ME0048 – ALTERNATIVE SOURCES OF ENERGY

COURSE MATERIALS

UNIT I. BIOMASS

BIOMASS

The biomass is biological material derived from living or recently living organism. It's an organic matter derived from biological organism - plants, algae, animals etc. The biomass for energy mean plant based material but biomass can equally apply to both animal and vegetable derived material.

The sources of biomass are the forest and agricultural waste, animal waste, energy crops, co-products in the crop field or industrial process wastes or by-products.

There are five basic categories of biomass source materials:

1. Wood: From forestry, agricultural activities or from wood processing.
2. Energy crops: High yield crops grown specifically for energy applications.
3. Agricultural residues: Residues from agriculture harvesting or processing.
4. Food waste: Waste from food manufacture, preparation and processing as well as post-consumer wastes.
5. Industrial waste and co-products : From manufacturing and industrial processes

The energy conversion from biomass can be either bio-chemical (Fermentation or digestion) or thermo-chemical methods to covert the biomass (solid fuel) into liquid or gaseous fuels. For electricity generation, two most competitive technologies are direct combustion and gasification. Typical plant sizes at present range from 0.1 to 50 MW. Co-generation applications are very efficient and economical. Fluidized bed combustion (FBC) is efficient and flexible in accepting varied types of fuels. Gasifiers first convert solid biomass into gaseous fuels which is then used through a steam cycle or directly through gas turbine/I.C.engine. Biomass materials used for power generation include bagasse, rice husk, straw, cotton stalk, coconut shells, soya husk, de-oiled cakes, coffee waste, jute wastes, ground nut shells and saw dust etc.

Biomass is renewable, widely available, carbon-neutral and has the potential to provide significant employment in the rural areas. Biomass is also capable of providing firm energy. About 32% of the total primary energy use in the country is still derived from biomass and more than 70% of the country's population depends upon it for its energy needs.

Ministry of New and Renewable Energy has realised the potential and role of biomass energy in the Indian context and hence has initiated a number of programmes for promotion of efficient technologies for its use in various sectors of the economy to ensure derivation of maximum benefits Biomass power generation in India is an industry that attracts investments of over Rs.600 Crores every year, generating more than 5000 million units of electricity and yearly employment of more than 10 million man-days in the rural areas. For efficient utilization of biomass, bagasse based cogeneration in sugar mills and biomass power generation have been taken up under biomass power and cogeneration programme. The following diagram indicates various biomass energy sources.

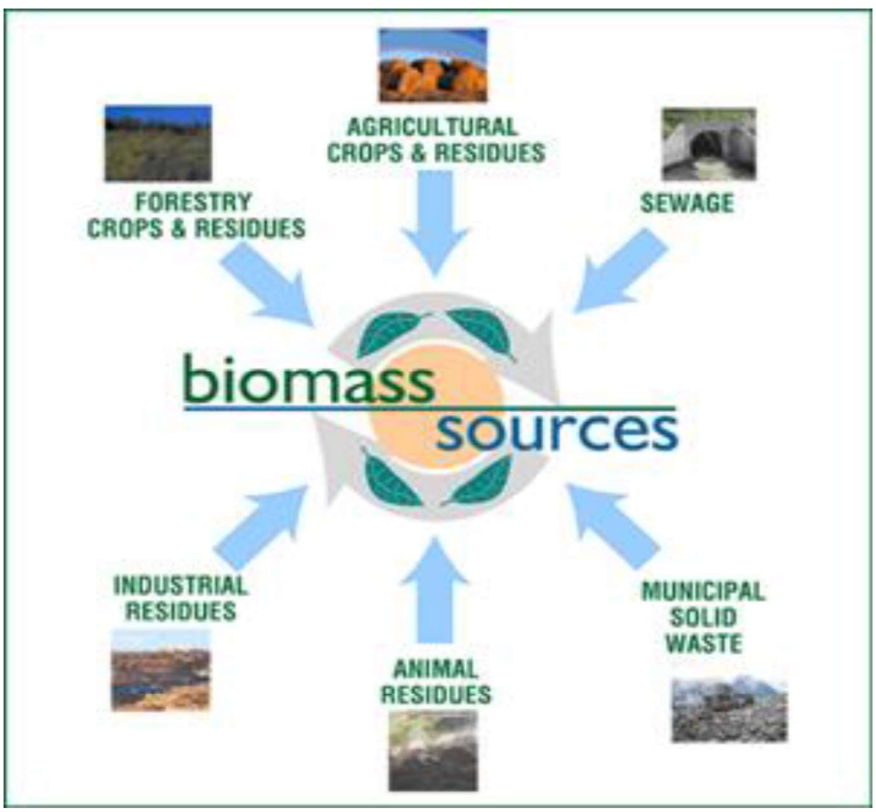


Fig.1.1 Sources of Biomass

FERMENTATION

The process of bio-chemical degradation or decomposition of organic matter with the help of micro-organisms (bacteria/yeast) is called fermentation.

e.g. Chemical equations fermentation

Starch into Dextrose in the presence of enzyme at 20-30^{0}C and then dextrose into ethanol in the presence of yeast at 20-30 ^{0}C in 50 hours.

$(C_6H_{10}O_5)_n$ (Starch)+ nH_2O ------- n $C_6H_{12}O_6$ (Dextrose)

$(C_6H_{12}O_6)_n$ ------------------ 2 C_2H_5OH (Ethanol) + 2 CO_2

PYROLYSIS

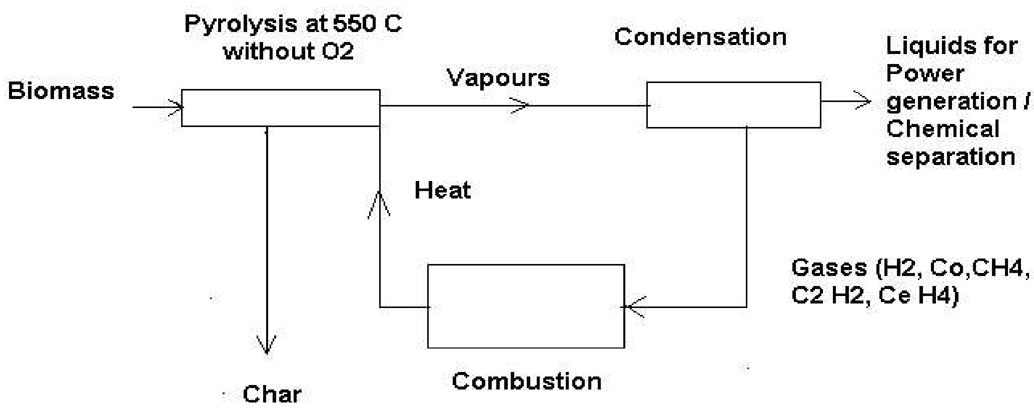
Pyrolysis is the thermal decomposition of biomass occurring in the absence of oxygen. It is the fundamental chemical reaction that is the precursor of both the combustion and gasification processes and occurs naturally in the first two seconds. A wide range of biomass feed stocks can be used in pyrolysis processes. The pyrolysis process is very dependent on the moisture content of the feedstock, which should be around 10%. The efficiency and nature of the pyrolysis process is dependent on the particle size of feedstocks. Most of the pyrolysis technologies can only process small particles to a maximum of 2 mm keeping in view the need for rapid heat transfer through the particle. The demand for small particle size means that the feedstock has to be size-reduced before being used for pyrolysis.

TYPES OF PYROLYSIS

Pyrolysis processes can be categorized as **slow pyrolysis** or **fast pyrolysis**. Fast pyrolysis is currently the most widely used pyrolysis system. Slow pyrolysis takes several hours to complete and results in biochar as the main product. On the other hand, fast pyrolysis yields 60% bio-oil and takes seconds for complete pyrolysis. In addition, it gives 20% biochar and 20% syngas. Fast pyrolysis processes include open-core fixed bed pyrolysis, ablative fast pyrolysis, cyclonic fast pyrolysis, and rotating core fast pyrolysis systems.

The essential features of a fast pyrolysis process are given below:

1. Very high heating and heat transfer rates, which require a finely ground feed
2. Carefully controlled reaction temperature of around 500^{o}C in the vapour phase
3. Residence time of pyrolysis vapours in the reactor less than 1 sec
4. Quenching (rapid cooling) of the pyrolysis vapours to give the bio-oil product.



Pyrolysis of Biomass (Liquefaction - Conver ting solid to liquid fuel)

Fig.1.2. Biomass Pyrolysis flow chart

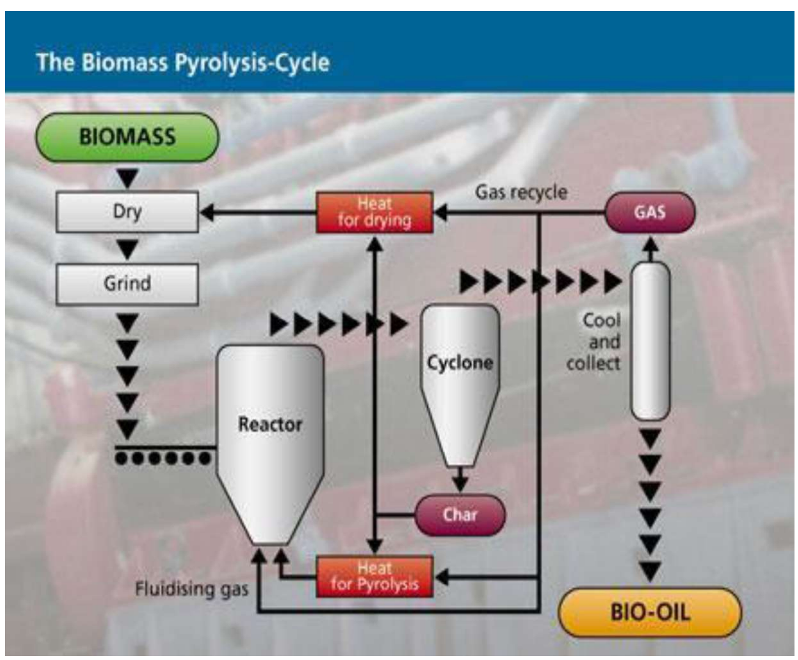


Fig.1.3 Biomass pyrolysis plant cycle

The products of biomass pyrolysis include biochar, bio-oil and gases including methane, hydrogen, carbon monoxide, and carbon dioxide. Depending on the thermal environment and the final temperature, pyrolysis will yield mainly biochar at low temperatures, less than 450^{0}C, when the heating rate is quite slow, and mainly gases at high temperatures, greater than 800^{0}C, with rapid heating rates. The processes in the pyrolysis chamber are given below:

1. The dehydration or drying process occurs at around 100°C by the resulting steam mixed into the gas flow and may be involved with subsequent chemical reactions, notably the water-gas reaction if the temperature is sufficiently high enough.
2. The pyrolysis (or devolatilization) process occurs at around 200-300°C. Volatiles are released and char is produced, resulting in up to 70% weight loss for coal.
3. The combustion process occurs as the volatile products and some of the char reacts with oxygen to primarily form carbon dioxide and small amounts of carbon monoxide, which provides heat for the subsequent gasification reactions. $C + O_2$ ------------ CO_2
4. The gasification process occurs as the char reacts with carbon and steam to produce carbon monoxide and hydrogen, via the reaction, $C + H_2O$ ------------ $CO + H_2$
5. In addition, the reversible gas phase water gas shift reaction reaches equilibrium very fast at the temperatures in a gasifier. This balances the concentrations of carbon monoxide, steam, carbon dioxide and hydrogen. $CO + H_2O$ ------------ $CO_2 + H_2$

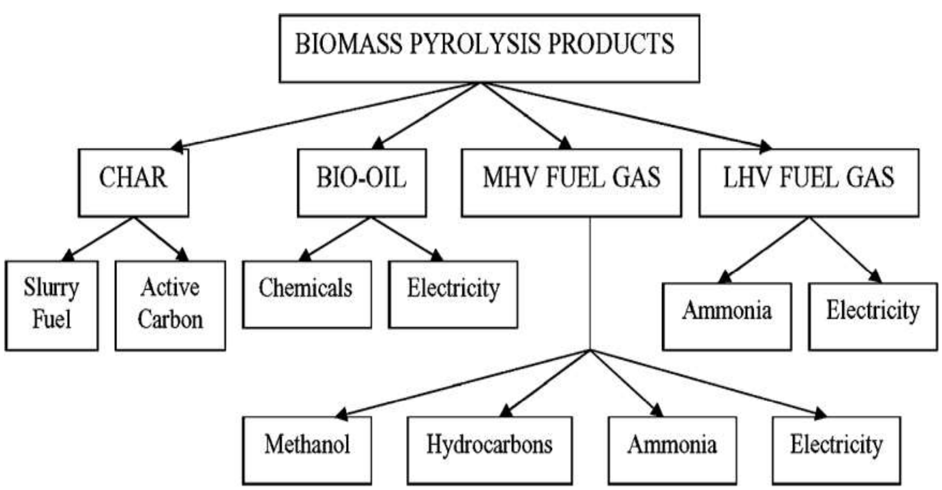


Fig.1.4 Biomass Pyrolysis Products

Pyrolysis can be performed at relatively small scale and at remote locations which enhance energy density of the biomass resource and reduce transport and handling costs. Heat transfer is a critical area in pyrolysis as the pyrolysis process is endothermic and sufficient heat transfer surface has to be provided to meet process heat needs.

Pyrolysis offers a flexible and attractive way of converting solid biomass into an easily stored and transported liquid, which can be successfully used for the production of heat, power and chemicals.

GASIFICATION

Gasification is thermo-chemical conversion process that converts organic or fossil based carbonaceous material into carbon monoxide, hydrogen and carbon dioxide (gaseous fuels). This is achieved by reacting the material at high temperatures (>700 °C), without combustion, with a controlled amount of oxygen and/or steam. The resulting gas mixture is called *syngas* (from *synthesis gas* or *synthetic gas*) or *producer gas* and is itself a fuel.

TYPES OF GASIFIERS

The gasifiers are classified based on the gas flow direction in the bed. The gas flow is upward in the up-draft, downward in down-draft, perpendicular in the cross flow type. A fixed bed of carbonaceous fuel (e.g. coal or biomass) through which the "gasification agent" (steam, oxygen and/or air) flows in counter-current configuration. The ash is either removed in the dry condition or as a slag.

The slagging gasifiers have a lower ratio of steam to carbon, achieving temperatures higher than the ash fusion temperature. Thermal efficiency is high as the temperatures in the gas exit are relatively low. In the gasification of fine, undensified biomass such as rice hulls, it is necessary to blow air into the reactor by means of a fan. This creates very high gasification temperature, as high as 1000 °C.

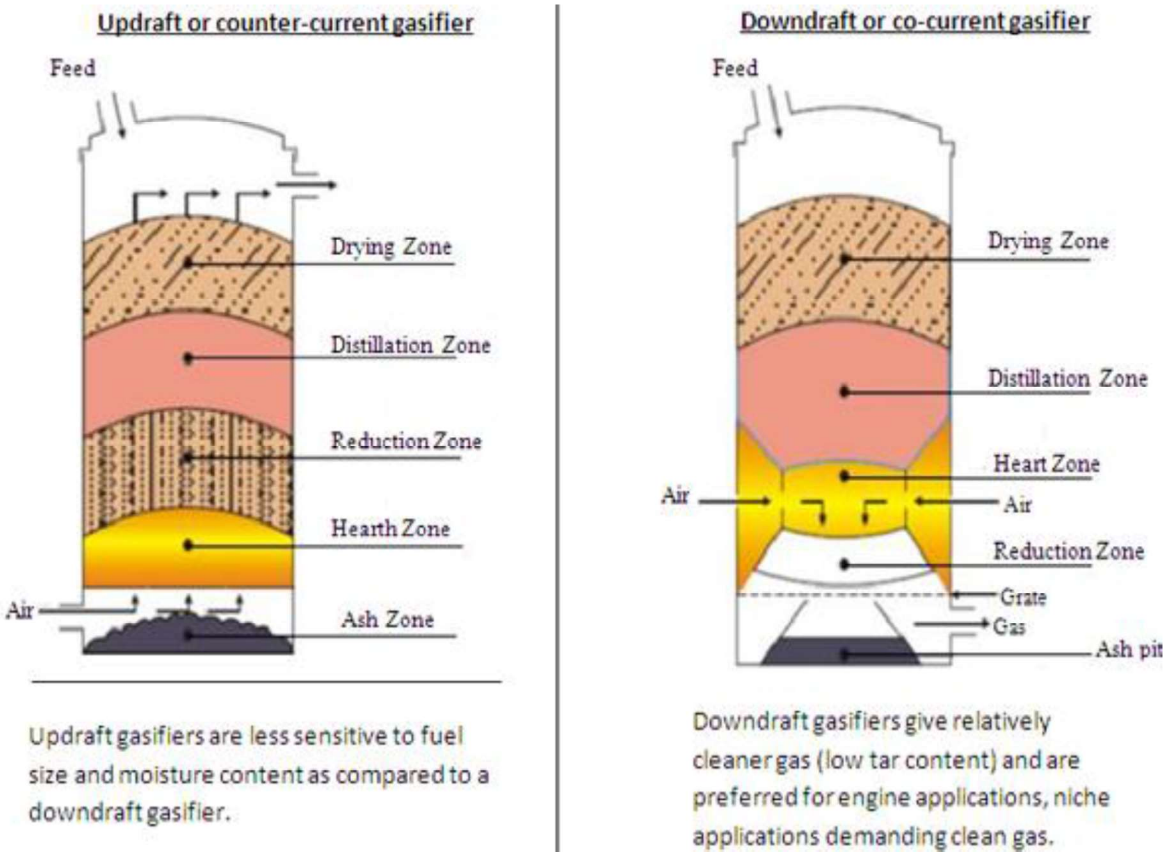


Fig.1.5. Updraft and Down Draft Gasifiers

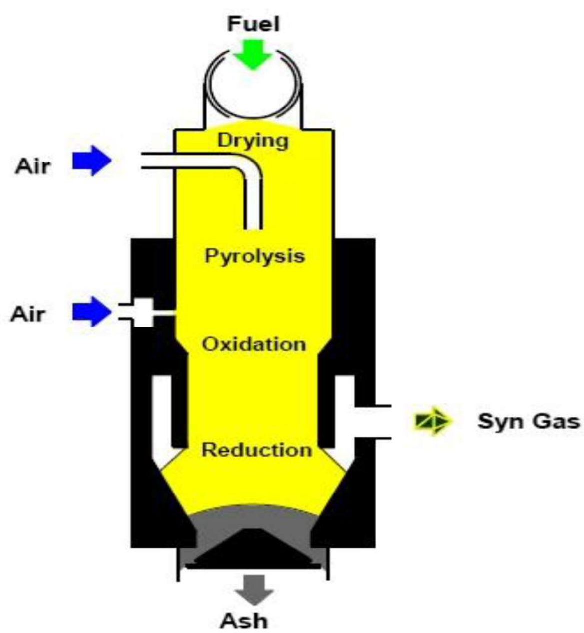


Fig.1.6 Cross Flow Gasifier

Comparison of advantages/disadvantages of updraft, downdraft and crossdraft gasifiers

Table 1.1. Comparison of conventional gasifiers

Type of Gasifiers	Advantages	Disadvantages
Updraft	Small pressure drop, good thermal efficiency, small tendency to slag	Great sensitivity to tar/moisture , long time, poor reaction capability
Downdraft	Flexible adaptation of gas production to load, low sensitivity to charcoal dust and tar content	Taller design, no feasibility for small particle size of fuel
Crossdraft	Shorter design height, quick response to loads, flexible gas production	Very high sensitivity to slag formation, high pressure drop

FLUIDIZED BED GASIFICATION/COMBUSTION

The fluidized bed can be classified as bubbling fluidized bed and circulation fluidized bed. The unburnt fuel particles and bed particles are recovered in circulating bed and this gives better conversion (gasification) efficiency than the bubbling bed gasifier. The prepared biomass fuel has been sent to the gasifier and the fluidization velocity is given to the bed through fan. The fluidized biomass particles are gasified through the partial combustion of biomass and the producer gas in cleaned through cyclone separator and scrubber/filters before admitting the gas to applications. In the fluidized bed concept, the biomass particles are gasified and burnt in the floating condition by supplying air with the fluidization velocity. The fluidized bed can be operated as atmospheric or pressurized bed conditions.

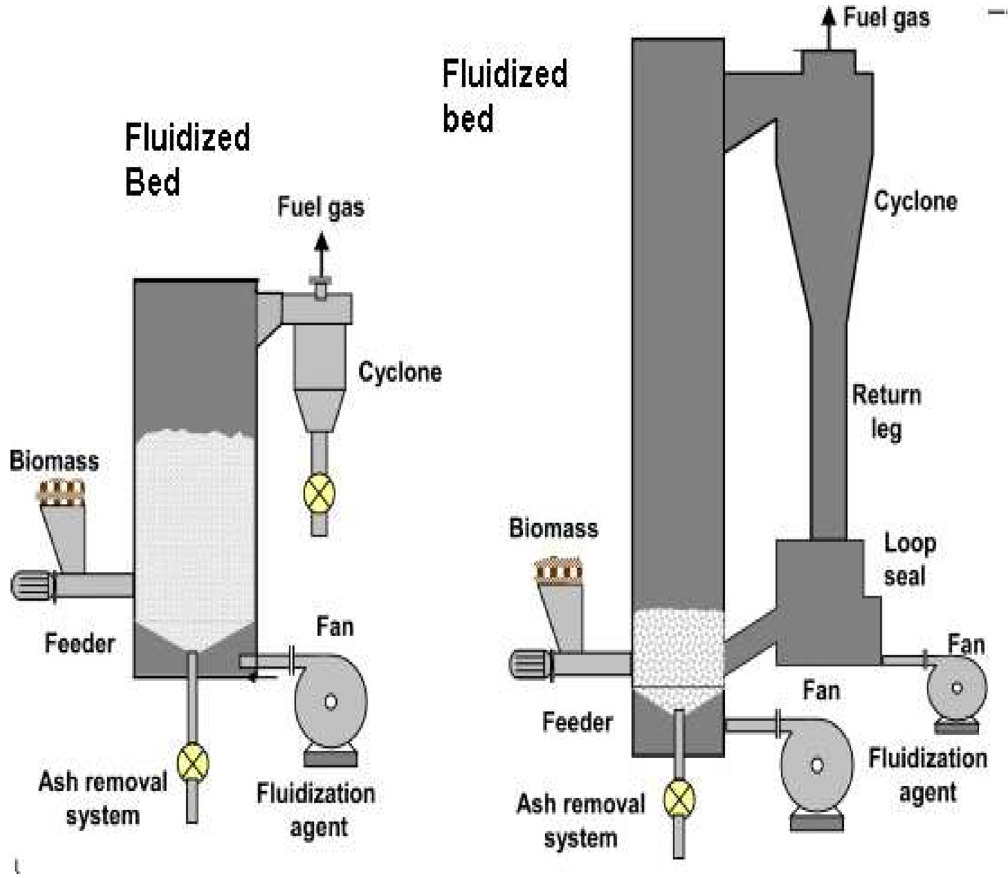


Fig.1.7. Bubbling and Circulating Fluidised Bed Gasification/Combustion

ADVANTAGES OF FLUIDIZED BED GISIFICATION/COMBUSTION

- Greater fuel flexibility and types of fuels of CV from 3,300 kJ/kg to 33,000 kJ/kg.
- Good heat storage capacity ensures complete combustion.
- Quick start up.
- Higher combustion efficiency (99%) and high output rate.
- Consistency in combustion rate and usage of high moisture fuels.
- Low temperature combustion leads to less corrosion due to alkali compounds.
- Less boiler floor area than other grate systems
- Uniform temperature throughout the furnace volume.
- Reduced emission due to NOx.
- Reduced SOx with less expense with limestone addition in bed.
- Operation is as simple as oil fired boiler.

CALORIFIC VALUE

The quantity of heat liberated during complete burning of 1 kg of fuel. The products of combustion is cooled to the original room temperature (initial condition) and the total heat value obtained is called as Gross calorific value (GCV) or Higher heating value whereas the products of combustion is not cooled and the heat obtained in this combustion process is called as Net calorific value (NCV) or lower heating value. The GCV is an indicative value and it can be calculated using Dulong's formula based on its components fraction. The NCV is useful while designing the furnace or combustor.

GCV = 33800 C + 144000 (H – O/8) + 9270 S …………… kJ/kg

NCV = GCV – 2466 x (9 H + Moisture) ……………………………… kJ/kg

Where, C, H, O and S are in mass fraction.

NCV for wood having 25% Moisture = 14000 kJ/kg

NVC for charcoal having 8% moisture = 28000 kJ/kg

BIOMASS FUEL PROPERTIES FOR BIOMASS GASIFIER SELECTION

Need for selection of right gasifier for each fuel. Biomass fuels available for gasification include charcoal, wood and wood waste (branches, twigs, roots, bark, wood shavings and sawdust) as well as a multitude of agricultural residues (maize cobs, coconut shells, coconut husks, cereal straws, rice husks, etc.) and peat. The following are the data required while choosing a fuel and gasifier and the producer gas produced is dependent on these:

1. Energy Content (Higher and lower heating values)
2. Moisture content
3. Volatile matter
4. Ash content and ash chemical composition
5. Reactivity
6. Particle size and distribution
7. Bulk density (e.g for Wood = 400 kg/m^3)

Gasifier Design Calculations

Let FCR - Fuel consumption rate in kg/h

SGR - Specific gasification rate in kg/m^2-h

Diameter of the Reactor, $D = (1.27 \times FCR / SGR)^{0.5}$

Height the reactor, $H = SGR \times T / \rho$

Time required to completely gasify the biomass, $T = \rho V_R / FCR$

(e.g. SGR - specific gasification rate of rice husk, 110-210 kg/m^2 –h)

H - Length of the reactor in m

T - Time required for consuming biomass in h

ρ – Density of biomass in kg/m^3

V_R – Volume of the reactor in m^3

TYPES OF BIOGAS DIGESTER PLANTS

1. Fixed Dome Digester plant
2. Floating Dome Digester plant

Floating gas-holder type of plant

A well is made out of concrete called the digester tank T, which is divided into two parts. One part is an inlet, from where the slurry is fed to the tank. The cylindrical dome H of the tank is made out of stainless steel that floats on the slurry and collects the gas generated. Hence it is called floating gas-holder type of bio gas plant. The slurry is fermented for about 50 days. As more gas is made by the bacterial fermentation, the pressure inside H increases. The gas can be taken out from outlet pipe V. The decomposed matter expands and overflows into the next chamber in tank T, which is removed by the outlet pipe to the overflow tank and used as manure for cultivation purposes.

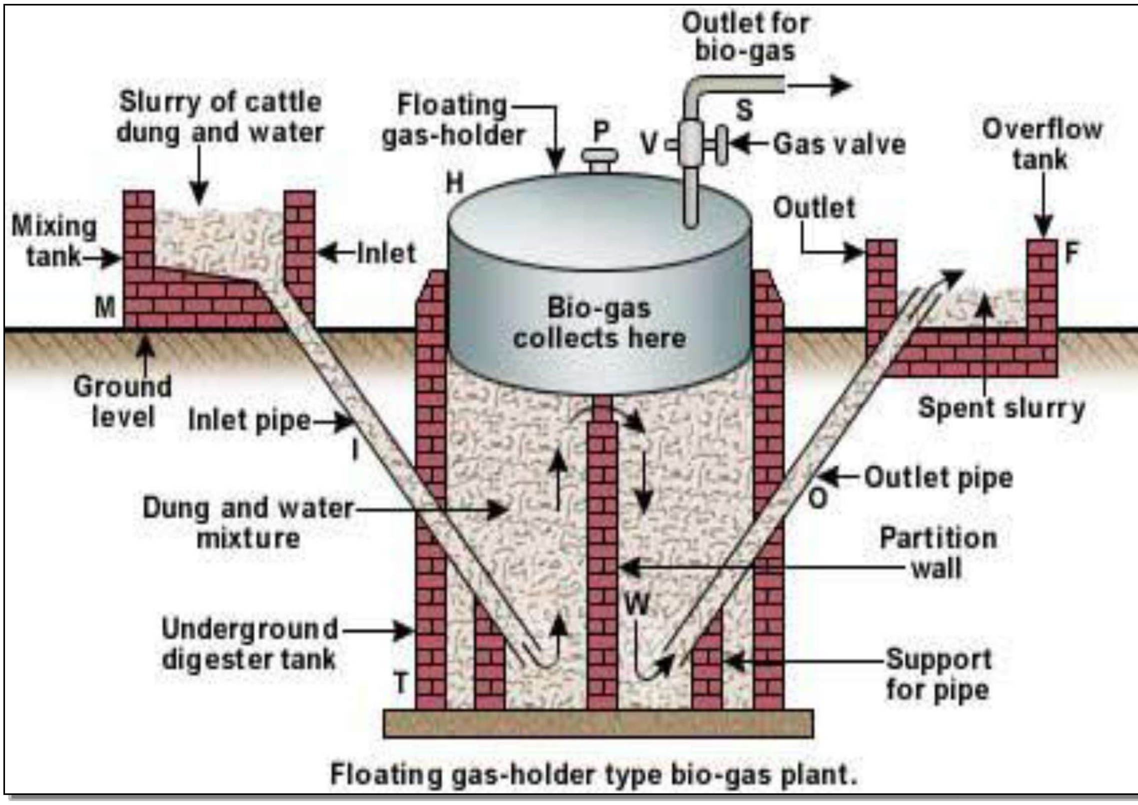


Fig.1.8 Floating dome type of plant

A well and a dome are made out of concrete called the digester tank T. This dome is fixed and thus it is called fixed dome type of bio gas plant. The function of the plant is similar to the floating holder type bio gas plant. The used slurry expands and overflows into the overflow tank. The cobar gas is cleaned by supplying through water and then used in cooking or heating applications.

In the floating gas-holder type of plant, the floating chamber is made of stainless steel. This is expensive and needs continuous maintenance and supervision for non-rust. This does not arise in the fixed dome type of bio gas plant as everything is made of concrete. The volume of fixed dome type of biogas is fixed. So if the gas pressure increases inside, it may cause damage to the concrete dome. This does not happen in the floating holder type of bio gas plant.

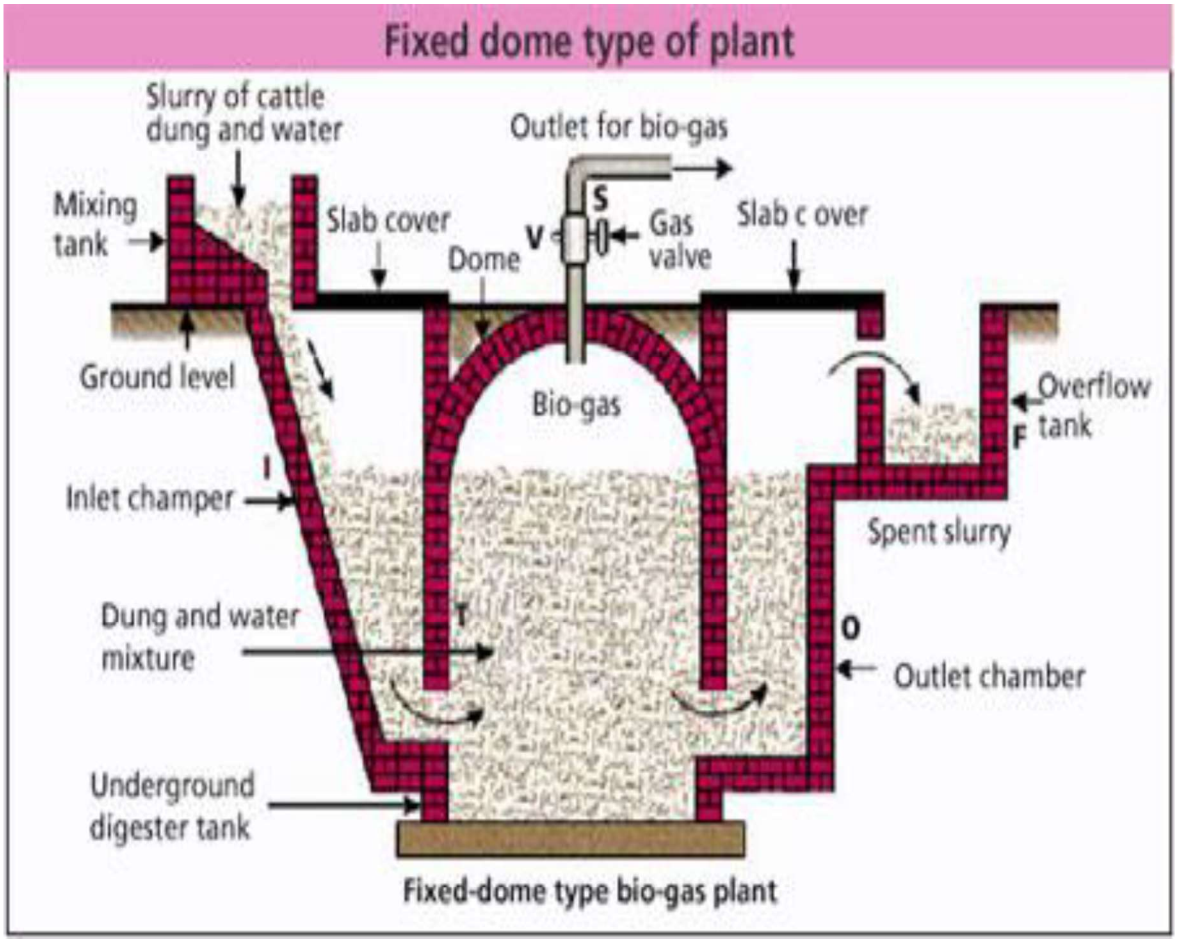


Fig.1.9. Fixed Digester biogas plant

BIOGAS

The biogas power plant works on fermentation concept. The feed is mixed with water and supplied to the digester and allowed there several days. The combustible gas contains methane comes out of it.

The typical composition of biogas is given below:

CH_4 = 60 %, CO_2 =35%, H_2 = 3.5%, N_2= 1%, H_2S = 0.3 %, CO = 0.2%.

The percent of methane gas plays major role in combustion and the quality of gas depends on the methane only.

Gross Calorific value: 23 MJ/m^3.

Ignition temperature: 650 °C.

Comparision of fixed dome and floating drum biogas plant

Table.1.2 Comparison of biogas plants

FIXED DOME BIOGAS PLANT	FLOATING DOME BIOGAS PLANT
Completely masonry concrete structure	Masonry digester with steel or composite or plastic gas holder
Lower cost	Higher cost 20-30% more than fixed dome
Low maintenance	High maintenance
Low reliability	Highly reliable
High masonry skill is required	Low masonry skill is required
High supervision is required	Less fabrication skill is required
Gas pressure is variable so complicated appliance design	Gas pressure is constant so simple appliance design

BIOGAS POWER PLANT

The biogas power plant consists of more number of biogas plants are connected to produce large quantity of biogas to produce electricity using IC engines and the effluent is de-watered and converted as compost and manure. The major parts of the plants are fuel preparation systems, anaerobic digester, anaerobic digestrate storage, power generation unit and effluent treatment systems.

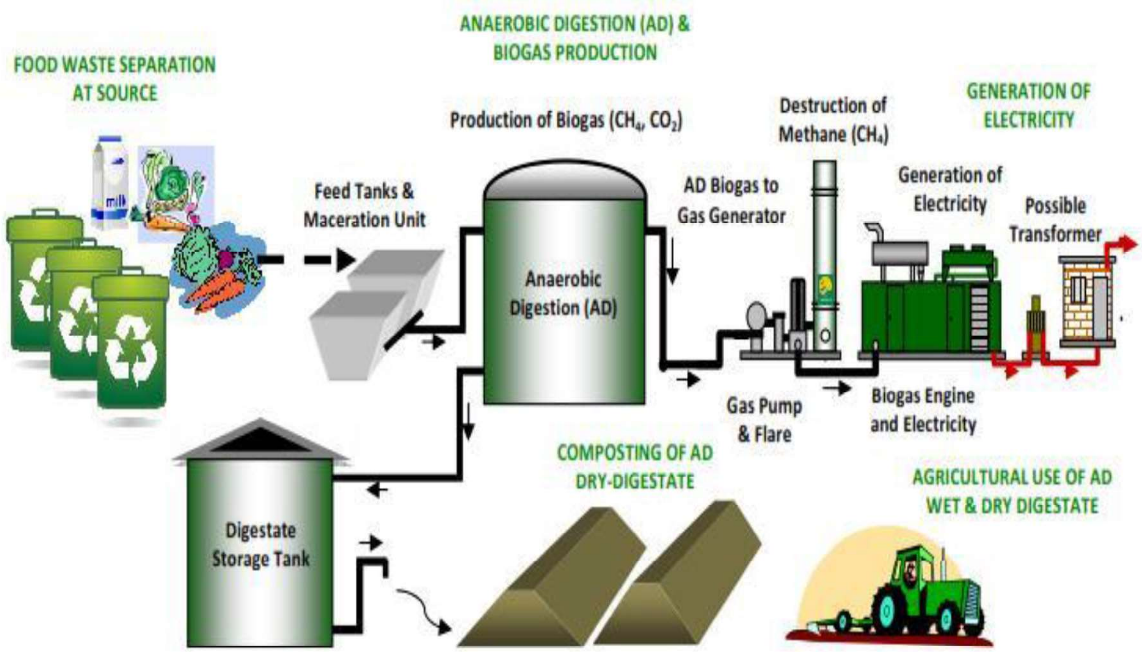


Fig.1.10 Anaerobic digester based biogas power plant (courtesy kznenergy.org.za)

Problems related to bio-gas plants operation:

All are controllable but reasons may be natural or man-made.

1. Handling of effluent slurry requires open space or compost pits to get the slurry dry.
2. Press filters and transportation are expensive.
3. Methanogenic bacteria are very sensitive to the temperatures. During the winter, the reduced temperature leads to reduced bacteria activity and less gas production. This effect can be reduced by any one of the following activities: a. Use of solar hot water to make slurry b. circulation of hot water from IC engines c. Green house effect. d. Manual or auto stirring of slurry e. Addition of various nutrients for bacteria f. Covering plant by rice straws to warm up in night time.
4. Lack of proper training of biogas plant owners.
5. Addition of urea mixed water or soap or shampoo water mixing may leads to reduced bio-gas production.
6. pH level and volatile fatty acids play important role in gas production. Lime can be added to maintain pH level above 6-7.
7. Leakage of gas from gas holder. Quality construction is important.
8. Slurry preparation in correct water content and periodic effluent removal are important.

Selection of site for a biogas plant

Considerable site selection factors are given below:

1. **Distance** between the plant and gas consumption should be less to minimize gas leakage and pumping power. e.g. Optimum distance is 10m for 2 m^3 plant capacity.
2. Preferred **minimum gradient** for conveying the gas is 1% for the line.
3. **Open space** is required for sun radiation to maintain temperature between 15 -30 °C.
4. **Water table** should not be less than 3 m. It leads to seepage of water into the plant and reduces the methane production.
5. Proper care is to be taken against **seasonal run-off**.
6. **Distance from wells** to avoid pollution of well water by entry of slurry. Keep 15 m distance from wells.
7. **Sufficient Space requirements.** 10-12 m2 area required per m3 of gas capacity.

8. **Availability of water**
9. **Source of cowdung/materials for biogas production.**

Digester design

Energy available from a biogas plant, $\mathbf{E = \eta H_b V_b}$

η - Combustion efficiency of burner (around 60%)

H_b – Heat of combustion per unit volume in kJ/m^3 = CV of methane x Fraction of methane

V_b - Volume of the biogas, m^3 = C m_d

Where C – Volume of biogas per unit dry mass (0.2-0.4 m^3 per kg)

m_d – Mass of dry input (kg)

Volume of fluid in the digester, $V_f = m_d / \rho$

Where ρ - density of dry material in the fluid (around 50 kg/m^3)

Volume of the digester, V_d = Volume flow rate of digester fluid x retention time

Retention time is usually 8 – 20 days.

<u>Problem.1.1</u>

The following data are given for a family biogas digester suitable for the output of five cows: 20 days retention time, 30 °C temperatures, 2 kg dry matter consumed per day, biogas yield 0.24 m3 per kg. The efficiency of burner is 60%, methane proportion is 0.8. Heat of combustion of methane is 28 MJ/m3. Find the volume of biogas plant digester and power available from the digester. Assume density of dry matter = 50 kg/m^3.

Solution:

Mass of dry input per day, m_d = 2 x 5 = 10 kg

Fluid volume, Vf = m_d / ρ = 10/50 = 0.2 m^3.

Digester volume, V_d = 0.2 x 20 days **= 4 m^3.**

Volume of biogas, V_b = C m_d = 0.24 x 10 = 2.4 m^3 per day.

Power available from the digester, E = η **H_b V_b** = 0.6 x (28x0.8)x 2.4 = **32.25 MJ/day**

E = 32.25/3.6 = **8.8 kWh per day**

E = 32.25 x 10^6 / (24 x 3600) = **373 W. (Continuous thermal output)**

Problem 1.2

The following data are given for a community biogas digester suitable for the output of 125 cows: 20 days retention time, 30 °C temperatures, 2 kg dry matter consumed per day, biogas yield 0.25 m3 per kg. The efficiency of burner is 60%, methane proportion is 0.7. Heat of combustion of methane is 30 MJ/m3. Find the size of biogas plant digester and power available from the digester. Assume density of dry matter = 50 kg/m^3.

Solution:

Mass of dry input per day, m_d = 2 x 125 = 250 kg

Fluid volume, Vf = m_d / ρ = 250/50 = 5 m^3.

Digester volume, V_d = 5 x 20 days = 100 m^3.

Volume of biogas, V_b = C m_d = 0.25 x 250 = 62.5 m^3 per day.

Power available from the digester, E = η **H_b V_b** = 0.6 x (30x0.7)x 62.5 = **787.5 MJ/day**

E = 787.5 x 10^6 / (24 x 3600) = **9115 W. (Continuous thermal output)**

Digester volume, $V_d = \pi D^2 \times H / 4$ ….. (Cylindrical volume, D-Diameter, H-Height)

Preferred size is D = H, $100 = \pi D^3 / 4$. $D = (4 \times 100 / \pi)^{1/3}$ = 5 m.

Size of digester: Diameter = 5m, Height = 5m.

Advantages of biomass energy

1. Versatile and renewable

2. No net CO_2 emissions (ideally) and emits less SO_2 and NO_x than fossil fuels

3. Production of alternate fuels like alcohol fuels.

4. Methanol and ethanol can be blended with diesel fuels for IC engine applications.

Disadvantages of biomass energy

1. Low energy density/yield

2. Land conversion (Biodiversity loss, possible decrease in agricultural food productivity)

3. Usual problems associated with intensive agriculture

- Nutrient pollution,
- Soil depletion,
- Soil erosion,
- Other water pollution problems etc.