UNIT IV - BIOMASS ENERGY

Introduction-Bio mass resources –Energy from Bio mass: conversion processes-Biomass Cogeneration-Environmental Benefits. Geothermal Energy: Basics, Direct Use, Geothermal Electricity. Mini/micro hydro power: Classification of hydropower schemes, Classification of water turbine, Turbine theory, Essential components of hydroelectric system.

Introduction

Biomass refers to the organic material that is used for the production of energy referred to as Bioenergy. Biomass is primarily found in the form of living or recently living plants and biological wastes from industrial and domestic use. The process of energy conversion from biomass includes thermal conversion, chemical conversion, biochemical conversion and electrochemical conversion. A geothermal power plant works by tapping the steam or hot water reservoirs underground the earth and the heat is used to drive an electrical generator. Hydroelectric energy is a form of energy that harnesses the power of water in motion such as water flowing over a waterfall to generate electricity. A water turbine is a rotary machine that converts kinetic energy and potential energy of water into mechanical work. The conversion efficiency of a hydroelectric power plant depends mainly on the type of water turbine employed and can be as high as 95% for large installations.

Bio mass resources

Biomass resources, sometimes referred to as bio-renewable resources are all forms of organic materials, including plant matter both living and in waste form, as well as animal matter and their waste products. Biomass resources are generally classified as being either waste materials or dedicated energy crops.

A waste material can be any municipal solid waste and industrial waste material that has been discarded because it no longer has any apparent value to the user or which represents a nuisance or even a potential pollutant to the local environment. If the organic waste products from one process, was used as primary source of feedstock in another process, for example, waste cardboard, wood and paper recycled into newspapers, books and magazines, then if these waste materials were economically converted into electricity, heat, liquid biofuels, or chemicals, then they could be considered as a biomass resource rather than an unwanted waste stream. Waste materials that would qualify as a bio-renewable resource include agricultural residues, yard and garden waste, municipal solid waste, food processing waste, animal manure, etc.,

Solid Biomass Resources

- **Agricultural Residues** are the non-edible stalk type materials that remain after the harvest of the edible portions of the crops, such as corn, wheat, grain and sugar cane. Agricultural residues also includes plant leaves, husks, some roots and stems. The residues of dedicated bioenergy non-food crops are grown for their starches, sugars, or oils for the conversion into bioethanol and bio-lubricants. The advantage of agricultural residues is that they do not require the use of additional land space because they are grown together with the food crops.
- **Food Processing Waste** is the effluent wastes from a wide variety of industrial processes ranging from breakfast and cereal bar manufacturers to fresh and frozen vegetable manufacturers to alcohol breweries. These residues and wastes can be in the form of either dry solids or watery liquids. Fermentation of liquid wastes and oils from food processing can produce Ethanol.
- **Municipal Solid Waste** is the items that are thrown away in the garbage and trash and is collected by the dustbin men or sent to the recycling centre. Municipal solid waste such as particularly paper, cardboard, and discarded food products, is an attractive source of endless biomass feedstock. However, not all municipal waste is suitable as a biomass resource, especially metallic and plastic waste.
- **Animal Waste** from farms, ranches, slaughterhouses, fisheries and dairies or any concentration of animals into giant livestock farming facilities produces large amounts of manure and sewage sludge. Liquid sewage, animal wastes, and also human waste from urban areas, provides a constant source of chemical energy and gases which can be converted into electrical power at wastewater treatment

India produces about 450-500 million tonnes of biomass per year.

plants. The treatment of animal waste produces combustible methane and biogas which can then be used for heating and transportation.

- **Dedicated Biomass Energy Crops** can be grown specifically as an energy source. These dedicated energy crops are not only greener and cleaner with respect to solid waste materials, but their use represents a closed and balanced carbon cycle with regards to atmospheric carbon dioxide.

  Energy crops are defined as plants and crops grown specifically as an energy resource. The current production of biomass resources includes primarily agricultural byproducts, (Herbaceous crops) and forestry byproducts, (woody biomass crops). But when agricultural crops are grown solely for their energy production, either as a biomass resource or as a biofuel, than the plant species that offers the highest efficiency and the least pollution potentials are usually selected. Energy crops grown specifically as biomass resources include energy cane, sorghum, sugar cane, eucalyptus trees, switch grass, miscanthus, giant reeds, and leauceana lucacephala, etc., which are then planted and harvested periodically. Dedicated energy crops contain significant quantities of one or more of four important energy-rich components: oils, sugars, starches, and fibre.
- **Herbaceous Energy Crops** that have little or no woody tissue such as grasses and legumes grown on grasslands. Generally, food crops, such as maize, wheat, rice and sugarcane represent good sources of herbaceous biomass. Some byproducts or residues of crop cultivation, such as stalks and stems, can also be considered as herbaceous biomass.

  Switchgrass and miscanthus form the primary production of herbaceous crops as these tropical grasses tend to grow faster than woody trees and can produce higher amounts of biomass feedstock in a much shorter period. Generally the growth of these herbaceous plants usually lives for only a single growing season.
- **Woody Energy Crops** include hardwoods and softwoods form the basis of most biomass resources. The primary source of woody energy crops comes from fast growing trees and plantations, but woody biomass can also be a residue from forestry activities (timber waste), from wood processing (industrial wood, sawdust, wood shavings), and end-of-life wood products (bulky waste, demolition, pallets). Woody biomass is cut into uniform, small pieces called wood chips. Highly efficient and non-polluting burners and stoves can be designed to burn these chips for cooking and heating.
- **Lipids** are water insoluble oils and fats obtained from recently living biomass. For example, soya bean oil, palm oil, rapeseed oil, waxes and animal fats and greases, etc. Renewable lipid feedstock also includes algae, bacteria's and other such micro-organisms. Algae are among the fastest growing types organisms in the world, with about half of their weight being oil. The liquid biofuel, usually in the form of alcohol or ethanol, can be used to produce biodiesel to power cars, trucks, and even aeroplanes.

  Biomass Resources available for energy production encompasses a wide range of plants and materials ranging from agricultural and forest crops specifically grown for energy purposes, agricultural and forest wastes and residues, wastes from food processing and fisheries, municipal waste including sewage sludge, as well as aquatic plants and algae.

Biomass provides 32% of all the primary energy use in the country at present.

Energy from Bio mass: conversion processes

There are five fundamental forms of biomass energy use.

(1) The "traditional domestic" use in developing countries (fuelwood, charcoal and agricultural residues) for household cooking (e.g. the "three stone fire"), lighting and space-heating. In this role-the efficiency of conversion of the biomass to useful energy generally lies between 5% and 15%.

(2) The "traditional industrial" use of biomass for the processing of tobacco, tea, pig iron, bricks & tiles, etc, where the biomass feedstock is often regarded as a "free" energy source. There is generally little incentive to use the biomass efficiently so conversion of the feedstock to useful energy commonly occurs at an efficiency of 15% or less.

(3) "Modern Industries" are experimenting with technologically advanced thermal conversion technologies. Expected conversion efficiencies are between 30 and 55%.

(4) Newer "chemical conversion" technologies ("fuel cell") which are capable of by-passing the entropy-dictated Carnot limit which describes the maximum theoretical conversion efficiencies of thermal units.

(5) "Biological conversion" techniques, including anaerobic digestion for biogas production and fermentation for alcohol.

In general, biomass-to-energy conversion technologies have to deal with a feedstock which can be highly variable in mass and energy density, size, moisture content, and intermittent supply. Therefore, modern industrial technologies are often hybrid fossil-fuel/biomass technologies which use the fossil fuel for drying, preheating and maintaining fuel supply when the biomass supply is interrupted.

Biomass can be converted into useful forms of energy using a number of different processes. Factors that influence the choice of conversion process are: the type and quantity of biomass feedstock, the desired form of the energy, i.e. end-use requirements, environmental standards, economic conditions, and project specific factors. In many situations the form in which the energy is required determines the process route followed by the available types and quantities of biomass. The conversion technologies to utilize biomass can be classified into three basic categories

- Direct combustion processes.
- Thermochemical processes.
- Biochemical processes.

Direct combustion processes.

Feedstocks used are often residues such as woodchips, sawdust, bark, hogfuel, black liquor, bagasse, straw, municipal solid waste (MSW), and wastes from the food industry.

Direct combustion furnaces can be divided into two broad categories and are used for producing either direct heat or steam. Dutch ovens, spreader-stoker and fuel cell furnaces employ two-stages. The first stage is for drying and possible partial gasification, and the second for complete combustion. More advanced versions of these systems use rotating or vibrating grates to facilitate ash removal, with some requiring water cooling.

The second group, include suspension and fluidised bed furnaces which are generally used with fine particle biomass feedstocks and liquids. In suspension furnaces the particles are burnt whilst being kept in suspension by the injection of turbulent preheated air which may already have the biomass particles mixed in it. In fluidised bed combustors, a boiling bed of pre-heated sand (at temperatures of 500 to 900°C) provides the combustion medium, into which the biomass fuel is either dropped (if it is dense enough to sink into the boiling sand) or injected if particulate or fluid. These systems obviate the need for grates, but require methods of preheating the air or sand, and may require water cooled injection systems for less bulky biomass feedstocks and liquids.

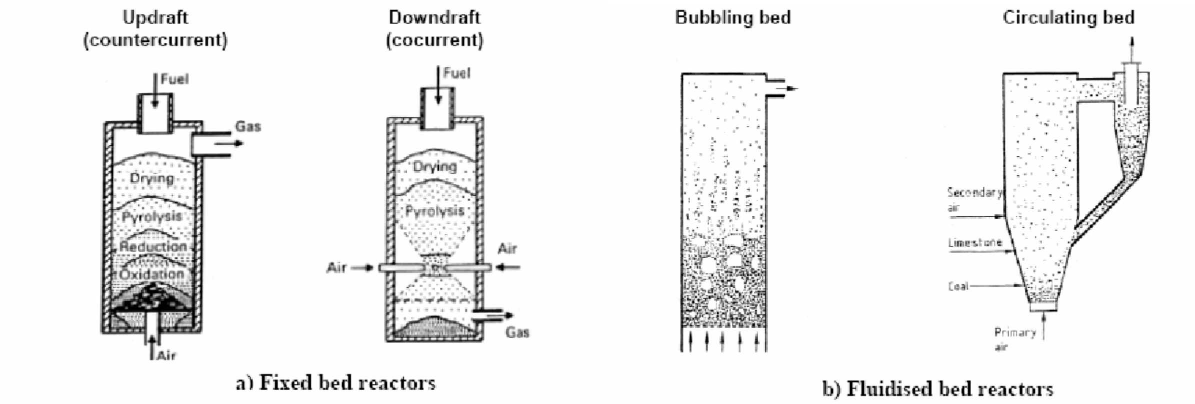

Fig.1. Direct combustion process

Co-firing.

A modern practice which has allowed biomass feedstocks an early and cheap entry point into the energy market is the practice of co-firing a fossil-fuel (usually coal) with a biomass feedstock. Co-firing has a number of advantages, especially where electricity production is an output.

There are three different concepts for co-firing biomass in coal boilers.

- **Direct co-firing** – The biomass and the coal are burned in the same furnace. The mills for the grinding of the fuel and the burners may be separate. This depends on the biomass used and its fuel properties. This concept is most commonly used, because it is the easiest to implement and most cost-effective.
- **Indirect co-firing** – In this concept, the solid biomass is converted to a clean fuel gas, using a biomass gasifier. The gas can be burnt in the same furnace as the coal. For this reason, it is also possible to use biomass, which, for example is difficult to grind. The gas can be cleaned and filtered before use, to remove impurities .
- **Parallel co-firing** – It is also possible to install a completely separate biomass boiler for increasing the steam parameters, like pressure or temperature, in the steam system of the coal power plant. This method allows a high amount of biomass.

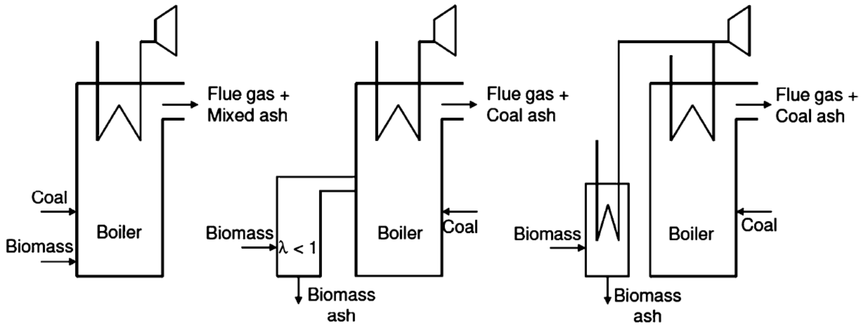

Fig.2. Cofiring

India has ~5+ GW capacity biomass powered plants: 83% are grid connected, 17% are off-grid plants. More than 70% of the country's population depends upon biomass for its energy needs.

Thermochemical processes.

- Pyrolysis.
- Carbonisation.
- Gasification.
- Catalytic Liquefaction.

These processes do not necessarily produce useful energy directly, but under controlled temperature and oxygen conditions are used to convert the original biomass feedstock into more convenient forms of energy carriers, such as producer gas, oils or methanol. These carriers are either more energy dense and therefore reduce transport costs, or have more predictable and convenient combustion characteristics allowing them to be used in internal combustion engines and gas turbines.

Pyrolysis

Pyrolysis is the technique of applying high heat to organic matter (lignocellulosic materials) in the absence of air or in reduced air. The process can produce charcoal, condensable organic liquids (pyrolytic fuel oil), non-condensable gasses, acetic acid, acetone, and methanol. The process can be adjusted to favour charcoal, pyrolytic oil, gas, or methanol production with a 95.5% fuel-to-feed efficiency.

Sixty-eight percent of the energy in the raw biomass is contained in the charcoal and fuel oils made at the facility. The charcoal has the same heating value in Btu(British thermal Unit) as coal, with virtually no sulphur to pollute the atmosphere. The remaining energy is in non-condensable gases that are used to co-generate steam and electricity. Every ton of biomass converted to fuels in this manner produces approximately 27% charcoal, 14% pyrolytic fuel oil, and 59% intermediate-Btu gas.

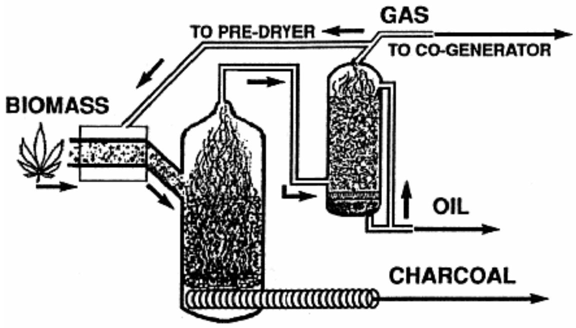

Fig. 3. Pyrolysis

The biomass feedstock is subjected to high temperatures at low oxygen levels, thus inhibiting complete combustion, and may be carried out under pressure. Biomass is degraded to single carbon molecules (CH_4 and CO) and H_2 producing a gaseous mixture called "producer gas." Carbon dioxide may be produced as well, but under the pyrolytic conditions of the reactor it is reduced back to CO and H_2O; this water further aids the reaction.

Carbonisation

This is an age old pyrolytic process optimised for the production of charcoal. Traditional methods of charcoal production have centred on the use of earth mounds or covered pits into which the wood is piled. Control of the reaction conditions is often crude and relies heavily on experience. The conversion efficiency using these traditional techniques is believed to be very low.

During carbonisation most of the volatile components of the wood are eliminated; this process is also called "dry wood distillation." Carbon accumulates mainly due to a reduction in the levels of hydrogen and oxygen in the wood.

The modernisation of charcoal production has lead to large increases in production efficiencies with large-scale industrial production achieving efficiencies of over 30% (by weight).

There are three basic types of charcoal-making:

a) internally heated (by controlled combustion of the raw material),

b) externally heated (using fuelwood or fossil fuels), and

c) hot circulating gas (retort or converter gas, used for the production of chemicals).

Externally heated reactors allow oxygen to be completely excluded, and thus provide better quality charcoal on a larger scale. They do, however, require the use of an external fuel source, which may be provided from the "producer gas" once pyrolysis is initiated. Recirculating heated gas systems offer the potential to generate large quantities of charcoal and associated by-products, but are presently limited by high investment costs for large scale plant.

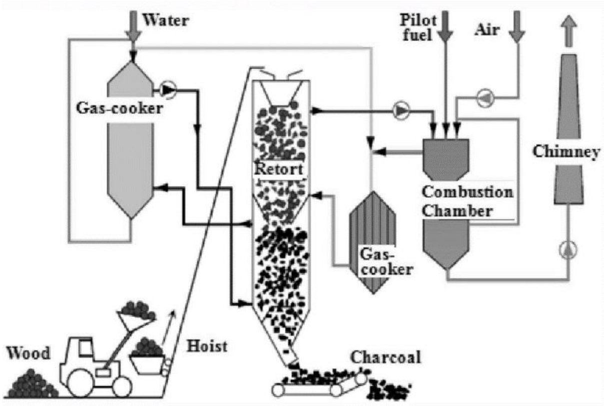

Fig. 4. Carbonisation

The United States is the world's largest producer of ethanol, having produced nearly 16 billion gallons in 2017 alone. Together, the U.S. and Brazil produce 85% of the world's ethanol.

Gasification

Biomass gasification is a thermal process which converts organic carbonaceous materials (such as wood waste, shells, pellets, agricultural waste, energy crops) into a combustible gas comprised of carbon monoxide (CO), hydrogen (H) and carbon dioxide (CO_2). This is achieved by reacting the material at high temperatures, without fully combusting it, using a controlled oxygen (O) inlet. The resulting gas mixture is called syngas. At temperatures of approximately 600 to 1000°C, solid biomass undergoes thermal decomposition to form gas-phase products which typically include CO, H, CH_4, CO_2, and H_2O.

There are four stages involved in gasification process:

- **Drying:** In the drying zone, moisture in the feedstock is evaporated by the heat from the lower zones at a temperature of between 150 and 200°C. Vapours move down and mix with vapours originating in the oxidation zone. A part of the vapour is converted into oxygen with the remainder being retained in the producer gas.
- **Pyrolysis:** This is the thermal decomposition of biomass in low oxygen conditions at temperatures ranging from 200 to 600°C.
- **Combustion:** Oxidation occurs in the presence of a reactive gas (air or pure oxygen) which affect the calorific value of the gas leaving the gasifier. The use of air as reactive gas is the more common.
- **Reduction:** The products of the oxidation zone, hot gases and glowing char, move into the reduction zone. Since there is insufficient O_2 in this high- temperature zone for continued oxidation, a number of reduction reactions take place between the hot gases (CO, H_2O, CO_2, and H_2) and char.

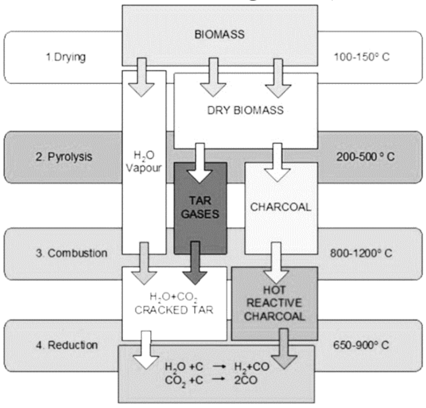

Fig.5. Gasification

Catalytic Liquefaction

This technology has the potential to produce higher quality products of greater energy density. These products also require less processing to produce marketable products. Catalytic liquefaction is a low temperature, high pressure thermochemical conversion process carried out in the liquid phase. It requires either a catalyst or a high hydrogen partial pressure. A homogeneous hydrotreating catalyst is added directly to the reaction mixture to facilitate hydrogenation. As in the case with non-catalytic liquefaction, a hydrogen-donor solvent is employed to stabilise the cracked products by hydrogen transfer, but additionally, the feed, cracked products and the dehydrogenated solvent are hydrogenated in situ with molecular hydrogen (H_2). The solvent is usually recovered and recycled in the process.

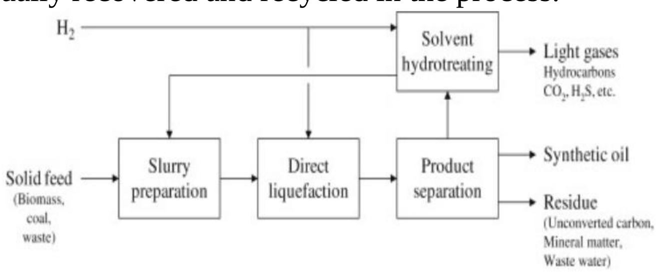

Fig.6. Catalytic liquefaction

Biochemical processes.

- Anaerobic Fermentation.
- Methane Production in Landfills.
- Ethanol Fermentation.
- Biodiesel.

Micro organisms have become regarded as biochemical "factories" for the treatment and conversion of most forms of human generated organic waste. Microbial engineering has encouraged the use of fermentation technologies (aerobic and anaerobic) for use in the production of energy (biogas) and fertiliser, and for the use in the removal of unwanted products from water and waste streams.

Anaerobic Fermentation.

Anaerobic reactors are generally used for the production of methane rich biogas from manure (human and animal) and crop residues. They utilise mixed methanogenic bacterial cultures which are characterised by defined optimal temperature ranges for growth. These mixed cultures allow digesters to be operated over a wide temperature range i.e. above 0°C up to 60°C.

When functioning well, the bacteria convert about 90% of the feedstock energy content into biogas (containing about 55% methane), which is a readily useable energy source for cooking and lighting. The sludge produced after the manure has passed through the digester is non-toxic and odourless. Also, it has lost relatively little of its nitrogen or other nutrients during the digestion process thus, making a good fertiliser. In fact, compared to cattle manure left to dry in the field the digester sludge has a higher nitrogen content; many of the nitrogen compounds in fresh manure become volatised while drying in the sun. On the other hand, in the digested sludge little of the nitrogen is volatilised, and some of the nitrogen is converted into urea. Urea is more readily accessible by plants than many of the nitrogen compounds found in dung, and thus the fertiliser value of the sludge may actually be higher than that of fresh dung.

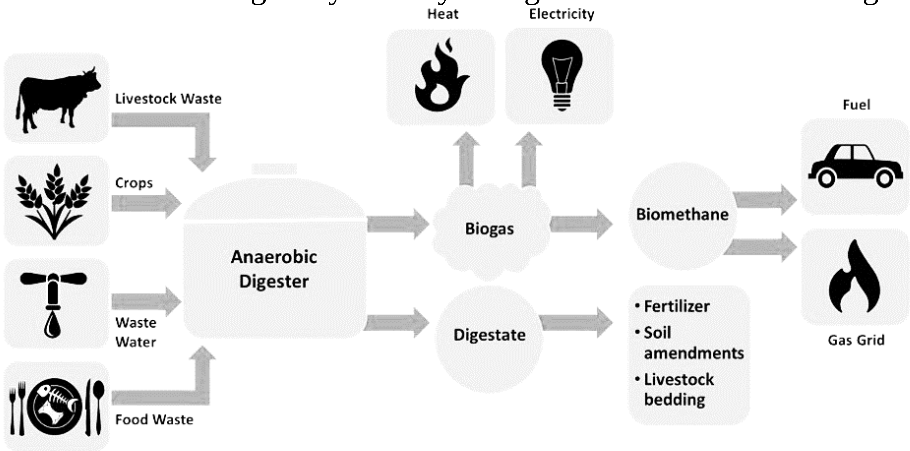

Fig. 7. Anaerobic Fermentation

Methane Production in Landfills

Landfills for municipal solid waste are a source of biogas. Biogas is produced naturally by anaerobic bacteria in municipal-solid-waste landfills and is called landfill gas. Some landfills reduce landfill gas emissions by capturing and burning or flaring the landfill gas. Burning the methane in landfill gas produces CO_2, but CO_2 is not as strong a greenhouse gas as methane. Many landfills collect landfill gas, treat it to remove CO_2, water vapour, and hydrogen sulphide, and then sell the methane. Some landfills use the methane gas to generate electricity.

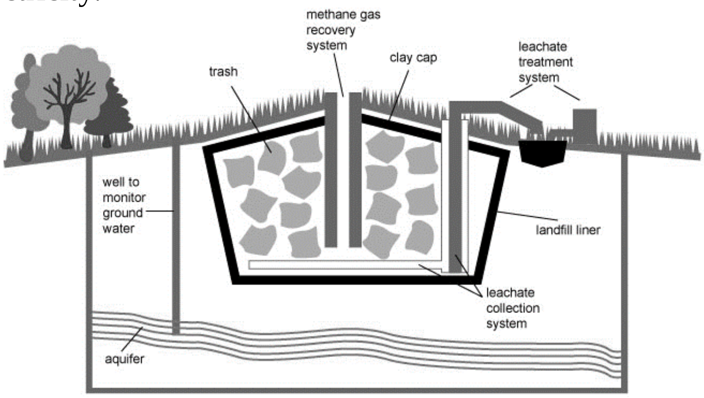

Fig. 8. Methane Production in Landfills

US is leading producer of biofuel in the world on 2018 with production of 1,190.2 thousand barrels/day

Ethanol Fermentation.

Ethanol is mainly used as a substitute for imported oil in order to reduce their dependence on imported energy supplies. The substantial gains made in fermentation technologies now make the production of ethanol for use as a petroleum substitute and fuel enhancer, both economically competitive (given certain assumptions) and environmentally beneficial.

The most commonly used feedstock in developing countries is sugarcane, due to its high productivity when supplied with sufficient water. Where water availability is limited, sweet sorghum or cassava may become the preferred feedstocks. Other advantages of sugarcane feedstock include the high residue energy potential and modern management practices which make sustainable and environmentally benign production possible while at the same time allowing continued production of sugar. Other feedstocks include saccharide-rich sugarbeet, and carbohydrate rich potatoes, wheat and maize.

Conversion of biomass to ethanol includes (1) pretreatment, (2) enzymatic hydrolysis, (3) fermentation, and (4) distillation. Pretreatment sometimes includes mechanical size reduction which must be followed by a strong thermochemical pretreatment to break up lignocellulosic structure solubilizing hemicellulose and/or lignin to make cellulose more accessible to hydrolytic enzymes. Enzymatic hydrolysis releases glucose from cellulose for ethanol fermentation. The two steps can be done together in a single step called simultaneous saccharification and fermentation (SSF). In order to obtain high ethanol concentration for distillation in lignocellulosic biorefinery process, steps such as enzymatic hydrolysis or SSF need to be operated at high solid loading.

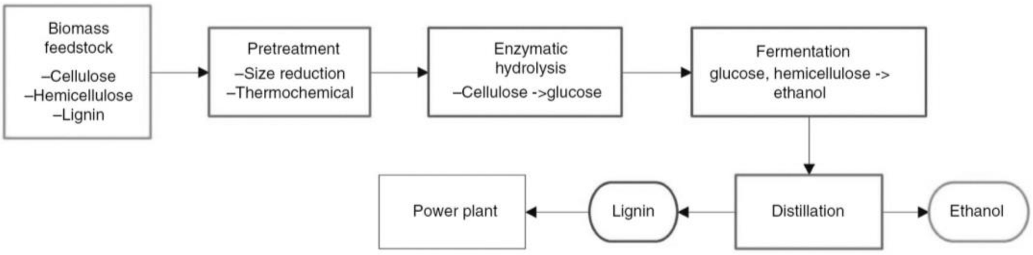

Fig. 9. Ethanol Fermentation

Biodiesel

The use of vegetable oils for combustion in diesel engines has occurred for over 100 years. The raw oil can be obtained from a variety of annual and perennial plant species. Perennials include, oil palms, coconut palms, physica nut and Chinese Tallow Tree. Annuals include, sunflower, groundnut, soybean and rapeseed. Many of these plants can produce high yields of oil, with positive energy and carbon balances.

Transformation of the raw oil is necessary to avoid problems associated with variations in feedstock. The oil can undergo thermal or catalytic cracking, Kolbe electrolysis, or transesterification processes in order to obtain better characteristics. Untreated oil causes problems through incomplete combustion, resulting in the build up of sooty residues, waxes, gums etc. Also, incorrect viscosities can result in poor atomization of the oil also resulting in poor combustion. Oil polymerisation can lead to deposition on the cylinder walls.

Biodiesel is produced from vegetable oils, yellow grease, used cooking oils, or animal fats. The fuel is produced by transesterification; a process that converts fats and oils into biodiesel and glycerin (a coproduct). Approximately 100 pounds of oil or fat are reacted with 10 pounds of a short-chain alcohol (usually methanol) in the presence of a catalyst (usually sodium hydroxide [NaOH] or potassium hydroxide [KOH]) to form 100 pounds of biodiesel and 10 pounds of glycerin (or glycerol). Glycerin, a co-product, is a sugar commonly used in the manufacture of pharmaceuticals and cosmetics.

Raw or refined plant oil, or recycled greases that have not been processed into biodiesel, are not biodiesel and should not be used as vehicle fuel. Fats and oils (triglycerides) are much more viscous than biodiesel, and low-level vegetable oil blends can cause long-term engine deposits, ring sticking, lube-oil gelling, and other maintenance problems that can reduce engine life.

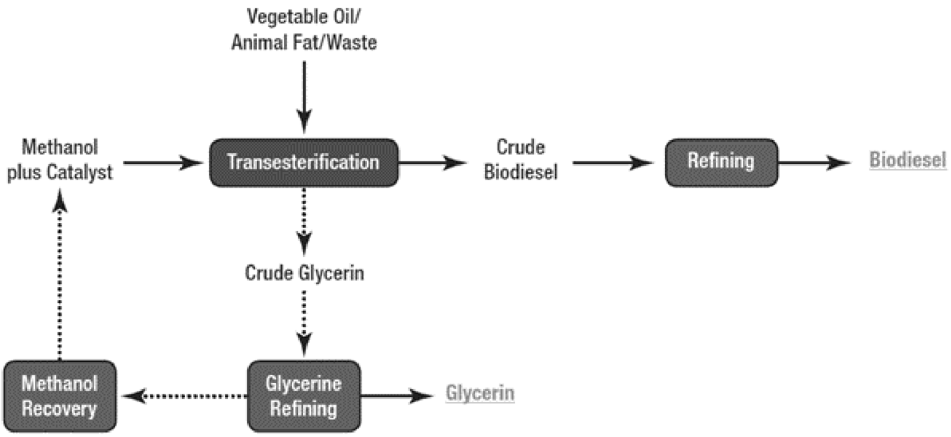

Fig.10. Biodiesel

Biomass Cogeneration

Cogeneration is a combined production of heat and electricity, suitable for fossil fuel or biofuel (biomass) combustion systems. Cogeneration is the best solution for energy saving and environmental preservation. Cogeneration requires a heat exchanger to absorb and recover exhaust heat. Biomass cogeneration is considered an effective alternative to reduce greenhouse gas emissions due to their low CO_2 emission. Many researches have been conducted in recent years to improve the economic and environmental efficiency and effectiveness of biomass cogeneration systems. Biomass cogeneration systems are becoming increasingly popular. Several cogeneration technology and systems have been developed in recent years, some of which are suitable for large power plants and other for medium power and micro-cogeneration.

Steam Cycle

The operating principle is in line with the classic Clausius-Rankin process. High temperature, high pressure steam generated in the boiler and then enters the steam turbine. In the steam turbine, the thermal energy of the steam is converted into mechanical work. The low-pressure steam leaving the turbine enters the condenser housing and condenses on the condenser tubes. The condensate is transported by the water supply system to the boiler, where it is reused in a new cycle.

The process of producing electricity and heat from steam includes the following components: a biomass combustion system (combustion chamber), a steam system (boiler plus distribution systems), a steam turbine, an electricity generator and the heat distribution system for heating from the condenser. At present, electricity and heat generation in biomass power plants with a steam cycle remains the most developed technology, adapted to high temperatures and high power; however, this technology is not suitable for cogeneration systems with a power of less than 100 kW compared to its low electrical efficiency and high investment costs.

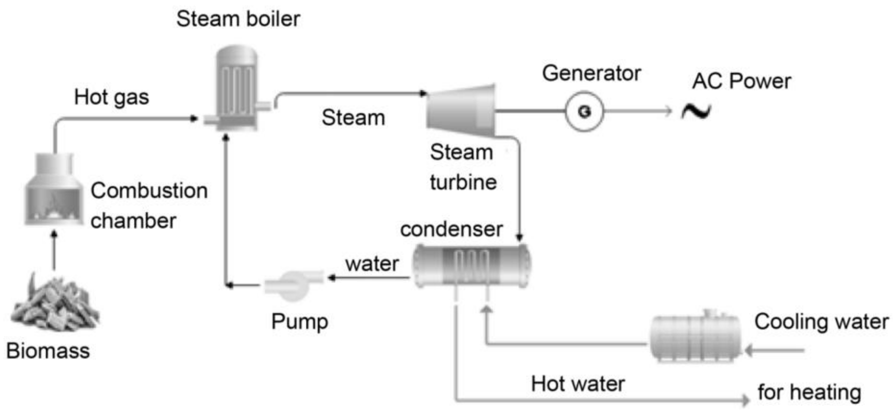

Fig. 11. Principle of operation of a steam turbine biomass cogeneration plant.

Biomass cogeneration plants generally use grid combustion systems with a thermal combustion capacity of 20 to 30 MW. In the case where chemically untreated wood biomass is used, the steam temperature reaches 540˚C. The achievable annual electrical efficiency depends on the steam parameters (temperature and pressure) and the temperature level required for the heating process. Annual electricity efficiencies generally range from 18% to 30% for biomass cogeneration plants between 2 and 25 MW. Below are the advantages of the use of steam cycle:

- The use of water as a heat transfer fluid has great advantages, such as its high availability, non-toxic, non-flammable, chemical stability, low viscosity (less friction losses);
- Thermal efficiency greater than 30%;
- Low pump consumption.

Major pollutant produced from burning biomass is most dangerous: particle pollution, known as soot

Environmental Benefits

Biomass benefits are still subject of many debates when compared with other renewable energy sources. However, biomass has many advantages over fossil fuels due to reduction of the amount of carbon emissions. The main benefits of biomass are:

- **Biomass is a renewable energy source:** The benefit of biomass energy is that biomass is renewable source of energy and it cannot be depleted. Biomass mostly derived from plants, that means as long as plants are going on this planet, biomass will be available as renewable energy source.
- **Biomass helps climate change by reducing GHG:** Biomass indeed helps reduce the amount of greenhouse gas emissions that give more impact to global warming and climate change. Though biomass is connected with certain level of emissions this level is far smaller compared to currently dominant energy sources, fossil fuels. The basic difference between biomass and fossil fuels when it comes to amount of carbon emissions is that all the CO_2 which has been absorbed by plant for its growth is going back in the atmosphere during its burning for the production of biomass energy while the CO_2 produced from fossil fuels is only going to atmosphere where it increases Earth's greenhouse effect and adds to global warming.
- **Cleaner environment:** The third main benefit of biomass energy is that biomass can help clean our environment. World population is constantly increasing, and with the increase in population there is also a problem of increased waste which needs to be properly disposed. Many of the garbage ends up in rivers, water streams, oceans harming nearby ecosystems and having negative impact on human health. Instead of pollution our planet with all this garbage we could use it for the production of this energy and it helps cleaning our environment from many different form of pollution.
- **Biomass is widely available source of energy:** Biomass is widely available energy source. The sources are from agriculture, forestry, fisheries, aquaculture, algae and waste. Many energy experts agree that when you combine economic and environmental character of energy sources biomass is on top of the list as one of the best energy sources.
- **GHG emission balances for biomass-fuelled electricity and heat applications:** Some biomass systems show net GHG emissions savings of more than 40% of the substituted fossil alternatives, while some others only score 4%. Thus, the span of the environmental benefit is wide, and the effective value will depend on the particular application situation (technology, scale etc). The total GHG emissions from contaminated biomass fuels (non-tradables) are set at 0, since these fuels are available anyway. There existence cannot be avoided, and all GHG emissions associated with their production should be allocated to the products from which they are the unavoidable result.
- **Biomass Power is Carbon Neutral:** Biomass power is carbon neutral. Any carbon that is released into the atmosphere during combustion of biomass is absorbed from the atmosphere at one point in the tree's life – so what it took out ends up going back. In many cases, the carbon released is re-absorbed by another plant so it never reaches the atmosphere in the first place. With fossil fuels, the carbon released during combustion has been inaccessible to the atmosphere for millennia and therefore adds additional carbon to the atmosphere.
- **Reduces amount of waste in landfills:** Most waste produced in homes is either plant matter or biodegradable. This kind of waste can be channeled to more profitable use. Biomass energy generation utilizes any waste that would have otherwise found way into landfills. This minimizes the impacts of waste in landfills to the environment. This impact may be compounded by contamination of local habitats and destruction of wildlife ecosystems. Minimized waste means reduction of land intended for landfills, hence, more space for human habitats.

Geothermal Energy: Basics

The word geothermal comes from the Greek words geo (earth) and therme (heat). So, geothermal energy is heat from within the Earth. We can recover this heat as steam or hot water and use it to heat buildings or generate electricity. Geothermal energy is a renewable energy source because the heat is continuously produced inside the Earth.

Volcanoes, hot springs, and geysers, are all examples of concentrated geothermal energy that has made its way to the surface. In general, however, it is not obvious where pockets of concentrated geothermal energy are located because most sources occur unevenly and deep underground. To find and access a geothermal reservoir, water or steam wells are generally drilled to test temperatures. Beyond concentrated geothermal pockets, there is some degree of geothermal potential almost everywhere because temperatures just several feet below the earth's surface tend to remain a relatively constant 50 to 60 °F.

Worldwide geothermal power capacity is around 12.8 gigawatts, and it is expected to rise to about 18 gigawatts by 2020

Geothermal Energy Generated Deep Inside the Earth

Geothermal energy is generated in the Earth's core. Temperatures hotter than the sun's surface are continuously produced inside the Earth by the slow decay of radioactive particles, a process that happens in all rocks. The Earth has a number of different layers:

- The core itself has two layers: a solid iron core and an outer core made of very hot melted rock, called magma.
- The mantle surrounds the core and is about 1,800 miles thick. It is made up of magma and rock.
- The crust is the outermost layer of the Earth, the land that forms the continents and ocean floors. It can be 3 to 5 miles thick under the oceans and 15 to 35 miles thick on the continents.

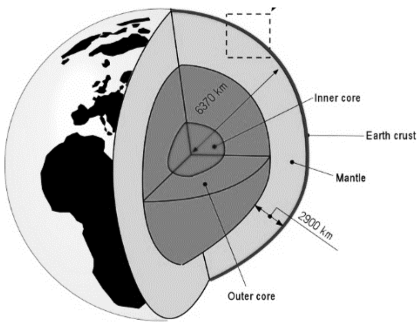

Fig. 12. Earth core

Use of Geothermal Energy

Some applications of geothermal energy use the Earth's temperatures near the surface, while others require drilling miles into the Earth. The three main uses of geothermal energy are:

- **Direct use** and district heating systems use hot water from springs or reservoirs near the surface.
- **Electricity generation power plants** require water or steam at very high temperature (300° to 700°F)
- **Geothermal heat pumps** use stable ground or water temperatures near the Earth's surface to control building temperatures above ground.

Geothermal energy is generated in the earth's core, almost 4,000 miles beneath the earth's surface.

Direct Use

Direct or non-electric use of geothermal energy refers to the immediate use of the energy for both heating and cooling applications. The primary forms of direct use include heating swimming pools and baths or therapeutic use (i.e., balneology), space heating and cooling (including district heating), agriculture (mainly greenhouse heating, crop drying, and some animal husbandry), aquaculture (heating mainly fish ponds and raceways), and providing heat for industrial processes and heat pumps (for both heating and cooling).

Heat exchangers

The principle heat exchangers used in geothermal systems are the plate, shell-and-tube, and downhole types. The plate heat exchanger consists of a series of plates with gaskets held in a frame by clamping rods. The counter-current flow and high turbulence achieved in plate heat exchangers provide for efficient thermal exchange in a small volume. In addition, compared to shell-and-tube exchangers, they have the advantage of occupying less space, they can easily be expanded when additional load is added, and are typically 40% cheaper. The plates are usually made of stainless steel, but titanium can be used when the fluids are especially corrosive.

- Shell-and-tube heat exchangers may be used for geothermal applications, but are less popular due to problems with fouling, greater approach temperature (the difference between incoming and outgoing fluid temperature), and the larger size as compared to the plate type.
- Downhole heat exchangers eliminate the problem of disposal of geothermal fluid, since only heat is taken from the well. However, their use is limited to small heating loads, such as the heating of individual homes, a small apartment, house, or business.

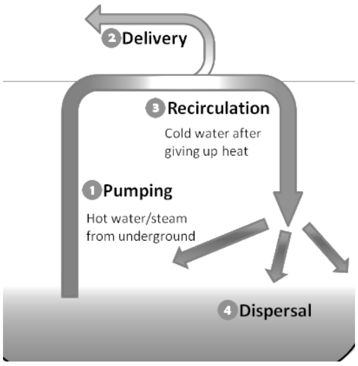

Fig.13. Deep hole geothermal

Refrigeration systems

Cooling can be accomplished from geothermal energy using lithium bromide and ammonia absorption refrigeration systems.

- The lithium bromide system is the most common because it uses water as the refrigerant. However, it is limited to cooling above the freezing point of water. The major application of lithium bromide units is for the supply of chilled water for space and process cooling in either one- or two-stage units. The two-stage units require higher temperatures (about 320°F), but they also have high efficiency. The single-stage units can be driven with hot water at temperatures as low as 180°F. Lower geothermal water temperatures result in lower efficiency and require a higher flow rate.
- For geothermally driven refrigeration below the freezing point of water, the ammonia absorption system must be considered. However, these systems are normally applied in very large capacities and have seen limited use. For the lower temperature refrigeration, the driving temperature must be at or above 250°F for a reasonable performance.

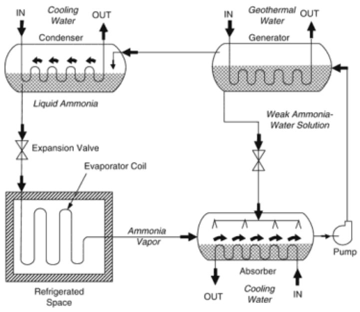

Fig.14. Refrigeration system

Distribution networks

Supply and distribution networks can consist of either a single-pipe or a two-pipe system. The single-pipe system is a once-through system where the fluid is disposed of after use. This distribution system is generally preferred when the geothermal energy is abundant and the water is pure enough to be circulated through the distribution system. In a two-pipe system, the fluid is re-circulated so the fluid and residual heat are conserved.

A two-pipe system must be used when mixing of spent fluids is called for, and when the spent cold fluids need to be injected into the reservoir. Two-pipe distribution systems cost typically 20% to 30% more than single-pipe systems.

Heating mode

- **Circulation:** The above-ground heat pump moves water or another fluid through a series of buried pipes or ground loops.
- **Heat absorption:** As the fluid passes through the ground loop, it absorbs heat from the warmer soil, rock, or ground water around it.
- **Heat exchange and use:** The heated fluid returns to the building where it is used for useful purposes, such as space or water heating. The system uses a heat exchanger to transfer heat into the building's existing air handling, distribution, and ventilation system, or with the addition of a desuperheater it can also heat domestic water.
- **Recirculation:** Once the fluid transfers its heat to the building, it returns at a lower temperature to the ground loop to be heated again. This process is repeated, moving heat from one point to another for the user's benefit and comfort.

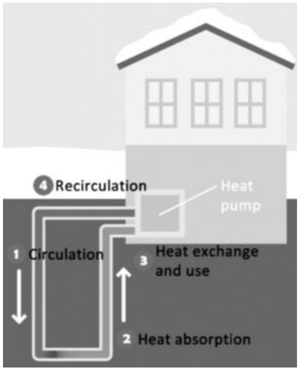

Fig. 15. Heating mode

Cooling mode

- **Heat exchange and absorption:** Water or another fluid absorbs heat from the air inside the building through a heat exchanger, which is the way a typical air conditioner works.
- **Circulation:** The above-ground heat pump moves the heated fluid through a series of buried pipes or ground loops.
- **Heat discharge:** As the heated fluid passes through the ground loop, it gives off heat to the relatively colder soil, rock, or ground water around it.
- **Recirculation:** Once the fluid transfers its heat to the ground, the fluid returns at a lower temperature to the building, where it absorbs heat again. This process is repeated, moving heat from one point to another for the user's benefit and comfort.

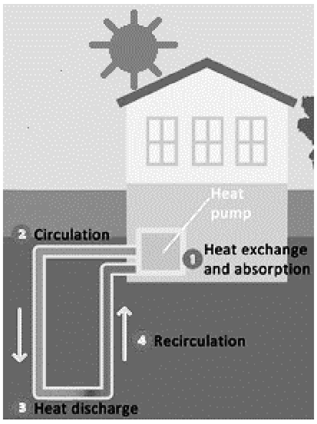

Fig. 16. Cooling mode

Geothermal Electricity

All geothermal energy plants literally uses super hot steam to run large turbines, coupled with generators to produce electricity. In the Geysers geothermal area, dry steam from the below ground is used directly in the steam turbine. Where as in some areas, super hot water is flashed in to steam within the power plant and that steam turns the turbine. There are another type of geothermal energy plants, which uses

The largest hot spring in the world is Frying Pan Lake in New Zealand. It's spans around nine acres and its average temperature is 131 degrees Fahrenheit.

different type of fluid instead of hydro thermal fluids to drive the turbine by using a heat exchanger to transfer heat from the water to special fluid.

Direct Dry Steam

Steam plants use hydrothermal fluids that are primarily steam. The steam goes directly to a turbine, which drives a generator that produces electricity. The steam eliminates the need to burn fossil fuels to run the turbine. (Also eliminating the need to transport and store fuels) This is the oldest type of geothermal power plant. It was first used at Lardarello in Italy in 1904. These plants emit excess steam and very minor amounts of gases.

They work by piping hot steam from underground reservoirs directly into turbines from geothermal reservoirs, which power the generators to provide electricity. After powering the turbines, the steam condenses into water and is piped back into the earth via the injection well.

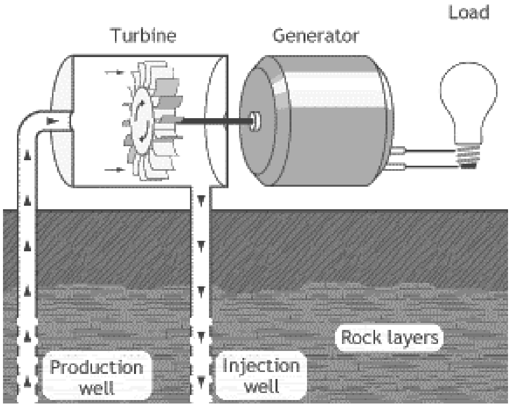

Fig. 17. Direct Dry Steam

Flash and Double Flash Cycle

Hydrothermal fluids above 360°F (182°C) can be used in flash plants to make electricity. Fluid is sprayed into a tank held at a much lower pressure than the fluid, causing some of the fluid to rapidly vaporize, or "flash." The vapor then drives a turbine, which drives a generator. If any liquid remains in the tank, it can be flashed again in a second tank (double flash) to extract even more energy. Flash steam plants differ from dry steam because they pump hot water, rather than steam, directly to the surface. These flash steam plants pump hot water at a high pressure from below the earth into a “flash tank” on the surface.

The flash tank is at a much lower temperature, causing the fluid to quickly “flash” into steam. The steam produced powers the turbines. The steam is cooled and condensed into water, where it is pumped back into the ground through the injection well.

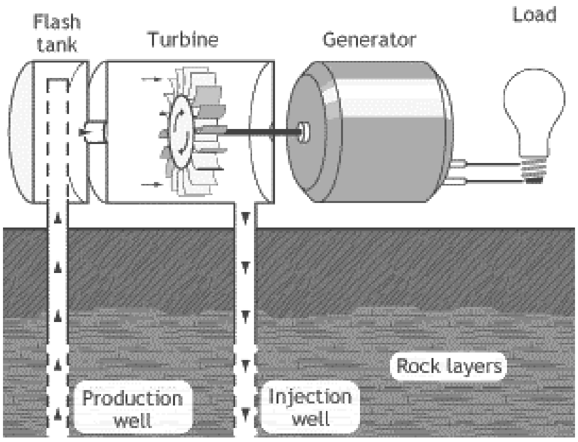

Fig. 18. Flash and Double Flash Cycle

Geothermal energy produces 0.03% of the emissions that coal produces and .05% of the emissions that natural gas produces.

Binary Cycle

Most geothermal areas contain moderate-temperature water (below 400°F). Energy is extracted from these fluids in binary-cycle power plants. Hot geothermal fluid and a secondary (hence, "binary") fluid with a much lower boiling point than water pass through a heat exchanger. Heat from the geothermal fluid causes the secondary fluid to flash to vapour, which then drives the turbines. Because this is a closed-loop system, virtually nothing is emitted to the atmosphere. Moderate-temperature water is by far the more common geothermal resource, and most geothermal power plants in the future will be binary-cycle plants.

In these binary cycle plants, the main difference is that the water or steam from below the earth never comes in direct contact with the turbines. Instead, water from geothermal reservoirs is pumped through a heat exchanger where it heats a second liquid—like isobutene (which boils at a lower temperature than water.) This second liquid is heated into steam, which powers the turbines that drives a generator. The hot water from the earth is recycled into the earth through the injection well, and the second liquid is recycled through the turbine and back into the heat exchanger where it can be used again.

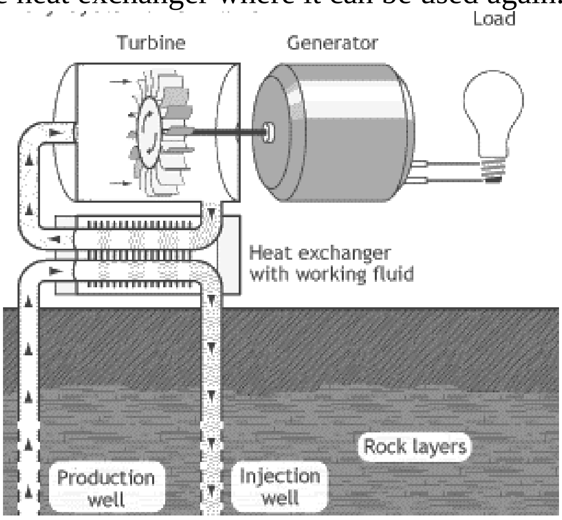

Fig. 19. Binary Cycle

Mini/micro hydro power: Classification of hydropower schemes

The hydroelectric power plants may be classified according to:-

A. Classification According to the Extent of Water Flow Regulation Available
   i. Run off river power plants without pondage
   ii. Run off river power plants with pondage
   iii. Reservoir power plants
B. Classification According to Availability of Water Head
   i. Low Head
   ii. Medium Head
   iii. High Head
C. Classification According to Type of Load Supplied
   i. Base Load
   ii. Peak Load
   iii. Pumped storage plants for the peak load
D. Classification of Hydroelectric Power Plants Based on Installed Capacity.
   i. Large hydro
   ii. Medium hydro
   iii. Small hydro
   iv. Mini hydro
   v. Micro hydro
   vi. Pico hydro

A. Classification According to the Extent of Water Flow Regulation Available

As of 31 March 2020, India's installed utility-scale hydroelectric capacity was 45,699 MW, or 12.35% of its total utility power generation capacity.

i. Run off river power plants without pondage: In this type of hydroelectric power plant, water is not available all the time. So this type of power station is not suitable for constant steady load. There is no pondage or storage facility available in such type of power plant. Plant is placed in such a area, where water is coming directly from the river or pond. This type of hydroelectric power plant is called run off power plant without pondage. Plant produces hydro electricity only when water is available. This type of plant cannot be used all the time. During high flow and low load period, water is wasted and the lean flow periods the plant capacity is very low. Power development capacity of this type of plant is very low and it produces power incidentally. The development cost of such a plant is relatively cheaper than full-time power development hydro electric power plant. Though it is not used for constant steady load supply, it's objective is to generate electricity by using excessive flow of water during flood or rainy season or whatever flow is available to save some sort of our natural resource of energy such as coal etc., diesel etc.

ii. **Run off river power plants with pondage:** This type of plant is used to increase the capacity of pond. The pond is used as a storage water of hydro electric power plant. Increased pond size means more water is available in the plant, so such type of hydro electric power plant is used during fluctuating load period depending on the size of pondage. On a certain limitation, this type of power plant can be a part of load curve and it is more reliable than a hydro plant without pondage. Such type of plant is suitable for both base load or peak load period. During high flow period, this plant is suitable for base load and during lean flow period it is used to supply peak loads only. During high flood period, the flood should not raise tail-race water level. Such types of power plant save conservation of coal.

iii. **Reservoir power plants:** Most hydroelectric power plant in the world is reservoir power plant. In this type of plant, water is stored behind the dam and water is available throughout the year even in dry season. This type of power plant is very efficient and it is used during both base and peak load period as per requirement. It can also take a part of load curve in grid system.

B. Classification According to Availability of Water Head

Though there is no rule regarding water head height but below 30 meters is considered as low head, above 30 meters to 300 meters is called medium head and above 300 meters is known as high head hydro electric power plant.

i. **Low head hydro electric power plant:** Francis, Kaplan or propeller turbines are used for this type of hydro electric power plant. To create a low head, dam construction is essential. Water resource level i.e. river or pond is placed just behind the dam to create a necessary water head level. Water is led to the turbine through the penstock. This type of hydro plant is located just below the dam and it creates useful water level as well. No surge tank is required for this plant, dam itself discharges the surplus water from the river. Science head is low, huge amount of water is required for desire output. That's why large diameter and low length pipe is used for this plant. Such types of power plant use low speed and large diameter type generators.

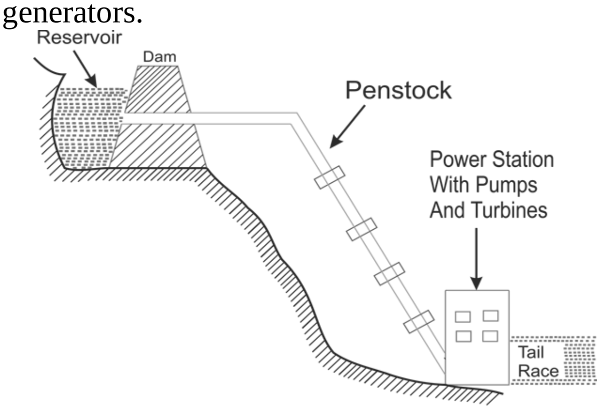

Fig. 20. Low head hydro electric power plant

ii. **Medium head hydro electric power plant:** In these power plants, the river water is usually tapped off to a forebay on one bank of the river as in case of a low head plant. From forebay the water is led to the turbines through penstocks. The forebay provided at the beginning of penstock serves as a water reservoir for such power plants. In these plants, water is usually carried in open channel from main reservoir to the forebay and then to the turbines through the penstock. The forebay itself serves as the surge tank in this case. In these plants horizontal shaft Francis, propeller or Kaplan turbines are used.

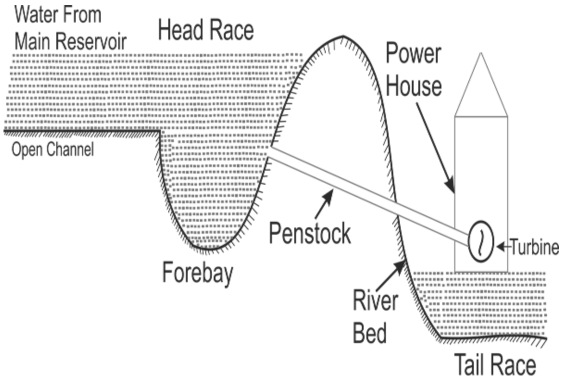

Fig. 21. Medium head hydro electric power plant

As of 31 January 2020, Tamilnadu's installed capacity of Hydro power is 2,178 MW

iii. **High head hydro electric power plant:** The head of this power plant is more than 300 meters. A dam is constructed in such a level that maximum reserve water level is formed. A pressure tunnel is constructed which is connected to the valve house. Water is coming from reservoir to valve house via this pressure tunnel and it is the starting of penstock. A surge tank is also constructed before valve house which reduces water hammering to the penstock in case of sudden closing of fixed gates of water turbine. Surge tank also store some extra water which is useful for picking load demand because it will serve extra water to the turbine. Valve house consists of a main valve sluice valves and automatic isolating valves, which operate on bursting of penstock and cut off further supply of water to penstock. The penstock is a connecting pipe which supplies water from valve house to turbine. For high head more than 500 meters, Pelton wheel turbine is used for lower head Francis turbine.

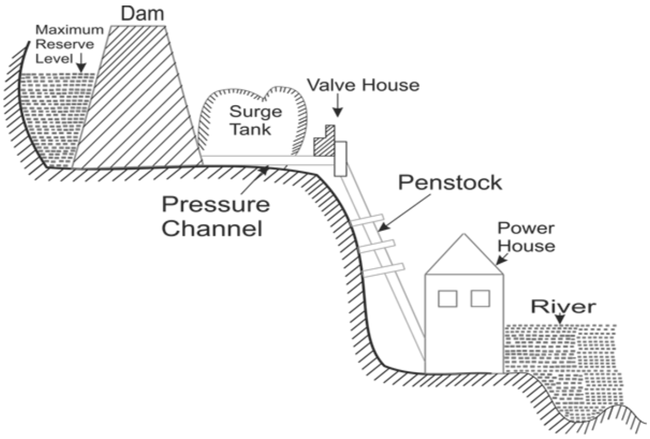

Fig. 22. High head hydro electric power plant

C. According to the types of load supply

i. **Base load hydro electric power plant:** This is a large capacity power plant. This plant work as a base portion of load curve of power system, that's why it is called base load plants. Base load plant is suitable for constant load. load factor of this plant is high and it is performed as a block load. Run off river plants without pondage and reservoir plants are used as base load plants.

ii. **Peak load hydro electric power plant:** This plant is suitable for peak load curve of power system. when demand is high, this type of plant do their job very well. Run off river plants with pondage can be employed as peak load plants. If water supply is available, it generates large portion of load at a peak load period. It needs huge storage area. Reservoir plants can be used as peak load plants. This type of plant can serve power throughout the year.

iii. **Pumped storage hydro electric power plant for the peak load:** This is unique design of peak load plants. Here two types of water pond is used, called upper head water pond and tail water pond. Two water ponds are connected each other by a penstock. Main generating pumping plant is lower end. During the off load period, surplus energy of this plant is utilized to pumping the lower head pond water to upper head pond water. This extra water is used to generate energy at pick load periods. By doing this arrangement, same water is used again and again. Extra water is required only to take care of evaporation and seepage.

D. Classification of Hydroelectric Power Plants Based on Installed Capacity.

i. Large hydro	Exceeding 100 MW and usually feeding into a large grid.
ii. Medium hydro	15 – 100 MW and usually feeding into a grid
iii. Small hydro	1-15 MW and usually feeding into the grid
iv. Mini hydro	100 kW – 1 MW either isolated or feeding into the grid
v. Micro hydro	100 kW – 1 MW usually provides power for a small community or rural industry in remote areas away from the grid
vi. Pico hydro	From few hundred watts upto 5 kW

Classification of water turbine

Water turbines or hydraulic turbines are rotary prime movers which convert the potential or kinetic energy of water into mechanical energy in the form of rotational energy. A water turbine when coupled with an electrical generator produces electrical energy. It is one of the most suitable means of electric power generation system. It is estimated that about 20% of the total electric power in the world comes from hydro power plants. The only limitation is that it can be operated through the turbine, if there is a continuous flow of water.

In the areas which are surrounded by hills and mountains known as catchment area, water turbine systems can be installed. The small rivers form a big river to flow. By constructing a machinery dam across flowing rivers, a water reservoir can be formed. The water is carried from the reservoir to water turbine by a long pipe known as penstock and the hydraulic energy possessed by water is converted into mechanical energy and then to electrical energy.

The main classification of water turbines depend upon the type of action of the water on the turbine. These are mainly categorized into two categories.

i. **Impulse turbine:** In this case, the total potential energy of water is converted to kinetic energy in the nozzles. The impulse due to the high velocity jet coming out of the nozzles is used to turn the turbine wheel. The pressure inside the turbine is atmospheric. It is found suitable when the available potential energy is high and flow available is comparatively low. E.g. Pelton wheel

ii. **Reaction Turbines:** In these turbines, water enters the runner under pressure having some velocity head. While the water passes over the runner, its pressure is gradually converted into velocity head until its pressure is reduced to atmospheric pressure along with the change in K.E based on its absolute velocity.

Water turbines are classified on various parameters:

A. Based on Direction of Flow of Water Through the Runner:
   i. Radial flow:
      - Inward radial flow: E.g. Old francis turbine, Girard radial flow turbine, etc.
      - Outward radial flow: E.g Fourneyron turbine
   ii. Axial Flow Turbines:
      These are also called as parallel flow turbines. E.g Kaplan and propeller turbines
   iii. Mixed Flow Turbines:
      E.g Modern francis turbine

B. Based on Available Head and Discharge

Reaction turbines are used for low and medium heads.
   i. Medium Head Turbines:
      - 60m-250m- Medium flow rate E.g. Modern Francis
   ii. Low Head Turbines:
      - Head<60m- Large flow rates E.g. Axial flow Kaplan and propeller turbines.

C. Based on Specific Speed, Ns:
   - Pelton turbine, Ns=9 to 35
   - Francis turbine, Ns=50 to 250
   - Kaplan turbine, Ns=250 to 850

D. Based on position of Shaft
- Horizontal shaft type
- Vertical shaft type

Tehri Dam Hudro Electric project is the highest Hydal project in India which generates 2400MW capacity of power and 575m in length

a) Impulse Turbine: In an impulse turbine, the total potential energy available with water is fully converted into kinetic energy by means of nozzle. The turbine is quite suitable for high head and low discharge available with it. In this type of turbine, there is a water nozzle which converts the total potential energy available with water into kinetic energy. Water is discharged from the nozzle in the form of water jet and high kinetic energy.

The high kinetic energy jet is made to strike on a series of curved buckets or blades mounted on the periphery of a wheel which is placed on the turbine shaft. This is the type of impulse turbine which requires high head and less water availability.

Pelton wheel is one of the most commonly used impulse turbines. A Pelton turbine or Pelton wheel is a type of hydro turbine (specifically an impulse turbine) used frequently in hydroelectric plants. These turbines are generally used for sites with heads greater than 300 meters.

The operation of a Pelton turbine is fairly simple. In this type of turbine, high speed jets of water emerge from the nozzles that surround the turbine. These nozzles are arranged so the water jet will hit the buckets at splitters, the center of the bucket where the water jet is divided into two streams. The two separate streams then flow along the inner curve of the bucket and leave in the opposite direction that it came in. This change in momentum of the water creates an impulse on the blades of the turbine, generating torque and rotation in the turbine.

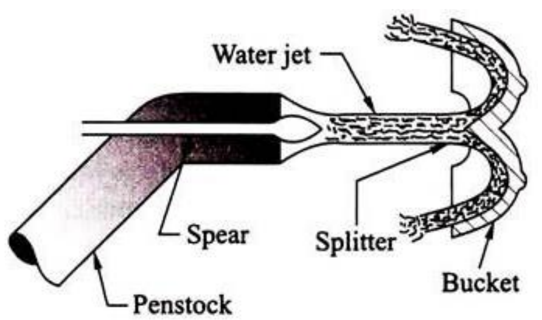

Fig.23. Discharge of water from nozzle

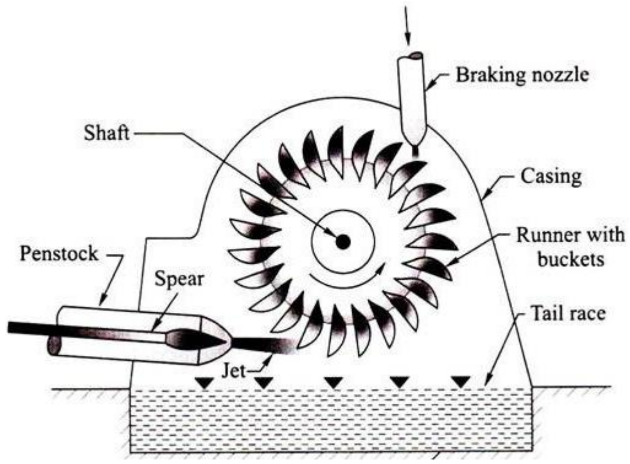

Fig. 24. Pelton turbine

b) Reaction Turbine:

Reaction turbine is quite suitable for low head and high discharge. The water supplied to the reaction turbine possesses both pressure as well as kinetic energy. The total pressure energy is not fully converted to kinetic energy initially, as it happens in impulse turbine. The water flows first of all to guide blades which supply water in a proper direction and then it is passed through moving blades which are mounted on the wheel. A part of the pressure energy of water, when flowing through the moving blades, is converted into kinetic energy which is absorbed by the turbine wheel. The water leaving the moving blades is at low pressure. Thus, there is a difference in pressure between the entrance and exit of the moving blades.

Due to this difference in pressure, there is an increase in kinetic energy and hence a reaction is developed in opposite direction which acts on the moving blades. The rotation of the wheel is set up in opposite direction. In case of reaction turbine, the water is discharged at the tail race through draft tube.

i. Francis Turbine:

Francis turbine is also called medium head turbine. In this turbine, water flows radially and finally discharges axially. Hence, this turbine is also called mixed flow turbine. It consists of a spiral casing, inside which there are large numbers of stationary guide blades/guide vanes. They are fixed all around the circumference of an inner ring of moving vanes called runner. The runner is fixed on the turbine shaft.

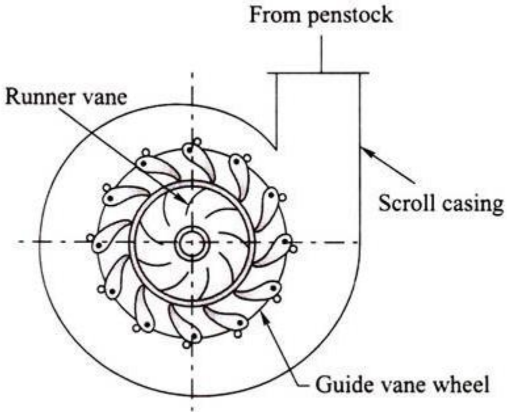

Fig. 25. Components of Franics Turbine

The runner consists of a series of curved blades numbering 16-24. The runner vanes are so well-designed in shape that water enters the runner radially and leaves the runner axially. Water with pressure energy enters through the passage into the casing radially through the guide vanes. It flows from the outer periphery of the runner in the radial direction over the moving vanes and finally it is discharged at the centre axially at low pressure. The kinetic energy is imparted to the runner when it flows over the moving vanes which produce rotation to the shaft. Water is then discharged at lower pressure through a diverging conical tube known as draft tube, which is fitted at the centre of the runner.

The draft tube converts kinetic energy into pressure energy and hence the pressure available at the exit of draft tube is the atmospheric pressure. The other end of the tube is immersed in water known as tail race.

ii. Kaplan Turbine:

Kaplan turbine is also called as low head reaction turbine which is suitable for comparatively low discharge and is known as axial flow reaction turbine. It is similar to Francis turbine. It consists of a spiral casing in which there are large numbers of stationery guide vanes. They are fixed all around the circumference of an inner ring of moving vanes called runner.

High-pressure water enters the turbine casing and enters into the guide vanes. The water strikes the runner and flows axially through guide vanes and imparts kinetic energy to the runner which produces rotation. The water is then discharged at the centre of the runner in axial direction into the draft tube. The outlet of the draft tube is immersed in water. The construction of Kaplan turbine is just similar to Francis turbine except the shape of runner. The runner of Kaplan turbine has only 3, 4, or 6 blades, either fixed or adjustable on hub The latter is known as propeller turbine.

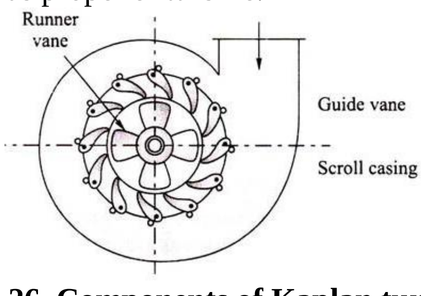

Fig. 26. Components of Kaplan turbine

Turbine theory

Like steam turbines, water turbines may depend on the impulse of the working fluid on the turbine blades or the reaction between the working fluid and the blades to turn the turbine shaft which in turn drives the generator. Several different families of turbines have been developed to optimise the performance for particular water supply conditions.

Turbine Power Output

The turbine converts the kinetic energy of the working fluid, in this case water, into rotational motion of the turbine shaft. Swiss mathematician Leonhard Euler showed in 1754 that the torque on the shaft is equal to the change in angular momentum of the water flow as it is deflected by the turbine blades and the power generated is equal to the torque on the shaft multiplied by the rotational speed of the shaft.

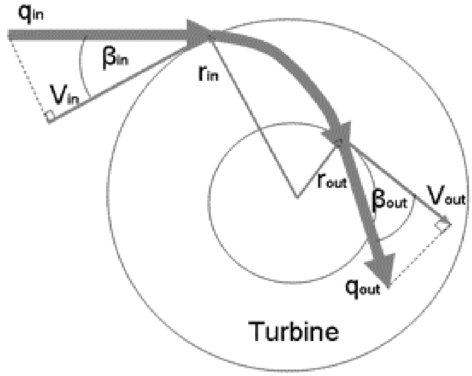

Fig.27. Turbine power

Torque $T = \rho Q(r_{in}V_{in} - r_{out}V_{out})$
Power $P = \omega T = \omega\rho Q(r_{in}q_{in}\cos\beta_{in} - r_{out}q_{out}\cos\beta_{out})$
Q = Fluid flow rate
P = Fluid density
q = Fluid velocity
β = incident angle
V = Tangential fluid velocity
V = qcosβ
r = turbine radius
ω = turbine rotation speed
T = torque
P = Power output

In most types of power generation the kinetic energy of a moving fluid is converted by a turbine into the rotational motion of a shaft. The turbine blades deflect the fluid and the rate of change of angular momentum of the fluid is equal to the net torque on the shaft.

A fluid of density ρ flowing through the turbine with a volume flow rate Q has a mass flow per second given by ρQ. Suppose that the fluid enters at a radius r_1 with a circumferential velocity v_{t1} and exists at a radius r_2 with a circumferential v_{t2}.

The torque exerted on the turbine is equal to the rate of change of angular momentum. Thus

$T = \rho Q(r_1Vt_1 - r_2V_{t2})$ (1)

The power delivered to a turbine rotating with angular velocity ω is given by

$P = \omega T$ (2)

Substituting for T from eqn 1 in eqn 2 yields the power as

$P = \omega\rho Q(r_1v_{t1} - r_2v_{t2})$ (3)

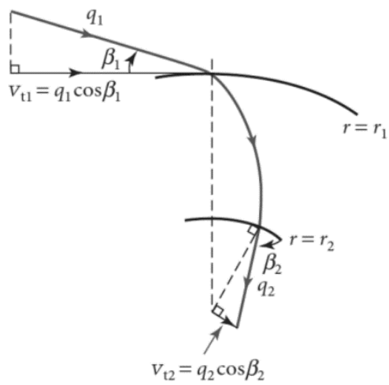

Fig. 28. Triangle diagram

Writing the tangential velocity in the form $v_t = q\cos\beta$, where q is the total quality of the fluid and β is the angle between the direction of motion of the fluid and the tangent to the wheel,

$P = \omega\rho Q(r_1q_1\cos\beta_1 - r2q2\cos\beta_2)$ (4)

Eqn 4 is known as the Euler's turbine equation. The importance of Euler's turbine equation is that the details of the flow inside the turbine are irrelevant. All that matters is the total change in the angular momentum of the fluid between the inlet and the outlet. The maximum torque is achieved when the fluid flows out in the radial direction, i.e when cos $\beta_2 = 0$ Eqn 4 reduces to

$$P = \omega\rho Q r_1 q_1 \cos\beta_1 \quad (5)$$

Essential components of hydroelectric system

The main components of a Hydro electric power plant are given below.

1. Power House
2. Penstock
3. Water Reservoir
4. Water Turbine or Hydraulic Turbine (Prime mover)
5. Spillway
6. Dam
7. Surge Tank
8. Draft Tube
9. Tail Race Level
10. Gate
11. Pressure Tunnel

1. **Power House:** Power house contains generator, water turbine, with transformer and control room. When the water rushes through the turbine, it turns the turbine shaft, which is attached to electric generator. Generator has a rotary electromagnet called as rotor with a stationary element called as stator. Rotors generates magnetic fields that create an electric charge in stator. Charge is transmitted as electricity. Step up transformer increase the voltage coming from the stator. Electricity is than dispersed through power lines.
2. **Penstock:** Penstock pipe is use to convey water from the dam to hydraulic turbine. Penstock pipes are made of steel or reinforced material. Turbine is installed at a lesser level from the dam. Penstock is connected by a gate valve at inlet to totally close the water supply. It has a control valve to control water flow rate into turbine.
3. **Water Reservoir:** In reservoir, water is collected at the catchment area during raining period and is stored at the dam. Catchment area obtains its water from rains and streams. Permanent accessibility of water is a essential necessity for hydroelectric power plant. The stage of water surface in reservoir is call Head water level. Eater head presented for power generation depends on reservoir height.
4. **Water Turbine or Hydraulic Turbine (Prime mover):** Hydraulic turbines change energy of water into mechanical energy. Mechanical energy (revolution) accessible on turbine shaft is attached to shaft of an electric generator were electricity is created. Water after performing work on turbine blade is discharge through draft tube. Prime movers which are in regular use are Francis turbine, Pelton wheel, Kaplan turbine.
5. **Spillway:** Overload addition of water endanger the strength of dam construction. Also in order to avoid the overflow of water out of dam mainly during raining seasons spillways are provided. This prevents the increase of water level in dam. Spillways are passage which allows excess water to flow to a dissimilar storage area away from the dam.
6. **Dam:** The function of dam is to store water and control the outgoing flow of water. Dam helps to store all incoming water. It also helps to raise the head of water. In order to make a necessary quantity of power, it is needed that an enough head is available.
7. **Surge Tank:** Surge tank is a little tank or reservoir in which water level rise or fall due to unexpected changes in pressure. There might be rapid enhancement of pressure in penstock pipe due to rapid backflow of water, as load on turbine is condensed. This rapid rise of pressure in penstock pipe is identified as water hammer.

   Surge tank is initiated from the dam with the turbine and serves the follow reason:

   - To decrease the distance among the free water surface in dam and turbine, thus dropping the water hammer cause. Otherwise, penstock will damage the water effect.

- To provide as a supply tank to turbine while the water in pipe accelerates during amplified load situation and as a storage tank while the water is decelerating during reduced load situation.

8. **Draft Tube:** Draft tube is joined to outlet of turbine. It changes the kinetic energy available in water in pressure energy in diverge section. Therefore, it retains a pressure of just above the atmospheric level at the end of draft tube to travel the water into a tail race. Water from the tail race is free for irrigation.
9. **Tail Race Level:** Tail race is a water path to guide the water discharged from the turbine to river or canal. Water held in the tail race is call Tail race water level.
10. **Gate:** Gate is use to adjust or control the flow of water from the dam.
11. **Pressure Tunnel:** It carries the water from the reservoir to surge tank.

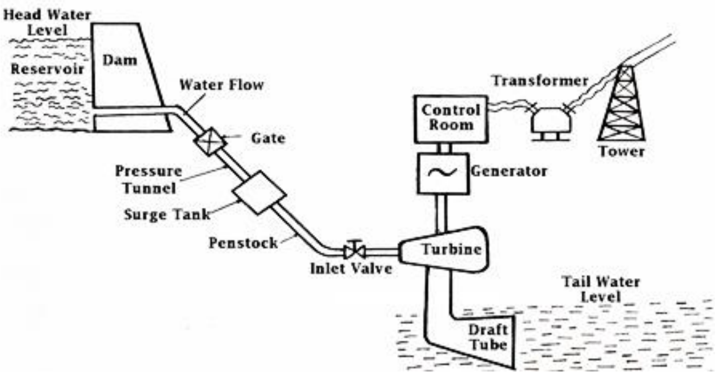

Fig. 29. Components of Hydro power plant