CHAPTER

6 Biomass Energy

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6.1. INTRODUCTION TO BIOMASS

Biomass is *an organic matter from plants, animals and micro-organisms grown on land and water and their derivatives.* The *energy obtained from biomass is called* **biomass energy.** "***Biomass***" is considered as a *renewable source of energy because the organic matter is generated everyday.*

— Coal, petroleum, oil and natural gas *do not* come in the category of 'biomass', because they are produced from dead, burried biomass under pressure and temperature during millions of years.

- "*Biomass*" can *also be considered a form of solar energy as* the latter *is used indirectly* to grow these plants by *photosynthesis.*

- "***Biomass fuel***" is used over 85 percent of rural households and in about 15 percent urban dwellings. Agriculture products rich in starch and sugar like wheat, maize, sugarcane can be fermented to produce *ethanol* (C_2H_5OH). *Methanol* (CH_3OH) is also produced by distillation of biomass that contains cellulose like wood and begasse. *Both these alcohols can be used to fuel vehicles and can be mixed with 'diesel' to make* **biodiesel**.

6.2. BIOMASS RESOURCES

In our country, there is a great potential for *application of biomass as an 'alternate source of energy'*. We have plenty of agricultural and forest resources for reproduction of biomass. The following are the *biomass resources* :

1. Concentrated wastes :

(*i*) Municipal solid (*ii*) Sewage wood products (*iii*) Industrial waste (*iv*) Manure at large lots. **2. Dispersed waste residue :**

(*i*) Crop residue (*ii*) Logging residue

(*iii*) Disposed manure.

3. Harvested biomass :

(*i*) Standing biomass (*ii*) Biomass energy plantations. The biomass sources are highly dispersed and bulky and contain large amount of water (50 to 90%). Thus, it is not economical to transport them over long distances, and as such *conversion into usable energy must take place close to the source, which is limited to particular regions. However, biomass can be converted to liquid or gaseous fuels, thereby increasing its energy density and making transportation feasible over long distances.*

6.2.1. Availability of Biomass

The total terrestrial crop alone is about 2×10^{12} metric tonnes. This includes : (i) Sugar crops such as sugarcane and sweet sorghum; (ii) Herbaceous crops, which are non woody plants that are easily converted into liquid or gaseous fuels; and (iii) Sihiriculture (forestry) plants such as cultured hybrid poplar , sycamore, sweatgum, alder, eucalyptus, and other hardwoods.

- The terrestrial crops have energy potential of 3×10^{22} joules. The efficiency of solar energy utilisation in natural photosynthesis is only 0.1 to 2 percent. At present only 1 percent of world biomass is used for energy conversion. Current *research* focuses on the screening and identification of species that are suitable for short-rotation growing and on optimum techniques for planting, fertilization, harvesting, and conversion. Fast growing trees, sugar, starch and oil containing plants can be cultivated which have about 5 percent efficiency of solar energy utilisation.
- The estimated production of agricultural residue in India is 200 million tonnes per year and that of wood is 130 million tonnes.
- Aquatic crops are grown in fresh sea and backish waters, both submerged and emergent plants. These include seaweeds, marine algae etc.
- *Animal and human wastes* are an *indirect terrestrial crop* from which *methane* for combustion, and *ethylene* can be produced while *retaining the fertilizer value of the*

manure. The daily produce of cowdung is about 13.5 kg per cattle which can be used to produce 0.46 m^3 of *biogas* in 'Gobar gas plant'. This gas is sufficient to produce 1 kWh of electricity in a biogas engine.

The *human waste* can also be used for production of biogas. *Community latrines* can be planned in the villages for collection of night soil for feeding to biogas plants. Wastes of 200 persons can be used to produce about 5 m^3 of gas per day to extract 12 kWh of equivalent energy by running a biogas engine.

6.2.2. Limitations of Utilising Biomas

Following are the *limitations* of utilising biomass :

1. Relatively *expensive energy conversion.*
2. *Low conversion efficiency* (*i.e.* small percentage of sun light is converted to biomass by plants).

3. Relatively low concentration of biomass per unit area of land and water.

6.3. ENVIRONMENTAL EFFECTS OF BIOMASS/BIOFUELS

Following are the *effects/benefits* of biomass/biofuels :

1. Biomass can pollute air when it is burned but less than those of fossil fuels. 2. Biomass, when burned, does not release green-house gases (or CO_2). 3. Burning biofuels do not produce pollutants like sulphur, that results in acid rain. 4. When biomass crops are grown, nearly equivalent amount of CO_2 is captured through photosynthesis.

6.4. PHOTOSYNTHESIS

The preparation of food by the leaves of green plant and micro-organism in presence of sunlight, chlorophyll, water and "CO_2" is called **photosynthesis**. In this process, the CO_2 from the atmosphere combines with water and light energy to produce *carbohydrates* (i.e., sugars, starches etc.) and *oxygen.*

The *photosynthesis process* can be represented by the following *reaction* :

$$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6CO_2$$

Biomass does *not add* CO_2 to the atmosphere as it *absorbs* the same amount of carbon in growing the plants as it is released when consumed as fuel. It is a *superior fuel* as the energy produced by biomass is *'carbon cycle neutral'*.

The **conditions** *necessary for photosynthesis* are :

(*i*) ***Light :*** The intensity of solar radiation of 400-700°A wavelength is one of the important inputs for biomass production; this range of light is called '*Photosynthetically active radiation (PAR)*'. The upper limit of photosynthesis efficiency is about 5 per cent.

(*ii*) ***CO_2 concentration :*** *CO_2 is the primary raw material for photosynthesis*. *The main sources of CO_2 are :*

— Animal respiration;

— Combustion of fuel;

— Decay of organic matter by bacteria;

— Ocean (respiration of marine plants and animal releases CO_2 into the water).

(*iii*) ***Temperature :*** The process of photosynthesis is *restricted* to temperature range of 0°C to 60°C which can by *tolerated by proteins*.

The energy stored in the plants by way of carbon fixation in the form of chemical bond energy when expressed as a fraction of total insolation falling on the plant, is called as **photosynthetic efficiency***.*

6.5. BIOMASS CONVERSION PROCESSES

The following *processes* are used for the **biomass conversion to energy or to biofuels***:*

1. Densification.
2. Combustion and incineration.
3. Thermo-chemical conversion.
4. Biochemical conversion.

6.5.1. Densification

In this process bulky biomass is *reduced to a better volume-to-weight ratio by compressing in a die at a high temperature and pressure.* The biomass pressed into briquettes or pellets (easier to transport and store) can be *used* as clean fuel in *domestic chulhas, bakeries and hotels.*

6.5.2. Combustion and Incineration

Combustion :

Combustion *is the process of burning in presence of oxygen to produce heat* (utilised for cooking, space heating, industrial purposes and for electricity generation), *light* and *by products.*

The combustion of biomass is *more difficult* than other fuels since it contains relatively *higher moisture content. Biomass is free from toxic metals and its ash*.

This method is *very inefficient* with heat losses to 30 to 90% of the original energy contained in the biomass.

- The technology of *"fluidised bed combustion"* may be used for the efficient combustion of forestry and agricultural waste material such as sawdust, wood chips, hog fuel, rice husks, straws, nutshells and chips.

In **fluidised bed combustion** of *biomass, the biomass is fed into a bed of hot inert particles,* such as sand kept in fluidised state with air at sufficient velocity from below. The operating temperature is normally controlled within the range 750- 950°C; ideally it is kept as high as possible in order to maximise the rate of combustion and heat transfer but low enough to avoid the problem of sintering of the bed particles. *The rapid mixing and turbulence within the fluidised bed enables efficient combustion to be achieved with high heat releases, as well as effective transfer,* than in a conventional boiler. This can *result in more compact boiler with less number of tubes*.

Incineration :

It is the process of burning completely the solid masses to 'ashes' by high temperature oxidation.

Although the terms 'combustion' and 'incineration' are synonymous, yet the *"combustion process"* is *applicable to all fuels* (i.e., solid, liquids and gases); *"incineration"* is a special process which is used for incinerating municipal solid waste to *reduce* the volume of solid refuse (90 per cent) and to *produce heat steam and electricity*.

Pyrolysis. Wood, dung, vegetable waste can be *dried and burnt to provide heat or converted into low calorific value by* ***pyrolysis****.* In the pyrolysis process, the organic material is converted to gases, solids and liquids by heating to 500 to 900°C in the *absence of oxygen*.

6.5.3. Thermo-chemical Conversion

It is a process to decompose biomass with various combinations of temperatures and pressures. Thermo-chemical conversion takes the following *two* forms :

(*i*) Gasification;

(*ii*) Liquification.

(*i*) Gasification:

It is the process of heating the biomass with limited oxygen to produce 'low heating value' or by reacting it with steam and oxygen at high pressure and temperature to produce 'medium heating value gas'.

The *output gas is known as* ***"producer gas"****,* a mixture of H_2 (15-20%), CO (10 to 20%), CH_4 (1 to 5%), CO_2 (9 to 12%) and N_2 (45 to 55%). As compared to solid mass the gas is more *versatile,* it can be burnt to *produce heat and steam*, *or used in I.C. engines or gas turbines to generate electricity*.

(*ii*) Liquification:

• Biomass can be *liquified* through *fast* or *flash pyrolysis,* called *"pyrolytic oil"* which is a dark brown liquid of low viscosity and a mixture of hydrocarbons. • Biomass can also be liquified by *"methanol synthesis"*. Gasification of biomass produces synthetic gas containing a mixture of H_2 and CO. The gas is *purified* by adjusting the composition of H_2 and CO. Finally, the purified gas is subjected to liquefication process, *converted to methanol* over a zinc, chromium catalyst. — *Methanol* can be used as *liquid fuel.*

6.5.4. Biochemical Conversion

In biochemical conversion there are *two principal conversion processes*:

1. Anaerobic digestion;
2. Fermentation.

1. Anaerobic digestion:

This process involves '*microbial digestion*' of biomass and is done in the '*absence of oxygen*'.

The process and *end products* depend upon the *micro-organisms cultivated under culture conditions.* (An *anaerobe* is a microscopic organism that can live and grow *without external oxygen or air;* it extracts oxygen by decomposing the biomass at low temperatures upto 65°C, in presence of moisture).

This process generates mostly *methane* (CH_4) and *CO_2 gas* with small impurities such as hydrogen sulphide.

The *output gas* obtained from anaerobic digestion can be *directly burnt*, or *upgraded to superior fuel gas (methane)* by removal of CO_2 and other impurities. The residue may consist of protein-rich sludge and liquid effluents which can be used as animal feed or for soil treatment after certain processing.

- **Aerobic decomposition** is done in the *presence of oxygen* and it produces CO_2, NH_3 and some other gases in small quantities and *large quantity of heat*. The final by-product of this process can be used as *fertilizer*.

2. Fermentation:

***Fermentation** is the process of decomposition of organic matter by micro-organisms especially bacteria and yeasts.*

- It is a well established and widely used technology for the conversion of grains and sugar crops into *ethanol* (ethyl alcohol):
- Ethanol can be blended with gasoline (petrol) to produce gasohol (90% petrol and 10% ethanol). Processes have been developed to produce various fuels from various types of fermentations.

$$\underset{\text{Sucrose}}{C_{12}H_{22}O_{11}} + H_2O \rightarrow \underset{\text{Glucose}}{2C_6H_{12}O_6}$$

$$C_6H_{12}O_6 \xrightarrow{\text{Fermentation}} \underset{\text{Ethanol}}{2C_2H_5OH} + 2CO_2$$

Fig. 6.1, shows the biomass and conversion technologies and products.

Biomass
Wood, Crop residues,
Biological wastes

Preparation

Air O_2

Combustion

Hydrolysis Solvent

digestion Biophotolysis Pyrolyser Gasifier
(dry)
Anaerobic

extraction

Steam Medium heat gas H_2 Char Oil Fermentation Synthetic Low heat gasoline
Direct use Electricity
gas
Medium heat gas
Ethanol

Direct use Synthetic natural gas

Product synthesis

Synthetic natural gas

Methanol Ammonia Hydrogen Synthetic gasoline

Fig. 6.1. Biomass conversion technologies and products .

6.6. BIOGAS

6.6.1. Introduction

The *main source for biogas is* **wet cattle dung**. Some of the *other sources are*:

(*i*) Sewage (*ii*) Crop residue

(*iii*) Vegetable wastes (*iv*) Water hyacinth

(*v*) Alga (*vi*) Poultry droppings

(*vii*) Pig-manure (*viii*) Ocean kelp

- Biomas, a mixture containing *55-65% methane, 30-40% carbon dioxide* and the rest being the impurities (hydrogen, hydrogen sulphide and some nitrogen), can be produced from the decomposition of animal, plant and human waste.
- It is a clean but slow-burning gas and usually has a heating value about 18 kJ/m^3.
- It can be used directly in cooking, reducing the demand for firewood.

- The material from which the biogas is produced retains its value as *fertilizer* and can be returned to soil.
- 'Biogas' *is produced by digestion, pyrolysis or hydrogasification*. **Digestion** is a biological process that occurs in the absence of oxygen and in the presence of anaerobic organisms at ambient pressures and temperatures of 35-70°C. The container in which this digestion takes place is known as the *digester.*

6.6.2. Biogas Applications

Biogas is a flammable fuel gas usually with 60% CH_4 and rest CO_2. The gas can be upgraded by removal of CO_2 with water scrubbing and the gas with high heating value can be used in I.C. engine.

The main *applications of biogas* are :

(*i*) Cooking.

(*ii*) Domestic lighting and heating.

(*iii*) I.C. engines.

(*iv*) Fuel cells–electricity can be produced by using biogas in a fuel cell with air as oxidant. The electrolyte is usually potassium hydroxide (KOH).

Application of biogas in petrol engines :

— Biogas can be used in petrol engines after initial starting of the engine on petrol. It needs about 550 litres of gas per kWh to run a petrol engine.

— Engine can also run as *duel fuel engine* either on biogas or petrol. It has the *advantage* that the engine can run on petrol if the biogas is not available or vice versa.

Application of biogas in "Diesel engines" :

— Biogas can be better used in diesel engines (as a duel fuel engine). — It is more convenient to use biogas since it has high self ignition temperature of about 730°C.

Advantages of using biogas in engines :

1. It has ample flexibility of operation.
2. A uniform gas-air mixture is available in multicylinder engines.

3. Clean combustion reduces the wear of engine parts.
4. Lubricating oil consumption is reduced.
5. Emissions of CO are greatly reduced.
6. NO_x emissions are also reduced.

6.6.3. Anaerobic Digestion System (Biogas Technology)

Anaerobic digestion system consists of the following *three* stages :

1. Hydrolysis (Stage–1)
2. Acidification (Stage–2)
3. Methane formation (Stage–3).

These stages are shown in the Fig. 6.2 shown below:

Fig. 6.2. Anaerobic digestion system.

1. Hydrolysis (Stage–1) :

In this stage, the complex compounds, such as *fats*, *proteins* and *carbohydrates* are *broken into small size compounds* through the effluence of *water* and *enzymes* called *"Hydrolysis"*.

Reaction of hydrolysis:

$$(C_6H_{10}O_5)n + nH_2O \xrightarrow{\text{Enzymes}} n(C_6H_{12}O_6)$$

Cellulose Nutrients Soluble glucose Nutrient **+ +** *s*

2. Acidification (Stage 2).

In this stage, the soluble glucose and nutrients are converted into *simpler volatile fatty acid and acetic acid as byproduct,* that accounts for 70 per cent of *methane* by product with the help of *acid forming bacteria.*

Reaction of acidification:

$$C_6H_{12}O_6 \xrightarrow[\text{bacteria}]{\text{Acid producing}} 2CH_3CH_2OH \text{ (Ethylalcohol)} + 2CO_2 + \text{Fatty acid} + H_2 + \text{other products}$$

3. Methane formation (Stage-3) : During this stage, the *methane producing bacteria converts the organic acid into* ***biogas*** having its *main constituent as "methane".*

Reactions of methane formation:

$$2CH_3CH_2OH + CO_2 \xrightarrow[\text{bacteria}]{\text{Methane producing}} 2CH_3COOH + CH_4$$

$$CH_3COOH \longrightarrow \underset{\text{Methane}}{CH_4} + CO_2$$

6.6.4. Advantages of Anaerobic digestion

Anaerobic digestion claims the following *advantages* :

1. The *biogas* produced as a byproduct, has a *calorific value* (which can be used as energy source for producing steam or hot water).
2. Low nutrient requirement.
3. Low odour.
4. Reduction of pathogens.
5. Stable sludge.
6. New sludge production.
7. Sludge acts as a soil conditioner.

8. Low running cost.

6.6.5. Advantages of Biogas Production

1. Gas production is cheap.
2. Less pollution.
3. Waste material can be used as fertilizer.
4. Gas is used for cooking, lighting, as fuel etc.

6.6.6. Factors affecting Generation of Biogas

The generation of biogas is affected by the following *factors :*

1. Temperature, 2. Loading rate,
3. Solid concentration, 4. pH value,

5. Retention period, 6. Nutrients concentration, and 7. Toxic substances.

1. **Temperature.** The anaerobic fermentation process is *temperature dependent.* The process of the digestion and gasification proceeds at the *highest rate* when the temperature lies between 35°C – 38°C. The process becomes *slow* within temperature range of 45°C – 45°C and then *rises to a peak* between 55°C – 60°C. Thus, the *rate of gas production 'increases' with the increase in temperature* but the *percentage of methane 'decreases'*.
2. **Loading rate.** *"Loading rating"* is the *weight of volatile solids fed to a digester per day.* It depends upon the *plant capacity* and also the *retention period.* Thus, for a given capacity of the digester, if the *loading rate* is *increased* the *'retention period'* is correspondingly *decreased*.
3. **Solid concentration.** Normally, 7 to 9 parts of solid in 100 parts of the slurry is considered ideal.

— It is recommended that 4 parts of the *cattle dung* to be mixed with *5 parts* of *water.* **4. pH value.** pH denotes the acidity and alkalinity of the substrate. The pH *less* than 7 is called '*acidic*' and pH *more* than 7 is called '*alkaline*' and pH solution of 7 is called '*neutral*'.

5. **Retention period.** It is the time period for which fermentable material *resides inside the digester.* This period ranges from 30 days to 50 days depending upon the *climatic conditions.*

- Generally it is observed that *maximum gas production takes place within 'first four weeks'* and it *tapers off gradually.*

6. **Nutrients concentration.** The major nutrients required by the bacteria in the digester are C, H_2, O_2, N_2, P and S. To maintain proper balance of nutrients an extra raw material, rich in P and N_2, should be added along with cattle dung *to obtain maximum gas production*.
7. **Toxic substance.** The presence of ammonia, pesticides, detergents and heavy metals are considered as toxic substances to micro-organisms, since their *presence reduces fermentation rate.*

6.7. BIOGAS PLANTS

6.7.1. Introduction

Biogas plants *converts wet biomass into biogas (methane) by the process of "anaerobic fermentation".*

The bacteria called *"anaerobe"* carrier out digestion of biomass *without oxygen* and produces methane (CH_4) and carbon dioxide (CO_2).

Biogas plants are very popular in India particularly in rural areas.

6.7.2. Raw Materials used in Biogas Plant

1. *Animal wastes :* Cattle dung, urine, fish wastes, piggery wastes etc.
2. *Human wastes :* Waste matter, urine etc.
3. *Agriculture wastes :* Sugarcane trash, tobacco waste, oil cake, vegetable wastes etc.
4. *Industrial wastes :* Sugar factory, paper factory etc.

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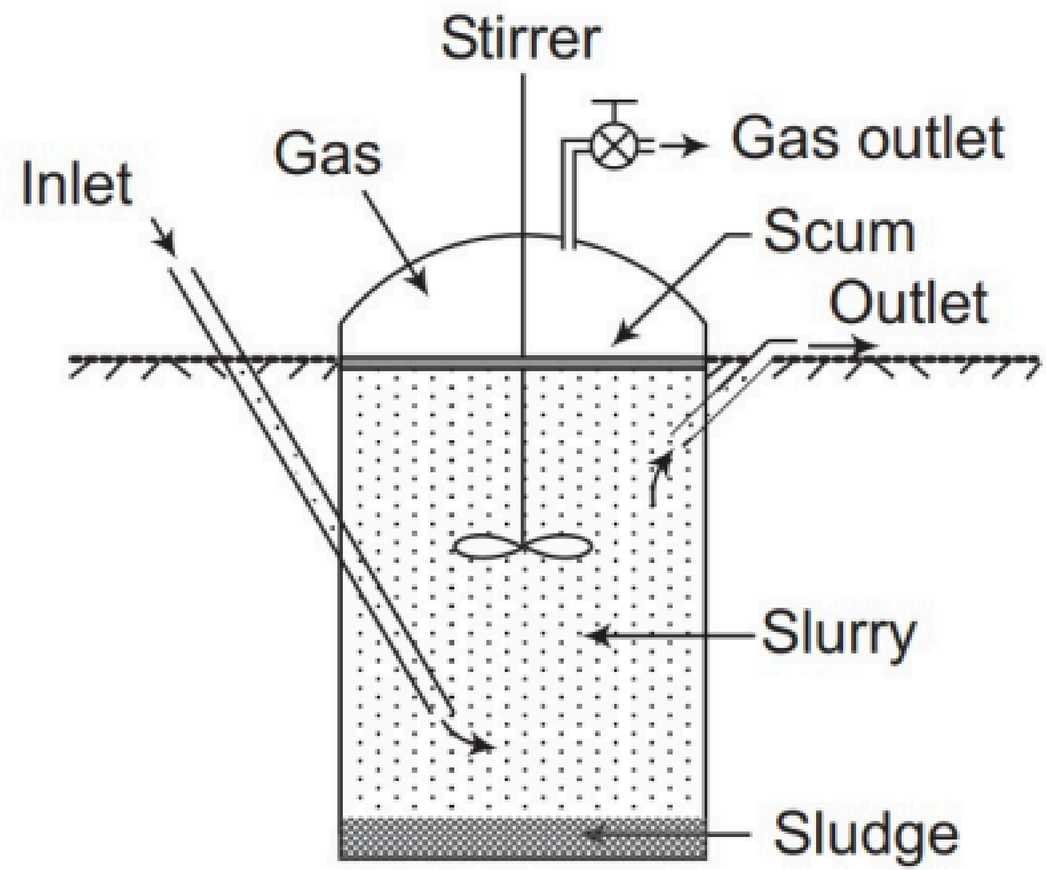

Basic features of a continuous type biogas plant

6.7.3. Main Components of a Biogas Plant

The *main components of a biogas plant* are enumerated and briefly described below:

1. Digester; 2. Gas holder;
3. Inlet; 4. Outlet;
5. Slurry mixing tank; 6. Gas outlet pipe;
7. Stirrer.

1. **Digester.** A digester is also called "*fermentation tank*" and is mostly embedded partly or fully in the ground. It is generally cylindrical in shape and is made of bricks. It holds the slurry for a sufficiently long time to complete the digestion.
2. **Gas holder.** Its function is to *keep the gas for subsequent use.* The gas connection for use is taken from the top of the gas holder. In some designs of biogas plants, it

may be separable from the digester whereas in other designs it may be an integral part of the digester.

3. Inlet. An inlet is provided to *add* the mixture of dung and water to the digester, and is sloped accordingly.

4. Outlet. The provision of an outlet is made to *take out* the digested portion of slurry.

5. Slurry mixing tank. This tank carries out *mixing of the dung with water* for induction in the digester, through the inlet.

6. Gas outlet pipe. It is used for *taking out gas* from the gas holder and is connected to its *top*. The other end of the pipe is connected with the *device using biogas.* **7. Stirrer.** The stirrers are *provided in biogas plants of large size* for *stirring the slurry for fermentation* inside the fermentation chamber to *ensure the normal production of gas.*

— The small size biogas plants can function without a stirring device. • Some biogas plants also have the *arrangement of external heating by solar / electrical energy etc. under colder climates.*

• The biogas plants are built in several sizes, small (0.5 m^3/day) to *very large* (2500 m^3/day). Accordingly, the configurations are *simpler to complex.*

6.7.4. Classification of Biogas Plants

The biogas plants may be *classified* as follows :

1. Continuous type biogas plant :

(*i*) *Single stage type;*

(*ii*) *Double stage type.*

2. Batch type biogas plant.

3. Floating drum type biogas plant.

4. Fixed dome type (Janta model or chinese model).

5. Modified fixed dome type biogas plant – This type of plant has an *additional displacement tank and water seal gas tank.*

Description of these biogas plants is given in the following Articles.

6.7.5. Continuous Type Biogas Plant

In this type of plant the *biomass is fed regularly to the digester and it supplies the gas continuously*.

These are *two* types of continuous biogas plant :

1. Single stage type 2. Two stage type

1. Single stage continuous biogas plant. In this type of plant, the entire process of conversion of biomass into biogas are carried in a *single digester.* This chamber is regularly fed with the raw materials while the spent residue keeps moving out.

Advantages :

(*i*) Simple in construction.

(*ii*) It does not need skilled labour.

(*iii*) It is easy to operate and control.

(*iv*) These are preferred for *small and medium sized biogas plants.*

• *Serious problems are encountered with agricultural residues when fermented in a single stage continuous process*.

2. Two stage continuous type biogas plant. These plants have *two digesters* for digestion of biomass. In the '*first digester*' the biomass is fed in which the *acid* *production* is carried out and then only dilute acids are fed into the '*second digester*' where *bio-methanation* takes place and biogas can be collected from the second digester/chamber.

Advantages :

(*i*) It produces *more gas* than the single stage plants.

(*ii*) It requires *lesser period of digestion* as compared to single stage plants.

(*iii*) These plants are preferred for *large size biogas plants.*

Advantages of continuous type biogas plants :

Following are the *advantages* of continuous type biogas plants :

1. *Continuous* gas production.
2. *Less* retention period.
3. *Small digestion chambers* required.
4. *Less problems* as compared to batch type plants.

6.7.6. Batch Type Biogas Plant

In a batch type plant, the biomass feeding is done in *batches with large time interval between two consecutive batches.*

A batch loaded digester is filled to its capacity and given sufficient retention time (35 to 45 days) for digestion of biomass. After the completion of digestion, the residue is emptied and filled again. Gas production is '*uneven' due to slow start of bacterial* digestion and to overcome this difficulty, *several digesters are used which are fed and emptied in sequential manner.* Thus, the regular supply of gas is maintained.

The **"salient features"** *of batch type plant are :*

1. Gas production *uneven/intermittent*, depending upon the cleaning of the digester.
2. *Several digesters required,* to get continuous supply of gas.
3. *High space requirements,* due to several digesters.
4. *High initial cost,* due to large volume of digester.

5. *Needs addition of fermented slurry to start the digestion process*.
6. Operational and maintenance problems.

6.7.7. Floating Drum Type Biogas Plant

Khadi Village Industries Commission (KVIC) standardised a model in 1961 (Fig. 6.3). It consists of an underground *"cylindrical masonary digester"* having an "*inlet pipe*" for feeding animal dung slurry and an *"outlet pipe"* for sludge. There is a *"steel dome"* for gas collection which *floats on slurry*. It moves up and down depending upon accumulation and discharge of gas guided by the domeguide itself. A *"partition wall"* provided in the digester *improves circulation*, necessary for fermentation.

Gas pipe
Floating
Mixing pit
Gas out
gas holder
Spent slurry
Outlet tank
Steel drum
Ground level
Inlet pipe
Outlet sludge

pipe

Slurry

Partition wall

Masonary work

Fig. 6.3. Floating drum biogas plant (KVIC model)

A pressure of about 100 mm of water column is built in the "*floating gas holder*", which is sufficient to supply gas upto 100 metres. This gas pressure also forces out the *spent slurry* through a *sludge pipe.*

Advantages :

1. *Gas pressure is constant.*
2. *Less scum problem.*
3. *No danger of explosion* since there is no possibility of mixing of biogas and external air. 4. *No gas leakage problem.*

Disadvantages :

1. *High cost.*
2. *High maintenance cost.*
3. There is a *loss of heat* through gas holder.
4. The outlet pipe, which should be flexible, *requires regular attention*.

6.7.8. Janata Model Biogas Plant (Fixed dome)

Constructional features. This plant consists of the following *parts*:

Refer to Fig. 6.4.

1. Foundation 2. Digester
3. Dome 4. Inlet Chamber
5. Outlet Chamber. 6. Mixing Tank
7. Gas outlet pipe.

Fig. 6.4. Janata model gober gas plant.

Foundation. The foundation is the amply compacted base of the digester made of cement concrete and brick ballast. Its construction is so carried out that it may provide a stable foundation to the digester walls and bear full load of slurry filled in the digester. It should be waterproof so that no percolation or water leakage takes place.

Digester. It is underground cylindrical wall portion made of bricks, sand and cement. It is this place where fermentation of dung takes place. It is also sometimes called 'fermentation tank'. Two rectangular openings facing each other are provided for inflow and outflow at almost middle of its height.

Dome. It is a hemispherical roof of the digester; has a fixed height and forms the *critical part* in the construction of Janata gobar gas plant. The gas gets collected in the space of the dome and exerts pressure on the slurry in the digester.

Inlet chamber. An inlet chamber has a bell mouth shape and is made of bricks, cement and sand. It has its top opening at the ground level. Its outlet wall is made inclined/slopy to enable the daily cattle dung feed to move easily into the digester.

Outlet chamber. It is that part of the plant through which digested slurry moves out of the digester at a predetermined height. It has a small rectangular cross-section and above this it becomes larger to a defined height. For easy cleaning of the digester two steps are provided in it which enable a man to climb down. Its top opening is also at the ground level. Just near the top opening is provided a small outlet through which the digested/spent slurry flows to a compost pit.

Mixing tank. It is this tank where dung and water are mixed properly in the ratio of 1 : 1 to make slurry which is then poured into the inlet chamber.

Gas outlet pipe. It is a small piece of G.I. Pipe which is fitted at the top of the dome for conveying the gas to the points of use. A valve is fitted at its end to regulate the flow of gas to the gas connections.

Site selection. While selecting the construction of Janata gober gas plant the following *points* should be given due consideration :

(*i*) The surface should be plane/even and be at a higher elevation so that during rainy season the water level is at least at 3 m depth. The higher level will discourage water logging and ensure easy discharge of spent slurry from the outlet chamber. Preferably this place should be beyond the reach of children.

(*ii*) The site should be as far as possible near the cattle shed and points of gas utilisation.

(*iii*) It should be at least 2 metres away from the foundation of the house/building. (*iv*) The sun light should be available during whole of the day round the year. (*v*) The site should be atleast 10-15 metres away from the any water drinking source. (*vi*) There should not be any big tree near the plant whose roots may cause any harm with the passage of time.

(*vii*) There should be an easy availability of water near the plant.

(*viii*) To avoid carrying spent slurry to a very far distance there should be some space for making compost pit.

(*ix*) The earth should have adequate bearing stress to avoid any possibility of caving in or collapse of the plant.

Nature of soil and corresponding precautions :

1. ***Soil formed of clay :***

— Related problem Easy expansion and contraction of soil as the moisture content increases and decreases.

— Precautions Do not disturb the primitive soil; Or Take measures for excess or less of water; Or Drain the surface water.

2. ***Non-uniform soil structure :***

(*e.g.* partly soft soil and partly rocky)

— Related problem Crack may appear in digester wall due to uneven settlement.

— Precautions Provide a uniform kind of soil under the digester; Or — Remove a portion of the soft soil and put lime concrete and rubble in its place; Or

— Remove a part of the rock and add medium and coarse sand, cinders, clay or clay gravel.

3. ***Soil with high water table :***

— Related problem There is an upward force on the digester due to pressure of ground water.

— Precautions Construct the plant in low water seasons. — Dig a trench around the digester to collect the water; this water may be occassionally pumped out.

— Divert the ground water, if possible, to other places *e.g.*, well points.

— Increase the strength of the base of the digester by increasing its thickness. It will counter act the buoyancy force of ground water.

Initial loading of the plant. After completion of the plant it is to be charged with cattle dung and water in the ratio of 1 : 1. Since Janata Plant is designed for 50 days retention period, therefore initial loading will comprise of 50 times of gobar needed for daily feed. Naturally to arrange such a large quantity of gobar by farmers who have a few cattle is a problem. This difficulty can be overcome if the gobar is collected regularly during the period of construction of plant and by the time the plant is completed the large quantity of gobar collected can be then fed.

— Before feeding into the digester the dung should be properly mixed with water in the ratio of 1 : 1 in the mixing tank to get the slurry.

— The slurry is then fed to the digester upto the step provided on the Outlet chamber. Thereafter the fermentation starts.

— *Initially allow the gas which comprises of large percentage of a carbondioxide, oxygen and hydrogen sulphide to escape since it will not burn*.

— The gas obtained after this release will have a right combination of methane (60%) and carbondioxide (40%) and burn with odourless blue flame in the gas chulha/burner/stove.

— Now, at this stage start feeding the plant with dung slurry.

— Regular, proper and careful feeding will ensure flawless gas service.

How does the plant function ?

— The cattle dung and water are mixed properly in the ratio 1 : 1 to form slurry which is then filled in the digester upto the height of its cylindrical portion. — As soon as the fermentation of dung picks up the generated gas starts accumulating in the dome. This gas then *exerts pressure on the slurry and displaces it into the Inlet and Outlet chambers*. Consequently the slurry level in the digester falls and rises in the Outlet chamber.

— This fall in the level of slurry continues (if the outlet pipe valve is closed) till the slurry level reaches the upper ends/edges of the Inlet and Outlet gates. — After this stage any further accumulation of gas would exert pressure and start escaping through these gates into the atmosphere. This condition is indicated by *bubbling* and froth formation on the surface of the slurry in the inlet and outlet chambers.

— *The quantity of usable gas can be determined by calculating the increase in slurry volume in the inlet and outlet chambers*.

— In the event of using gas the slurry level in the digester rises while that in the inlet and outlet comes down.

— The increase in gas pressure due to increased generation in comparison to its utilisation will push/displace the slurry up in the inlet and outlet chambers while the decrease in pressure is balanced by the return flow of slurry back in the digester.

— During the process *approximately* equivalent quantity of spent/digested slurry (top layer slurry) is discharged from the outlet chamber through the outlet opening; this is so because fresh/undigested slurry which is fed into the inlet chamber is heavier than the digested/spent slurry and settles down in the digester.

Chemistry of gas generation. In this gas plant the feed which comprises mainly of cattle dung is subjected to anaerobic fermentation as a result of which is produced combustible gas and fully matured organic manure which is *superior to green manure* available from dung otherwise. The whole process of feeding slurry of dung and water and extraction of spent slurry in gobar gas plant is *continuous one*.

The cattle dung (and other fermentable materials like night soil, poultry or piggery droppings etc.) when confined in a place where there is *no air* gives rise to mainly two types of bacteria *viz. Acid forming bacteria* and *Gasifying bacteria.*

Acid forming bacteria convert carbohydrates, proteins, fats into volatile acids and carbon dioxide is produced during the process. This phase is also known as "*liquification phase*" and is brought about by a set of *saprophytic bacteria* by means of extracellular enzyme. These bacteria are less sensitive and can exist, develop and *multiply in wide range of conditions*.

Liquification phase is followed by "*gasification phase*" which is actively carried out by *methane bacteria.* They work upon volatile acid produced during the previous phase, with the help of intracellular enzyme and convert it into methane and carbondioxide.

The whole process of gas generation is governed by the factors *viz.* Temperature of substrate, Loading rate, Solid concentration, Detention period, pH value, Nutrients concentration and Toxic substances etc.

The composition of the gas produced varies with the type of fermentable material used. In case of cattle dung on an average the gas produced consists of 55 to 60% methane and 40 to 45% carbondioxide with little quantity of hydrogen, hydrogen sulphide. With night soil the percentage may be : Methane = 65%, carbondioxide 34%, hydrogen sulphide = 0.6% and other gas 0.4%.

Diphasic anaerobic digestion. To tide over the problems generally associated with maintaining optimum fermentation conditions inside the digester, diphasic anaerobic digestion seems to be probable solution. In this system *two separate digesters* are used which separate the hydrogen and acid formation phases from methane formation phase; this separation of phases is brought out by kinetic control. The acid phase is operated at low retention times so that only the fast growing acidogens of first hydrolysis and acid forming stages are retained in the digester and methogens are washed out. The methane phase takes place in a *separate digester* with the acid phase effluent as the feed material.

This system facilitates provision of optimum environment conditions for growth of two physiologically different types of bacteria which in turn ensures *higher efficiency of the process with subsequent reduction in the size of digester and their cost.* In this process system monitoring is also rendered *easier*.

How to accelerate gas generation. The gas production is usually satisfactory during summer season but it falls considerably during coldest months of the year. *The gas production can be enhanced / accelerated by following the* ***tips*** *given below :*

(*i*) Add about *1 litre of cattle urine daily for every 5 kg slurry fed to the plant*. It will augment the fermentation process and eventually increase gas production. The urine can be collected in the sump connected through a drain to the animal shed.

(*ii*) Feed back about *10%* of the fresh spent/digested slurry to the plant. The micro organisms available in the spent slurry will *stimulate fermentation*.

(*iii*) Prepare the dung slurry with *hot water*. Water may be kept exposed to Sun during the day and be used in the evening to produce slurry. This process will prove helpful in increasing the temperature of slurry in the digester and subsequently actify the bacteria to generate more gas.

(*iv*) *Cover the plant with rice straw or gunny bags* during late evenings and nights; it will check fall of temperature and keep the bacteria *active* in gas generation. (*v*) Add *1 kg of powdered leaves for every 50 kg dung* fed to the plant; it will help creating warmer environment suitable to bacteria for actified fermentation.

(*vi*) Addition of *poultry droppings (5 to 10%) and piggery waste* helps to bring about increase in gas generation.

(*vii*) Provision of a *compost pit around the plant* assists in keeping the *plant warm* due to which gas generation is improved.

Advantages and disadvantages of "Fixed dome type plants" :

Advantages :

1. No maintenance problems due to absence of moving parts.
2. Low cost.
3. Low operating cost.
4. Longer working life.
5. Due to underground construction, heat insulation is better and therefore, rate of gas production is uniform during night and day.
6. Quantity of gas producd is higher than movable drum type plants.
7. No corrosion problem.
8. Space above the plant can be used for other purposes.

Disadvantages :

1. *Variable gas pressure.*
2. Gas production per cm^3 of the digester volume is *less*.
3. Problem of *scum formation.*
4. For construction work *skilled* masons are required.

6.7.9. Deenbandhu Biogas Plant (DBP)

Refer to Fig. 6.5. This is *fixed dome* plant developed by Action for Food Production (AFPRO) in 1984. It is appropriate for *all types of wastes and minimises biogas losses from inlet chamber.*

Construction. It has *'curved bottom'* and *'hemispherical top'* which are joined at their bases with *no* cylindrical portion in between. An *'inlet pipe'* connects *'mixing tank'* with the *'digester'*.

Fig. 6.5. Deenbandhu biogas plant.

Working. Cattle dung slurry prepared in 1 : 1 ratio with water is fed upto the level of second step in the outlet tank. As the gas generates and accumulates in the empty portion of the plant, it presses the slurry of the digester and displaces it into the outlet *'displacement chamber'*. The slurry level in the digester falls whereas in the outlet chamber it starts rising. This fall and rise continues till the level in the digester reaches the upper end of the outlet opening and at this stage the slurry level in the outer tank reaches the height of discharge opening.

Advantages :

1. This plant required *less space* being mainly underground.
2. Its *cost is reduced* as the surface area is minimised by joining segments of two different diameter spheres at their bases.
3. It is 30 percent economical as compared to Janata biogas plant.

6.7.10. Comparison Between Fixed Dome Type and Movable Drum Type Biogas Plants

The comparison between fixed dome type and movable drum type biogas plants is given below :

S.No.	**Aspects**	**Fixed dome type plant**	**Movable drum type plant**
1.	*Material used*	Bricks, cement, sand, steel and lime/cement.	Concrete, bricks, sand, lime and steel.
2.	*Cost factor*	Bricks and cement.	Bricks, cement and steel.
3.	*Cost*	Less costlier.	More costly due to steel.
4.	*System used*	Regular filling and irregular discharge.	Regular filling and regular discharge.
5.	*Feed stock*	Agriculture waste, other organic matter, animal and human waste.	Animal and human wastes and chopped agricultural wastes as additive.
6.	*Digestion period*	30-60 days	40-60 days.
7.	*Gas-tightness*	Gas storage dome is required to give special treatment for gas tightness and painted periodically.	No such problems.
8.	*Thermal insulation*	Due to underground construction the temperature and heat insulation is uniform.	Digester heat is lost through gas holder, therefore, less suitable for colder region.

6.7.11. Methods of Maintaining Biogs Production

Following techniques are suggested for maintaining the biogas production :

1. Insulating the gas plant.
2. Compositing.
3. Hot water circulation.
4. Use of chemicals.
5. Solar energy systems.

6.7.12. Community Night-soil Based Biogas Plant

Such plants have been developed to facilitate sanitary treatment of *human waste* at community and institutional level.

Fig. 6.6 shows the cross-section of a community night-soil based biogas plant. It consists of a *'floating metal drum'* with a *'water jacket'*. It is linked with community toilets. It can serve a population of 1000 persons, and can provide fuel for *cooking, operating duel fuel engines for water supply and generate electric power.*

Guide frame

Community
toilets

masonary
drum

Compost
Gas outlet
Floating metal

Stirrer

Outlet
pipe

Digester

Water
jacket
Inlet pipe

Brick

Fig. 6.6. Community night-soil based biogas plant.

6.7.13. Guidelines for fixing Optimum Size of a Biogas Plant

The following *guidelines* may be used to fix optimum size of biogas plant :

1. Type of waste.
2. Daily rate of waste to be digested.
3. Digestion period.
4. Method of stirring, if any.
5. Arrangement for raw waste feeding and discharge of digested slurry.
6. Climatic conditions.
7. Mix of raw waste.
8. Water table and sub-soil conditions.
9. Type of dome.

6.7.14. Site Selection of a Biogas Plant

While selecting a site for a biogas plant, the following *factors* must be considered :

1. Less distance. In order to achieve *economy in pumping of gas*, the distance between the plant and site of gas consumption should be *less*. The optimum distance for a plant of 2 *m^3 capacity is 10 metres*.

- A *minimum gradient of 1 percent* must be made available for the line to convey the gas.

2. Open space. For gas generation at adequate rate, there should an open space sufficient enough for the sunlight to fall on the plant to provide essential temperature between 15 to 30°C.

3. Space requirements. To carry out day-to-day operation and maintenance, sufficient space must be available. As a guideline 10 to 12 m^2 area is required per m^3 of the gas.

4. Availability of water. Availability of plenty of water must be ensured, to prepare proper cattle dung slurry for gas generation.

5. Water table. As the biogas plant is normally constructed underground, care should be taken to prevent seepage of water. In case the water table is less than 3 metres, the plant should *not* be constructed.

6. **Transportation cost of cattle dung/materials.** To reduce the transportation cost of cattle dung/materials for biogas generation, the distance between the materials and site of the biogas plant should be *minimum*.
7. **Distance from wells.** A biogas plant should be constructed at a minimum distance of 15 metres to check the seepage of fermented slurry which *may pollute* the water of well.
8. **Seasonal run-off.** To prevent the interference of run-off water during monsoon, *intercepting ditches or bunds* may be constructed.

6.7.15. Reasons why Biogas Plants are not much Successful in India

Reasons why biogas plants are not much successful in India, even after the subsidies provided by Government of India (or *problems related to biogas plants*) are as follows : 1. Gas forming methanogenic bacteria are very sensitive towards temperature. During *winter* the temperature falls and there is decrease in activity of the bacteria and the *gas production rate reduces.*

2. A lot of problem arises due to *lack of training* to the biogas plant owners for the operation of plant.
3. Collecting dung, mixing with water and draining out the waste is tiresome and time consuming process.
4. Some persons add urea-fertilizer (to augment gas production) in *large quantities* due to which toxicity of ammonia, nitrogen may cause a *decrease in gas production.* 5. The *cleaning* and recharging of whole tank of biogas plant is necessary after 3 or 4 years, which is *not so easy*.
6. *Handling of effluent slurry* is major problem. For domestic plant, 200 litres capacity oil drums can be used to carry this effluent; this will require some human labour. 7. In some areas like Himachal, Jammu and Kashmir the average annual temperature is *low* which is not adequate for anaerobic digestion.

6.7.16. Fuel Properties of Biogas

The important *properties of biogas, generated by anaerobic fermentation of organic wastes* are as follows :

Composition – *Percentage by volume :*

Methane = 50–60; Carbon dioxide = 30–45; Hydrogen = 5–10;

Nitrogen = 0.5–0.7; Hydrogen sulphide and oxygen = Traces.

Calorific value :

60% methane : 22.35 to 24.22 MJ/m^3
without CO_2 : 33.52 to 35.39 MJ/m^3

Octane rating :

Without CO_2 : 130
With CO_2 : 110

Ignition temperature : 650°C

Air-to-methane ratio for complete

Combustion **(*by volume*)** : 10 to 1

Explosive limits to air (by volume): 5 to 15

- The main products of the biogas plant are *'fuel gas' and 'organic manure'*. Biogas is a flammable gas. '*Methane*' is the *only combustible portion in the gas* and hence *around 60% by volume only is usable for combustion.*

6.7.17. Methods to obtain Energy from Biomass

Energy from biomass can be *obtained* by using the following *methods* :

1. Combustion; 2. Anaerobic digestion;

3. Pyrolysis; 4. Hydrolysis and ethanol fermentation; 5. Gasifier.

1. Combustion. *'Combustion' is the process*, now in commercial operation, that *uses biomass to produce energy*. Direct combustion requires biomass with a moisture content around 15% or less, so it may require drying prior to combustion for most of the crops.

2. Anaerobic digestion. The biogas plants using anaerobic digestion are *simple in construction* with *low capital outlay.* The anaerobic digestion process has the following *advantages :*

(*i*) It utilises biomass with high percentage of water.

(*ii*) Small units are available, which can be operated as individual farms.

(*iii*) The residue has fertilizer value.

The major *"limitation"* with this process is that large quantity of waste water is to be disposed of after digestion.

3. Pyrolysis : '*Pyrolysis*' is an *irreversible change* brought about by the action of heat in the *absence of oxygen;* the energy *splits* the chemical bonds and leaves the energy stored in biomass. It may yield either solid, liquid or gaseous fuel.

***Advantages* :**

(*i*) Compactness;

(*ii*) Simple equipment;

(*iii*) Low pressure operation;

(*iv*) High conversion efficiency of the order of 83 percent

(*v*) Negligible waste product.

4. Hydrolysis and ethanol fermentation. The process of *hydrolysis* converts cellulose to alcohols through fermentation. Ethyl alcohol can be produced from variety of sugar by fermentation with yeasts.

5. Gasifier. *Pyrolysis-gasification* is a promising conversion technology. It appears to be *economically competitive with natural gas*, using *biomass wastes*.

6.8. BIOMASS GASIFICATION

Gasification *implies converting a solid or liquid into a gaseous fuel without leaving any solid carbonaceous residue.* This process is carried out in a *'gasifer'*.

6.8.1. Gasifiers

Gasifiers (*essentially a chemical reactor*) *is an equipment which can gasify a variety* of biomass such as *woodwaste, agricultural waste like stalks*, and *roots of various crops, maize cobs* etc. In a gasifier, the biomass (as it flows) gets dried, heated, pyrolysed, partially oxidised and reduced.

Advantages, following are the *advantages of a gasifier :*

1. Very easy operation.
2. Reliable operation.
3. Easy maintenance.
4. Sturdy construction.

Classification of gasifiers :

Biomass gasifiers may be *classified as follows :*

A. According to the "type of bed" :

1. *Fixed bed gasifiers :*

(*i*) Updraft,

(*ii*) Downdraft, and Depending upon the *direction of airflow*.

(*iii*) Crossdraft

B. According to the "output power" :

(i) Small size gasifiers – Output upto 10 kW.

(ii) Medium size gasifiers – Output in the range of 10 kW to 50 kW. (iii) Large size gasifiers – Output in the range of 50 kW to 300 kW. and (iv) Very large gasifiers – Output of 300 kW and above.

6.8.2. Fixed Bed Gasifiers

(*i*) **Updraft (or counter current) gasifier :** Refer to Fig. 6.7

In such a gasifier (where fuel and air move in *counter current manner*) air enters *below* the combustion zone and the '*producer gas*' leaves near the *top* of the gasifier. The gas produced contains tar and water vapour and the *ash content is almost nil*.

- These gasifiers are suitable for *stationary engines* (which use tar free fuels like charcol).

Fig. 6.7. Updraft gasifier. **Fig. 6.8.** Downdraft gasifier.

2. Downdraft (or cocurrent) gasifier. Refer to Fig. 6.8.

In downdraft gasifier (where fuel and air move in a *cocurrent manner*, air *enters at the combustion zone* and the gas produced leaves *near the bottom of the gasifier.*