MODULE - 03 BIOMASS ENERGY

Biomass :- It is an organic material that reacts with oxygen in combustion and natural metabolic process to release heat.

Advantages of biomass energy:

i) It is a renewable source
ii) The energy storage is its in-built feature.
iii) The pollutant emissions from the combustion of biomass are lower than fossil fuels.
iv) Commercial use of biomass reduces the waste disposal problem.
v) The nitrogen rich bio digested slurry and sludge from biogas plant improves the soil fertility.
vi) No seasonality.

Dicadvantages of biomass energy:

i) It is dispersed and land intensive source.
ii) It is of low energy density.
iii) It is also a labour intensive.
iv) Capacity is determined by availability of biomass and not suitable for varying loads.
v) Not feasible to set up at all locations.

Photosynthesis Process:

"It is the process of combining CO_2 from the atmosphere with water and light energy to produce oxygen and carbohydrates".

$$xCO_2 + yH_2O + \text{light energy} \xrightarrow{\text{Photosynthesis}} xO_2 + C_x(H_2O)_y$$

$C_x(H_2O)_y$ → Generalized symbol to indicate carbohydrates.

Basic reaction of photosynthesis to produce Hexose is

$$6CO_2 + 6H_2O + \text{light energy} \xrightarrow{\text{Photosynthesis}} 6O_2 + C_6H_{12}O_6$$

Respiration: The reverse of photosynthesis process is called respiration, in which CO_2, H_2O and energy are produced using carbohydrate and oxygen.

In green plants, both photosynthesis and respiration occurs during the day and during night only respiration. The energy is gained during photosynthesis and lost during respiration. But there is a net overall gain of energy in the process, as the rate of energy loss in respiration is much less ~~than~~ as compared to the rate of energy gain during photosynthesis. The net energy absorbed from solar radiation during photosynthesis can be measured from its combustion:

$$xCO_2 + yH_2O + \Delta Q \underset{\text{combustion}}{\overset{\text{Photosynthesis}}{\rightleftharpoons}} xO_2 + C_x(H_2O)_y$$

where ΔQ - enthalpy change of the combustion process

$\Delta Q = 4.8 \text{ eV/carbon atom} = 16 \text{ MJ/Kg}$ of dry carbohydrate material.

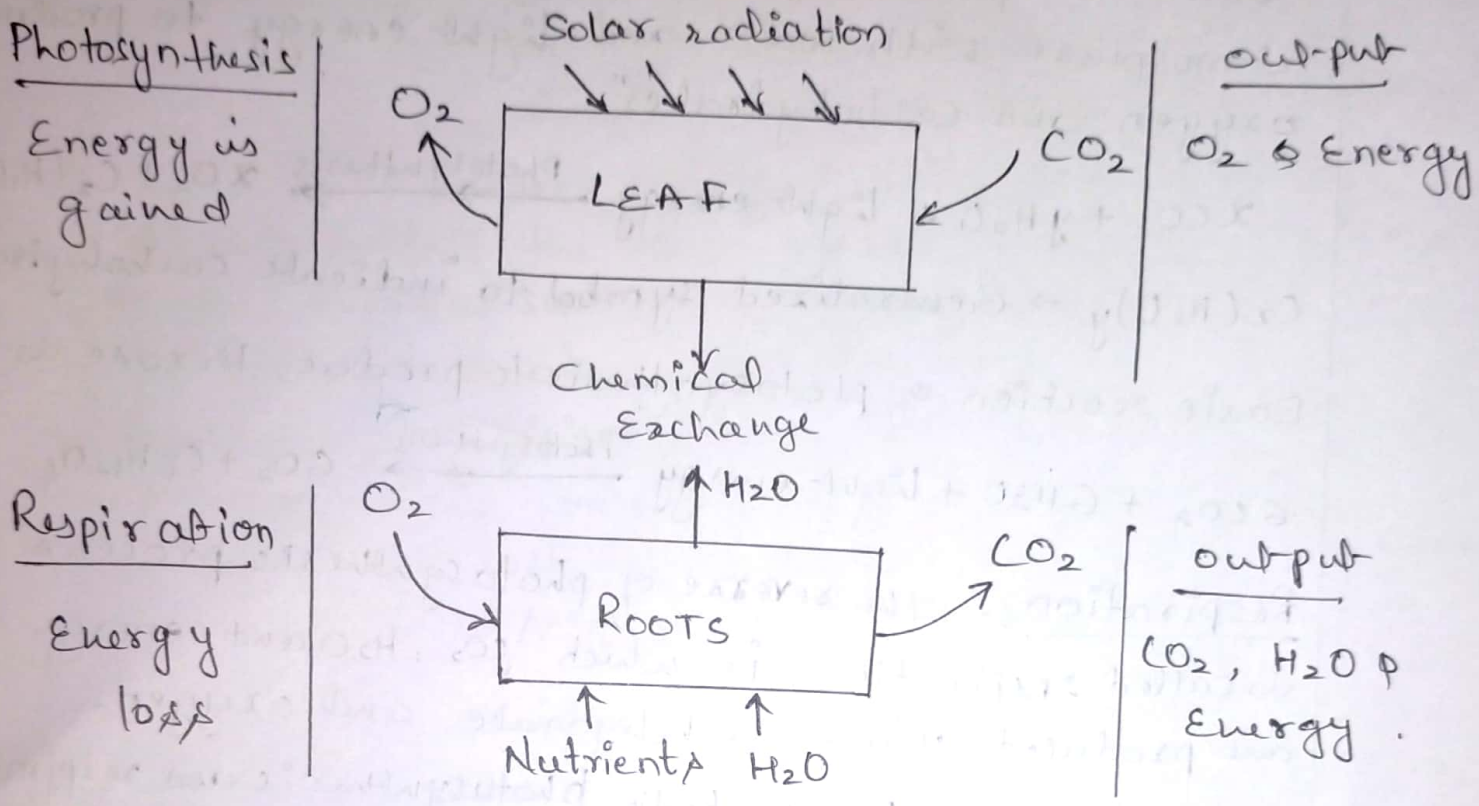

fig 1.: Photosynthesis & Respiration process in plant.

Biofuels :-

1) **Fuel wood** : It is an oldest source of biomass energy. Direct combustion is the simplest way to obtain heat-energy. Its energy density is 16-20 MJ/kg.

About half of the world population depends on fuel wood or other biomass such as cow dung, crop residue etc. for cooking and other domestic uses.

Because of insufficient use of fuel wood in conventional house hold stove only 5% heat is utilized. The remainder is lost due to wind, incomplete combustion etc. radiation losses and other losses.

2) **Charcoal** : It is a clean, dry, solid fuel of black colour. It has 75-80% carbon content & has energy density of about 30 MJ/kg. It is obtained by carbonization process of woody biomass. ~~to each it is obtained~~ It can be used as fuel in domestic environment as it burns without smoke.

It is more economical to transport, its carbon content is more and sulphur content is less hence is used in industrial sectors. Chemical grade charcoal is used in laboratory, industrial chemical process and also used in for making high quality steel.

3) **Fuel Pellets** : Crop residues such as straw, rice husk etc. and waste wood are pressed to form lumps, known as fuel pellets and used as solid fuel. The purpose is to reduce moisture content and increase the energy density of biomass making it more feasible for long distance transportation.

4) Bio-diesel: Some vegetable oils (edible & non-edible) can be used in pure form or its blend with petroleum diesel as fuel.
Bio diesel is simple to use, biodegradable, nontoxic & free of sulfur & aromatics.
Diesel engine is invented by Rudolf Diesel on 10th Aug 1893 & he used peanut oil for the demonstration & he believed that the utilization of biomass fuel was the real future of his engine.
The raw vegetable oil is upgraded as ~~bio fuel~~ bio-diesel through a chemical process called 'trans-esterification' where by glycerin is separated from the animal fat or vegetable oil. The process leaves methyl or ethyl, esters (chemical name for bio-diesel) and glycerin. as biproducts.
Jatropa and Karanj are the most promising bio-diesel resources.

5) Biogas: Organic wastes from plants, animals and humans contain enough energy to contribute significantly to energy supply in many areas particularly the rural regions of developing contries.
Biogas is produced in a biogas fermenter or digester. Nitrogen rich sludge is produced as a byproduct. ~~with~~ If the biogas is prepared with cowdung/cow Manure the gas will contain about 50-60% CH_3, 30-40% CO_2 5-10% H_2, 0.5-0.7% of N_2 with small amount of O_2 & H_2S. Its intensity is about 23 MJ/m^3. It is used for cooking, lighting, ~~heat~~ heating and operating small IC engines

6) Producer gas :- Woody matter such as crop residue, wood chips, bagass, rice husk, coconut shell etc can be transformed to producer gas & synthetic gas by a method known as "thermal gasification" of solid fuel. The composition of gas produced depends upon the type of biomass and the design of gasifier. for wood chips as input the typical gas composition is 19% CO, 18% H_2, 1% CH_4, 11% CO_2 & the rest N_2. It has the energy density of 5-10 MJ/kg. This can be used to fuel IC engines for irrigation pumps, motor vehicles, & small scale power generation & to produce process heat.

7) Bio-ethanol :- Ethanol (C_2H_5OH) is a colourless liquid biofuel. Its boiling point is 78°c and energy density is 26.9 MJ/kg. It can be obtained from wet biomass containing sugars, starches or cellulose. Ethenol is largly produced from sugar cane. Commercial ethanol is used in specially designed IC Engines with 25% milege.

→ Starch plants: These are tubular plant and can be grown on the lands having poor soil. It can be able to withstand an adverse weather conditions.

* Jerusalem artichoke provides raw material for bio ethanol

* Cassava is also a tubular plant which can be cultivated in areas with acidic infertile soil. It provides raw material for bio-ethanol.

* Potato, sweet potato etc also fall in the starch plants category.

→ Oil producing plants: These are includes sunflower, palm oil, castrol oil, soyabean, ground nut & cotton seed.

The benefits to be derived from a plant oil fuel industry are

* Most of these plants are very adaptable and hardy.
* Because of the relatively simple technology involved in oil extraction and filtering, the oil can be produced right on the farm.
* The left over biomass after the extraction of oil can be used to produce biogas in biogas plant.
* The byproducts from the oil press can be used as high protein animal feed.

4) Aquatic Plants: Some water plants grow faster than land based plants and provide raw materials for producing biogas & ethanol. Eg:
Ex:- Water hyacinth, kelp, seaweed and algae etc.

5) Urban Waste: Urban waste is of two types:

→ Municipal Solid Waste (MSW & garbage):- Energy from MSW can be obtained from direct combustion/incineration

→ Sewage (Liquid Waste): It can be used to produce biogas after some processing.

BIOMASS Resources :

1) Forests :- these are natural as well as cultivated serve as a source of fuel wood, charcoal and producer gas. forest resources are used not just for firewood but also for sawn timber, papermaking & other industrial purposes. Some fast growing energy intensive trees such as eucalyptus, poplar, pine are specially cultivated for the purpose of energy. Some plants produce seeds or nuts ~~gives~~ to yield vegetable oil. This serves as liquid bio-fuel. There are two categories of oil producing plants:

→ Wild plants ex: Jojaba (produces nuts), Karanj (produces seeds) etc which take care of themselves

→ Agricultural crops ex: Jatropa curcas (produces seeds) etc which require common agricultural techniques to grow.

2) Agricultural Residues :- crop residues such as rice husk, straw, coconut shell, groundnut shell, sugarcane bagas etc. are gasified to pro obtain producer gas. Alternatively, these are converted to fuel pellets and used as solid fuel.

3) Energy Crops :- Certain cultivated ~~crops~~ plants produce raw material for bio-fuels.

→ Sugar plants : sugar cane is a major raw material source for bio-ethanol. As shown in the fig ② fig ② shows the various products from sugarcane
* Alcohol represents only 30% of total sugarcane energy
* Bagas gives 35% of sugarcane energy
* leaves represents 35% of sugarcane energy.

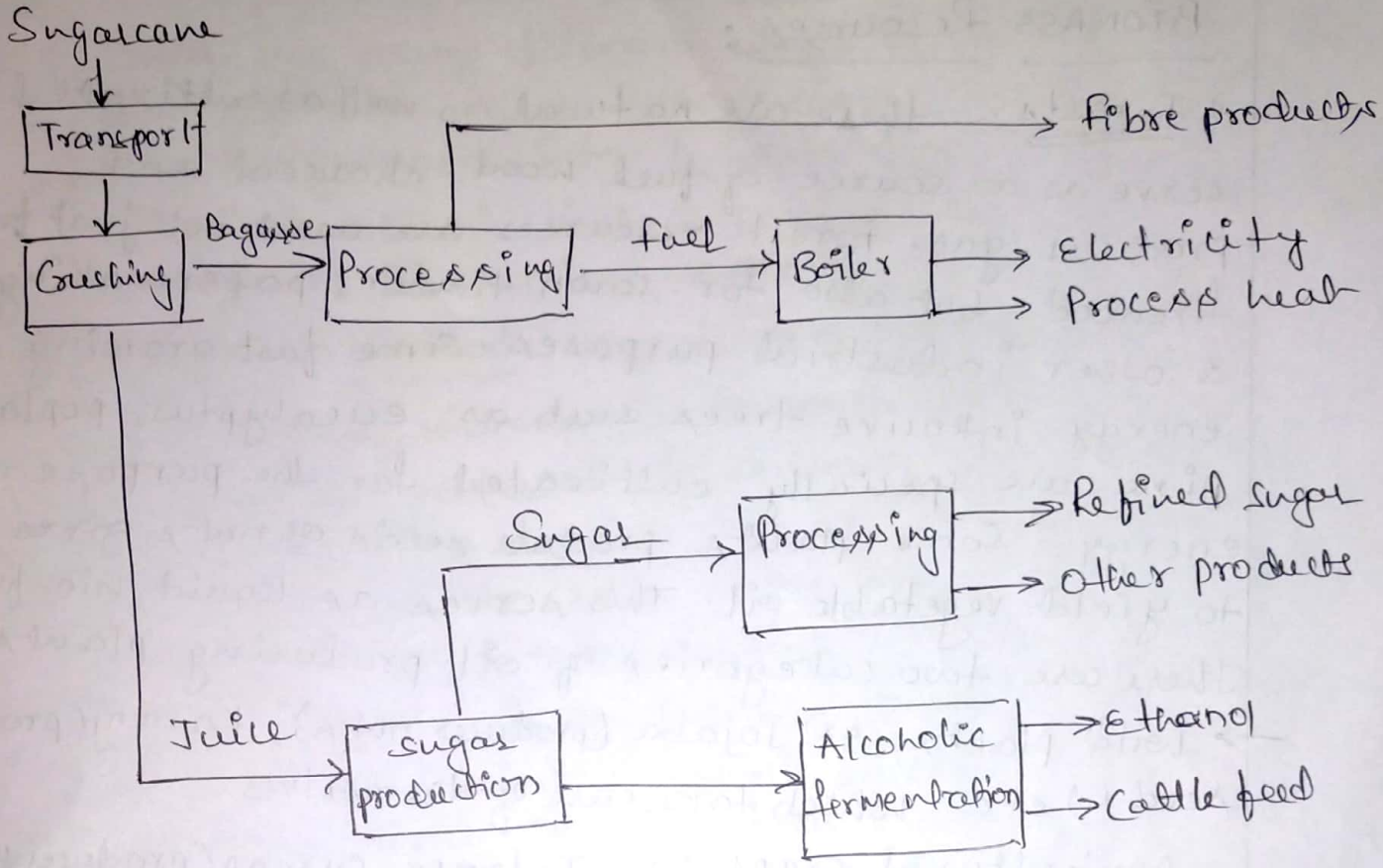

fig ② Sugar industry products.

Unit

Biomass Conversion Technologies :→

There are many different ways of extracting energy from biomass. These energy conversion technologies may be grouped into 4 basic types:
i) Physical method ii) Incineration iii) Thermo-chemical method iv) Biochemical method.

→ i) Physical Method : The simplest form of physical conversion of biomass is through compression of combustible material. By reducing the volume of the biomass its density can be increased. and the volume can be reduced by the process called
*) Pelletization *) Briquetting.

*) Pelletization :- is the process in which waste wood is pulverized, dried & applied pressure using an extrusion device. The extracted mass is in the form of pellets (rods) of 5-10 mm dia & 12 mm long.

*) Briquetting :- ~~These are brought about by compressing~~ Briquettes are made from woody matter like agricultural waste, saw dust etc.
Briquetting is the process in which the woody matter ~~are~~ is compressed and the moisture is squeze out and the elasticity of the wood and bark is broken down. The briquettes serves as replacement for fossil fuels such as oil & coal.

ii) Incineration : It is nothing but direct combustion of biomass for immediate useful heat. The heat produced are either used to generate electricity or provide the heat for industrial process, space heating, cooking or district heating.
To get steam from the boiler large quantity of various biomass need to burn in the furnace such as. The various types of biomass can be used to burn such as wood, waste wood, pulp industry waste (black liquid), food industry waste and MSW.

iii) Thermochemical Method : In thermochemical process the biomass is converted into more valuable and convenient product. By Heating the biomass in the absence of oxygen or in restric partial burning of the biomass in restricted oxygen is a thermochemical process and this process is known as "pyrolysis".

basic

Depends upon the biomass used, pressure and temperature there are 3 types of pyrolysis

*) Gasification → is a high temperature pyrolysis (1000°C) gives the gaseous product like (H_2, CO, CO_2, CH_4 & N_2)

*) Carbonization → is a low temperature pyrolysis (600°C) gives the char as output

*) Liquification → is a low temperature (250-450°C), high pressure (270 atm) thermo-chemical conversion of wet biomass gives oil like liquid as output.

iv) Biochemical Method : It is the process which makes use of metabolic action of microbial organism on biomass to produce liquid and gaseous fuel. There are two main biochemical process:

a) Ethanol Fermentation / Alcoholic Fermentation: It is the decomposition, in absence of air. of simple hexose sugars

$$C_6H_{12}O_6 \xrightarrow[\text{Fermentation}]{32^\circ C} \underbrace{2C_2H_5OH}_{\text{ethanol}} + \underbrace{2CO_2}_{\text{carbon dioxide}}$$

The Alcoholic fermentation takes place in aqueous solution by the action of enzyme in acidic conditions (pH values 4 to 5)

The products are Ethanol and Carbon dioxide.

b) Anaerobic Fermentation: This process converts decaying wet biomass and animal wastes into biogas through decomposition process by the action of anaerobic bacteria.

The carbon present in biomass is devided between fully oxidized CO_2 and fully reduced CH_4

Thus:

Decaying wet biomass $\xrightarrow[\text{Anaerobic Fermentation}]{20-55^\circ C}$ Biogas (CH_4 & CO_2)

The most useful biomass materials are animal manure, algae, kelp, plant-residues etc.

Fixed Dome / Constant Volume Type Biogas plant

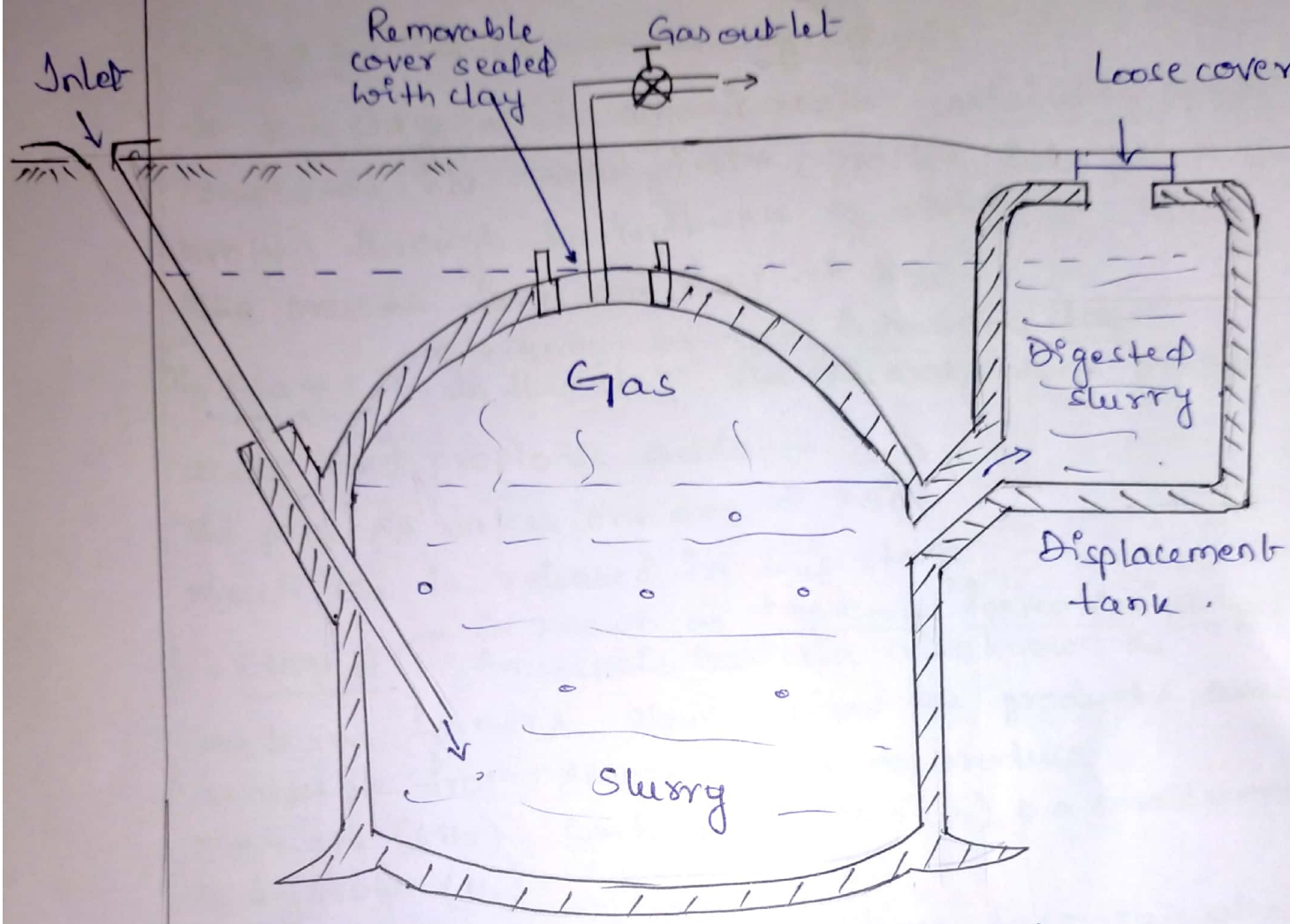

fig: fixed dome type biogas plant (Janata Model)

Construction :

→ The complete structure is contains only masonry work. The constructed dome structure is very strong for outside pressures but weak for inner pressures.

→ The dome is constructed underground to maintain pressure over it

→ The slurry enters from inlet and the digested slurry is collected in a displacement tank.

→ Stirring is requed if the biomass is crop residue.

Working :- The biochemical processes in 3 stages as shown below..

i) Stage I :- is known as Hydrolysis
In this stage all the organic matter containing complex compounds like carbohydrates, protien, fats etc are is broken through the influence of water.
The process takes one day at 25°c.

ii) Stage II :- is known as Acid formation stage
In this stage the microorganisms produce acetic and propionic acids.
The process takes one day at 25°c.
Much CO_2 is released in this stage.

iii) Stage III :- is known as Methane formation stage
Anaerobic bacteria also known as methane formers slowly digest the products available from second stage to produce methane (CH_4), carbon dioxide (CO_2) & a small amount of hydrogen (H_2).
The process takes two weeks time to complete at 25°c.

Advantages :
* Cost is less as only masonry work is required.
* As the dome is has masonry construction hence there is no corrosion and less maintenance.
* Thermal insulation is good due to complete underground construction.
* The dome construction is very strong for outside pressures
* The temperature remains constant as the whole construction is underground.
* This plant works efficiently for other biomass organic material along with cow dung slurry.

Disadvantages :-

- Chances of gas bakage is more hence skilled masnory workmanship is required.
- Gas pressure, ~~varies~~ in the dome varies depending on the production.
- External stirrer is required to break the scum.
- Gas production per unit volume is low.
- As the structure is underground, repairing of defects in gas holder is difficult.
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Urban Waste to Energy Conversion

i) MSW (Municipal Solid Waste) Incineration Plant

MSW is a solid waste generated by households, commercial and institutional operations.
Disposal of MSW is a major problem in big cities where the large quantities of waste is to be disposed off, far away from the city centers.
The solution is to use this waste as an energy resource in a waste-to-energy conversion plant near the city & the energy thus generated is used within city itself.

The block diagram of MSW incineration plant is shown in fig ① below.

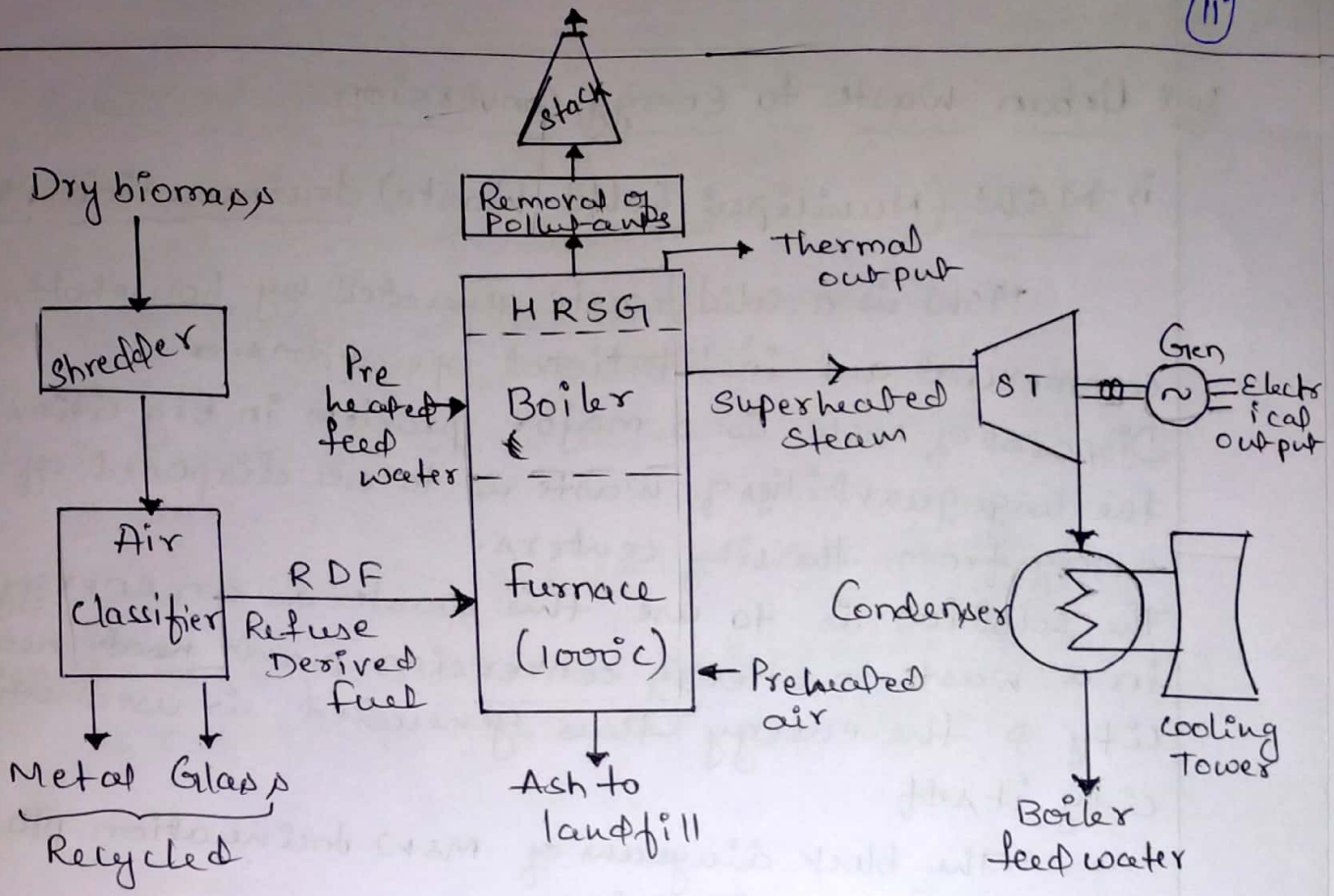
→ **Shredder** :- It is used to shred out the dry biomass in small pieces of about 2.5 C.M diamt.

→ **Air classifies** :- In this a stream of air is used to segregate RDF (Refuse Derived fuel) from metal & glass pieces. The RDF is lighter than the metal & glass pieces The RDF is fed to the furnace for burning and the heavier metal & glass pieces are recycled.

→ **Furnace** :- The RDF is burnt in the furnace at 1000°C to produce steam in the boiler. Preheated air is fed to the furnace from outside.

→ **Boiler** :- Preheated water is fed to the boiler where the water converts in the form of steam (superheated steam) which is blown on the steam turbine blades

→ **Turbine & Generator** :- The superheated, high pressure steam is blown on the turbine blades due to which it rotates and the generator will produce electrical energy.



fig① MSW to energy incineration plant

→ **Condenser** :- The low pressure steam from the turbine is collected in the condenser and convert it into water droplets with the help of cooling tower.

→ **Stack** :- The flue gases are discharged to the atmosphere through stack after removal of pollutants (SO_x & NO_x)

→ **HRSG** : (Heat-Recovery Steam Generator)
HRSG extracts maximum heat from flue gases to form thermal output.

The Ash is removed and disposed of to landfills.

Advantages :-

The main drawback of this system is pollutants emmited during combustion.
Because of various materials contained in the solid waste, pollutants in the flue gases includes sulpher, Chlorine, flaorine, nitrogen and heavy metals which causes cancer in an & other health issues in animals.

The residual ash has high metal concentration hence cant be used to fill the lands because during rainy season the contamination of metals with the groundwater takes place.

Biomass Gasification :

It is the process of converting solid fuel into a gaseous fuel by thermo-chemical process-method. Gasification involves partial combustion and reduction operation of biomass.
The combustion products are mainly CO_2, H_2O, CO, N_2 & H_2

following are the reactions which occur during gasification.

*) $C + O_2 \longrightarrow CO_2$ (combustion -394 kJ/mole)

The moisture in the biomass converts into steam.
Thus the product of combustion results in CO_2 & H_2O which further react with char.

*) $C + CO_2 \rightarrow 2CO$ (Boudouard reaction 164.9 kJ/mole)

*) $C + H_2O \rightarrow CO + H_2$ (Water Gas reaction 122.6 kJ/mole)

*) $CO + H_2O \rightarrow CO_2 + H_2$

*) $C + 2H_2 \rightarrow CH_4$ (Methane reaction 83.3 kJ/mole)

The gasifiers are broadly classified into

i) fixed bed gasifies
   - a) Downdraft
   - b) Updraft
   - c) Cross draft.

ii) Fluidized bed gasifies

a) Down draft type gasifier

→ In this type of gasification material and air moves simultaneously from top to bottom of the gasifier.

→ A downdraft gasifier is a reactor with 4 stages.

i) Drying zone :- In this zone the moisture is lost from the biomass at a temperature of 350°C.

ii) Pyrolysis zone :- The dried biomass moves downwards to the pyrolysis zone where the pyrolysis & the tar conversion reaction takes place at a temperature of 350 - 600°C.

iii) Oxidation zone :- The unconverted tars and gases move towards the oxidation zone where the air is transferred upwards through air nozzle and hence combustion takes place at 1000 - 1200°C. In this zone pyrolysis loses 70-80% of its weight.

iv) Reduction zone :- The product gases from the oxydation/combustion zone further moves to reduction zone where CO & H_2 are the main gases.

The gas produced is withdrawn from an exit at the bottom and reintraduced in the annular jacket. The hot gases which enters the annular jacket is of 500°C. & it transfers some amount of heat to the wood chips present inside to improve the thermal efficiency of the system. The producer gas is obtained and can be used for thermal applications.

Advantages :- * Less tar content is found in the producer gas.
* Downdraft is best suited for a variety of biomass.
* It produces a relatively clean gas.

Disadvantages:

*) Low thermal efficiency
*) Small size (1-3cm) biomass is used.
*) Fuel with only low water content can be gasified.

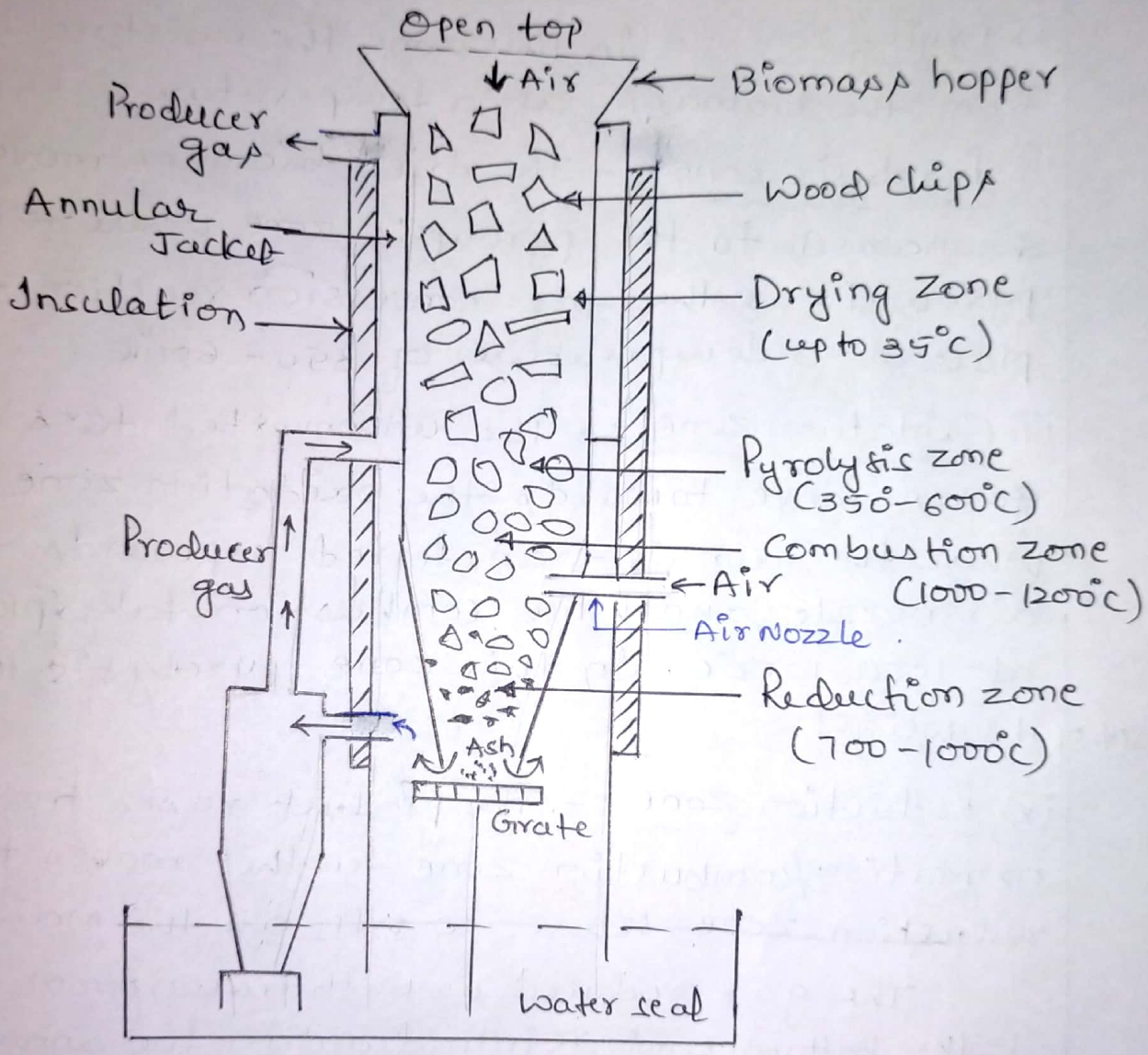


fig: Downdraft biomass gasification plant.