available to produce biogas from the municipal waste.[2] The aims in developing the fixed film anaerobic digester for the flushed dairy manure wastewater has been discussed further.[3]

Biogas is identified as one of the future fuel of the modern world. Biogas is the gas obtained from the biological origin. Biogas typically consists mainly of methane, with a significant proportion of carbon dioxide, and smaller quantities of other gases such as nitrogen and hydrogen, which is mainly produced by the bacteria degrading waste materials.

Biogas with methane content higher than 45% is flammable. This whole process of anaerobic digestion takes place in a sealed, waterproof chamber known as an anaerobic digester. The digesters are generally cubical or cylindrical in shape. [4,7]

The recovered gas is 60 - 80 percent methane, in compared to natural gas having 95% of methane content. With a methane content of 60-80%, biogas has the heating value of approximately 600 -800 Btu/ft^3. Gas of this quality can be used to generate electricity; it may be used as fuel for a boiler, space heater, or refrigeration equipment; or combusted as a cooking and lighting fuel. The left over slurry after producing the biogas can be used as fertilizer which is rich in organic material.

II. MATERIALS AND METHODS

Raw meterials for the production of biogas

The main raw material for the production of biogas is the waste produced. Daily thousands of tons of waste are produced in each city. Waste disposal in these areas has become a major problem. One of the major causes for the large production of waste is population. In the city areas very large population is accumulated in the small areas producing enormous quantity of waste. Disposal of wastes near the human habitat cause various health problems and diseases. Biogas can also be produced using the cow dung in small scale and can be used for the domestic purpose. In rural areas of India biogas is also called ‗**gobor gas**' where the gas is produced using cow dung. [4,5,8]

It is also produced in the swine farms using the waste produced. Waste produced in this modern world is divided into 4 major types,

1. Municipal waste
2. Industrial Waste
3. Agricultural Waste and Residues
4. Hazardous Waste

Municipal solid waste

Municipal solid waste (MSW) is generated from households, offices, hotels, shops, schools and other institutions. The major components are food waste ,paper, plastic, rags, metal and glass, although demolition and construction debris is often included in collected waste, as are small quantities of hazardous waste, such as electric light bulbs, batteries ,automotive parts and discarded medicines and chemicals.[2]

Taking the example of Bangalore, this is one of the fastest growing cities in Asia.Bangalore has the total area of 531 sq km where the city centre is an area approximately 226 sq km and it is also the 5th largest city in all of India as well as one of the fastest growing metropolitan areas.

According to the BMP (Bangalore Mahanagara Palike) survey 2004 the amount of municipal waste generated by the Bangalore (with the population of 5.8 million)

Source	Quantity (Tons/day)
Residences & Shops	1562
Markets	84
Hotels and Restaurants	96
Commercial Premises	6
TOTAL	**1783**

Fig 1: Tons of waste produced per day in Bangalore

All the waste which is produced is simply dumped in the government area. If we use the same waste to produce biogas and in turn electricity which can power 1050 houses throughout the day, the growing problem of energy crisis can be successfully encountered.[6]

Industrial waste

Industrial solid waste encompasses a wide range of materials of varying environmental toxicity. Typically this range would include paper, packaging materials , waste from food processing, oils, solvents, resins ,paints and sludges, glass, ceramics, stones, metals ,plastics, rubber, leather, wood, cloth, straw, abrasives ,etc. Industrial solid waste generation varies, not only between countries at different stages of development but also between developing countries.

Based on an average ratio for the region, the industrial solid waste generation in the region is equivalent to 1900 million tons per annum. This amount is expected to increase substantially and at the current growth rates, it is estimated that it will double in less than 20 years.

Agricultural Waste and Residues

Expanding agricultural production has naturally resulted in increased quantities of livestock waste, agricultural crop residues and agro-industrial by-products. Among the countries in the Asian and Pacific Region, People‘s Republic of China produces the largest quantities of agriculture waste and crop residues followed by India. In People‘s Republic of China, some 587 million tones of residues are generated annually from the production of rice, corn and wheat alone.

Hazardous Waste

With rapid development in agriculture, industry, commerce, hospital and health-care facilities, significant quantities of toxic chemicals and produces a large amount of hazardous waste. Currently, there are about 110000 types of toxic chemicals commercially available. Each year, another 1000 new chemicals are added to the market for industrial and other uses.

Most hazardous waste is the by-product of a broad spectrum of industrial, agricultural and manufacturing processes, nuclear establishments, hospitals and health-care facilities. Primarily, high-volume generators of industrial hazardous waste are the chemical, petrochemical, petroleum, metals, wood treatment, pulp and paper, leather, textiles and energy production plants (coal-fired and nuclear power plants and petroleum production plants).Small- and medium-sized industries that generate hazardous waste include auto and equipment repair shops, electroplating and metal finishing shops, textile factories, hospital and health-care centers, drycleaners and pesticide users.

DIGESTER

The organic waste is generally processed, liquefied, and pasteurized to rid it of pathogens and make its breakdown easier for the anaerobic bacteria. These bacteria, commonly found in soil and water, first employ enzymes to convert the waste matter into amino acids and sugars and then ferment these into fatty acids. The fatty acids are then transformed into a gas.[8]

This whole process of anaerobic digestion takes place in a sealed, waterproof chamber known as an anaerobic digester. The digester is generally cubical or cylindrical in shape and may be constructed of brick, concrete, steel or plastic. The liquefied organic waste is fed into the digester chamber through a pipe and exposed to the anaerobic bacteria that flourish there under optimum

temperature ranging between 95 degrees Fahrenheit (35 degrees Celsius) and 140 degrees Fahrenheit (60 degrees Celsius).[7]
Using anaerobic digestion for biogas generation is a clean, environment friendly way of energy production. It effectively disposes of waste matter that might otherwise have littered and polluted the environment. [5]

Reaction Taking Place In The Digester

The reaction taking place in the anaerobic digester while breaking down the organic waste into the simpler material and intern the methane and other gases is,

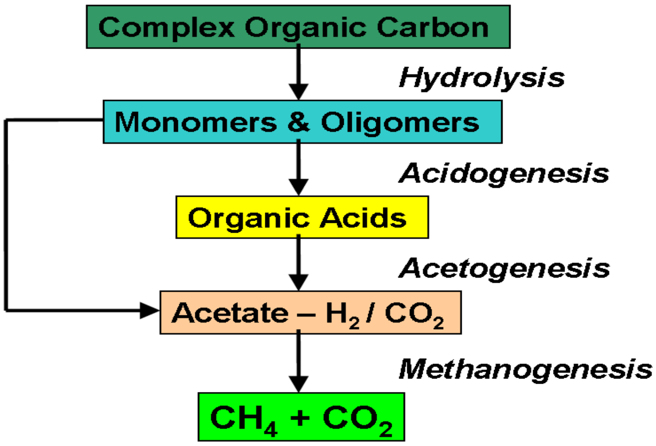

Fig 2: Reaction taking place in the anaerobic digester

Hydrolysis: It is one of the first steps to occur in the anaerobic digester. It is a chemical process in which a molecule is cleaved into two parts by the addition of a molecule of water. One fragment of the parent molecule gains a hydrogen ion (H^+) from the additional water molecule. The other group collects the remaining hydroxyl group (OH^-). In case of anaerobic digester the enzyme from the fermentative bacteria convert complex, un-dissolved materials like proteins, carbohydrate, fats into fewer complex materials.
Acidogenesis: It is the second reaction taking place in the anaerobic digester. It is a biological reaction where simple monomers and dissolved compounds are converted into volatile fatty acids, alcohols, lactic acid etc.
Acetogenesis: It is the third reaction taking place in the anaerobic digester. It is a biological reaction where volatile fatty acids are converted into acetic acid, carbon dioxide, and hydrogen.
Methanogenesis: It is the fourth and final reaction taking place in the anaerobic digester. It is a biological reaction where acetates are converted into methane and carbon dioxide, while hydrogen is consumed.

Types of Digester

There are 4 type of digester which is used to produce the biogas,

1. Plug flow digester,
2. Complete mix digester,
3. Covered lagoon digester,
4. Fixed film digester.

Plug flow digester

A plug flow digester vessel is a long narrow insulated and heated tank made of reinforced concrete, steel with a gas tight cover to capture the biogas. These digesters can operate at a mesophilic or thermophilic temperature. The plug flow digester has no internal agitation and is loaded with thick manure of 11 – 14 percent total solids. This type of digester works well with a scrape manure management system with little bedding and no sand. Retention time is usually 15 to 20 days.

The term "plug flow" derives from the fact that the manure in principle flows through the digester vessel as a "plug," gradually being pushed toward the outlet as new material is added. Raw manure enters one end of the plug-flow digester and decomposes as it moves through the digester. New manure added to the digester tank pushes older material through the digester to the discharge end. Coarse solids in the manure form a thick sticky material as they are digested, limiting separation of solids and forming a ―plug." A flexible, impermeable cover on the digester traps the biogas as the manure is digested. The first documented use of this type of reactor was in South Africa in 1957 where it was insulated and heated to 35^0C. Specific yields (volume of gas per volume of digester per day) of 1:1.5 were obtained with retention time of forty days and loading rates of 3.4Kg of total solids per m^3 per day. Jewell and his colleagues at Cornell University have carried out a considerable amount of work on this design over the last eight years. Hayes et al. in 1979 described a comparison between a rubber lined plug flow reactor and a completely mixed digester. Both had a total volume of 38 m^3 and were fed on dairy manure at 12.9% total solids. Their results are summarized in the table given below. Digester temperatures were assumed to maintain at 35^0C.

Table 1: comparison of completely mixed digester with plug flow digester

PROPERTIES	MIXED	PLUG
HRT(d)	30	15
Specific volume(m^3 gas per m^3 reactor per days)	1.13	2.32
Specific gas production(m^3 per kg VS added)	0.310	0.337
Gas composition(% CH_4)	58	55
Volatile solids reduction(%)	31.7	

The Plug Flow reactor gave higher gas production rates than the completely mixed one. The high specific yield, compared with figures for typical Fixed Film and Covered Lagoon designs, of 0.1 and 0.3 are due to higher temperature and higher loading rates. At 20^0C the plug flow reactor yields about 0.42 volume of gas per volume of digester per day. At typical loading rates (9% versus 12.9% total solids) this figure would decrease to around 0.29.

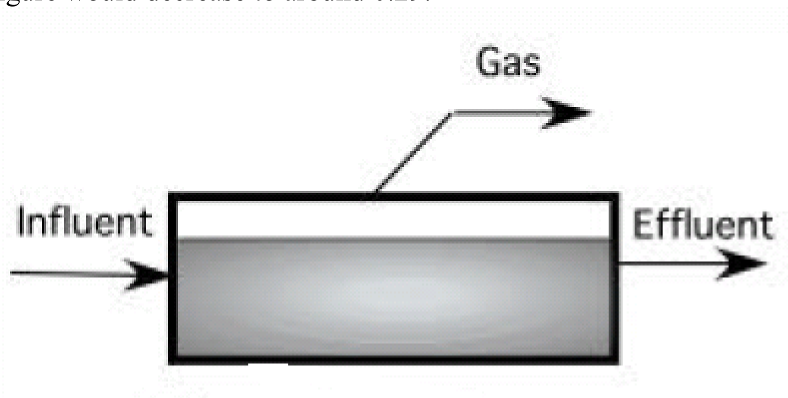

Fig 3: Plug flow digester

Design of Plug flow digester

Design considerations:

Following are the main components of Plug flow digester plants:

1. Digestion chamber or digester
2. Provision for collection and delivery of gas ie; gas holder
3. Arrangements for dialing feeding ie; inlet tank/mixing tank
4. Arrangements for discharge of the digested slurry-outlet
5. Arrangements for gas distribution-Pipe flow

Main items for designing of a Biogas plant:

1. Volume of digester.
2. Storage capacity of the gas holder.
3. Delivery pressure of the gas.
4. Volume of mixing tank, which is dependent on the quantity of daily feeding and proportion of water to be mixed.
5. Arrangements of heating and insulation.
6. Materials and method of construction.

Shape of the digester:

A biogas digester could be a cylindrical square, or rectangular in shape. Generally the cylindrical shape is preferred because:

1. The cylindrical shape has a better load bearing capacity.
2. A cylindrical gas holder can have a rotatory motion in a cylindrical digester due to which scum beaker can be fixed break in the gas holder to break the scum just by rotating the gas holder.

Main items for designing a gas holder:

1. Volume of gas holder, which is dependent upon the required gas storage capacity and rate of gas generation in the digester.
2. Required delivery pressure of the gas, which can be obtained by fixing the bottom surface area and weight of the gas holder.
3. Materials to be used for the manufacture of the gas holder and standard dimensions of these material with a view to keep the wastage of materials at minimum while manufacturing gas holder.
4. Shape of the gas holder.

Construction of the material required for the biogas plant are carbon steel, polyvinyl chloride, polyethylene etc.

Designing part:
Length L=12 meter
Circumference=4 meter
Assume
Retention time or residence time= 15 days
Circumference $2\pi r= 4$
R=0.6366m
Diameter D=1.273m
Hence volume of the digester= 15.277m3
Biogas bell(25%)= 3.819 m3
Liquid phase(75%)=11.45 m3
Biogas produced everyday 35% of liquid phase GP= 0.35×11.45
= 4.0075 m3/day
Quantity of water to be mixed for feeding1.1 proportion of weight
Density of slurry having 10% solid concentration= 1100 (Approximately)
Specific gravity of biogas = 0.84
Hence density = 0.84×1000=8400Kg/ m3
Hence volumetric flow rate F= Volume of digester/ Residence time
=15.277/15
F= 1.018 m3/day
Mass flow rate= Volumetric flow rate × density of slurry
= 1.018×1100
=1119.8/2 Kg/day
Daily feeding = 559.5 Kg/day
Water feeding = 559.5 Kg/day
If you increased residence time feed rate will become less.
Design of gas holder:
Gasholder volume Vg= 60% of GP
= 0.60×4.0075
=2.404 m3
Digester to gasholder ratio = Vd:Vg

= 15.277/2.404
= 6.355

Assume the diameter of the gasholder is 80% of the digester= 0.80×1.273
= 1.018m

r =0.509m
Circumference=2πr= 3.198 m
Volume Vg= π×r×r×L
2.404= π×0.509×0.509×L
=> L= 2.953m
Ratio of length of digester to the gasholder=12:2.953
=4:1

Advantages:
1. Very low capital cost.
2. Simplest digester used.
3. Reasonable retention time.
4. Can be ambient to thermophilic temperature.

Disadvantages:
1. Slurry does not mix longitudinally.
2. No agitation.
3. Slow solid conversion.
4. Biogas production is low.
5. Periodic cleaning is necessary.

Feed preparation should contain 11 to 15% of solids.

Complete mix digester

Complete mixed digester vessels are insulated and maintained at a constant elevated temperature, in the mesophilic or thermophilic range. The digester vessel is usually a round insulated tank, above or below ground and made from reinforced concrete, steel. Heating coils with circulating hot water can be placed inside the digester or, depending on the consistency of the feedstock, the contents can be circulated through an external heat exchanger to maintain desired temperatures. They can be mixed with a motor driven mixer, a liquid recirculation pump. A gas tight cover (floating or fixed) traps the biogas.

The complete mixed digester is best suited to process manure with 3 - 10 percent total solids. Retention time is usually 10 to 15 days.

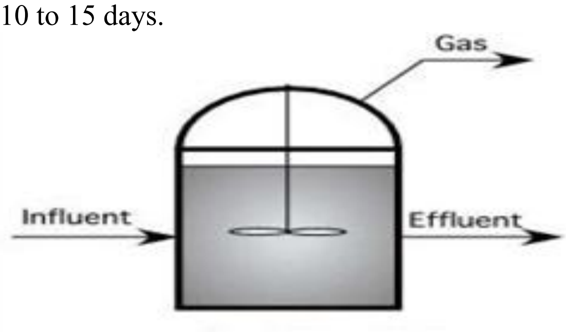

Fig 4: Complete mix digester

Advantages:
1. Biogas production is good.
2. Handle wide range of concentration.
3. Mixing is good within the reactor.
4. Retention time is less.
5. Bacteria and liquid have very good contact.

Disadvantages:
1. Capital and energy cost is usually high.
2. Bacteria loss can be an issue.
3. Mechanical problems.

Feed preparation should contain 3 to 10% of total solids.

Covered lagoon digester

A covered lagoon digester is a large anaerobic lagoon with a long retention time and a high dilution factor. Typically covered lagoons are used with flush manure management systems that discharge manure at 0.5 to 2 percent solids. The in-ground, earth or lined lagoon is covered with a flexible or floating gas tight cover. They are not heated. Retention time is usually 30-45 days or longer depending on lagoon size.

This type of digester is used in the region where the regional harvesting of biogas takes place, because of the variation in the temperature in these places. This type of digester is also used in the places where large quantity of liquid waste is produced such as swine farm, milk and milk products industry etc.

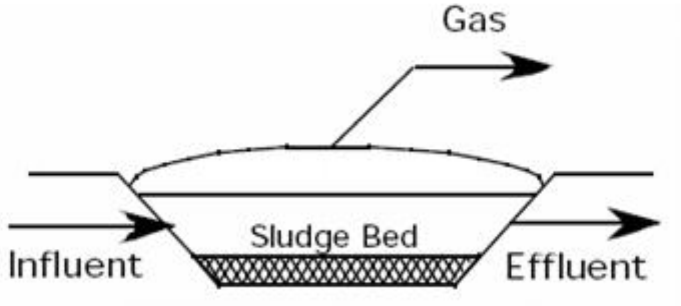

Fig 5: Covered lagoon digester

Advantages:
1. Happens in the ground temperature, no need of heater.
2. Good for seasonal harvesting.
3. Very low capital.
4. Good in handling liquid waste.

Disadvantages:
1. Very high retention times.
2. Slow solids conversion.
3. Bacteria and liquid have limited contact.
4. Biogas production lower.
5. Periodic cleaning is necessary.
6. Maintenance of lagoon is difficult.

Feed preparation should contain 0.5 to 2% of solids.

Fixed film digester

Fixed-film digesters consist of a tank filled with plastic media. The media supports a thin layer of anaerobic bacteria called biofilm (hence the term "fixed-film"). As the waste manure passes through the media, biogas is produced. Like covered lagoon digesters fixed-film digesters are best suited for dilute waste streams typically associated with flush manure handling or pit recharge manure collection. Fixed-film digesters can be used for both dairy and swine wastes.

Immobilization of the bacteria as a biofilm prevents washout of slower growing cells and provides biomass retention independent of hydraulic retention time (HRT). The Fixed film digester is best suited to process manure with 1 - 3 percent total solids. Retention time is usually 3 to 5 days.

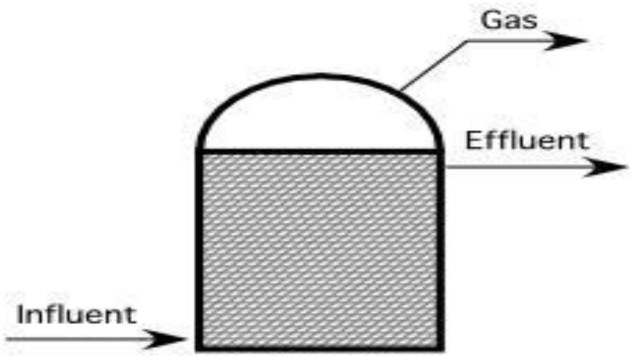

Fig 6: Fixed film digester

Advantages:

1. Less retention time.
2. Easy to construct.
3. Easy to operate.
4. Moderate biogas yield.
5. Bacteria is retained by the bed.

Disadvantages:

1. Periodic cleaning is necessary.
2. Periodic replacement of the film is necessary.
3. Pluggage-a problem with high solids.
4. No uniform temperature distribution.

Feed preparation should contain 1 to 3% of solids.

III. FACTORS INFLUENCING THE BIOGAS PRODUCTION

Since the reaction taking place in the digester is the enzymatic process in the presence of microorganism, the recovery of the gas from the digester depends on many of the factors such as
Nutrient: C-N= 30:1(may vary from 20: 1 to 40:1)
Solid Concentration : 12% (8% volatile matter)
Temperature Generation: 35^0c (less than 15 ^{0}c is not favorable for gas)
Retention Period: 30-35 days (varies from place to place)
P^H: 6.6 to 8(7.2 is optimum for gas generation)
Toxic substance: Fungicide, Insecticide, Pesticides, Heavy metals, Detergents, Phenyl, Dettol etc are harmful for biogas generation.
Particle size: As small as possible (By chopping or grinding)
Mixing formation: It is required to prevent the digester from scum

IV. CONCLUSION

Biogas is one of the future fuel, but it difficult to obtain when compared to the other most efficient fossil fuel today. But if we apply the ideas and modern technology to produce biogas from waste, we can increase the methane yield and hence the efficiency. It is proven that one ton of municipal waste can produce up to 250kg's of biogas. If we utilize the waste produced in the urban cities to produce biogas it is possible to eliminate the energy crisis which we are facing today. For example if we use the waste produced in the Bangalore alone, which is about 2000 tons per day, we can produce up to 5lakh kg of biogas daily, from which we can light up about 1000 houses.

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