ME8792 - POWER PLANT ENGINEERING

UNIT- I

COAL BASED THERMAL POWER PLANTS

Rankine cycle - improvisations, Layout of modern coal power plant, Super Critical Boilers, FBC Boilers, Turbines, Condensers, Steam & Heat rate, Subsystems of thermal power plants – Fuel and ash handling, Draught system, Feed water treatment. Binary Cycles and Cogeneration systems.

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RANKINE CYCLE

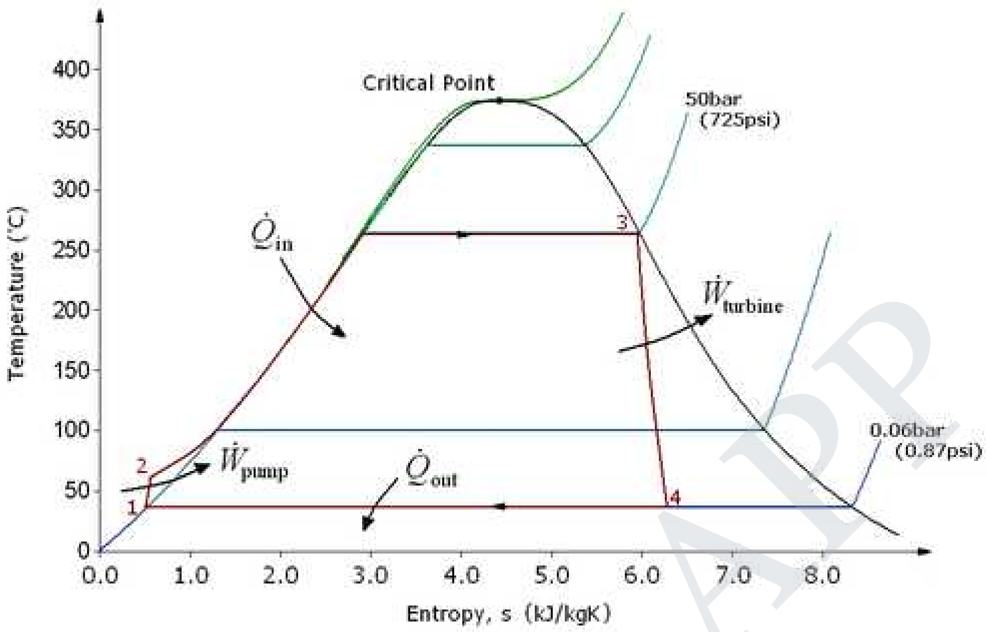
The **Rankine cycle** is a model used to predict the performance of steam turbine systems. It was also used to study the performance of reciprocating steam engines. The Rankine cycle is an idealized thermodynamic cycle of a heat engine that converts heat into mechanical work while undergoing phase change. The heat is supplied externally to a closed loop, which usually uses water as the working fluid. It is named after William John Macquorn Rankine, a Scottish polymath and Glasgow University professor.

There are four processes in the Rankine cycle. These states are identified by numbers (in brown) in the above T–s diagram.

- **Process 1–2**: The working fluid is pumped from low to high pressure. As the fluid is a liquid at this stage, the pump requires little input energy.
- **Process 2–3**: The high-pressure liquid enters a boiler, where it is heated at constant pressure by an external heat source to become a dry saturated vapour. The input energy required can be easily calculated graphically, using an enthalpy–entropy chart (h–s chart, or Mollier diagram), or numerically, using steam tables.
- **Process 3–4**: The dry saturated vapour expands through a turbine, generating power. This decreases the temperature and pressure of the vapour, and some condensation may occur. The output in this process can be easily calculated using the chart or tables noted above.
- **Process 4–1**: The wet vapour then enters a condenser, where it is condensed at a constant pressure to become a saturated liquid.

In an ideal Rankine cycle the pump and turbine would be isentropic, i.e., the pump and turbine would generate no entropy and hence maximize the net work output. Processes 1–2 and 3–4 would be represented by vertical lines on the T–s diagram and more closely resemble that of the Carnot cycle. The Rankine cycle shown here prevents the vapor ending up in the superheat region after the expansion in the turbine, [1] which reduces the energy removed by the condensers.

The actual vapor power cycle differs from the ideal Rankine cycle because of irreversibilities in the inherent components caused by fluid friction and heat loss to the surroundings; fluid friction causes pressure drops in the boiler, the condenser, and the piping between the components, and as a result the steam leaves the boiler at a lower pressure; heat loss reduces the net work output, thus heat addition to the steam in the boiler is required to maintain the same level of net work output.



$$\eta_{th} = \frac{W_T - W_P}{Q_{in}} = \frac{(h_1 - h_2) - (h_4 - h_3)}{(h_1 - h_4)} = 1 - \frac{(h_2 - h_3)}{(h_1 - h_4)}$$

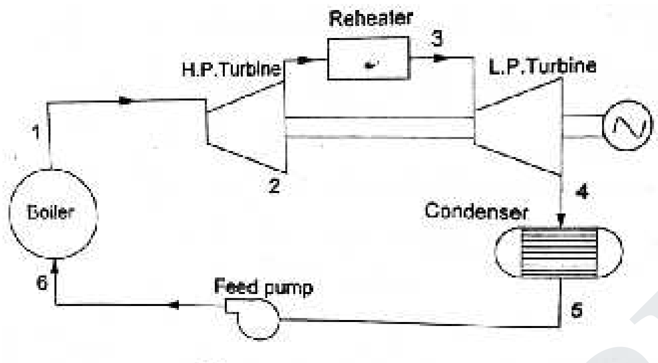
IMPROVISATIONS OF RANKINE CYCLE

Rankine cycle efficiency can be improved by using the following three methods.

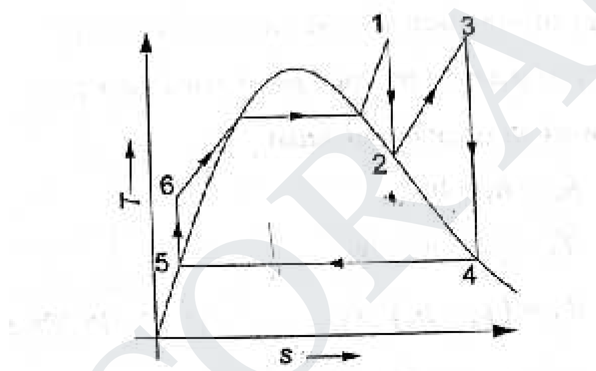
1. Reheating
2. Regeneration
3. Combined reheating and regeneration

Reheat Rankine Cycle

In the reheat cycle, the steam is extracted from a suitable point in the turbine and it is reheated with the help of flue gases in the boiler furnace.



Reheat Rankine cycle

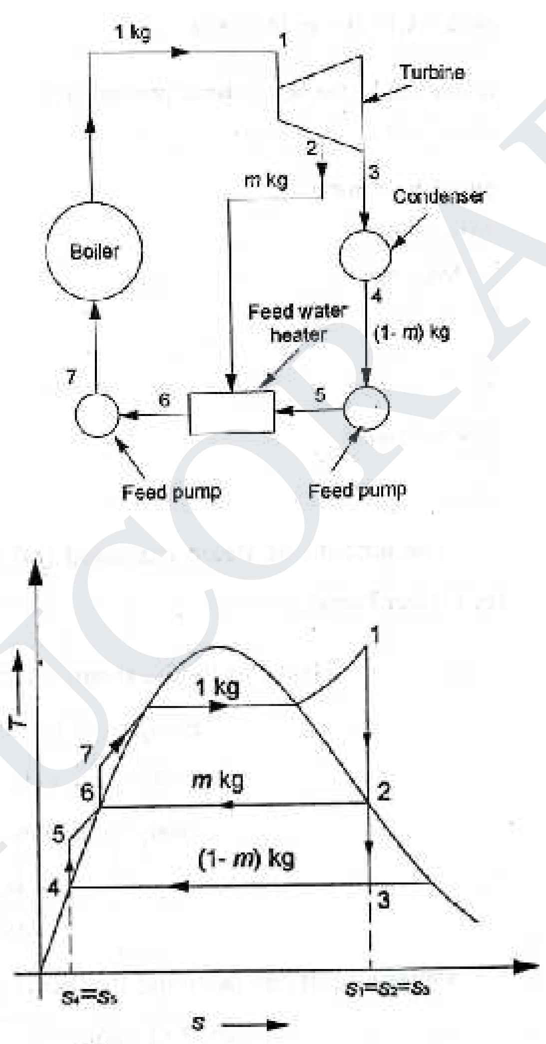


T-s diagram for reheat Rankine cycle

The purpose of a reheating cycle is to remove the moisture carried by the steam at the final stages of the expansion process. In this variation, two turbines work in series. The first accepts vapor from the boiler at high pressure. After the vapor has passed through the first turbine, it re-enters the boiler and is reheated before passing through a second, lower-pressure, turbine. The reheat temperatures are very close or equal to the inlet temperatures, whereas the optimal reheat pressure needed is only one fourth of the original boiler pressure. Among other advantages, this prevents the vapor from condensing during its expansion and thereby reducing the damage in the turbine blades, and improves the efficiency of the cycle, because more of the heat flow into the cycle occurs at higher temperature. The reheat cycle was first introduced in the 1920s, but was not operational for long due to technical difficulties. In the 1940s, it was reintroduced with the increasing manufacture of high-pressure boilers, and eventually double reheating was introduced in the 1950s. The idea behind double reheating is to increase the average temperature. It was observed that more than two stages of reheating are unnecessary, since the next stage increases the cycle efficiency only half as much as the preceding stage. Today, double reheating is commonly used in power plants that operate under supercritical pressure.

REGENERATIVE CYCLE

SINGLE STAGE REGENERATIVE RANKINE CYCLE



The regenerative Rankine cycle is so named because after emerging from the condenser (possibly as a subcooled liquid) the working fluid is heated by steam tapped from the hot portion of the cycle. On the diagram shown, the fluid at 2 is mixed with the fluid at 4 (both at the same pressure) to end up with the saturated liquid at 7. This is called "direct-contact heating". The Regenerative Rankine cycle (with minor variants) is commonly used in real power stations.

Another variation sends *bleed steam* from between turbine stages to feedwater heaters to preheat the water on its way from the condenser to the boiler. These heaters do not mix the input steam and condensate, function as an ordinary tubular heat exchanger, and are named "closed feedwater heaters".

Regeneration increases the cycle heat input temperature by eliminating the addition of heat from the boiler/fuel source at the relatively low feedwater temperatures that would exist without regenerative feedwater heating. This improves the efficiency of the cycle, as more of the heat flow into the cycle occurs at higher temperature.

LAYOUT OF MODERN COAL POWER PLANT

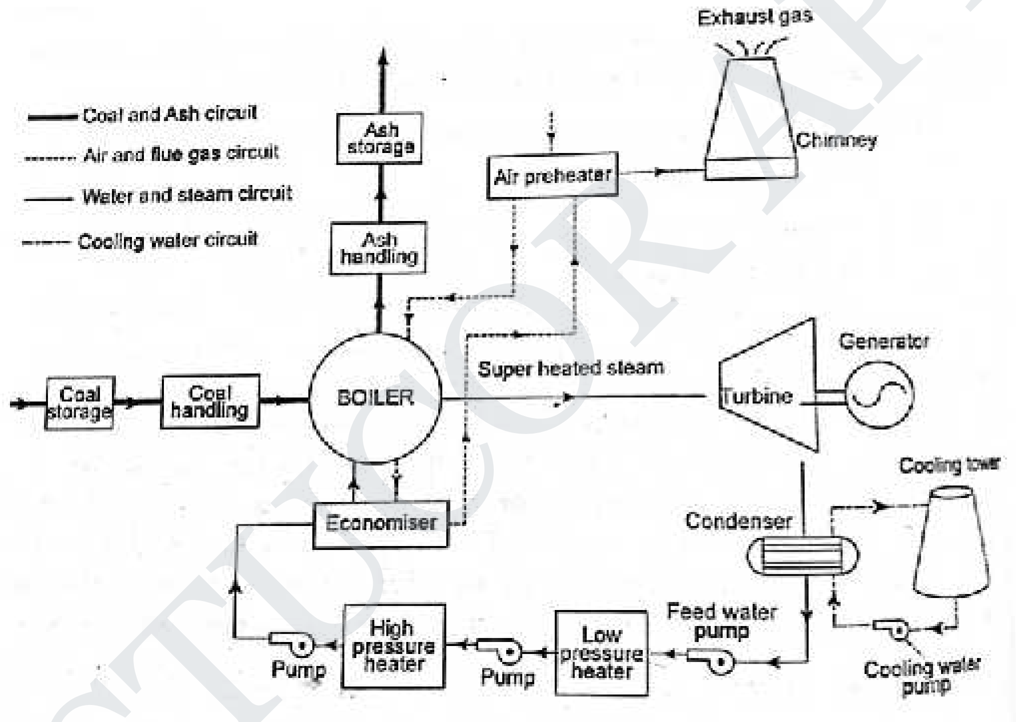


Figure 1.1 Layout of steam or thermal power plant

The layout of modern steam power plant comprises of four main circuits namely

1. Coal and ash circuit
2. Air and gas circuit
3. Feed water and steam flow circuit
4. Cooling water circuit

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Advantages

1. They respond rapidly to the load variations without difficulty.
2. Can be located very conveniently near to load centre.
3. Transmission cost is reduced.
4. Less space is required compared to hydel power plants
5. Cheaper in production and initial cost compared to diesel power stations.

Disadvantages

1. Maintenance and operating cost are high.
2. Plant construction time is more.
3. Very large quantity of water is required.
4. Coal handling is a tedious process.

BOILERS

- A boiler is a closed vessel in which the steam is generated from water by applying heat.
- A boiler or steam generator is used where a source of steam is needed.
- The boilers are mainly used in mobile steam engines such as
    1. Steam locomotives
    2. Portable engines
    3. Steam powered road vehicles
    4. Industrial installations
    5. Power stations

Types of Boilers

1. **Fire tube boiler**

If the hot gas is passed through tubes and the water is circulated around tubes, it is called fire tube boiler.

Examples: Cochran boiler and Locomotive boiler

2. **Water tube boiler**

If the water is circulated through a large number of tubes and the hot gases pass around the tubes, it is called water tube boiler. Examples: Babcock and Wilcox boiler

3. **Low pressure and High pressure boiler**
   1. Low pressure boiler: Steam pressure range from 3.5 to 10 bar. Example: Cochran boiler
   2. High pressure boiler: Steam pressure greater than 25 bar and temperature of 500^{o}C. Examples: Babcock and Wilcox boiler.

SUPER CRITICAL BOILERS (SCB)

- It is a type of boiler which is operated at supercritical pressure and is frequently used in the production of electrical power.
- Working in the range of 125 bar and 510 ^{o}C to 300 bar and 660 ^{o}C.
- Once through boiler is the only type suited for super critical pressure or in other words once through boiler is a super critical boilers.

ONCE THROUGH BOILER

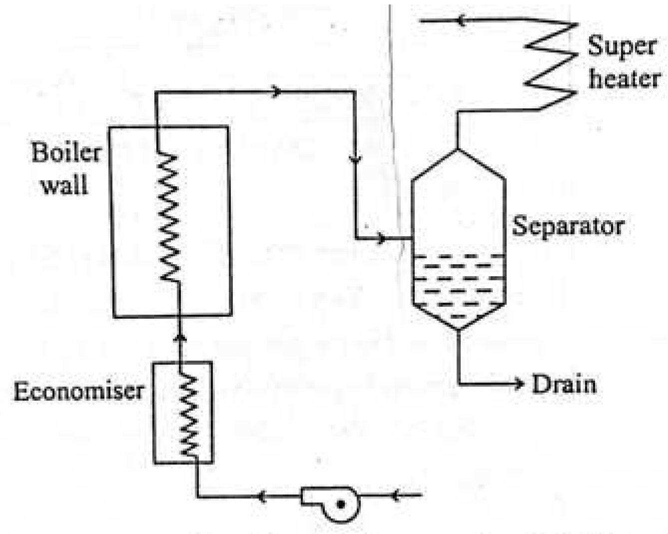
In once through boiler if the water is fed to the boiler, it will be fully converted into dry or superheated steam without any water content present in it.

Economizer

A common application of economizers in steam power plants is to capture the waste heat from boiler stack gases (flue gas) and transfer it to the boiler feed water. This raises the temperature of the boiler feed water, lowering the needed energy input, in turn reducing the firing rates needed for the rated boiler output.

Separator

A steam *separator*, sometimes referred to as a moisture *separator*, is a device for separating water droplets from steam.

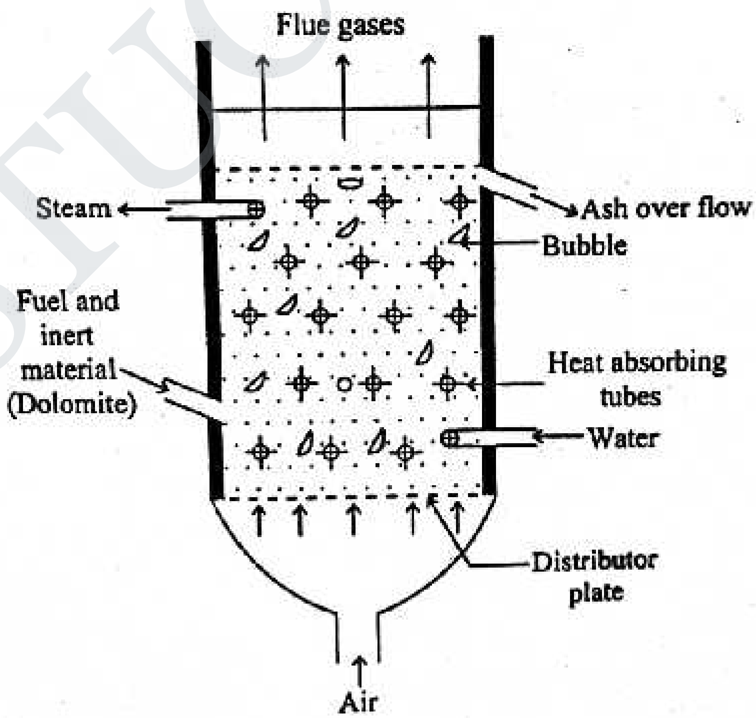


One through (or monotype) boiler

Advantages

1. Easy control of steam temperature.
2. Easy to adopt variable pressure operation.
3. Starting and cooling down of the boilers is fast.
4. It is smaller in size and weighs less.

FLUIDIZED BED COMBUSTION BOILERS (FBC BOILERS)



- When a gas is passed through a packed bed of finely divided solid particles, it experiences a pressure drop across the bed.
- When the velocity of the gas is increased further, at a stage the particles get suspended in the gas stream and the new packed bed becomes a fluidized bed. Burning of a fuel in such as state is known as fluidized bed combustion.

TYPES OF FBC

1. **Bubbling Fluidized Bed Boilers (BFB)**

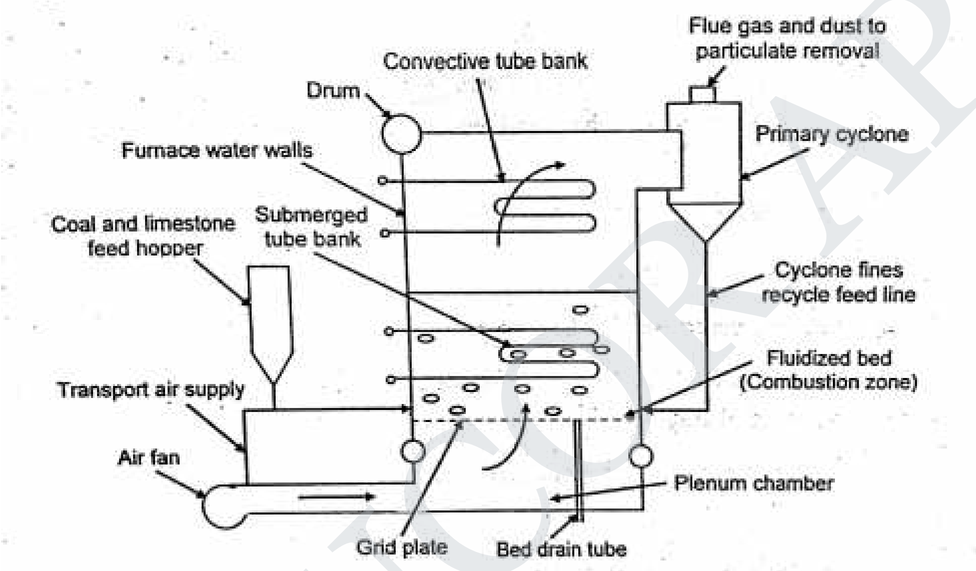
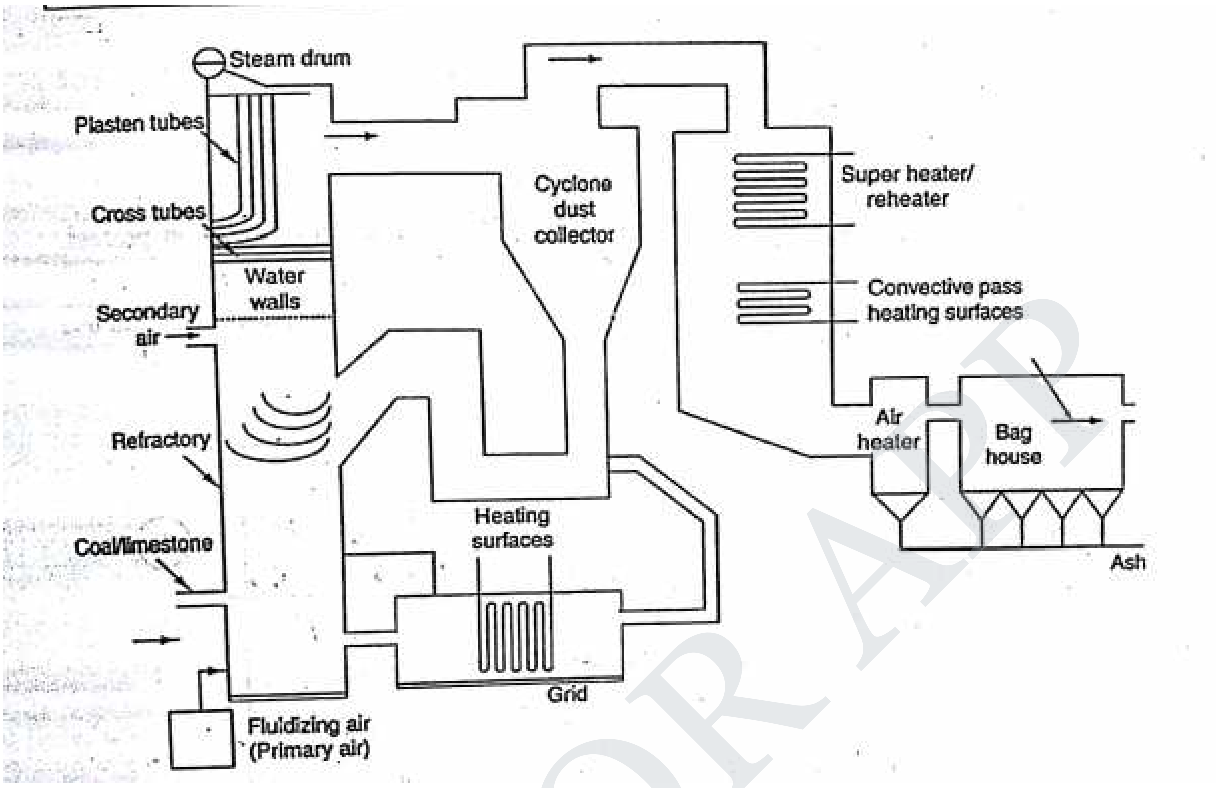


Figure 1.38 Bubbling fluidized bed boiler

Advantages of FBC boilers

1. Size is small hence capital costs are reduced.
2. Responds rapidly to changes In load demand.
3. Less pollution.
4. Combustion temperature can be controlled accurately.

2. Circulating Fluidized Bed Boilers (CFB)



Generally, CFBC consists of a boiler and a high-temperature cyclone. The intra-furnace gas velocity is as high as 4 to 8 m/s. A coarse fluidizing medium and char in the flue gas are collected by the high-temperature cyclone and recycled to the boiler. Recycling maintains the bed height and increases the denitration efficiency. To increase the thermal efficiency, a pre-heater for the fluidizing air and combustion air, and a boiler feed water heater, are installed. Most of the boiler technologies are manufactured overseas, mainly from Foster Wheeler, Lurgi, Steinmuller, ALSTOM, and Babcock & Wilcox.

STEAM TURBINES

- Steam turbine is a device which is used to convert the kinetic energy of steam into mechanical energy.

- The steam turbine depends completely on the dynamic action of steam. According to Newton's second law of motion, the force is proportional to the rate of change of momentum (mass x velocity).

- ❖ High velocity steam impinges on curved blades and its direction of flow is changed. It causes a changes in momentum and thus, the force developed drives the turbine shaft.
- ❖ The steam turbine has been used as a prime mover in all steam power plants.
- ❖ Now a days, a single steam turbine of 1000 MW capacity is built in many countries.

CLASSIFICATION OF STEAM TURBINES

1. On the basis of method of steam expansion
   a. Impulse turbine
   b. Reaction turbine
   c. Combination of impulse and reaction turbine

2. On the basis of number of stages
   a. Single stage turbines
   b. Multi-stage turbines

3. On the basis of steam flow directions
   a. Axial turbine
   b. Radial turbine
   c. Tangential turbine
   d. Mixed flow turbine

4. On the basis of pressure of steam
   a. Low pressure turbine
   b. Medium pressure turbine
   c. High pressure turbine

IMPULSE TURBINE

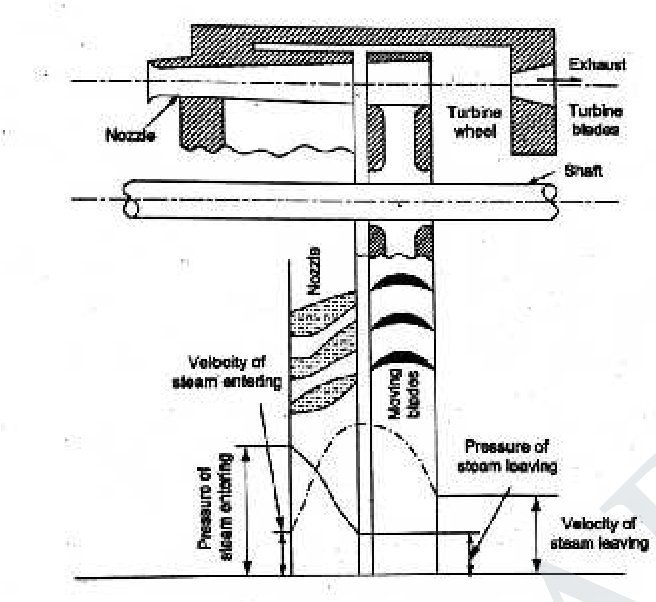


Figure 1.45 Simple impulse turbine

- In impulse turbine, the steam at high pressure and temperature with low velocity is expanded through nozzles where the pressure reduces and the velocity increases.
- Nozzles are stationary and blades are rotating or moving.
- The high velocity jet of steam from the nozzle impinges on blades fixed on a rotor. It causes the change in momentum and the force developed due to this drives the turbine rotor.

REACTION TURBINE

- In reaction turbines, the steam expands both in fixed and moving blades continuously as the steam passes over them.
- As it expands, there is some increase in steam velocity thereby resulting the reaction force which is used to drive the turbine rotor.
- Fixed blades guide the steam as well as allow it to expand in high velocity. Moving blades converts the kinetic energy of the steam into useful mechanical energy.

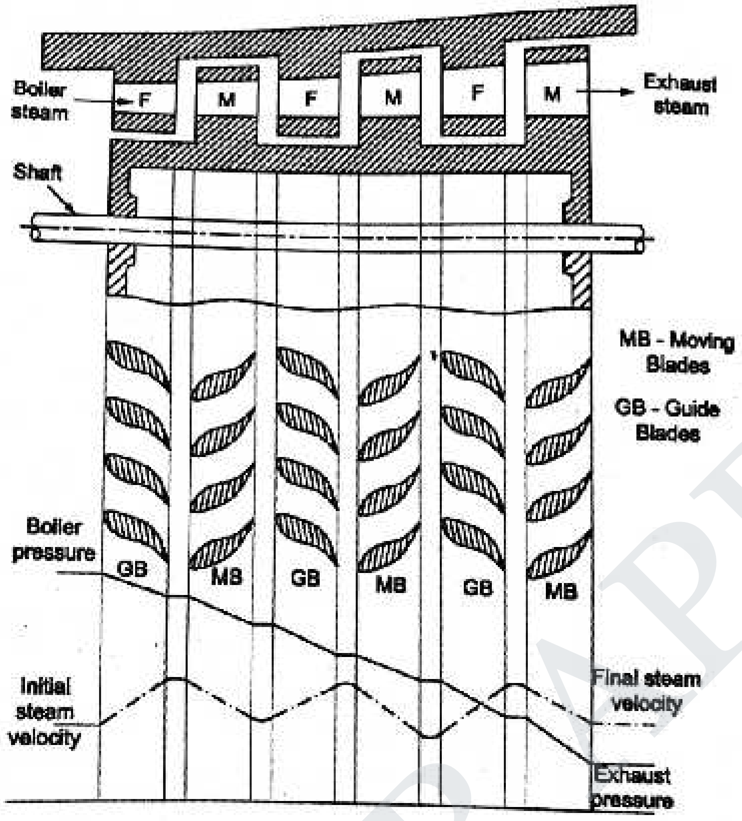


Figure 1.46 Compound reaction turbine

Comparison between impulse and reaction turbine

Impulse turbine	Reaction turbine
It consists of nozzles and moving blades	Fixed and moving blades
Pressure drop occurs in nozzles	Pressure drop occurs in fixed and moving blades
It has constant blade channel area	It has varying blade channel area
Power developed is less	Power developed is high
Occupies less space	Occupies more space
Efficiency is low	Efficiency is high

Advantages of steam turbines

1. It requires less space.
2. Simple in mechanism.
3. It is quiet and smooth in operation.
4. Its over load capacity is large.
5. The power is generated at uniform rate, therefore the flywheel is not needed.
6. It can be designed for much higher speed.
7. Efficiency is high.

COMPOUNDING OF STEAM TURBINES

- If the expansion of steam takes place from the boiler pressure to condenser pressure in a single stage turbine, the velocity of steam at the exit of turbine is very high. Also the speed of the rotor is very high (up to 30000 rpm).
- Compounding is a method of absorbing the jet velocity in more than one stage when the steam flows over moving blades.
- The different methods of compounding are as follows.

1. Velocity compounding
2. Pressure compounding
3. Pressure-velocity compounding

1. VELOCITY COMPOUNDING

- The pressure drops fully at the nozzle itself and the pressure remains constant in moving blades and fixed blades.
- The velocity of steam coming out of nozzle is very high and it is reduced in stage-by-stage on moving blades. Hence it is known as velocity compounding.
- Example of this type of turbine is Curtis turbine.

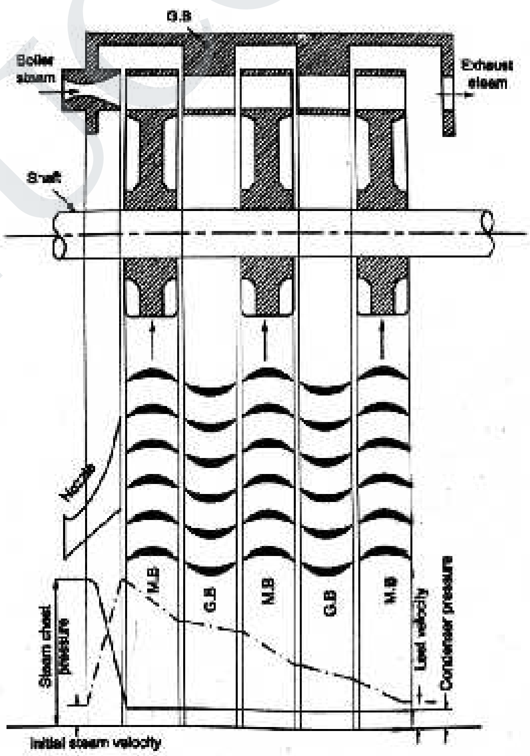


Figure 1.47 Velocity compound impulse turbine

Advantages:

1. Its initial cost is less.
2. Less space is required.

Disadvantages:

1. Frictional losses are high.
2. Efficiency is low

2. PRESSUE COMPOUNDING

- ❖ In this method the numbers of simple impulse turbine stages are arranged in series as shown in fig.
- ❖ The steam velocity increases when it is passed through nozzles, so pressure gets dropped.
- ❖ The pressure is reduced in each stage of nozzle and hence it is called pressure compounding.

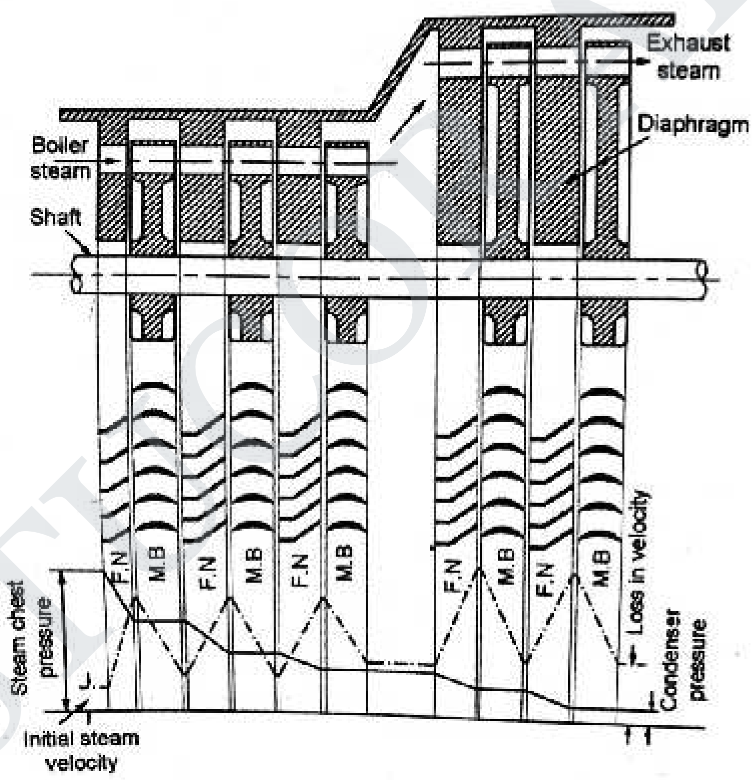


Figure 1.48 Pressure compound impulse turbine

3. PRESSURE-VELOCITY COMPOUNDING

- ❖ This method is a combination of pressure and velocity compounding.
- ❖ The total pressure drop is obtained in stages through nozzle sets and the velocity changes takes place through moving blades.
- ❖ This method is used in Curtis and Moore turbine.

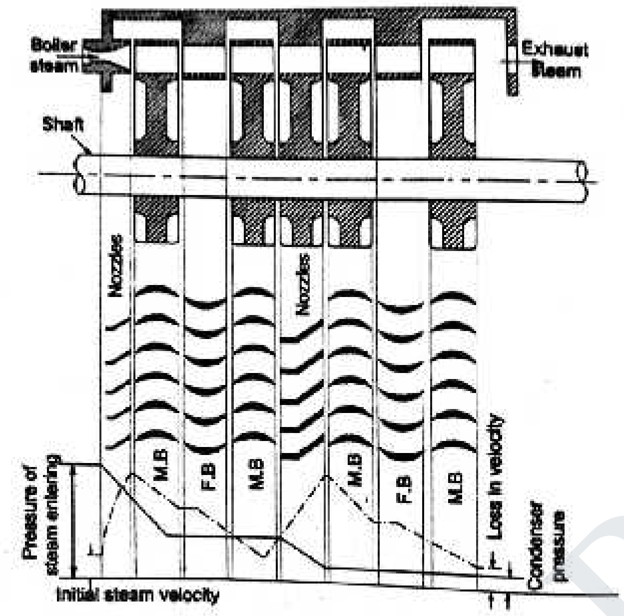


Figure 1.49 Pressure-velocity compounding

GOVERNING OF TURBINES OR SPEED REGULATION OF TURBINES

- The method of maintaining the speed of the turbine constant irrespective of variation of the load on the turbine is known as governing of turbines.

- The various methods of steam turbine governing are as follows.

1. Throttle governing
2. Nozzle control governing
3. By-pass governing
4. Combination of throttle and nozzle or throttle and by-pass governing

- **Throttle governing**

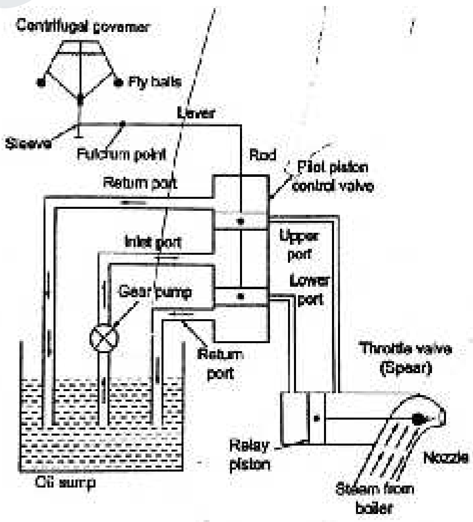


Figure 1.50 Throttle governing

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❖ Nozzle control governing

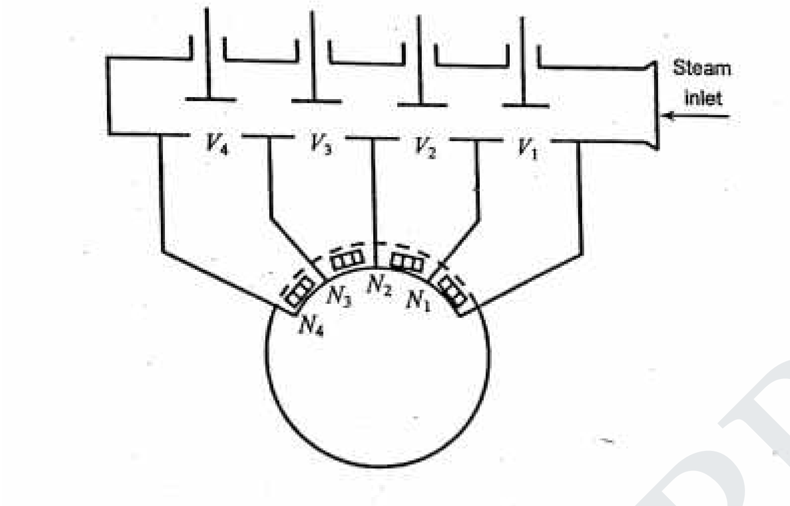


Figure 1.51 Nozzle control governing

❖ By-pass governing

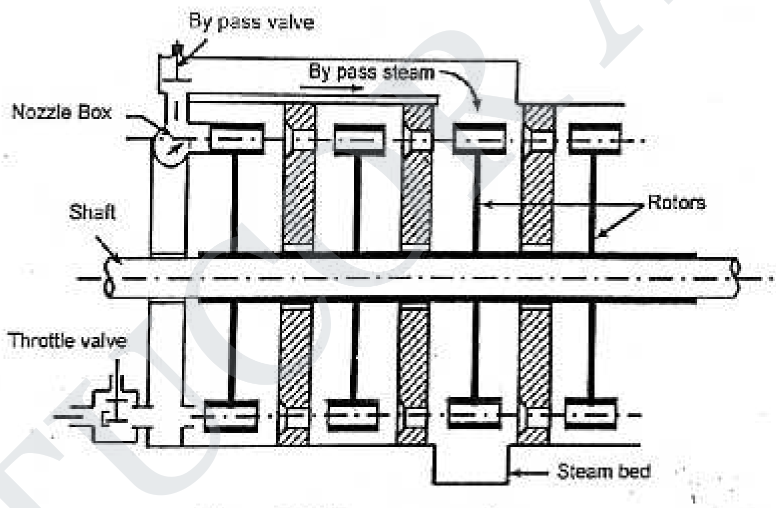


Figure 1.52 By pass governing

CONDENSERS

❖ Condenser is a closed vessel in which steam is condensed by abstracting the heat and where the pressure is maintained below atmospheric pressure.

1. DOWN FLOW CONDENSER

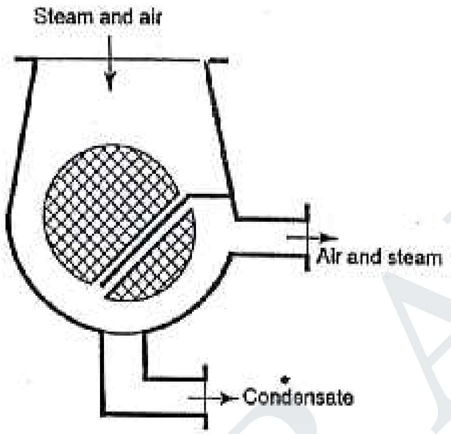


Figure 1.53 Sectional view of down flow condenser

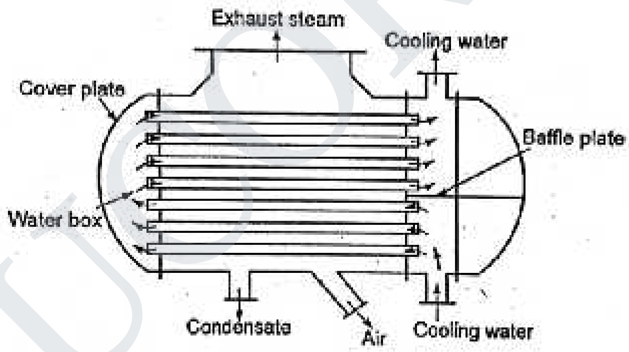


Figure 1.54 Longitudinal section of a two pass down-flow condenser

In Down flow surface condenser, steam enters on the top of the condenser vessel and it comes down over the cooling water pipes. the steam as a result is condensed and the condensate is extracted from the bottom by the condensate extraction pump. The temperature of condensate gets decrease as it passes downwards. Also the partial pressure of steam decreases from top to bottom of the **steam condenser**. The air exit is shielded from the down stream of the condensate by means of buffle plate and thus air is extracted with only a comparatively small amount of water vapour. As the air comes down, it is progressively cooled and becomes denser and hence it is extracted room the lowest convenient point.

2. CENTRAL FLOW CONDENSER

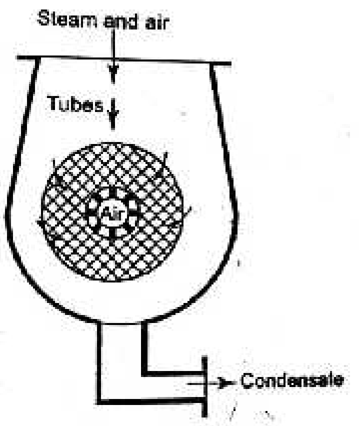


Figure 1.55 Central flow condenser

In this type of surface condenser the suction pipe of the air extraction pump is placed in center of the tubes nest, this causes the condensate to flow radially towards the center as shown by arrows in the figure. The condensate leaves at the bottom where the condensate extraction pump is situated. The air is withdrawn from the center of the nest of tubes. This method is an improvement on the down flow type as the steam is directed radially inward by a volute casting around the tube nest it has thus access to the whole periphery of the tubes.

3. EVAPORATION CONDENSER

As a water-cooled condensers, evaporative cooling ofcondensers first transfer of heat into the water, and then from the water outdoors. Evaporative condenser, however, combines the functions of a cooling tower and condenser are located in one package.

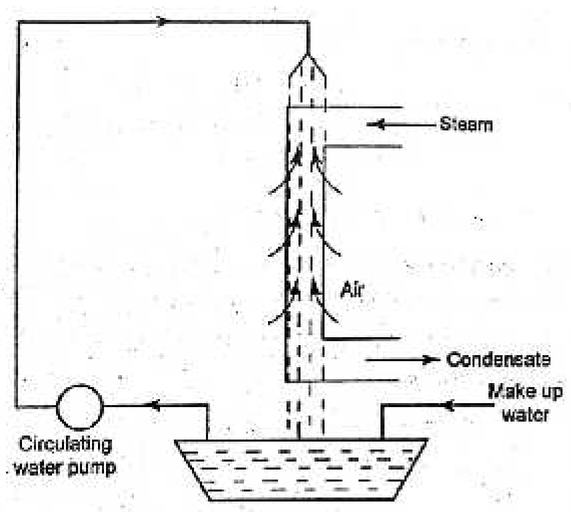
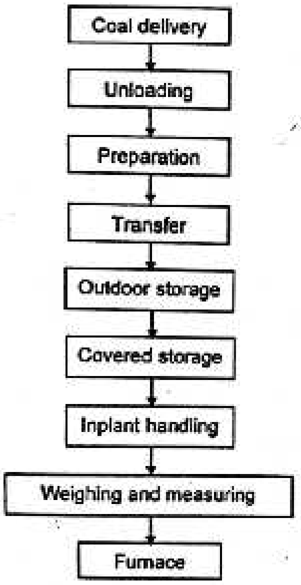


Figure 1.56 Evaporation condenser

COAL HANDLING



Coal delivery equipment is one of the major components of plant cost. The various steps involved in coal handling are as follows:

1. Coal delivery 2. Unloading 3. Preparation 4. Transfer
5. Outdoor Storage 6. Covered Storage 7. In plant Handling 8. Weighing and Measuring

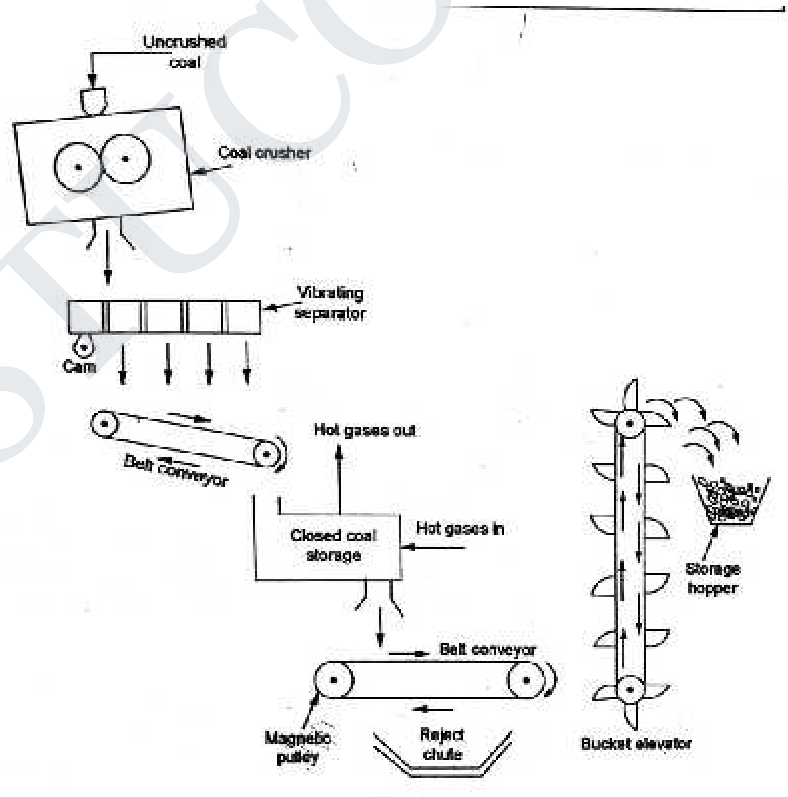


Figure 1.58 Coal preparation plant

DRAUGHT SYSTEM

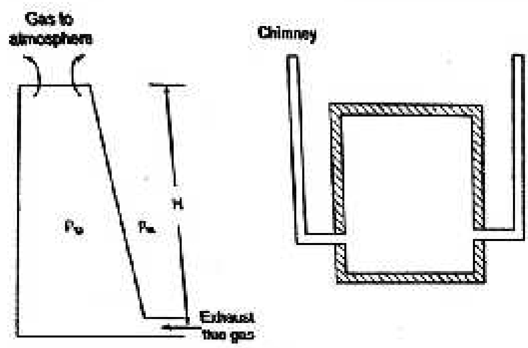


Figure 1.98 Chimney design

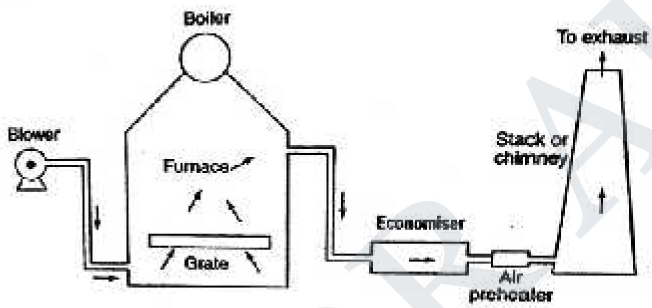


Figure 1.99 Forced draught

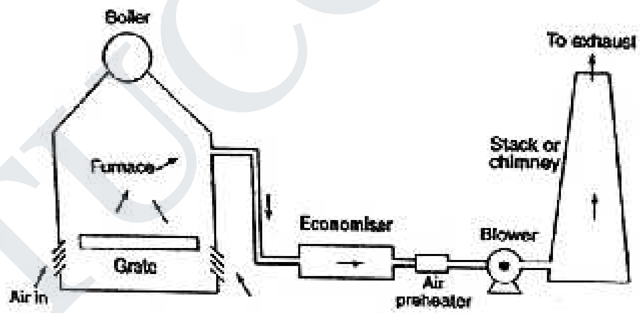


Figure 1.100 Induced draught

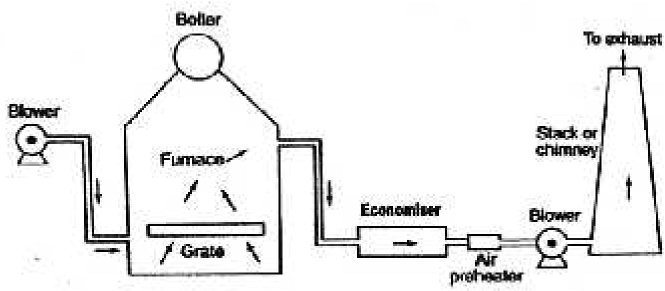


Figure 1.101 Balanced draught

Because of the emission of large amount of flue gases and other materials environment is polluted, thus to decrease the environmental pollution some techniques and equipments are used. Generally Electrostatic precipitators and Draughts system is used by coal gas plants to decrease the environment pollution.

Natural draught:

The natural draught is obtained with the use of tall chimney which may be sufficient or insufficient to overcome the losses in the system. Its usefulness depends upon the capacity of the plant and duct work. This system of producing the draught is useful for small capacity boilers and it does not play much important role in the present high capacity thermal power plants. A chimney is a vertical structure of masonry; brick, steel or reinforced concrete built for the purpose of enclosing a column of hot gases to produce the draught and discharge the gases high enough which will prevent an air pollution the draught produced by the chimney is due to the temperature difference of hot gases in the chimney and cold air outside the chimney.

Artificial draught:

Artificial draught can be further classified as:

Forced draught:

In a forced draught system, a lower is installed near the base of the boiler and Air is forced to pass through the furnace, flues, economizer, air-preheater and to the stack. This draught system is known as positive draught or forced draught system because the pressure of air throughout the system is above atmospheric draught system or forced draught system because the pressure of air throughout the system is above atmospheric pressure and air is forced to flow through the system. A stack or chimney is also used in this system but its function is to discharge gases high in the atmosphere to prevent the contamination. It is not much significant for producing draught therefore height of the chimney may not be very much.

Induced draught:

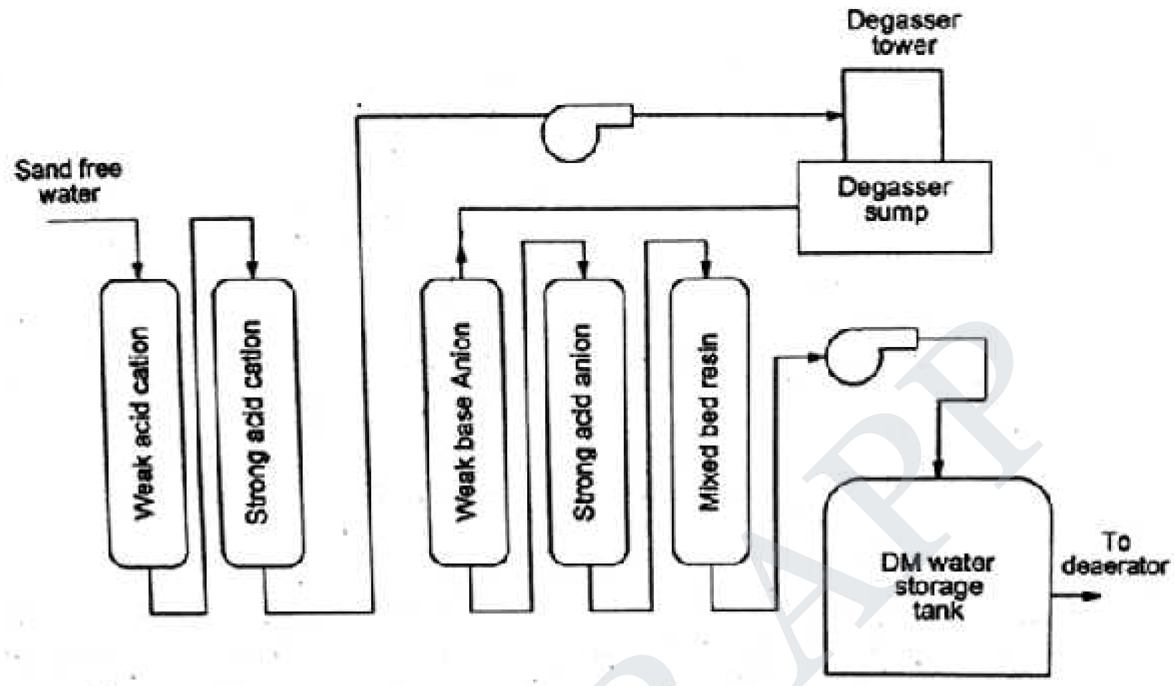
In this system, the blower is located near the base of the chimney instead of near the grate. The air is sucked in the system by reducing the pressure through the system below atmosphere. The induced draught fan sucks the burned gases from the furnace and the pressure inside the furnace is reduced below atmosphere and induces the atmospheric air to flow through the furnace. The action of the induced draught is similar to the action of the chimney. The draught produced is independent of the temperature of the hot gases therefore the gases may be discharged as cold as possible after recovering as much heat as possible in the air-preheater and economizer.

This draught is used generally when economizer and air-preheater are incorporated in the system. The fan should be located at such a place that the temperature of the gas handled by the fan is lowest. The chimney is also used in this system and its function is similar as mentioned in forced draught but total draught produced in induced draught is the sum of the draught produced by the chimney and the fan.

Balanced draught:

It is always preferable to use a combination of forced draught and induced draught instead of using any one of these system alone. If the forced furnace is used alone, then the furnace cannot be opened either for inspection or for firing because the high pressure air inside the furnace will try to blow out suddenly and there us every chance of blowing out the fire completely and furnace stops. If the induced draught is used alone, then also furnace cannot be opened either for firing or inspection because the cold air will try to rush into the furnace as the pressure inside the furnace is below the atmospheric pressure. This reduces the effective draught and dilutes the combination. To overcome both the difficulties mentioned above either using forced draught or induced draught alone, a balanced draught is always preferred. The balanced draught is a combination of forced and induced draught. The forced draught overcomes the resistance of the fuel bed therefore sufficient air is supplied to the fuel bed for proper and complete combustion. The induced draught fan removes the gases from the furnace maintaining the pressure inside the furnace just below atmosphere. This helps to prevent the blow-off of flames when the doors are opened as the leakage of air is inwards. The pressure inside the furnace is near atmospheric so there is no danger of blowout of flames or there is no danger of inrushing the air into the furnace when the doors are opened for inspection. The pressure of air below the grate is above atmosphere and it helps for proper and uniform combustion. The pressure of air above the grate is just below the atmosphere and it helps to remove the exhaust gases as quick as possible from the combustion zone.

FEED WATER TREATMENT



Demineralization plant

Boiler water treatment is used to control alkalinity, prevent scaling, correct pH, and to control conductivity. The boiler water needs to be alkaline and not acidic, so that it does not ruin the tubes. There can be too much conductivity in the feed water when there are too many dissolved solids. These correct treatments can be controlled by efficient operator and use of treatment chemicals. The main objectives to treat and condition boiler water is to exchange heat without scaling, protect against scaling, and produce high quality steam. The treatment of boiler water can be put into two parts. These are internal treatment and external treatment. The internal treatment is for boiler feed water and external treatment is for make-up feed water and the condensate part of the system. Internal treatment protects against feed water hardness by preventing precipitating of scale on the boiler tubes. This treatment also protects against concentrations of dissolved and suspended solids in the feed water without priming or foaming. These treatment chemicals also help with the alkalinity of the feed water making it more of a base to help protect against boiler corrosion. The correct alkalinity is protected by adding phosphates. These phosphates precipitate the solids to the bottom of the boiler drum. At the bottom of the boiler drum there is a bottom blow to remove these solids. These chemicals also include anti-scaling agents, oxygen scavengers, and anti-foaming agents. Sludge can also be treated by two approaches. These are by coagulation and dispersion. When there is a high amount of sludge content it is better to coagulate the sludge to form large particles in order to just use the bottom blow to remove them from the feed water. When there is a low amount of sludge content it is better to use dispersants because it disperses the sludge throughout the feed water so sludge does not form.

BINARY CYCLES

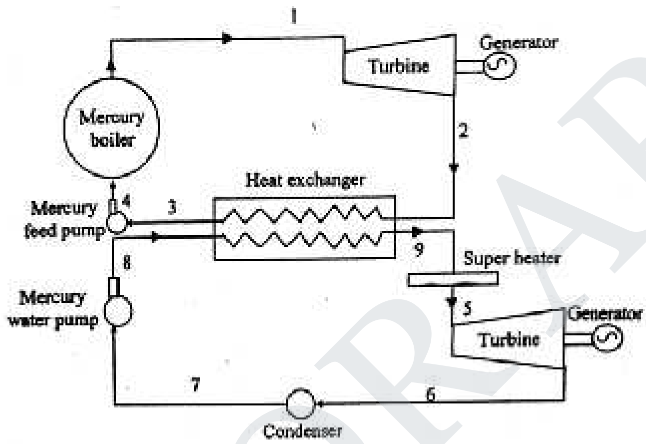


Figure 1.113 Layout of binary vapour cycle

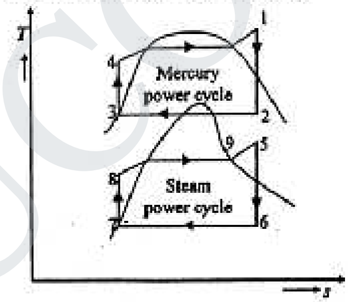


Figure 1.114 T-s diagram of binary vapour cycle

A binary cycle power plant is a type of geothermal power plant that allows cooler geothermal reservoirs to be used than is necessary for dry steam and flash steam plants. As of 2010, flash steam plants are the most common type of geothermal power generation plants in operation today, which use water at temperatures greater than 182 °C (455 K; 360 °F) that is pumped under high pressure to the generation equipment at the surface. With binary cycle geothermal power plants, pumps are used to pump hot water from a geothermal well, through a heat exchanger, and the cooled water is returned to the underground reservoir. A second "working" or "binary" fluid with a low boiling point, typically a butane or pentane hydrocarbon, is pumped at fairly high pressure

(500 psi (3.4 MPa) through the heat exchanger, where it is vaporized and then directed through a turbine. The vapor exiting the turbine is then condensed by cold air radiators or cold water and cycled back through the heat exchanger.

A binary vapor cycle is defined in thermodynamics as a power cycle that is a combination of two cycles, one in a high temperature region and the other in a lower temperature region.

COGENERATION SYSTEMS

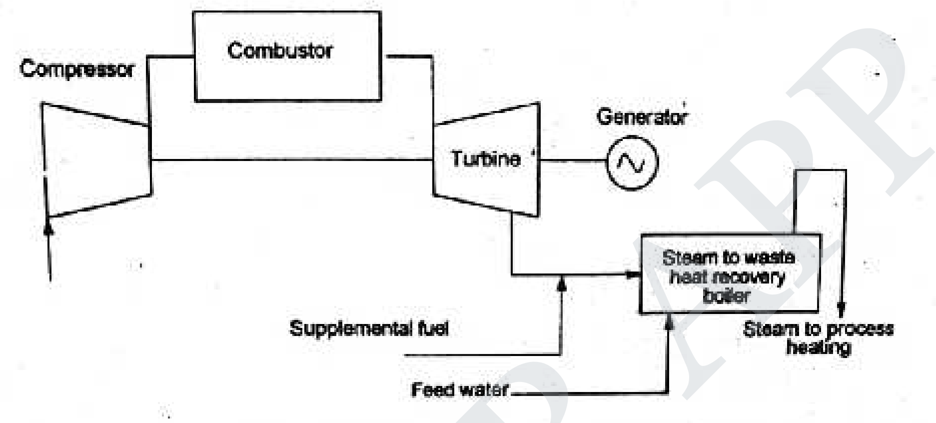


Figure 1.116 Gas turbine topping CHP plant

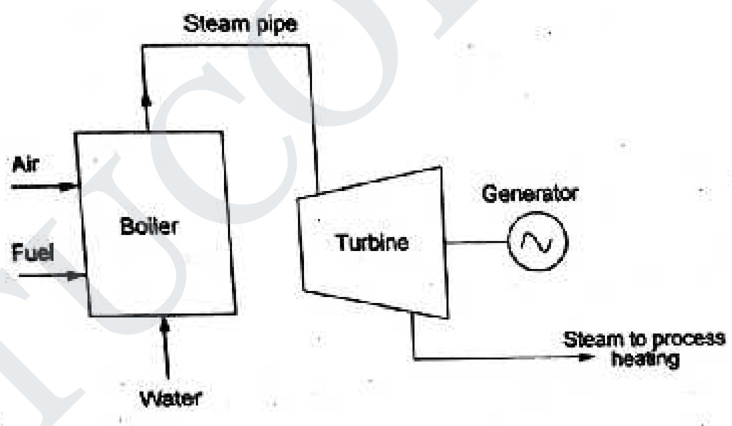


Figure 1.117 Steam-turbine topping CHP Plant

Cogeneration or combined heat and power (CHP) is the use of a heat engine or power station to generate electricity and useful heat at the same time. *Trigeneration* or *combined cooling, heat and power* refers to the simultaneous generation of electricity and useful heating and cooling from the combustion of a fuel or a solar heat collector. The terms *cogeneration* and *trigeneration* can be also applied to the power systems generating simultaneously electricity, heat, and industrial chemicals – e.g., syngas or pure hydrogen (article: combined cycles, chapter: natural gas integrated power & syngas (hydrogen) generation cycle).

Cogeneration is a more efficient use of fuel because otherwise wasted heat from electricity generation is put to some productive use.

Combined heat and power (CHP) plants recover otherwise wasted thermal energy for heating. This is also called combined heat and power district heating. Small CHP plants are an example of decentralized energy. By-product heat at moderate temperatures (100–180 °C, 212–356 °F) can also be used in absorption refrigerators for cooling.

The supply of high-temperature heat first drives a gas or steam turbine-powered generator. The resulting low-temperature waste heat is then used for water or space heating. At smaller scales (typically below 1 MW) a gas engine or diesel engine may be used. Trigeneration differs from cogeneration in that the waste heat is used for both heating and cooling, typically in an absorption refrigerator. Combined cooling, heat and power systems can attain higher overall efficiencies than cogeneration or traditional power plants. In the United States, the application of trigeneration in buildings is called building cooling, heating and power. Heating and cooling output may operate concurrently or alternately depending on need and system construction.

Cogeneration was practiced in some of the earliest installations of electrical generation. Before central stations distributed power, industries generating their own power used exhaust steam for process heating. Large office and apartment buildings, hotels and stores commonly generated their own power and used waste steam for building heat. Due to the high cost of early purchased power, these CHP operations continued for many years after utility electricity became available.

ME8792 - POWER PLANT ENGINEERING

UNIT- II

DIESEL, GAS TURBINE AND COMBINED CYCLE POWER PLANTS

Otto, Diesel, Dual & Brayton Cycle - Analysis & Optimisation. Components of Diesel and Gas Turbine power plants. Combined Cycle Power Plants. Integrated Gasifier based Combined Cycle systems.

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OTTO CYCLE

An **Otto cycle** is an idealized thermodynamic cycle that describes the functioning of a typical spark ignition piston engine. It is the thermodynamic cycle most commonly found in automobile engines.

The Otto cycle is a description of what happens to a mass of gas as it is subjected to changes of pressure, temperature, volume, addition of heat, and removal of heat. The mass of gas that is subjected to those changes is called the system. The system, in this case, is defined to be the fluid (gas) within the cylinder. By describing the changes that take place within the system, it will also describe in inverse, the system's effect on the environment. In the case of the Otto cycle, the effect will be to produce enough net work from the system so as to propel an automobile and its occupants in the environment.

The Otto cycle is constructed from:

Top and bottom of the loop: a pair of quasi-parallel and isentropic processes (frictionless, adiabatic reversible).

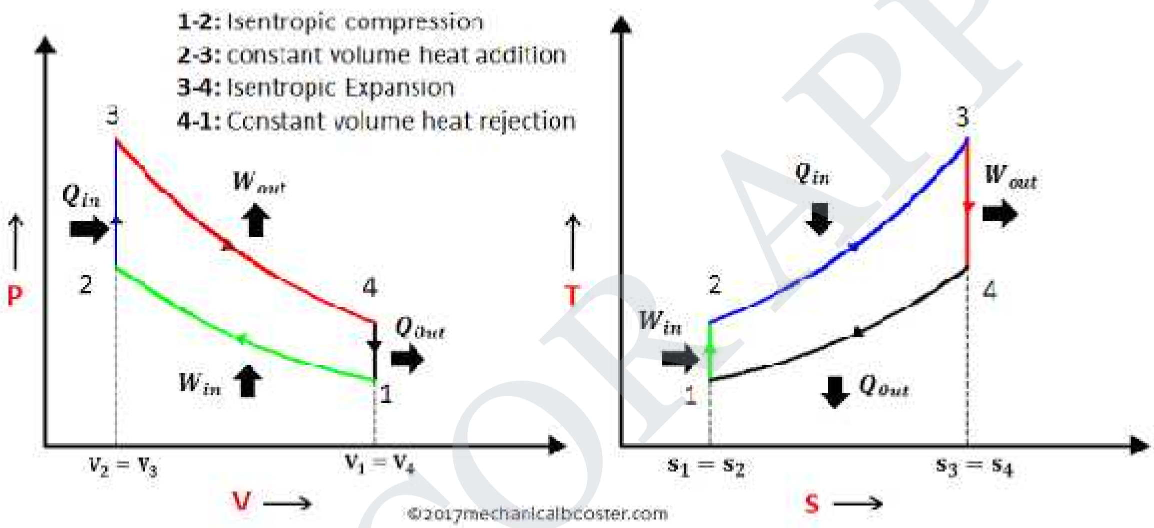
Left and right sides of the loop: a pair of parallel isochoric processes (constant volume).

The isentropic process of compression or expansion implies that there will be no inefficiency (loss of mechanical energy), and there be no transfer of heat into or out of the system during that process. Hence the cylinder, and piston are assumed impermeable to heat during that time. Work is performed on the system during the lower isentropic compression process. Heat flows into the Otto cycle through the left pressurizing process and some of it flows back out through the right depressurizing process. The summation of the work added to the system plus the heat added minus the heat removed yields the net mechanical work generated by the system.

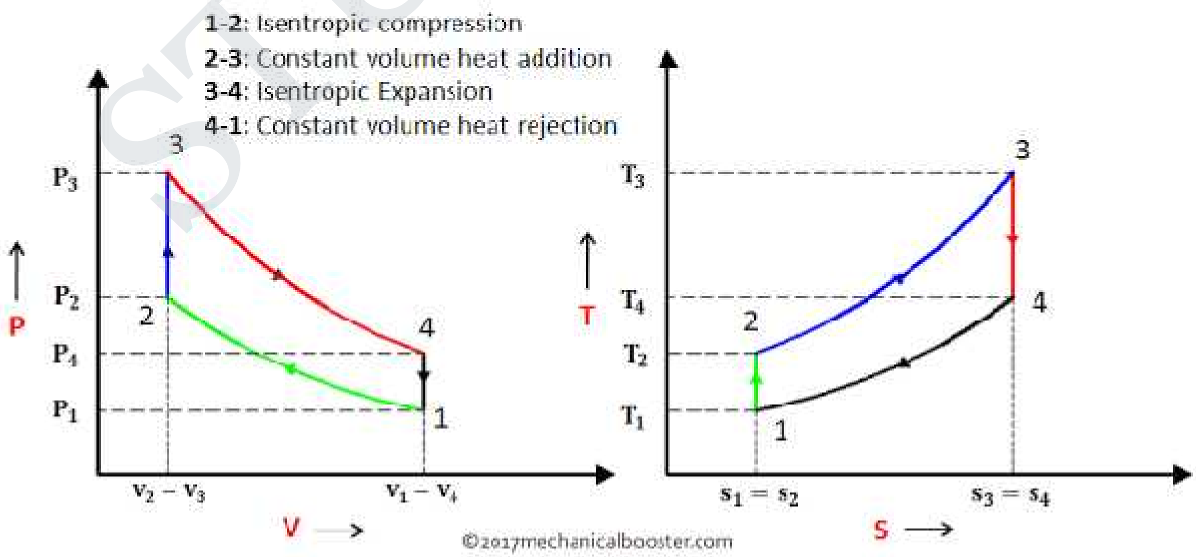
The processes are described by:

- Process 0–1 a mass of air is drawn into piston/cylinder arrangement at constant pressure.
- Process 1–2 is an adiabatic (isentropic) compression of the charge as the piston moves from bottom dead centre (*BDC*) to top dead centre (*TDC*).

- Process 2–3 is a constant-volume heat transfer to the working gas from an external source while the piston is at top dead centre. This process is intended to represent the ignition of the fuel-air mixture and the subsequent rapid burning.
- Process 3–4 is an adiabatic (isentropic) expansion (power stroke).
- Process 4–1 completes the cycle by a constant-volume process in which heat is rejected from the air while the piston is at bottom dead centre.
- Process 1–0 the mass of air is released to the atmosphere in a constant pressure process.



P-V and T-S Diagram of Otto Cycle



P-V and T-S Diagram of Otto Cycle

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The efficiency of Otto cycle is given by

$$\eta_{Otto} = \eta_{th} = 1 - \frac{T_4 - T_3}{T_2 - T_1} = 1 - \frac{1}{r^{(\gamma-1)}}$$

$$\eta_{th} = 1 - \frac{T_4 - T_3}{T_2 - T_1} = 1 - \frac{1}{r^{(\gamma-1)}}$$

$$r = Compression\ ratio = \frac{V_1}{V_2} = \frac{V_4}{V_3}$$

$$\gamma = adiabatic\ index$$

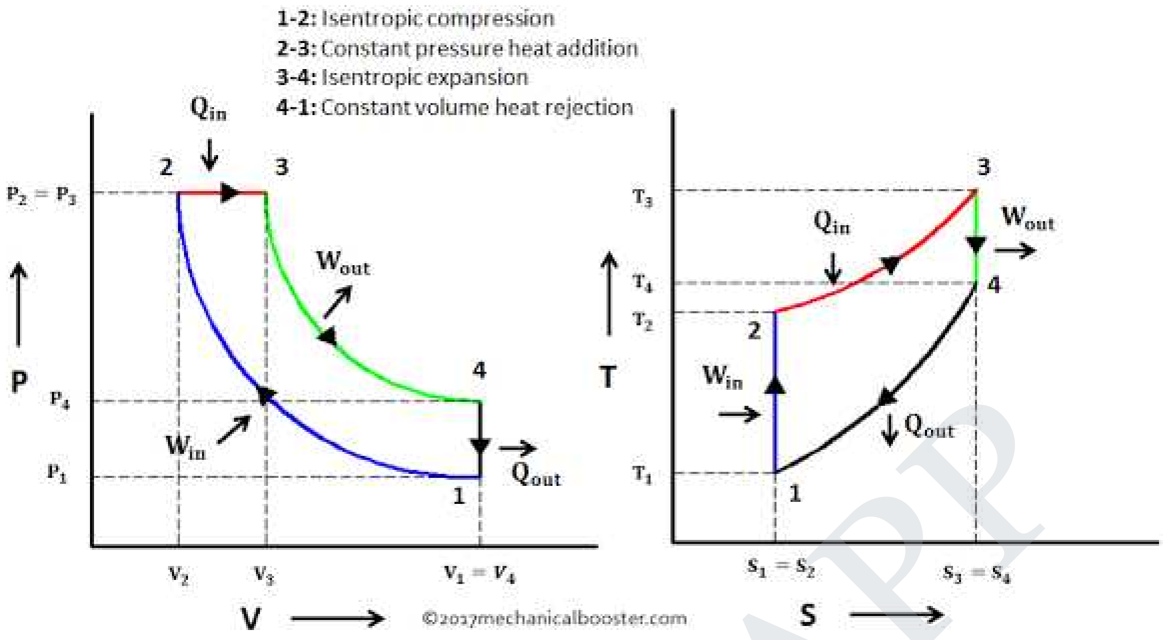
DIESEL CYCLE

Diesel cycle was invented by Rudolph Diesel in 1893. He put forward an idea by which we can attain higher thermal efficiency, with a high compression ratio. All diesel engine works on this cycle. Diesel is used as fuel in this cycle as it can be compressed at higher compression ratio. It is also known as constant pressure cycle because heat is added in it at constant pressure. It has high thermal efficiency and compression ratio (11:1 to 22:1) as compared with Otto cycle.

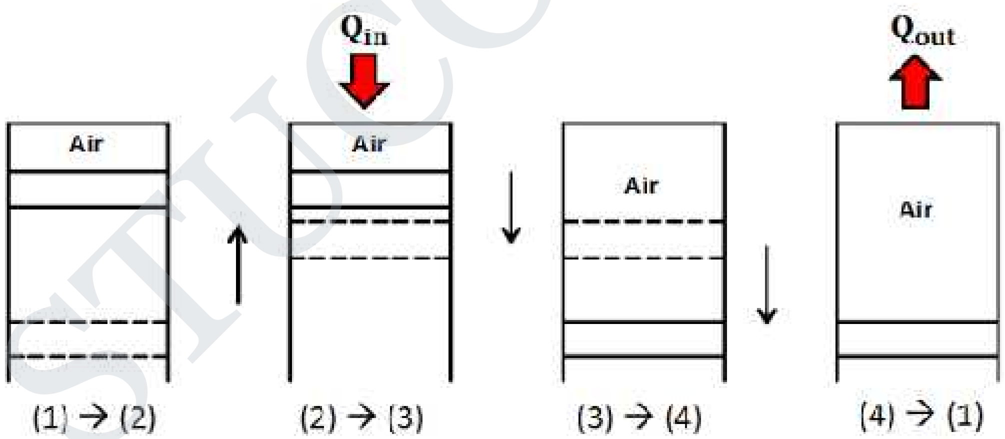
The engine that is put forward by Rudolph consists of an enclosed air in the cylinder. The cylinder walls are perfectly non-conductors of heat, but the bottom is a perfect conductor of heat. It has a hot body, cold body and an insulating cap, which are alternately brought in contact with the cylinder.

The ideal Diesel cycle consist of 4 process, two isentropic processes, one constant pressure and one constant volume process.

The 4 process are as follows
1. Isentropic (reversible adiabatic) Compression
2. Constant pressure heat addition
3. Isentropic Expansion
4. Constant volume heat rejection.



P-V and T-S Diagram of Diesel Cycle



Piston Position in Diesel Cycle Process

$$\eta_{th} = 1 - \frac{1}{r^{\gamma-1}} \left(\frac{\alpha^{\gamma} - 1}{\gamma(\alpha - 1)} \right)$$

where

η_{th} is thermal efficiency

α is the cut-off ratio $\frac{V_3}{V_2}$ (ratio between the end and start volume for the combustion phase)

r is the compression ratio $\frac{V_1}{V_2}$

γ is ratio of specific heats (C_p/C_v)

The cut-off ratio can be expressed in terms of temperature as shown below:

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = r^{\gamma-1}$$

$$T_2 = T_1 r^{\gamma-1}$$

$$\frac{V_3}{V_2} = \frac{T_3}{T_2}$$

$$\alpha = \left(\frac{T_3}{T_1}\right)\left(\frac{1}{r^{\gamma-1}}\right)$$

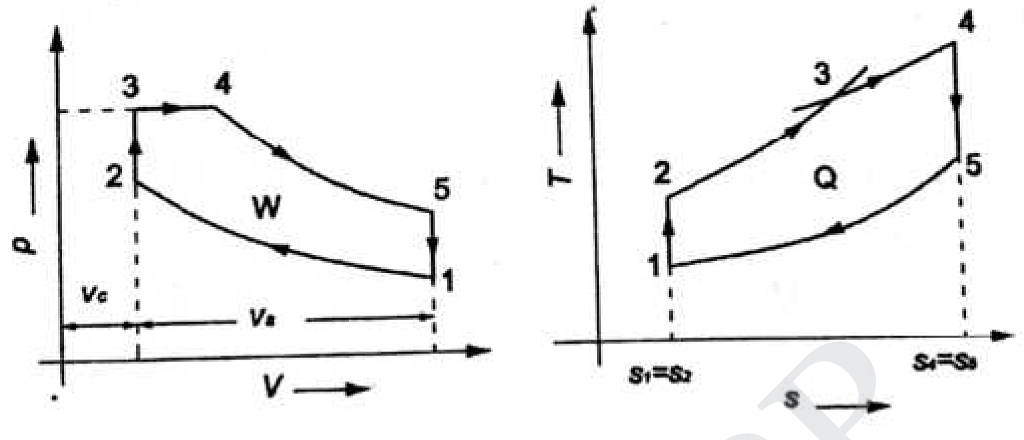
DUAL CYCLE

The **dual combustion cycle** (also known as the **mixed cycle**, **Trinkler cycle**, **Seiliger cycle** or **Sabathe cycle**) is a thermal cycle that is a combination of the Otto cycle and the Diesel cycle, first introduced by Russian-German engineer Gustav Trinkler. Heat is added partly at constant volume and partly at constant pressure, the advantage of which is that more time is available for the fuel to completely combust. Because of lagging characteristics of fuel this cycle is invariably used for Diesel and hot spot ignition engines. It consists of two adiabatic and two constant volume and one constant pressure processes. Efficiency lies between Otto and Diesel cycle.

The dual cycle consists of following operations:

- Process 1-2: Isentropic compression
- Process 2-3: Addition of heat at constant volume.
- Process 3-4: Addition of heat at constant pressure.
- Process 4-5: Isentropic expansion.
- Process 5-1: Rejection of heat at constant volume.

p-V and T-s diagrams for dual cycle are shown in Figure



p-V diagram T-s diagram

Dual cycle

Air Standard Efficiency

$$\text{Heat supplied} = m\,C_v(T_3 - T_2) + m\,C_p(T_4 - T_3)$$

$$\text{Heat rejected} = m\,C_v(T_5 - T_1)$$

$$\text{Net work done} = m\,C_v(T_3 - T_2) + m\,C_p(T_4 - T_3) - m\,C_V(T_5 - T_1)$$

$$\eta_{th} = \frac{m\,C_v(T_3 - T_2) + m\,C_p(T_4 - T_3) - m\,C_v(T_5 - T_1)}{m\,C_v(T_3 - T_2) + m\,C_p(T_4 - T_3)}$$

$$\eta_{th} = 1 - \frac{T_5 - T_1}{(T_3 - T_2) + \gamma(T_4 - T_3)}$$

$$\text{Let, } \frac{P_3}{P_2} = r_p\ ;\ \frac{v_4}{v_3} = r_c\ ;\ \frac{v_1}{v_2} = r$$

$$T_2 = T_1\, r^{\gamma - 1}$$

$$T_3 = T_2\, r_p = T_1\, r^{\gamma - 1}\, r_p$$

$$T_4 = T_3\, r_c = T_1\, r^{\gamma - 1}\, r_p\, r_c$$

$$\frac{T_5}{T_4} = \left(\frac{v_4}{v_5}\right)^{\gamma - 1} = \left(\frac{v_4}{v_2} \cdot \frac{v_2}{v_5}\right)^{\gamma - 1} = \left(\frac{r_c}{r}\right)^{\gamma - 1}$$

$$T_5 = T_4 \left(\frac{r_c}{r}\right)^{\gamma - 1} = T_1 \, r_p \, r_c^{\gamma}$$

$$\eta_{th} = 1 - \frac{T_1 \, r_p \, r_c^{\gamma} - T_1}{\left\{\left(T_1 \, r^{\gamma - 1} \, r_p - T_1 \, r^{\gamma - 1}\right) + \gamma\left(T_1 \, r^{\gamma - 1} \, r_p \, r_c - T_1 \, r^{\gamma - 1} \, r_p\right)\right\}}$$

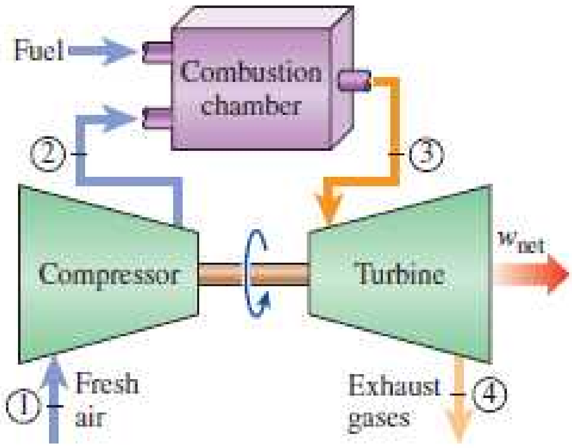
$$= 1 - \frac{\left(r_p \, r_c^{\gamma} - 1\right)}{\left\{\left(r_p \, r^{\gamma - 1} - r^{\gamma - 1}\right) + \gamma\left(r_p \, r_c \, r^{\gamma - 1} - r_p \, r^{\gamma - 1}\right)\right\}}$$

$$\eta_{th} \; 1 - \frac{1}{r^{\gamma - 1}}\left\{\frac{r_p \, r_c^{\gamma} - 1}{\left(r_p - 1\right) + \gamma r_p \left(r_c - 1\right)}\right\}$$

BRAYTON CYCLE

The Brayton cycle is the ideal cycle for gas-turbine engines. Today, it is used for gas tubines in which both the compression and expansion processes are implemented. There are two different types of the Brayton cyle; the open gas turbine cyle and the closed gas turbine cyle respectively. The difference between these two cycles is that during the open gas turbine cycle, a combustion process takes place, and exhaust gases are thrown out, in other words the exhaust gases cannot be recirculated, while in the other cycle (the closed gas turbine cycle), the combustion process is replaced by a heat-addition process, the exhaust gases are also utilized so as to increase the temperature of the air which enters the compressor.

In Figure 1, the open gas turbine cycle is shown. First, fresh air at ambient condition is taken into the compressor, and here the air temperature and pressure are raised, resulting of the compression process. Second, the high-pressure air draws into the combustion chamber, and it mixes with the fuel. Here, the combustion process occurs at constant temperature. Third, the resulting high-temperature gases enter the turbine to generate power. In this operation, the hot gases are expand to the atmospheric pressure. Finally, the exhaust gases leaving the turbine are discharged.



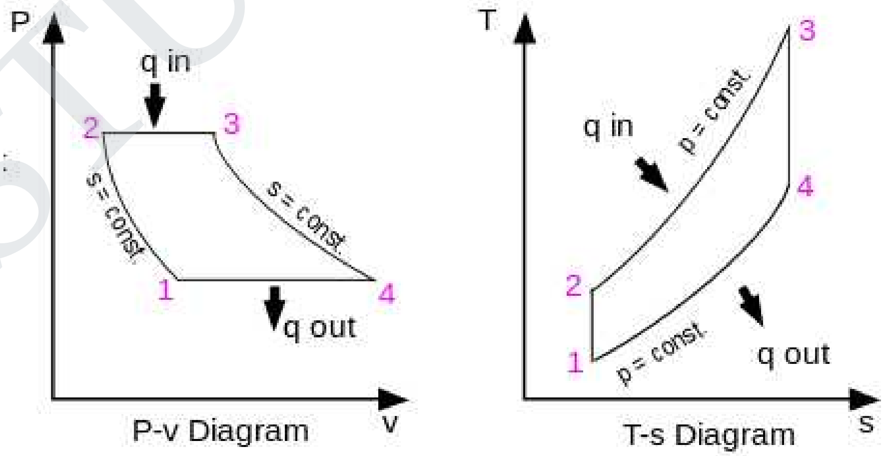
In the closed-gas turbine cycle, although the compresson and expansion process have in common, combustion chamber is replaced by a heat exchanger in which increases the compressed air temperature. As given in Figure 2, ideal Brayton cyle is actually a closed-gas turbine cycle, and the steps of the Brayton cycle are like following;

1–2 Isentropic compression in the compressor

2–3 Constant pressure heat addition

3–4 Isentropic expansion in the turbine

4–1 Constant pressure heat rejection



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$$\eta_{th} = \frac{\text{Heat added - Heat rejected}}{\text{Heat added}}$$

$$\eta_{th} = \frac{mC_p(T_3 - T_2) - mC_p(T_4 - T_1)}{mC_p(T_3 - T_2)} = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

For isentropic processes, we have,

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} \text{ and } \frac{T_3}{T_4} = \left(\frac{p_3}{p_4}\right)^{\frac{\gamma-1}{\gamma}}$$

But, $p_2 = p_3$ and $p_1 = p_4$, thus,

$$\frac{T_2}{T_1} = \frac{T_3}{T_4}$$

and we can write,

$$\eta_{th} = 1 - \frac{T_4}{T_3} = 1 - \frac{T_1}{T_2}$$

$$\frac{T_4}{T_3} = \frac{T_1}{T_2} = \frac{v_2}{v_1} = \frac{1}{r^{\gamma-1}}$$

$$\frac{1}{r^{\gamma-1}} = \left(\frac{v_2}{v_1}\right)^{\gamma-1} \left\{\left(\frac{p_2}{p_1}\right)^{\frac{1}{\gamma}}\right\}^{\gamma-1} = (r_p)^{\frac{\gamma-1}{\gamma}}$$

$$\eta_{th} = 1 - \frac{1}{r_p^{\frac{\gamma-1}{\gamma}}}$$

IMPROVISATION OF BRAYTON CYCLE

The efficiency of gas turbine power plant can be improved in four ways such as

1. Brayton cycle with regeneration
2. Brayton cycle with intercooling
3. Brayton cycle with reheating
4. Brayton cycle with combined regeneration, intercooling and reheating

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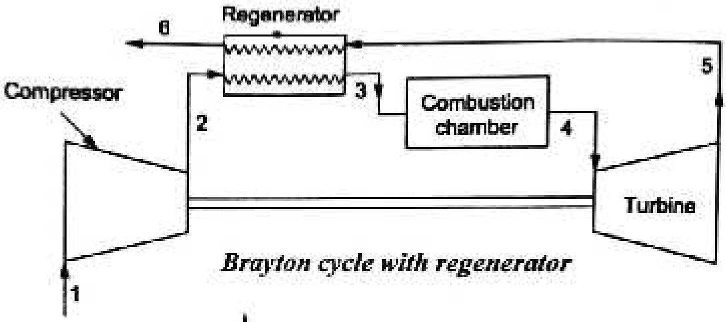
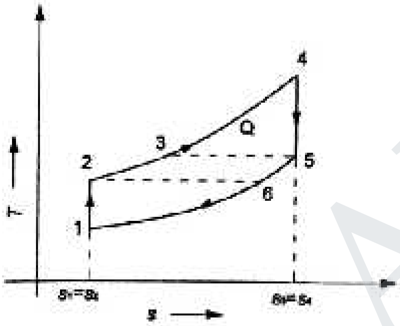
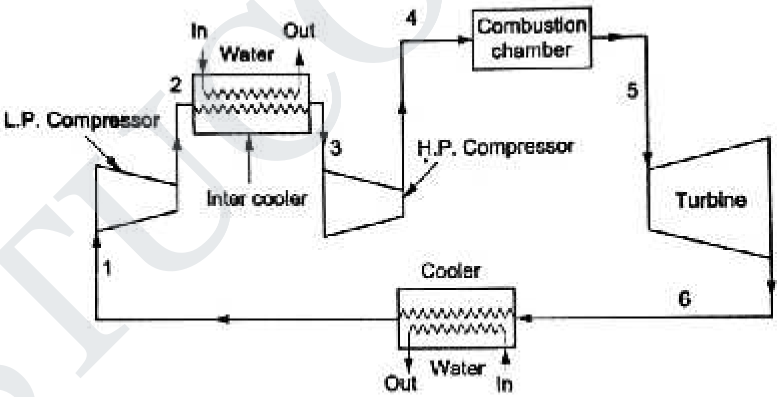
1. **Brayton cycle with regeneration**



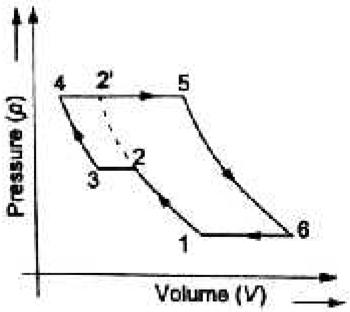
Brayton cycle with regenerator



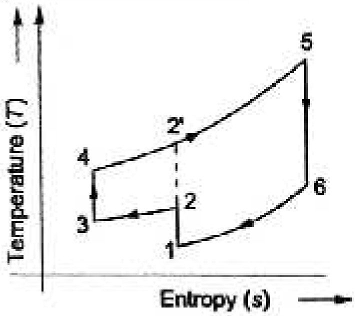
2. **Brayton cycle with intercooling**



Brayton cycle with intercooler



p-V diagram



T-s diagram

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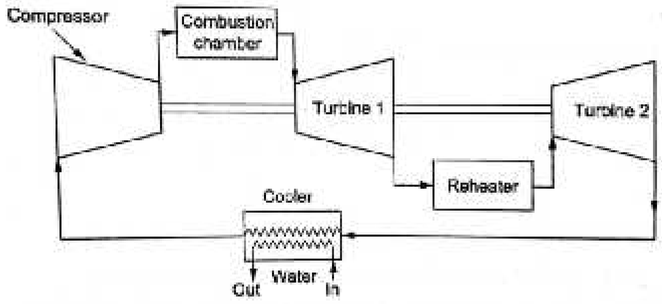
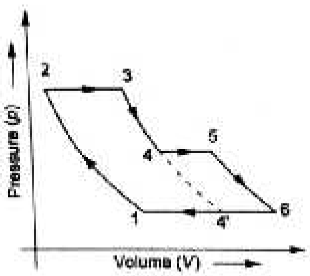
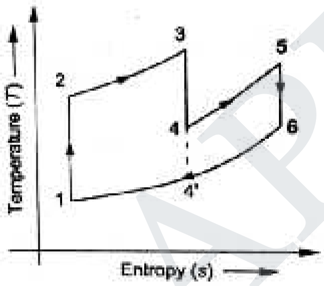
3. Brayton cycle with reheating



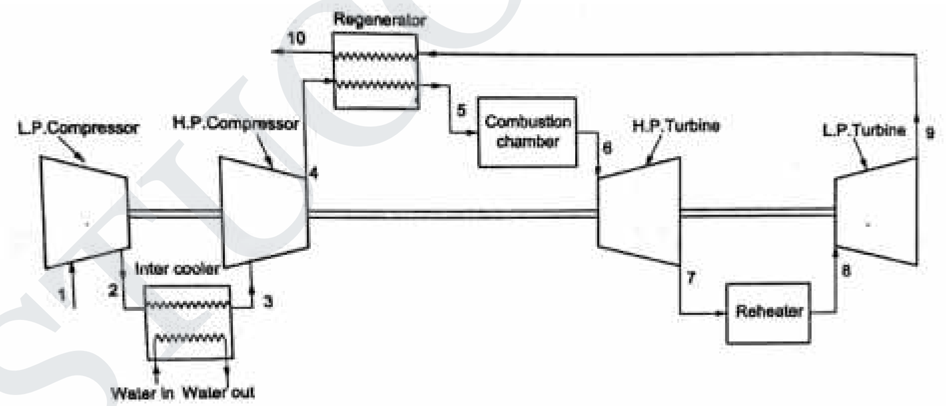
Brayton cycle with reheater



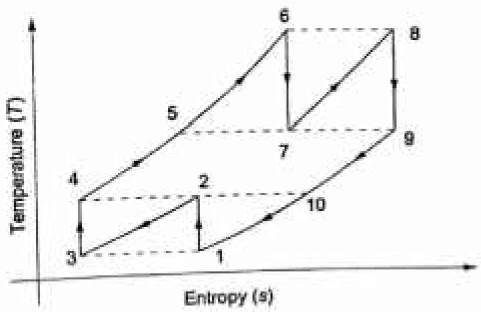


p-V diagram *T-s diagram*

4. Brayton cycle with combined regeneration, intercooling and reheating



Brayton cycle with intercooler, reheater and regenerator



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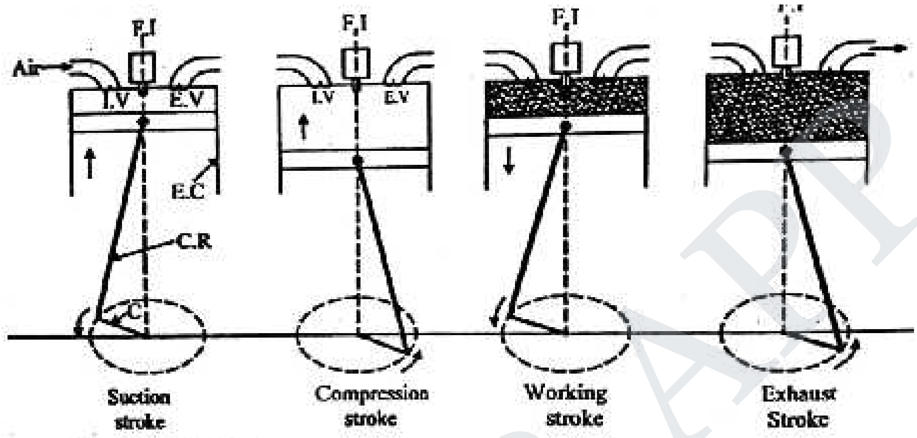
COMPONENTS OF DIESEL POWER PLANT

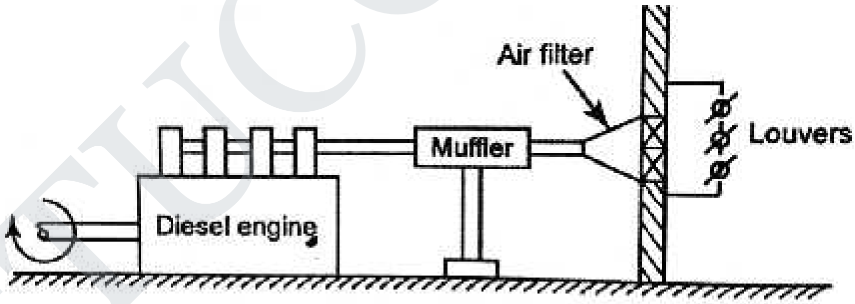
1. Engine
2. Air intake system
3. Engine starting system
4. Fuel system
5. Exhaust system
6. Cooling system
7. Lubricating system

1. Engine



Four stroke diesel cycle engine

2. Air intake system



Air intake system

3. Engine starting system

The various methods used for starting are

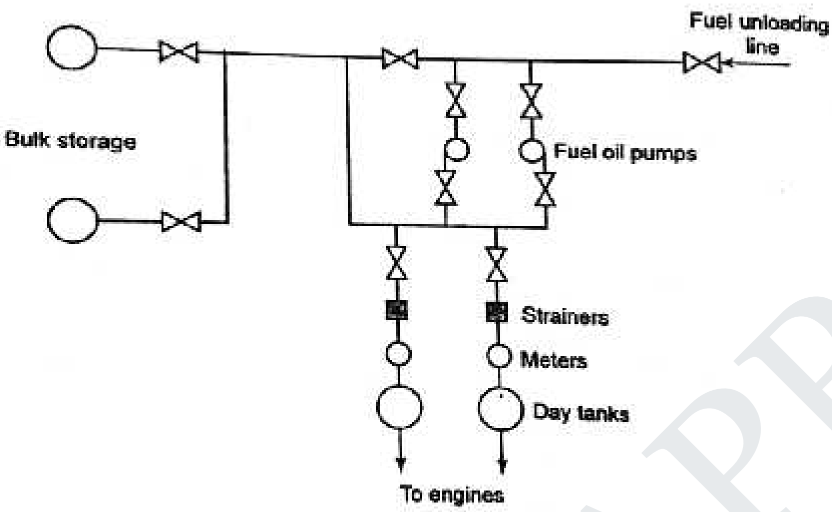
a. Starting by an auxiliary engine
b. Use of electric motors or self starters
c. Compressed air system

The compressed air system includes the following

1. Storage tank/vessel
2. A safety valve

3. Interconnecting pipe work

4.Fuel System



Fuel system for a diesel power plant

a. **Fuel injection system**

The functions of the fuel injection system are to meter a small amount of oil, inject into the cylinder at a proper time, atomize and mix with the air.

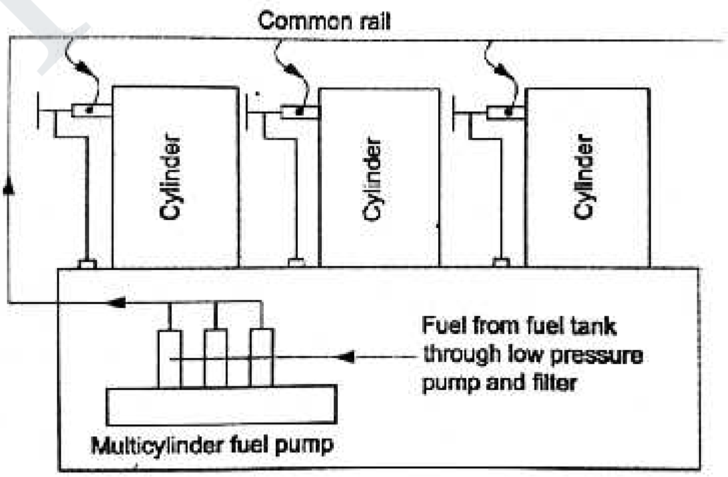
Types of fuel injection system

1.Common rail injection system

2.Individual pump injection system

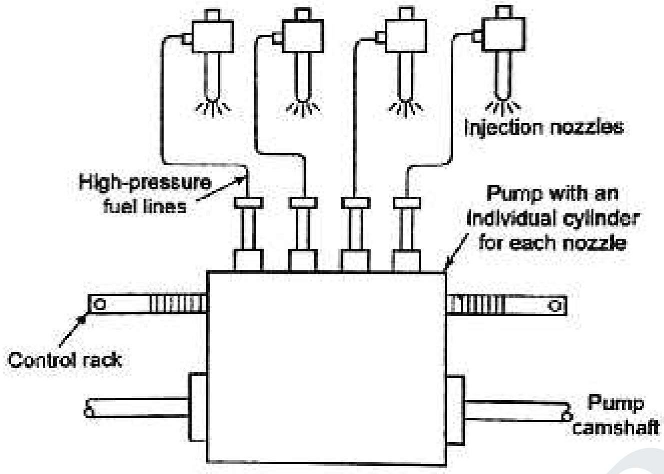
3.Distributor system

1.Common rail injection system



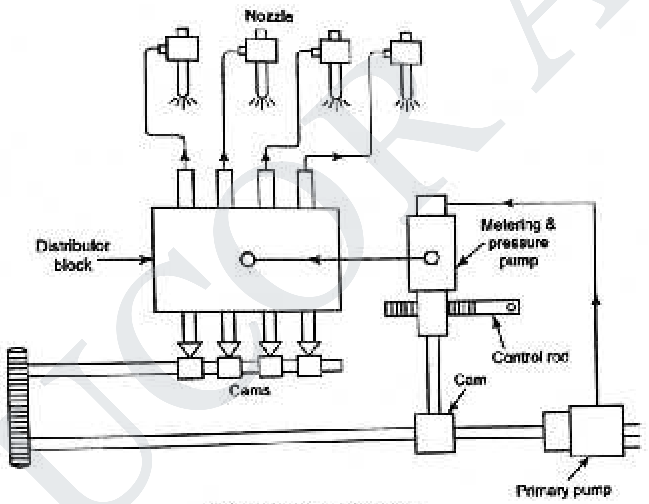
Common rail injection system

2.Individual pump injection system



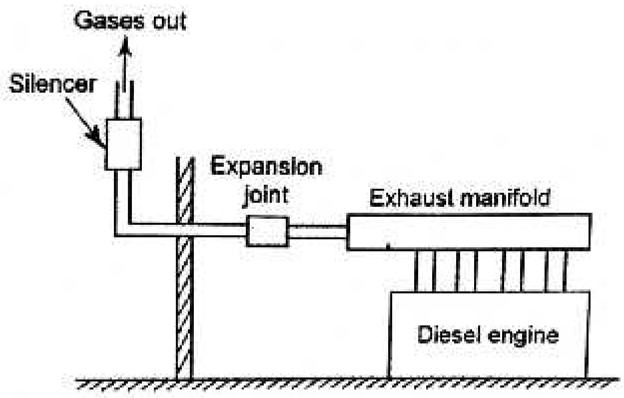
Individual pump injection system

3.Rotary distributor system



Rotary distributor system

5.EXHAUST SYSTEM



Exhaust system

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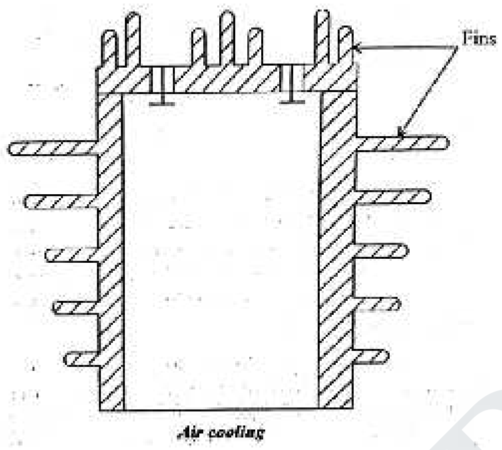
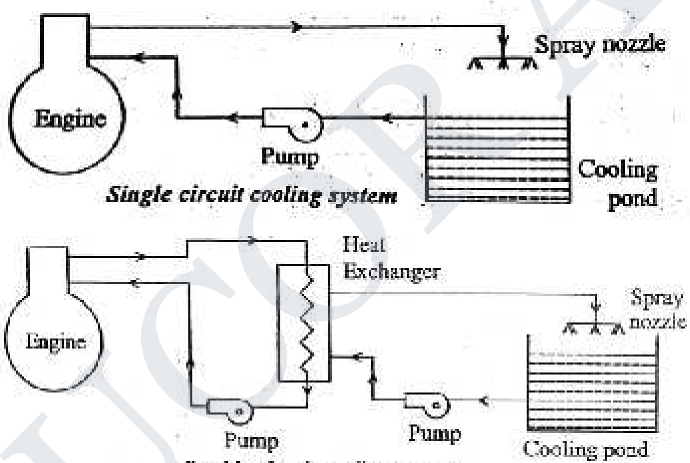
6. COOLING SYSTEM

a. Air cooling



Air cooling

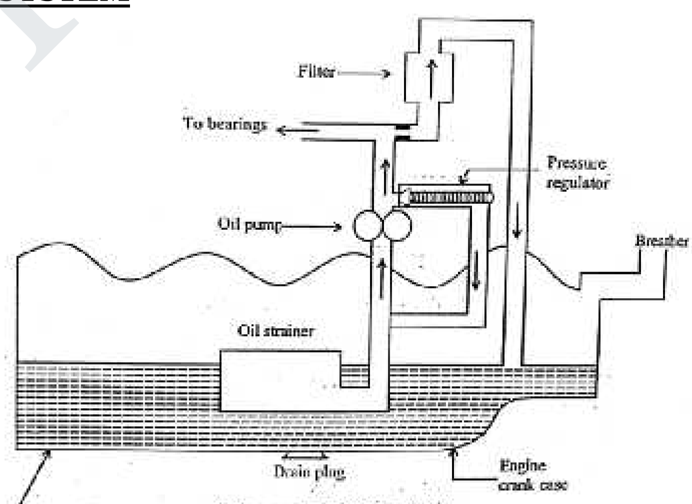
b. Liquid cooling



Single circuit cooling system

Double circuit cooling system

7.LUBRICATING SYSTEM



Wet sump lubricating system

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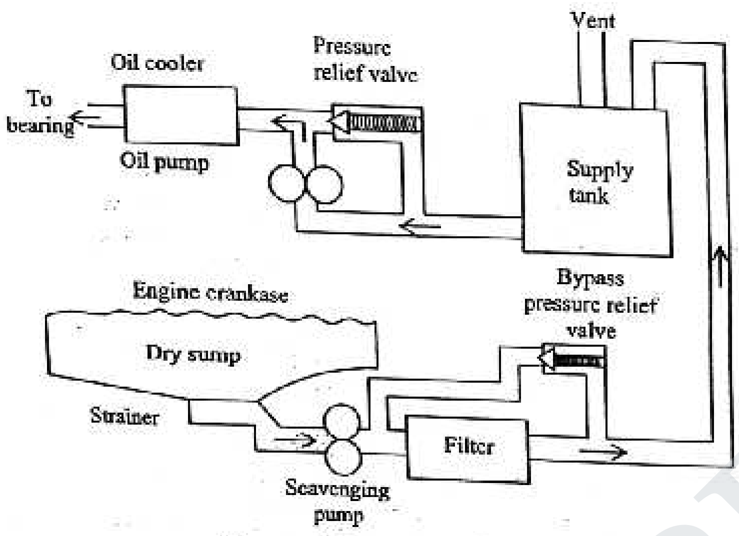


Dry sump lubrication system.

In a diesel power station, diesel engine is used as the prime mover. The diesel burns inside the engine and the products of this combustion act as the working fluid to produce mechanical energy. The diesel engine drives alternator which converts mechanical energy into electrical energy.

APPLICATION OF DIESEL POWER PLANT

1. It is suitable for mobile power generation.
2. It is used as peak load plants in combined with thermal and hydro plants.
3. It is used as stand by plants for emergency service.

ADVANTAGES

1. Fuel handling is easy and there is no problem of ash disposal.
2. Layout is simple.
3. Quick starting and easy pickup of loads.
4. Skilled manpower is not required.
5. It requires less quantity of water for cooling purposes.

DISADVANTAGES

1. The repair and maintenance cost are high.
2. The plant capacity is limited to about 50 MW of power.
3. Noise is a serious problem.
4. The efficiency is low.
5. Life of the plant is low.

GAS TURBINE POWER PLANT

A gas turbine, also called a combustion turbine, is a type of continuous combustion, internal combustion engine. There are three main components:

1. An upstream rotating gas compressor;
2. A downstream turbine on the same shaft;
3. A combustion chamber or area, called a combustor, in between 1. and 2. above.

A fourth component is often used to increase efficiency (turboprop, turbofan), to convert power into mechanical or electric form (turboshaft, electric generator), or to achieve greater power to mass/volume ratio (afterburner).

The basic operation of the gas turbine is a Brayton cycle with air as the working fluid. Fresh atmospheric air flows through the compressor that brings it to higher pressure. Energy is then added by spraying fuel into the air and igniting it so the combustion generates a high-temperature flow. This high-temperature high-pressure gas enters a turbine, where it expands down to the exhaust pressure, producing a shaft work output in the process. The turbine shaft work is used to drive the compressor; the energy that is not used for shaft work comes out in the exhaust gases that produce thrust. The purpose of the gas turbine determines the design so that the most desirable split of energy between the thrust and the shaft work is achieved. The fourth step of the Brayton cycle (cooling of the working fluid) is omitted, as gas turbines are open systems that do not use the same air again.

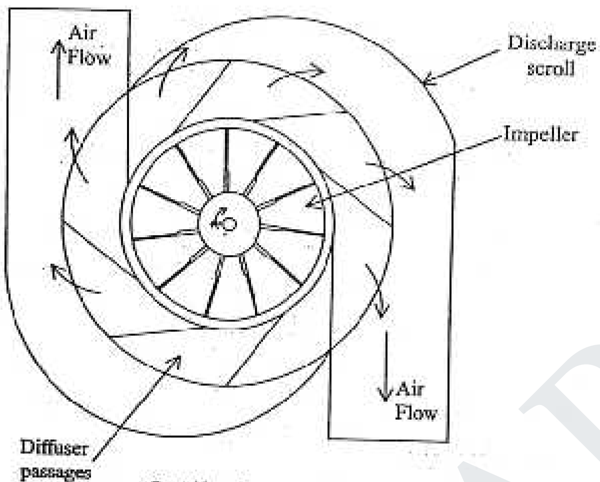
Gas turbines are used to power aircraft, trains, ships, electrical generators, pumps, gas compressors, and tanks.

COMPONENTS OF GAS TURBINE POWER PLANT

1. Compressor
2. Combustion chamber
3. Gas Turbine
4. Intercoolers and Regenerators

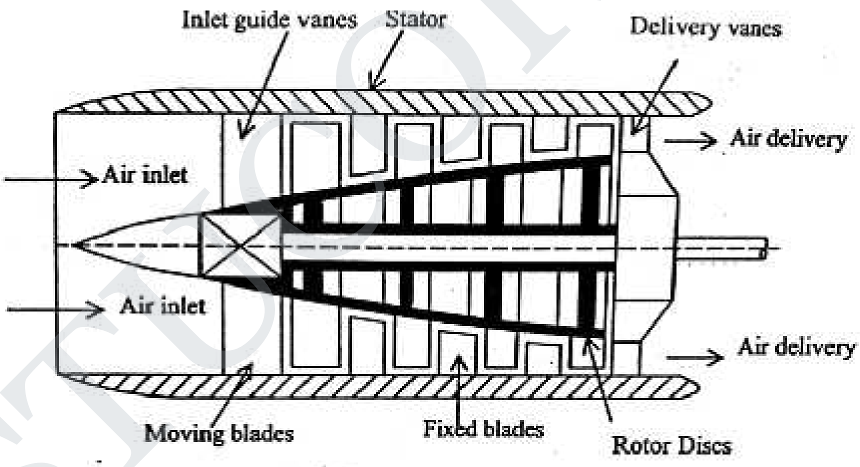
1. COMPRESSOR

a. Centrifugal compressor



Centrifugal compressor

b. Axial Flow Compressor



Axial flow compressor

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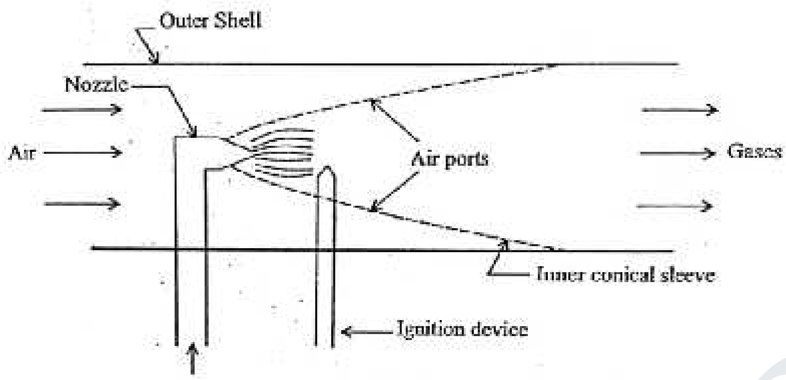
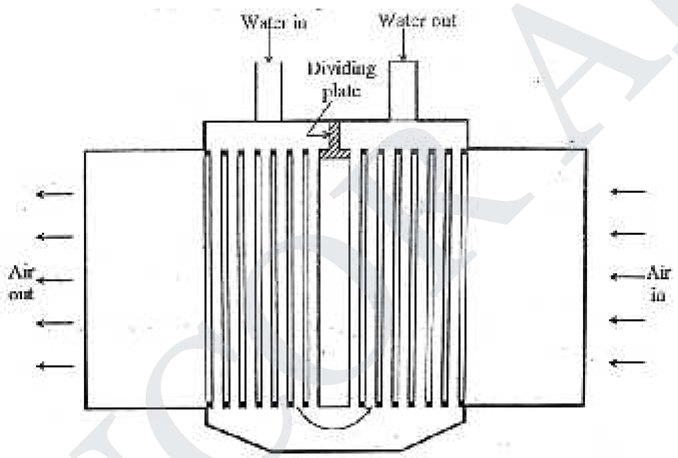
2. COMBUSTION CHAMBER

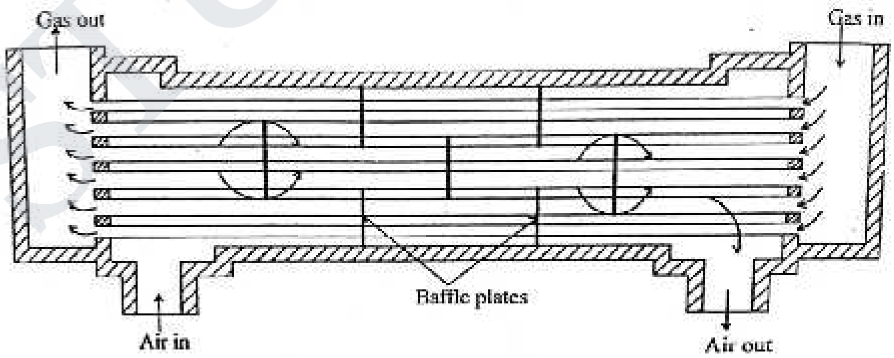


Combustion chamber/ combustor

4.INTERCOOLER AND REGULATOR



intercooler



Regenerator

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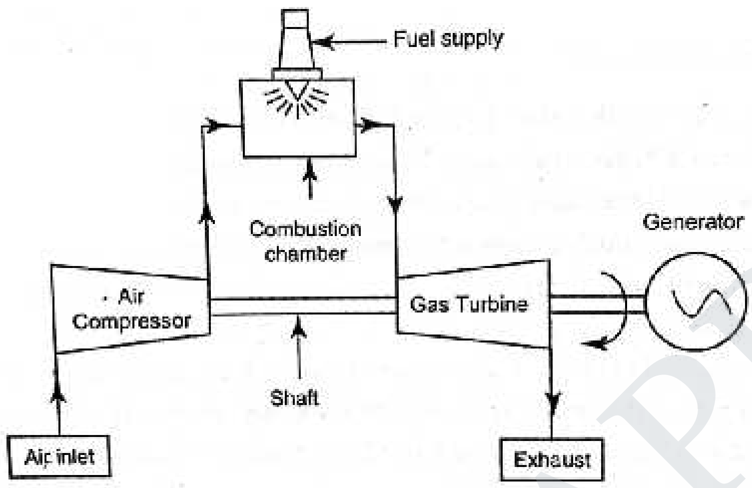
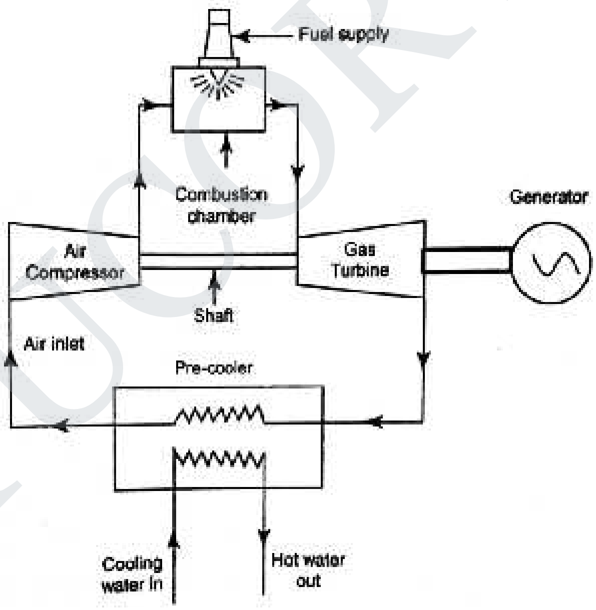
WORKING OF GAS TURBINE POWER PLANT

a. Open cycle gas turbine power plant



Open cycle gas turbine

b. Closed cycle gas power plant



Closed cycle gas turbine

Advantages of gas turbine power plants

1. Smaller in size.
2. Natural gas is a very suitable fuel.
3. Subjected to less vibration
4. Requires less water
5. Less maintenance
6. Exhaust of the gas turbine is free from smoke.

Disadvantage

1. Efficiency is poor.
2. The devices that are operated at high temperature are complicated.

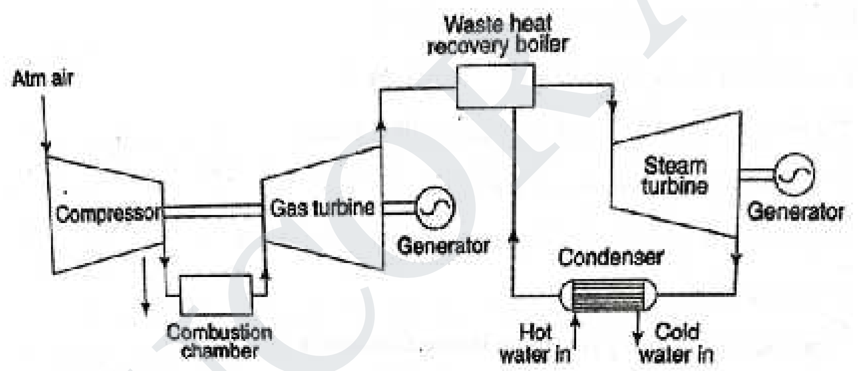
COMBINED CYCLE POWER PLANTS

The Combined Cycle Power Plant or ***combined cycle gas turbine***, a gas turbine generator generates electricity and waste heat is used to make steam to generate additional electricity via a steam turbine.

The gas turbine is one of the most efficient one for the conversion of gas fuels to mechanical power or electricity. The use of distillate liquid fuels, usually diesel, is also common as alternate fuels.

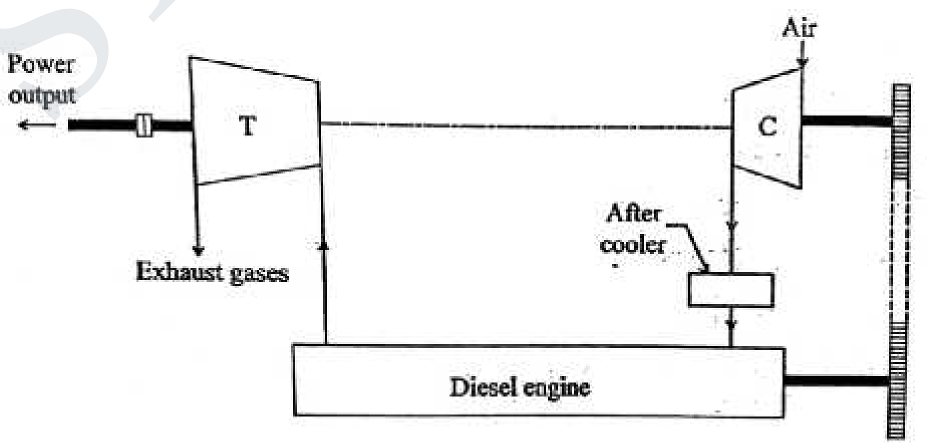
More recently, as simple cycle efficiencies have improved and as natural gas prices have fallen, gas turbines have been more widely adopted for base load power generation, especially in combined cycle mode, where waste heat is recovered in waste heat boilers, and the steam used to produce additional electricity.

a. Gas turbine-Steam Turbine plant



Combined gas turbine-steam turbine power plant

b. Gas turbine-Diesel power plant



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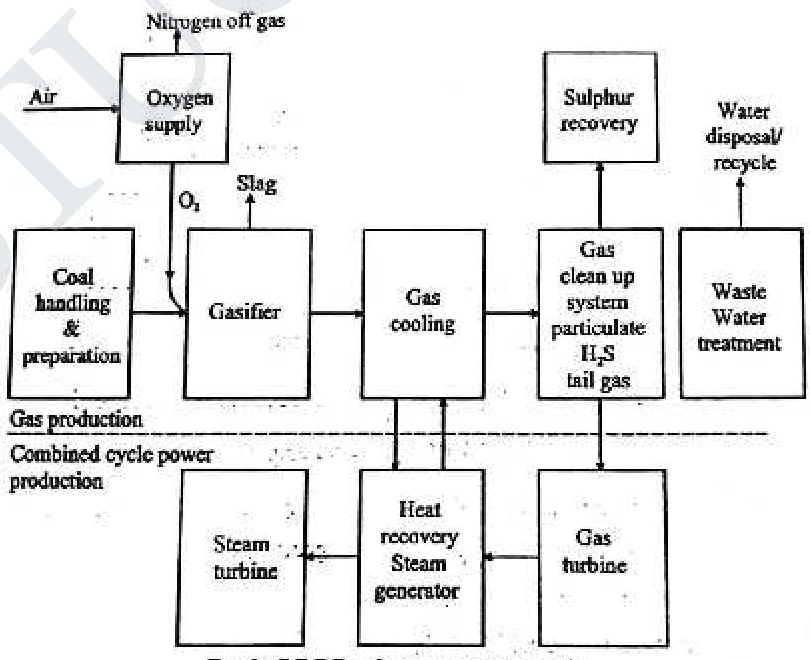
Advantages

1. Efficiency is high
2. Suitable for rapid start and shutdown.
3. High ratio of power output to occupy ground space.

INTEGRATED GASIFIER BASED COMBINED CYCLE SYSTEMS

An integrated gasification combined cycle (IGCC) is a technology that uses a high pressure gasifier to turn coal and other carbon based fuels into pressurized gas—synthesis gas (syngas). It can then remove impurities from the syngas prior to the power generation cycle. Some of these pollutants, such as sulfur, can be turned into re-usable byproducts through the Claus process. This results in lower emissions of sulfur dioxide, particulates, mercury, and in some cases carbon dioxide. With additional process equipment, a water-gas shift reaction can increase gasification efficiency and reduce carbon monoxide emissions by converting it to carbon dioxide. The resulting carbon dioxide from the shift reaction can be separated, compressed, and stored through sequestration. Excess heat from the primary combustion and syngas fired generation is then passed to a steam cycle, similar to a combined cycle gas turbine. This process results in improved thermodynamic efficiency compared to conventional pulverized coal combustion.

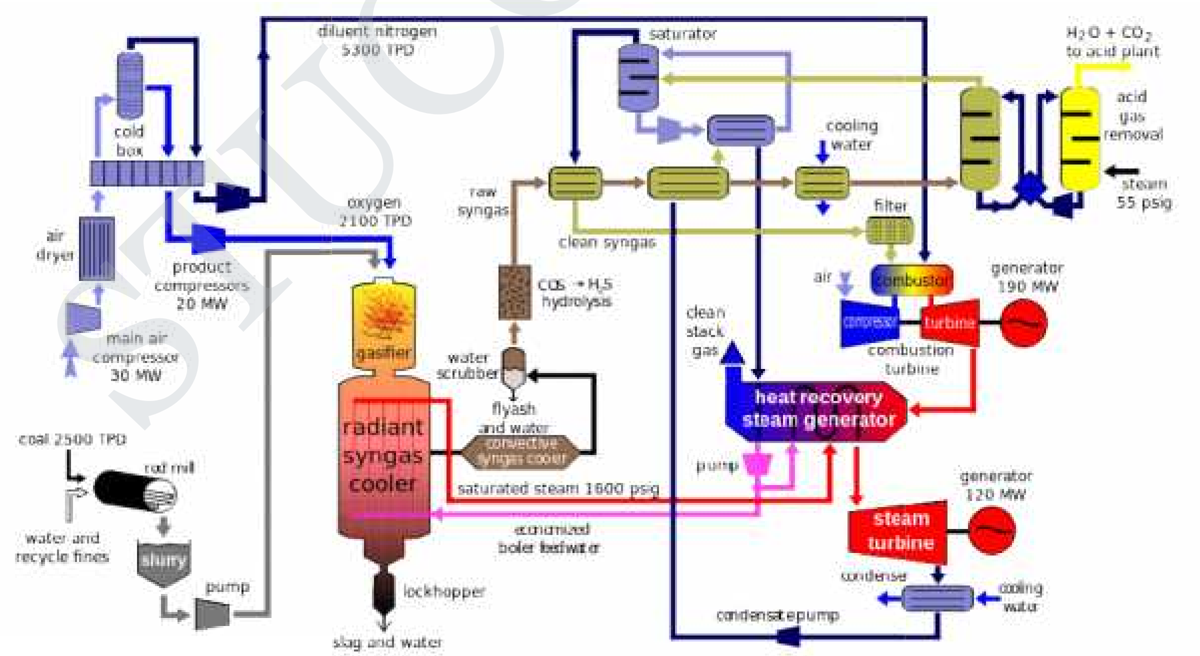


Basic IGCC plant arrangement

The gasification process can produce syngas from a wide variety of carbon-containing feedstocks, such as high-sulfur coal, heavy petroleum residues, and biomass.

The plant is called *integrated* because (1) the syngas produced in the gasification section is used as fuel for the gas turbine in the combined cycle and (2) the steam produced by the syngas coolers in the gasification section is used by the steam turbine in the combined cycle. In this example the syngas produced is used as fuel in a gas turbine which produces electrical power. In a normal combined cycle, so-called "waste heat" from the gas turbine exhaust is used in a Heat Recovery Steam Generator (HRSG) to make steam for the steam turbine cycle. An IGCC plant improves the overall process efficiency by adding the higher-temperature steam produced by the gasification process to the steam turbine cycle. This steam is then used in steam turbines to produce additional electrical power.

IGCC plants are advantageous in comparison to conventional coal power plants due to their high thermal efficiency, low non-carbon greenhouse gas emissions, and capability to process low grade coal. The disadvantages include higher capital and maintenance costs, and the amount of CO2 released without pre-combustion capture.



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UNIT- III

NUCLEAR POWER PLANTS

Basics of Nuclear Engineering, Layout and subsystems of Nuclear Power Plants, Working of Nuclear Reactors: Boiling Water Reactor (BWR), Pressurized Water Reactor (PWR), CANada Deuterium-Uranium reactor (CANDU), Breeder, Gas Cooled and Liquid Metal Cooled Reactors. Safety measures for Nuclear Power plants.

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R.M.D. ENGINEERING COLLEGE

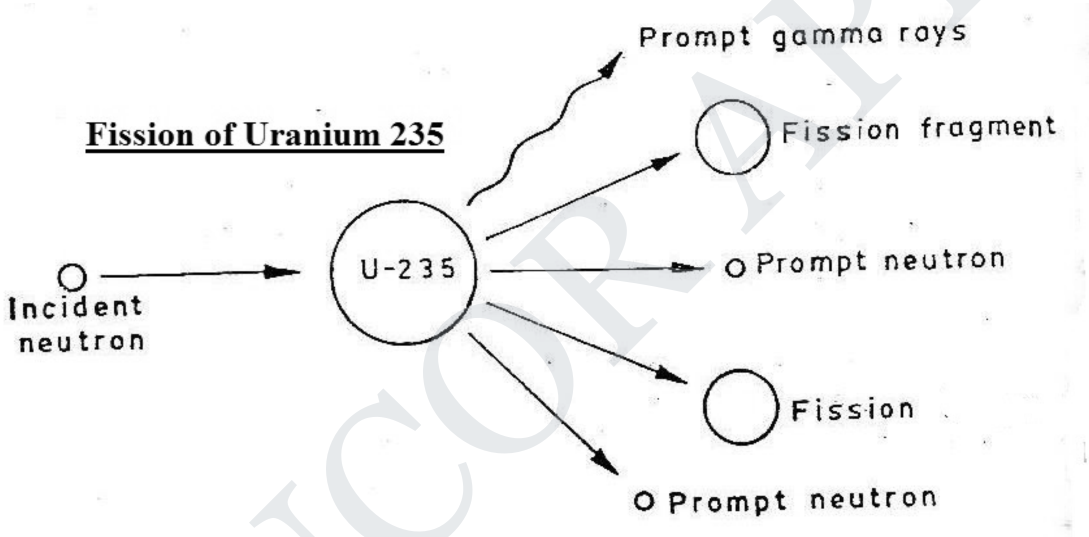
BASICS OF NUCLEAR ENGINEERING

1. **NUCLEAR FISSION**

Fission is the process that occurs when a neutron collides with the nucleus of certain of the heavy atoms, causing the original nucleus to split into two or more unequal fragments which carry of most of the energy of fusion as kinetic energy. This process is accompanied by the emission of neutron and gamma rays.

Fig. below is a representation of the fission of Uranium 235. The energy released as a result of fission is the basis for nuclear power generation. The release of about 2.5 neutrons / fission makes it possible to produce sustained fissioning.

Fission of Uranium 235

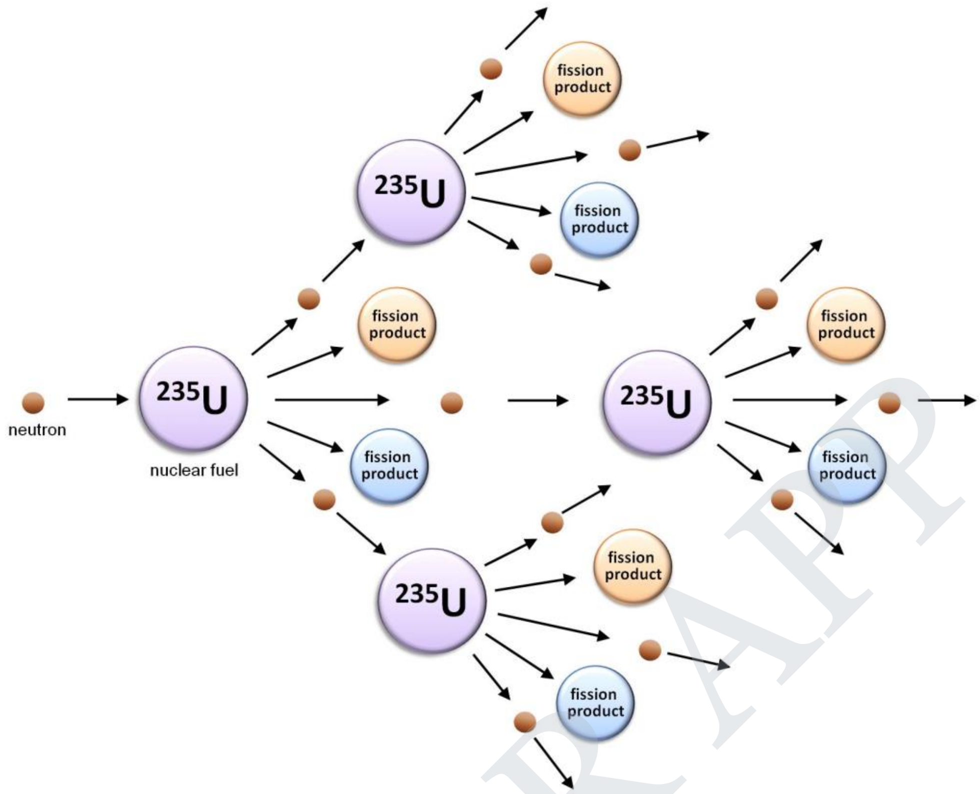


2. **NUCLEAR FUSION**

It is the process of combining or fusing two lighter nuclei into a stable and heavier nuclide. In this case also, a large amount of energy is released because mass of the product nucleus is less than the masses of the two nuclei which are fused.

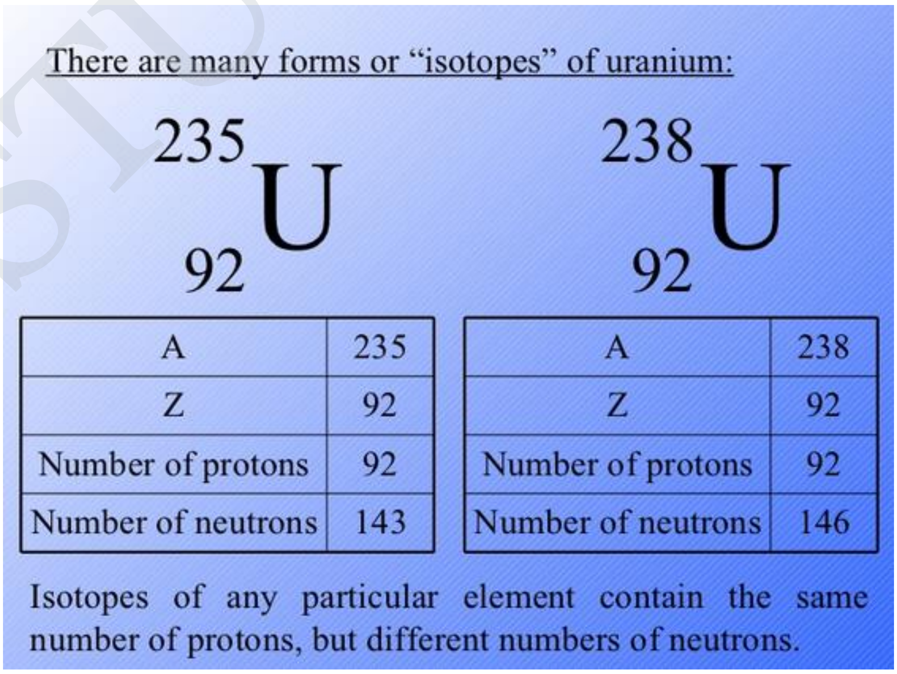
3. **CHAIN REACTION**

A chain reaction is that process in which the number of neutrons keeps on multiplying rapidly (in geometrical progression) during fission till whole of the fissionable material is disintegrated. The chain reaction will become self-sustaining or self propagating only if, for every neutron absorbed, at least one fission neutron becomes available for causing fission of another nucleus.



4. ISOTOPES

Isotopes are atoms of the same element having the same numbers of protons (atomic number), but different numbers of neutrons. They have same chemical properties due to the same electron configuration, but different physical properties.



A	235
Z	92
Number of protons	92
Number of neutrons	143

A	238
Z	92
Number of protons	92
Number of neutrons	146

5. NUCLEAR FUEL

Nuclear fuel is a substance that is used in nuclear power stations to produce heat to power turbines. Heat is created when nuclear fuel undergoes nuclear fission. Most nuclear fuels contain heavy fissile elements that are capable of nuclear fission, such asUranium-235 or Plutonium-239. When the unstable nuclei of these atoms are hit by a slow-moving neutron, they split, creating two daughter nuclei and two or three more neutrons. These neutrons then go on to split more nuclei. This creates a self-sustaining chain reaction that is controlled in a nuclear reactor.

6. URANIUM ENRICHMENT

Enriched uranium is a type of uranium in which the percent composition of uranium-235 has been increased through the process of isotope separation. Natural uranium is 99.284% ^{238}U isotope, with ^{235}U only constituting about 0.711% of its mass. ^{235}U is the only nuclide existing in nature (in any appreciable amount) that is fissile with thermal neutrons.

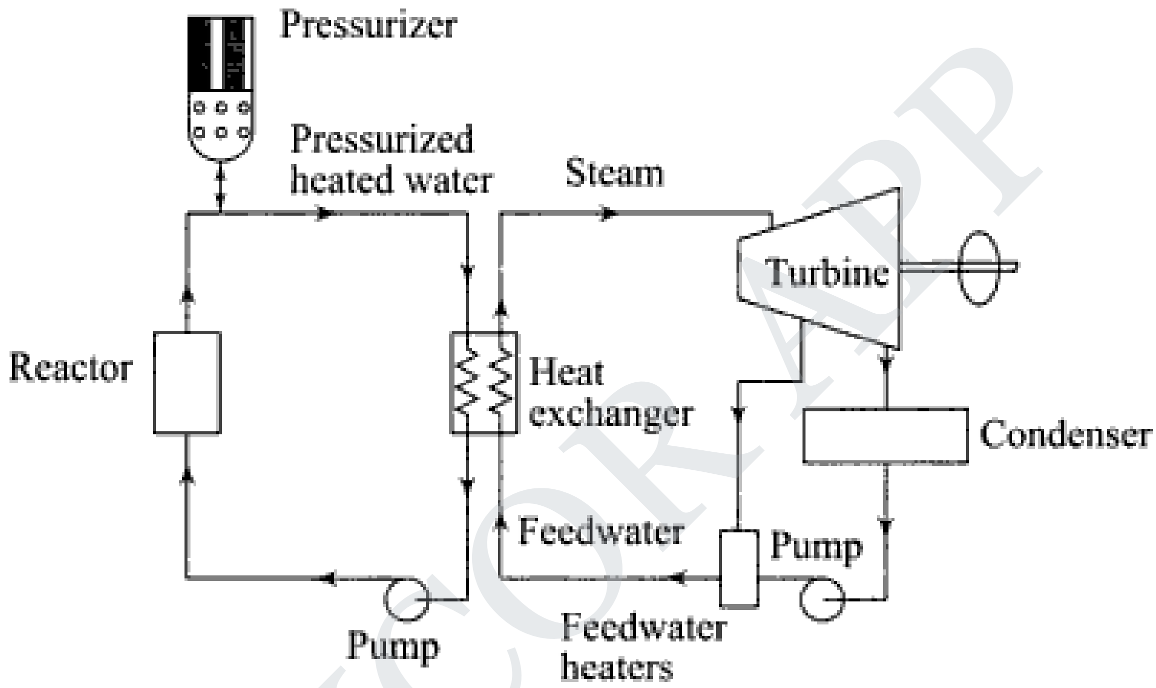
Uranium found in nature consists largely of two isotopes, U-235 and U-238. The production of energy in nuclear reactors is from the 'fission' or splitting of the U-235 atoms, a process which releases energy in the form of heat. U-235 is the main fissile isotope of uranium.

Natural uranium contains 0.7% of the U-235 isotope. The remaining 99.3% is mostly the U-238 isotope which does not contribute directly to the fission process (though it does so indirectly by the formation of fissile isotopes of plutonium). Isotope separation is a physical process to concentrate (‘enrich’) one isotope relative to others. Most reactors are light water reactors (of two types – PWR and BWR) and require uranium to be enriched from 0.7% to 3-5% U-235 in their fuel. This is normal low-enriched uranium (LEU). There is some interest in taking enrichment levels to about 7%, and even close to 20% for certain special power reactor fuels, as high-assay LEU (HALEU).

Uranium-235 and U-238 are chemically identical, but differ in their physical properties, notably their mass. The nucleus of the U-235 atom contains 92 protons and 143 neutrons, giving an atomic mass of 235 units. The U-238 nucleus also has 92 protons but has 146 neutrons – three more than U-235 – and therefore has a mass of 238 units.

The difference in mass between U-235 and U-238 allows the isotopes to be separated and makes it possible to increase or "enrich" the percentage of U-235. All present and historic enrichment processes, directly or indirectly, make use of this small mass difference.

LAYOUT OF NUCLEAR POWER PLANT



COMPONENTS OF NUCLEAR POWER PLANT

1. Nuclear reactor
2. Heat exchanger or steam generator
3. Steam turbine
4. Condenser
5. Electric generator or Alternator

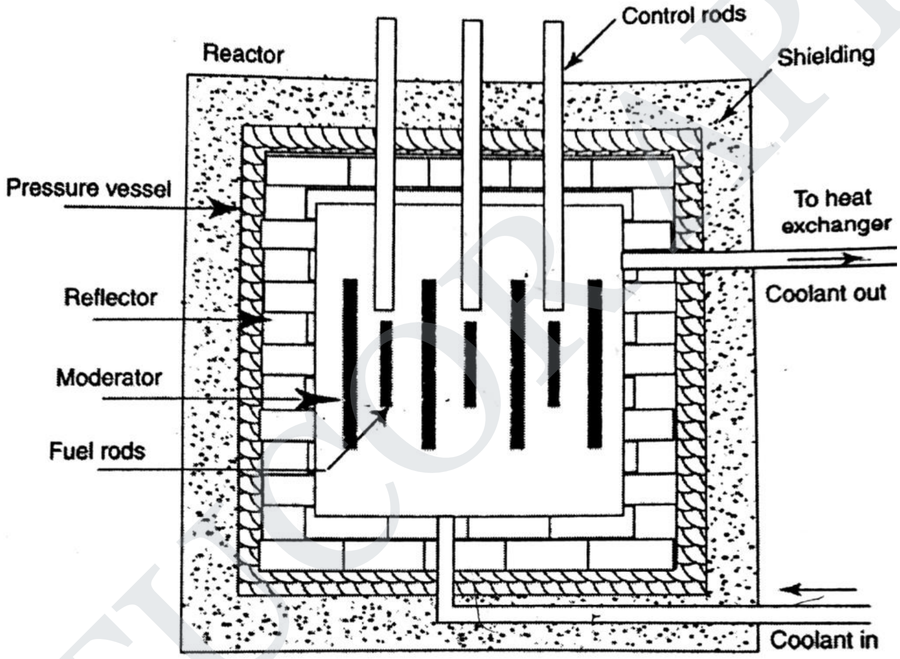
COMPONENTS OF NUCLEAR REACTOR

There are several components common to most types of reactors:

Fuel. Uranium is the basic fuel. Usually pellets of uranium oxide (UO_2) are arranged in tubes to form fuel rods. The rods are arranged into fuel assemblies in the reactor core. In a 1000 MWe class PWR there might be 51,000 fuel rods with over 18 million pellets.

Moderator. Material in the core which slows down the neutrons released from fission so that they cause more fission. It is usually water, but may be heavy water or graphite.

Control rods. These are made with neutron-absorbing material such as cadmium, hafnium or boron, and are inserted or withdrawn from the core to control the rate of reaction, or to halt it.* In some PWR reactors, special control rods are used to enable the core to sustain a low level of power efficiently. (Secondary control systems involve other neutron absorbers, usually boron in the coolant – its concentration can be adjusted over time as the fuel burns up.) PWR control rods are inserted from the top, BWR cruciform blades from the bottom of the core.



Nuclear reactor

Coolant. A fluid circulating through the core so as to transfer the heat from it. In light water reactors the water moderator functions also as primary coolant. Except in BWRs, there is secondary coolant circuit where the water becomes steam. (See also later section on primary coolant characteristics.) A PWR has two to four primary coolant loops with pumps, driven either by steam or electricity – China's Hualong One design has three, each driven by a 6.6 MW electric motor, with each pump set weighing 110 tonnes.

Pressure vessel or pressure tubes. Usually a robust steel vessel containing the reactor core and moderator/coolant, but it may be a series of tubes holding the fuel and conveying the coolant through the surrounding moderator.

Steam generator. Part of the cooling system of pressurised water reactors (PWR & PHWR) where the high-pressure primary coolant bringing heat from the reactor is used to make steam for the turbine, in a secondary circuit. Essentially a heat exchanger like a motor car radiator.* Reactors have up to six 'loops', each with a steam generator. Since 1980 over 110 PWR reactors have had their steam generators replaced after 20-30 years service, 57 of these in USA.

[* These are large heat exchangers for transferring heat from one fluid to another – here from high-pressure primary circuit in PWR to secondary circuit where water turns to steam. Each structure weighs up to 800 tonnes and contains from 300 to 16,000 tubes about 2 cm diameter for the primary coolant, which is radioactive due to nitrogen-16 (N-16, formed by neutron bombardment of oxygen, with half-life of 7 seconds). The secondary water must flow through the support structures for the tubes. The whole thing needs to be designed so that the tubes don't vibrate and fret, operated so that deposits do not build up to impede the flow, and maintained chemically to avoid corrosion. Tubes which fail and leak are plugged, and surplus capacity is designed to allow for this. Leaks can be detected by monitoring N-16 levels in the steam as it leaves the steam generator.]

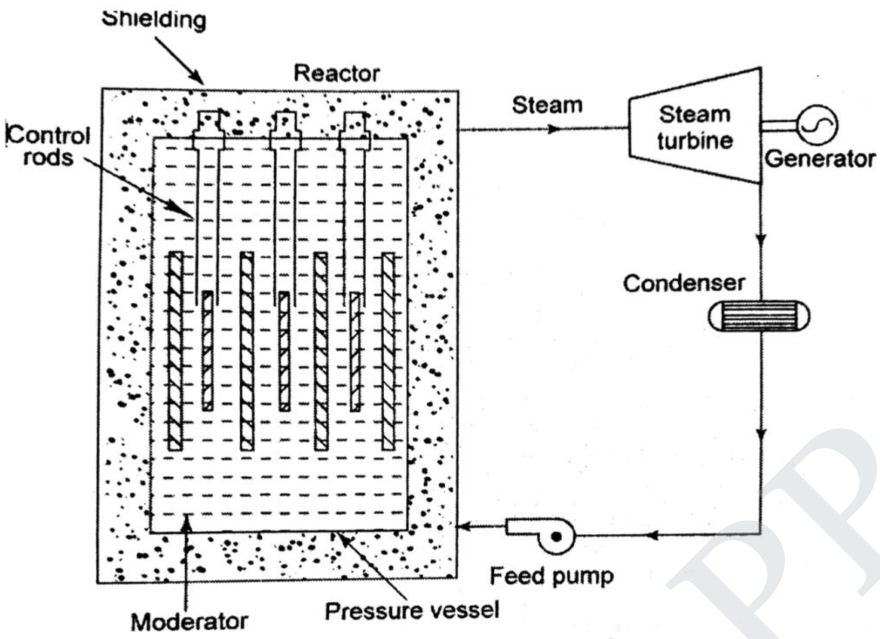
Containment. The structure around the reactor and associated steam generators which is designed to protect it from outside intrusion and to protect those outside from the effects of radiation in case of any serious malfunction inside. It is typically a metre-thick concrete and steel structure.

Newer Russian and some other reactors install core melt localisation devices or 'core catchers' under the pressure vessel to catch any melted core material in the event of a major accident.

BOILING WATER REACTOR (BWR)

In a boiling water reactor enriched fuel is used. As compared to PWR, the BWR plant is simple. The plant can be safely operated using natural convection within the core or forced circulation as shown in the fig. below.

For the safe operation of the reactor the pressure in the circulation must be maintained constant irrespective of the load. In case of part load operation of the turbine some steam is bypassed.



Boiling water reactor (BWR)

Advantages of BWR:

1. Heat exchanger circuit is eliminated and consequently there is gain thermal efficiency.

2. There is use of a lower pressure vessel for the reactor which further reduces cost and simplifies containment problems.

3. The metal temperature remains low for given output conditions.

4. The cycle for BWR is more efficient than PWR for given containment pressure, the outlet temperature of steam is appreciably higher in BWR.

5. The pressure inside the pressure vessel is not high so a thicker vessel is not 'required.

Disadvantages of PWR: -

1. Possibility of radioactive contamination in the turbine mechanism, should there be any failure of fuel elements.

2. More elaborate safety precautions needed which are costly.

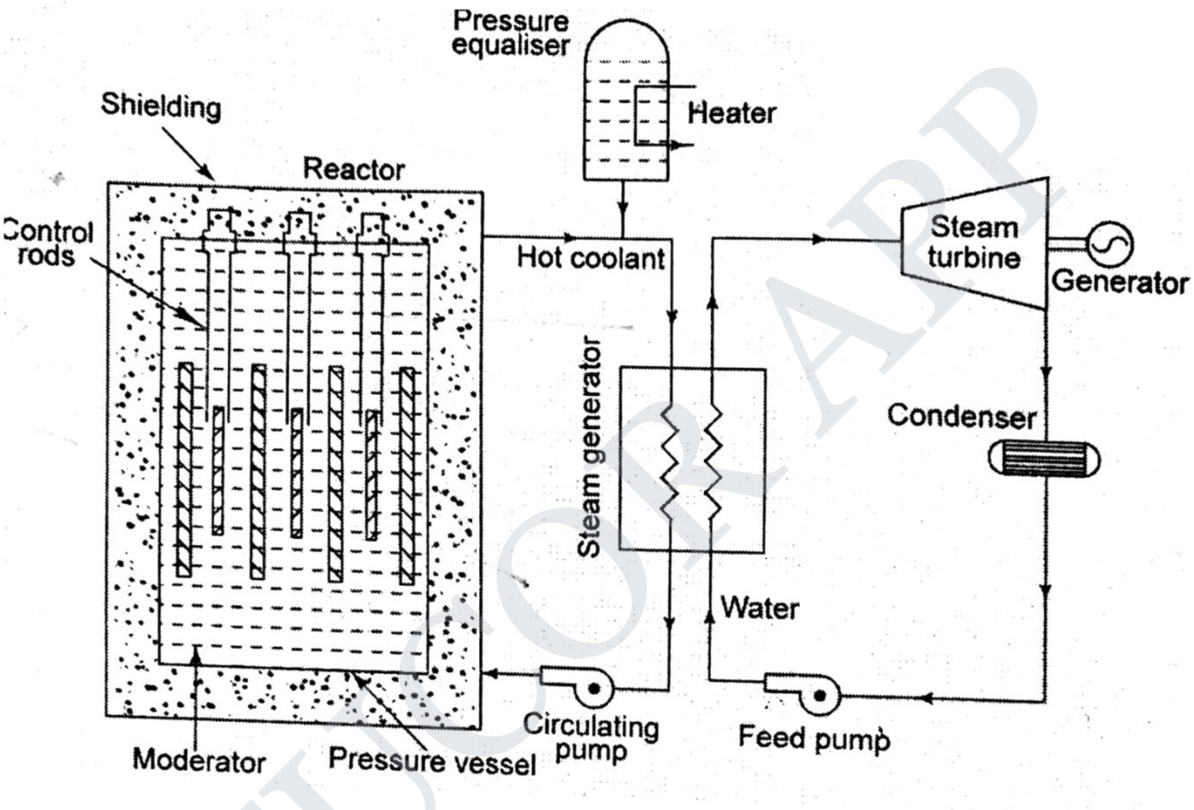
3. Wastage of steam resulting in lowering of thermal efficiency on part load operation.

4. Boiling limits power density ; only 3 to 5% by mass can be converted to steam per pass through the boiler.

5. The possibility of burn out of fuel is more in this reactor than PWR as boiling of water on the surface of the fuel is allowed.

PRESSURIZED WATER REACTOR (PWR)

A pressurized water reactor, in its simplest form, is a light water cooled and moderated reactor having an unusual core design, using both natural and highly enriched fuel. Refer Fig. below, in PWR, there are two circuits of water, one primary circuit which passes through the fuel core and is radioactive.



Pressurised water reactor

This primary circuit then produces steam in a secondary circuit which consists of heat exchanger or the boiler and the turbine. As such the steam in the turbine is not radioactive and need not be shielded. The pressure in the primary circuit should be high so that the boiling of water takes place at high pressure. A pressurising tank keeps the water at about 100 kgf/cm^2 so that will not boil.

Electric heating coils in the pressurized boil some of the water to form steam that collects in the dome. As more steam is forced into the dome by boiling, its pressure rises and pressurises the entire circuit. The pressure may be reduced by providing cooling coils or spraying water on the steam. Water acts both as coolant as well as moderator.

Either heavy water or the light water may be used for the above purpose.
A pressurized water reactor can produce only saturated steam. By providing a separate furnace, the steam formed from the reactor could be super-heated.

Advantages of PWR: -

1. Water used in reactor (as coolant, moderator and reflector) is cheap and easily available.
2. The reactor is compact and power density is high.
3. Fission products remain contained in the reactor and are not circulated.
4. A small number of control rods is required.
5. There is a complete freedom to inspect and maintain the turbine, feed heaters and condenser during operation. .
6. This reactor allows to reduce the fuel cost extracting more energy per unit weight of fuel as it is ideally suited to the utilization of fuel designed for higher burn-ups.

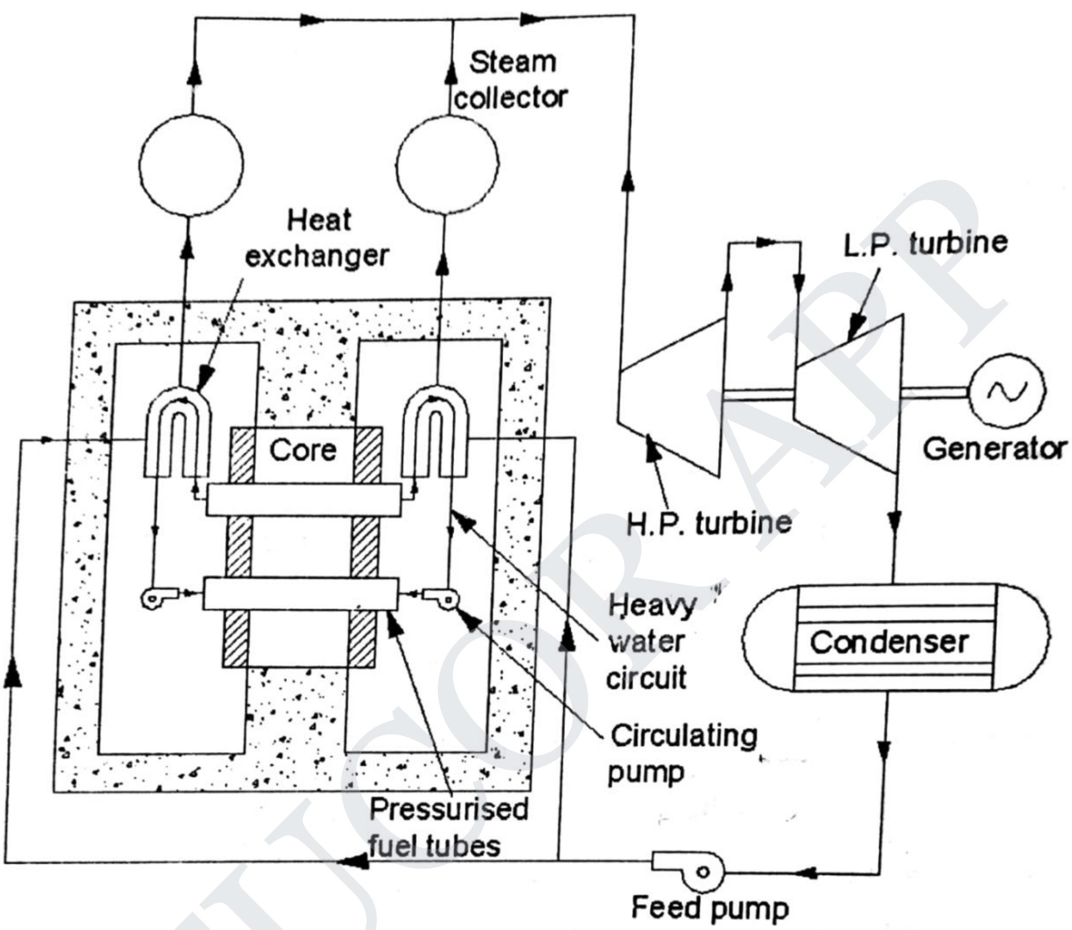
Disadvantages of PWR: -

1. Capital cost is high as high primary circuit requires strong pressure vessel.
2. In the secondary circuit the thermodynamic efficiency of this plant is quite low
3. Fuel suffers radiation damage and, therefore its reprocessing is difficult.
4. Severe corrosion problems.
5. It is imperative to shut down the reactor for fuel charging which requires a couple of month's time.
6. Low volume ratio of moderator to fuel makes fuel element design and insertion of fuel rods difficult.
7 Fuel element fabrication is expensive.

<u>CANDU REACTOR</u>

CANDU is a thermal nuclear power reactor in which heavy water (99 8% deuterium oxide D_2O) is the moderator and coolant as well as the neutron reflector. This reactor was developed in Canada and is being extensively used in that company. A few CANDU reactors are operating or under construction in some other countries as well.

In this type of reactor the natural uranium (0.7% U^{235}) is used as fuel and heavy water as moderator. These reactors are more economical to those countries which do not produce enriched uranium as the enrichment of uranium is very costly.



CANDU reactor

CANDU (heavy water) reactor, differs basically from light-water reactors (LWRS) in that in the latter the same water serves on both moderator and coolant, whereas in the CANDU reactor the moderator and coolant are kept separate. Consequently unlike the pressure vessel of a LWR, the CANDU reactor vessel, which contains the relatively cool heavy water moderator, does not have to WITHSTAND a high pressure. Only the heavy water coolant circuit has to be pressurized to inhibit boiling reactor core.

There are two coolant outlet (and two inlet) headers, one at each end of the reactor vessel, corresponding to the opposite directions of coolant flow through the core. Each inlet (and outlet) header is connected to a separate steam generator and pimp loop. A single pressuriser (of the type in pressurised water reactors) maintains an essentially constant coolant system pressure. The reactor vessel and the steam generator system are' enclosed by a concrete containment structure. A water spray in the containment would condense the steam and reduce the pressure that would result from a large break in the coolant circuit.

Advantages of CANDU reactor

1. Heavy water is used as moderator, which has higher multiplication factor and low fuel consumption.
2. Enriched fuel is not required.
3. The cost of the vessel is less as it has not to withstand a high pressure.
4. Less time is needed (as compared to PWR and BWR) to construct the reactor.
5. The moderator can be kept at low temperature which increases its effectiveness in slowing down neutrons.

Disadvantages of CANDU reactor

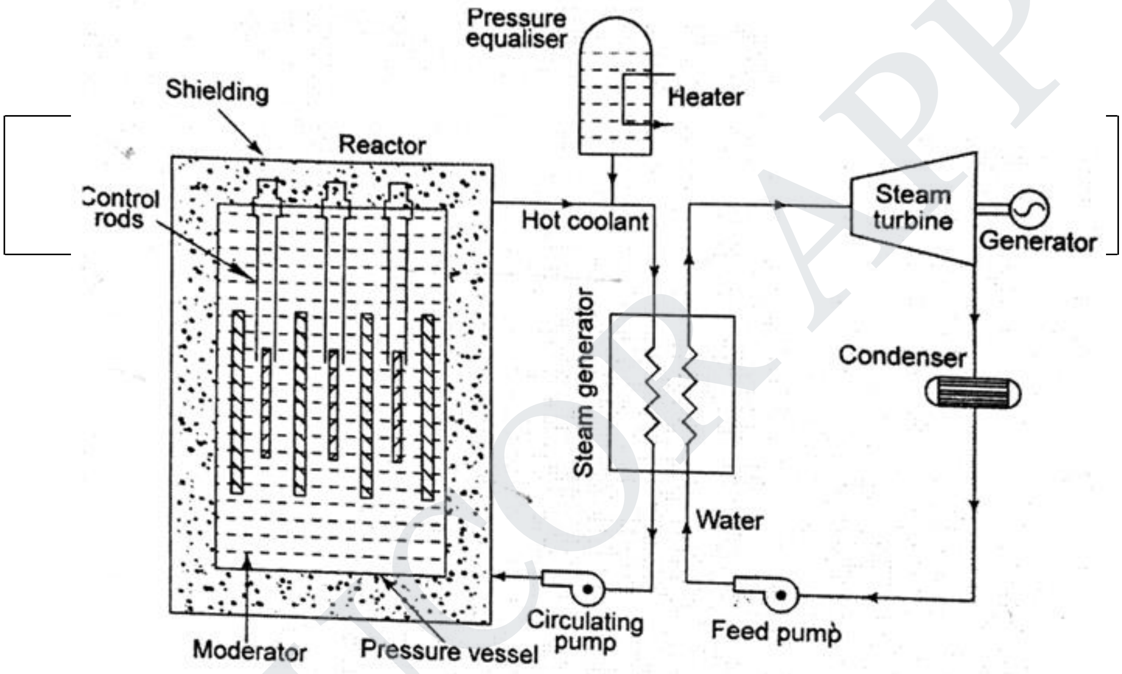
1. It requires a very high standard of design, manufacture and maintenance
2. The cost of heavy water is very high.
3. There are leakage problems.
4. The size of the reactor is extremely large as power density is low as compared with PWR and BWR.

BREEDER

Breeder reactors could, in principle, extract almost all of the energy contained in uranium or thorium, decreasing fuel requirements by a factor of 100 compared to widely used once-through light water reactors, which extract less than 1% of the energy in the uranium mined from the earth. The high fuel-efficiency of breeder reactors could greatly reduce concerns about fuel supply or energy used in mining.

GAS COOLED REACTOR

In such a type of reactor, the coolant used can be air, hydrogen, helium or carbon dioxide. Generally inert gases are used such as helium and carbon dioxide. The moderator used is graphite. The problem of corrosion is reduced much in such reactors. This type of reactor is more safe specially in case of accidents and the failure circulating pumps. The thickness of gas cooled reactor shield is much reduced. as compared to the other type of reactor. Arrangement of high temperature, gas cooled reactor is shown below:



There are two principal types of gas cooled reactors developed for centre station service and these are :

(1) The gas cooled, graphite moderator reactor (GCGM)

(2) The high temperature gas cooled reactor (HTGC).

Both types are graphite moderated. The former (GCGM) uses natural uranium fuel while the latter (HTGC) employs highly enriched uranium carbide mixed with thorium carbide and clad with graphite.

The coolant pressure and temperature in GCGM are about 7bar 336^{0}C respectively, for HTGC, these figures are 15 to 30 bar and 700^{0}C to 800^{0}C.

Advantages of Gas cooled reactor :-

1. The processing of the fuel is simpler.

2. No corrosion problem

3. As a result of low parasitic absorption it gives better neutron economy.

4. Graphite remains stable under irradiation at high temperature

5. The use of carbon dioxide as coolant completely eliminates the possibility of explosion in the reactor which is always present in water-cooled plants.

6 The uranium carbide and graphite are able to resist high temperatures, and, therefore the problem of limiting fuel element temperature is not as serious as in other reactors.

Disadvantages of Gas cooled reactor :-

1. Fuel loading is more elaborate and costly.

2. Power density is very low (due to low heat transfer coefficient), therefore lard vessel is required.

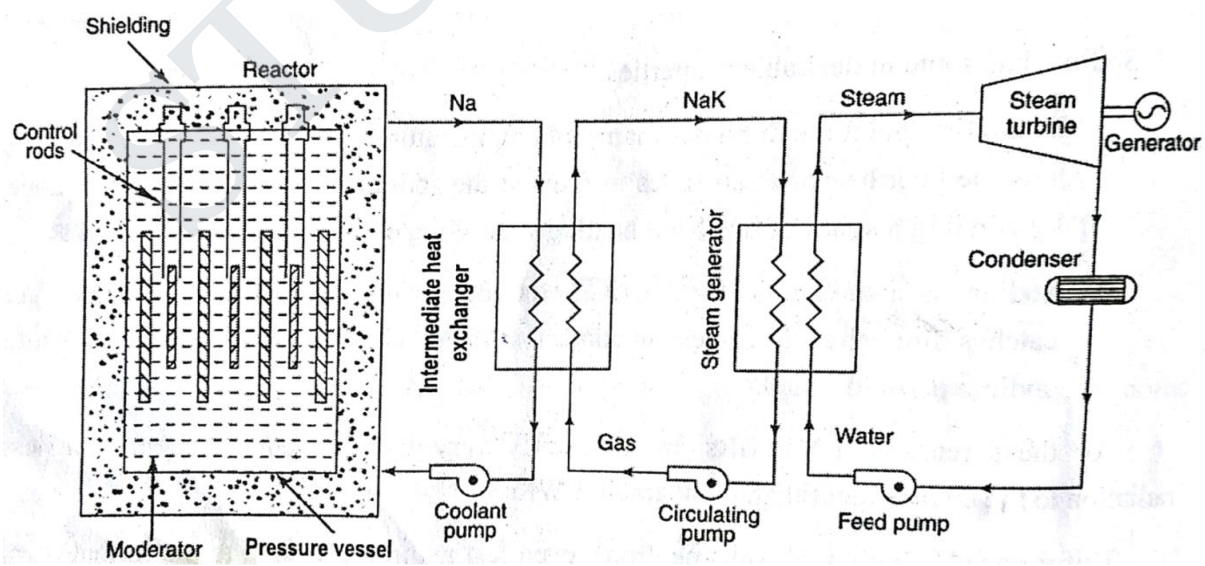
3. Since the critical mass is high therefore large amount of fuel loading is initially required.

4. If helium is used instead of carbon dioxide, the leakage of gas is a major problem.

5. More power is required for coolant circulation (as compared with water-cooled reactors).

6. The fontal is more complicated due to low negative coefficient as helium does not absorb neutrons.

LIQUID METAL COOLED REACTORS



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Sodium-graphite reactor (SGR) is one of the typical liquid metal reactors. In this reactor sodium works as a coolant and graphite works as a moderator. Sodium boils at 880^{0}C under atmospheric pressure and freezes at 95^{o}C. Hence sodium is first melted by electric heating system and be pressurized to about 7 bar. The liquid sodium is then circulated by the circulation plump. The reactor will have two coolant circuits or loops.

(1) The primary circuit has liquid sodium which circulates through the fuel core and gets heated by the fissioning of the fuel. This liquid sodium gets cooled in the intermediate heat exchanger and goes back to the reactor vessel.

(2) The secondary circuit has an alloy of sodium and potassium in liquid form. This coolant takes heat from the intermediate heat exchanger and gets heat from liquid sodium of primary circuit.

The liquid sodium-potassium then passes through a boiler which is once through type having tubes only. The steam generated from this boiler will be superheated. Feed water from the condenser enters the boiler, the heated sodium-potassium passing through the tubes gives it heat to the water thus converting it into steam. The sodium-potassium liquid in the second circuit is then pumped back to the intermediate heat exchanger thus making it a closed circuit.

The reactor vessel, primary loop and the intermediate heat exchanger is to be shielded for radio-activity. The liquid metal be handled under the cover of an inert gas, such as helium, to prevent contact with air while charging or draining the primary or secondary circuit / loop.

Advantages of SGR

1.The sodium as a coolant need not be pressurized.

2. High thermal efficiency at low cost.

3. The low cost graphite moderator can be used as it can retain its mechanical strength ant purity at high temperatures.

4. Excellent heat removal.

5. High conversion ratio.

6. Superheating of steam is possible.

7. The size of the reactor is comparatively small.
8. The neutron absorption cross-section of sodium is low and, therefore, it is best suited to thermal reactor with slightly enriched fuel.

Disadvantages of SGR

1. Sodium reacts violently with water wed actively with air.
2. Thermal stresses are a problem.
3. Intermediate system is necessary to separate active sodium from water.
4. Heat exchanger must be leak proof.
5. It is necessary to shield the primary and secondary cooling systems with concrete blocks as sodium becomes highly radioactive.

SAFEY MASURES FOR NUCLEAR POWER PLANTS

In case of nuclear power plants, the three main sources of radio-active contamination of the air are: -

1. Fission of nuclei of nuclear fuels
2. The effect of neutron fluxes on the heat carries in the primary cooling system and on the ambient air
3. Damage of fuel element shells the above explained air- contamination can cause health hazard to worker and community and negative effect on the surrounding forests.

Hence requires the following safety measures: -

1. The nuclear power plant should be constructed away from human habitation. An exclusion zone around the plant should be provided where no public habitation is permitted.
2. The materials to be used for the construction of a nuclear power plant should be of required high quality standards.
3. Waste water from the nuclear power plant should be treated and purified
4. The nuclear power plant must be provided with a safety system which should safely

shut-down the plant as and when necessity arises.

5. There must be periodic checks to ensure that the radio-activity does not exceed the permissible value n the environment.

6. While disposing of the waste from the nuclear plant , it should be ensured that there is no pollution of water of river or sea where these wastes are disposed.

REVIEW QUESTIONS

1. (i) Explain CANDU (Canadian-Deuterium-Uranium) reactor with neat diagram also mention its merits and demerits.
   (ii)Discuss about the safety measures adopted in modern nuclear plants.
   [AU NOV/DEC 2016]
2. What is meant by uranium enrichened? Describe some methods of Uraniurn enrichment
   [AU JUNE 2010]
3. Explain the Construction and working of nuclear power plant with a layout.
   [AU DEC 2010, 2012, 2013]
   [AU NOV/DEC 2016]
4. Explain the different types of nuclear reactions and initiation of nuclear reactions.
   [AU JUNE 2013]
5. Explain with a neat sketch a boiling water reactor. [AU DEC 2007,2005/NOV 2007]
6. Explain the working of pressurized water reactor. [AU MAY 2011,2014/DEC 2014]
7. What is chain reaction? How it is maintained? What is the difference between controlled and uncontrolled chain reaction? Explain with neat sketches and with examples'
   [AU DEC 2004/NOV 20007]
8. Discuss the various factors to be considered while selecting the site for nuclear power station.
   [AU DEC 2014]
9. Explain gas cooled reactor with neat diagram.
10. Explain liquid cooled reactor with neat sketch and also mention its merits and demerits.

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UNIT- IV

POWER FROM RENEWABLE ENERGY

Hydro Electric Power Plants – Classification, Typical Layout and associated components including Turbines. Principle, Construction and working of Wind, Tidal, Solar Photo Voltaic (SPV), Solar Thermal, Geo Thermal, Biogas and Fuel Cell power systems.

HYDRO ELECTRIC POWER PLANTS

In hydro electric power plants Kinetic Energy of water is converted into mechanical energy by a turbine and then electrical energy by a generator.

CLASSIFICATION

1. Classification according to the availability of load
   a. Low head power plant
   b. Medium head power plant
   b. High head power plant

2. Classification according to the nature of load
   a. Base load plant b. Peak load plant

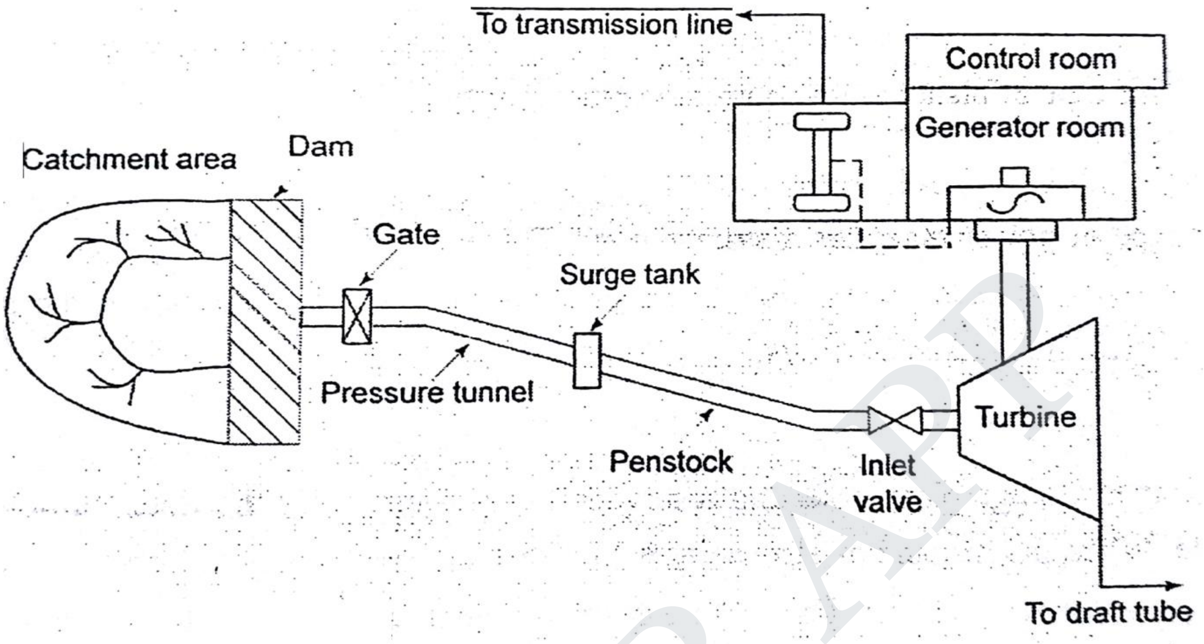
3. Classification according to the quantity of water available
   a. Run-off river plant without pondage
   b. Run-off river plant with pondage
   c. Pumped storage plant

4. Classification based on the power developed by the plant

Large hydro	More than 100 MW
Medium hydro	15-100 MW
Small hydro	1-14 MW
Mini hydro	Above 100kW but below 1 MW
Micro hydro	From 5 kW upto 100 kW
Pico hydro	From few hundred watts upto 5 kW

LAYOUT OF HYDRO ELECTRIC POWER PLANT

Fig. shows the typical layout of a hydroelectric power plant and its basic components.



Layout of hydroelectric power plant

The different parts of a hydroelectric power plant are

(1) Dam

Dams are structures built over rivers to stop the water flow and form a reservoir. The reservoir stores the water flowing down the river. This water is diverted to turbines in power stations. The dams collect water during the rainy season and stores it, thus allowing for a steady flow through the turbines throughout the year. Dams are also used for controlling floods and irrigation. The dams should be water-tight and should be able to withstand the pressure exerted by the water on it. There are different types of dams such as arch dams, gravity dams and buttress dams. The height of water in the dam is called *head race*.

(2) Spillway

A spillway as the name suggests could be called as a way for spilling of water from dams. It is used to provide for the release of flood water from a dam. It is used to prevent over toping of the dams which could result in damage or failure of dams. Spillways could be controlled type or uncontrolled type. The uncontrolled types start releasing water upon water rising above a particular level. But in case of the controlled type, regulation of flow is possible.

(3) Penstock and Tunnel

Penstocks are pipes which carry water from the reservoir to the turbines inside power station. They are usually made of steel and are equipped with gate systems.Water under high pressure flows through the penstock. A tunnel serves the same purpose as a penstock. It is used when an obstruction is present between the dam and power station such as a mountain.

(4) Surge Tank

Surge tanks are tanks connected to the water conductor system. It serves the purpose of reducing water hammering in pipes which can cause damage to pipes. The sudden surges of water in penstock is taken by the surge tank, and when the water requirements increase, it supplies the collected water thereby regulating water flow and pressure inside the penstock.

(5) Power Station

Power station contains a turbine coupled to a generator (see the cross section of a power house on the left). The water brought to the power station rotates the vanes of the turbine producing torque and rotation of turbine shaft. This rotational torque is transferred to the generator and is converted into electricity. The used water is released through the *tail race*. The difference between head race and tail race is called gross head and by subtracting the frictional losses we get the net head available to the turbine for generation of electricity.

Advantages

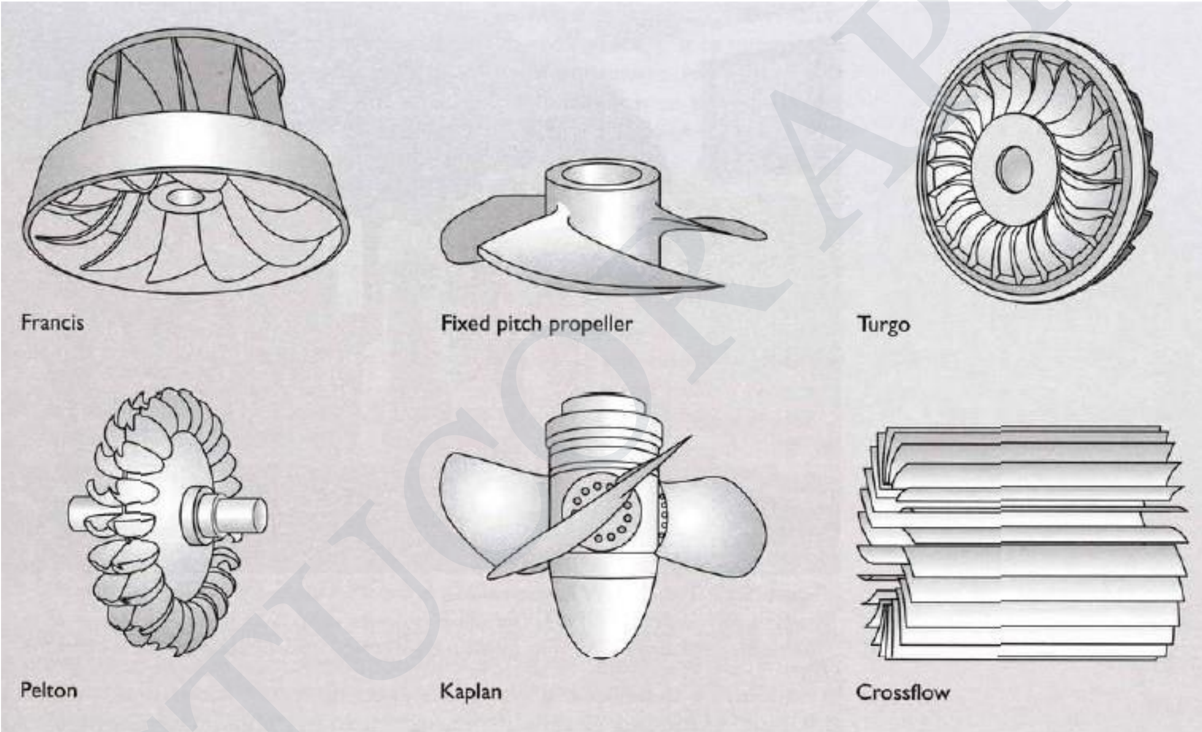
- No fuel is required as potential energy is stored water is used for electricity generation
- Neat and clean source of energy
- Very small running charges - as water is available free of cost
- Comparatively less maintenance is required and has longer life
- Serves other purposes too, such as irrigation

Disadvantages

- Very high capital cost due to construction of dam
- High cost of transmission – as hydro plants are located in hilly areas which are quite away from the consumers

WATER TURBINE

There are two main categories of hydro turbines: impulse and reaction, as described above. The type of hydropower turbine selected for a project is based on the height of standing water—referred to as "head"—and the flow, or volume of water, at the site. The most common type of impulse turbine is Pelton turbine. There are also Turgo turbine, Cross-flow turbine (also known as the Bánki-Michell turbine, or Ossberger turbine), Jonval turbine, Reverse overshot water-wheel,Screw turbine.On the other side,the most common reaction turbine is Francis turbine but there are also Kaplan turbine,Tyson turbine,Gorlov helical turbine.



1. PELTON TURBINE

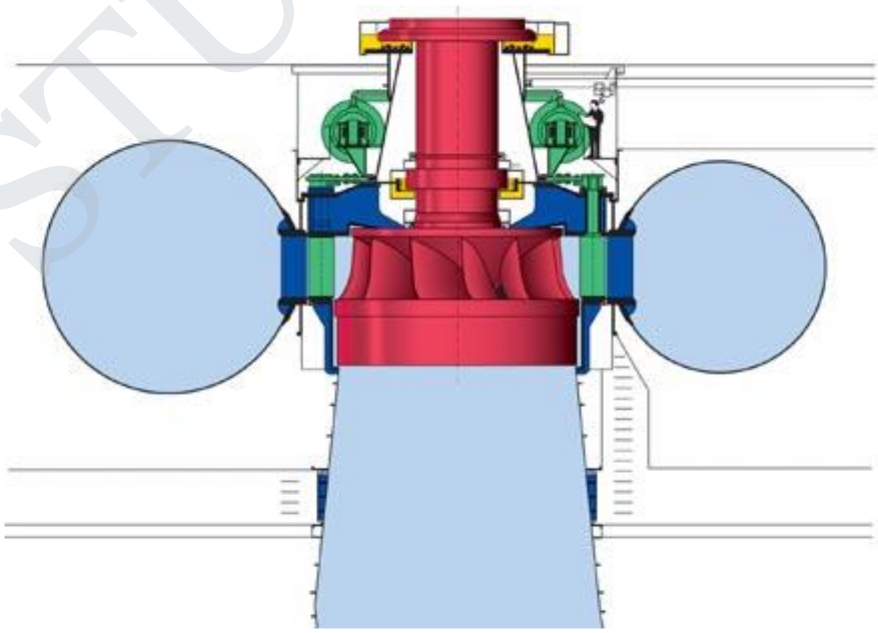
Pelton turbine or wheel is an impulsive turbine used mainly for high head hydroelectric schemes. The Pelton wheel is among the most efficient types of water turbines. The fluid power is converted into kinetic energy in the nozzles. The total pressure drop occurs in the nozzle. The resulting jet of water is directed tangentially at buckets on the wheel producing impulsive force on them.

Nozzles direct forceful, high-speed streams of water against a rotary series of spoon-shaped buckets, also known as impulse blades, which are mounted around the circumferential rim of a drive wheel. As the water jet impinges upon the contoured bucket-blades, the direction of water velocity is changed to follow the contours of the bucket. Water impulse energy exerts torque on the bucket and wheel system, spinning the wheel, the water stream itself does a "u-turn" and exits at the outer sides of the bucket, decelerated to a low velocity. In the process, the water jet's momentum is transferred to the wheel and thence to a turbine. Thus, "impulse" energy does work on the turbine. For maximum power and efficiency, the wheel and turbine system is designed such that the water jet velocity is twice the velocity of the rotating buckets. A very small percentage of the water jet's original kinetic energy will remain in the water, which causes the bucket to be emptied at the same rate it is filled and thereby allows the high-pressure input flow to continue uninterrupted and without waste of energy. Typically two buckets are mounted side-by-side on the wheel, which permits splitting the water jet into two equal streams. This balances the side-load forces on the wheel and helps to ensure smooth, efficient transfer of momentum of the fluid jet of water to the turbine wheel.

Pelton wheels are the preferred turbine for hydro-power, when the available water source has relatively high hydraulic head at low flow rates, where the Pelton wheel is most efficient. Thus, more power can be extracted from a water source with high-pressure and low-flow than from a source with low-pressure and high-flow, even when the two flows theoretically contain the same power. Also a comparable amount of pipe material is required for each of the two sources, one requiring a long thin pipe, and the other a short wide pipe. Pelton wheels are made in all sizes. There exist multi-ton Pelton wheels mounted on vertical oil pad bearings in hydroelectric plants. The largest units can be up to 200 megawatts. The smallest Pelton wheels are only a few inches across, and can be used to tap power from mountain streams having flows of a few gallons per minute. Some of these systems use household plumbing fixtures for water delivery. These small units are recommended for use with 30 feet (9.1 m) or more of head, in order to generate significant power levels. Depending on water flow and design, Pelton wheels operate best with heads from 49–5,905 feet (14.9–1,799.8 m), although there is no theoretical limit.

2. FRANCIS TURBINE

The Francis turbine is a reaction turbine where water changes pressure as it moves through the turbine, transferring its energy. A watertight casement is needed to contain the water flow. Generally such turbines are suitable for sites such as dams where they are located between the high pressure water source and the low pressure water exit. Francis turbines are the most common water turbine in use today. They operate in a water head from 40 to 600 m (130 to 2,000 ft) and are primarily used for electrical power production.



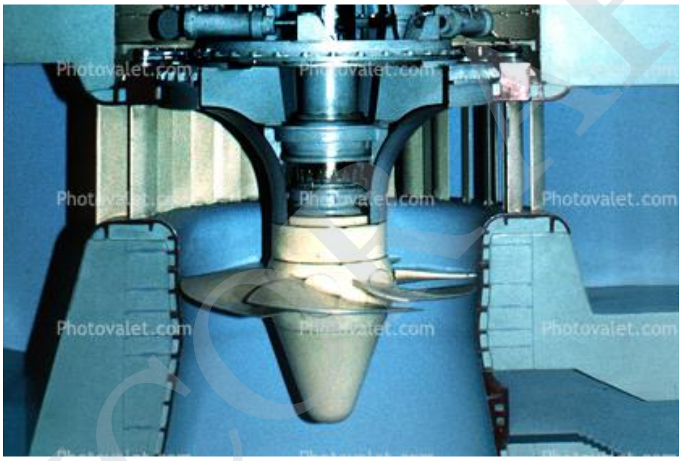
Water flows from the penstock into the spiral casing. In the spiral casing the water is distributed around the complete periphery. The water is then guided by the stay vanes and guide vanes in the correct angle towards the runner. The guide vanes are adjustable and can change the angle depending on the inlet and outlet conditions of the turbine, they are controlled by a governor servo motor. The runner transfers the energy from the pressure and velocity in the water to a rotational momentum. The water exits through a draft tube that extracts the remaining energy in the water. The torque produced in the runner is transferred to a power producing generator through a shaft.

Francis turbines may be designed for a wide range of heads and flows. This, along with their high efficiency, has made them the most widely used turbine in the world. Francis type units cover a head range from 40 to 600 m (130 to 2,000 ft), and their connected generator output power varies from just a few kilowatts up to 800 MW. Large Francis turbines are individually designed for each site to operate with the given water supply and water head at the highest possible efficiency, typically over 90%. In addition to electrical production, they may also be used for pumped storage, where a reservoir is filled by the turbine (acting as a pump) driven by the generator acting as a large electrical motor during periods of low power demand, and then reversed and used to generate power during peak demand. These pump storage reservoirs, etc. act as large energy storage sources to store "excess" electrical energy in the form of water in elevated reservoirs. This is one of only a few ways that temporary excess electrical capacity can be stored for later utilization.

3. KAPLAN TURBINES

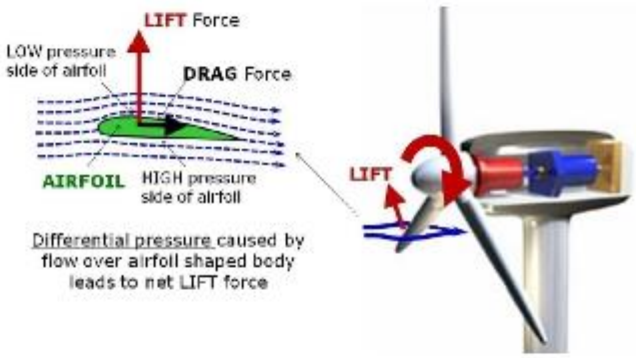
The Kaplan turbine has adjustable blades and was developed on the basic platform (design principles) of the Francis turbine by the Viktor Kaplan in 1913. The main advantage of Kaplan turbines is its ability to work in low head sites which was not possible with Francis turbines. Kaplan turbines are widely used in high-flow, low-head power production. The Kaplan turbine is an inward flow reaction turbine, which means that the working fluid changes pressure as it moves through the turbine and gives up its energy. The design combines radial and axial features. The inlet is a scroll-shaped tube that wraps around the turbine's wicket gate. Water is directed tangentially through the wicket gate and spirals onto a propeller shaped runner, causing it to spin.

The outlet is a specially shaped draft tube that helps decelerate the water and recover kinetic energy. The turbine does not need to be at the lowest point of water flow, as long as the draft tube remains full of water. A higher turbine location, however, increases the suction that is imparted on the turbine blades by the draft tube that may lead to cavitations due to the pressure drop. Typically the efficiencies achieved for Kaplan turbine are over 90%, mainly due to the variable geometry of wicket gate and turbine blades. This efficiency however maybe lower for very low head applications. Since the propeller blades are rotated by high-pressure hydraulic oil, a critical design element of Kaplan turbine is to maintain a positive seal to prevent leakage of oil into the waterway. Kaplan turbines are widely used throughout the world for electrical power production. They are especially suited for the low head hydro and high flow conditions – mostly in canal based hydro power sites.



PRINCIPLE, CONSTRUCTION AND WORKING OF WIND POWER SYSTEM

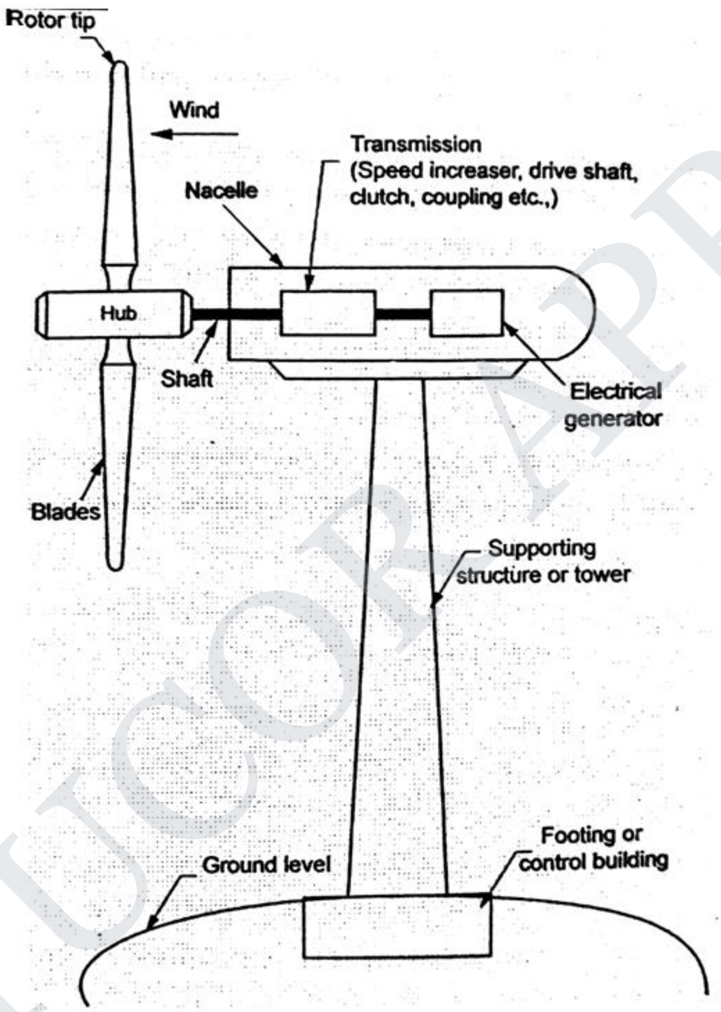
PRINCIPLE OF WIND ENERGY CONVERSION



Lift-based Wind Turbine Concept

Airflow over any surface creates two types of aerodynamic forces— drag forces, in the direction of the airflow, and lift forces, perpendicular to the airflow. Either or both of these can be used to generate the forces needed to rotate the blades of a wind turbine.

WIND TURBINE



Components of wind turbine

Figure shows the various parts of a wind-electric generating power plant. These are:

1. Wind turbine or rotor
2. Wind mill head – it houses speed increaser, drive shaft, clutch, coupling etc.
3. Electric generator.
4. Supporting structure.

The most important component is the **rotor**. For an effective utilization, all components should be properly designed and matched with the rest of the components.

The wind mill head performs the following functions:

(i) It supports the rotor housing and the rotor bearings.

(ii) It also houses any control mechanism incorporated like changing the pitch of the blades for safety devices and tail vane to orient the rotor to face the wind, the latter is facilitated by mounting it on the top of the supporting structure on suitable bearings. The wind turbine may be located either unwind or downwind of the power. In the unwind location the wind encounters the turbine before reaching the tower. Downwind rotors are generally preferred especially for the large aero generators.

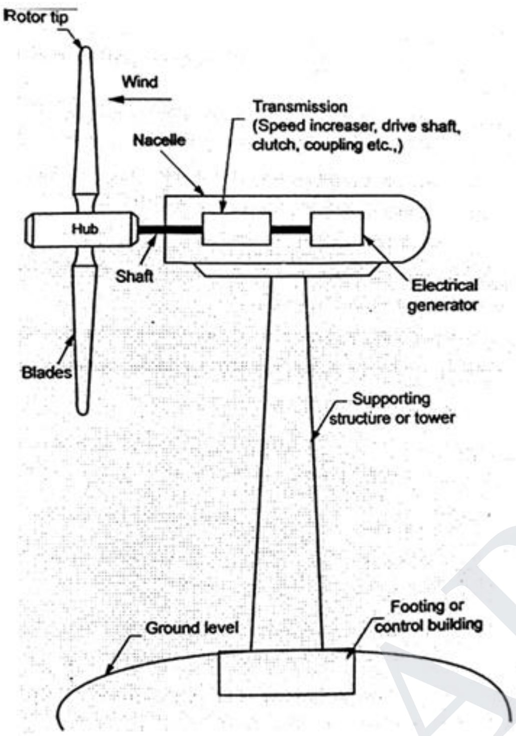
The **supporting structure** is designed to withstand the wind load during gusts. Its type and height is related to cost and transmission system incorporated. Horizontal axis wind turbines are mounted on towers so as to be above the level of turbulence and other ground related effects.

Types of Wind Machines

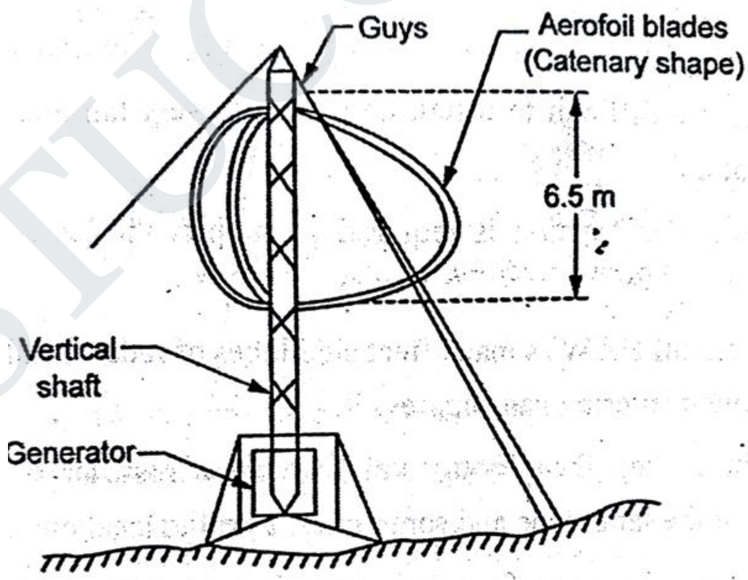
Wind machines are generally classified as follows:

1. Horizontal axis wind machines.
2. Vertical axis wind machines.

Horizontal axis wind machines. Figure shows a schematic arrangement of horizontal axis machine. Although the common wind turbine with horizontal axis is simple in principle yet the design of a complete system, especially a large one that would produce electric power economically, is complex. It is of paramount importance's that the components like rotor, transmission, generator and tower should not only be as efficient as possible but they must also function effectively in combination.



Vertical axis wind machines. Figure shows vertical axis type wind machine. One of the main advantages of vertical axis rotors is that they do not have to be turned into the wind stream as the wind direction changes. Because their operation is independent of wind direction, vertical axis machine are called panemones.



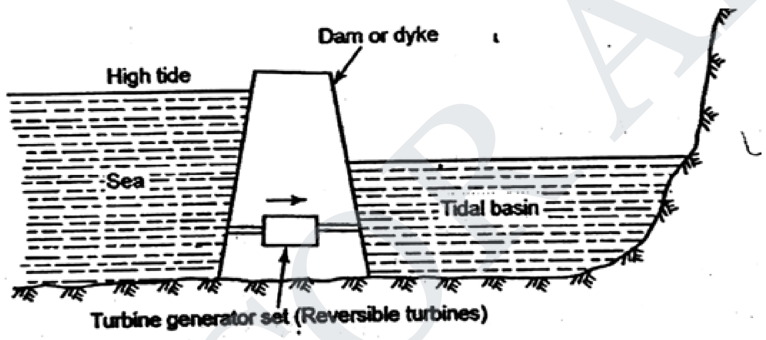
Vertical axis wind machines

TIDAL POWER SYSTEM

Tide or wave is periodic rise and fall of water level of the sea. Tides occur due to the attraction of sea water by the moon. Tides contain large amount of potential energy which is used for power generation. When the water is above the mean sea level, it is called flood tide. When the water level is below the mean level it is called ebb tide.

Working

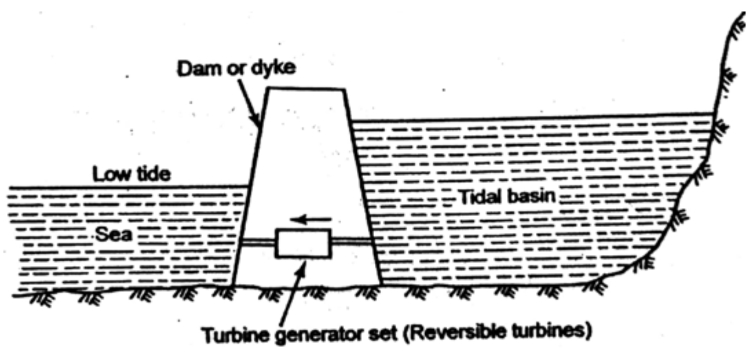
The arrangement of this system is shown in figure. The ocean tides rise and fall and water can be stored during the rise period and it can be discharged during fall. A dam is constructed separating the tidal basin from the sea and a difference in water level is obtained between the basin and sea.



(a) High Tide

During high tide period, water flows from the sea into the tidal basin through the water turbine. The height of tide is above that of tidal basin. Hence the turbine unit operates and generates power, as it is directly coupled to a generator.

During low tide period, water flows from tidal basin to sea, as the water level in the basin is more than that of the tide in the sea. During this period also, the flowing water rotates the turbine and generator power.



(b) Low Tide

The generation of power stops only when the sea level and the tidal basin level are equal. For the generation of power economically using this source of energy requires some minimum tide height and suitable site. Kislaya power plant of 250 MW capacity in Russia and Rance power plant in France are the only examples of this type of power plant.

Advantages of tidal power plants.

1. It is free from pollution as it does not use any fuel.
2. It is superior to hydro-power plant as it is totally independent of rain.
3. It improves the possibility of fish farming in the tidal basins and it can provide recreation to visitors and holiday makers.

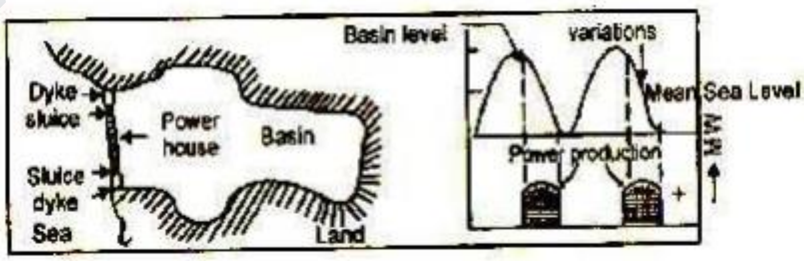
Disadvantages

1. Tidal power plants can be developed only if natural sites are available on the bay.
2. As the sites are available on the bays which are always far away from load centres, the power generated has to be transmitted to long distances. This increases the transmission cost and transmission losses.

Working of different tidal power plants

1. Single basin-one-way cycle

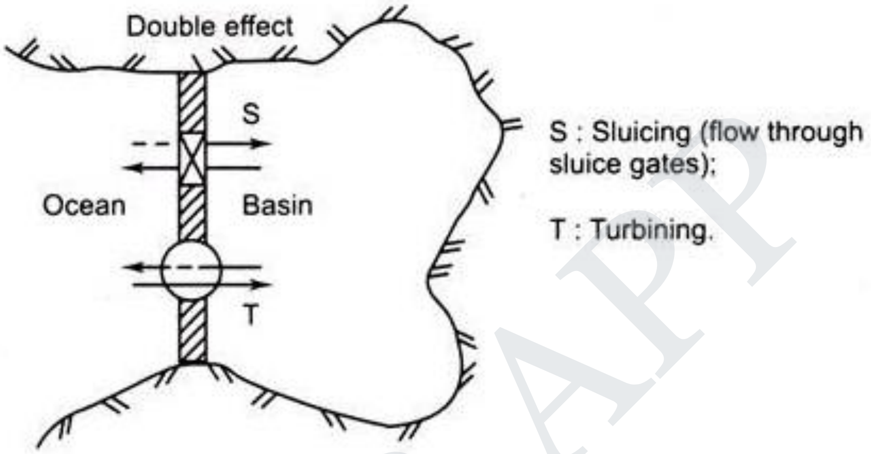
This is the simplest form of tidal power plant. In this system a basin is allowed to get filled during flood tide and during the ebb tide, the water flows from the basin to the sea passing through the turbine and generates power. The power is available for a short duration ebb tide.



Single basin, one –way tidal power plant

2. Single-basin two-way cycle

In this arrangement, power is generated both during flood tide as well as ebb tide also. The power generation is also intermittent but generation period is increased compared with one-way cycle. However, the peak obtained is less than the one-way cycle. The arrangement of the basin and the power cycle is shown in figure.



Single-basin double-effect tidal plant, sluicing and turbining flow directions.

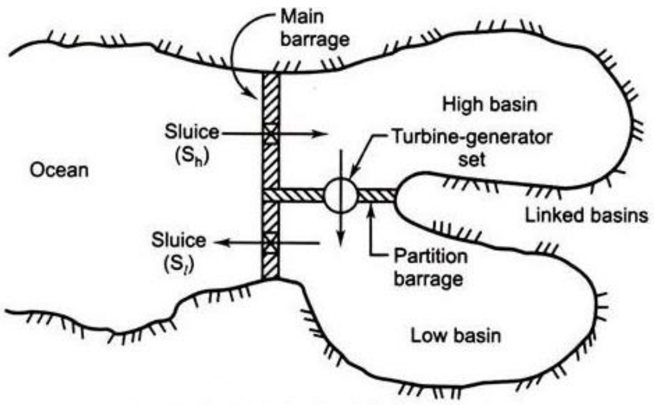
The main difficulty with this arrangement, the same turbine must be used as prime mover as ebb and tide flows pass through the turbine in opposite directions. Variable pitch turbine and dual rotation generator are used of such scheme.

3. Single – basin two-way cycle with pump storage

In this system, power is generated both during flood and ebb tides. Complex machines capable of generating power and pumping the water in either directions are used. A part of the energy produced is used for introducing the difference in the water levels between the basin and sea at any time of the tide and this is done by pumping water into the basin up or down. The period of power production with this system is much longer than the other two described earlier. The cycle of operation is shown in figure.

4. Double basin type

In this arrangement, the turbine is set up between the basins as shown in figure. One basin is intermittently filled tide and other is intermittently drained by the ebb tide. Therefore, a small capacity but continuous power is made available with this system as shown in figure. The main disadvantages of this system are that 50% of the potential energy is sacrificed in introducing the variation in the water levels of the two basins.



Double-basin, linked-basin scheme.

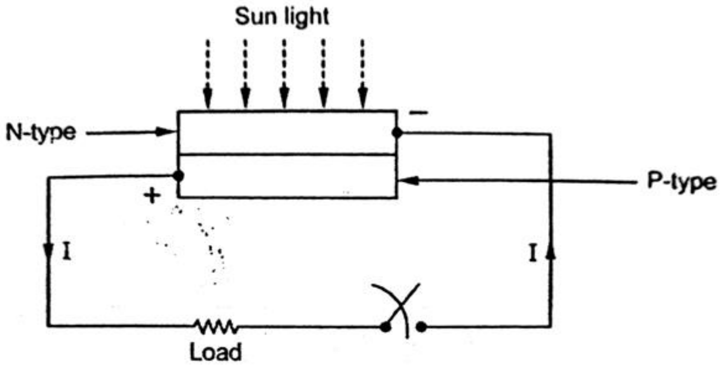
5. Double basin with pumping

In this case, off peak power from the base load plant in a interconnected transmission system is used either to pump the water up the high basin. Net energy gain is possible with such a system if the pumping head is lower than the basin-to-basin turbine generating head.

SOLAR PHOTOVOLTAIC POWER SYSTEM

Principle of photovoltaic or solar cell

Conversion of light energy in electrical energy is based on a phenomenon called photovoltaic effect. When semiconductor materials are exposed to light, the some of the photons of light ray are absorbed by the semiconductor crystal which causes a significant number of free electrons in the crystal. This is the basic reason for producing electricity due to photovoltaic effect. **Photovoltaic cell** is the basic unit of the system where the photovoltaic effect is utilised to produce electricity from light energy. Silicon is the most widely used semiconductor material for constructing the photovoltaic cell.

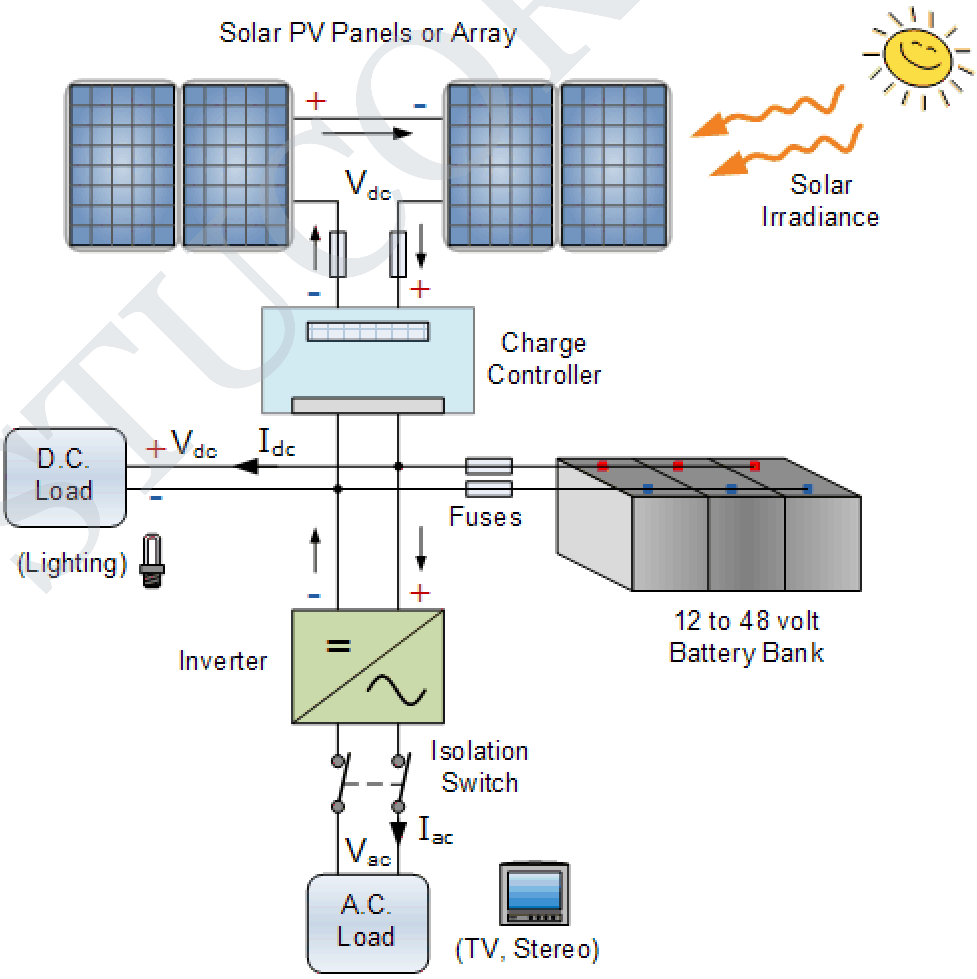


Principle of solar cell

Standalone PV power system

While a major component and cost of a standalone PV system is the solar array, several other components are typically needed. These include:

- Batteries: Batteries are an important element in any stand alone PV system but can be optional depending upon the design. Batteries are used to store the solar-produced electricity for night time or emergency use during the day. Depending upon the solar array configuration, battery banks can be of 12V, 24V or 48V and many hundreds of amperes in total.
- Charge Controller: A charge controller regulates and controls the output from the solar array to prevent the batteries from being over charged (or over discharged) by dissipating the excess power into a load resistance. Charge controllers within a standalone PV system are optional but it is a good idea to have one for safety reasons.



- Fuses and Isolation Switches: These allow PV installations to be protected from accidental shorting of wires allowing power from the PV modules and system to be turned "OFF" when not required saving energy and improving battery life.
- Inverter: The inverter can be another optional unit in a standalone system. Inverters are used to convert the 12V, 24V or 48 Volts direct current (DC) power from the solar array and batteries into an alternating current (AC) electricity and power of either 120 VAC or 240 VAC for use in the home to power AC mains appliances such as TV's, washing machines, freezers, etc.
- Wiring: The final component required in and PV solar system is the electrical wiring. The cables need to be correctly rated for the voltage and power requirements. Thin telephone wire will not work!.

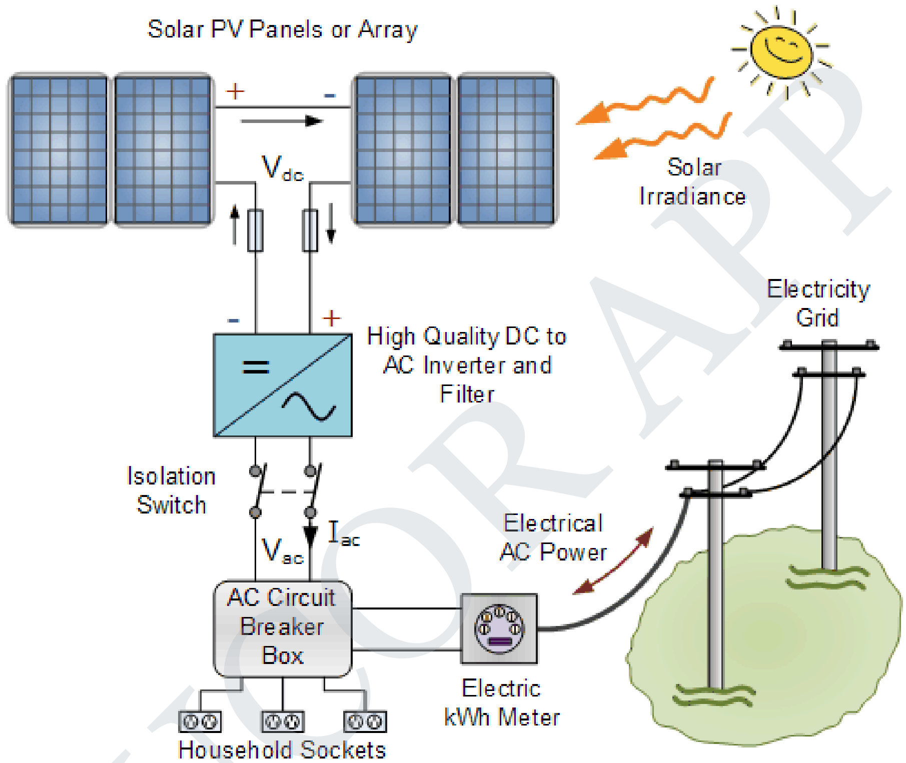
Batteries are an important element and the heart of any stand alone solar power system, whether that is one using a large array of panels to power a home or a small pico solar system used to power the garden, shed or fish pond.

Batteries are needed because of the fluctuating nature of the output being delivered by the PV panels or array. They also convert the electrical energy into stored chemical energy for use when the solar array is not producing power. During the hours of sunshine, the PV system is directly fed to the load, with excess electrical energy being stored in the batteries for later use. During the night, or during a period of low solar irradiance, such as a cloudy, rainy days, energy is supplied to the load from the battery.

So battery storage allows a standalone PV system to be run when the solar panels are not producing enough energy on their own with the battery storage size tied to the electrical usage.

Grid connected PV systems always have a connection to the public electricity grid via a suitable inverter because a photovoltaic panel or array (multiple PV panels) only deliver DC power. As well as the solar panels, the additional components that make up a grid connected PV system compared to a stand alone PV system are:

- Inverter: The inverter is the most important part of any grid connected system. The inverter extracts as much DC (direct current) electricity as possible from the PV array and converts it into clean mains AC (alternating current) electricity at the right voltage and frequency for feeding into the grid or for supplying domestic loads. It is important to choose the best quality inverter possible for the budget allowed as the main considerations in grid connected inverter choice are: *Power* – Maximum high and low voltage power the inverter can handle and *Efficiency* – How efficiently does the inverter convert solar power to AC power.



- Electricity Meter: The electricity meter also called a Kilowatt hour (kWh) meter is used to record the flow of electricity to and from the grid. Twin kWh meters can be used, one to indicate the electrical energy being consumed and the other to record the solar electricity being sent to the grid. A single bidirectional kWh meter can also be used to indicate the net amount of electricity taken from the grid. A grid connected PV system will slow down or halt the aluminium disc in the electric meter and may cause it to spin backwards. This is generally referred to as *net metering*.

- AC Breaker Panel and Fuses: The breaker panel or fuse box is the normal type of fuse box provided with a domestic electricity supply and installation with the exception of additional breakers for inverter and/or filter connections.

- Safety Switches and Cabling: A photovoltaic array will always produce a voltage output in sunlight so it must be possible to disconnect it from the inverter for maintenance or testing. Isolator switches rated for the maximum DC voltage and current of the array and inverter safety switches must be provided separately with easy access to disconnect the system. Other safety features demanded by the electrical company may include earthing and fuses. The electrical cables used to connect the various components must also be correctly rated and sized.
- The Electricity Grid: Finally the electricity grid itself to connect too, because without the utility grid it is not a Grid Connected PV System.

An grid connected system without batteries are the simplest and cheapest solar power setup available, and by not having to charge and maintain batteries they are also more efficient. It is important to note that a grid connected solar power system is not an independent power source unlike a stand alone system. Should the mains supply from the electrical grid be interrupted, the lights may go out, even if the sun is shining. One way to overcome this is to have some form of short term energy storage built into the design.

Advantages

1. Sun is essentially an infinite source of energy. Therefore solar energy is a very large inexhaustible and renewable source of energy and is freely available all over the world.
2. It is environmentally very clean and is hence pollution-free.
3. It is a dependable energy source without new requirements of a highly technical and specialized nature for its wide spread utilization.
4. It is the best alternative for the rapid depletion of fossil fuels.

Disadvantages

1. It is available in a dilute and is at low potential. The intensity of solar energy on a sunny day in India is about 1.1 kW/square meter area. Hence very large collecting areas are required.
2. Also the dilute and diffused nature of the solar energy needs large land area for the power plant for instance, about 30 square kilometers area is required for a solar power station to replace a nuclear plant on a 1 square kilometer site. Hence capital cost is more for the solar plant.

3. Solar energy is not available at night or during cloudy or rainy days.

Applications of Solar Energy:

Applications of solar energy enjoying most success today are:

1. Solar engines for pumping.
2. Solar water heaters.
3. Solar cookers.
4. Solar driers.
5. Solar furnaces.
6. Photo-voltaic conversion (solar cells)
7. Solar power generation.

SOLAR THERMAL POWER SYSTEM

SOLAR COLLECTOR

A **solar collector** is a device that collects and/or concentrates solar radiation from the Sun. These devices are primarily used for active solar heating and allow for the heating of water for personal use. These collectors are generally mounted on the roof and must be very sturdy as they are exposed to a variety of different weather conditions.

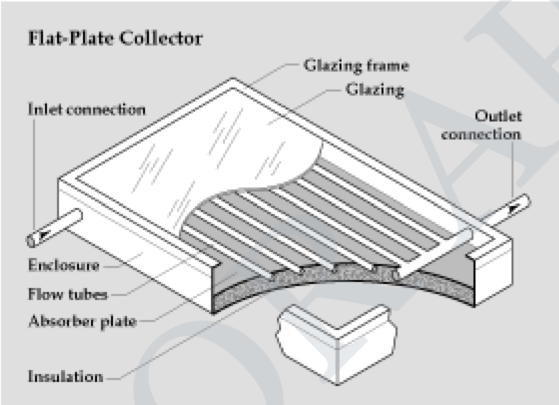
The use of these solar collectors provides an alternative for traditional domestic water heating using a water heater, potentially reducing energy costs over time. As well as in domestic settings, a large number of these collectors can be combined in an array and used to generate electricity in solar thermal power plants.

TYPES OF SOLAR COLLECTORS

There are many different types of solar collectors, but all of them are constructed with the same basic premise in mind. In general, there is some material that is used to collect and focus energy from the Sun and use it to heat water. The simplest of these devices uses a black material surrounding pipes that water flows through. The black material absorbs the solar radiation very well, and as the material heats up the water it surrounds. This is a very simple design, but collectors can get very complex. Absorber plates can be used if a high temperature increase isn't necessary, but generally devices that use reflective materials to focus sunlight result in a greater temperature increase.

1. FLAT PLATE COLLECTOR

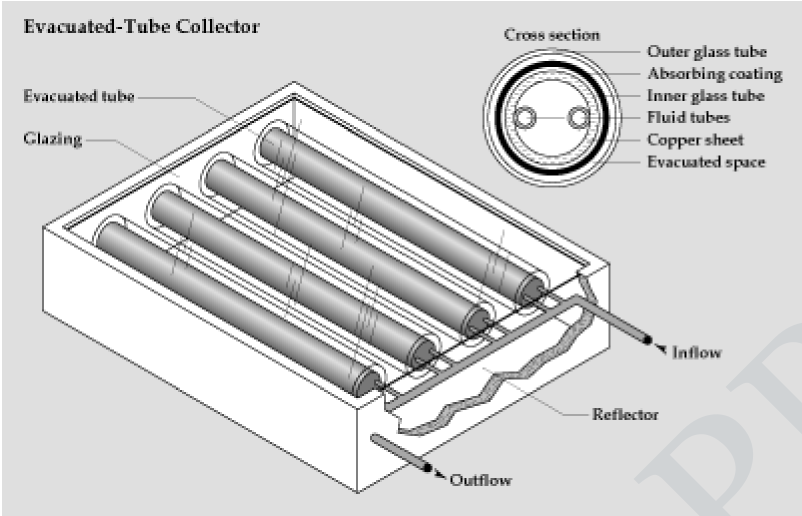
These collectors are simply metal boxes that have some sort of transparent glazing as a cover on top of a dark-coloured absorber plate. The sides and bottom of the collector are usually covered with insulation to minimize heat losses to other parts of the collector. Solar radiation passes through the transparent glazing material and hits the absorber plate.



This plate heats up, transferring the heat to either water or air that is held between the glazing and absorber plate. Sometimes these absorber plates are painted with special coatings designed to absorb and retain heat better than traditional black paint. These plates are usually made out of metal that is a good conductor - usually copper or aluminum.

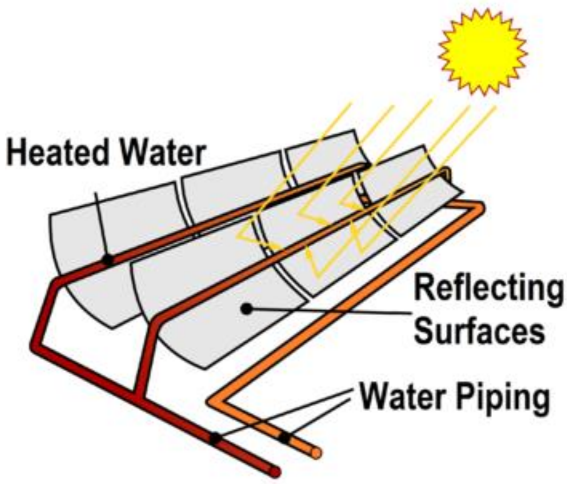
2. EVACUATED SOLAR COLLECTOR

This type of solar collector uses a series of evacuated tubes to heat water for use. These tubes utilize a vacuum, or evacuated space, to capture the suns energy while minimizing the loss of heat to the surroundings. They have an inner metal tube which acts as the absorber plate, which is connected to a heat pipe to carry the heat collected from the Sun to the water. This heat pipe is essentially a pipe where the fluid contents are under a very particular pressure. At this pressure, the "hot" end of the pipe has boiling liquid in it while the "cold" end has condensing vapour. This allows for thermal energy to move more efficiently from one end of the pipe to the other. Once the heat from the Sun moves from the hot end of the heat pipe to the condensing end, the thermal energy is transported into the water being heated for use.



3. LINE FOCUS SOLAR COLLECTOR

These collectors, sometimes known as parabolic troughs, use highly reflective materials to collect and concentrate the heat energy from solar radiation. These collectors are composed of parabolically shaped reflective sections connected into a long trough. A pipe that carries water is placed in the center of this trough so that sunlight collected by the reflective material is focused onto the pipe, heating the contents. These are very high powered collectors and are thus generally used to generate steam for Solar thermal power plants and are not used in residential applications. These troughs can be extremely effective in generating heat from the Sun, particularly those that can pivot, tracking the Sun in the sky to ensure maximum sunlight collection.



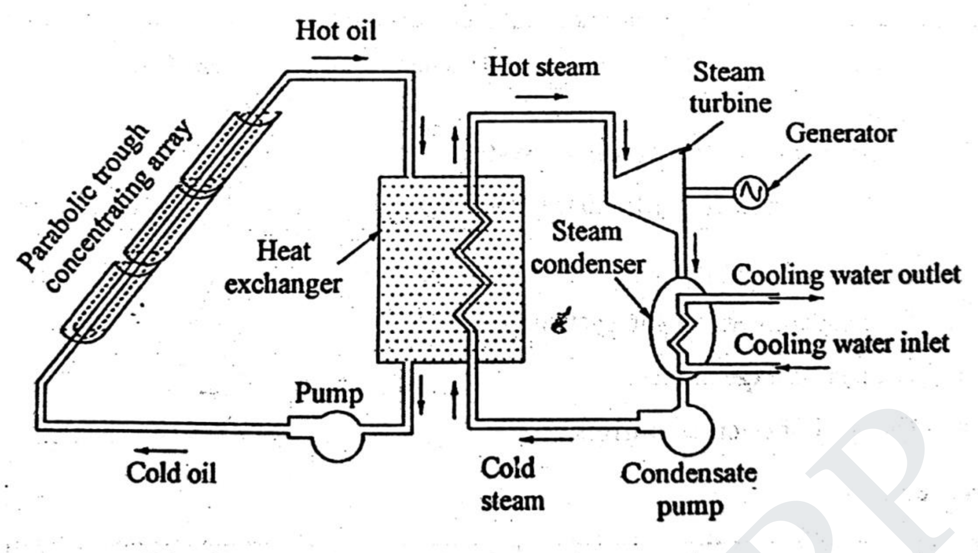
4. POINT FOCUS COLLECTOR

These collectors are large parabolic dishes composed of some reflective material that focus the Sun's energy onto a single point. The heat from these collectors is generally used for driving Stirling engines. Although very effective at collecting sunlight, they must actively track the Sun across the sky to be of any value. These dishes can work alone or be combined into an array to gather even more energy from the Sun.

Point focus collectors and similar apparatuses can also be utilized to concentrate solar energy for use with Concentrated photovoltaics. In this case, instead of producing heat, the Sun's energy is converted directly into electricity with high efficiency photovoltaic cells designed specifically to harness concentrated solar energy.

DISTRIBUTED COLLECTOR SOLAR THERMAL POWER PLANT

In parabolic trough collector, long, U-curved mirrors focus the rays of the sun into an absorber pipe. The mirrors track the sun on one linear axis from north to south during the day. The pipe is seated above the mirror in the center along the focal line and has a heat-absorbent medium (mineral oil, synthetic oil, molten salt etc.) running in it. The sun’s energy heats up the oil, which carries the energy to the water in a boiler heat exchanger, reaching a temperature of about 400°C. The heat is transferred into the water, producing steam to drive turbine. Turbine is the prime mover for the generator and generator produce electrical power.



Distributed collector solar thermal power plant

GEO THERMAL POWER PLANT

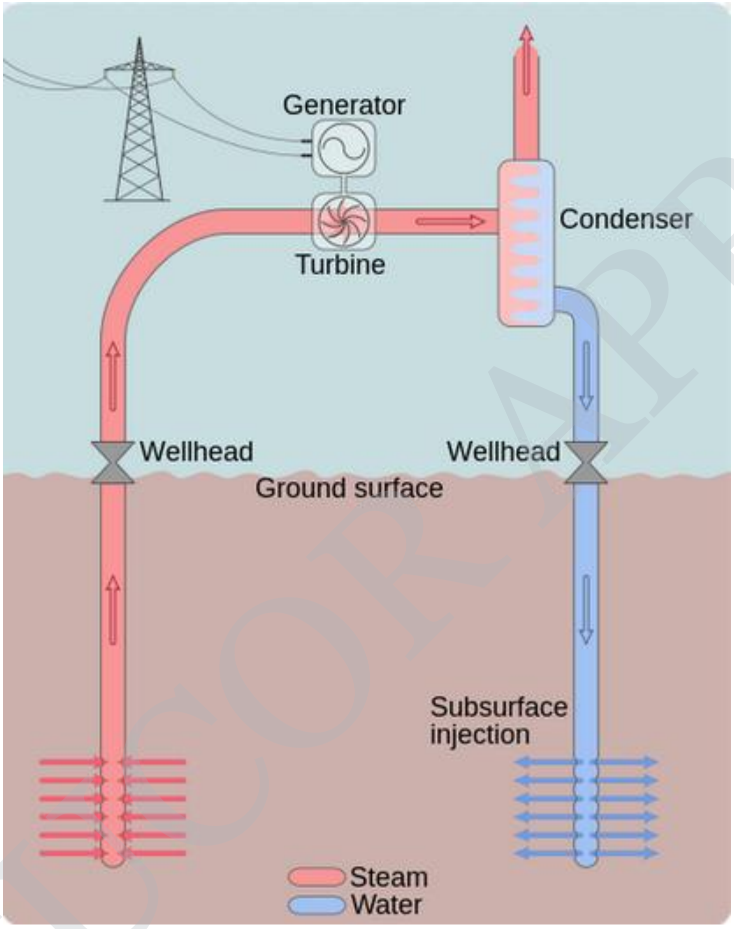
Geothermal power plants are used in order to generate electricity by the use of geothermal energy (the Earth's internal thermal energy). They essentially work the same as a coal or nuclear power plant, the main difference being the heat source. With geothermal, the Earth's heat replaces the boiler of a coal plant or the reactor of a nuclear plant.

Hot water or steam is extracted from the Earth through a series of wells and feeds the power plant. In most geothermal plants the water pulled up from the ground is returned back to the subsurface. The rate of water used is often larger than the rate of water returned, so make-up water supplies are generally needed.

There are 3 main types of geothermal power plants, with the flash cycle being the most common. The choice of plant depends on how much geothermal energy is available, and how hot the resource is. The hotter the resource, the less fluid needs to flow from the ground to take advantage of it, the more useful it is. Some details of each plant may be seen below:

1. DRY STEAM PLANTS

These plants use dry steam that is naturally produced in the ground. This steam travels from the production well to the surface and through a turbine, and after transferring its energy to the turbine it condenses and is injected back into the Earth. These types are the oldest types of geothermal power plants, the first one was built back in 1904 in Italy. Because this type of power plant requires the highest temperatures they can only be used where the temperature underground is quite high, but this type requires the least fluid flow.

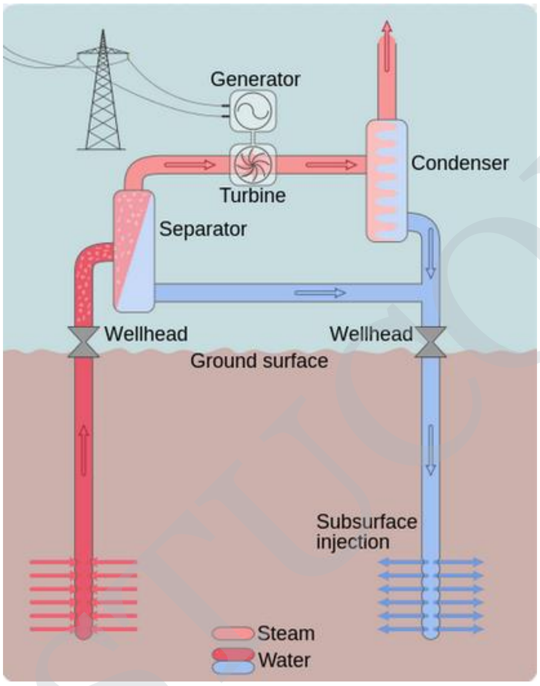


2. FLASH CYCLE STEAM PLANT

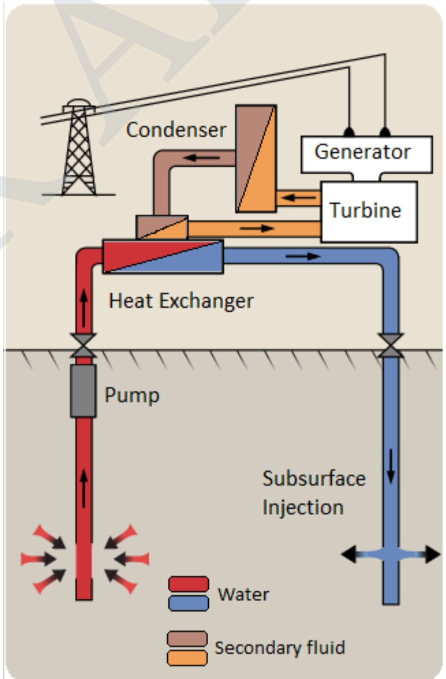
These types are the most common due to the lack of naturally occurring high-quality steam. In this method, water must be over 180°C, and under its own pressure it flows upwards through the well. This is a lower temperature than dry steam plants have. As its pressure decreases, some of the water "flashes" to steam, which is passed through the turbine section. The remaining water that did not become steam is cycled back down into the well, and can also be used for heating purposes. The cost of these systems is increased due to more complex parts, however they can still compete with conventional power sources.

3. BINARY CYCLE PLANT

Binary power plants are expected to be the most commonly used type of geothermal power plant in the future, as locations outside of the known hot spots begin to use geothermal energy.[3] This is because binary cycle plants can make use of lower temperature water than the other two types of plants. They use a secondary loop (hence the name "binary") which contains a fluid with a low boiling point, such as pentane or butane. The water from the well flows through a heat exchanger which transfers its heat to this fluid, which vaporizes due to its low boiling point. It is then passed through a turbine, accomplishing the same task as steam.



Flash cycle steam plant



Binary cycle plant

BIO MASS POWER SYSTEMS

Biomass is used for facility heating, electric power generation, and combined heat and power. The term biomass encompasses a large variety of materials, including wood from various sources, agricultural residues, and animal and human waste.

Biomass can be converted into electric power through several methods. The most common is direct combustion of biomass material, such as agricultural waste or woody materials. Other options include gasification, pyrolysis, and anaerobic digestion. Gasification produces a synthesis gas with usable energy content by heating the biomass with less oxygen than needed for complete combustion. Pyrolysis yields bio-oil by rapidly heating the biomass in the absence of oxygen. Anaerobic digestion produces a renewable natural gas when organic matter is decomposed by bacteria in the absence of oxygen.

Different methods work bet with different types of biomass. Typically, woody biomass such as wood chips, pellets, and sawdust are combusted or gasified to generate electricity. Corn stover and wheat straw residues are baled for combustion or converted into a gas using an anaerobic digester. Very wet wastes, like animal and human wastes, are converted into a medium-energy content gas in an anaerobic digester. In addition, most other types of biomass can be converted into bio-oil through pyrolysis, which can then be used in boilers and furnaces.

Most biopower plants use direct-fired combustion systems. They burn biomass directly to produce high-pressure steam that drives a turbine generator to make electricity. In some biomass industries, the extracted or spent steam from the power plant is also used for manufacturing processes or to heat buildings. These combined heat and power (CHP) systems greatly increase overall energy efficiency to approximately 80%, from the standard biomass electricity-only systems with efficiencies of approximately 20%. Seasonal heating requirements will impact the CHP system efficiency.

A simple biomass electric generation system is made up of several key components. For a steam cycle, this includes some combination of the following items:

- Fuel storage and handling equipment
- Combustor / furnace
- Boiler
- Pumps
- Fans
- Steam turbine

- Generator
- Condenser
- Cooling tower
- Exhaust / emissions controls
- System controls (automated).

Direct combustion systems feed a biomass feedstock into a combustor or furnace, where the biomass is burned with excess air to heat water in a boiler to create steam. Instead of direct combustion, some developing technologies gasify the biomass to produce a combustible gas, and others produce pyrolysis oils that can be used to replace liquid fuels. Boiler fuel can include wood chips, pellets, sawdust, or bio-oil. Steam from the boiler is then expanded through a steam turbine, which spins to run a generator and produce electricity.

In general, all biomass systems require fuel storage space and some type of fuel handling equipment and controls. A system using wood chips, sawdust, or pellets typically use a bunker or silo for short-term storage and an outside fuel yard for larger storage. An automated control system conveys the fuel from the outside storage area using some combination of cranes, stackers, reclaimers, front-end loaders, belts, augers, and pneumatic transport. Manual equipment, like front loaders, can be used to transfer biomass from the piles to the bunkers, but this method will incur significant cost in labor and equipment operations and maintenance (O&M). A less labor-intensive option is to use automated stackers to build the piles and reclaimers to move chips from the piles to the chip bunker or silo.

Wood chip-fired electric power systems typically use one dry ton per megawatt-hour of electricity production. This approximation is typical of wet wood systems and is useful for a first approximation of fuel use and storage requirements but the actual value will vary with system efficiency. For comparison, this is equivalent to 20% HHV efficiency with 17 MMBtu/ton wood.

Most wood chips produced from green lumber will have a moisture content of 40% to 55%, wet basis, which means that a ton of green fuel will contain 800 to 1,100 pounds of water. This water will reduce the recoverable energy content of the material, and reduce the efficiency of the boiler, as the water must be evaporated in the first stages of combustion.

The biggest problems with biomass-fired plants are in handling and pre-processing the fuel. This is the case with both small grate-fired plants and large suspension-fired plants.

Drying the biomass before combusting or gasifying it improves the overall process efficiency, but may not be economically viable in many cases.

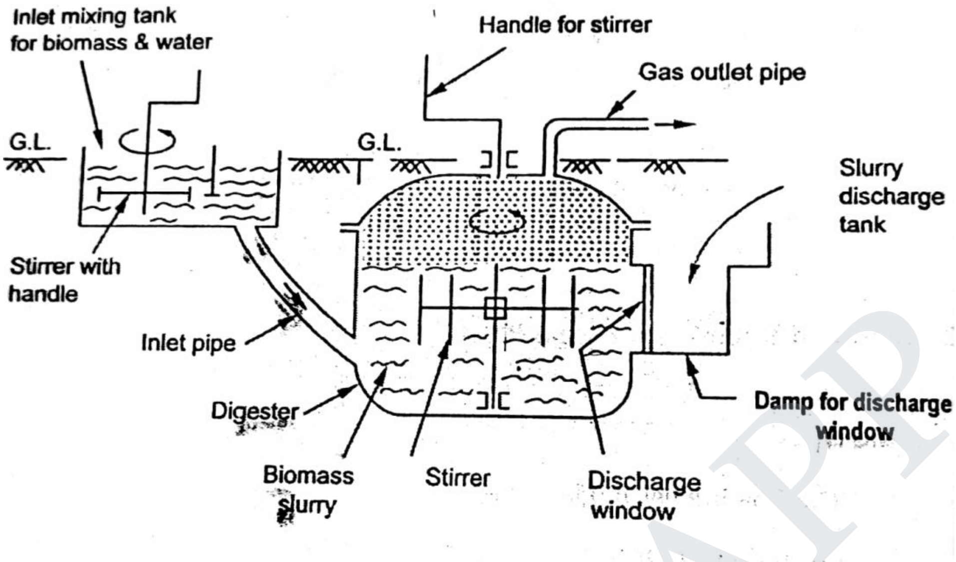
Exhaust systems are used to vent combustion by-products to the environment. Emission controls might include a cyclone or multi-cyclone, a baghouse, or an electrostatic precipitator. The primary function of all of the equipment listed is particulate matter control, and is listed in order of increasing capital cost and effectiveness. Cyclones and multi-cyclones can be used as pre-collectors to remove larger particles upstream of a baghouse (fabric filter) or electrostatic precipitator.

In addition, emission controls for unburned hydrocarbons, oxides of nitrogen, and sulfur might be required, depending on fuel properties and local, state, and Federal regulations.

1. FIXED DOME TYPE DIGESTER BIOGAS PLANT

A fixed-dome plant consists of a digester with a fixed, non-movable gas holder, which sits on top of the digester. When gas production starts, the slurry is displaced into the compensation tank. Gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the compensation tank. The costs of a fixed-dome biogas plant are relatively low. It is simple as no moving parts exist. There are also no rusting steel parts and hence a long life of the plant (20 years or more) can be expected. The plant is constructed underground, protecting it from physical damage and saving space. While the underground digester is protected from low temperatures at night and during cold seasons, sunshine and warm seasons take longer to heat up the digester. No day/night fluctuations of temperature in the digester positively influence the bacteriological processes. The construction of fixed dome plants is labor-intensive, thus creating local employment. Fixed-dome plants are not easy to build. They should only be built where construction can be supervised by experienced biogas technicians. Otherwise plants may not be gas-tight (porosity and cracks).

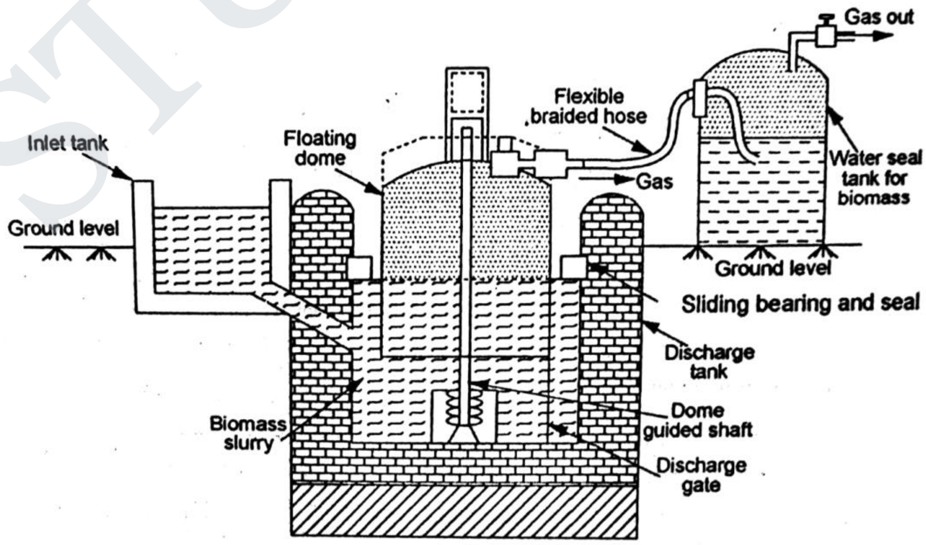
A fixed-dome plant comprises of a closed, dome-shaped digester with an immovable, rigid gas-holder and a displacement pit, also named 'compensation tank'. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored, i.e. with the height difference between the two slurry levels. If there is little gas in the gas-holder, the gas pressure is low.



Fixed dome type digester biogas plant

2. FLOATING GASHOLDER TYPE DIGESTER

The floating gas holder type bio gas plant consists of a dome shaped gas holder made of steel for collecting bio gas. The dome shaped gas holder is not fixed but is moveable and floats over the slurry present in the digester tank. Due to this reason, this biogas plant is called floating gas holder type biogas plant.



Floating gasholder type digester

Slurry is prepared by mixing water in cattle dung in equal proportion in mixing tank. The slurry is then injected into a digester tank with the help of inlet pipe. The digester tank is a closed underground tank made up of bricks. Inside the digester tank, the complex carbon compounds present in the cattle dung breaks into simpler substances by the action of anaerobic microorganisms in the presence of water. This anaerobic decomposition of complex carbon compounds present in cattle dung produces bio gas and gets completed in about 60 days. The bio gas so produced starts to collect in floating gas holder and is supplied to homes through pipes. And the spent slurry is replaced from time to time with fresh slurry to continue the production of bio gas.

FUEL CELL POWER SYSTEMS

1. HYDROGEN-OXYGEN FUEL CELL

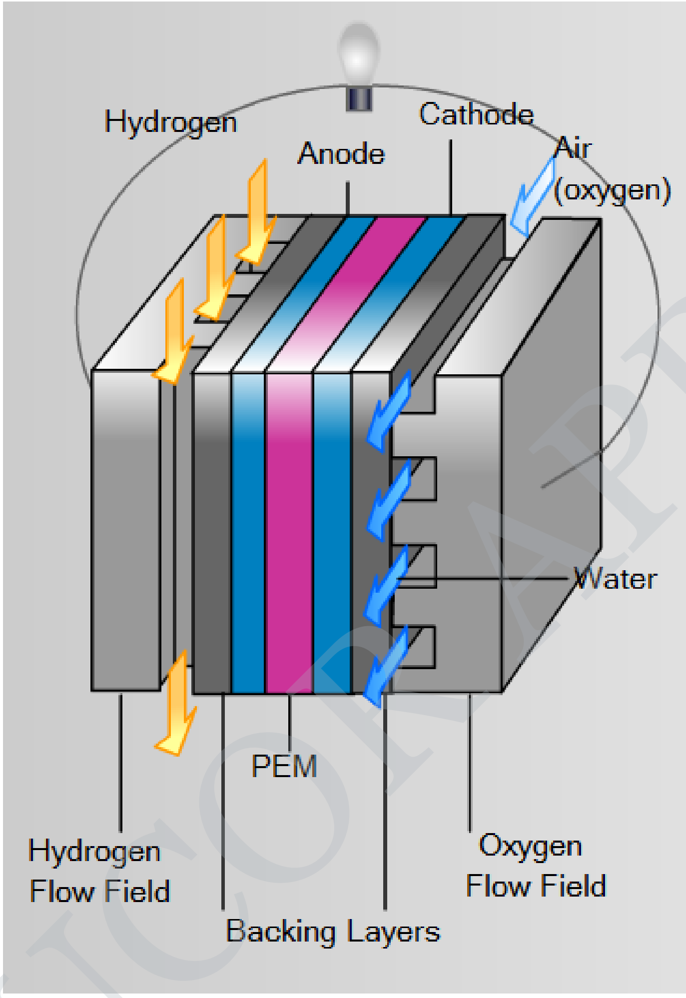
A fuel cell is a device that converts chemical potential energy (energy stored in molecular bonds) into electrical energy. A PEM (Proton Exchange Membrane) cell uses hydrogen gas (H_2) and oxygen gas (O_2) as fuel. The products of the reaction in the cell are water, electricity, and heat. This is a big improvement over internal combustion engines, coal burning power plants, and nuclear power plants, all of which produce harmful by-products

The anode, the negative post of the fuel cell, has several jobs. It conducts the electrons that are freed from the hydrogen molecules so that they can be used in an external circuit. It has channels etched into it that disperse the hydrogen gas equally over the surface of the catalyst.

The cathode, the positive post of the fuel cell, has channels etched into it that distribute the oxygen to the surface of the catalyst. It also conducts the electrons back from the external circuit to the catalyst, where they can recombine with the hydrogen ions and oxygen to form water.

The electrolyte is the proton exchange membrane. This specially treated material, which looks something like ordinary kitchen plastic wrap, only conducts positively charged ions. The membrane blocks electrons. For a PEMFC, the membrane must be hydrated in order to function and remain stable.

The catalyst is a special material that facilitates the reaction of oxygen and hydrogen. It is usually made of platinum nanoparticles very thinly coated onto carbon paper or cloth. The catalyst is rough and porous so that the maximum surface area of the platinum can be exposed to the hydrogen or oxygen. The platinum-coated side of the catalyst faces the PEM.



As the name implies, the heart of the cell is the proton exchange membrane. It allows protons to pass through it virtually unimpeded, while electrons are blocked. So, when the H_2 hits the catalyst and splits into protons and electrons (remember, a proton is the same as an H+ ion) the protons go directly through to the cathode side, while the electrons are forced to travel through an external circuit. Along the way they perform useful work, like lighting a bulb or driving a motor, before combining with the protons and O_2 on the other side to produce water.

How does it work? Pressurized hydrogen gas (H_2) entering the fuel cell on the anode side. This gas is forced through the catalyst by the pressure. When an H_2 molecule comes in contact with the platinum on the catalyst, it splits into two H+ ions and two electrons (e-). The electrons are conducted through the anode, where they make their way through the external circuit (doing useful work such as turning a motor) and return to the cathode side of the fuel cell.

Meanwhile, on the cathode side of the fuel cell, oxygen gas (O_2) is being forced through the catalyst, where it forms two oxygen atoms. Each of these atoms has a strong negative charge. This negative charge attracts the two H+ ions through the membrane, where they combine with an oxygen atom and two of the electrons from the external circuit to form a water molecule (H_2O).

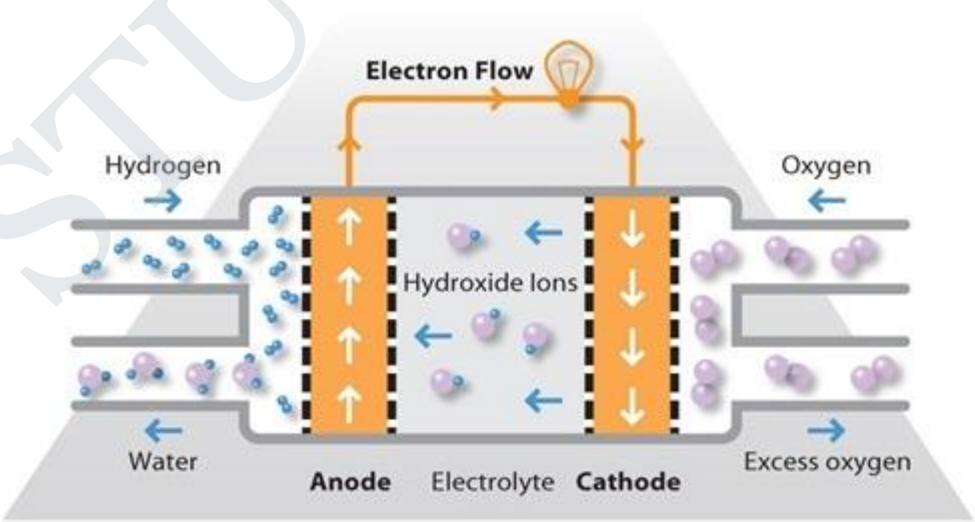
All these reaction occurs in a so called cell stack. The expertise then also involves the setup of a complete system around core component that is the cell stack.

The stack will be embedded in a module including fuel, water and air management, coolant control hardware and software. This module will then be integrated in a complete system to be used in different applications.

Due to the high energetic content of hydrogen and high efficiency of fuel cells (55%), this great technology can be used in many applications like transport (cars, buses, forklifts, etc) and backup power to produce electricity during a failure of the electricity grid.

2. ALKALINE FUEL CELLS

Alkaline fuel cells (AFCs) were one of the first fuel cell technologies to be developed and were originally used by NASA in the space programme to produce both electricity and water aboard spacecraft. AFCs continued to be used on NASA space shuttles throughout the programme, alongside a limited number of commercial applications.



AFCs use an alkaline electrolyte such as potassium hydroxide in water and are generally fuelled with pure hydrogen. The first AFCs operated at between 100ºC and 250ºC but typical operating temperatures are now around 70ºC. As a result of the low operating temperature, it is not necessary to employ a platinum catalyst in the system and instead, a variety of non-precious metals can be used as catalysts to speed up the reactions occurring at the anode and cathode. Nickel is the most commonly used catalyst in AFC units.

Due to the rate at which the chemical reactions take place these cells offer relatively high fuel to electricity conversion efficiencies, as high as 60% in some applications.

REVIEW QUESTIONS

1. What are the essential elements of hydro power plant? Explain with a neat sketch. **[AU NOV 2008/MAY 2011/DEC 2012]**
2. Explain the working of Pelton turbine with a neat diagram. What is the function of a draft tube? **[AU NOV 2012/MAY 2012]**
3. Describe the working of a low head hydro plant with a neat diagram. **[AU DEC 2014][AU Nov/Dec 2016]**
4. Compare and contrast Kaplan turbine and Francis turbine. **[AU APR 2004]**
5. Discuss various components of wind energy system. **[AU DEC 2014]**
6. Explain with a neat sketch a pumped storage power plant **[AU NOV 2007/MAY 2010, DEC 2012]**
7. Explain the spring tides and neap tides. Discuss the different tidal power schemes and configurations with neat sketches. **[AU NOV 2008]**
8. Draw a schematic diagram of a solar power plant and explain the operation of it. Also mention its merits and demerits. **[AU NOV 2009]**
9. Explain the construction and working of geo thermal power plant and tidal power plants. **[AU MAY 2011]**
10. Define the terms anaerobic digestion, Fermentation and What are the advantages and disadvantages of floating drum plant Give the list of the materials used for biogas generation. **[AU DEC 2014]**
11. Describe the principle of a fuel cell and discuss the choice of fuels required. **[AU DEC 2013]**
12. (i) Explain the construction and working of fuel cell also mention its merits and demerits.
    (ii)List the advantages and disadvantages of wind energy system. **[AU Nov/Dec 2016]**
13. Explain with a neat sketch working of a distributed (Parabolic) trough Solar Power Plant. **[AU DEC 2012]**

UNIT- V

ENERGY, ECONOMIC AND ENVIRONMENTAL ISSUES OF POWER PLANTS

Power tariff types, Load distribution parameters, load curve, Comparison of site selection criteria, relative merits & demerits, Capital & Operating Cost of different power plants. Pollution control technologies including Waste Disposal Options for Coal and Nuclear Power Plants.

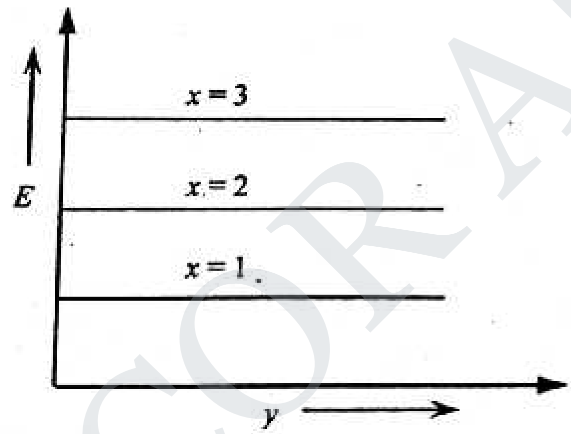
POWER TRAIFF TYPES

Energy Rates or Power Tariffs are the different methods of charging the consumers for the consumption of electricity. It is desirable to charge the consumer according to his maximum demand (kW) and the energy consumed (kWh).

1. **Flat demand rate**

In this type of charging, the charging depends only on the connected load and fixed number of hours of use per month or year.

This can be given by the following equation E = Ax



Flat demand rate

Here no metering equipments and manpower are required for charging. In this system, the consumer can theoretically use any amount of energy upto that consumed by all connected loads. The unit energy cost decreases progressively with an increased energy usage. The variation in total cost and unit cost are shown in fig.

2. **Straight line meter rate**

This type of charging depends upon the amount of total consumed by the consumer. The bill charge is directly proportional to the energy consumed by the consumer.

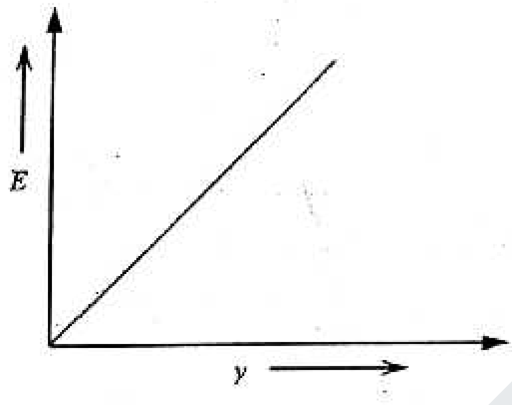
This can be represented by the following equation E = By

The major drawbacks of this system are:

1. In this type of system, the consumer using no energy ay any amount although he has incurred some expenses to the power station
2. The rate of energy is fixed, therefore this method of does not encourage the

consumer to use more power.

The variation in total cost and unit consumed are shown in the figure.



Straight meter rate

3. Block meter rate

In previous straight line meter rate the unit charge is same for all magnitudes of energy consumption. The increased consumption spreads the item of fixed charge over a greater number of units of energy.

Therefore, the price of energy should decrease with an increase in consumption. The block meter rate is used to overcome this difficulty.

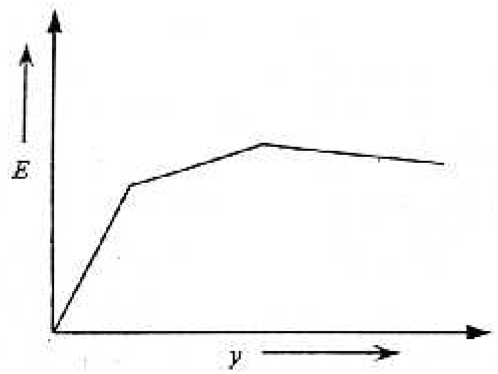
This method of charging is represented by the equation.

$E = B_1y_1 + B_2y_2 + B_3y_3 + \ldots\ldots.$

Where, $B_3 < B_2 < B_1$ and

$(y_1 + y_2 + y_3 + \ldots\ldots) = y$ (total energy consumption)

The level of $\mathbf{y_1}$ **,** $\mathbf{y_2}$ **,** $\mathbf{y_3}$ **……** is decided by the government to recover the capital cost, In this system, the rate of unit charge decrease with increase in consumption of energy as shown in fig.



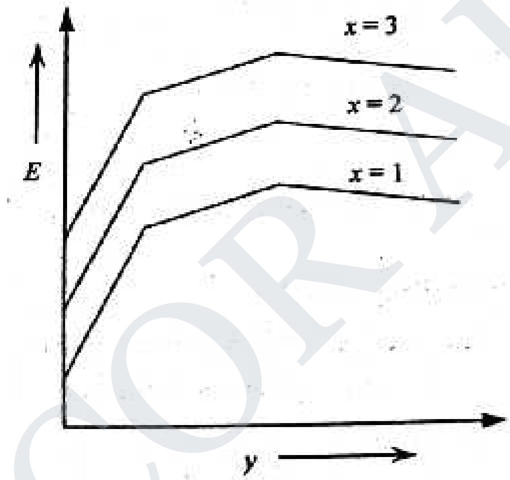
Block meter rate

4. Hopkinson demand rate or two part tariff

In this method of charging depends upon the maximum demand and energy consumption. This method is proposed by Dr.' John Hopknson in 1982.

This method of charging is represented by the equation E = A + By.

In this method two meters are required to record the maximum demand and the energy consumption of the consumer. This method is generally used for the industrial consumers. The variation in total cost with respect to the total energy consumption taking x as parameter is shown in fig.



Hopkinson method of charging

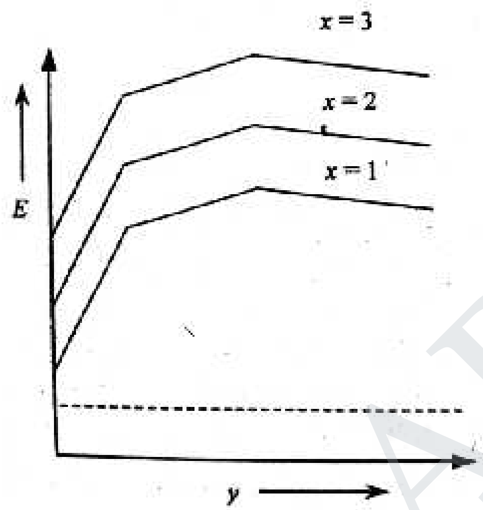
5. Doherty rate or three part tariff

This method is proposed by Henry L. Doherty. In this method of charging, the consumer has to pay some fixed amount in addition to the charges for maximum demand and energy consumed. The fixed amount to be charged depends upon the occasional increase in prices and wage charges of the workers etc.

This method of charging is expressed by the equation E = Ax + By + C.

This Doherty method of charging is most commonly used in Tamilnadu and all over India. In this method the customers are discouraged to use more power when the generating capacity is less than the actual demand.

For example, for the first 50kW-hr units the charging rate is fixed as, say, Rs. 2.5/Kwhr and if it exceeds than this charge is rapidly increased as Rs. 3.5/kW-hr for next 100 kW-hr units (i.e from 51Kw-hr to 150kW-hr). This method is unfair to the customer, but very common in India and many developing nations.



Doherty method of charging

The variation in total cost with respect to the total energy consumption taking x as parameter is shown in fig.

LOAD DISTRIBUTION PARAMETERS

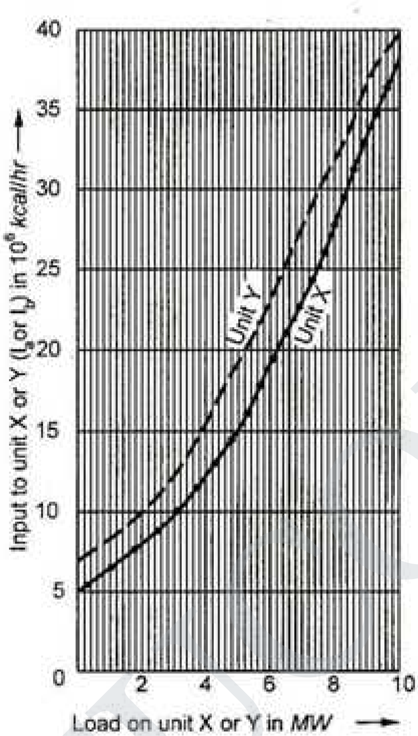
1. **Economics of load sharing between generators**

During design of power plants, prime importance is given to the economics of load sharing. Engineers are designing the power plant components such as boilers, heat turbines, heat exchangers, condensers, and generators etc for getting the highest thermal efficiency of the plant.

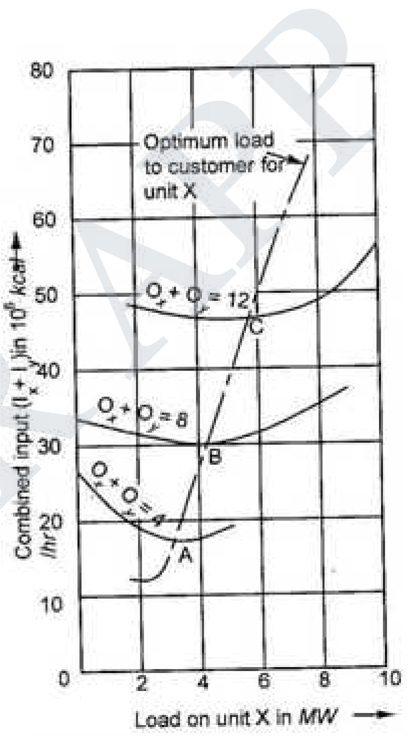
Various methods have been developed for economic operation of the power plant under varying load conditions. Transmission loss is also minimized by introducing the successful design of transmission lines.

The main problem for the electrical power engineers is the economic load sharing of the output of the generators. The proper sharing of load between two generators to give maximum overall efficiency is the major problem in load distribution among generators.

This input-output carries for two generators within a power plant which are operating in parallel and supply a common load is shown in fig below. From this fig, it is evident that the generator X is more efficient than Y throughout its load range as the output of X is more than the output of Y for the same input. Therefore, the engineers may think that they can load generator X first to its full capacity and then for generator Y for the remaining load. But it is not proper distribution as the overall efficiency of the system would not be highest with the distribution of loads as mentioned above.



Input-output curves of unit X and Y



Variation of combined input with varying load sharing between X and Y

This problem can be resolved by plotting the sum of the inputs of X and Y against the load x for a given constant load on the two limits, as shown in fig above.

The condition of minimum input for any combined constant output is given by

$$\frac{d(I_x + I_y)}{dO_x} = 0$$

$$\therefore \quad \frac{dI_x}{dO_x} + \frac{dI_y}{dO_x} = 0$$

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$$\frac{dI_x}{dO_x} = -\frac{dI_y}{dO_x} \quad \ldots (5.1)$$

But
$$\frac{dI_y}{dO_x} = \frac{dI_y}{dO_y} \cdot \frac{dO_y}{dO_x} \quad \ldots (5.2)$$

But
$$O_y = O_c - O_x \quad \ldots (5.3)$$

$\therefore$ $O_c = O_x + O_y$ combined output of X and Y.

Differentiating the equation (5.3) with respect to 'x',

$$\frac{dO_y}{dO_x} = \frac{dO_c}{dO_x} - \frac{dO_x}{dO_x}$$

where O_c = constant

$$\therefore \quad \frac{dO_y}{dO_x} = -1$$

Substituting this value in equation (5.2)

$$\frac{dI_y}{dO_x} = -\frac{dI_y}{dO_y} \quad \ldots (5.4)$$

This is the condition for the maximum input for the combined constant output. If there are n units supplying a constant load, then the required condition for the minimum input or maximum system efficiency is given by

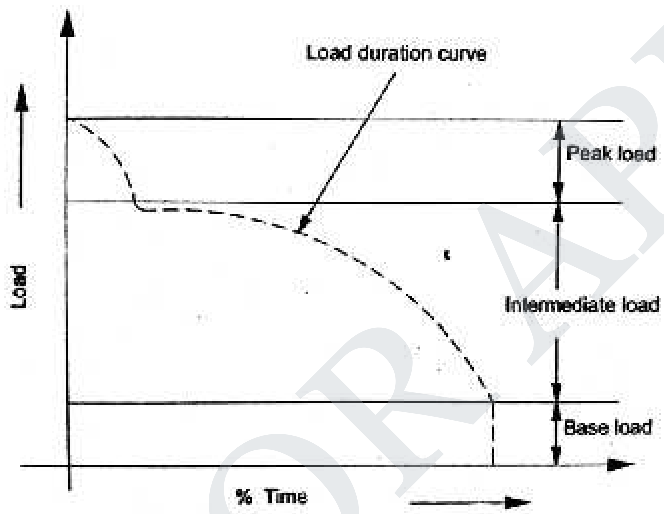
$$\frac{dI_1}{dO_1} = \frac{dI_2}{dO_2} = \frac{dI_3}{dO_3} = \ldots\ldots\ldots = \frac{dI_n}{dO_n}$$

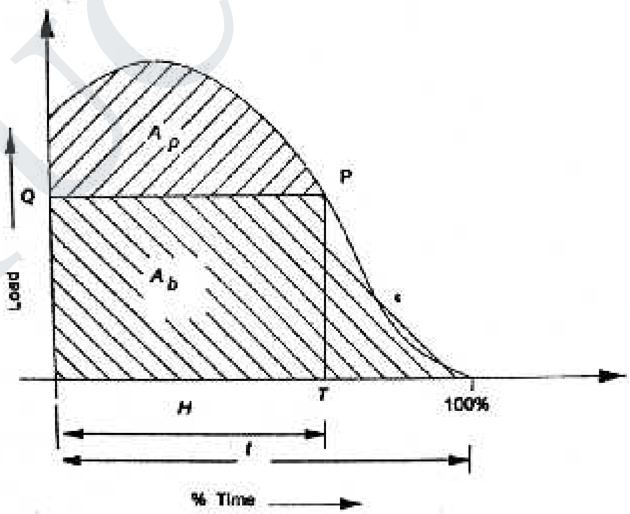
2. Economic load sharing between power plants

Different power plants such as hydro, thermal, nuclear, gas turbine, MHD, etc are operated combinedly to give greater reliability and maximum economic benefits. When the number of power stations works in combination with each other to supply the power to the consumers, the system is known as **interconnected system**.

In an interconnected system, the major problem is division of load among the power plants. The load distribution among the power plants depends upon the operating characteristics of the power plant. The distribution of load among the power plant in an interconnected system is done in such a way that the overall efficiency is achieved.

In the load duration curve, as shown below, the entire area under the load curve is divided into three parts as base load, intermediate load, and peak load. It is not economical to design a power plant to load to the maximum peak load as it works in under-load condition for the most of the time. In order to achieve the maximum possible is the loading of the most efficient power station in the order of merit of low fuel cost. It is made possible by establishing central control room which can control number of power plants simultaneously in the grid system. This also saves the fuel consumption per kW of power generation. In addition to the fuel consumption, there is also savings due to reduced spare capacity required and also due to the employment of large size units.





Peak load plants operate only when required for short time and takes up the load on upper part of the load curve. Plant capacity factor is low as it is operated for short duration. Fuel cost is very high but the total capital cost is less. Diesel and gas turbine plants are classified under this category.

For a known load duration curve, the economic load sharing between base load and peak load plants operating in parallel can be found as follows.

Let, the operating costs are known and they are given by

$$C_1 = A_1/(kW) + B_1/(kWhr) \quad \text{--- for base load plant}$$

$$C_2 = A_2/(kW) + B_2/(kWhr) \quad \text{--- for peak load plant}$$

where A_1 and A_2 = Fixed cost of base load and peak load plants respectively, and

B_1 and B_2 = Running cost of base load and peak load plants respectively

Peak load of the peak load plant is given by

$$P_p = P - P_b$$

where P = Peak load of the system in kW

P_b = Peak load on the base plant in kW

Number of units generated by the peak load plant N_p is given by

$$N_p = N - N_b$$

where N = total number of units generated by the system in kWh

N_b = units generated by base load plant

$$\therefore \quad C_1 = A_1P_b + B_1N_b$$

$$C_2 = A_2P_p + B_2N_p = A_2(P - P_b) + B_2(N - N_b)$$

Cost of the system C is given by

$$C = C_1 + C_2 = (A_1P_b + B_1N_b) + [A_2(P - P_b) + B_2(N - N_b)]$$

Minimum total cost can be calculated by

$$\frac{dC}{dP_b} = 0$$

$$\therefore (A_1 - A_2) + (B_1 - B_2)\frac{dN_b}{dP_b} = 0$$

$$\therefore \frac{dN_b}{dP_b} = \left(\frac{A_1 - A_2}{B_1 - B_2}\right) hrs$$

Thus, for economic load sharing, the area under the load curve is divided by a horizontal line. Its magnitude is given by

$$H = \frac{A_1 - A_2}{B_2 - B_1} \quad \text{in hours}$$

It indicates that for economic load sharing, the peak load plant should work for H hours per year. The value of H should always be higher.

$$\therefore A_1 > A_2 \quad \text{and} \quad B_2 > B_1$$

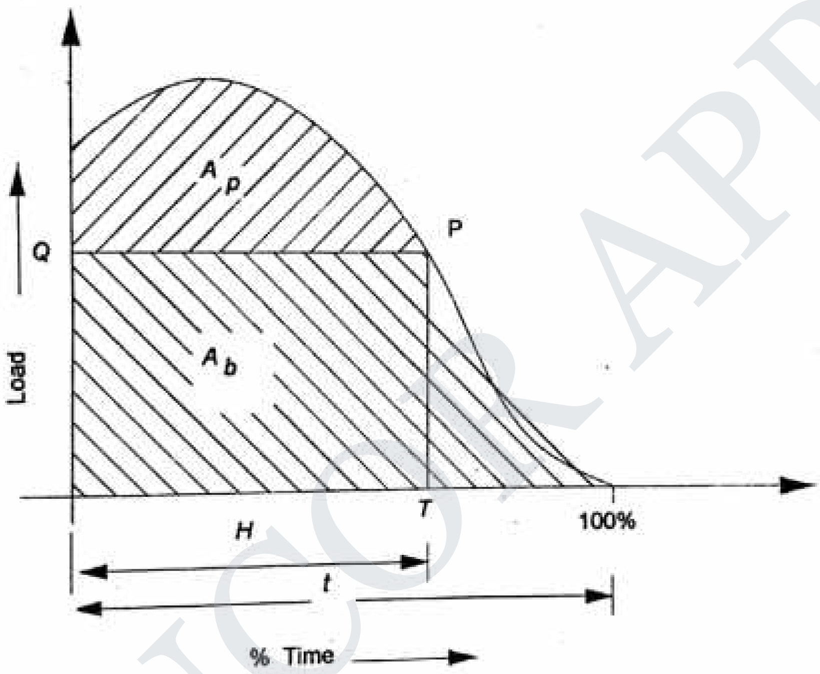


Figure 5.10

A_1 is higher and B_1 is lower for base load plant as compared to peak load plants. The point T is marked on the x-axis of load curve for the distance of H hours in percentage $\left(\frac{H}{8760} \times 100\right)$. The vertical line is drawn through T which meets the load curve at point P. The horizontal line PQ is drawn as shown in Figure 5.10. Now, the area A_p above the line PQ gives the energy generated by peak load plant and area below gives the energy generated by the base load plant. The scale taken for drawing load curve is $1cm = x$ % along time axis and $1cm = y$ in kW along the load axis.

$$\therefore \; 1cm^2 = (x\%) \times y$$

$$100\% = 8760 \text{hrs}$$

$$1cm^2 = \left(\frac{x}{100}\times 8760\right)\times y \text{ in } kWh$$

If areas A_b and A_p in cm^2 are known, then

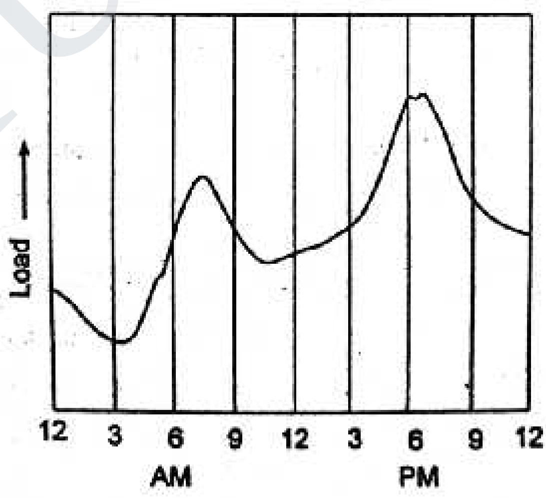
$$N_b = A_b \times \left(\frac{x}{100}\times 8760\right)\times y \text{ in } kWh \text{ for base load plant}$$

$$N_p = A_p \times \left(\frac{x}{100}\times 8760\right)\times y \text{ in } kWh \text{ for peak load plant}$$

Thus, the load sharing between two power plants can be achieved and it results the overall efficiency of operation.

LOAD CURVE

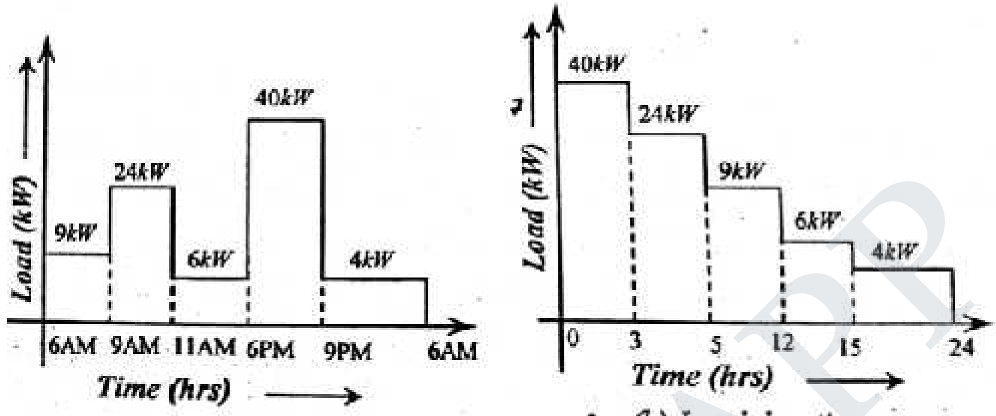
It is the graphical representation showing the power demand for every instant during a certain time period. It is drawn between load in kW and time in hours, if it is plotted for one hour, it is called as **hourly load curve** and if the time considered is of 24 hours then it is called **daily load curve,** and if plotted for one year (8760 hours) , then it is **annual load curve.** The area under the load curve represents the energy generated in the period considered. If we divide the area under the curve by the total number of hours, then it will give the average load on the power station. The peak load indicated by the load curve represents the maximum demand of the power station.



Load curve

LOAD DURATION CURVE

This curve represents the re-arrangement of all the load elements of load curve in order of decreasing magnitude. This curve is derived from load curve.



(a) Load curve (b) Load duration curve

COST OF ELECTRICITY

A power plant should provide a reliable supply of electricity at minimum cost to the consumers / customers. The cost of electricity may be determined by the following: Fixed cost or capital cost and Operating costs. The total cost of energy produced is the sum total of fixed charges and operating charges.

Total cost = Fixed costs + Operating costs

Fixed cost or capital cost: It is the cost required for the installation of the complete power plant. This cost includes

1. The cost of land, equipments, buildings, transmission and distribution lines cost of planning and designing the plant and many others.
2. Interest,
3. Depreciation cost,
4. Insurance,
5. Management costs, etc

1. **The cost of land, equipments, buildings** - The cost of land and buildings does not change much with different types of power plants but the equipment cost changes considerably. The cost of buildings can be reduced by eliminating the superstructure on the oiler house and turbine house. To reduce the cost of equipment, unit system may be adopted, reduced by simplifying the piping system and elimination of duplicate system such as steam headers and boiler feed heaters.The cost of equipment or the plant investment cost is usually expressed on the basis of kW capacity installed. The per kWcapacity may not vary for various thermal power plant where as for hydro-electric power plant, it changes a lot because the cost of hydro-electric power plant depends on the foundation availability, types of dam, available head and spillways used.

2. **Interest: -** the money needed or an investment may be obtained as loans, through bonds and shares. The interest is the difference between money borrowed and money returned. The rate of interest may be simple rate expressed as % per annum or may be compounded. A suitable rate of interest must be considered on the capital invested.

3. **Depreciation cost**: - it is the amount to be set aside per year from income to meet the depreciation caused by the ages of service, wear and tear of machinery, and the decrease in the value of equipment due to obsolescence. The power plant and equipment in the plant will have a certain period useful life. After years of use, the equipment loses its efficiency or becomes obsolete and needs replacement. Sometimes equipment may have to be replaced even when they fairly new, due to more efficient machines are available in the market. Some money is put aside annually to enable for this replacement, when necessary. This is known as depreciation fund.

Methods for calculating the depreciation cost: -

- Straight line method
- Sinking fund method
- Diminishing value method

4. **Insurance: -** nowadays, it becomes necessary to insure the costly equipments especially for the fire or accident risks. A fixed sum is set aside per year as insyrance charges. The insurance premium may be 2 to 3% of the equipment cost but annual installment is quite heavy when the capital cost of the equipment is high.

5. **Management cost; -** this cost includes the salary of the management employees working in the plant. This must be paid whether the plant is working or not. Therefore, this cost is included in the fixed cost.

<u>**Operatring cost**</u>**:** - the operational cost includes

a) The cost of fuel,
b) The cost of lubricatibg oil, greases, cooling water,
c) The cost of maintenance and repairs,
d) The cost of operating labour,
e) The supervision cost and
f) Taxes.

These costs vary with the amount of electrical energy produced.

a) Cost of fuel: - the fuel consumption depends on the amount of energy produced. As load increases the fuel consumption will increase so does the cost of fuel. The efficiency of the prime mover is the highest at the rated load.

At lower loads, efficiency decreases and so the fuel consumption will increase. The selection of the fuel and the maximum economy in its use are, therefore, very important consideration in thermal plant design. The cost of the fuel includes not only its price but also its transportation and handling costs also. The cost of fuel depends on the calorific value and its availability.

b) The cost of lubricating oil, greases, cooling water: - the cost of these materials also proportional to the amount of energy generated. this cost increases with an increase in life of the power plant as the efficiency of the power plant decreases with age.

c) The cost of maintenance and repairs: - in order to avoid breakdowns, maintenance is necessary. it includes periodic cleaning, adjustments and overhauling of equipments. the materials used for maintenance and repairs are also charged under this head. it is necessary to repair when the plant breakdown or steps due to fault in mechanism. the repairs may be major or minor and are charged to the depreciation fund of the equipment. the cost is higher for thermal power plants than hydro power plants.

d) The cost of operating labour: - this includes the salary and wages for the operating labour working in the plant. maximum labours are needed in a thermal power plant using coal as a fuel. a hydro power plant or a diesel power plant of same capacity requires a less number of labours. in automated power plant, labour cost is reduced to a greater extent.

e) The supervision cost: - it includes the salary of the supervising staff and executives. a good supervision reduces the breakdowns and extends the plant life. the supervising staff includes chief engineer, superintendent, engineers, stores in charges, purchase officers, other supporting staffs and executives, etc.

f) Taxes: - the various taxes are included in this head. These are income tax, sales tax, provisional tax, commercial tax, etc.

EXAMPLE: 01

Determine the annual cost of diesel power station from the following data:

Capital cost = Rs. 60 × 10^5

Salvage value = 6%

Life = 20 years

Annual repair and maintenance cost = Rs. 32000

Annual cost of fuel = Rs. 80000

Labour cost per month = Rs. 900

Interest on sinking fund = 5%

Solution:

Capital cost, P = Rs. 60 × 10^5

Salvage value, $S = \frac{6}{100} \times 60 \times 10^5$ = Rs. 360000

Life, n = 20 years

Rate of interest on sinking fund = 5% = 0.05

∴ Annual sinking fund payment

$$= \left[\frac{i}{(i+1)^n - 1}\right](P - S)$$

$$= \left[\frac{0.05}{(1+0.05)^{20} - 1}\right]\left[60 \times 10^5 - 360000\right] = \text{Rs. } 170568$$

Total cost per year

Annual sinking fund payment = Rs. 170568

Annual repair and maintenance cost = Rs. 32000

Actual cost of fuel = Rs. 80000

Annual labour cost = Rs. 900 × 12 = Rs. 10800

Total cost = **Rs. 293388**

EXAMPLE: 02

A plant costing Rs. 70000 has a useful life of 15 years. Find the amount which should be annually saved to replace the equipment at the end of time by (a) straight line method and (b) sinking fund method, if the annual rate of compound interest is 5%. Assume that the salvage value of the equipment is Rs.8000.

☺Solution:

(a) Straight line method:

According to this method, annual amount to be kept aside is calculated by the equation.

$$A = \frac{P-S}{n} = \frac{70000-8000}{15} = \text{Rs. } 4133.3$$

(b) Sinking fund method:

According to this method, annual amount to be kept aside is calculated by

$$A = \left[\frac{i}{(i+1)^n - 1}\right](P-S) = \left[\frac{0.05}{(1+0.05)^{15}-1}\right](70000-8000) = \text{Rs. } 2873.2$$

EXAMPLE: 03

The loads on a power plant with respect to 24 hours are listed below.

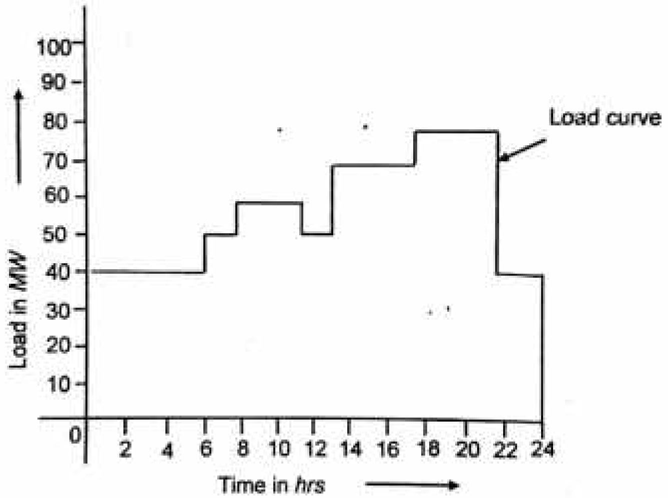
Time in hours	*0 – 6*	*6 – 8*	*8 – 12*	*12 – 14*	*14 – 18*	*18 – 22*	*22 – 24*
Load in MW	*40*	*50*	*60*	*50*	*70*	*80*	*40*

(a) Draw the load curve and find out the load factor of the power station.

(b) If the loads above 60 MW are taken by a standby unit of 20 MW capacity, find the load factor and use factor of the standby unit.

☺Solution:

(a) Based on the data given, the load curve is drawn as shown in Figure 5.22.



Energy generated = area under the load curve

$$= 40\times6 + 50\times2 + 60\times4 + 50\times2 + 70\times4 + 80\times4 + 40\times2$$

$$= 1360 MWh$$

Average load $= \frac{1360}{24} = 56.667 MW$

Load factor $= \frac{\text{Average load}}{\text{Maximum demand}} = \frac{56.667}{80} = 0.708$

(b) If the load above 60 MW is supplied by a standby unit of 20MW capacity, the energy generated by it can be calculated as follows:

Only 70 MW and 80 MW powers are more than 60 MW power. Therefore,

Energy generated by 70 MW power between 14 - 18 hours i.e. 4 hours is

$$= 10 \times 4 = 40 \, MWh$$

Energy generated by 80 MW power between 18 - 22 hours i.e. 4 hours is

$$= 20 \times 4 = 80 \, MWh$$

Total Energy generated by 70 MW and 80 MW power is

$$= 40 + 80 = 120 \, MWh$$

Time during which the standby unit remains in operation = 4 + 4 = 8 *hours*

Average load $= \frac{120}{8} = 15 \, MW$

Load factor $= \frac{15}{20} = 0.75$

Use factor $= \frac{\text{Energy generated}}{\text{Plant capacity} \times \text{Operating hours}} = \frac{120}{20\times8} = 0.75$

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SELECTION OF SITE FOR HYDRO ELECTRIC POWER PLANT

1. Water Available. To know the available energy from a given stream or river, the discharge flowing and its variation with time over a number of years must be known. Preferably, the estimates of the average quantity of water available should be prepared on the basis of actual measurements of stream or river flow. The recorded observation should be taken over a number of years to know within reasonable, limits the maximum and minimum variations from the average discharge. The river flow data should be based on daily, weekly, monthly and yearly flow ever a number of years. Then the curves or graphs can be plotted between tile river flow and time. These are known as hygrographs and flow duration curves.

The plant capacity and the estimated output as well as the need for storage will be governed by the average flow. The primary or dependable power which is available at all times when energy is needed will depend upon the minimum flow. Such conditions may also fix the capacity of the standby plant. The, maximum of flood flow governs the size of the headwords and dam to be built with adequate spillway.

2. Water-Storage. As already discussed, the output of a hydropower plant is not uniform due to wide variations of rain fall. To have a uniform power output, a water storage is needed so that excess flow at certain times may be stored to make it available at the times of low flow. To select the site of the dam ; careful study should be made of the geology and topography of the catchment area to see if the natural foundations could be found and put to the best use.

3. Head of Water. The level of water in the reservoir for a proposed plant should always be within limits throughout the year.

4. Distance from Load Center. Most of the time the electric power generated in a hydro-electric power plant has to be used some considerable distance from the site of plant. For this reason, to be economical on transmission of electric power, the routes and the distances should be carefully considered since the cost of erection of transmission lines and their maintenance will depend upon the route selected.

5. Access to Site. It is always a desirable factor to have a good access to the site of the plant. This factor is very important if the electric power generated is to be utilized at or near the plant site. The transport facilities must also be given due consideration.

SELECTION OF SITE FOR NUCLEAR POWER PLANT

The various factors to be considered while selecting the site for nuclear plant are as follows :

1. Availability of water. At the power plant site an ample quantity of water should be available for condenser cooling and made up water required for steam generation. Therefore the site should be nearer to a river, reservoir or sea.

2. Distance from load center. The plant should be located near the load center. This will minimise the power losses in transmission lines.

3. Distance from populated area. The power plant should be located far away from populated area to avoid the radioactive hazard.

4. Accessibility to site. The power plant should have rail and road transportation facilities.

5. Waste disposal. The wastes of a nuclear power plant are radioactive and there should be sufficient space near the plant site for the disposal of wastes.

SELECTION OF SITE FOR THERMAL POWER PLANT

1. Land Availability. Power plant needs a wide range of land requirements. For example, coal plants tend to need larger areas to support rail lines, coal piles, and landfills. Natural gas-fired power plants may only need area for the generation facilities and support equipment. Needed information includes the site size (acres), and the portion of the site (acres) that would be occupied by plant buildings and systems.

2. Water Availability. Many power plant technologies use water from lakes, rivers, municipal water utilities, or groundwater. Surface water is used for plant cooling and groundwater is used for plant processes. Generally, the presence of adequate and usable water resources at or near a site is preferred over sites with remote, inadequate, or low-quality water resources.

3. Fuel Availability. Fuel availability influences choices positively; its marginal utility is diminishing with supply. Without a higher level of availability, alternative fuels are unlikely to be adopted.

4. Skilled Manpower. Availability A power plant requires labor for construction and operation. Local communities can benefit from these employment opportunities. Generally, sites that can make use of local labor are more desirable. These sites would have a larger skilled work force within a short distance from the plant site.

5. Land Acquisition Cost. Each site will have unique land acquisition requirements and effects. Generally, sites that have lower land acquisition costs and require shorter acquisition times are more desirable.

6. Future Development Limitations. The construction of a plant at a particular site may create limitations on future development in the local area through its effect on land use or through its consumption of local PSD air increments, water resources, or water discharge capacity. Generally, sites that impose fewer limitations on future development may be more desirable.

7. Possibility of Site Expansion. A site might be able to support more generating capacity than proposed. It's usually more economical and environmentally acceptable to add generating capacity at an existing site than to build at a new site.. Often, an expandable site may be more desirable. But, a potential concern of local property owners is the effect of plant siting on nearby property values. Generally, sites that enhance property values or minimize the decrease in property values may be more desirable.

WASTE DISPOSAL OPTIONS FOR THERMAL POWER PLANT

The disposal of the increasing amounts of solid waste from coal-fired thermal power plants is becoming a serious concern to the environmentalists. Coal ash, 80% of which is very fine in nature and is thus known as fly ash is collected by electrostatic precipitators in stacks. A 400 *MW* thermal power plant emits 500 *tons* of fly ash per day and the ash content of coal in India varies from 3 to 42%. In India, nearly 85 million tonnes per year of flyash is generated per annum at present and is largely responsible for environmental pollution. Although the scope for use of ash in concrete, brick making, soil-stabilization treatment and other applications has been well recognized, only a small quantity of the total ash produced in India is currently utilized in such applications. Most of the ash generated from the power plants is disposed off in the vicinity of the plant as a waste material covering several hectares of valuable land. The bulk utilization of ash is possible in two areas, namely, ash dyke construction and filling of low-lying areas.

(i) Flyash disposal in ash ponds:

Primarily, the flyash is disposed off using either dry or wet disposal scheme. In *dry disposal*, the flyash is transported by truck, chute or conveyor at the site and disposed off by constructing a dry embankment (dyke). In *wet disposal*, the flyash is transported as slurry through pipe and disposed off in impoundment called "ash pond". Most of the power plants in India use wet disposal system, and when the lagoons are full, four basic options are available:

(a) Constructing new lagoons using conventional constructional material,

(b) Hauling of flyash from the existing lagoons to another disposal site,

(c) Raising the existing dyke using conventional constructional material, and

(d) Raising the dyke using flyash excavated from the lagoon ("ash dyke").

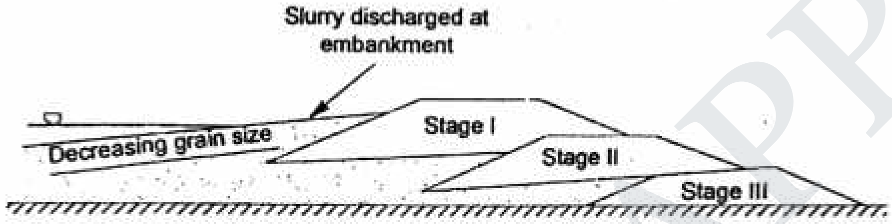
The option of raising the existing dyke is very cost effective because any fly ash used for constructing dyke would, in addition to saving the earth filling cost, enhance disposal capacity of the lagoon. The constructional methods for an ash dyke can be grouped into three broad categories:

(a) Upstream method,

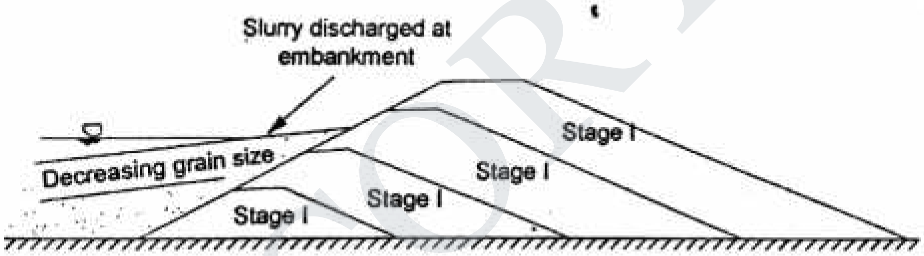
(b) Downstream method and

(c) Centerline method.

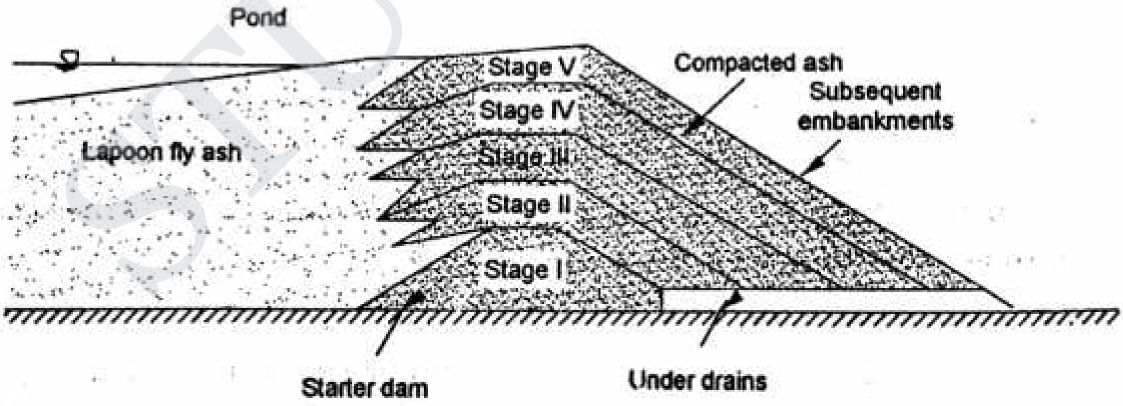
Figure shows typical configurations of embankments constructed using the different methods. The construction procedure of an ash dyke includes surface treatment of lagoon ash, spreading and compaction, benching and soil cover.



(a) Upstream Method



(b) Downstream Method



(c) Centreline Method

Typical ash dyke raising configurations

According to the hazardous waste management and handling rule of 1989, flyash is considered as non-hazardous. With the present practice of fly-ash disposal in ash ponds (generally in the form of slurry), the total land required for ash disposal would be about 82,200 hectare by the year 2020 at an estimated 0.6 hectare per MW. Flyash can be treated as a by-product rather than waste.

(ii) Treatment of wastewater of steam power plant:

If the waste water from the power plant is not properly handled, it will pollute the water basin. Various types of waste water collected from the steam power plant are given below.

(i) Waste water from water treatment plants.

(ii) Water from hydraulic ash disposal system.

(iii) Rainwater collected on the territory of power plant.

(iv) Cooling waters used in power plants.

The waste water from water treatment plants contains various metal salts, acids and alkalis which may affect the water basin. It ensures the waste water of hydraulic ash disposal system not having any contaminations before it goes to the water basin. The cooling water of plant carries an enormous amount of heat. This heat will affect the water basin. So, the heat is to be reduced before it goes to the basin. The water purification is done by the following methods.

1. Filtering
2. Flotation
3. Centrifuging
4. Coagulation
5. Setting and clarifying
6. Bio-chemical methods.

POLLUTION CONTROL TECHNOLOGIES INCLUDING WASTE DISPOSAL OPTIONS FOR NUCLEAR POWER PLANTS

Nuclear power is classified as a clean energy source because of absence of noxious combustion products and the supply of fuel which will last for centuries when breeder reactors become operational. The nuclear power generation poses mainly two problems as follows.

(i) The management of radioactive waste, and

(ii) The danger passed in case of accident is very high and long standing.

The radioactive emission during the operation of the power plant is negligible but the emission intensity is very high which comes out from wastes. They emit large quantities of γ-rays which are very danger for living matters.

The radioactive waste coming out of 400 *MW* power plant would be equal to 100 *tons* of radium daily. This much of radioactive waste disposed to the atmosphere would kill all living organisms within the area of about 100 *square kilometers*. Therefore, safe disposal of nuclear waste is a major problem and it is very much essential. Many numbers of methods are developed for the last 25*years* to dispose off various types of nuclear waste safely.

TYPES OF NUCLEAR WASTES

The nuclear wastes are classified as follows.

(i) On the basis of half-life time

(a) Fission products

(b) Actirides

(c) The neutron activation products.

(ii) On the basis of the intensity of radiation

(a) Low level waste

(b) Medium level waste

(c) High level waste.

1. Fission products:

The wastes produced from reactor operations include fission products and Plutonium. The half-lives of most of the fission products are 30 *years* or less. Their toxic lifetime is in the order of 500 *years* to 1000 *years*. Most of the fission products are initially radioactive and decay with the emission of β and γ-rays.

2. Actinides:

Actinides are produced in nuclear reactors as a result of neutron capture by Uranium. The most important is Plutonium. The other actinides are neptunium, americium and curium. The actinides decay mainly by emission of α-particles until a stable isotope of load is formed.

α-particles can be easily stopped. Therefore, actinides do not require thick shieling. However, α-particles are very energetic and toxic if inhaled as dusts.

3. Neutron activation products:

These are produced when fast neutrons are absorbed by structural materials in reactors as coolant, fuel cladding etc. These products decay with the emissions of β and γ radiations.

4. Low level wastes:

Low level wastes contain less than 10 *nanocuries per gram* of trans uranium contaminants. They have low but potentially hazardous concentration of radioactive materials. Low level wastes are produced in almost all activities such as power generation, medical, Industrial etc. They involve with radioactive materials. They require little or no shielding and they are usually disposed off in liquid form through shallow land burial.

5. Medium level wastes:

Medium level wastes contain more than 10 nanocuries but they are less than 100 nanocuries per *gram* of trans uranium contaminants. These wastes are mainly contaminated with neutron activation product isotopes.

6. High level wastes:

The high level wastes contain more than 100 *nanocuries per gram* of trans uranium contaminants. These are generated by reprocessing of spent fuel. The spent fuel is withdrawn from the reactor and placed in a water pond. The heat is removed from the water pond. The pond wastes are continually treated to remove activity due to release of fuel from defective cladding. The spent fuel is then transferred to the reprocessing plant where the cladding contains the fuel to be removed and the fuel is dissolved in nitric acid. U^{235} and Pu^{239} are then removed around 99% non-volatile fission products behind in solution known as "*highly active liquid waste*".

Effects of High-Level Wastes

It is important to study the effects of high level wastes to biological systems. The principle effect is the destruction of body cells in the vicinity of the irradiated region due to interaction of the radiation and tissue. The interaction between radiation and tissue is manifested in three ways.

1. Ionization:

The formation of ion-pair in tissue requires $32.5eV$ of energy when a single $1Mev$ β-particle is stopped by tissue about 3100 *ion-pairs* formed. If $1cm^2$ area of tissue surface is subjected to a beam of β-particles/cm^2/s, 31×10^6 *ion-pairs* will be formed in each second. This absorption results the complete damage of tissues in the body of man or beast or bird.

2. Displacement:

If the energy of the impinging particle is sufficiently high, an atom in the tissue is displaced from its normal lattice position with possible adverse effects. Neutron and γ-radiation result the atomic displacement.

3. Absorption:

Absorption of neutron by a tissue nucleus results the formation of a radioactive nucleus and it changes the chemical nature of the nucleus. It causes malfunctioning of the tissue cell and the cell damage causes severe biological effects including genetic modifications.

NUCLEAR WASTE DISPOSAL

These wastes must be disposed off in such a manner that there is no harm to human, animal or plant lives. Solids of low and medium level wastes are buried at a depth of few meters at carefully selected sites. Gaseous wastes are discharged to the atmosphere through high stacks. Liquids having low or medium level of radioactivity are given preliminary treatment to remove the most of activity in the form of solid precipitate and then it is discharged in dry wells or deep pits. Different methods for various nuclear wastes disposed are discussed below.

Disposal of Low Level Solid Waste

Low level solid waste requires little or no shielding. It is usually disposed off by keeping it in a steel or concrete tank. These tanks are buried either few meters below the soil or kept at the bed of the Ocean shown in Figure

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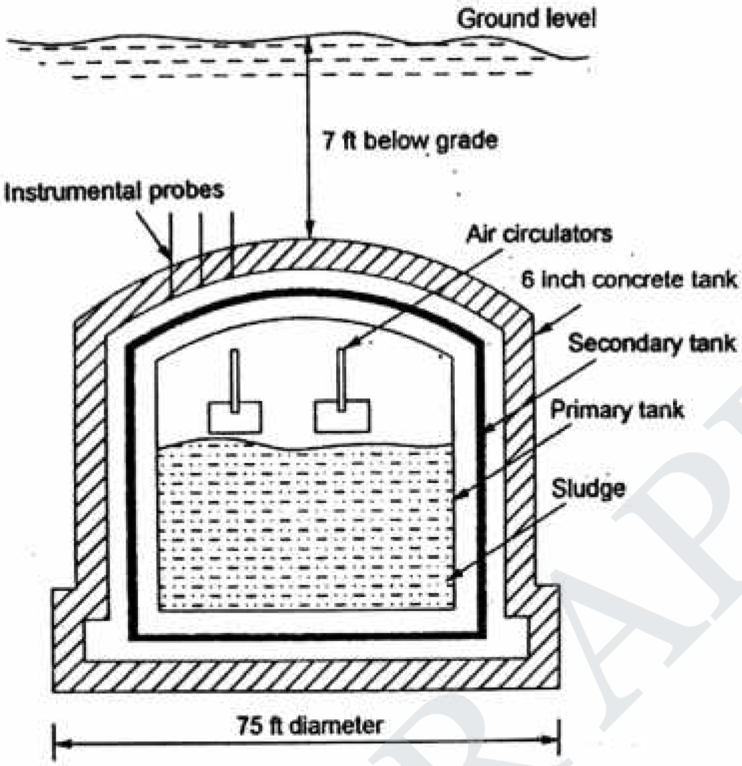


Figure Disposal of low level solid waste

Disposal of Medium Level Solid Wastes

Medium level wastes are mainly contaminated with neutron activation product isotopes. They are incorporated into cement cylinders. Cement is non-combustible material and it provides shielding against the external exposure. Cement is also having the ability of resistance to reach by ground water.

Disposal of High Level Wastes

Spent fuel from the nuclear reactor can either be stored directly or reprocessed. The storage system avoids the cost and hazards associated with a reprocessing plant. The second method utilizes reprocessing of unused uranium and converted into Plutonium and other radioisotopes for the use in wide variety of services such as isotope generators, medicine, agriculture and industry.

Reprocessing of the spent fuel is done by dissolving it in nitric acid and then removing the converted Plutonium and unspent uranium by solvent extraction. The remaining solution contains more than 99.99% of the non-volatile fission products plus some constituents of the cladding of fuel elements, traces of plutonium and Uranium.

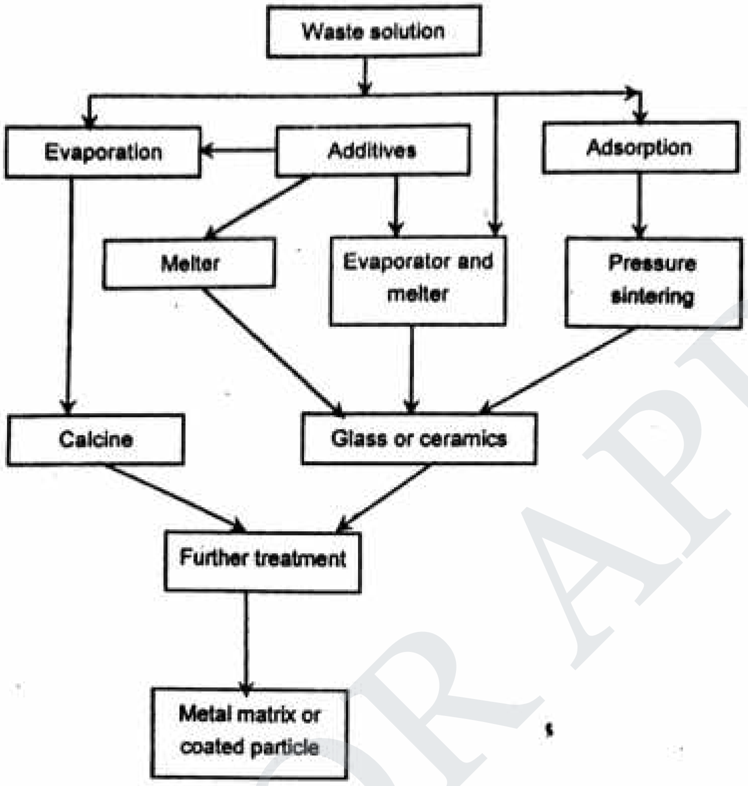


Figure 5.30 Basic high level waste solidification processes

The remaining solution consists of high level wastes. It is usually concentrated by evaporation. It is then stored as an aqueous nitric acid solution usually in high integrity stainless steel tanks. However, the permanent storage in liquid form requires continuous supervision and tank replacement over an indefinite period of time.

The conversion of the liquid wastes to a solid form is very important. It avoids leakages. It requires less supervision and it is more suitable for final disposal. Advanced processes are currently being developed. This solid product should maintain its mechanical strength. Ideally, it should have a low leak rate.

Glasses and ceramics are now considered to be most suitable forms for this final disposal. The basic processes are shown in Figure 5.30. It involves in evaporation and de-nitration (or calcinations) to form a granular or solid calcine. It is considered an interim product since it does not meet all above requirements. It is treated further by being mixed with additives and it is then melted to form glasses or ceramics.

A second process involves mixing of additives with the original waste solution, evaporating, de-nitrating and melting this mixture to form glasses or ceramics.

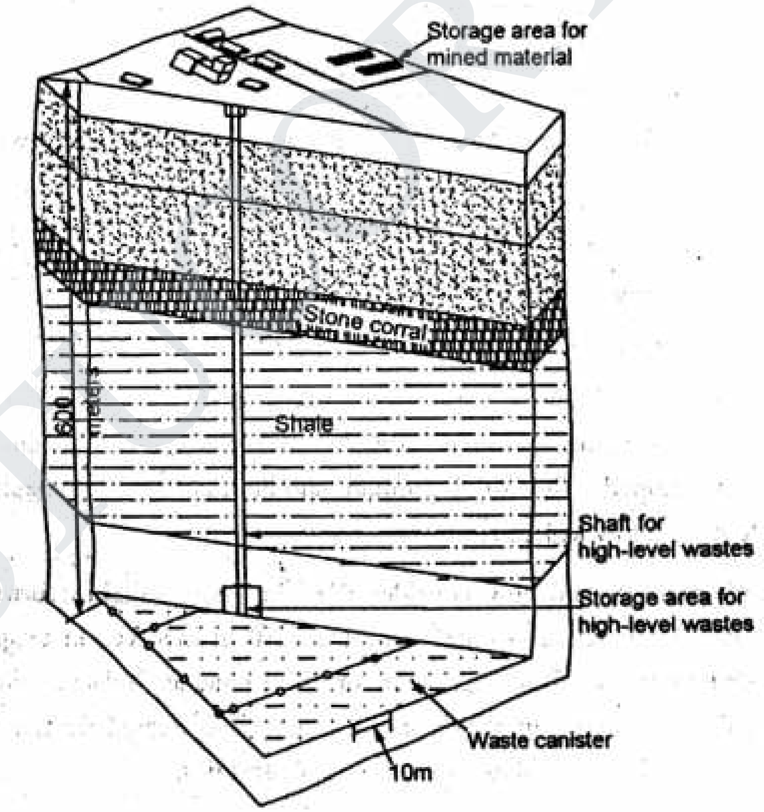
A third process uses an adsorption process and treatment at high temperature to produce ceramics.

Most solidification plants produce steam from off-gases and oxides of nitrogen that usually contain some fine particulate carryover and volatile radio-nuclides. These gases must be treated. All processes involve high temperature as well as high level of radioactivity.

Underground Disposal of High Level Waste

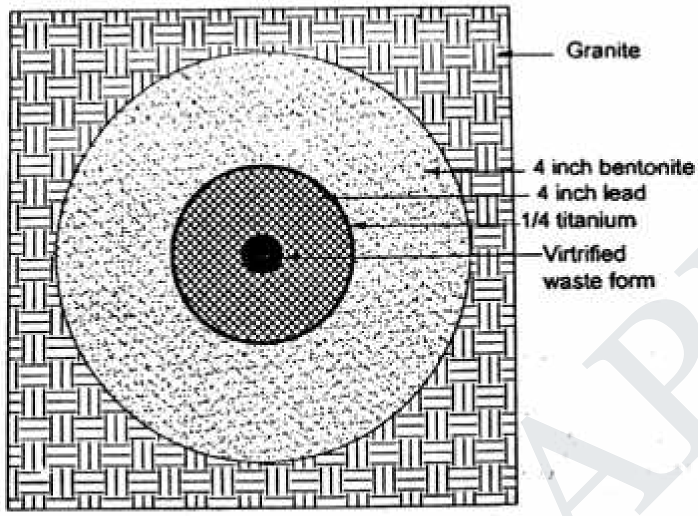
The final disposal of wastes with or without above treatments is also a major concern. Many countries are undertaking activities involving underground disposal in deep geological formation. These activities include the investigation of suitable sites and suitable methods of storing in these sites.

The main objectives are the protection of present and future populations from potential hazards. The suitable sites must be free of flowing ground wastes but the storage vessels must demonstrate the reliability even in flowing condition.



Underground disposal of high level nuclear waste

A cavity is excavated 511*m* depth in salt mine and cylinders are stored in this cavity as shown in Figure 5.31. It has a special advantage that the salt is strong absorber of radioactive emissions and it has good thermal conducting property which helps to keep the temperature within the acceptable limit.



Nuclear Solid waste in canister

The solidified waste is placed in canisters which are stored in holes drilled in rock salt with a spacing of about 10 *m* to allow for the efficient dissipation of energy without exceeding the permissible temperature limits of salt in canisters. Each canister will require about 100 m^2 of salt for cooling.

Figure 5.32 shows the cross-section of a canister of Swedish design for the disposal in granite. It shows the vitrified waste surrounded by 4 inch of lead, 0.25 inch of titanium, 4 inch of bentonite and finally granite.

TWO MARKS

QUESTIONS AND ANSWERS

1. **What is main objective of tariff? [AU Nov/Dec 2016]**
   - Recovery of cost of producing electrical energy at the power station.
   - Recovery of cost on the capital investment in transmission and distribution systems.
   - Recovery of cost of operation and maintenance of supply of electrical energy *e.g.*, metering equipment, billing etc.
   - A suitable profit on the capital investment.

2. **Define law of conservation of Energy. (AU(EEE)DEC'13)**
   Energy may be neither create nor destroyed but it can be transferred from one form to another form.

3. **What is the significance of incremental rate for a power plant? (AU.DEC'04)**
   Boiler efficiency is defined as the ratio of heat energy used in system formation to the heat energy supplied by burning of fuel in the same period but the incremental heat rate is the reciprocal of boiler efficiency.

4. **What are the various operating costs of fired steam power plant? (AU.Apr'05)**
   a) Cost of fuel
   b) Lubricating oil, grease water cost
   c) Cost of maintenance and repairs
   d) Cost of operating labour
   e) Cost of supervision
   f) Taste.

5. **Define demand for electricity. (AU.(EEE)DEC'13)**
   It is defined as the electricity requirement during the period of time of high price or more stress.

6. **Define "Diversity factor". (AU.DEC'05)**
   Diversity factor is defined as the ratio of sum of the individual maximum demand to the actual peak load of the system.
   Diversity factor =Sum of individual maximum demand/Actual peak load of the system.

7. **Define plant use factor. [AU Nov/Dec 2016]**
The ratio of the average power load of a **plant** to its rated capacity.

8. **What are the major factors that Decide the economics of power plants? (AU.(MECH)Apr'08)**
   i. Connected load
   ii. Demand
   iii. Maximum demand
   iv. Demand factor
   v. Load factor
   vi. Capacity factor or plant capacity factor
   vii. Utilization factor
   viii. Reserve factor
   ix. Diversity factor
   x. Plant use factor

9. What do you understand by load duration curves?(AU.(MECH) May'14)

Re-arrangement of all load elements of load curve is in the order of decreasing magnitude.

10. State the importance of load curves. (AU.(MECH)May'11)

a. To obtain the average load on the power station and the maximum demand of the power station.
b. To know the incoming load thereby helping to decide the installed capacity of the power station.
c. To decide the economical sizes of various generating units.

11. What is the significance of load curve? (AU(MECH)May'13)

The load curve gives full information about the incoming load and it helps to decide the installed capacity of the power station. It is also useful to decide the economical sizes of various generating units.

12. What is the use of load curves in power plant? (AU(MECH)Apr'08)

Load curve is a graphical representation which shows the power demands for every instant during certain time period. By drawing these load curves, the peak load can be identified. Therefore, the capacity of power plant can be judged.

These curves give full information about the incoming load and they help to decide the installed capacity of the power station. It is also useful to decide the economical sizes of various generating units.

13. How does the fuel cost related to the load and the cost of power generation? (AU.(MECH)Nov'08 & Apr'11)

The cost of power generation is directly proportional to the fuel cost because the operating cost is directly linked with the fuel cost.

14. What are fixed? (AU.(MECH)DEC'12 & May'14)

Fixed costs are the cost required for the installation of complete power plant. This cost includes the cost of land, buildings, equipment, transmission and distribution lines, cost of planning and designing the plant and many others. It also consists of interest, taxes, depreciation, insurance etc.

15. Define flat rate tariff. (AU (MECH)May'11 & DEC'13) The charging of amount depending only on the connected load and fixed number of hours of use per month or year is called flat rat tariff.

16. List the types of tariffs to calculate energy rate. (AU (MECH)DEC'12)

a. Flat demand rate
b. Straight line meter rate
c. Block meter rate
d. Hopkinson demand rate of two-par tariff
e. Doherty rate or tree part tariff.

17. How the tariff for electrical energy is arrived? (AU (MECH)May'11)

Tariff is calculated by the following equation.

E= Ax+By+C

Where

E=Total amount of bill for the period considered

A=Rate per kW of maximum demand

X= Maximum demand in kW

B=Energy rate per kWh

Y= energy consumed in kWh during the period considered

C=Constant amount charged to the consumer during each bill period. This charge is independent of demand or total energy.

18. Define depreciation.
It is the amount to be set aside per year from income to meet the depreciation caused by the age of service, wear and tear of machinery.

19. Mention any four methods for calculating depreciation.
- Straight line method
- Sinking fund method
- Diminishing value method
- Net percent value method
- Double sinking fund method.

20. What is the reason for the operating cost of hydel power plant being high?
No fuel cost is required for running the power plant.

21. How can be the cost of power generation reduced?
- Periodic maintenance.
- Installing waste heat recovery system.
- Using energy efficient devices such as insulated
- Compressors and insulated turbines.
- Using higher grade fuels.

22. What are the factors that contribute for energy cost?
- Cost of fuel.
- Cost of operating labour.
- Cost of maintenance labour and rnaterials.
- Cost of supplies

23. A. List out four important factors to be considered for the selection of site for power plants,
- Cost of land as well as taxes on land.
- It should be near load centers.
- It should be accessible by road, rail etc.,
- Sufficient quantity of cooling water should be available.
- The selected site should be away from the populated area
- Enough space should be available for future expansion of plants.
- The selected site should satisfy geological factors.

24. What are the different pollutions in the flue gas?
- Oxides of nitrogen
- Oxides of sulphur
- Carbon monoxide
- Particulates.

25. What are the methods used for reduction of SO2 pollutant?
- Adding lime stone (CaCO) to the coal
- Using wet scrubbers
- Using electro static precipitator.

26. What are the methods used for controlling the NOx?

- Reduction of temperature in combustion zone.
- Reduction of residence time in combustion zone.
- Increase in equivalence ratio in the combustion zone.

27. What is Acid rain?

CO, SO and NO contact the water during rainy season. So, I {SO+ and HNO: acids are formed and mixed with water during rainfall.

28. What is the equipment used to control the particulates?

- Scrubbers
- Cyclone separator
- Fabric filters
- Electro static precipitators.

29. List down the nuclear waste disposal methods.

- Disposal in sea.
- Disposal in land.
- Disposal by reduction process through chemical reaction.
- Disposal by solidification process.

30. What are the various methods followed to transport solid waste?

(i) Wet slurry method: This method uses water slurry to transport the material to the disposal area.
(ii) Pneumatic method: This method uses the air to transport solid wastes to the disposal. area.
(iii) Trucking.
(iv) Rail transport.
(v) Conveyor usually fixed or movable belt conveyor systems is used, and
(vi) Barge uses waterways to transport waste materials.

31. What are operating costs? (AU.(MECH)DEC’12 & May’14)

Operating cost includes the cost of fuel, cost of lubricating oil, greases, cooling water, cost of maintenance and repairs, operating labour cost, supervision cost and taxes.

32. What are the costs involved in fired steam power plant?(AU.Apr’05)

- Maintenance and repairs cost
- Operating labour cost
- Supervision cost

REVIEW QUESTIONS

PART –B & C

1. Explain the methods to control pollution in thermal and nuclear power plants. **[AU Nov/Dec 2016]**
2. Write an explanatory note on the economics of power generation. **[AU DEC 2014]**
3. What is meant by load factor and diversity factor? **[AU APR 2005]**
4. Elucidate the objectives and requirements to tariff and general form of tariff. **[AU MAY 2013]**
5. What are the elements which contribute to the cost of, the electricity'? And how can the cost power generation be reduced? **[AU APR 2008]**
6. Explain briefly the various methods used to, calculate the depreciation cost. **[AU MAY 2013]**
7. What are the fixed and operating costs of steam power plant? How are they accounted for fixing cost of electricity? **[AU MAY 2011/2014]**
8. Explain the analysis of pollution from thermal power plants. What is methods used for control the pollutants?
9. Write short notes on nuclear waste disposal. **[AU APR 2008/NOV 2008]**
10. (i) Explain the site selection criterion of hydro power plant.
    (ii)A peak load on the thermal power plant is 75 MW. The loads having maximum demands of 35 kW, 20 MW, 15 MW and 18 MW are connected to the power plant. The capacity of the plant is 90 MW and annual load factor is 0.53. Calculate the average load on power plant, energy supplied per year, demand factor and diversity factor. **[AU Nov/Dec 2016]**

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