

LECTURE-8

BIOGASIFICATION OF COW DUNG

➤ INTRODUCTION

- cow dung or manure can be defined as the undigested residue of consumed food material being excreted by herbivorous bovine animal species which include domestic cattle (cows), bison (buffalo), yak and water buffalo
- it is a mixture of faeces and urine in the ratio of 3:1, it mainly consists of lignin, cellulose and hemicelluloses
- it also contains 24 different minerals like nitrogen, potassium, along with trace amount of sulphur, iron, magnesium, copper, cobalt and manganese
- it is a cheap and easily available **bioresource** on our planet
- many traditional uses of cow dung such as burning as fuel, mosquito repellent and as cleansing agent are already known in India
- cow dung harbours a diverse group of microorganisms that may be beneficial to humans due to their ability to produce a range of metabolites
- along with the production of novel chemicals, many cow dung microorganisms have shown natural ability to increase soil fertility through phosphate solubilisation
- nowadays, there is an increasing research interest in developing the applications of cow dung microorganisms for biofuel production and management of environmental pollutants
 - **Indian Scenario**
 - ✓ the indigenous Indian cow also contain higher amount of calcium, phosphorus, zinc and copper than the cross-breed cow
 - ✓ cow dung harbours a rich microbial diversity, containing different species of bacteria (*Bacillus* spp., *Corynebacterium* spp. and *Lactobacillus* spp.), protozoa and yeast (*Saccharomyces* and *Candida*)
 - ✓ some researchers have also isolated many different bacterial genera such as *Citrobacter koseri*, *Enterobacter aerogenes*, *Escherichia coli*, *Klebsiella oxytoca*, *Klebsiella pneumoniae*, *Kluyvera* spp., *Morgarella morganii*, *Pasteurella* spp., *Providencia alcaligenes*, *Providencia stuartii* and *Pseudomonas* spp. from cow dung
 - ✓ 69.9 % of Indian population resides in rural areas, where cow (*Bos indicus*) is major cattle and generates 9–15 kg dung
 - ✓ waste is generally meant for discarding because it may act as a source of pollution
 - ✓ however, if it is used in some other process such as feedstock it may be considered as co-product
 - ✓ people in Indian villages use cow dung for cooking purpose by direct burning
 - ✓ it is also used in plastering of walls and floor in rural houses for providing insulation during winter and summer
 - ✓ application of smoke generated from the burnt cow dung as mosquito repellent and subsequent ash as cleaning agent for kitchen utensils is an age old practice
 - ✓ it also depicts that cow plays an important role in village economy and has high socio-economic value
 - ✓ cow dung in India is also used as a co-product in agriculture, such as manure, and as a source of energy

➤ **BIOGASIFICATION OF COW DUNG**

• **Biogasification**

- ✓ anaerobic degradation or fermentation of organic matter (cellulose, hemicelluloses, lignin) to biogas, is known as biogasification
- ✓ biogas is a mixture of colourless, flammable gases obtained from the anaerobic digestion (biogasification) of plant based organic wastes materials
- ✓ biogas is typically made up of methane (50 – 70 %) and carbon dioxide (30 – 40%), and other trace gases
- ✓ when animal manure or cow dung (which contains the undigested biomass) is used as a substrate, the mixed culture naturally present in the dung breaks down the organic matter to biogas
- ✓ in the fermentation process the yield of microbial cells is very small
- ✓ when the organic matter is degraded by methano fermentation, about 90% of the energy available in the substrate is transferred to the easily purifiable biogas product
- ✓ though biogasification is an age-old technology, its potential for converting various biomass, namely, animal manure, agriculture waste (or residues) and municipal refuse into the gaseous fuel, CH₄, has been fully recognized

• **Significance of Biogasification**

- the two enormous problems that are increasingly threatening the living standards of many nations are:
 - (1) task of waste management, and
 - (2) inadequacy of energy supply
- the problem of fuel scarcity and sewage disposal in India and in many developing countries are alarming
- energy generated from the wastes materials is therefore needful as it will serve the dual purpose of cleaning the environment and providing a cheaper source of energy
- bio-gasification of cow dung may contribute in serving the purpose to some extent
- production of biogas, if carried out at commercial scale, would not only provide an alternate source of energy but would also be a means of waste disposal

• **Principle of Biogasification of Cow Dung**

- ✓ it is the multi-step biological process during which organic material (cellulose, hemicelluloses, lignin) is converted to biogas and digestate in the absence of oxygen
- ✓ biogasification of cow dung proceeds in the absence of oxygen and in the presence of anaerobic microorganisms
- ✓ it is the consequence of a series of metabolic interactions among various groups of microorganisms
- ✓ it occurs in four stages, **hydrolysis/liquefaction**, **acidogenesis**, **acetogenesis** and **methanogenesis**

- ✓ the various stages have been detailed below and shown in **Figure-3**

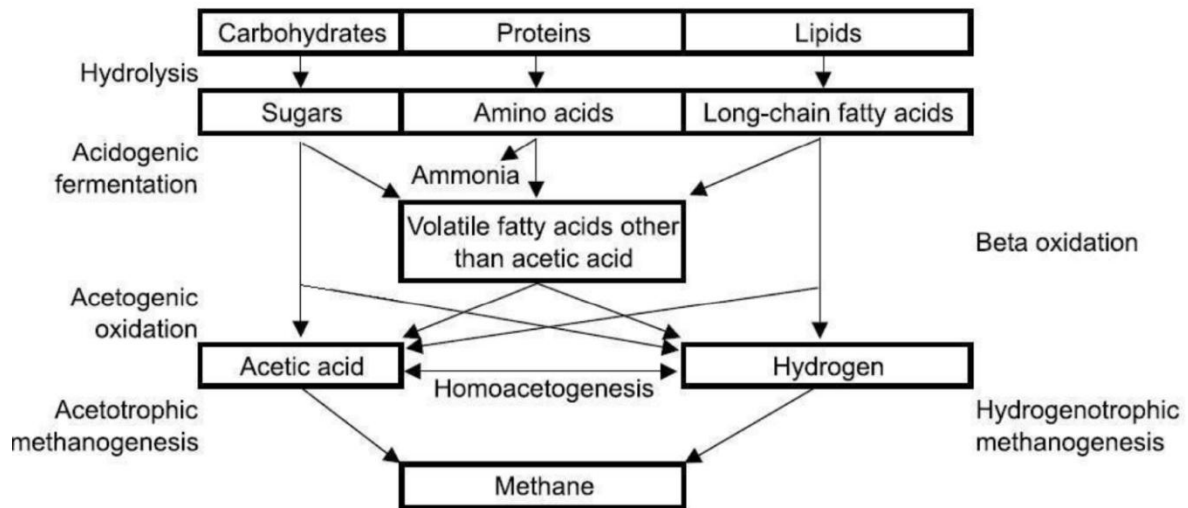


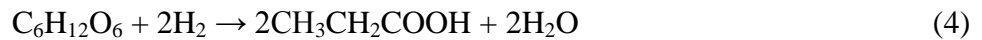
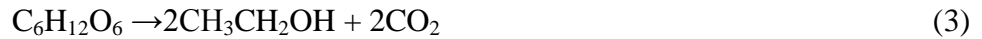
Figure-1: Anaerobic pathways in anaerobic degradation.

✓ **Hydrolysis/liquefaction**

- this step is very important for the anaerobic digestion process since polymers cannot be directly utilized by the fermentative microorganisms
- hydrolysis therefore renders the substrate accessible for the subsequent conversion steps
- in this step insoluble complex organic matter is broken down into their backbone constituents in order to allow their transport through microbial cell membrane
- hydrolysis is achieved through the action of hydrolytic enzymes
- in the first stage of hydrolysis, or liquefaction, fermentative bacteria convert the insoluble complex organic matter, such as cellulose, into soluble molecules such as sugars, amino acids and fatty acids
- proteases, secreted by proteolytic microbes, convert proteins into amino acids; celluloses and/or xylanases, produced by cellulytic and xylanolytic microbes, hydrolyze cellulose and xylose (both complex carbohydrates) into glucose and xylem (both sugars), respectively; finally lipases, created by lipolytic microbes, convert lipids (fats and oils) into long-chain fatty acids and glycerol
- the hydrolytic activity is of significant importance in high organic waste and may become rate limiting
- some industrial operations overcome this limitation by the use of chemical reagents to enhance hydrolysis
- the application of chemicals to enhance the first step has been found to result in a shorter digestion time and provide a higher methane
- Hydrolysis/Liquefaction reactions: (1)
 - Lipids → Fatty Acids
 - Polysaccharides → Monosaccharides
 - Protein → Amino Acids
 - Nucleic Acids → Purines & Pyrimidines

✓ **Acidogenesis (Fermentations)**

- fermentation involves the conversion of the sugars, amino acids and fatty acids to hydrogen, acetate, carbon dioxide, VFAs such as propionic, butyric and acetic acid, ketones, alcohols and lactic acid by facultative and anaerobic bacteria
- even though a simple substrate such as glucose can be fermented, different products are produced by the diverse bacterial community
- equations: 2, 3 and 4 show the conversion of glucose to acetate, ethanol and propionate, respectively.



- in an equilibrated system, most of the organic matter is converted into readily available substrates for methanogenic microbes (acetate, hydrogen and carbon dioxide), but a significant part (approximately 30%) is transformed to short chain fatty acids or alcohols
- degradable organic matter is removed in this stage
- by-product of amino acids fermentation, ammonia and hydrogen sulphide are released that can be inhibitory for anaerobic digestion

✓ **Acetogenesis**

- acetogenesis is the conversion of certain fermentation products such as volatile fatty acids (VFAs) with more than two carbon atoms, alcohols and aromatic fatty acids into acetate and hydrogen by obligate hydrogen producing bacteria
- in this stage, acetogenic bacteria, also known as acid formers, convert the products of the first phase to simple organic acids, carbon dioxide and hydrogen
- the principal acids produced are acetic acid (CH₃COOH), propionic acid (CH₃CH₂COOH), butyric acid (CH₃CH₂CH₂COOH), and ethanol (C₂H₅OH)
- the products formed during acetogenesis are due to a number of different microbes, e.g., *syntrophobacter wolinii*, a propionate decomposer and *syntrophomonos wolfei*, a butyrate decomposer
- other acid formers are *clostridium spp.*, *peptococcus anerobus*, *lactobacillus*, and *actinomyces*
- while hydrogen-producing acetogenic bacteria produce acetate, H₂ and CO₂ from volatile fatty acids and alcohol, homoacetogenic bacteria create acetate from CO₂ and H₂
- but most of the acetate is created by hydrogen-producing acetogenic bacteria
- an acetogenesis reaction is shown as: $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

✓ **Methanogenesis**

- a variety of methane-forming bacteria is required in the anaerobic digestion system, since no single species can degrade all the available substrates
- the methanogenic bacteria include *methanobacterium*, *methanobacillus*, *methanococcus* and *methanosarcina*
- methanogenesis can also be divided into two groups: acetate and H₂/CO₂ consumers
- *methanosarcina spp.* and *methanotherix spp.* (also, *methanosaeta*) are considered to be important in AD both as acetate and H₂/CO₂ consumers

- approximately 70% of the methane is produced from acetate, while the remaining 30% is produced from the reduction of carbon dioxide by hydrogen and other electron donors
- according to the type of substrate utilized by the methanogens, methanogenesis is divided into two main types:
 - a. hydrogenotrophic methanogenesis: hydrogen and carbon dioxide are converted into methane according to the reaction:

$$\text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O} \quad (5)$$
 - b. acetotrophic or acetoclastic methanogenesis: methane is formed from the conversion of acetate through the reaction:

$$\text{CH}_3\text{COOH} \rightarrow \text{CH}_4 + \text{CO}_2 \quad (6)$$

- **Factors Affecting Biogasification of Cow Dung in the Digester (Biogas Plant)**

The major factors which affect the formation of biogas from cattle dung are: temperature, pH, percentage of C and N, solid organic matter and water in the slurry, retention time, volumetric organic loading rate, and nutrients.

- ✓ **Temperatur**

- anaerobic fermentation of raw cow dung (gobar) can take place at any temperature between 8 and 55 °C
- the value of 35 °C is taken as optimum
- the rate of biogas formation is very low at 8 °C

- ✓ **pH**

- the pH of the gobar slurry can be varied from 6.8 to 7.8
- the pH above 8.5 should not be used as it is difficult for the bacteria to survive above this pH

- ✓ **Concentration of C and N**

- the methanogenic bacteria need both C and N for their survival
- because they consume C 30 – 35 times faster than N
- the optimum ratio of C, N may be taken as 30:1
- the fermentation should be strictly carried out anaerobically in the absence of oxygen

- ✓ **Proportion of Solid and Water**

- anaerobic fermentation or digestion of gabar proceeds well if the slurry contains 8 – 9% solid organic matter
- as the gobar contains 18% solid, gobar can be diluted in the ratio, cow dung:water = 1:1

- ✓ **Retention Time**

- the retention time of the system refers to the volume of fluid in the reactor (digester) per volume of the fluids passing into and out of the reactor per day.
- thus, a 20 litres reactor which is fed with a 4 litres volume per day so that the volume inside remains constant, will have a retention time of 5 days

- ✓ **Volumetric Organic Loading Rate**

- the volumetric organic loading rate is defined as the rate at which the organic waste is supplied to the digester
- it can be expressed as a percentage weight of organic matter added each day to the reactor volume

- It is related to the RT and the percentage organic matter present in the feed, according to the following equation:

$$\text{Reactor loading rate percent} = (\text{Percentage of organic matter in feed})/\text{RT}$$

✓ **Nutrients**

- methane forming bacteria have particular growth requirements
- it has been demonstrated that specific metals such as nickel, cobalt, molybdenum and iron are necessary for optimal growth and methane production
- trace metals play an important role to stimulate methanogenic activity
- selenium, molybdenum, manganese, aluminum, and boron have been recommended as additional components in media
- the recommended requirements for iron, cobalt, nickel, and zinc are 0.002, 0.004, 0.003 and 0.02mg/g acetate produced respectively
- it is noted that a requirement for nickel is quite unusual for biological systems, and this requirement uniquely characterizes methanogenic bacteria
- supplementation of anaerobic digesters with solutions of metal ions can improve the performance of the system

➤ **Digesters for Biogasification**

- in India the first biogas plant based on anaerobic digestion of cattle-dung was patented in 1946
- the earlier two models designed by Desai and Joshi are shown in the following Figures-2 (2A & 2B):

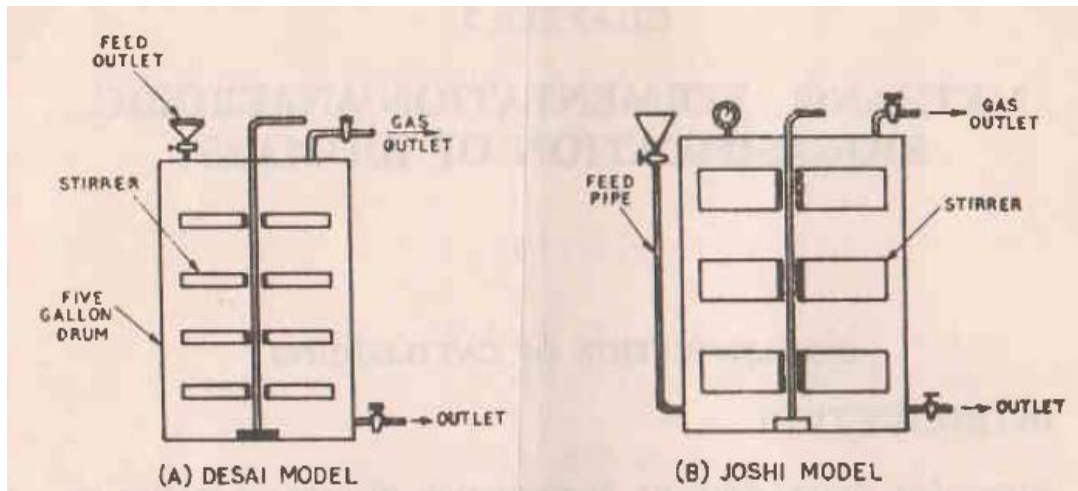


Figure-5; Experimental digester.

✓ **Indian Model Digester**

- the digester developed by Khadi and Village Industries Commission (KVIC), generally known as KVIC model developed in India has been shown in Figure-6
- floating dome gobar gas plant has been shown in Figure-7 for better understanding
- a mortar and cement-lined brick walled cylindrical tank is used as a digester, which is constructed underground
- the digester is divided into two equal halves by a wall extending up to half the height
- a MS circular structure, fitted to the centre wall supports the cylindrical G.I. gas holder
- a nipple with valve is used to draw the gas
- the clearance between the gas holder and the wall is sealed with oil/water

- two small tanks are installed at the ground level for feeding the raw gobar slurry and withdrawal of the digestate, respectively
- these two tanks called pits are connected to the digester through pipes
- initially the digester is filled with gobar slurry, until it comes to the level of discharge pit
- after 15 – 20 days the biogas starts filling up the gas holder
- which can be drawn for use after testing

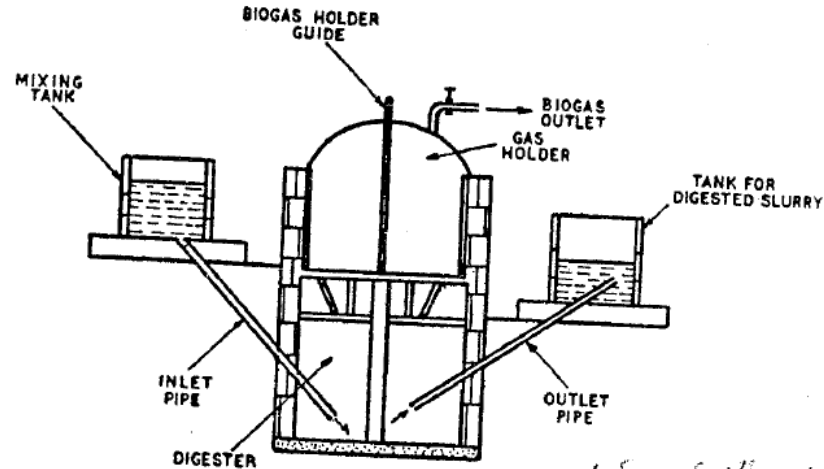
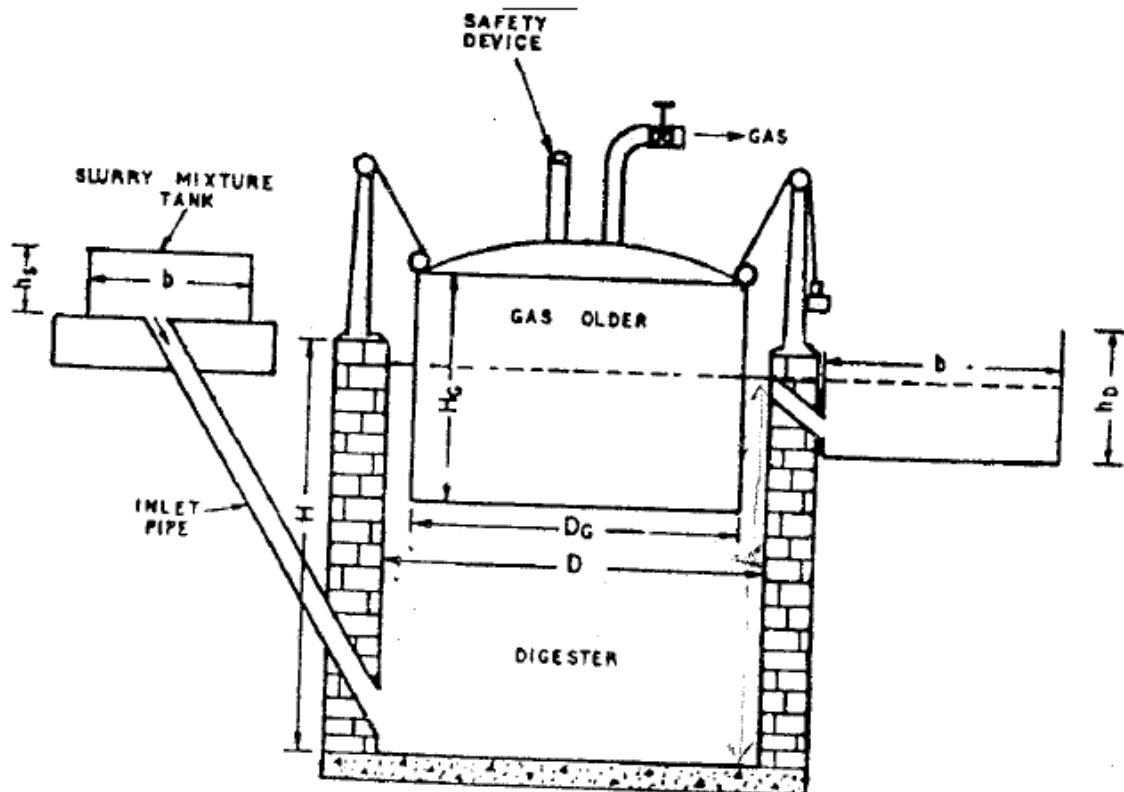


Figure-6: KVIC Model digester.



Figur-7; Floating dome type gobar gas plant.

✓ Types of Digesters

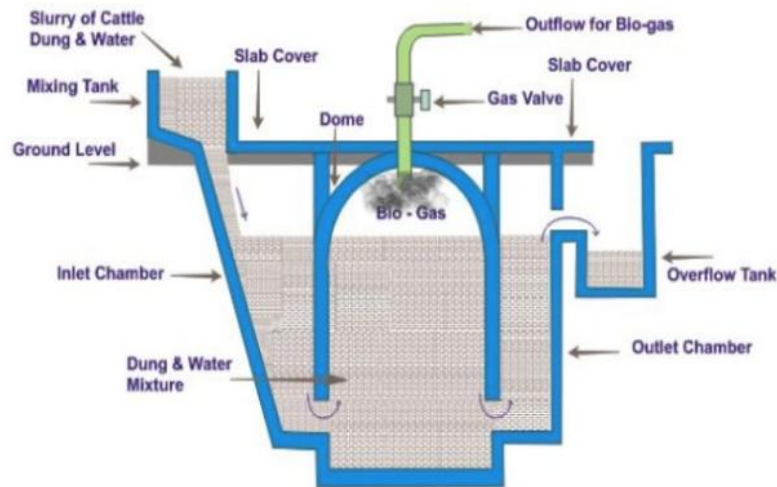
There are various types of digesters which are used biogasification of organic materials. The two main types are: Floating Dome and Fixed Dome Anaerobic Digester

- **Fixed Dome Type Digester**

- the digester has been shown by **Figure-8**, below

The biogas plant is a brick and cement structure having the following five sections:

- **Mixing tank** present above the ground level.
- **Inlet tank:** The mixing tank opens underground into a sloping inlet chamber.
- **Digester:** The inlet chamber opens from below into the digester which is a huge tank with a dome like ceiling. The ceiling of the digester has an outlet with a valve for the supply of biogas.
- **Outlet tank:** The digester opens from below into an outlet chamber.
- **Overflow tank:** The outlet chamber opens from the top into a small over flow tank.



Fixed Dome type Bio-gas Plant

Figure-8: Fixed dome type anaerobic digester or gobar gas plant

- The various forms of biomass are mixed with an equal quantity of water in the mixing tank. This forms the **slurry**.
- The slurry is fed into the digester through the inlet chamber.
- When the digester is partially filled with the slurry, the introduction of slurry is stopped and the plant is left unused for about two months.
- During these two months, anaerobic bacteria present in the slurry decomposes or ferments the biomass in the presence of water.
- As a result of anaerobic fermentation, biogas is formed, which starts collecting in the dome of the digester.

- As more and more biogas starts collecting, the pressure exerted by the biogas forces the spent slurry into the outlet chamber.
- From the outlet chamber, the spent slurry overflows into the overflow tank.
- The spent slurry is manually removed from the overflow tank and used as manure for plants.
- The gas valve connected to a system of pipelines is opened when a supply of biogas is required.
- To obtain a continuous supply of biogas, a functioning plant can be fed continuously with the prepared slurry.

Advantages of Fixed Dome Type Digester

- Requires only locally and easily available materials for construction.
- Inexpensive.
- Easy to construct.

Floating Dome Type Digester

The digester has been shown by **Figure-9**,

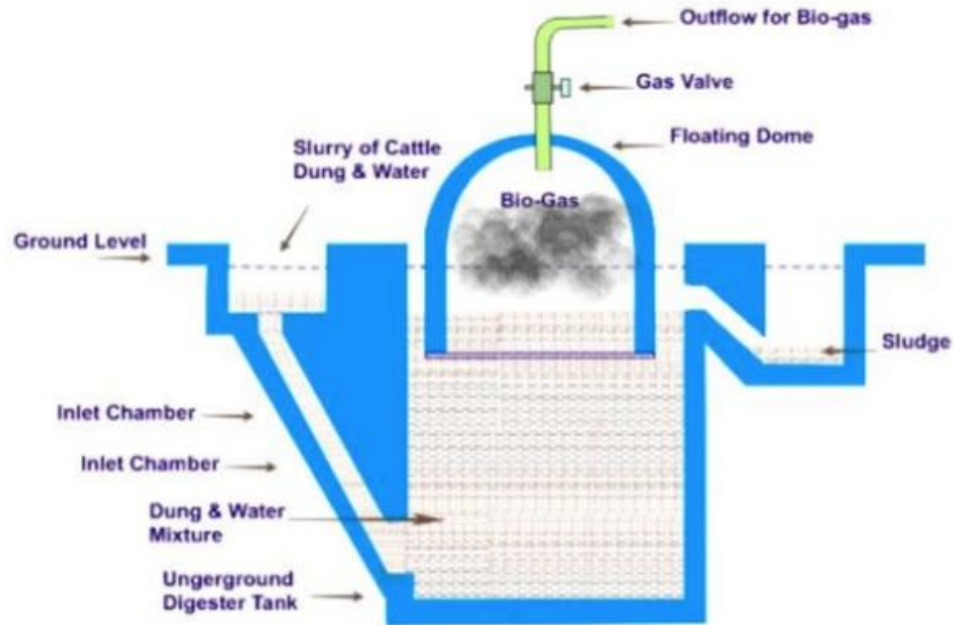
The floating gas holder type of biogas plant has the following chambers/ sections:

- **Mixing Tank** - present above the ground level.
- **Digester tank** - Deep underground well-like structure. It is divided into two chambers by a partition wall in between.
- It has two **long cement pipes**
 - i) **Inlet pipe opening** into the inlet chamber for introduction of slurry.
 - ii) **Outlet pipe opening** into the overflow tank for removal of spent slurry.
- **Gas holder** - an inverted steel drum resting above the digester. The drum can move up and down i.e., float over the digester. The gas holder has an outlet at the top which could be connected to gas stoves.
- **Over flow tank** - Present above the ground level.

Construction of Floating Dome Type

- Slurry (mixture of equal quantities of biomass and water) is prepared in the mixing tank.
- The prepared slurry is fed into the inlet chamber of the digester through the inlet pipe.
- The plant is left unused for about two months and introduction of more slurry is stopped.
- During this period, anaerobic fermentation of biomass takes place in the presence of water and produces biogas in the digester.
- Biogas being lighter rises up and starts collecting in the gas holder. The gas holder now starts moving up.

- The gas holder cannot rise up beyond a certain level. As more and more gas starts collecting, more pressure begins to be exerted on the slurry.
- The spent slurry is now forced into the outlet chamber from the top of the inlet chamber.
- When the outlet chamber gets filled with the spent slurry, the excess is forced out through the outlet pipe into the overflow tank. This is later used as manure for plants.
- The gas valve of the gas outlet is opened to get a supply of biogas.
- Once the production of biogas begins, a continuous supply of gas can be ensured by regular removal of spent slurry and introduction of fresh slurry.



Floating Dome type Bio-gas Plant

Figure-9: Floating dome type anaerobic digester or gobar gas plant

Disadvantages of Floating dome type anaerobic digester

- Expensive
- Steel drum may rust
- Requires regular maintenance

Biogas

- Biogas is a clean and efficient fuel.
- It is a mixture of:
 - Methane (CH_4)
 - Carbon dioxide (CO_2)
 - Hydrogen (H_2)
 - Hydrogen sulphide (H_2S)
- The chief constituent of biogas is **methane (65%)**.



Raw materials required

- Forms of biomass listed below may be used along with water.
- Animal dung
- Poultry wastes
- Plant wastes (Husk, grass, weeds etc.)
- Human excreta
- Industrial wastes(Saw dust, wastes from food processing industries)
- Domestic wastes (Vegetable peels, waste food materials)



Advantages of biogas as a fuel

- High calorific value
- Clean fuel
- No residue produced
- No smoke produced
- Non polluting
- Economical
- Can be supplied through pipe lines
- Burns readily - has a convenient ignition temperature



Advantages of biogas plants

- Reduces burden on forests and fossil fuels
- Produces a clean fuel - helps in controlling air pollution
- Provides nutrient rich (N & P) manure for plants
- Controls water pollution by decomposing sewage, animal dung and human excreta.

Uses of biogas

- Domestic fuel
- For street lighting
- Generation of electricity
- If compressed, it can replace compressed natural gas for use in vehicles



Applications



A biogas bus, Sweden



The Biogas Train "Amanda"
Sweden



BIOGAS PLANT



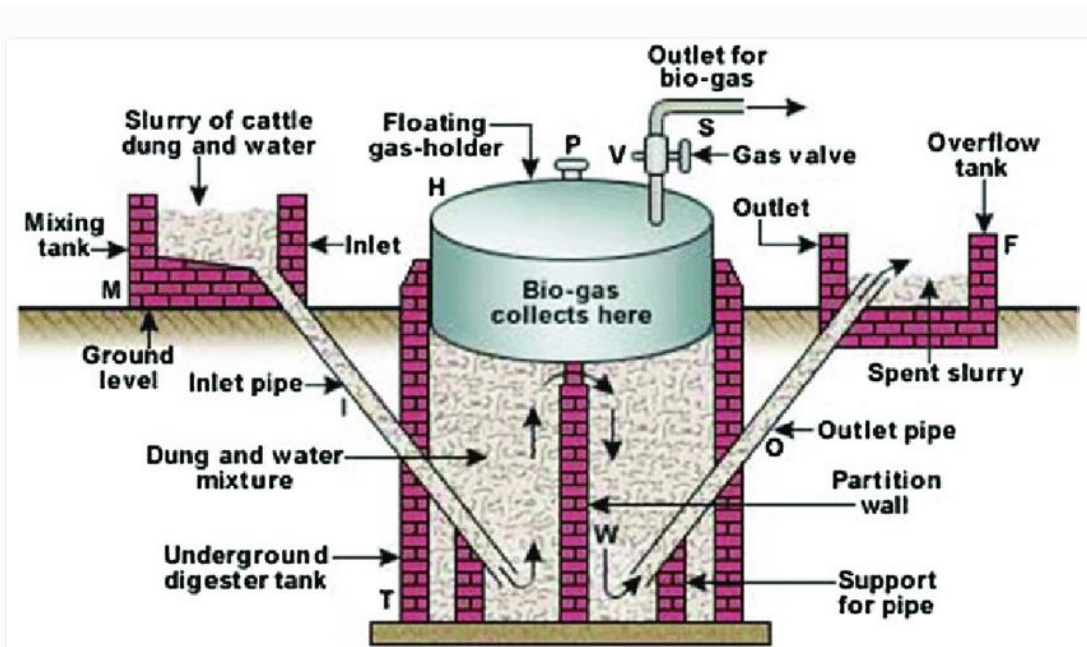
Limitations of biogas plants

- Initial cost of installation of the plant is high.
- Number of cattle owned by an average family of farmers is inadequate to feed a biogas plant.



Recent Developments

- With the many benefits of biogas, it is starting to become a popular source of energy and is starting to be used in the United States more.
- On 5 October 2010, biogas was injected into the UK gas grid for the first time. As of September 2013, there are about 130 non-sewage biogas plants in the UK.
- Germany is Europe's biggest biogas producer and the market leader in biogas technology.
- To create awareness and associate the people interested in biogas, the Indian Biogas Association was formed. India's Ministry of New and Renewable Energy offers some subsidy per model constructed.



➤ **DESIGN CALCULATION OF GOBAR GAS PLANT WITH RESPECT TO FIGURE-7**

QUESTION: There are 350 cows and 150 calves in a dairy farm. Average gobar available per cow perday is 12 kg. How would you design a gobar gas plant with the help of the following information:

- i. Average biogas available /kg of mixed gobar per day = 0.04 m^3
- ii. Average percentage of solid in gobar = 16%
- iii. Average bulk density of gobar = 920 kg/m^3
- iv. The maximum allowable capacity of digester = 350 m^3
- v. Optimum ratio of gobar to water in the slurry = 1:1

Compute the height and diameter of digester, dimension of the gas holder and slurry mixing tank. Also sketch the diagram of the digester.

SOLUTION:

Number of cows = 350

Number of calves = 150 \approx 75

(adult cows, assumed)

Therefore total number of cows = 350 + 75 = 425

Average gobar produced by 425 cows = $425 \times 12 = 5100 \text{ kg/day}$

Average biogas available per day = $5100 \times 0.04 = 204 \text{ m}^3 - 210 \text{ m}^3$ (Assumed)

Average volume of gobar available per day = $\frac{5100}{920} = 5.6 \text{ m}^3$

Volume of slurry to be prepared = $5.6 + 5.6 = 11.2 \text{ m}^3/\text{day}$

Volume of slurry to be accommodated in 30 days = $30 \times 11.2 = 336 \text{ m}^3$

Let us assume that

Height of the digester = H

Diameter of the digester = D

Volume of the digester = V

Height of the slurry in the digester = $h = 10 \text{ m}$ (assumed)

Now the volume of the slurry which would be accommodated by the digester = $\frac{\pi}{4} \times D^2 \times h$

$$= \frac{\pi}{4} \times D^2 \times 7$$

$$= 336 \text{ m}^3 \text{ (given)}$$

$$D = \sqrt{\frac{336 \times 4}{\pi \times 10}} = \sqrt{\frac{336 \times 4}{3.142 \times 6}} = \sqrt{\frac{1344}{31.42}} = \sqrt{42.80} = 6.5 \text{ m}$$

Let us say that the free space above the slurry = 0.5 m

Therefore, $H = 10 \text{ m} + 0.5 \text{ m} = 10.5 \text{ m}$

The gas produced per day is to be accommodated in the gas holder and in the pipeline. Let us assume that 50% of the gas produced is consumed and 50 % is stored in the gas holder.

Now volume of the gas over the slurry in the digester to be accommodated by the gas holder = $210/2 = 105 \text{ m}^3$ (this is the volume of the gas holder, V_G)

Let clearance around the gas holder = 0.05 m

Diameter of the gas holder, $D_G = \text{Diameter of the digester} - 2 \times 0.05 = 6.5 - 0.1 = 6.4 \text{ m}$

Volume of gas holder, $V_G = 105 = \frac{\pi}{4} \times D_G^2 \times H'_G = \frac{\pi}{4} \times (6.4)^2 \times H'_G$

$$\text{Or } H'_G = \frac{105 \times 4}{\pi \times (6.4)^2} = \frac{105 \times 4}{\pi \times 40.96} = \frac{105 \times 4}{\pi \times 40.96} = \frac{420}{128.7} = 3.26 \text{ m}$$

Let the height of the digester dipped into the slurry = 0.03 m

Thus height of the gas holder, $H_G = H'_G + 0.03 = 3.26 + 0.03 = 3.29 \text{ m}$

Now dimension of the slurry mixing tank is to be determine. Let us assume that the length and breadth of the tank is 2 m

Now the volume of the slurry tank = volume of the slurry prepared per day = 11.2 m^3
 $= 2 \times 2 \times h_s$

Height of the slurry mixing tank, $h_s = 2.8 \text{ m}$

Size of the slurry mixing tank = $2 \times 2 \times 2.8 \text{ m}^3$

Size of the digester: $V = 336 \text{ m}^3$, $H = 10.5 \text{ m}$, $D = 6.5 \text{ m}$

Size of the gas holder: $D_G = 6.4 \text{ m}$, $H_G = 3.29 \text{ m}$