(JAYASAKTHI EDUCATIONAL TRUST, CHENNAI 600 123)

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

ME6701 POWER PLANT ENGINEERING

LECTURE NOTES

UNIT I

COAL BASED THERMAL POWER PLANTS

NAME: ………..

YEAR: …….

PREPARED BY APPROVED BY PRINCIPAL

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

ME6701 POWER PLANT ENGINEERING

UNIT-I COAL BASED THERMAL POWER PLANTS

Rankine cycle-improvisations, Layout of modern coal power plant, Super critical boiler FBC boilers, Turbines, condensers, Steam and heat rate, subsystems of thermal power plants-Fuel and ash handling, draught system, Feed water treatment, Binary cycles and cogeneration systems.

RANKINE CYCLE-IMPROVISATIONS

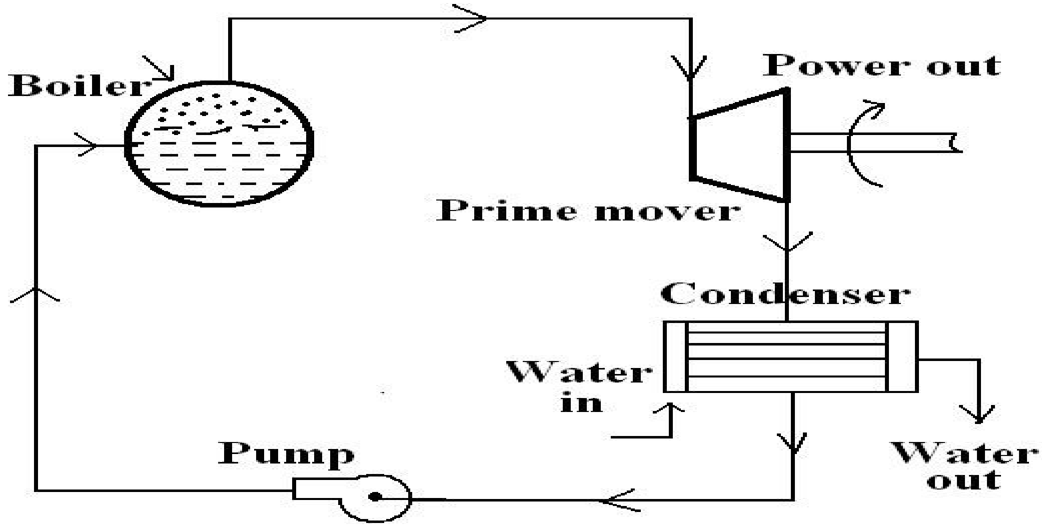


Fig.1 The arrangement of the components used for steam power plant working on rankine cycle.

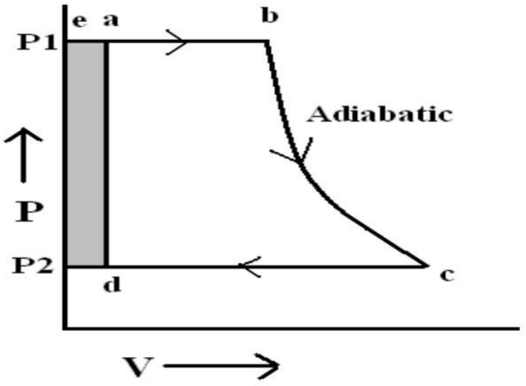
The line diagram of the power plant working on Rankine cycle is shown in Fig 1. The rankine cycle used for steam power plant is shown in Fig. 2 and Fig 3 on P-V and T-S diagrams.

The different processes of the Rankine cycle are described below:

(1) The point ‘d’ represents the water at condenser pressure P_2 and corresponding saturation temperature T_2. The process ‘de’ represents the adiabatic compression of water by the pump from pressure P_2 (condenser pressure) to pressure P_1 (boiler pressure). There is slight rise in temperature of water during the compression process ‘de’.

(2) During the processes ‘ea’ and ‘ab’, heat is supplied by the boiler to the water to convert into steam. The process ‘ea’ represents the supply of heat at constant

pressure till the saturation temperature of water is reached corresponding to boiler pressure P_1. The point's e and a are same on PV diagram as increase in volume of water during this heating process is negligible. The process 'ab' represents the addition of heat to the water at constant pressure till the water completely converted into steam. The final condition of steam 'b' may be wet, dry saturated or superheated depending upon the quantity of heat supplied by the boiler.



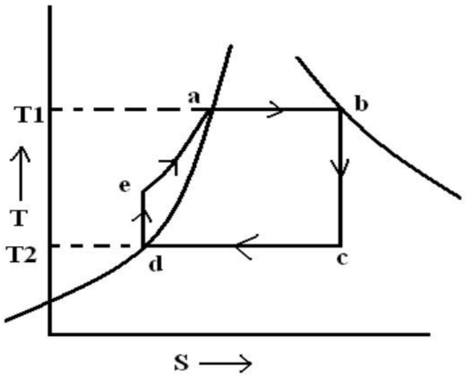


Fig 2.Rankine cycle On P-V diagram

Fig 3.Rankine cycle on T-S diagram

(3) The process 'bc' represents the isentropic expansion of steam in the prime mover as shown in Fig.3. During this expansion, external work is developed and the pressure of steam falls from P_1 and P_2 and its temperature will be T_2.

(4) The process 'cd' represents the condensation of steam coming out from the prime mover in the condenser. During the condensation of steam, the pressure is constant and there is only change of phase from steam to water as the latent heat of steam (x_2h_{fg2}) is carried by circulating water in the condenser.

(5) Again the process 'de' represents the adiabatic compression of water by the pump from the pressure P_2 to P_1 and the cycle is repeated

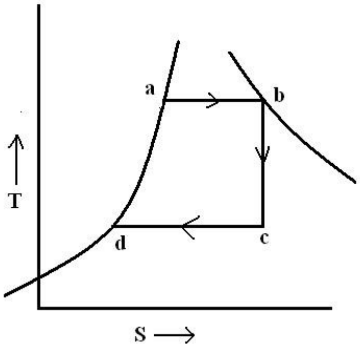


Fig.4 Rankine cycle neglecting pump

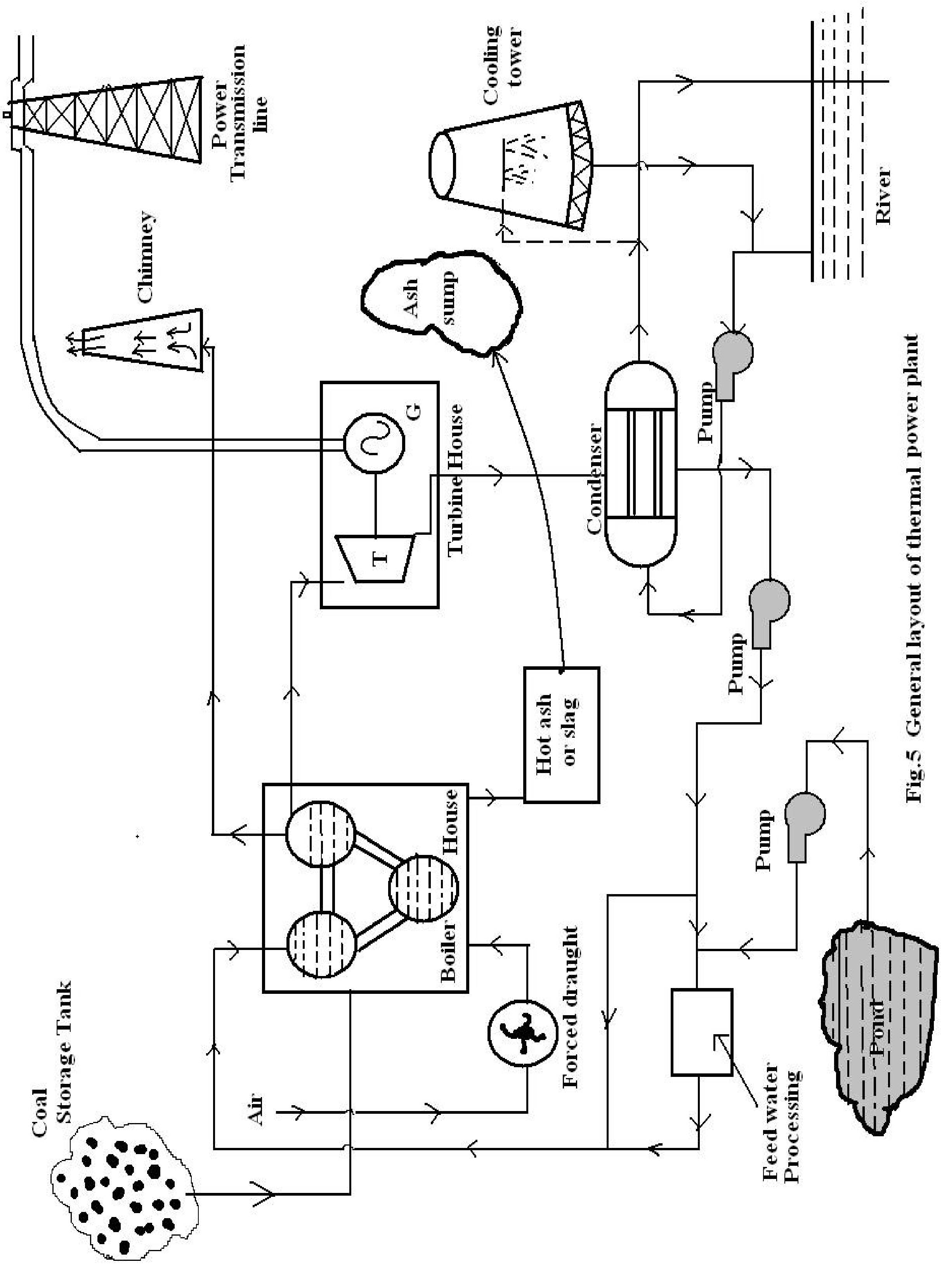


Fig.5 General layout of thermal power plant

LAYOUT OF MODERN COAL POWER PLANT(Anna university Nov/Dec 10,11,12)

Introduction

The development of power in any country depends upon the available resources in that country. The hydel power totally depends upon the natural sites available and hydrological cycle in that country. New sites cannot be humanly created for hydel power plants.

The development of nuclear power in a country requires advanced technological developments and fuel resources. This source of power generation is not much desirable for the developing countries as it is dependent on high technology and they are highly capital based systems.

Many times, hydel power suffers if draught comes even once during a decade and the complete progress of the nation stops. The calamity of rain draught on power industry has been experienced by many states of this country.

To overcome this difficulty, it is absolutely necessary to develop thermal plants in the country which are very much suitable for base load plants.

The general layout of the thermal power plant consists of mainly four circuits as shown in Fig.5 the four main circuits are:

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

1. Coal and ash circuit

   In this circuit, the coal from the storage is fed to the boiler through coal handling equipment for the generation of steam. Ash produced due to the combustion of coal is removed to ash storage through ash-handling system.

2. Air and Gas circuit

   Air is supplied to the combustion chamber of the boiler either through F.D or I.D or by using both. The dust from the air is removed before supplying to the combustion chamber.

   The exhaust gases carrying sufficient quantity of heat and ash are passed through the air-heater where the exhaust heat of the gases is given to the air and then it is passed through the dust collectors where most of the dust is removed before exhausting the gases to the atmosphere through chimney.

3. Feed water and Steam circuit

   The steam generated in the boiler is fed to the steam prime mover to develop the power. The steam coming out of prime mover is condensed in the condenser and then fed to the boiler with the help of the pump.

The condensate is heated in the feed-heaters using the steam tapped from different points of the turbine. The feed heaters may be of mixed type or indirect heating type.

Some of the steam and water is lost passing through different components of the system; therefore, feed water is supplied from external source to compensate this loss. The feed water supplied from external sourced is passed through the purifying plant to reduce the dissolved salts to an acceptable level. The purification is necessary to avoid the scaling of the boiler tubes.

4. Cooling water circuit

The quantity of cooling water required to condense the steam is considerably large and it is taken either from lake, river or sea. The cooling water is taken from the upper side of the river, it is passed through the condenser and heated water is discharged to the lower side of the river. Such system of cooling water supply is possible if adequate cooling water is available throughout the year. This system is known as open system.

When the adequate water is not available, them the water coming out from the condenser is cooled either in cooling pond or cooling tower. The cooling is effected by partly evaporating the water. This evaporative loss is nearly 2 to 5% of the cooling water circulated in the system.

To compensate the evaporative loss, the water from the river is continuously supplied. When the cooling water coming out of the condenser is cooled again and supplied to the condenser is cooled again and supplied to the condenser then the system is known as closed system.

When the water coming out from the condenser is discharged to river downward side directly, the system is known as open system. Open system is economical than closed system provided adequate water is available throughout the year.

Working of the thermal power

Steam is generated in the boiler of thermal power plant using the heat of the fuel burned in the combustion chamber. The steam generated is passed through steam turbine where part of its thermal energy is converted into mechanical energy which is further used for generating electric power.

Merits:

(i) Higher efficiency
(ii) Lower cost
(iii) Ability to burn coal especially of high ash content, and inferior coals.
(iv) Reduced environmental impact in terms of air pollution
(v) Reduced water requirement
(vi) Higher reliability and availability

Demerits:

(i) There are more chances of explosion as coal burns like a gas
(ii) Coal transportation is quite complicated.

SUPER CRITICAL BOILERS

The increasing fuel costs with decreasing fuel quantity have constantly persuaded power engineers to search for more economical methods of power generation. The most recent method to produce economical thermal power is by the use of super-critical steam cycle.

Between the working ranges of 125 bar and 510°C to 300 bar and 600°C, large numbers of steam generating units are designed which are basically characterized as sub-critical and super-critical. Usually a sub-critical boiler consists of three distinct sections as preheater (economizer), evaporator and superheater and in case of super-critical boiler, the only preheated and superheaters are required.

The constructural layouts of both types of boilers otherwise practically identical. With the recent experiments gained in design and construction of super-critical boilers, it has become a rule to use super-critical boilers above 300 MW capacity units.

The **advantages** of supercritical boilers over critical types are listed below:

(1) The heat transfer rates are considerably large compared with sub-critical boilers. The steam side heat transfer coefficient for sub-critical is 16500 kJ/m^2-hr°C when the steam pressure and temperature are 180 bar and 538°C whereas the steam side heat transfer, coefficient for super-critical boiler is 220000 kJ/m^2hr-°C when the steam is generated at 240°C.
(2) The pressure level is more stable due to less heat capacity of the generator and therefore gives better response.
(3) Higher thermal efficiency (40-42%) of power station can be achieved with the use of super critical steam.
(4) The problems of erosion and corrosion are minimized in super-critical boilers as two phase mixture does not exist.
(5) The turbo generators connected to super critical boilers can generate peal loads by changing the pressure of operation.
(6) There is a great ease of operation and their comparative simplicity and flexibility make them adaptable at load fluctuations.

FBC BOILERS

Fluidized bed boilers produce steam from fossil and waster fuels by using a technique called fluidized bed combustion. These can be of two types:

1. Bubbling fluidized bed (BFB) boilers
2. Circulating fluidized bed (CFB) boilers

Bubbling fluidized bed (BFB) boilers

In BFB boilers, crushed coal (6-20mm) is injected into the fluidized bed of limestone just above an air-distribution grid at the bottom of the bed (Fig.6)

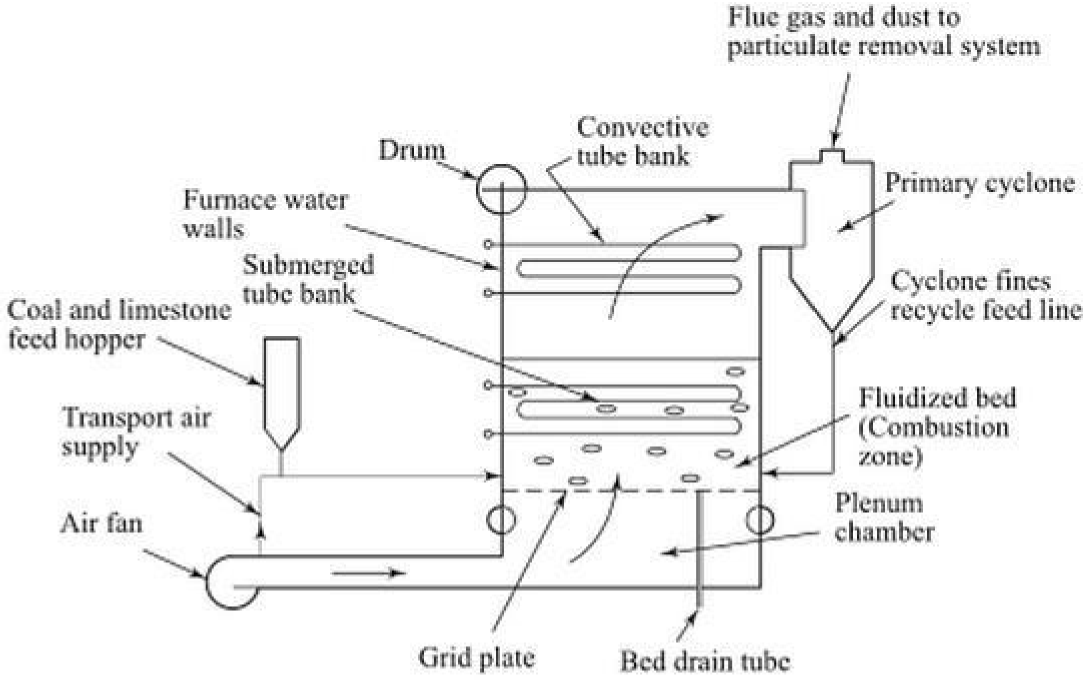


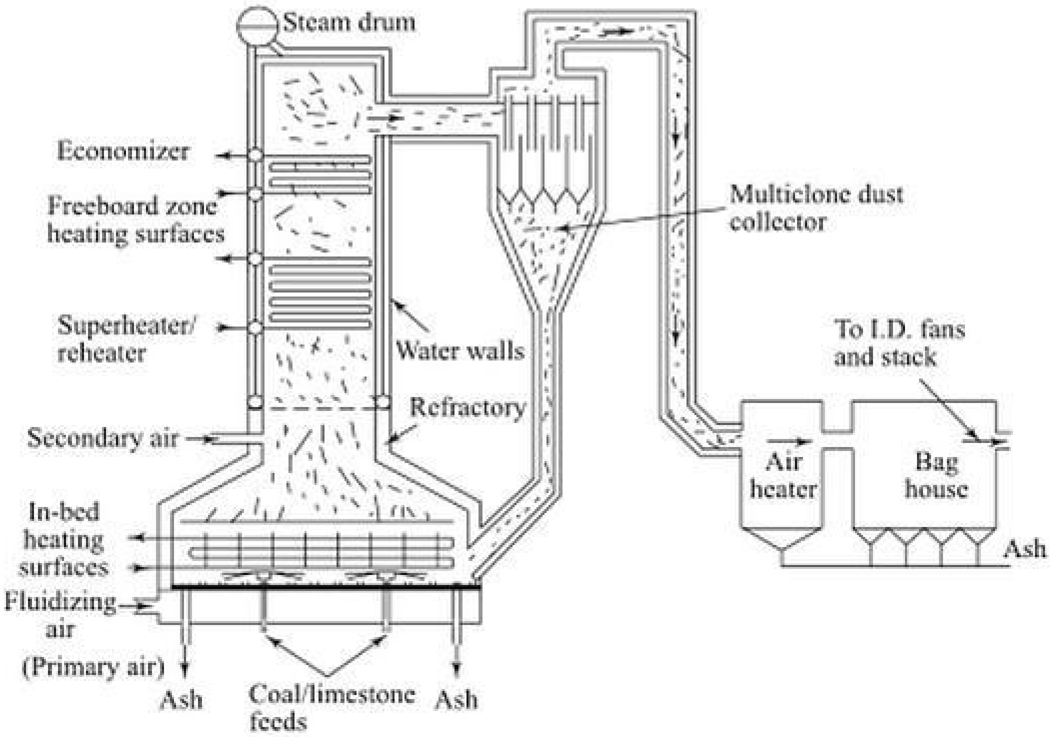
Fig.6 Schematic of bubbling fluidized bed boiler

The air flows upwards through the grid from the air plenum into the bed, where combustion of coal occurs. The products of combustion leaving the bed contain a large proportion of unburnt carbon particles which are collected in cyclone separator and fed back to the bed. The boiler water tubes are located in the furnace.

Since most of the sulphur in coal is retained in the bed by the material used (limestone), the gases can be cooled to a lower temperature before leaving the stack with less formation of acid (H_2SO_4). As a result of low combustion temperatures (800-900˚C), inferior gases of coal can be used without slagging problems and there is less formation of NO_x.

Cheaper alloy materials can be used, resulting in economy of construction. Further economies are achieved since no pulverizer is required. The volumetric heat release rates are 10 to 15 times higher and the surface heat transfer rates are 2 to 3 times higher than a conventional boiler. This makes the boiler make compact.

Fig.7 shows a bubbling bed boiler system operating at atmospheric pressure, similar to the one of 160 MWe Tennessee Valley Authority (TVA) project at Shawnee, USA, recently installed (1993).



An atmospheric bubbling fluid bed boiler system

Fig.7

Circulating fluidized bed (CFB) boilers

The CFB boiler is said to be the second generation fluidized bed boiler Fig.8. It is divided into two sections. The first section consists of

(a) Furnace or fast fluidized bed
(b) Gas-solid separator (cyclone)
(c) Solid recycle device (loop seal or L-value)
(d) External heat exchanger

These components from a solid circulation loop in which fuel is burned. The furnace enclosure of a CFB boiler is generally made of water tubes as in pulverized coal fired (PC)

boilers. A fraction of the generated heat is absorbed by these heat transferring tubes. The second section is the back-pass, where the remaining heat from the glue gas is absorbed by the reheater, , economizer and air preheater surfaces (as in a conventional boiler)

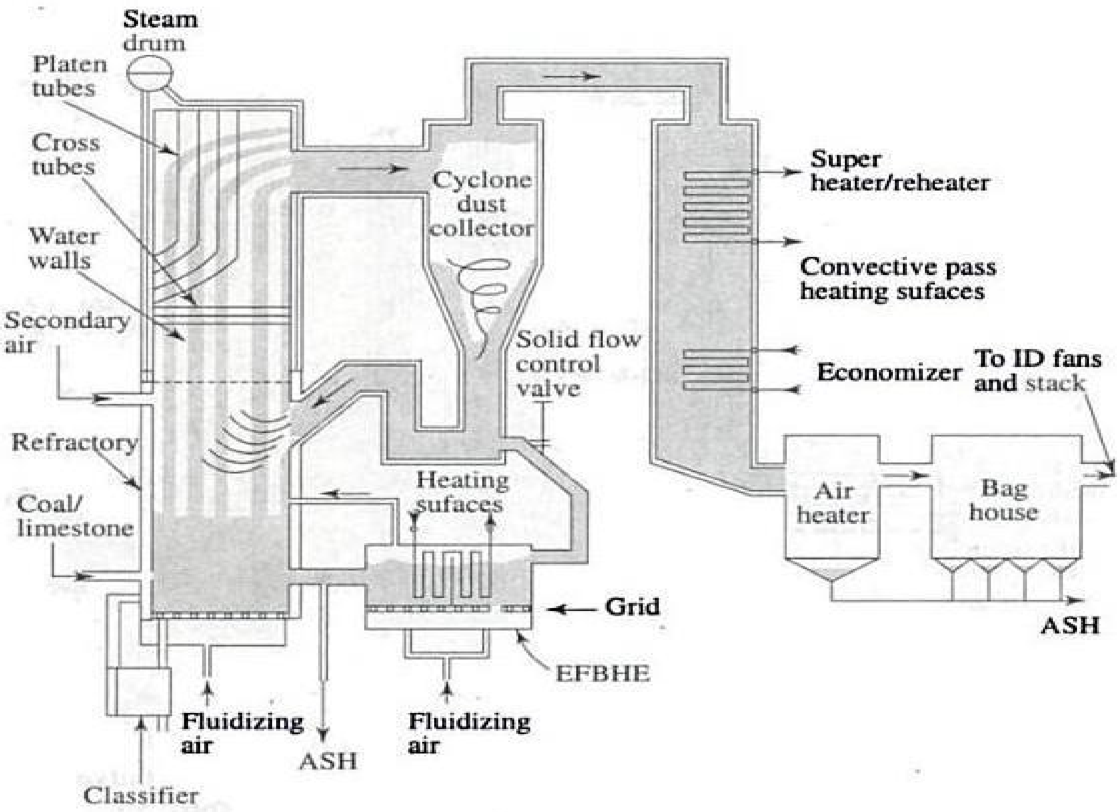


Fig.8 Schematic of a circulating fluidized bed boiler

The lower part o f the first section (furnace) is often tapered. Its walls are lined with refractory up to the level of secondary air entry. Beyond this the furnace walls are generally cooled by evaporative, superheater, or reheater surfaces. The gas-solid separator and the non-mechanical valve are also lined with refractory. In some designs, a part of hot solids recycling between the cyclone and the furnace is diverted through an external heat exchanger, which is a bubbling fluidized bed with heat transfer surfaces immersed in it to remove heat from the hot solids.

Coal is generally injected into the lower section of the furnace. It is sometimes fed into the loop-seal, from which it enters the furnace along with returned solids. Limestone is fed into the bed in a similar manner. Coal burns when mixed with hot bed solids.

The primary combustion air enters the furnace through an air distributor or grate at the furnace floor. The secondary air is injected at some height above the grate to complete the

combustion. Bed solids are well mixed throughout the height of the furnace. Thus, the bed temperature is nearly uniform in the range 800-900˚C, though heat is extracted along its height.

Relatively coarse particles of sorbent (limestone) and unburned char, larger than the cyclone cut-off size, are captured in the cyclone and are recycled back near the base of the furnace. Finer solid residues (ash and spent sorbents) generated during combustion and desulphurization leave the furnace, escaping through the cyclones, but they are collected by a bag-house or electrostatic precipitator located further downstream.

TURBINES

Steam turbine is a heat engine which uses the heat energy stored in steam and performs work. The main parts of s steam turbine are as follows:

(i) A rotor on the circumference of which a series of blades or buckets are attached. To a great extent of performance of the turbine depends upon the design and construction of blades.
The blades should be so designed that they are able to withstand the action of steam and the centrifugal force caused by high speed.
As the steam pressure drops the length and size of blades should be increased in order to accommodate the increase in volume. The various materials used for the construction of blades materials used for the construction of blades depend upon the conditions under which they operated steel or alloys are the materials generally used.
(ii) Bearing to support the shaft.
(iii) Metallic casing which surrounds blades, nozzles, rotor etc.
(iv) Governor to control the speed.
(v) Lubricating oil system.

Steam from nozzles is directed against blades thus causing the rotation. The steam attains high velocity during its expansion in nozzles and this velocity energy of the steam is converted into mechanical energy by the turbine.

As a thermal prime mover, the thermal efficiency of turbine is the usual work energy appearing as shaft power presented as a percentage of the heat energy available.

High pressure steam is sent in through the throttle valve of the turbine. From it comes torque energy at the shaft, exhaust steam, extracted steam, mechanical friction and radiation.

Depending upon the methods of using steam arrangement and construction of blades, nozzle and steam passages, the steam turbines can be classified as follows:

1. According to the action of steam
   (i) Impulse turbine
   (ii) Reaction turbine

(iii) Impulse and reaction turbine.

In impulse turbine (Fig.9) the steam expands in the stationary nozzles and attains high velocity. The resulting high velocity steam impinges against the blades which alter the direction of steam jet thus changing the momentum of jet and causing impulsive force on the blades.

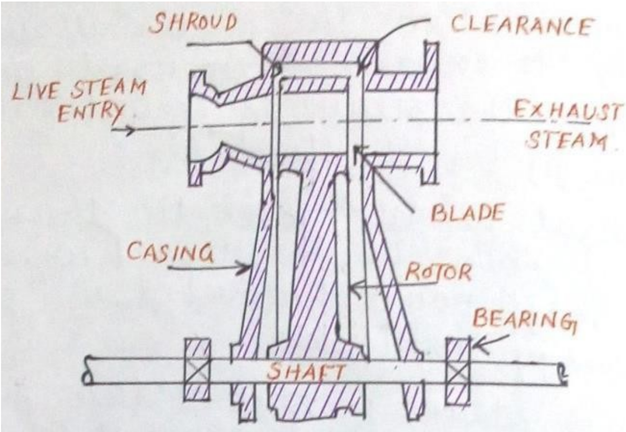


Fig.9 Impulse Turbine

In reaction turbine steam enters the fast moving blades on the rotor from stationary nozzles. Further expansion of steam through nozzles shaped blades changes the momentum of steam and causes a reaction force on the blades.

Commercial turbines make use of combination of impulse and reaction forces because steam can be used efficiently by using the impulse and reaction blading on the same shaft. Fig.10 shows impulsed reaction turbine.

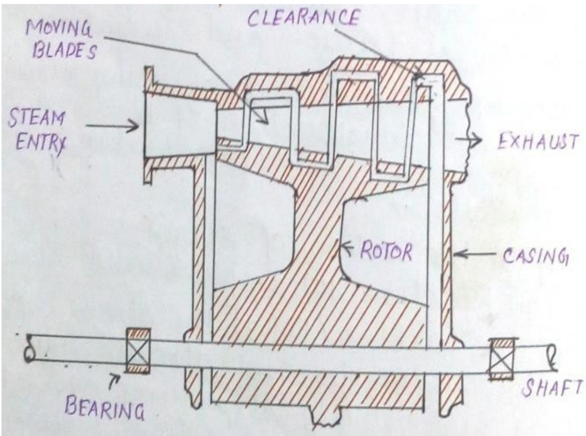


Fig.10 Reaction Turbine

2. According to the direction of steam flow
   (i) Axial
   (ii) Radial

(iii) Mixed

3. According to pressure of exhaust
   (i) Condensing
   (ii) Non-condensing
   (iii) Bleeder
4. According to pressure of entering steam
   (i) Low pressure
   (ii) High pressure
   (iii) Mixed pressure
5. According to step reduction
   (i) Single stage
   (ii) Multi-stage
6. According to method of drive such as
   (i) Direct connected
   (ii) Geared

CONDENSERS

The thermal efficiency of a closed cycle power developing system using steam as working fluid and working on carnot cycle is given by an expression $(T_1-T_2)/T_1$. This expression of efficiency shows that the efficiency increases with an increase in temperature T_1 and decrease in temperature T_2.

The maximum temperature T_2(temperature at which heat is rejected) can be reduced to the atmospheric temperature if the exhaust of the steam takes place below atmospheric pressure. If the exhaust is at atmospheric pressure, the heat rejection is at 100˚C.

Low exhaust pressure is necessary to obtain low exhaust temperature. But the steam cannot be exhausted to the atmosphere if it is expanded in the engine or turbine to a pressure lower than the atmospheric pressure. Under this condition, the steam is exhausted into a vessel known as condenser where the pressure is maintained below the atmosphere by continuously condensing the steam by means of circulating cold water at atmospheric temperature.

A closed vessel in which steam is condensed by abstracting the heat and where the pressure is maintained below atmospheric pressure is known as a condenser. The efficiency of the steam plant is considerably increased by the use of a condenser. In large turbine plants, the condensate recovery becomes very important and this is also made possible by the use of condenser.

The steam condenser is one of the essential components of all modern steam power plants. Steam condensers are of two types:

1. Surface condenser

(a) Down flow type
(b) Central flow condenser
(c) Evaporation condenser

2. Jet condenser
   (a) Low level jet condensers (parallel flow type)
   (b) High level or barometric condenser
   (c) Ejector condenser

Surface condensers

In surface condensers there is no direct contact between the steam and cooling water and the condensate can be re-used in the boiler. In such condenser even impure water can be used for cooling purpose whereas the cooling water must be pure in jet condensers. Although the capital cost and the space needed is more in surface condensers but it is justified by the saving in running cost and increase in efficiency of plant achieved by using this condenser. Depending upon the position of condensate extraction pump, flow of condensate and arrangement of tubes the surface condensers may be classified as follows:

(a) Down flow type

Fig.11(a) shows a sectional view of down flow condenser. Steam enters at the top and flows downward. The water flowing through the tubes in one direction lower half comes out in the opposite direction in the upper half. Fig.11(b) shows a longitudinal section of a two pass down-flow condenser.

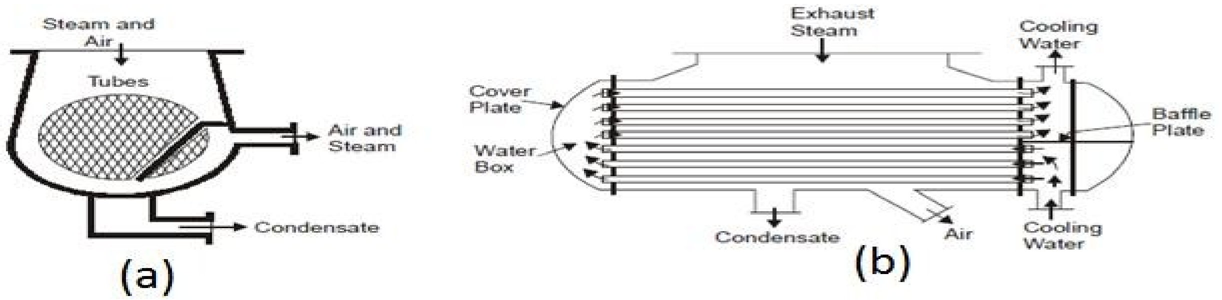


Fig.11

(b) Central flow condenser

Fig.12 shows a central flow condenser. In this condenser the steam passages are all around the periphery of the shell. Air is pumped away from the center of the condenser.

The condensate moves radially towards the center of tube nest. Some of the exhaust steam which moves towards the center meets the undercooling condensate and pre-heats it thus reducing under cooling.

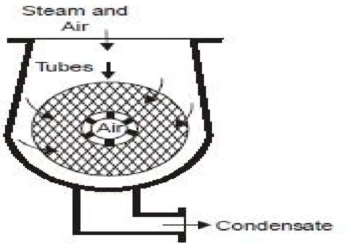


Fig.12

(c) Evaporation condenser.

In this condenser Fig.13 steam to be condensed in passed through a series of tubes and the cooling water falls over these tube in the form of spray. A steam of air flows over the tubes to increase evaporation of cooling water which further increases the condensation of steam.

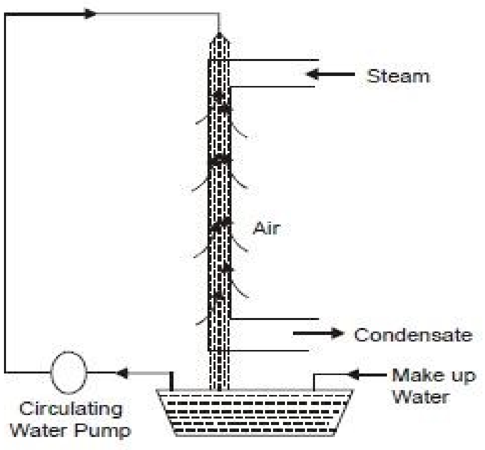


Fig.13 Evaporation condenser

Advantages

(i) The condensate can be used as boiler feed water.
(ii) Cooling water of even poor quality can be used because the cooling water does not come in direct contact with steam.
(iii) High vacuum (about 73.5 of Hg) can be obtained in the surface condenser. This increasing the thermal efficiency of the plant.

Disadvantages

(i) The capital cost is more
(ii) The maintenance cost and running cost this condenser is high
(iii) It is bulky and requires more space.

Jet condensers

In jet condensers the exhaust steam and cooling water come in direct contact with each other. The temperature of cooling water and the condensate is same when leaving the condensers.

Elements of the jet condenser are as follows:

(i) Nozzles or distributors for the condensing water.
(ii) Steam inlet
(iii) Mixing chambers: They may be (a) Parallel flow type (b) Counter flow type depending on whether the steam and water move in the same direction before condensation or whether the flows are opposite
(iv) Hot well

In jet condensers the condensing water is called injection water.

(a) Low level jet condensers (Parallel flow type)

In this condenser Fig.14 water is sprayed through jets and it mixes with steam. The air is removed at the top by an air pump.

In counter flow type of condenser the cooling water flows in the downward direction and the steam to be condensed moves upward.

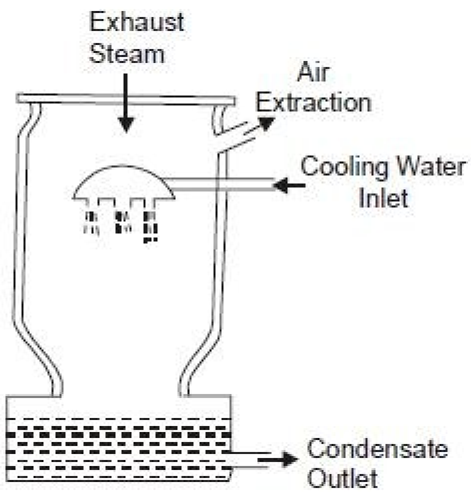


Fig.14

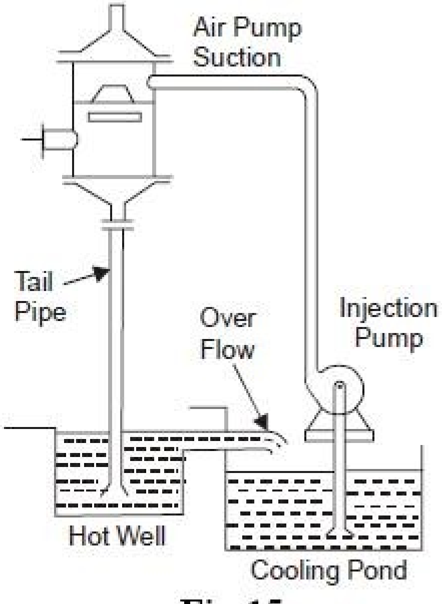


Fig.15

Low level and high level jet condenser

(b) High level or Barometric condenser

Fig.15 shows a high level jet condenser. The condenser shell is place at a height of 10.33m (barometric height) above the hot well. As compared to low level jet condenser this condenser does not flood the engine if the water extraction pumps facts. A separate air pump is used to remove the air.

(c) Ejector condenser

Fig.16 shows an ejector condenser. In this condenser cold water is discharged under a head of about 5 to 6m through a series of convergent nozzles. The steam and air enter the condenser through a non-return valve.

Steam gets condensed by mixing with water. Pressure energy is partly converted into kinetic energy at the converging cones. In the diverging cone the kinetic energy is partly converted into pressure energy and a pressure higher that atmospheric pressure is achieved so as to discharge the condensate to the hot well.

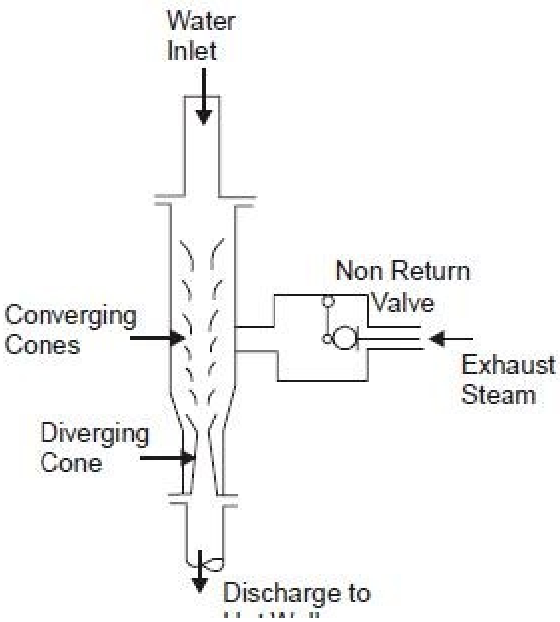


Fig.16 Ejector condenser

FUEL HANDLING SYSTEM (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. <u>Coal Delivery</u>

The coal from supply points is delivered by ships or boats to power stations situated near to sea or river whereas coal is supplied by rail or trucks to the power stations which are situated away from sea or river.

2. Unloading

The type of equipment to be used for unloading the coal received at the power station depends on how coal is received at the power station. If coal is delivered by trucks, there is no need of unloading device as the trucks may dump the coal to the outdoor storage. Coal is easily handled if the lift trucks with scoop are used.

In case the coal is brought by railway wagons, ships or boats, the unloading may be done by car shakes, rotary car dumpers, cranes, grab buckets and coal accelerators. Rotary car dumpers although costly are quite efficient for unloading closed wagons.

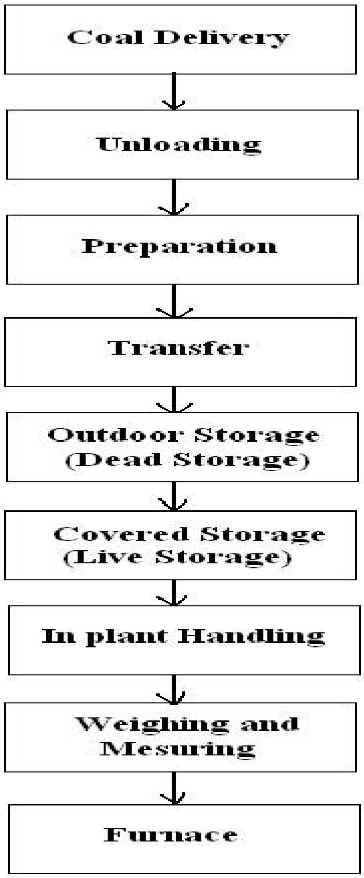


Fig.17 Steps in coal Handling

3. Preparation

When the coal delivered is in the form of big lumps and it is not of proper size, the preparation (sizing) of coal can be achieved by crushers, breakers, sizers driers and magnetic separators.

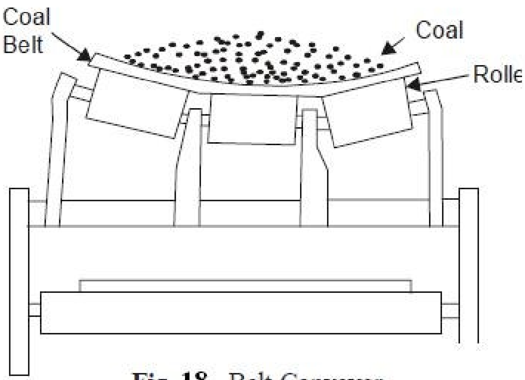


Fig. 18 . Belt Conveyor.

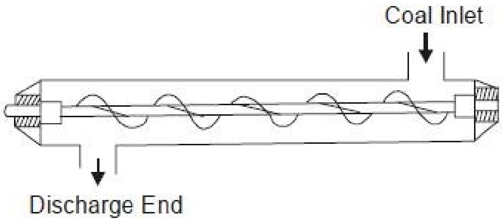


Fig. 19 Screw Conveyor.

Fig. 21 Grab Bucket Elevator.

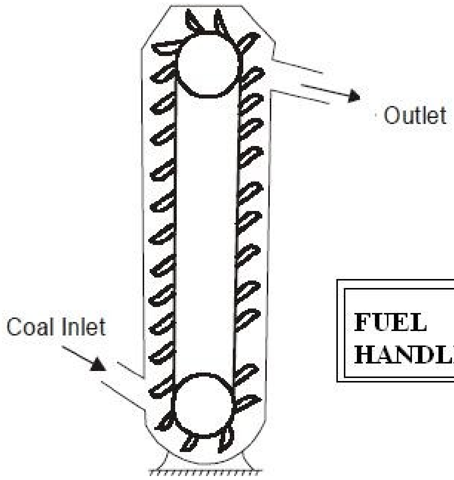


Fig. 20 Bucket Elevator.

FUEL HANDLING

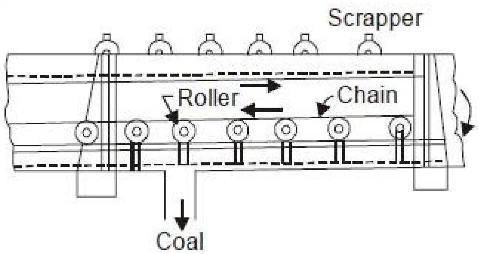


Fig. 23 . Flight Conveyor.

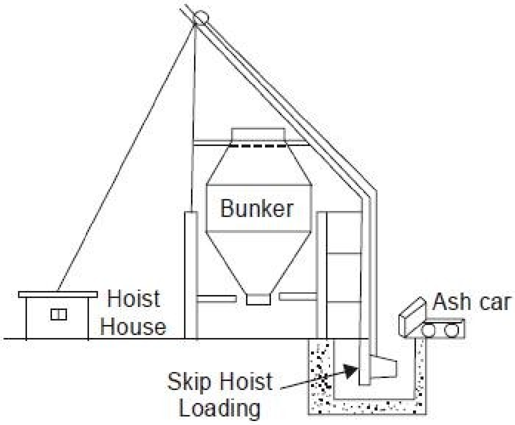


Fig. 22 Skip Hoist.

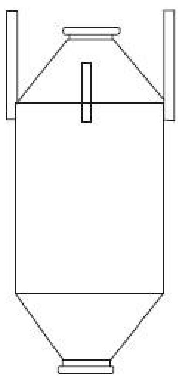


Fig. 24 Cylindrical Bucket

4. Transfer

After preparation of coal is transferred to the dead storage by means of the following systems:

(a) Belt conveyors
(b) Screw conveyors
(c) Bucket elevators
(d) Grab bucket elevators
(e) Skip hoists
(f) Flight conveyor

(a) Belt conveyor

Fig.18 shows a belt conveyor. It consists of an endless belt moving over a pair of end drums(rollers). At some distance a supporting roller is provided at the center.

The belt is made up of rubber or canvas. Belt conveyor is suitable for the transfer of coal over long distances. It is used in medium and large power plants. The initial cost of the system is not high and power consumption is also low.

The inclination at which coal can be successfully elevated by belt conveyor is about 20. Average speed of belt conveyor varies between 200-300 rpm. This conveyor is preferred than other types.

Advantages of belt conveyor:

(1) Its operation is smooth and clean
(2) It requires less power as compared to other types of systems.
(3) Large quantities of coal can be discharged quickly and continuously.
(4) Material can be transported on moderate inclines

(b) Screw Conveyor

It consists of an endless helicoids screw fitted to a shaft (Fig.19) The screw while rotating in a trough transfers the coal from feeding end to the discharge end.

This system is suitable, where coal is to be transferred over shorter distance and space limitations exist. The initial cost of the system is low. It suffers from the drawbacks that the power consumption is high and there is considerable wear of screw. Rotation of screw varies between 75-125 r.p.m.

(c) Bucket elevator

It consists of buckets fixed to a chain Fig.20. The chain moves over two wheels. The coal discharged at the top.

(d) Grab bucket elevator

It lifts and transfers coal on a single rail or track from one point to the other. The coal lifted by grab buckets is transferred to overhead bunker or storage. This system requires less power for operation and requires minimum maintenance.

The grab bucket conveyor can be used with crane or tower as shown in Fig.21 Although the initial cost of this system is high but operating cost is less.

(e) Skip hoist

It consists of a vertical or inclined hoist way a bucket or a car guided by a frame and cable for hoisting the bucket. It is simple and compact method of elevating coal or ash Fig.22 shows a skip hoist.

(f) Flight Conveyor

It consists of one or two strands of chain to which steel scrapes or flights are attached, which scrap the coal through a trough having identical shape. This coal is discharged in the bottom of trough. It is low in first cost but has large energy consumption. There is considerable water.

Skip hoist and bucket elevators lift the coal vertically while belts and flight conveyors move the coal horizontally or on inclines.

Fig. 23 shows a flight conveyor. Flight conveyors posses the following

advantages

(i) They can be used to transfer coal as well as ash.
(ii) The speed of conveyor can be regulated easily.
(iii) They have a rugged construction
(iv) They need little operational care.

Disadvantages:

(i) There is more wear due to dragging action.
(ii) Power consumption is more
(iii) Maintenance cost is high
(iv) Due to abrasive nature of material handle the speed of conveyors is low (10 to 30m/min).

5. <u>Storage of coal</u>

It is desirable that sufficient quantity of coal should be stored. Storage of coal gives protection against the interruption of coal supplies when there is delay in transportation of coal or due to strikes in coal mines.

Also when the prices are low, the coal can be purchased and stored for future use. The amount of coal to be stored depends on the availability of space for storage, transportation facilities, the amount of coal that will whether away and nearness to coal mines of the power station.

Usually coal required for month operation of power plant is stored in case of power stations situated at longer distance from the collieries whereas coal need for about 15 days is stored in case of power station situated near to collieries. Storage of coal for longer periods is not advantageous because it blocks the capital and results in deterioration of the quality of coal.

The coal received at the power station is stored in dead storage in the form of piles laid directly on the ground.

The coal stored has the tendency to whether (to combine with oxygen of air) and during this process coal has some of its heating value and ignition quality. Due to low oxidization the coal may ignite spontaneously. This is avoided by storing coal in the form of piles which consists of thick and compact layers of coal so that air cannot pass through the coal piles. This will minimize the reaction between coal and oxygen.

The other alternative is to allow the air to pass through layers of coal so that air may remove the heat of reaction and avoid burning. In case the outer coal is to be stored for longer periods the outer surface of piles may be sealed with asphalt or fine coal.

The coal is stored by the following methods.

(i) Stocking the coal in heats

The coal is piled on the ground up to 10-12m height. The pile top should be given a slope in the direction in which the rain may be drained off.

The sealing of stored pile is desirable in order to avoid the oxidation of coal after packing an air tight layer of coal.

Asphalt, fine coal dust and bituminuous coating are the materials commonly used for this purpose.

(ii) Under water storage

The possibility of slow oxidation and spontaneous combustion can be completely eliminated by storing the coal under water.

Coal should be stored at a site located on solid ground, well drained, free of standing water preferably on high ground not subjected to flooding.rr

6. <u>In plant Handling</u>

From the dead storage the coal is brought to covered storage (live storage)(bins or bunkers). A cylindrical bunker shown in Fig.24. In plant handling may include the equipment such as belt conveyors, screw conveyors, bucket elevators etc., to transfer the coal. Weigh lorries hoppers and automatic scales are used to record the quantity of coal delivered to the furnace.

7. <u>Coal weighing methods</u>

Weigh lorries, hoppers and automatic scales are used to weigh the quantity of coal. The commonly used methods to weigh the coal are as follows:

(i) Mechanical (ii) Pneumatic (iii) Electronics

The mechanical method works on a suitable lever system mounted on knife edges and bearing connected to a resistance in the form of a spring of pendulum.

The pneumatic weighters use a pneumatic transmitted weight head and the corresponding air pressure determined by the load applied.

The electronic weighing machines make use of load cells that produce voltage signals proportional to the load applied.

The important factors considered in selecting fuel handling surface systems are as follows:

(i) Plant flue rate
(ii) Plant location in respect to fuel shipping
(iii) Storage area available

ASH HANDLING SYSTEM

Boilers burning pulverized coal (PC) have dry bottom furnaces. The large ash particles are collected under the furnace in a water-filled ash hopper. Fly ash is collected in dust collectors with either an electrostatic precipitator or a bag house. A PC boiler generates approximately 80% fly ash and 20% bottom ash. Ash must be collected and transported from various points of the plants as shown in Fig.25. Pyrites, which are the rejects from the pulverizers, are disposed with the bottom ash systems. Three major factors should be considered for ash disposal systems.

1. Plant site
2. Fuel source
3. Environmental regulation

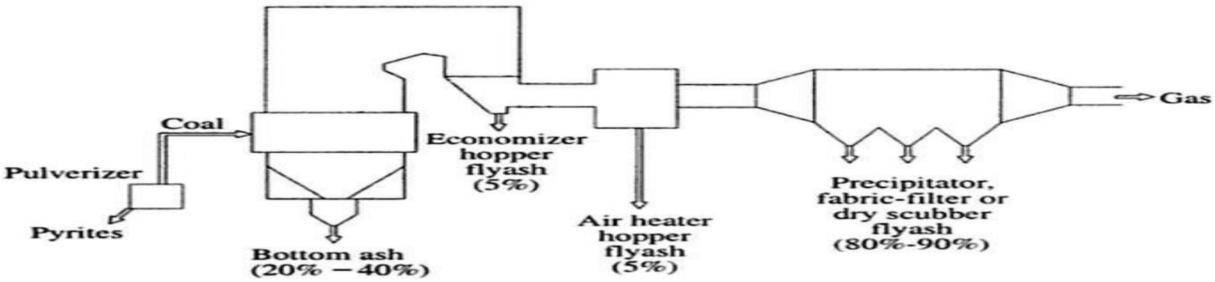
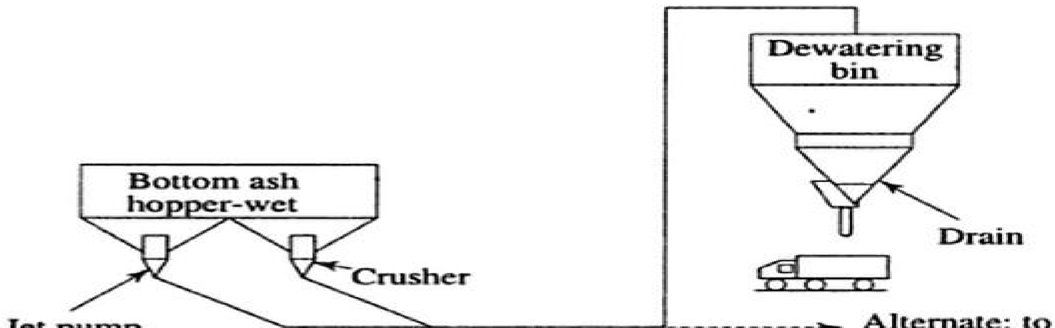


Fig.25 Ash collection and transportation

The sluice conveyor system (Fig. 26(a)) is the most widely used for bottom ash handling, while the hydraulic vacuum conveyor (Fig. 26(b)) is the most frequently used for fly ash systems.



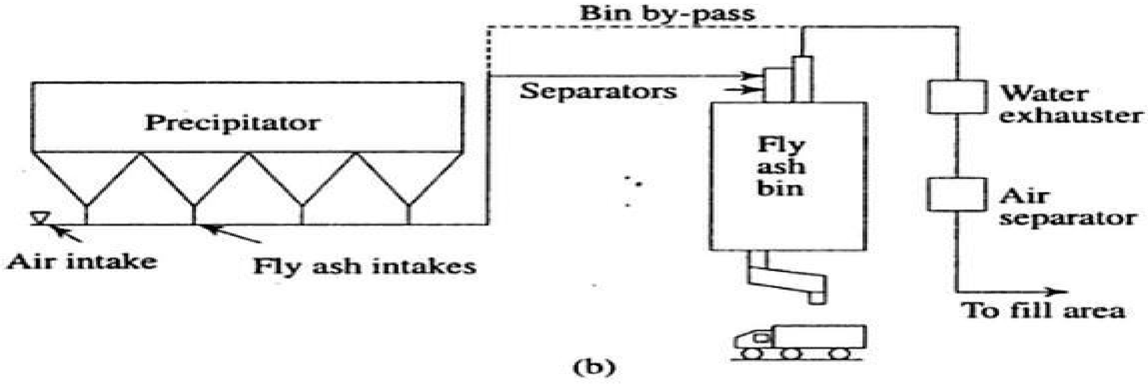


Fig. 26 (a) Bottom ash sluice conveyor, (b) fly ash hydraulic vacuum conveyor

Bottom ash and slag may be used as filling material for road construction. Fly ash can partly replace cement for making concrete. Bricks can be made with fly ash. These are durable and strong.

DRAUGHT SYSTEM

The purpose of draught is as follows:

(1) The supply required amount of air to the furnace for the combustion of fuel. The amount of fuel that can be burnt per square foot of grate area depends upon the quantity of air circulated through fuel bed.
(2) To remove the gaseous products of combustion

Definition

Draught is defined as the difference between absolute gas pressure at any point in a gas flow passage and the ambient (same elevation) atmospheric pressure.

Draught is plus is $P_{atm}<P_{gas}$ and it is minus $P_{atm}>P_{gas}$. Draught is achieved by small pressure difference which causes the flow of air or gas to take place. It is measured in millimeter (mm) of water.

If only a chimney is used to create the necessary draught, the system is called natural draught system and if an addition to chimney a forced draught(F.D) fan or an induced draught (I.D) fan or both are used the system is called mechanical draught system.

Fans or chimneys produce positive pressure and is called available draught whereas fuel bed resistance, turbulence and friction in air ducts, gas breechings, chimney etc., create negative pressure and is called the required draught.

The various types of draught system are as follows:

(i) Natural draught
(ii) Mechanical draught
(iii) Steam jet draught

Natural draught

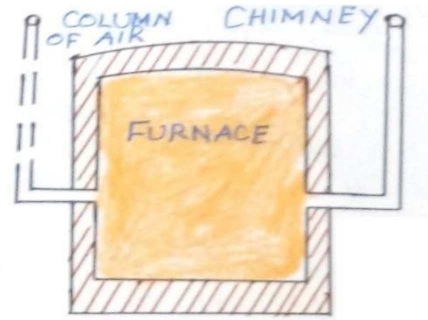


Fig.27 Natural Draught system

Natural draught system is used in boilers of smaller capacities. Natural draught is created by the difference in weight of a column of cold external air and that of a similar column of hot gases in the chimney. This system is dependent upon the height of chimney and average temperature of the gases in the chimney.

Now-a-days the chimney is not used for creating draught in steam power plants as it has no flexibility, the total draught produced is insufficient for high generating capacity.

By using chimney draught can be increased by allowing the flue gases to leave the combustion chamber at higher temperature and this reduced the overall efficiency of the power plant. The chimney is, therefore, used only to discharge the flue gases.

Mechanical Draught

In boilers of large capacities, fans are employed to create the necessary draught in order to reduce the height of chimney, to obtained draught that is independent of weather conditions and to control the draught easily.

Mechanical draught may be induced forced or balanced draught. Induced draught system shown in Fig. 28(a) is created by chimney and fan located in the gas passage on the chimney side of the boiler. In this system gas movement is achieved as result of vacuum

The various pressures indicated are as follows:

P1 = Inlet pressure for forced draught fan

P2 = Outlet pressure of forced draught fan

P3	=	Pressure below grate
P4	=	Pressure above the grate
P5	=	Inlet pressure of induced draught fan
P6	=	Outlet pressure of induced draught fan

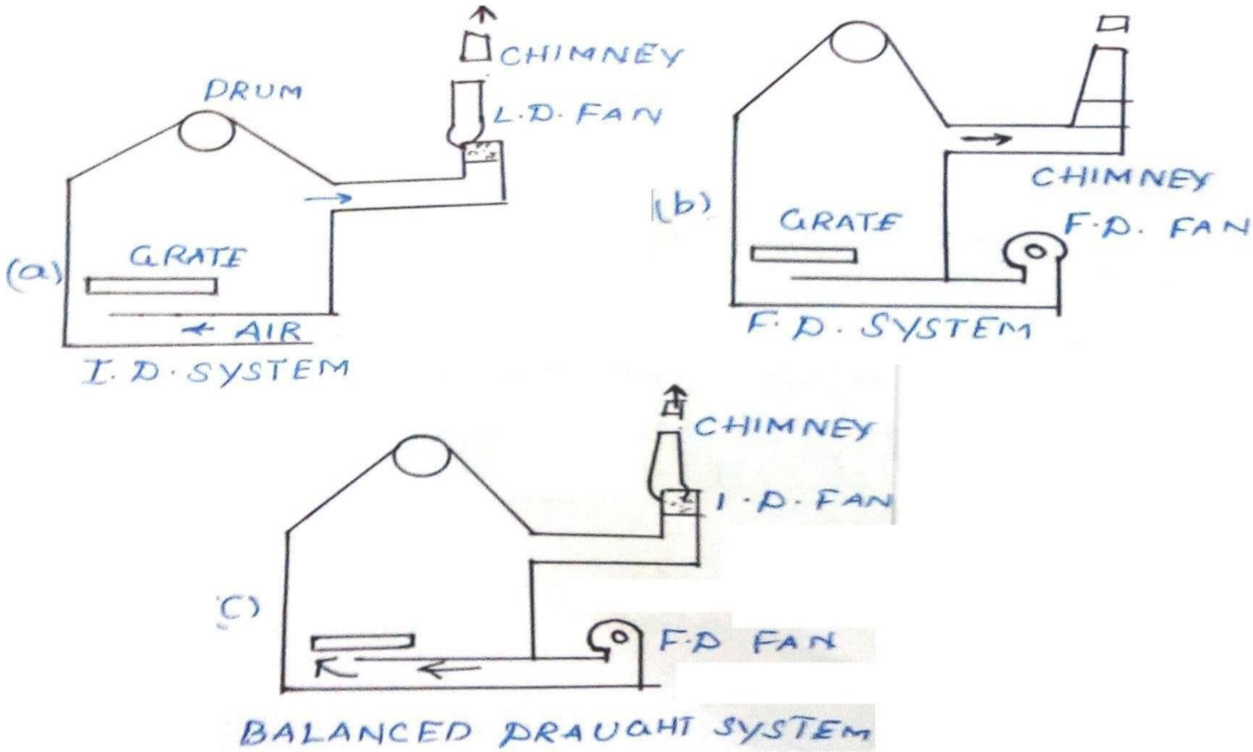


Fig.28 Mechanical draught system

Induced draught is not as simple and direct as forced because fans used in induced draught system operate in gases of much higher temperature (nearly 500˚-904˚F). Thus becomes more expensive.

The fan sucks in gas from the boiler side and discharges it to the chimney (stack)

The draught produced is independent of the temperature of the hot gases and, therefore, the gases may be discharged as cold as possible after recovering as much heat possible in air preheater and economizer.

In FD system (Fig.28 (b)) the fan installed near the boiler base supplies the air at a pressure above that of atmosphere and delivers it through air duct to the furnace

Most high rating combustion equipment employs forced draught fans for supplying air to the furnace. Forced draught is used in under fed stockers carrying a thick fuel bed. Balanced draught system is a combination of induced and forced draught systems.

The forced draught fan forces the air through the fuel bed on to the top of grate and the induced draught fan sucks in gases from the boiler side and discharges them to the chimney. This system is used where pressure above fire is slightly below atmosphere (Fig.32(c)) shows this system.

Steam Jet Draught

Steam jet draught may be induced or forced draught depending upon the location of steam jet producing the draught.

Induced draught produced by steam jet as shown in Fig.29. This system is used in locomotive boilers. Exhaust steam from the engine enters the smoke box through a nozzle to create draught. The air is induced through the flues, the grate and ash pit to the smoke box.

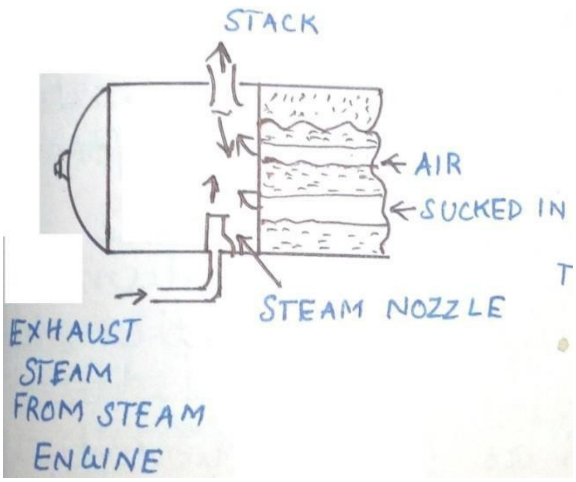


Fig.29 Steam Jet Induced Draught System

Fig.30 shows a forced draught developed by steam jet. Steam from the boiler is passed through a throttle valve, throttle pressure being 1.5 to 2kg/cm^2 gauge.

Then the steam passes through a nozzle projecting in diffuser pipe. The steam comes out of nozzle with great velocity and drags a column of air along with it thus allowing the fresh air to enter.

The mixture of steam and air possesses high kinetic energy and passes through the diffuser pipe. The kinetic energy gets converted into pressure energy and thus air is forced through the coal bed, furnace and flows to the chimney. Steam jet is simple, requires less space and is economical. But is can be used only if steam at high pressure is available.

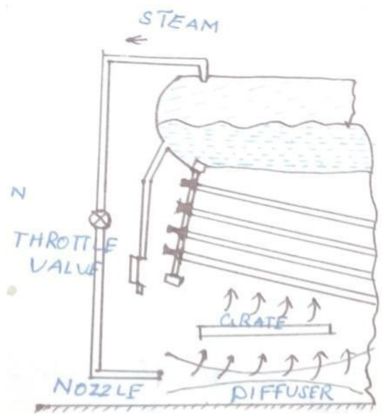


Fig.30 Steam-Jet forced draught system

FEEDWATER TREATMENT

Boiler make-up water to the extent of 1.5—2 percent of the total flow rate is required to replenish the losses of water through leakage from fittings and bearings, boiler blow down, escape with non-condensable gases in the deaerator, turbine glands, and other causes. This make-up water needs to be treated prior to feeding it to the boiler for

1. Prevention of hard scale formation on the heating surfaces
2. Elimination of corrosion
3. Control of carry-over to eliminate deposition on superheater tubes, and
4. Prevention of silica deposition and corrosion damage to turbine blades.

Raw water is, therefore, first pre-treated and then demineralized. For once through boilers and boiling water nuclear reactors, which require high water purity, a condensate polishing system is used to further polish the water. Raw water contains a variety of impurities, such as (a) Suspended solids and turbidity, (b) organics, (c) hardness (salts of calcium and magnesium), (d) alkalinity (bicarbonates, carbonates, and hydrates), (e) other dissolved ions (sodium, sulphate, chloride, etc.,), (f) silica and (g) dissolved gas(O_2, CO_2). The extent of pre-treatment depends on the source of raw water.

1. External treatment

   The first step of pre-treatment of boiler feed water is clarification, in which the water is chlorinated to prevent biofouling of the equipment. The suspended solids and turbidity are coagulated by adding special chemicals (like aluminiumsulphate, $Al_2(SO_4)_3$) and agitated. The coagulated matter settles at the bottom of the clarifier and is removed.

   If the turbidity of clarified effluent is high, positive filtration is needed. Both gravity filters and pressure-type filters are used, but the latter is preferred. A granular medium like sand is commonly used for filtration. The pressure difference across the filtering medium is an indication of solid accumulation. When it reaches a given limit,

the solids are removed from the bed by backwashing. Further filtration by activated carbon can absorb organics and remove residual chlorine from the chlorination process.

The dissolved salts of calcium and magnesium give to water a quality called hardness. Hardness is characterized by the formation of insoluble precipitates or curds with soaps, and is usually measured with a standard soap test. All natural waters are hard and contain scale-forming impurities which are mainly the salts of calcium and magnesium in the form of carbonates, bicarbonates, chlorides and sulphates. The hardness is expressed in ppm of dissolved salts. Softening of water, i.e removal of hardness from water, can be done by lime-soda process, phosphates process, zeolite process and demineralization.

2. Lime—soda process

In lime—soda softening, calcium and magnesium salts are removed using lime (calcium hydroxide) and soda ash (sodium carbonate). When this process is carried out at normal raw-water temperature, it is called a “cold process” softening; and when carried out at or near the boiling point, it is referred to as a “hot process” softening. Since heating greatly accelerates the necessary reactions, the hot process is preferred for boiler water treatment, where most of the energy used in heating the water may be retained in the cycle. The representative reactions are given below:

$$Ca(HCO_3)_2+Ca(OH)_2 = 2CaCO_3+2H_2O$$

$$MgCl_2+Ca(OH)_2=Mg(Oh)_2+CaCl_2$$

$$MgSO_4+Ca(OH)_2=Mg(OH)_2+CaSO_4$$

$$CaSO_4+N_a2CO_3=CaCO_3+Na_2SO_4$$

$$CaCl_2+Na_2CO_3=CaCO_3+2NaCl$$

The products, calcium carbonate and magnesium hydroxide are insoluble in water and settle to the bottom of the vessel. The softened effluent is then passed through sand or charcoal filters before usage.

3. Hot phosphate Softening

In the hot phosphate softening process, calcium and magnesium hardness is removed using phosphate and caustic soda, Tricalcium phosphate (Ca3(PO4)2) and magnesium hydroxide are precipitated. The process is carried out at a temperature of 100˚C or above. Since the hot phosphate process requires more expensive chemicals than the lime—soda process, it is used where the initial water hardness is 60 ppm or less. Where hardness is greater than this, a lime soda process may be used first, followed by a phosphate clean-up. The representative reactions are given below:

$$3Ca(HCO_3)_2+6NaOH=2CaCO_3+2Na_2CO_3+6H_2O$$

$$CaCO_3+2Na_3PO_4=Ca_3(PO_4)_2+2Na_2CO_3$$

$$Mg(HCO_3)_2+4NaOH=Mg(OH)_2+2Na_2CO_3+2H_2O$$

$$3CaSO_4+2Na_3PO_4=Ca_3(PO_4)_2+3Na_2SO_4$$

4. Sodium Zeolite Softening

Water can be softened by passing it through a bed of sodium zeolite, which may be natural compounds of sodium aluminium silicate, with the cations of calcium and magnesium removed in the process.

$$CaCO_3+Na_2A=CaZ+Na_2CO_3$$

$$MgSO_4+Na_2Z=MgZ+Na_2SO_4$$

$$Ca(HCO_3)_2+Na_2Z=CaZ+Na_2(HCO_3)_2$$

The softening capacity of the bed gets exhausted in course of time, and the bed can be regenerated by flushing it with brine (NaCl),

$$CaZ+2NaCl=Na_2Z+CaCl_2$$

$$MgZ+2NaCl=Na_2Z+MgCl_2$$

Zeolite softening is not ideal for the following reasons: (i) Water of high or low pH have a deleterious effect on zeolites, (ii) high temperatures also have a bad effect, (iii) turbid waters coat the zeolite material, reducing its efficiency, (iv) there is no reduction in alkalinity or total solids, (v) there can be silica gain in water from the zeolite, (vi) with low content of calcium, the water can be corrosive, sodium zeolite softening in conjunction with the use of evaporating may be more effective.

5. Hydrogen Zeolite softening

When water containing calcium, magnesium and sodium ions is passed through a hydrogen zeolite, these ions are exchanged for hydrogen and the bicarbonate, sulphate, chloride and nitrate radicals are converted to their respective acids. Typical reactions are:

$$\begin{matrix} Ca \\ (Mg) \\ (Na_2) \end{matrix}(HCO_3)_2+H2Z=\begin{matrix} Ca \\ (Mg) \\ (Na_2) \end{matrix}Z+2H_2CO_3$$

$$\begin{matrix} (Ca) \\ (Mg) \\ (Na_2) \end{matrix}SO_4+H_2Z = \begin{matrix} (Ca) \\ (Mg) \\ (Na_2) \end{matrix}Z+H_2SO_4$$

When the hydrogen zeolite becomes exhausted, it is backwashed and regenerated with acid. After being rinsed, it is ready for use again. Sulphuric acid is generally used for regeneration because of its relatively low cost.

$$MgZ+H_2SO_4=H_2Z+MgSO_4$$

$$CaZ+H_2SO_4=H_2Z+CaSO_4$$

6. Anion exchangers

Anion exchangers can remove the anions like chlorides, sulphates and nitrates (acid forms) present in hydrogen zeolite effluent by resinous materials which absorb them. Typical reactions are:

$$2HCl+RCO_3=RCl_2+H_2CO_3$$

$$H_2SO_4+RCO_3=RSO_4+H_2CO_3$$

$$2HNO_3+RCO_3=R(NO_3)_2+H_2CO_3$$

Carbonic acid is removed by aeration. When the acidic water is sprayed in a shower to expose large surface area, the carbon dioxide gas is released.

$$H_2CO_3 \rightarrow CO_2 + H_2O$$

When the anion exchanger is exhausted, it is regenerated by backwashing with soda ash

$$RCl_2 + Na_2CO_3 = RCO_3 + 2NaCl$$

$$RSO_4 + Na_2CO_3 + RCO_3 + Na_2SO_4$$

7. Demineralizing plant

The process of removing dissolved solids in water by ion exchange is called demineralization. Two types of resins, cation and anion, are used. The cation resin is the hydrogen zeolite where the hydrogen ion is exchanged for the cations calcium, magnesium and sodium, and the anion resin adsorbs the anions chlorides, nitrates and sulphates, as discussed above. Both ion-exchange processes are reversible, and the resins are restored to their original form by regeneration.

A typical Demineralizing plant consisting of a cation exchanger, an anion exchanger, a degasfier and a silica adsorber in series is shown in Fig.31. In the degasifier, carbon dioxide gas is removed by aeration. Silica in water is very detrimental at high pressure. It vaporizes at high pressure and flows with steam, condenses on turbine blades in the form of hard glassy scales which are difficult to remove. Magnesium hydroxide is often used to adsorb silica from water.

The membrane treatment for removing the total dissolved solids from make-up water is also an energy efficient process and is gradually gaining more acceptances. It uses the principle of either reverse osmosis or electro dialysis. The driving force for reverse osmosis is the application of counter pressure to normal osmotic pressure, driving water molecules through the membranes in preference to dissolved salts.

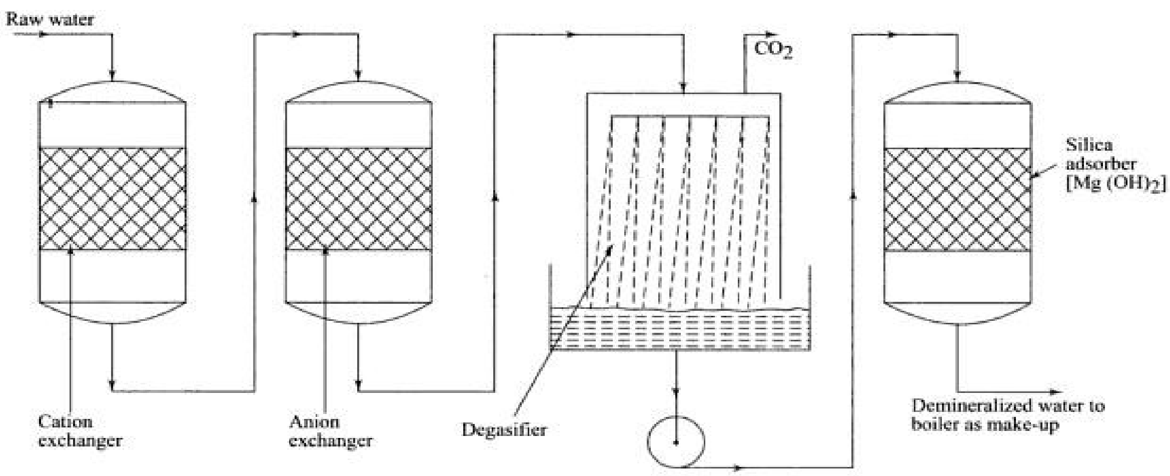


Fig.31 A typical Demineralizing plant

8. Condensate polishing

A high quality make-up water can be produced for the plant by using Demineralizing systems as discussed above. However, this treated water while flowing through the cycle can pick up impurities due to condenser leakage from the circulating water through the tubes as well as metallic ions, such as iron and copper, from pipelines.

Condensate polishing is accomplished by passing the condensate through large Demineralizing vessels, called mixed bed units, which contain both cation and anion resins. The resins not only remove dissolved salts in the above manner, but also act as filters for impurities or suspended solids. Power plants using once-through boilers and nuclear reactors generally require high quality water and use condensate polishing systems.

BINARY CYCLES

No single fluid can meet all the requirements as mentioned above. Although in the overall evaluation water is better than any other working fluid, at high temperatures, however, there are a few better fluids and notable among them are :

(a) Diphenyl ether $(C_6H_5)_2O$
(b) Aluminium bromide $AlBr_3$
(c) Liquid metals like mercury, sodium, potassium and so on. Among these only mercury has actually been used in practice.

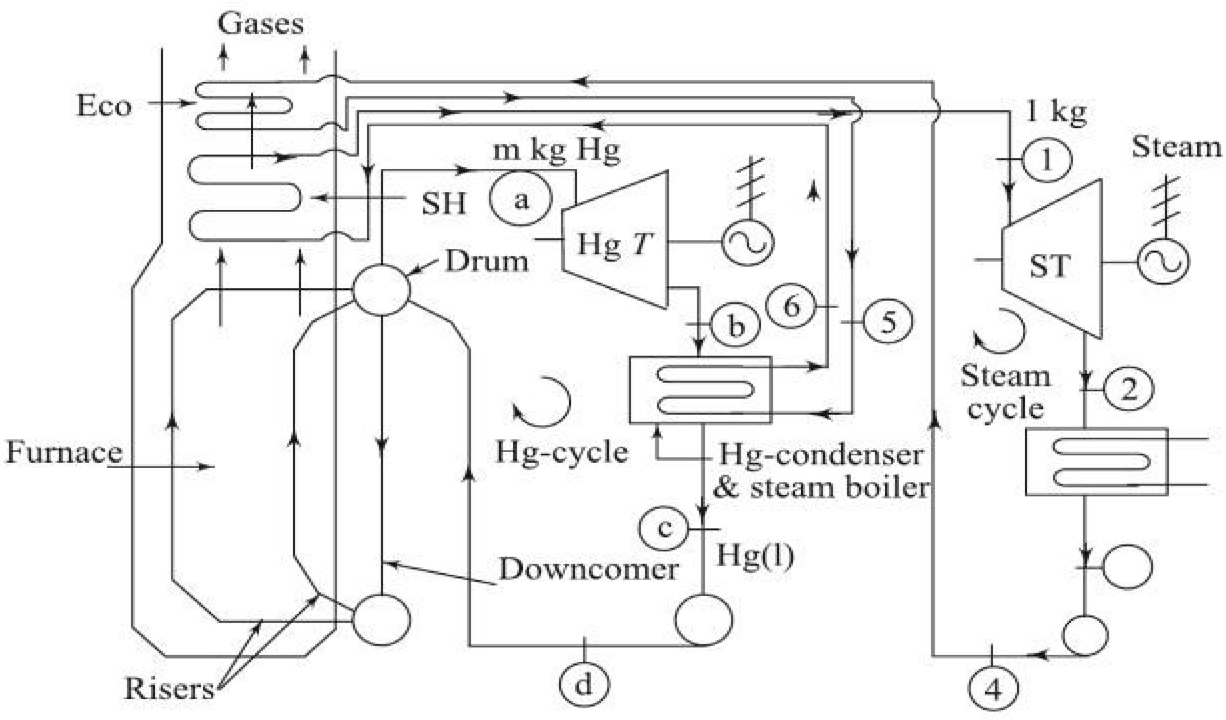


Fig.32 Flow diagram of mercury-steam binary cycle

Diphenyl ether could be considered but it has not yet been used because like most organic substances, it decomposes gradually at high temperatures. Aluminium bromide is a possibility and yet to be considered.

As at pressure of 12 bar, the saturation temperatures for water, aluminium bromide and mercury are 187˚C,482.5˚C and 560˚C, its vaporization pressure is relatively low. Its critical pressure and temperature are 1080 bar and 1460˚C respectively.

But in the low temperature range, mercury is unsuitable because its saturation pressure becomes exceedingly low, and it would be impractical to maintain such a high vacuum in the condenser.

At 30˚C the sayturation pressure of mercury is only $2.7 x 10^{-4}$cm Hg. Its specific volume at such a low pressure is very large, and it would be difficult to accommodate such a large volume flow.

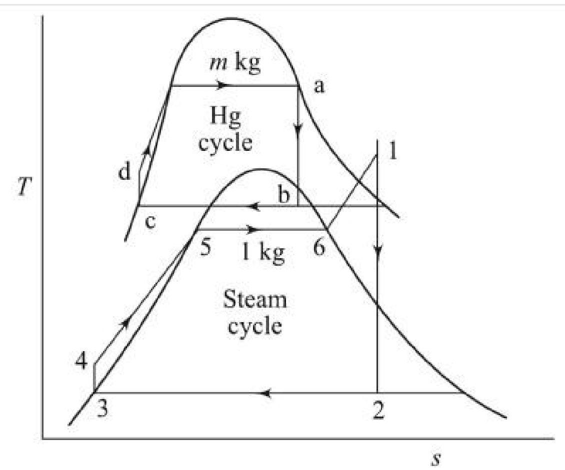


Fig.33 T-S diagram of mercury-steam binary cycle

For this reason, to make advantage o f the beneficial features of mercury in the high temperature range and to get rid of its deleterious effects in the low temperature range, mercury vapour leaving the mercury turbine is condensed at a higher temperature and pressure, and the heat released during the condensation of mercury is utilized in evaporating water to form steam to operate on a conventional turbine.

Thus, in the binary (or two fluid) cycle, two cycles with different working fluids are coupled in series, the heat rejected by on being utilized in the other.

The flow diagram of mercury-steam binary cycle and the corresponding T-S diagram are given in Fig.32&33 respectively.

The mercury cycle a-b-c-d is a simple rankine cycle saturated vapour. The heat rejected by mercury during condensation (process b-c) is transferred to boil water and form saturated vapour (process 5-6).

The saturated vapour is heated from the external source (furnace) in the super heater(process 6-1). Super heated steam expands in the turbine and is then condensed. The condensate is then pumped to the economizer where it is heated till it becomes saturated liquid by the outgoing flue gases (process4-5).

The saturated liquid then goes to the mercury condenser-steam boiler , where the latent heat is absorbed. In an actual plant, the steam cycle is always a regenerative cycle with feed water heating, but for the sake of simplicity, this complication has been omitted.

Let m represent the flow rate of mercury in the mercury cycle per kg of steam circulating in the steam cycle. Then , for 1 kg of steam,

$$\left.\begin{aligned} Q_1 &= m(h_a-h_d)+(h_1-h_6)+(h_5-h_4) \\ Q_2 &= h_2-h_3 \\ W_T &= m(h_a-h_b)+(h_1-h_2) \\ W_P &= m(h_d-h_c)+(h_4-h_3) \end{aligned}\right\} \quad \text{-------------(1)}$$

$$= \frac{1 - 2}{1} = \frac{-}{1}$$

$$(\quad) = \frac{3600}{-} \quad / \quad h$$

The energy balance of the mercury condenser-steam boiler gives

$$m(h_b-h_c) = (h_6-h_5)$$

therefore,

$$= \frac{h_6 - h_5}{h - h}$$

To vaporize one kg of water, 7 to 8 kg of mercury must be mercury.

COGENERATION SYSTEMS

There are several industries such as paper mills, textile mills, chemical factories, jute mills, sugar factories, rice mills and so on where saturated steam at the desired temperature is required for heating, drying etc.

For constant temperature heating (or drying), steam is a very good medium since isothermal condition can be maintained by allowing saturated steam to condensate at that temperature and utilizing the latent heat released for heating purposes.

Apart from the process heat, the factory also needs power to drive various machines, for lighting and other purpose.

Earlier, steam of power purposes was generated at a moderate pressure and saturated steam of process work was generated separately at a pressure which gave the desired heating temperature.

Having two separate units for process heat and power is wasteful, for the total heat supplied to the steam generator for power purposes, a greater part will normally be carried away by the cooling water in the condenser.

Back pressure Turbine

By modifying the initial steam pressure and exhaust pressure, it is possible to generate the required power and make available the required quantity of exhaust steam at the desired temperature for process work.

In Fig.34, the exhaust steam from the turbine is utilized for process heating, the process heater replacing the condenser of the ordinary rankine cycle.

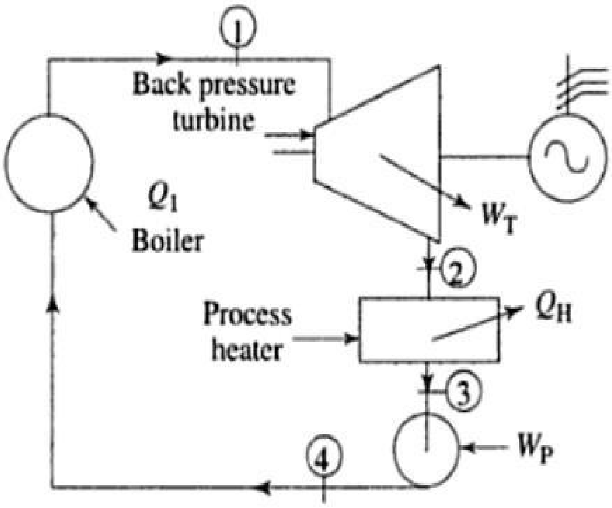


Fig.34 cogeneration plant with a back-pressure turbine

The pressure at exhaust form the turbine is the saturation pressure corresponding to the temperature desired in the process heater such a turbine is called a back pressure turbine.

A plant producing both electrical power and process heat simultaneously is called a **cogeneration plant**.

When the process steam is the basic need, and the power is produced incidentally as a by-produce the cycle is often called a byproduct power cycle.

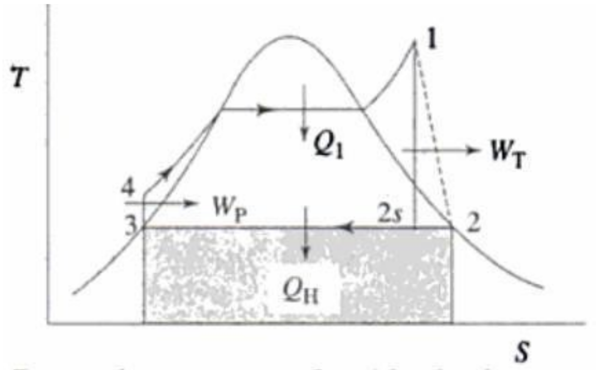


Fig.35 by product power cycle with a back-pressure turbine

Fig.35 shows the T-S plot for such a cycle. If WT is the turbine output in kW, QH is the process heat required in kJ/h, and ws are the steam flow rate in kg/h.

$$\times 3600 = (h_1 - h_2)$$

$$= (h_2 - h_3)$$

$$\times 3600 = \frac{\quad}{h_2 - h_3} (h_1 - h_2)$$

$$= \frac{\times 3600 \times (h_2 - h_3)}{(h_1 - h_2)} \quad \frac{\quad}{h} \quad ----(1)$$

Of the total energy input Q_1 (as heat) to the co-generation plant, W_T part of it only is converted into shaft work or electricity.

The remaining energy (Q_1-W_T), which would otherwise have been a waste, as in the rankine cycle, by second law, it is utilized as process heat.

The co-generation plant efficiency $\acute{\eta}_{co}$ is given by

$$= \frac{\quad + \quad}{1} \quad -----(2)$$

For separate generation of electricity and steam, the heat added per unit total energy output is,

1 1 −

Where e = electricity fraction of total energy output

=

$\acute{\eta}_e$= electric plant efficiency

$\acute{\eta}_h$= steam (or process heat) generator efficiency

The combined efficiency $\acute{\eta}_c$ for ~~separate~~ generation is therefore given by

= 1 (3)

Cogeneration is beneficial if the efficiency of the co-generation plant, equation (2), greater than that of separate generation, equation (3)

Back pressure turbines are quite small with respect to their power output because they have no great volume of exhaust to cope with, the density being high. They are usually single cylinder and hence, cheap in terms of cost per MW compared to condensing sets of the same power.

Besides their use in process industries and petrochemical installations, back pressure turbines are used for desalination of sea-water, district heating, and also for driving compressors and feed pumps.

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.

Definition of a Cycle.

A Cycle is defined as a repeated series of operation in a certain order. It may be repeated by repeating the processes in the same order. The cycle may be of imaginary perfect engine or actual engine. The former is called ideal cycle and the latter actual cycle.

In ideal cycle all accidental heat losses are prevented and the working substance is assumed to behave like a perfect working substance.

Air standard efficiency

To compare the effects of different cycles, it is of paramount importance that the effect of the calorific value of the fuel is altogether eliminated and this can be achieved by considering air (which is assumed to behave as a perfect gas) as the working substance in the engine cylinder. The efficiency of engine using air as the working medium is known as an "Air standard efficiency". This efficiency is oftenly called ideal efficiency.

The Actual efficiency of a cycle is always less than the air-standard efficiency of that cycle under ideal conditions. This is taken into account by introducing a new term "Relative efficiency" which is defined as:

$$\eta_{relative} = \frac{\text{Actual thermal efficiency}}{\text{Air standard efficiency}}$$

The analysis of all air standard cycles is based upon the following assumptions:

Assumptions:

1. The gas in the engine cylinder is a perfect gas, i.e., it obeys the gas laws and has constant specific heats.

2. The physical constants of the gas in the cylinder are the same as those of air at moderate temperature, i.e., the molecular weight of cylinder gas is 29.

$$C_p = 1.005 \text{ KJ/Kg-K}$$

$$C_v = 0.718 \text{ KJ/Kg-K}$$

3. The compression and expansion processes are adiabatic and they take place without internal friction, i.e., these processes are isentropic.

4. No chemical reaction takes place in the cylinder. Heat is supplied or rejected by bringing a hot body or a cold body in contact with cylinder at appropriate points during the process.

5. The cycle is considered closed with the same air always remaining in the cylinder to repeat the cycle.

CONSTANT VOLUME OR OTTO CYCLE:

This cycle is so named as it was conceived by 'Otto'. On this cycle, petrol, gas and many types of oil engines work. It is the standard of comparison for internal combustion engines.

Fig 1(a) and (b) shows the theoretical P-V diagram and T-S diagrams of this cycle respectively.

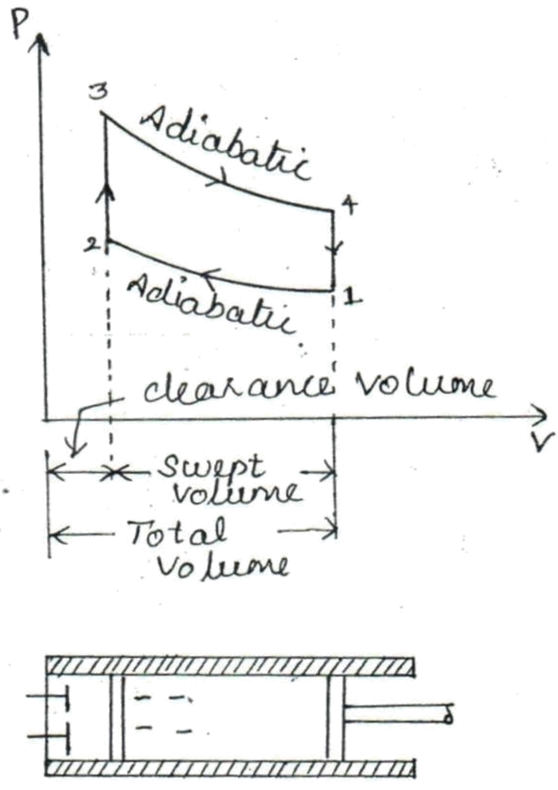
* The point 1 represents that cylinder is full of air with volume V_1, pressure P_1 and absolute temperature T_1.

* Line 1-2 represents the adiabatic compressi[on] [o]f air due to which P_1, V_1 and T_1 change to P_2, V_2 [a]nd T_2 respectively.

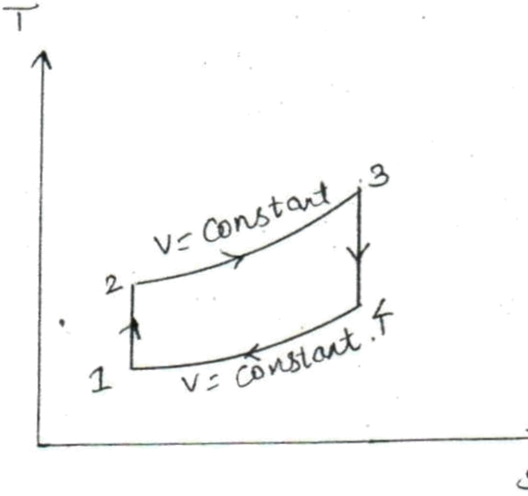
* Line 2-3 shows the supply of heat to the [air] [a]t constant volume so that P_2 and T_2 change to [P]$_3$ and T_3 (V_3 being the same as V_2)

* Line 3-4 represents the adiabatic expans[ion] [o]f the air. During expansion P_3, V_3 and T_3 chan[ge] [t]o a final value of P_4, V_4 or V_1 and T_4 respectiv[ely].

* Line 4-1 shows the rejection of heat by [the] air at constant volume till original state (point 1) reaches.



(a)



(b)

Figure 1

Consider 1 Kg of air (working substance):

Heat supplied at constant volume $= C_v (T_3 - T_2)$

Heat rejected at constant volume $= C_v (T_4 - T_1)$

But, work done = Heat supplied − Heat rejected

$= C_v (T_3 - T_2) - C_v (T_4 - T_1)$

$\therefore$ Efficiency $= \frac{\text{Work done}}{\text{Heat supplied}} = \frac{C_v(T_3 - T_2) - C_v(T_4 - T_1)}{C_v(T_3 - T_2)}$

$$= 1 - \frac{T_4 - T_1}{T_3 - T_2} \rightarrow (1)$$

Let compression ratio, $r_c (= r) = \frac{V_1}{V_2}$

and expansion ratio, $r_e (= r) = \frac{V_4}{V_3}$

(These two ratios are same in this cycle)

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

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

Illy $\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma - 1}$

or $T_3 = T_4 (r)^{\gamma - 1}$.

Inserting the values of T_2 and T_3 in eqn (1) we g

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

$\eta_{otto} = 1 - \frac{1}{\ldots} \rightarrow (2)$

This expression is known as the air standard efficiency of the otto cycle.

It is clear from the above expression that efficiency increases with the increase in the value of r, which means we can have maximum efficiency by increasing r to a considerable extent but due to practical difficulties its value is limited to about 8.

The net work done per kg in the otto cycle can also be expressed in terms of P.V. If p is expressed in bar i.e. $10^5 N/m^2$, then work done

$$W = \left(\frac{P_3V_3 - P_4V_4}{\gamma - 1} - \frac{P_2V_2 - P_1V_1}{\gamma - 1}\right) \times 10^2 KJ \rightarrow 3$$

Also $\frac{P_3}{P_4} = r^{\gamma} = \frac{P_2}{P_1}$

$\therefore \frac{P_3}{P_2} = \frac{P_4}{P_1} = r_p$ where r_p stands for pressure ratio

and $V_1 = rV_2 = V_4 = rV_3$ $\therefore \frac{V_1}{V_2} = \frac{V_4}{V_3} = r$

$$\therefore W = \frac{1}{\gamma - 1}\left[P_4V_4\left(\frac{P_3V_3}{P_4V_4} - 1\right) - P_1V_1\left(\left(\frac{P_2V_2}{P_1V_1}\right) - 1\right)\right]$$

$$= \frac{1}{\gamma - 1}\left[P_4V_4\left(\frac{P_3}{P_4 r} - 1\right) - P_1V_1\left(\frac{P_2}{P_1 r} - 1\right)\right]$$

$$= \frac{V_1}{\gamma - 1}\left[P_4(r^{\gamma-1} - 1) - P_1(r^{\gamma-1} - 1)\right]$$

$$= \frac{V_1}{\gamma - 1}\left[(r^{\gamma-1} - 1)(P_4 - P_1)\right]$$

$$= P_1V_1\left[(r^{\gamma-1} - 1)(r_p - 1)\right] \rightarrow (4)$$

[Me]an effective pressure (P_m) is given by :

$$P_m = \left[\left(\frac{P_3V_3 - P_4V_4}{\gamma - 1} - \frac{P_2V_2 - P_1V_1}{\gamma - 1}\right) + (V_1 - V_2)\right] \text{bar} \rightarrow (5)$$

[Al]so $P_m = \dfrac{\left[\dfrac{P_1V_1}{\gamma-1}(r^{\gamma-1} - 1)(r_p - 1)\right]}{(V_1 - V_2)}$

$$= \frac{\dfrac{P_1V_1}{\gamma-1}\left[(r^{\gamma-1} - 1)(r_p - 1)\right]}{V_1 - \dfrac{V_1}{r}}$$

$$= \frac{\dfrac{P_1V_1}{\gamma-1}\left[(r^{\gamma-1} - 1)(r_p - 1)\right]}{V_1\left(\dfrac{r-1}{r}\right)}$$

ie $$P_m = \frac{P_1 r\left[(r^{\gamma-1} - 1)(r_p - 1)\right]}{(\gamma - 1)(r - 1)} \rightarrow (6)$$

[CO]NSTANT PRESSURE OR DIESEL CYCLE

This cycle was introduced by Dr. R. Diesel in [18]97. It differs from Otto cycle in ~~that~~ this heat is [su]pplied at constant pressure instead of at constan[t] [vo]lume. Fig (2) (a) & (b) shows the P-V and T-S [d]iagrams of this cycle respectively.

This cycle comprises of the following operations

(i) 1-2 - Adiabatic compression

(ii) 2-3 - Addition of heat at constant pressure.

(iii) 3-4 - Adiabatic expansion

(iv) 4-1 - Rejection of heat at constant volume.

Point 1 represents that the cylinder is full of air. [Le]t P_1, V_1 and T_1 be the corresponding pressure, volume [an]d absolute Temperature.

The piston then compresses the air adiabatically (PV^{γ} = constant) till the values become P_2, V_2 and respectively (at the end of the stroke) at point 2.

Heat is then added from a hot body at constant pressure. During this addition of heat let volume increases from V_2 to V_3 and temperature T_2 to T_3, corresponding to point 3. This point (3) is called the point of cut-off.

The air then expands adiabatically to the conditions P_4, V_4 and T_4 respectively corresponding to point 4. Finally, the air rejects the heat to the cold body at constant volume till the point 1 where it returns to its original state.

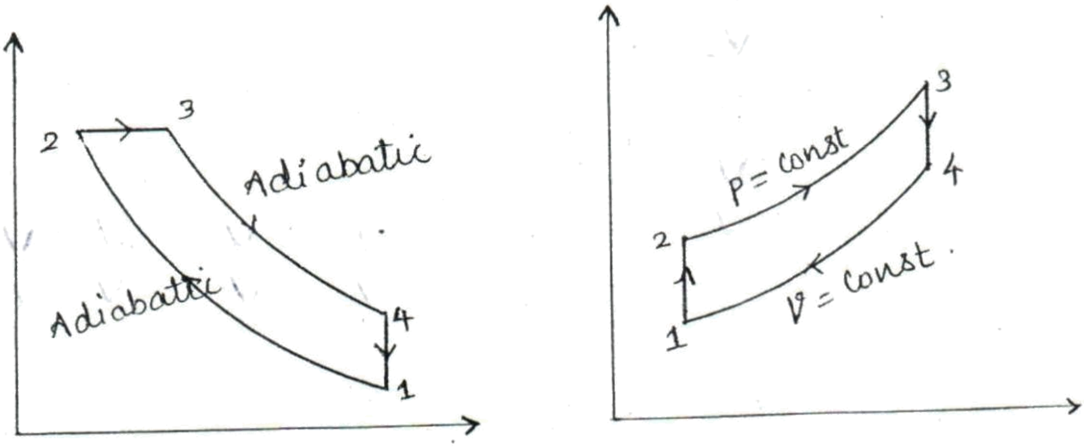


Figure 2.

Consider 1 Kg of air.

Heat supplied at constant pressure = $C_p(T_3 - T_2)$

Heat rejected at constant volume = $C_v(T_4 - T_1)$

Work done = Heat supplied - heat rejected

$= C_p(T_3 - T_2) - C_v(T_4 - T_1)$

$$\eta_{diesel} = \frac{\text{Work done}}{\text{Heat supplied}}$$

$= C_p(T_3 - T_2) - C_v(T_4 - T_1)$

$$= 1 - \frac{(T_4 - T_1)}{\gamma(T_3 - T_2)} \longrightarrow (1) \qquad \left[\because \frac{C_p}{C_v} = \gamma\right]$$

t compression ratio,

$$r = \frac{V_1}{V_2} \text{, and cut-off ratio}$$

$$e = \frac{V_3}{V_2} \text{ ie } \frac{\text{Volume at cut-off}}{\text{Clearance volume}}$$

ow, during adiabatic compression 1-2,

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

uring constant pressure process 2-3,

$$\frac{T_3}{T_2} = \frac{V_3}{V_2} = e \text{ or } T_3 = e \cdot T_2 = e \cdot T_1 \cdot (r)^{\gamma-1}$$

During adiabatic expansion 3-4

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1}$$

$$= \left(\frac{r}{e}\right)^{\gamma-1} \qquad \left(\because \frac{V_4}{V_3} = \frac{V_1}{V_3} = \frac{V_1}{V_2} \times \frac{V_2}{V_3} = \frac{r}{e}\right)$$

$$\therefore T_4 = \frac{T_3}{\left(\frac{r}{e}\right)^{\gamma-1}} = \frac{e \cdot T_1 (r)^{\gamma-1}}{\left(\frac{r}{e}\right)^{\gamma-1}} = T_1 \cdot e^{\gamma}$$

y inserting values of T_2, T_3 and T_4 in Eq (1), we get

$$\eta_{diesel} = 1 - \frac{(T_1 \cdot e^{\gamma} - T_1)}{\gamma(e \cdot T_1 \cdot (r)^{\gamma-1} - T_1 \cdot (r)^{\gamma-1})} = 1 - \frac{e^{\gamma} - 1}{\gamma (r)^{\gamma-1} (e-1)}$$

$$\therefore \eta_{diesel} = 1 - \frac{1}{\gamma (r)^{\gamma-1}} \left[\frac{e^{\gamma} - 1}{e - 1}\right] \longrightarrow (2)$$

It may be observed that eqn (2) for efficiency of diesel cycle is different from that of the otto cycle only in bracketed factor. This factor is always greater than unity, because $\rho > 1$. Hence for a given compression ratio, the otto cycle is more efficient.

The net work for diesel cycle can be expressed in terms of ρv as follows:

$$W = P_2(V_3 - V_2) + \frac{P_3V_3 - P_4V_4}{\gamma - 1} - \frac{P_2V_2 - P_1V_1}{\gamma - 1}$$

$$= P_2(\rho V_2 - V_2) + \frac{P_3\rho V_2 - P_4 r V_2}{\gamma - 1} - \frac{P_2V_2 - P_1 r V_2}{\gamma - 1}$$

$\therefore \frac{V_3}{V_2} = \rho \quad \therefore V_3 = \rho V_2$ and $\frac{V_1}{V_2} = r \quad \therefore V_1 = rV_2$

But $V_4 = V_1 \quad \therefore V_4 = rV_2$

$$= P_2V_2(\rho - 1) + \frac{P_3\rho V_2 - P_4 r V_2}{\gamma - 1} - \frac{P_2V_2 - P_1V_1}{\gamma - 1}$$

$$= P_2(\rho V_2 - V_2) + \frac{P_3\rho V_2 - P_4 r V_2}{\gamma - 1} - \frac{P_2V_2 - P_1 r V_2}{\gamma - 1}$$

$\left[\because \frac{V_3}{V_2} = \rho \quad \therefore V_3 = \rho V_2 \text{ and } \frac{V_1}{V_2} = r \quad \therefore V_1 = rV_2 \right.$

$\left. \text{But } V_4 = V_1 \quad \therefore V_4 = rV_2 \right]$

$$= P_2V_2(\rho - 1) + \frac{P_3\rho V_2 - P_4 r V_2}{\gamma - 1} - \frac{P_2V_2 - P_1 r V_2}{\gamma - 1}$$

$$= \frac{V_2[P_2(\rho - 1)(\gamma - 1) + P_3\rho - P_4 r - (P_2 - P_1 r)]}{\gamma - 1}$$

$$= \frac{V_2\left[P_2(\rho - 1)(\gamma - 1) + P_3\left(\rho - \frac{P_4 r}{P_3}\right) - P_2\left(1 - \frac{P_1 r}{P_2}\right)\right]}{\gamma - 1}$$

$$= \frac{P_2V_2[(\rho-1)(\gamma-1)+\rho-\rho^{\gamma}\cdot r^{1-\gamma}-(1-r^{1-\gamma})}{\gamma-1}$$

$$\left[\because \frac{P_4}{P_3}=\left(\frac{V_3}{V_4}\right)^{\gamma}=\left(\frac{\rho}{r}\right)^{\gamma}=\rho^{\gamma}r^{-\gamma}\right]$$

$$= \frac{P_1V_1r^{\gamma-1}[(\rho-1)(\gamma-1)+\rho-\rho^{\gamma}r^{1-\gamma}-(1-r^{1-\gamma})}{\gamma-1}$$

$$\left[\because \frac{P_2}{P_1}=\left(\frac{V_1}{V_2}\right)^{\gamma} \text{ or } P_2=P_1\cdot r^{\gamma} \text{ and } \frac{V_1}{V_2}=r \text{ or } V_2=V_1r^{-1}\right]$$

$$= \frac{P_1V_1r^{\gamma-1}[\gamma(\rho-1)-r^{1-\gamma}(\rho^{\gamma}-1)]}{(\gamma-1)} \rightarrow (3)$$

Mean effective pressure Pm is given by:

$$P_m = \frac{P_1V_1r^{\gamma-1}[\gamma(\rho-1)-r^{1-\gamma}(\rho^{\gamma}-1)]}{(\gamma-1)V_1\left(\frac{r-1}{r}\right)}$$

$$P_m = \frac{P_1r^{\gamma}[\gamma(\rho-1)-r^{1-\gamma}(\rho^{\gamma}-1)]}{(\gamma-1)(r-1)} \rightarrow (4)$$

DUAL COMBUSTION CYCLE

This Cycle (also Called the limited pressure cycle or mixed cycle) is a Combination of Otto and Diesel cycles, in a way, that heat is added partly at Constant Volume and partly at Constant pressure; the advantage of which is that more time is available to fuel (which is injected into the engine cylinder before the end of Compression stroke) for Combustion.

Because of lagging characteristics of fuel this cycle is invariably used for diesel and hot spot

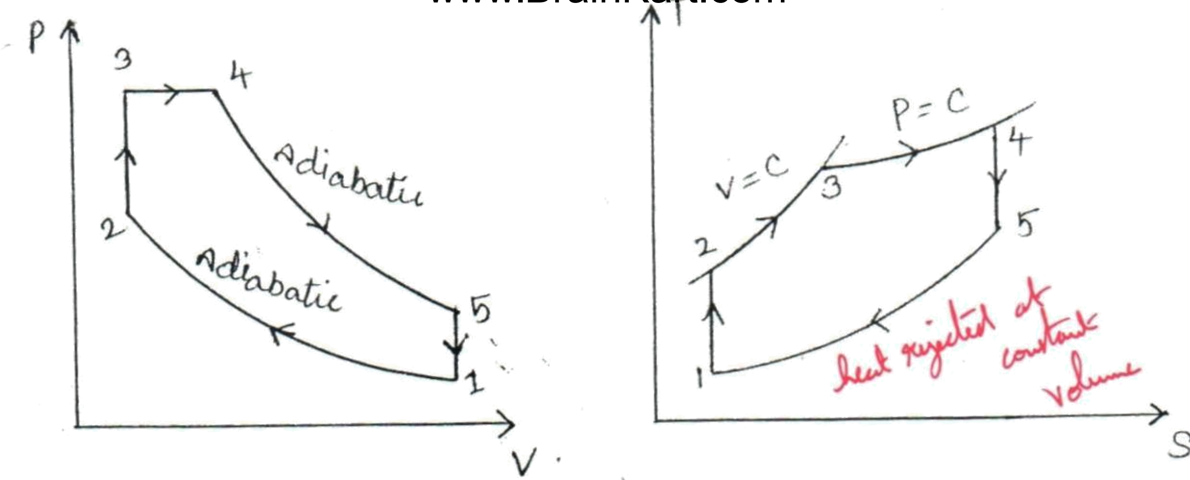


Figure. 3.

The dual Combustion cycle Fig(3) consists of th following operations:

(i) 1-2 - Adiabatic Compression

(ii) 2-3 - Addition of heat at Constant volume

(iii) 3-4 - Addition of heat at Constant pressu

(iv) 4-5 - Adiabatic expansion

(v) 5-1 - Rejection of heat at constant volu

Consider 1 Kg of air

Total heat supplied = Heat supplied during the operation 2-3 + heat suppli during the operation 3-4.

$$= C_v(T_3 - T_2) + C_p(T_4 - T_3)$$

Heat rejected during operation 5-1 $= C_v(T_5 - T_1)$

Work done = Heat supplied - heat rejec

$$= C_v(T_3 - T_2) + C_p(T_4 - T_3) - C_v(T_5$$

$$\eta_{dual} = \frac{\text{work done}}{\text{Heat supplied}} = \frac{C_v(T_3-T_2) + C_p(T_4 - T_3) - C_v(T_5}{C_v(T_3 - T_2) + C_p(T_4 - T_3)}$$

$$= 1 - \frac{C_v(T_5 - T_1)}{\ldots}$$

$$= 1 - \frac{C_v(T_5 - T_1)}{(T_3 - T_2) + \gamma(T_4 - T_3)} \rightarrow (1) \quad \because \gamma = \frac{C_p}{C_v}$$

mpression ratio, $r = \frac{V_1}{V_2}$

uring adiabatic Compression process 1-2,

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = (r)^{\gamma-1} \rightarrow (2)$$

uring constant volume heating process,

$$\frac{P_3}{T_3} = \frac{P_2}{T_2}$$

$$\frac{T_3}{T_2} = \frac{P_3}{P_2} = \beta,$$ where β is known as pressure or explosion ratio.

$$T_2 = \frac{T_3}{\beta} \longrightarrow (3)$$

uring adiabatic expansion process

$$\frac{T_4}{T_5} = \left(\frac{V_5}{V_4}\right)^{\gamma-1}$$

$$= \left(\frac{r}{\rho}\right)^{\gamma-1} \rightarrow (4)$$

$\left(\because \frac{V_5}{V_4} = \frac{V_1}{V_4} = \frac{V_1}{V_2} \times \frac{V_2}{V_4} = \frac{V_1}{V_2} \times \frac{V_3}{V_4} = \frac{r}{\rho}, \rho \text{ being the cut-off ratio}\right)$

uring constant pressure heating process,

$$\frac{V_3}{T_3} = \frac{V_4}{T_4}$$

$$T_4 = T_3 \frac{V_4}{V_3} = \rho T_3 \rightarrow (5)$$

utting the value of T_4 in the Eqn (4), we get.

$$\frac{\rho T_3}{T_5} = \left(\frac{r}{\rho}\right)^{\gamma-1} \text{ or } T_5 = \rho T_3 \left(\frac{\rho}{r}\right)^{\gamma-1}$$

Putting the value of T_2 in eqn. (ii) we get

$$\frac{T_3 / \beta}{T_1} = (r)^{\gamma-1}$$

$$T_1 = \frac{T_3}{\beta} \cdot \frac{1}{(r)^{\gamma-1}}$$

Now inserting the values of T_1, T_2, T_4 and T_5 in eqn (1), we get

$$\eta_{dual} = 1 - \frac{\left[\rho \cdot T_3 \left(\frac{\rho}{r}\right)^{\gamma-1} - \frac{T_3}{\beta} \cdot \frac{1}{(r)^{\gamma-1}}\right]}{\left[\left(T_3 - \frac{T_3}{\beta}\right) + \gamma(\rho T_3 - T_3)\right]}$$

$$= 1 - \frac{\frac{1}{(r)^{\gamma-1}}\left(\rho^{\gamma} - \frac{1}{\beta}\right)}{\left(1 - \frac{1}{\beta}\right) + \gamma(\rho - 1)}$$

ie, $$\eta_{dual} = 1 - \frac{1}{(r)^{\gamma-1}} \cdot \frac{(\beta \cdot \rho^{\gamma} - 1)}{[(\beta - 1) + \beta\gamma(\rho - 1)]} \rightarrow (6$$

Work done is given by

$$W = P_3(V_4 - V_3) + \frac{P_4V_4 - P_5V_5}{\gamma - 1} - \frac{P_2V_2 - P_1V_1}{\gamma - 1}$$

$$= \frac{P_3V_3(\rho - 1) + (P_4\rho V_3 - P_5 r V_3) - (P_2V_3 - P_1 r V_3)}{\gamma - 1}$$

$$= \frac{P_3V_3(\rho - 1)(\gamma - 1) + P_4V_3\left(\rho - \frac{P_5}{P_4} r\right) - P_2V_3\left(1 - \frac{P_1}{P_2} \ldots\right.}{\gamma - 1}$$

Also $\frac{P_5}{\ldots} = \left(\frac{V_4}{\ldots}\right)^{\gamma} = \left(\frac{\rho}{\ldots}\right)^{\gamma}$ and $\frac{P_2}{\ldots} = \left(\frac{V_1}{\ldots}\right)^{\gamma} = (r)^{\gamma}$

o, $P_3 = P_4$, $v_2 = v_3$, $v_5 = v_1$, $\frac{P_3}{P_2} = \beta$ $\beta = P_2\beta$

$$W = \frac{V_3[P_3(\rho-1)(\gamma-1) + P_3(\rho - \rho^{\gamma} r^{1-\gamma}) - P_2(1 - r^{1-\gamma})]}{(\gamma-1)}$$

$$= \frac{P_2 V_2[\beta(\rho-1)(\gamma-1) + \beta(\rho - \rho^{\gamma} r^{1-\gamma}) - (1 - r^{1-\gamma})]}{(\gamma-1)}$$

$$= \frac{P_1 (r)^{\gamma} V_1/r[\beta\gamma(\rho-1) + (\beta-1) - r^{1-\gamma}(\beta\rho^{\gamma-1})]}{(\gamma-1)}$$

$$= \frac{P_1 V_1 r^{\gamma-1}[\beta\gamma(\rho-1) + (\beta-1) - r^{\gamma-1}(\beta\rho^{\gamma-1})]}{(\gamma-1)} \rightarrow (7)$$

an effective pressure (P_m) is given by,

$$P_m = \frac{W}{V_1 - V_2} = \frac{W}{v_1\left(\frac{r-1}{r}\right)}$$

$$= \frac{\rho P_1 v_1[r^{1-\gamma}\beta\gamma(\rho-1) + (\beta-1) - r^{1-\gamma}(\beta\rho^{\gamma}-1)]}{(\gamma-1)v_1\left(\frac{r-1}{r}\right)}$$

$$P_m = \frac{P_1 (r)^{\gamma}[\beta(\rho-1) + (\beta-1) - r^{1-\gamma}(\beta\rho^{\gamma}-1)]}{(\gamma-1)(r-1)} \rightarrow (8)$$

AS TURBINE CYCLE - BRAYTON CYCLE

Brayton Cycle is a constant pressure cycle for a rfect gas. It is also Called Joule Cycle. The heat ansfers are achieved in reversible Constant essure heat exchangers.

An ideal gas turbine plant would perform the ocesses that make up a Brayton cycle. The Cycle shown in the Fig 4(a) and it is represented on v and T-S diagrams as shown in Fig 4(b) & (c).

e Various operations are as follows:

eration 1-2. The air is Compressed isentropically om the lower pressure P1 to the upper pressure

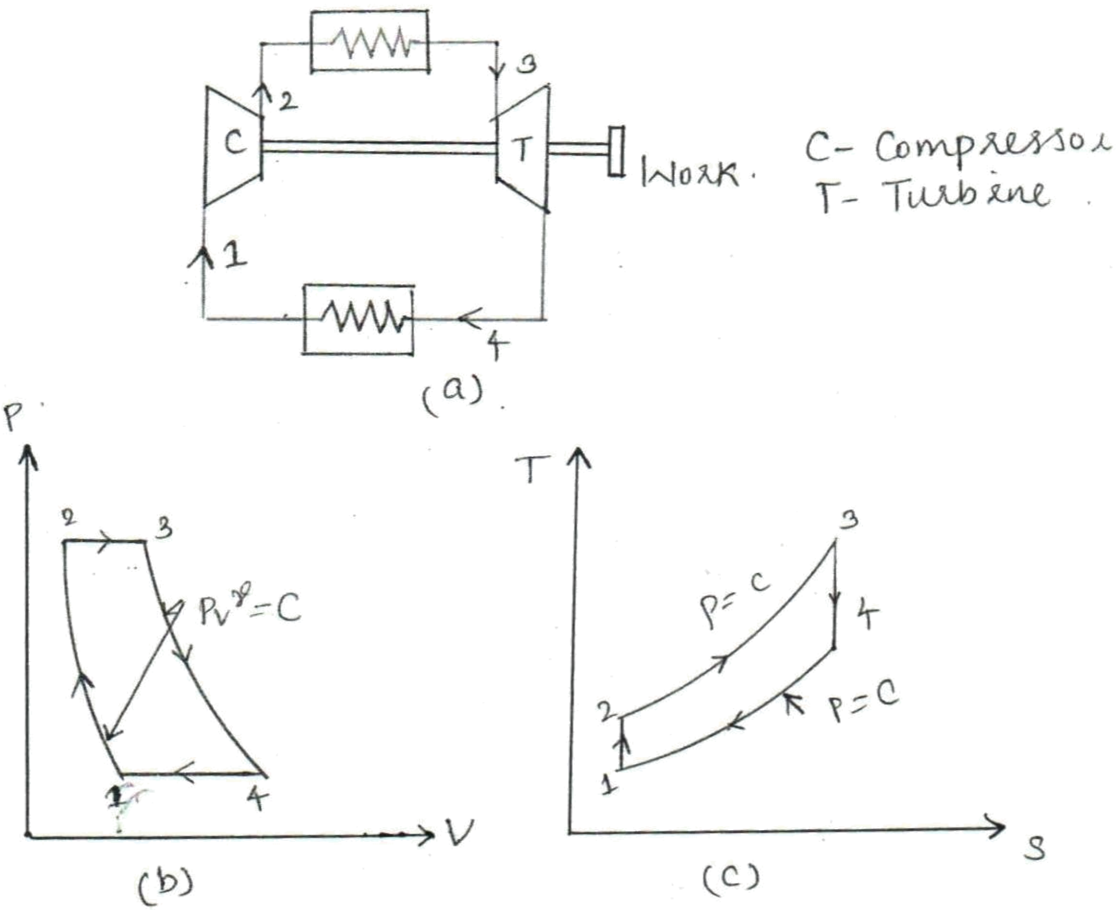


Figure (4) Brayton Cycle: (a) Basic components of a gas turbine power plant (b) P-V diagram (c) T-S diagram.

Operation 2-3. Heat flows into the system increasing the volume from V_2 to V_3 and temperature from T_2 to T_3 whilst the pressure remains constant at P_2. Heat received $= mC_p(T_3 - T_2)$.

Operation 3-4. The air is expanded isentropically from P_2 to P_1, the temperature falling from T_3 to T_4. No heat flow occurs.

Operation 4-1. Heat is rejected from the system as the volume decreases from V_4 to V_1 and the temperature from T_4 to T_1 whilst the Pressure

$\eta_{air\text{-}standard} = \dfrac{\text{Work done}}{\text{Heat received}}$

$= \dfrac{\text{Heat received/cycle} - \text{Heat rejected/}}{\text{Heat received/Cycle}}$

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

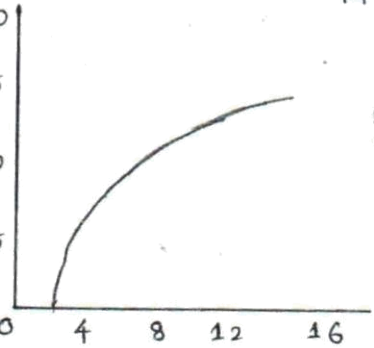
ow, from isentropic expansion,

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$T_2 = T_1 (\ \ p)^{\frac{\gamma-1}{\gamma}}$, where r_p = pressure ratio

ly $\dfrac{T_3}{T_4} = \left(\dfrac{P_2}{P_1}\right)^{(\gamma-1)/\gamma}$ or $T_3 = T_4 (r_p)^{\gamma-1/\gamma}$

$$\therefore \eta_{air\text{-}std} = 1 - \frac{T_4 - T_1}{T_4 (r_p)^{\frac{\gamma-1}{\gamma}} - T_1 (r_p)^{\frac{\gamma-1}{\gamma}}} = 1 - \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}} \rightarrow (1)$$



ig (5) Effect of pressure ratio on the efficiency Brayton Cycle.

The Eqn (1) shows that the efficiency of the ideal joule cycle increases with the pressure ratio.

The Absolute limit of upper pressure is determined by the limiting temperature of the materia of the turbine at the point at which this temperature is reached by the Compression process alone, no further heating of the gas in the cc would be ermissible and the work of expansion would ideally ust balance the work of Compression so that no excess work would be available for external use.

Various component of diesel power plant

COMPONENTS OF DIESEL POWER PLANTS

The essential components of a Diesel Electric plant are;

April/May 2010
Nov/Dec 2011, 12
14

(1) Engine
(2) Engine air intake system
(3) Engine fuel system
(4) Engine exhaust system
(5) Engine Cooling system
(6) Engine lubrication system
(7) Engine starting system

The diesel engine and the auxiliary equipm as stated above are discussed in detail in the following paragraphs. A typical schematic arrangement of the diesel plant installation is shown in Figure (6).

(1) The diesel Engine

This is the main Component of the plant wh develops power. Generally engine is Coupled directl the generator. Diesel engine may be a four stroke a two stroke engine. Four stroke engine is general preferred as it has higher efficiency, lower specif fuel consumption and more effective lubrication than a two stroke engine.

Other things which may be specified in diesel engines are: arrangement and number of Cylinders used, simple aspiration or supercharging efficiency and economical fuel consumption.

(2) Engine air intake system

This includes air filters, ducts and super-charger (an integral part of the engine). The system supplies the required quantity of air for Combusti

Air requirements of large diesel plants ar considerable, around ... per kWh.

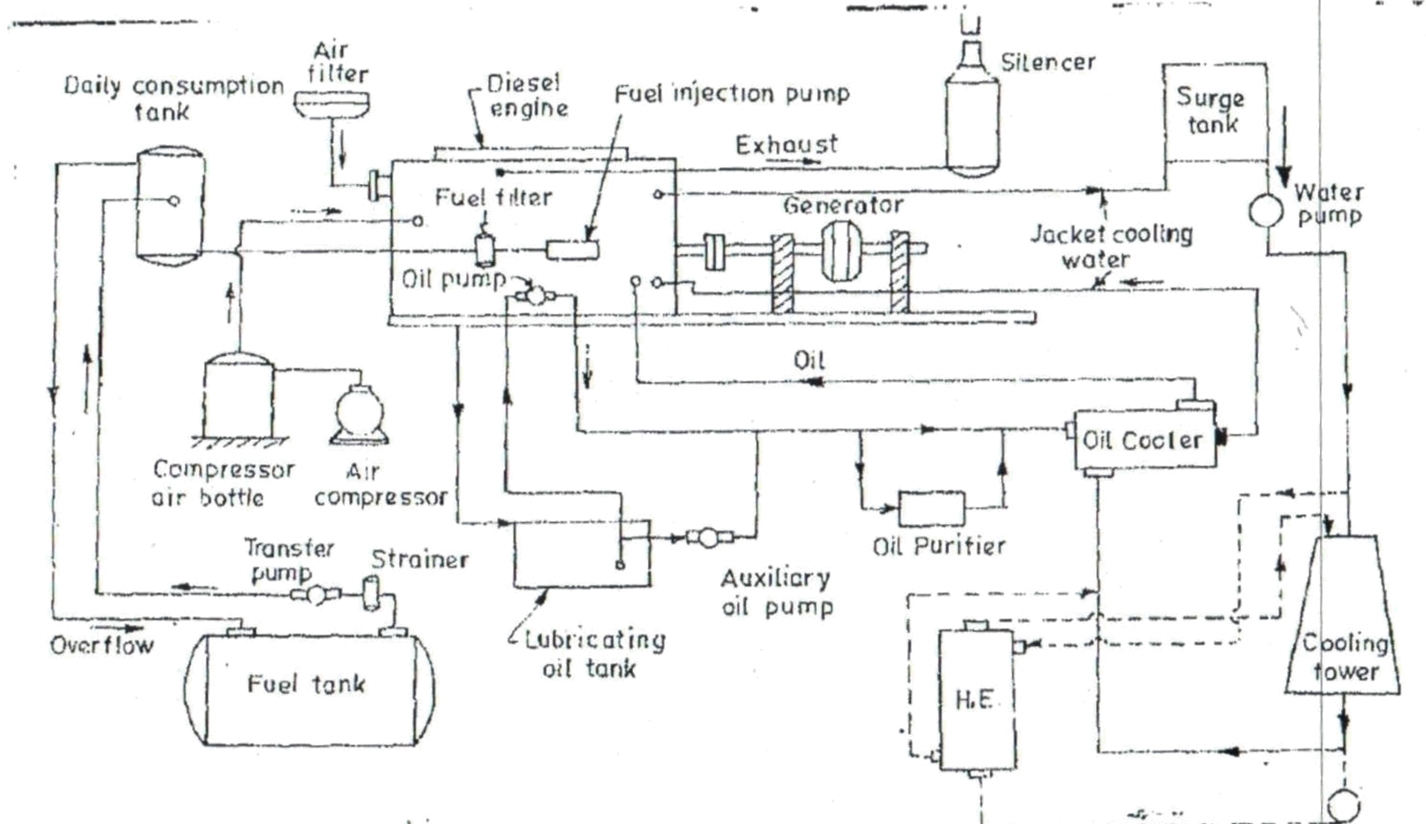


Figure (6) Schematic arrangement for a diesel engine power plant.

www.BrainKart.com

Air is drawn from outside the engine room and delivered to the intake manifold through the air fil which remove the dust and other suspended impurities from air.

The purpose of the filter is to catch any air borne dirt as it otherwise may cause the wear an tear of the engine. The filter should be cleaned Periodically.

Filters may be of dry type (made up of clot felt, glass wool etc) or oil bath type. In oil bath ty filter the air is swept over or through a bath of o in order that the particles of dust get coated.

The supercharger increases the pressure of a supplied to the engine so that it could develop an increased power output. Superchargers are general driven by the engine.

3) Fuel Systems

This include fuel storage tanks, fuel trans pumps, strainers, heaters are connecting pipe wo Fuel transfer pumps are required to transfer fue from delivery point to storage tanks and from storage tanks to engine.

Strainers (filters) are needed to ensure clean fuel. Heater for oil may be required especially during winter.

Fuel oil delivered to the power plant is recei in storage tanks. Oil is pumped from storage tan and supplied it to the smaller day tanks from where it is supplied to engine as show in Fig(7

Storage tank may be located underground Greater amount of impurities settle down in the storage tank and rest are removed by passing oil through the strainers.

The fuel oil which is transfered to the daily consumption tank [illegible] either above the

jection pump by a transfer pump driven from the gine shaft. The fuel injection system should be such at adequate quantity of fuel oil is measured by it

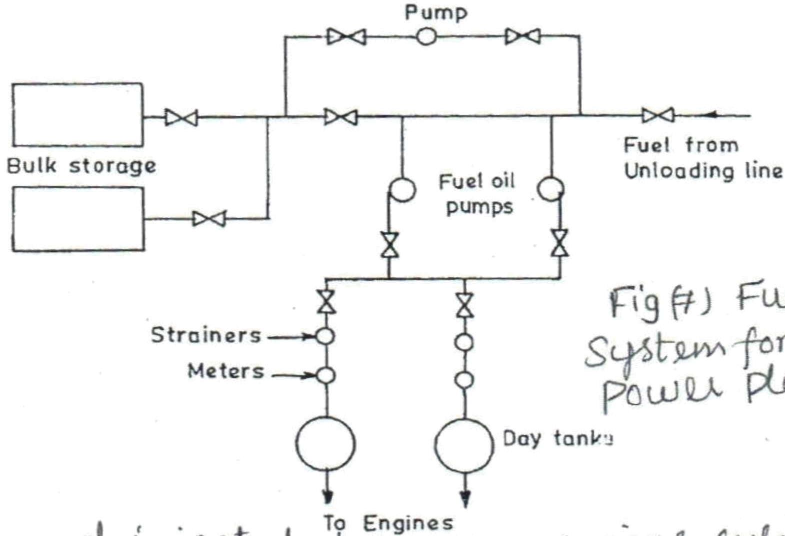


Fig (7) Fuel supply System for a diesel Power plant.

tomised and injected into the engine cylinder.

In diesel engines atomized fuel is sprayed in cylinders of the engine under pressure usally nging from approximately 100 to 120 Kg/cm².

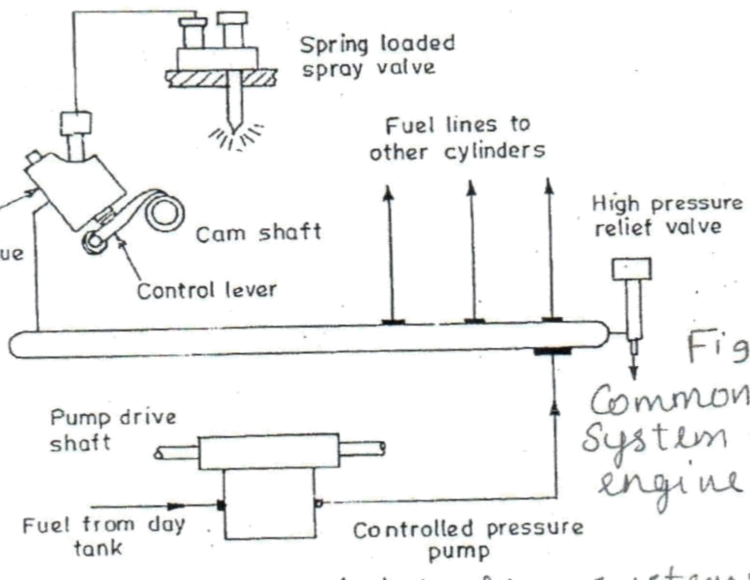


Fig (8). A typical Common rail injection System for a diesel engine.

The two common fuel injection systems are the air jection and solid or air less injection. In the air jection system, a multi stage Compressor is used supply air at a pressure of approximately -80 Kg/cm² into the [illegible] This system is

The fuel delivered to the nozzle by the pump thu discharged into the combustion chamber. The governi s effected by controlling the operation of the fuel pump.

The solid/mechanical-injection systems are available in three types:

1. The Common rail system;
2. The distributor-injection system; and
3. The pump and pressure operated nozzle sy

The last is the most often used.

Common rail injections.

This method uses a multi-cylinder fuel pu to maintain a constant high pressure in the fue discharge line which supplies fuel to all injector valves of the engine, these valves being always under pump pressure.

A typical common rail injection system for diesel engine is shown in Fig(8). A high pressure head or 'Common rail' is supplied by a single pump with built in pressure regulation which adjusts pumping rate to maintain the desired injection pressure.

The function of the pressure relief and tim valves is to regulate the injection time and amo Spring loaded safety valve acts merely as a ch

When injection valve lifts to admit high pressu fuel to spray valve, its needle rises against the Spring when the pressure is vented to the atmosphere, the spring shuts the valve.

Distribution system.

A typical distributor injection system is sho Fig (9). It is also called unit injector method, i the whole process of metering, pressurizing and injection take place in a pump-cum-

jector being used for one cylinder. The high pressure l pipes are eliminated and the device is fitted in e cylinder head, actuated by a push rod and

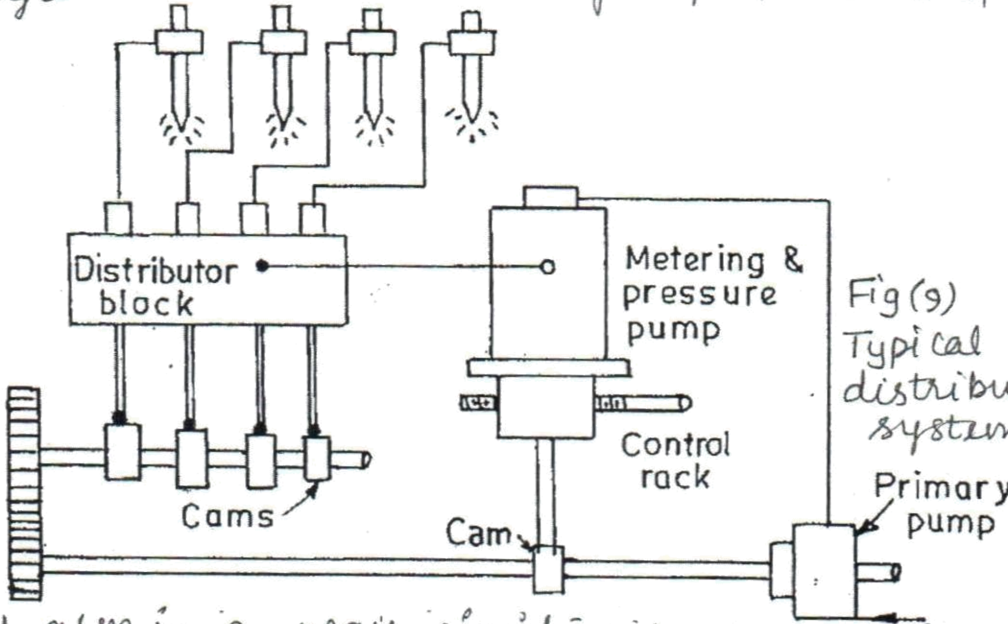
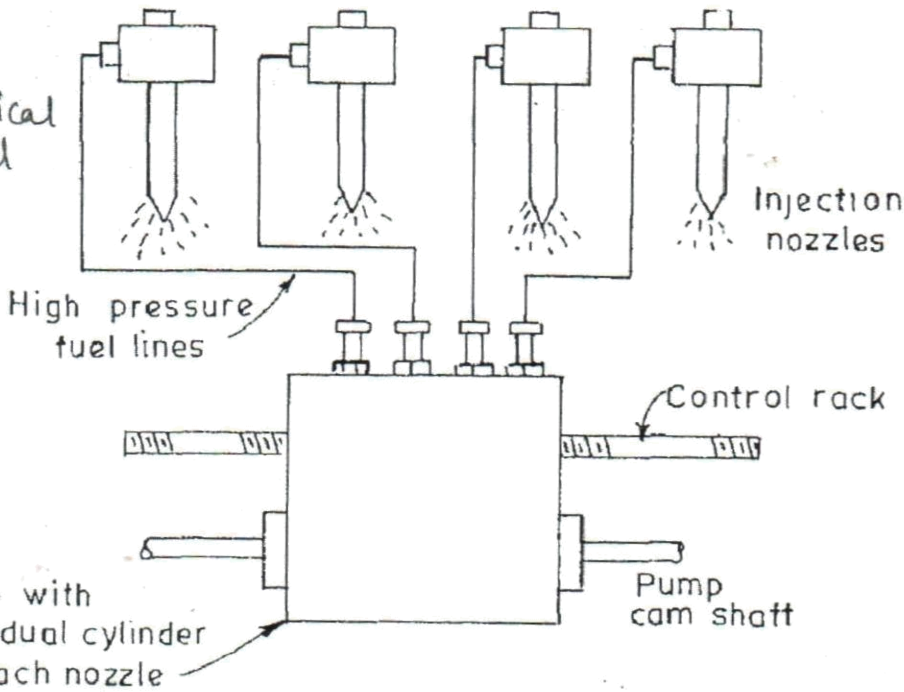


Fig (9) Typical distributor system

ocker arm in a way similar to the operation of e Overhead valve.



'g (10) Typical ump and ressure perated ozzle ystem.

In the distributor block, Cam operated popp alves feed fuel to the cylinders in proper fi der by opening just before injection.

Controlling a by pass valve in the pump or in the pump discharge line or varying the time of closure of the fuel pump inlet valve generally provides the governing effect.

pump injector method.

A Typical pump and pressure operated nozzle system is shown in Fig(10). In this system fuel nozzle is connected to a separate injection pump. The measuring of the fuel charge and control of the injection timing are done by the pump itself.

The delivery valve in the nozzle is actuated by fuel oil pressure. The atomizers or the injection valves which are spring loaded inject the fuel into the combustion chamber in a fine spray.

4. Engine Exhaust System.

The function of the exhaust system is to discharge the engine exhaust to the atmosphere outside the building. This includes silencers (muffler) and connecting ducts/pipes.

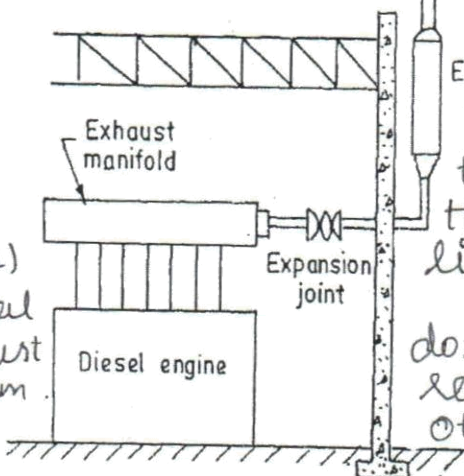
A good exhaust system should keep the noise a low level, exhaust well above the ground level to reduce the air pollution at breathing level and should isolate the engine vibrations from the building by using a flexible selection of exhaust p

The Exhaust pipe is provided with a muffler to reduce pressure in the exhaust line and reduce the noise level. A typical exhaust system is shown in Fig(11). The exhaust stack usually stands on the muffler top.

As the temperature of the exhaust gases is sufficiently high, heat of these gases is utilized in heating oil or air supplied to the engine. ~~The heat of exhaust gases may also be recovered in~~

Engine Cooling system.

This includes Coolant pumps, spray ponds, water treatment or filtration plant and connecting pipe work.



...g(11) ...pical ...haust ...stem.

The purpose of the cooling system is to carry heat from engine cylinder to keep the temperature of the cylinder within safe limits.

The extra heat, not used for doing useful work, has to be removed from the engine, otherwise this extra heat may disintegrate the lubricating ...il film on the cylinder walls and damage the cylinder ...iners, heads, walls, piston and rings.

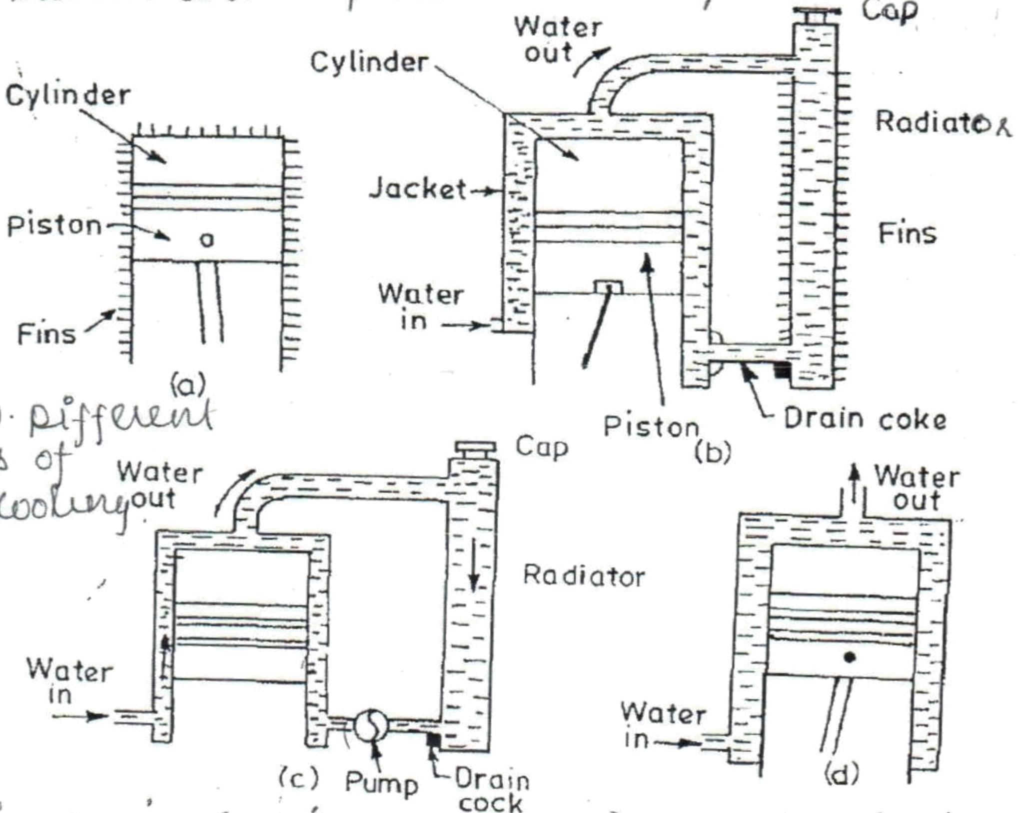


Fig (12). Different ...ethods of ...ngine cooling

(a) Direct air cooling (b) Indirect system (natural circulation) ...) Indirect cooling with forced circulation of ... d) ... circulating cooling system with ...

Small engines may be air cooled, but large stationary engines use water circulating in cylinder jacket with the help of a pump. The hot water is cooled in a spray pond and recirculated.

Cooling water must be controlled in temperature when too low, the lube oil (lubricating oil) will not spread properly and will result in cylinder and piston wear; when too high, the lube oil burn.

It is necessary to keep the exist temperature of the cooling water around 70°C. The cooling water requirement of diesel engine (for 10°C temperature rise) is around 2-4 litres per bhp per minute.

It is possible to utilize the heat of exit cooling water for heating oil or buildings. It is necessary treat the make up water to remove the scale forming impurities, zeolite softener or lime or lime ash treatment is employed.

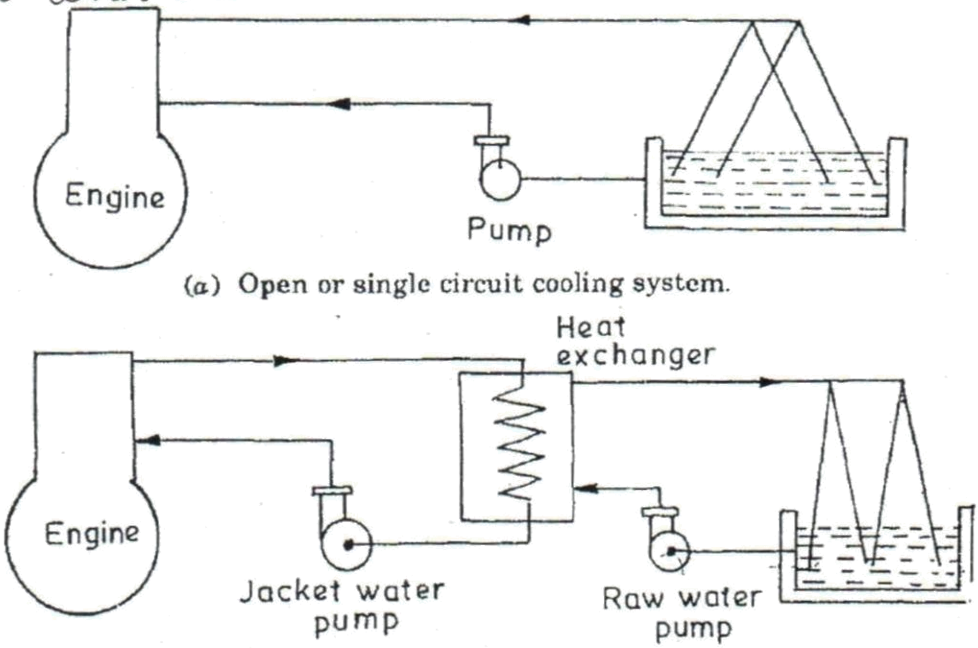
There are three system for the recooling of water for continuous use:

1. Open system or direct evaporation.
2. closed system including heat exchangers with a secondary water circulation.
3. Radiators.

The simplest cooling system would need only a water source, a pump and place of disposal of hot water. Usually, however the same water is recirculated by cooling it in devices such as radiators, evaporative coolers, cooling towers, spray pond etc.

Fig (12) a, b, c, d shows the different methods of Engine Cooling.

irect air Cooling method employs fins Casted on
e cylinder head to increase the exposed surface of
ontact with air.



(a) Open or single circuit cooling system.

(b) Closed or double circuit system.

Fig (13) Water cooling systems for stationary
iesel plants.

Air for cooling the fins, may be obtained from a
ower or fan driven by the engine. Air movement
lative to engine may be used to cools the
gine as in case of motor cycle engine. The
irect air cooling is employed in small industrial
gines, motor cycle and air craft engines.

The indirect cooling system may use natural
irculation (thermosiphon) or forced circulation of
ater. In the thermo-syphon method the change
the density of water due to change in temperature
uses it to circulate in the system.

As the water is cooled in the radiator is
escends while the hot water in the jacket rises
nd flows to the radiator at the top.

This system is simple but the motive force
roducing circulation of water is small and can

Some times a water tank of sufficient capacity may be used instead of the radiator to provide thermo-siphon coolings.

The forced circulation, indirect cooling system is most widely in large and medium sized units. Cold water is passed through the cylinder jacket with the help of a pump usually mounted on the engine frame and getting the power from the engine crank shaft.

The hot-water is sent to a cooling device, such cooling tower or a spray pond, whence it is taken in again for circulation after being cooled.

Water cooling systems in stationary diesel plants are of two types as shown Fig (13) a & b.

a) Open or single circuit system in this system pump draws the water from cooling pond and forces it into the main engine jackets. After circulating through the engine jacket, water is returned to the cooling pond. This system may subject to corrosion in the cylinder jackets because of dissolved gases in the cooling water.

b) Closed or double circuit system. In this system raw water is made to flow through the heat exchanger when it takes up the excess heat of the jacket water and then is returned back to cooling pond.

The double-circuit system largely eliminates internal jacket corrosion but may have corrosion in the raw water circuit of the heat exchanger.

) Lubrication system.

High pressure and small clearances necessiat[e] a good lubrication system for a diesel engine. The [l]ife of the engine and the efficiency depend largely [o]n the lubrication system.

[M]ain Function:

1. To lubricate the moving parts
2. To remove the heat from the cylinders and bearings.
3. To help the piston rings to seal the gases in the cylinder.
4. To carry away the solid dirt particles from the rubbing parts.

[Th]e parts of the engine, which need lubrication [i]nclude piston and cylinders, gears, crank shafts, [a]nd connecting rod, bearing etc. piston and [c]ylinder need special-lubricating oil.

) Engine starting system.

Because of the high compression pressure [e]ven a small diesel engine in a power plant [ca]n not be started by hand cranking. The [v]arious methods used for starting are.

(1) Compressed air starting for medium and [l]arge capacity stationary and mobile units.

(2) Electric-motor starting for small high-spe[ed] [g]asoline and diesel engine, and

(3) Auxiliary-engine starting for medium [c]apacity mobile units.

the functions of Various Components of gas turbine power plant

COMPONENTS OF GAS TURBINE POWER PLANTS.

A simple gas turbine cycle consists of Nov/Dec 11,1

(1) a compressor

(2) a Combustion chamber

(3) a turbine

Classification of Gas turbine power plant.

(a) open cycle gas turbine

(b) Closed cycle gas turbine.

(a) open cycle Gas turbine power plant

A simple open cycle gas turbine consists of a compressor, Combustion chamber and a turbine as shown in Fig (14). The Compressor takes in ambient air and raises its pressure. Heat is added to the air in combustion chamber by burning the fuel and raises its temperature

The heated gases coming out of combustion chamber are then passed to the turbine where it expands doing mechanical work. Part of the power developed by the turbine is utilized in driving the compressor and other accessories and remaining is used for power generation.

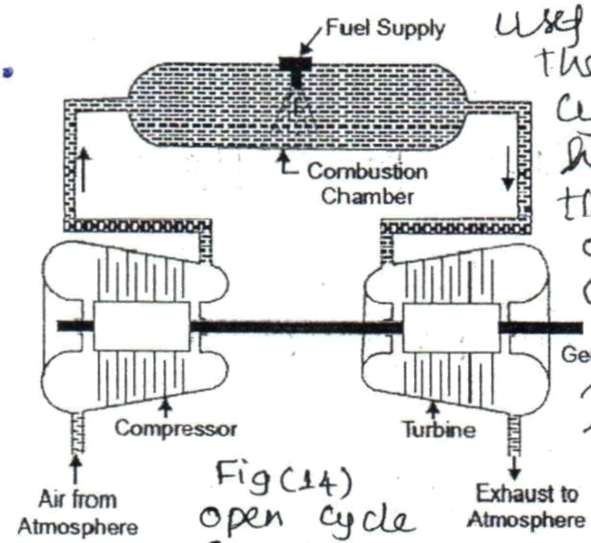
Since ambient air enters into the compressor and gases coming out of turbine are exhausted into the atmosphere, the working medium must be replaced continuously. This type of cycle is known as open cycle gas turbine plant and is mainly used in majority of gas turbine power plants as it has many inherent advantages.

Closed cycle gas turbine power plant.

Closed cycle gas turbine plant was originated and developed in Switzerland. In the year 1935 J. Ackeret and C. Keller first proposed this type of machine and first plant was completed in

The arrangement of the components of the closed cycle gas turbine plant is show in Fig(15).

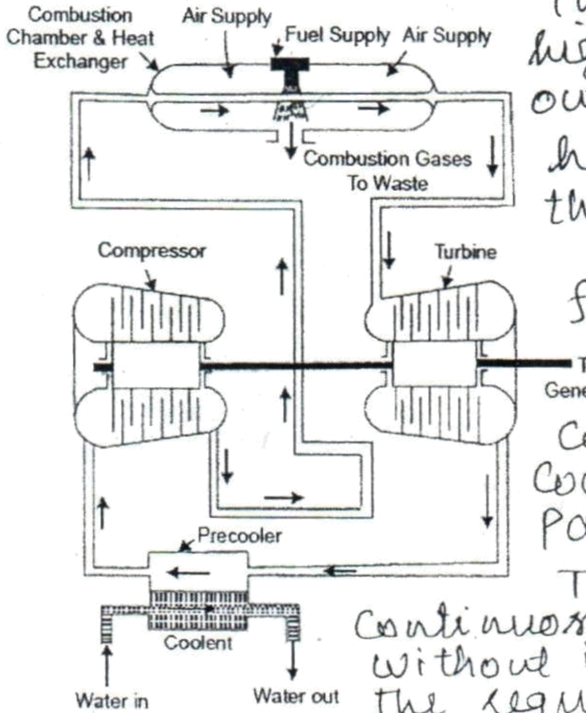
It used air as working medium and had a useful output of 2MW. Since then, a number of closed cycle gas turbine plants have been built all over the world and largest of 17MW capacity is at Gelsenkirchen, Germany and has been successfully operating since 1967.



Fig(14) open cycle Gas turbine

In closed cycle gas turbine plant, the working fluid coming out from compressor is heated in a heater by an external source at constant pressure.

The high temperature and high-pressure air coming out from the external heater is passed through the gas turbine.



The fluid coming out from the turbine is cooled to the original temperature in the cooler using external cooling source before passing to the compressor.

The working fluid is continuously used in the system without its change of phase and the required heat is given to the working fluid in the heat exchanger.

Fig (15) Closed cycle Gas Turbine

COMPRESSORS:

The high flow rates of turbines and relatively moderate pressure ratios necessitate the use of rotary compressors. The types of compressors, which are commonly used, are of two types, centrifugal and axial flow types.

The centrifugal compressor consists of an impeller (rotating component) and a diffuser (stationary component). The impeller imparts the high kinetic energy to the air and diffuser converts the kinetic energy into the pressure energy.

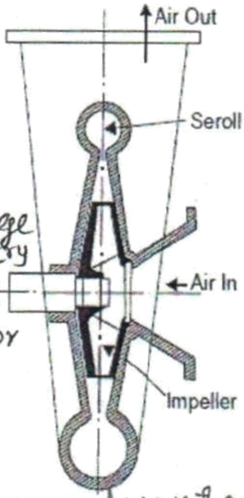
The pressure ratio of 2 to 3 is possible with single stage compressor and it can be increased upto 20 with three stage compressor. The compressors may have single or double inlet. The single inlet compressors are designed to handle the air in the range of 15 to 300 m³/min and double inlets are preferred above 300 m³/min capacity.

The single inlet centrifugal compressor is shown in Fig (16). The efficiency of centrifugal compressor lies between 80 to 90%. The efficiency of multistage compressor is lower than a single stage due to the losses.

The axial flow compressor consists of a series of rotor and stator stages with decreasing diameters along the flow of air. The blades are fixed on the rotor and rotors are fixed on the shaft. The stator blades are fixed on the stator casing.

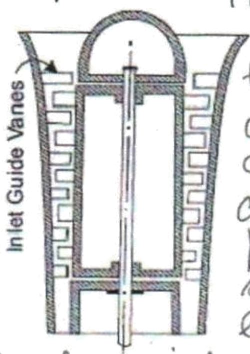
The stator blade guide the air flow to the next rotor stage coming from the previous rotor stage. The air flows along the axis of the rotor. The kinetic energy is given to the air as it passes through the rotor and part of it is converted into

he axial flow compressor is shown in Fig (17). The umber of stages required for pressure ratio of 5 is s large as sixteen or more.



ig (16) ingle stage ingle Entry entrifugal ompressor

Fig (17) Axial Flow Air Compressor.



A satisfactory air filt is absolutely necessary for cleaning the air befor it enters the compresso because it is essentia to maintain the designed profile of the aerofoil blades. The deposition of dust particles on the blade surfaces reduces the efficiency rapidly.

The advantages of axial flow compressor over entrifugal compressor are high isentropic efficienc (90-95%), high flow rate and small weight for the ame flow quantity. The axial flow compressors e very sensitive to the changes in airflow and speed, which result in rapid drop in efficiency.

In both types of compressors, it has been found at lowering of the inlet air temperature by 15 to °C gives almost 25% greater output with an increase of 5% efficiency.

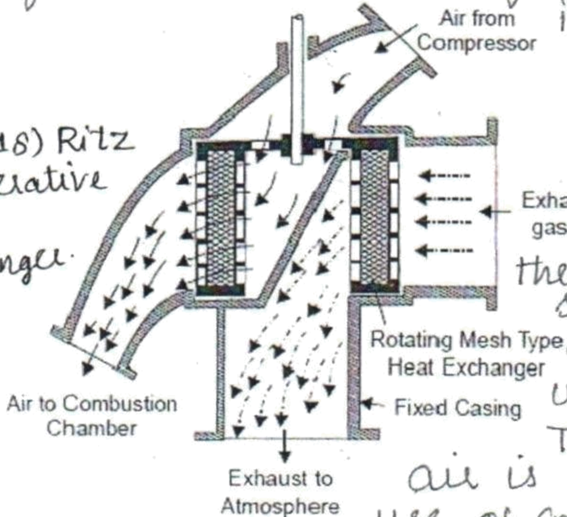


Fig (18) Ritz Regenerative Heat xchanger.

INTERCOOLERS AND HEAT EXCHANGERS.

The intercooler is generally used in ga turbine plant when the pressure ratio used is sufficiently large and the compression is completed with two or more stages. The cooling of compressed air is generally done with the use of cooling water. A cross-flow ype intercooler is generally preferred for effective eat transfer.

- The regenerators, which are commonly used in gas turbine plant, are of two types, recuperator and regenerator.

In a recuperative type of heat exchanger, the air and hot gases are made to flow in counter direction as the effect of counterflow give high average temperature difference causing the higher heat flow.

A number of baffles in the path of air flow are used to make the air to flow in contact for longer time with heat transfer surface.

The regenerator type heat exchanger consists of a heat-conducting member that is exposed alternately to the hot exhaust gases and the cooler compressed air. It absorbs the heat from hot gases and gives it up when exposed to the air.

The heat capacity member is made of a metal mesh or matrix, which is rotated slowly (40-60 r.p.m) and continuously exposed to hot and cold air.

Prof. Ritz suggested the first application of regenerative heat exchanger to gas turbine plant of Germany and the heat exchanger was titled against his name. The arrangement of Ritz heat exchanger is shown in Fig.(5).

The heat-exchanging element A is slowly rotated by a drive from the gas turbine via shaft. The rotation places the heat-transferring element A in the exhaust gas passage for one half of the time required for one r.p.m and in the air supply passage for the remaining half.

The heat element absorbs heat from the hot gases, when exposed to hot gases and gives out the same heat to the cold air when the heated part moves in the air region.

By suitable design of the speed of rotation of

o be transferred. it is possible to secure a high
effectiveness, values of 90% are claimed. The princip
advantages claimed of this heat exchanger over the
recuperative type are lightness, smaller mass, cine
small size for given effectiveness and low-pressure d

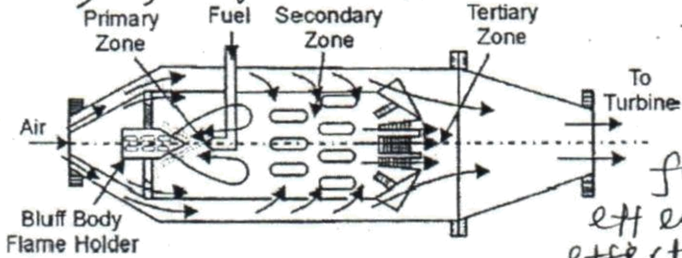


Fig (19) Combustion chamber with Upstream Injection with Bluff-body Flame Holder.

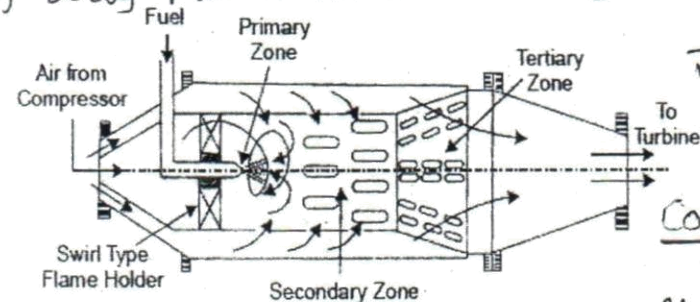


Fig (20) combustion chamber with Downstream injection and Swirl Holder.

The performance of the heat exchanger is determined by a factor known as effectiveness. This effectiveness of the heat exchanger is defined as

$$\epsilon = \frac{\text{actual heat transfer to the air}}{\text{maximum heat transfer theoretically possible}}$$

COMBUSTION CHAMBER

The gas turbine is flow system; therefore the combustion in the gas turbine differs from the combustion in diesel engines. High rate of mass flow results in high velocities at various points throughout the cycle (300m/sec). One of the vital problems associated with the design of gas turbine combustion chamber is to secure a steady and stab flame inside the combustion chamber.

The gas turbine combustion system has to functi under certain different operation conditions which a not usually met with the combustion systems diesel engines. A few of them are listed below.

(1) Combustion in the gas turbine takes place in continuous flow system and, therefore, the advant of high pressure and restricted volume available

e chemical reaction takes place relatively slowly
us requiring large residence time in the combusti
amber in order to achieve complete combustion

2. The gas turbine requires about 100:1 air-fuel
atio by weight for the reasons mentioned earlier-
ut the air-fuel ratio required for the combustion
diesel engine is approximately 15:1.

Therefore, it is impossible to ignite and
aintain a continuous combustion with such wea
ixture. It is necessary to provide rich mixture
om ignition and continuous combustion, and
erefore, it is necessary to allow required air in
e combustion zone and the remaining air must
e added after complete combustion therefore to
educe the gas temperature before passing into
e turbine.

3. A pilot or recirculated zone should be created
n the main flow to establish a stable flame tha
elps to ignite the combustible mixture continuously

4. A stable continuous flame can be maintained
nside the combustion chamber when the stream
elocity and fuel burning velocity are equal.
nfortunately most of the fuels have low burning
elocities of the order of a few meters per second,
herefore, flame stabilization is not possible unle
ome technique is employed to anchor the flame in
e combustion chamber.

The common methods of flame stabilization u
n practice are bluff body method and swirl flow
method. Two types of CC using bluff body and
swirl for flame stabilization are shown in Fig (1
20). The major difference between two is the use o
different methods to create pilot zone for flame
stabilization.

AS TURBINES:

The Common types of turbines, which are in use, re axial flow type. The basic requirements of the rbines are lightweight, high efficiency reliabilit operation and long working life. Large work tput can be obtained per stage with high blade speed hen the blades are designed to sustain higher ers.

More stages of the turbine are always preferred gas turbine power plant because it helps to duce the stresses in the blades and increases the erall life of the turbine. More stages are rther preferred with stationary power plants cause weight is not the major consideration in e design which is essential in aircraft turbine ant.

The cooling of the gas turbine blade is essential r long life as it is continuously subjected to gh temperature gases. There are different methods cooling the blades. The common method used is e air-cooling. The air is passed through the holes ovided through the blade.

MBINED CYCLE POWER PLANTS:

It has been found that a considerable amou heat energy goes as a waste with the exhaust the gas turbine. The energy must be utilized. e complete use of the energy available to a ystem is called the total energy approach.

The objective of this approach is to use all o e heat energy in a power system at the differen mperature levels at which it becomes available produce work, or steam, or the heating of air r water, thereby rejecting a minimum of energy aste. The best app[...] use of combined

important in present day scenario

There may be various combinations of the combined cycles depending upon the place or country requirement. Even nuclear power plant may be used in the combined cycles.

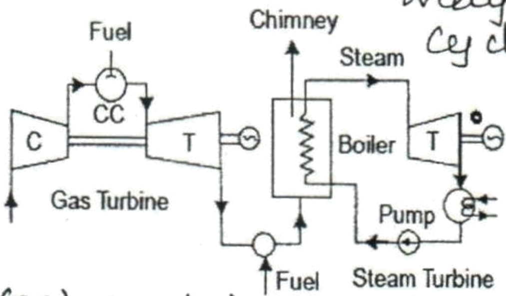


Fig (21) combine cycle (Co-generation)

In Fig (21) shows a combination of an open cycle gas turbine and steam turbine. The exhaust of gas turbine which has high oxygen content is used as the inlet gas to the steam generator where the combustion of additional fuel takes place. This combination allows nearer equality between the power outputs of the two units than is obtained with the simple recuperative heat exchanger.

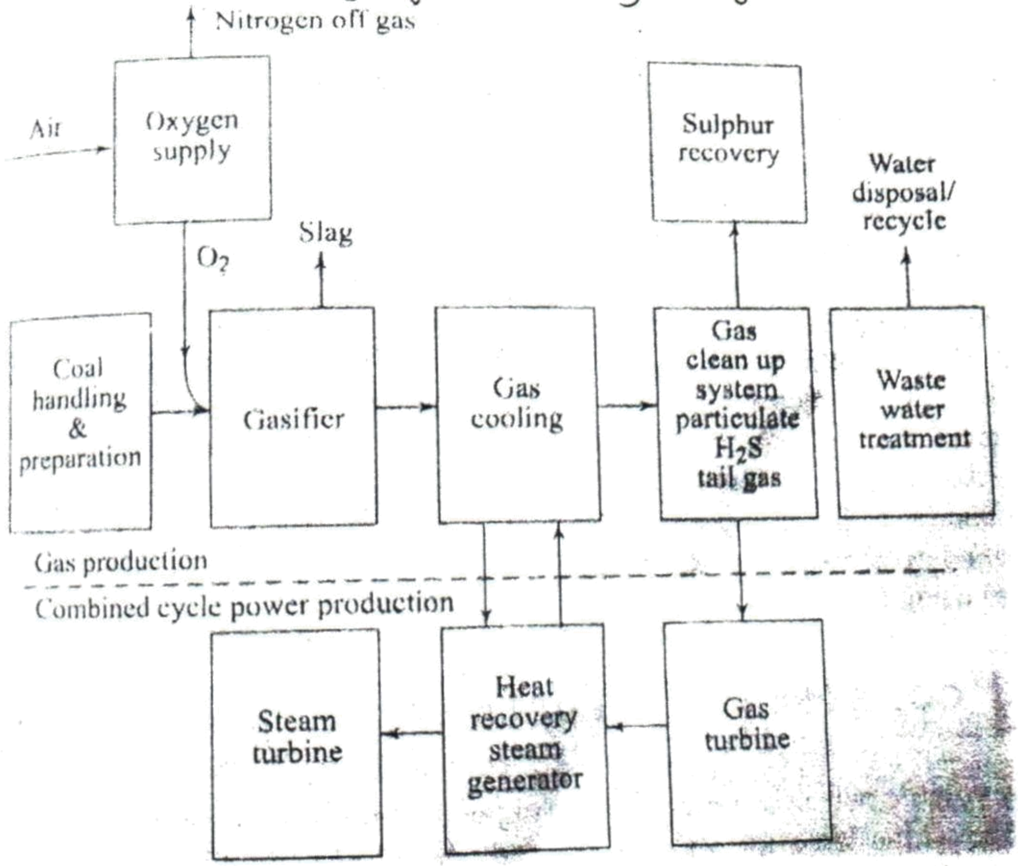
For a given total power output the energy input is reduced (ie saving in fuel) and the installed cost of gas turbine per unit of power output is about one-fourth of that steam turbine.

In other words, the combination cycles exhibit higher efficiency. The greater disadvantage include the complexity of the plant, different fuel requirements and possible loss of flexibility and reliability.

The most recent technology in the field of co-generation developed in USA utilizes the gaseous fuel in the combustion chambers produced by the gasification of low quality of coal. The system is efficient and the cost of power production per KW is less.

NTEGRATED GASIFIER BASED COMBINED CYCLE SYSTEMS

The synthetic gas (syngas) exiting a typical gasifier is cooled by generating high pressure stea



Fig(22). Basic IGCC plant arrangement

which is subsequently expanded in a steam turb generator to produce electricity. The syngas is then cleaned of particulates, by cyclones, filters, and/or water scrubbing, following by heat exchange to cool the gas to near ambient temperature (Fig(22)).

Sulphur compounds in the gas, primarily, H and some Carbonyl sulphide (COS), are removed, which is ultimately converted to elemental sulphur for sale. The cleaned fuel is finally sent t the combined cycle where it is combustioned an expanded in the gas turbine to produce electrici

Typical gasification plant includes the following blocks:

1. Coal preparation to prepare coal to meet gasifier specification.

2. Air separation - to generate 95% pure oxygen for feeding the gasifier, and to generate gaseous nitrogen for injection into the gas turbine and for plant inert gas uses.

3. Coal gasification - to convert the coal to gas by partial oxidation.

4. Ash/slag removal - includes the removal of ash/slag from the gasifier, dewatering and disposal.

5. Syngas cooling - to remove sensible heat from the gasifier effluent gas and to facilitate gas cleaning.

6. Particulate removal - to remove fine particulates in the raw gas stream.

7. Acid gas removal - to remove sulphur bearing gases in the syngas.

8. sulphur recovery - to convert the sulphur bearing gases to elemental sulphur.

The system incorporates one advanced gas turbine-generator similar to a General Electric MS7001F gas turbine (inlet temperature 1260°C), which, apart from the engine, includes auxiliaries such as fuel system, lube oil system and control system.

The unit also includes one heat recovery steam generator (HRSG) having superheater, reheater and economiser, one steam turbine-generator, a surface condenser, an integral deaerator, boiler feed water pumps, and a stack.

The steam turbine normally produces 30-40% of the total energy output of an IGCC plant.

Typical steam conditions and approach
nperature differences are given below. (Blamire 1984)

HP steam pressure	101 bar
HP Steam superheat temperature	540° C
IP steam pressure	22 bar
Reheat temperature	540° C
LP steam pressure	4 bar
Boiler pinch temperature difference	14 °C
Economiser approach	25°C
Dearator pressure	1.25 bar
Condenser pressure	0.047 bar
Stack temperature	120° C

The gas turbine exhaust flows successively
rough the superheater, reheater, boiler and
onomiser sections.

A unique characteristic of an IGCC plant is its
ility to take advantage of phased construction.
aking turbines and/or a combined cycle plant
required capacities initially fuelled with fuel
l or natural gas may first be installed.

It may then the followed by the addition of a
oal gasification plant to refuel the combined cycle
with coal-derived fuel gas. It has a higher
erall efficiency and is more friendly with
vironment.

* —— * —— *

ME 6701 POWER PLANT ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

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.

3.1 Basics of Nuclear Engineering

Cheap and abundant power is essential to the modern world in coming years. The rapid increase in industry and living standard of the people advance the pressure on conventional sources of power i.e. coal, oil and hydro. The resources of these fuels are becoming depleted in many countries, and thus there is a tendency to seek alternative sources of energy. Hydro-electric stations produce cheap power, but need a thermal backing to increase the firm capacity.

In a nuclear power station instead of a furnace, there is a nuclear reactor, in which heat is generated by splitting atoms of radioactive material under suitable conditions. This splitting or nuclear fission of materials like uranium (U), Plutonium (Up), has opened up a new source of power of great importance.

The heat produced due to fission of uranium and plutonium is used to heat water to generate steam which is used for running turbo generators.

A nuclear power plant differs from a conventional power plant only in the steam generating part. The schematic arrangement of a simple nuclear power plant using liquid coolant with and without heat exchanger is shown in Fig 3.1 other type of nuclear power station will be considered latter.

The main parts of a nuclear power station are the nuclear reactor and a heat exchanger, together with the familiar steam turbine, condenser and a generator. Heat is provided by fashioning or splitting of uranium atoms, in a reactor.

A cooling medium takes up this heat and deliver it to the heat exchanger, where steam for the turbine is raised. The reactor and heat exchanger are equivalent to the furnace and boiler in a conventional steam plant. When the uranium atoms split, there is radiation as well, so that the reactor and its cooling circuit must be heavily shielded against radiation hazards. The rest of the plant is similar to the ordinary steam plant.

The steam generated in the heat exchanger is admitted to the turbine, and after work has been done by the expansion of steam through the turbine, the steam is condensed into the condensate in the condenser.

The condensate pump sends the condensate back to the heat exchanger, thus forming a closed feed system. The other auxiliaries are similar to those in a familiar steam station.

For economical use in a power system a nuclear power station generally has to be large, and where large units are justifiable, nuclear power stations are considered as alternatives to conventional stations.

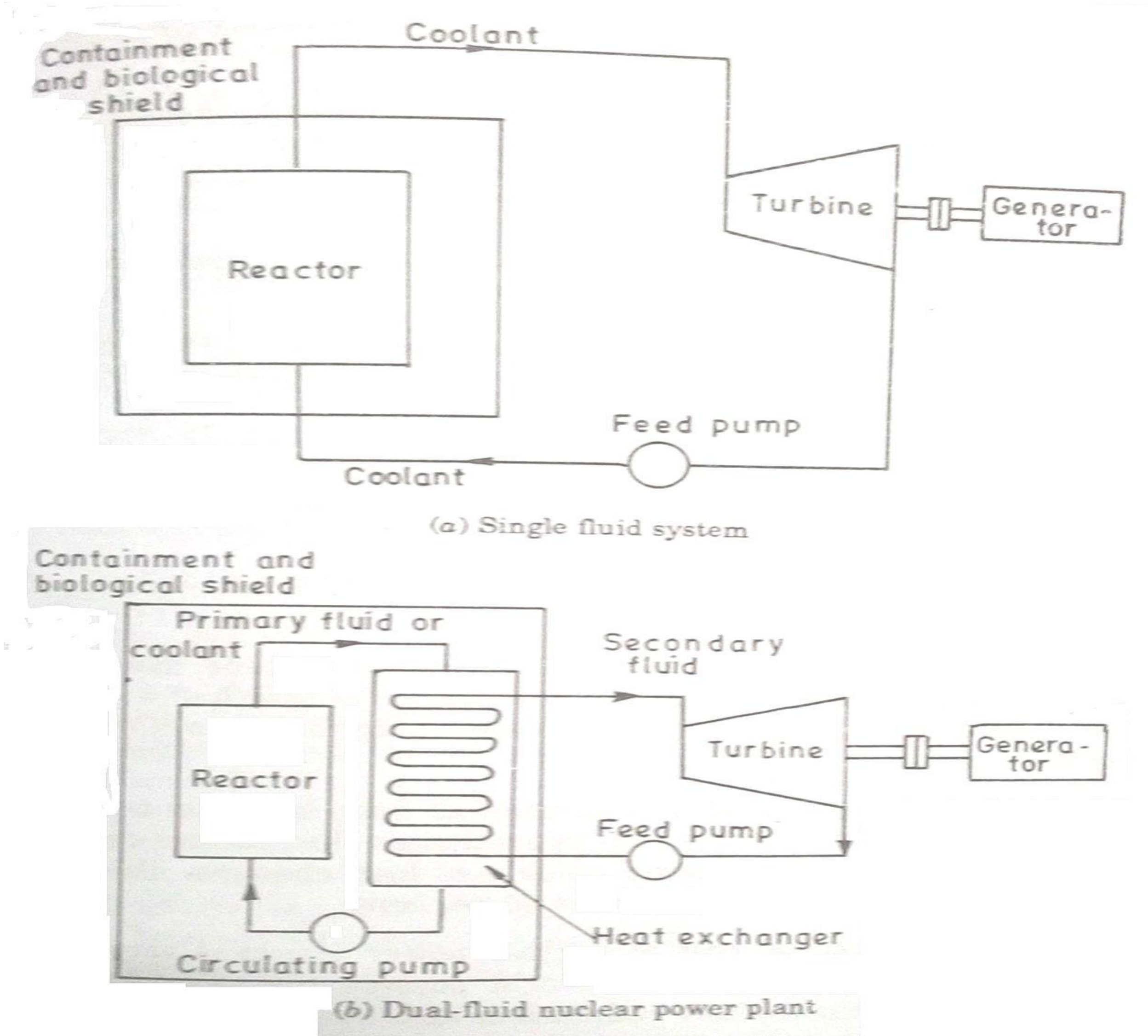


Fig 3.1 simple nuclear power plant with and without heat exchanger

Advantages of nuclear power station compared to the conventional thermal power station

1. It reduces the demand for coal, oil and gas, the costs of which are tending to rise as the stocks become depleted. The amount of fuel used in the plant is small. Greater nuclear power production leads to conversion of coal oil etc.

2. Since the amount of fuel needed is small, there are no problems of fuel transportation, storage etc. It has been found that one kilogram me of uranium can produce, as much energy as can be produced by running 4500 tones of high trade coal.
3. Nuclear power plant requires less space compared to any other plant of the equivalent size.
4. Besides producing large amounts of power, the nuclear power plant can produce valuable fissile material, which is extracted when the fuel has to be renewed.
5. Bigger capacity of these plants in an additional advantage.
6. Nuclear plants create no smog, and are unaffected by adverse weather condition
7. Greater nuclear power production leads to conservation of coal, oil etc.

Limitations

1. The nuclear power plants include danger of radioactivity, detrimental working conditions to health of workers, the problem of disposal of radioactive waste, high salaries of trained personnel etc.
2. Nuclear power plants can be used as base load plants. They are not suitable for variable load operation as the reactors cannot be easily controlled to respond quickly to load changes. They are used at a load factor of not less than 80 per cent.
3. The initial capital cost of nuclear power plant is very high only very few countries in the world possess the technology to manufacture nuclear reactors and nuclear fuel. Inspire of this, nuclear power is likely to supply greater and greater portion of future power needs of the world.

3.2 Layout and subsystems of Nuclear power plants

A nuclear reactor is basically a furnace where the fashioning of atoms can be controlled and the heat put to useful work. In a nuclear fission reactor, the conditions are such that fission energy is released at a controlled rate.

The fission energy is converted into heat in the reactor, and this heat is utilized to raise steam directly or indirectly. The steam then drives a turbine-generator to produce electricity in the conventional manner.

Fig 3.3 shows the main components of a reactor. The location of fuel, moderator, control rods and coolant in a typical power reactor are shown. These components are enclosed in a pressure vessel.

The coolant heated in passing by the fuel elements, flows through a heat exchanger where it turns water in a secondary circuit, into steam. The steam is then used to drive a turbine generator.

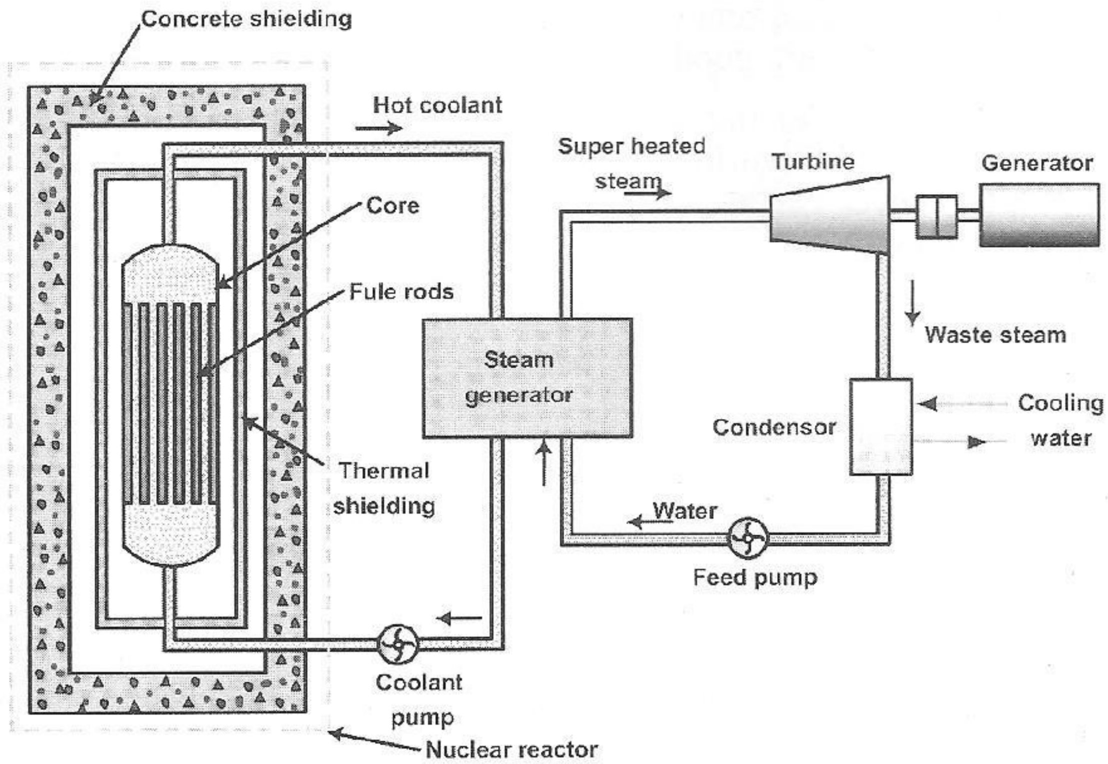


Fig 3.2 Layout

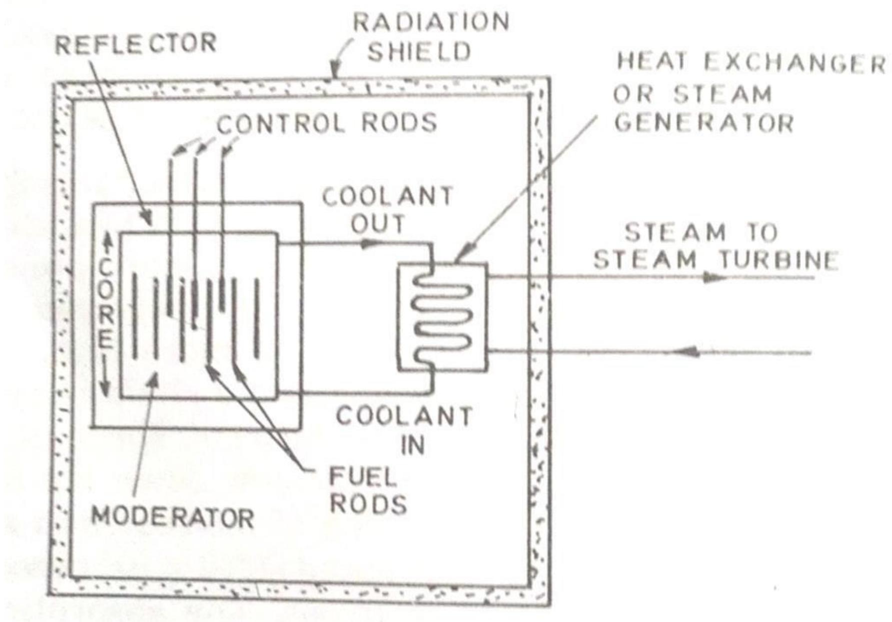


Fig 3.3 Basic components of a nuclear power reactor

Nuclear reactors may be used in addition to power generation for several purposes such as to produce heat for the thermoelectric power, process work or space heating to produce fissionable materials, radio isotopes, neutron etc.; to proper ships, submarines, aircrafts etc.; and for research testing and irradiation work.

A nuclear reactor consists of the following basic parts:

1. The **core** which is the part containing the fuel elements.
2. The **neutron moderator** which aids the fission process by slowing down the neutrons.
3. The **reflector** which scatters back neutrons escaping from the core.
4. **Controller's** means for controlling the rate of fission and consequently the power level of the reactor.
5. The **coolant** or the cooling system which removes the heat generated in the core.
6. The **radiation shield** which protects the operating personnel from radiations emitted during fission. Description of each of these components is given in the following paragraphs.

1. **Core:** fuel all reactors have a central core in which fissions occur and most of the fission energy appears as heat. The core contains the nuclear fuel consisting of a fissile species (i.e. uranium^{233}, uranium^{235} or plutonium^{239}) and usually a fertile material (i.e. thorium^{232} or uranium^{238}).

   In some thermal reactors, the fuel is natural uranium with roughly 0.7 weight percent of uranium ^{235} and 99.3 percent of uranium^{238}. Most commercial power reactors a uranium fuel enriched to about 2.5 to 3 percent in uranium^{235}.

   For a fast reactor a more highly enriched fuel is required. A typical fast reactor fuel might contain 15 to 20 percent of uranium^{235} or plutonium^{239}; the remainder is uranium^{238} to serve as fertile material.

   The fuel elements are made of plates or rods of uranium metal or ceramic. The plates or rods are usually clad in a thin sheath of stainless steel, zirconium, or aluminum to provide corrosion resistance, retention of radioactivity and, in some cases, structural support. Space is provided between the individual fuel plates to allow for passage of the coolant.

2. **Core-moderator**

   The moderator, commonly water or graphite, is dispersed between the fuel assemblies. It serves to slow down or moderate, the fast neutrons produced in fission. These lower velocities provide a better opportunity for the neutrons to cause further fission.

   Fission neutrons escaping from the fuel rods at high velocity are slowed down as a result of collisions with moderator nuclei. The slow (approximately thermal) neutrons may then be absorbed generally in other fuel rods, and these cause fissions.

In this way, slow neutrons can maintain the fission chain. The actual energy (or speed) distribution of the neutrons causing most of the fissions is determined by the nature and proportions of the fuel and moderator, as well as by the temperature.

The best moderators are materials consisting of elements of low mass number, preferably with little or no tendency to capture neutrons. Ordinary water (H_2O) for example, is a common moderator; two of its three atoms are hydrogen with a mass number of unity.

The great majority of power reactors are of these types known as light-water reactors because these use ordinary (or light) water as the moderator.

In some power reactors, the moderator is deuterium oxide (D_2O), also heavy water; this is a form of water containing deuterium, the heavier, naturally occurring isotope of hydrogen with a mass number of two.

Such reactors are heavy water reactors. The only other moderator material used to any significant extent is graphite which is essentially pure carbon, with a mass number of 12.

3. Control Rods

The control rods are made of a neutron absorbing material and upon movement in or out of the core, vary the number of neutrons available to maintain the chain reaction. The rate of fashioning may thereby be controlled. The materials employed are those with high absorption cross sections, such as boron, cadmium, hafnium, silver and indium. The materials are formed into solid rods which may be withdrawn or inserted in the reactor core at selected points to raise or lower the effective multiplication factor.

For normal operation the multiplication constant must be maintained at unity. This will ensure the neutron flux is held at constant value. The control rods are moved in and out of channels in the core by control rod devices.

The diagram of a heterogeneous reactor in which reactivity is controlled by the movement of neutron absorbed rod is shown in Fig 3.3. To ensure even distribution of neutron flux it is necessary to employ large number of rods—the number generally exceeding hundred.

When rods are fully inserted, the neutron absorption will be maximum, K will be much less than 1 and reactor shut down. Generally the control rods divided into three categories. Shut off rods, coarse and fine regulation rods.

The shut off rods are normally kept out and are used for reducing the reactivity in the case of emergency. The regulation rods for starting and continuous control. The coarse control rods are for taking the reactor to the required power level after it has been started and for effecting large changes.

However the reactivity should not be changed at a dangerous rate. The fine control rods are for maintaining the reactor critical when running under normal conditions. They can adjust reactivity to a fine degree of accuracy.

Control rods drives are hydraulic or electric motor driven; rack and pinion and screw drives are common.

4. Reflector

The main purpose of the reflector which surrounds the core is to decrease the loss of neutrons. It is another method of lowering the neutron leakage and improving the neutron economy by providing a reflector around the reactor core. Neutrons escaping from the core enter the reflector where many collide with reflector nuclei and are turned back into the core. The critical mass of fuel is then less, than it would be without a reflector; consequently the size and cost of the reflector are reduced.

A reflector material is one with a high neutron scattering cross section, a low absorption cross section, and a good slowing down ration, for the speed of escaping neutrons is likely to be slightly higher than thermal speed. In fact most of the materials that make good moderators such as graphite, light water and beryllium, also make good reflector materials.

In a fast reactor the reflector must be a material of high mass number to avoid slowing down the neutrons. The core is then surrounded by a layer (or blanket) consisting of uranium2^{38}, either as natural uranium or uranium that has been depleted in Uranium^{235} (Depleted Uranium is the residual material from the Uranium^{235} enrichment operation).

The uranium blanket acts as a reflector in returning some of the neutrons escaping from the core. However, an important purpose of the blanket is to serve as a fertile material; capture of neutrons by Uranium^{238} followed by two stages of beta particle emission, results in the formation of fissile Pu^{239}. In some fast reactors designs a stainless neutron reflector surrounds the fertile blanket.

5. Coolant

The heat generated in the fuel by fissions is removed by circulation of a coolant through the reactor core. The coolant transfers heat out of the reactor core is circulated either directly or indirectly as the thermodynamic medium for conversion of the heat energy to electrical energy.

As a direct cycle, the coolant, either steam or hot gas, drives a steam turbine or a gas turbine, respectively. This is a single cycle system, used in boiling water reactors (BWRs). A dual cycle can be installed in most of the gaseous or pressurized water reactors (PWRs).

In PWR, the pressure in the reactor vessel, which contains the core and coolant, is so high that the water does not boil. After passing through the core to remove fission heat, the high pressures water is pumped through the tubes in a heat exchanger and returned to the reactor vessels.

Heat is transferred from the reactor water to feed water at a lower pressure surrounding the steam generator tubes; because of lower pressure, the feed water boils and produces steam to drive the turbines. The exhaust steam from the turbines is condensed and returned as feed water to the steam generator.

A triple cycle has been postulated for liquid-metal coolant reactors in which an intermediate coolant is used between the primary (sodium) coolant and the final steam to prevent possible contact of the hot sodium and water. The primary coolant is circulated through annular spaces in the fuel elements themselves or in channels formed by adjacent fuel elements in the core.

Water cannot be used as coolant in fast reactors because of its moderating effect on neutron energy. Consequently, most current fast reactor designs are based on molten sodium as the coolant.

6. Radiation shielding or biological shielding

Shielding is necessary in order to protect the walls of the reactor vessel from radiation damage, and also to protect operating personnel from exposure to radiation. The first known as the internal or thermal shield is provided through steel lining, while the other called external or biological shield; is generally made of thick concrete (about 1.8 to 2.4m) surrounding the reactor installation.

The components of a nuclear emission alpha and beta particles, neutrons and gamma rays vary in their energy and/or intensity and their ability to travel and penetrate material of these—only the fast neutrons and gamma rays present some serious difficulty in designing the reactor shielding, since alpha and beta particles can be stopped by a fraction of an cm. of solid substance, while thermal neutrons can be automatically guarded against with a shield thick enough to provide protection against fast neutrons and gamma rays, alpha particles cannot penetrate the skin.

However it is necessary to prevent spreading of alpha particles to environment to eliminate contamination. A sheet of paper is a sufficient shield against alpha particles. A beta particle is an electron emitted from a radioactive nucleus.

This particle can travel several meters in air but is unable to penetrate thick materials being easily stopped by a thin sheet of aluminum/lead/brick. Over exposure to beta particle can cause skin burns and repeated over exposure may result in malignant growths.

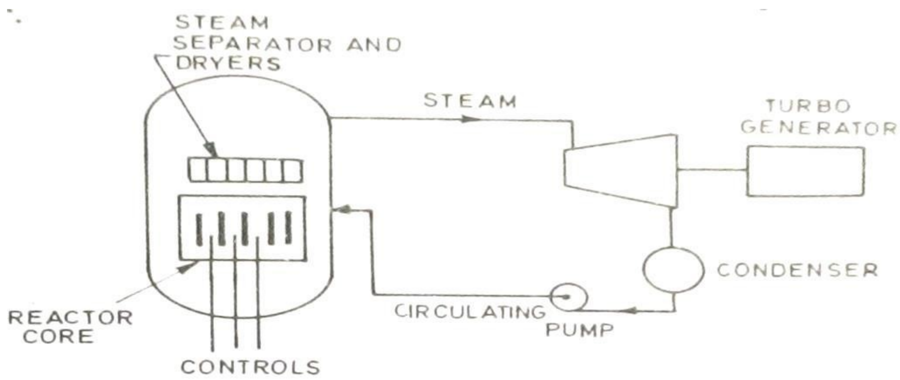
3.3 Working of Nuclear Reactors

3.3.1 Boiling Water Reactor (BWR)

A thermal nuclear power reactor in which ordinary (or light) water is the moderator and coolant, as well as the neutron reflector. The system pressure is high, but not as high as in a pressurized water reactor, so that the water boils and steam is generated within the reactor core, so that the water boils and steam is generated within the reactor core.

In this plant cycle, also known as direct steam cycle, steam is produced in the reactor itself instead of in a heat exchanger. Since auxiliary power is reduced from 6% to 1% by elimination of the heat transfer circuit between reactor and steam generator, the overall plant efficiency increases with a BWR.

Boiling water reactor use enriched uranium as a fuel (enriched uranium contains more fissionable isotope U^{235} than the naturally occurring percentage 0.7%). The fuel rods contain small cylindrical pellets of uranium dioxide with an average initial enrichment of about 2.6% in $uranium^{235}$.



(a) Direct cycle boiling water reactor.

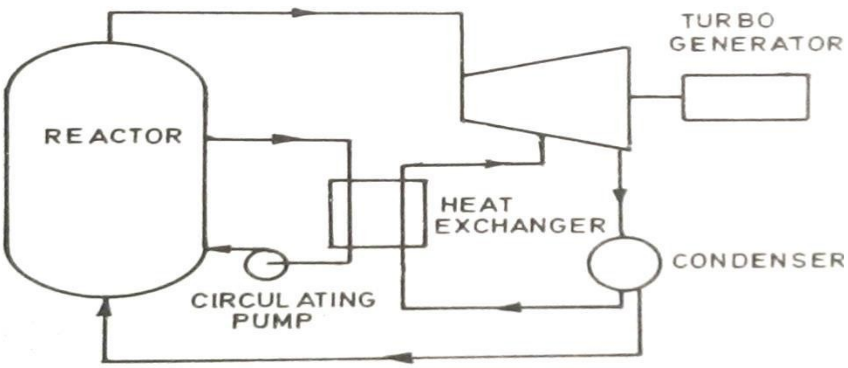


Fig 3.4 BWR cycles

Fig 3.4 shows the arrangement of direct cycle boiling water reactor. The uranium elements are arranged in a particular lattice from inside a steel pressure vessel containing water. Fission heat is removed from the reactor by conversion of water to steam in the core. It is a direct cycle reactor.

The steam is generated in the reactor itself and this steam after passing through turbine and condenser returns to reactor. Feed water enters the reactor tank below to pass through the fuel elements in the core as coolant and also as moderator.

The control elements in a BWR have a cruciform cross section; each element had four blades containing stainless steel tubes filled with neutron poison (i.e., absorber) boron as boron carbide. The blades can move up and down in the spaces between the fuel assemblies with one control element between four assemblies in most cases. Some 180(or so) such elements are distributed evenly throughout the core.

The controls of a BWR are inserted from the bottom of the core, rather than the top as in other reactors. This is convenient, because the space above the core us occupied by steam-water separators and desirable because the neutron absorber at the bottom of the core can compensate for the steam bubbles formed bubbles formed higher up in the core.

As the coolant water flows upward through the core, it removes the fission heat from the fuel rods and boils. The wet steam enters a bank of water separators and then passes on to dryers in the upper part of the reactor vessel. The relatively dry steam then proceeds to turbine to generate electricity. The turbine condensate is returned to the reactor as feed water.

The various cycles used in BWR are:

(1) Natural circulation single cycle
(2) Forced circulation single cycle
(3) Forced circulation dual cycle

In the natural circulation, single, cycle, no pump is used to circulate the water through the reactor core and such a plant is best suited for capacity of 50—100MW. In the forced circulation plant the coolant is pumped through the core. This design is preferred in 100 —1000MW size range.

In the dual cycle plant, part of the heat of circulation is used for generate additional low pressure steam for the turbine. A steam to steam heat exchanger is required which adds cost.

India's first nuclear power plant at Tarapur has two reactors (each 200MW capacity) of BWR type.

Advantages

1. Heat exchangers pump and auxiliaries equipment requirements are reduced or eliminated, resulting gain in thermal efficiency with reduction in cost.
2. The pressure inside the pressure vessel is not high so a thicker vessel is not required which further reduces cost, and simplifies containment problems,
3. It is more efficient cycle than the PWR since for a given containment pressure the outlet temperature of the steam is appreciably higher.
4. Thermal efficiency of BWR to about 30% as compared to 20-22% in PWR.
5. The metal temperature remains low for given output conditions.
6. The reactor is capable of promptly meeting the fluctuating load requirements.

Disadvantages

1. Possible carryover of radioactivity to steam equipment. There is possibility of radioactive contamination in the turbine mechanism. Turbines may require shielding.
2. On part load operation, there is wastage of steam resulting in lowering of thermal efficiency.
3. More elaborate safety precaution needed, which are costly.
4. More biological protection is required.

3.3.2 Pressurized water reactor (PWR)

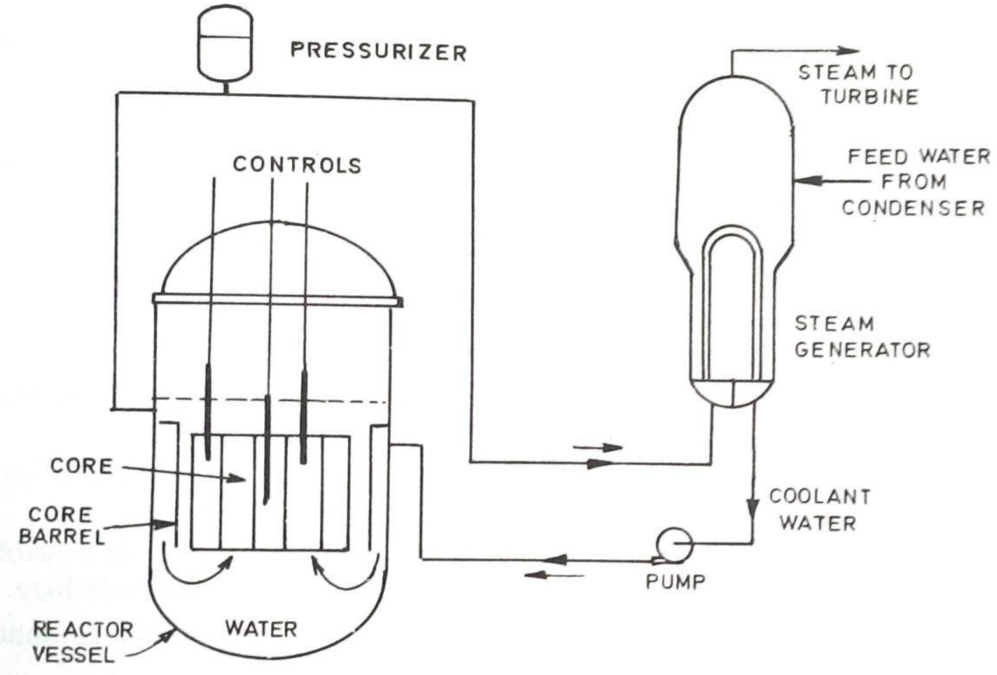


Fig 3.5 Pressurized-water reactor (PWR)

The PWR is a thermal reactor, generally using enriched fuel (uranium oxide) and depending on the type of moderator used clad with stainless steel or zirconium alloy and the

pressure vessel is of steel. Light or heavy water may be used as the combined coolant cum moderator.

The pressure vessel and the heat exchanger are surrounded by a concrete shield. Heat exchanger is used to develop steam, the primary loop being formed by the coolant moderator.

The water under pressure is used as both the moderator and coolant. To prevent boiling of coolant in the core, it is maintained under pressure of 153 atm. (15.5MPa) (at this pressure water boils at 345˚ C).

As shown in Fig 3.5, a pump circulates water at high pressure round the core so that the water in the liquid state absorbs heat from the uranium and transfers it to the secondary loop, heat exchanger or boiler. After giving up some of its heat to boil water and produced steam in the steam generator, the high pressure water is pumped back into the reactor vessel.

It enters just above the core and flows down through the annular region called the down comer, between the core barrel and the pressure vessel wall. At the bottom of the core, the water reverses direction and flows upward through the core to remove the heat generated by fission.

The coolant steam pressure is maintained within a limited range by means of a pressurized connected between the reactor vessel and a steam generator. The pressurizer is a large cylindrical steel tank containing some 60% by volume of liquid water and 40% steam during steam operation.

A large PWR may have from two to four independent steam generators loops in parallel. Most steam generators consists of a large number of inverted U-shaped tubes enclosed in a casing called the shell. The high pressure, high temperature water from the reactor flows through the inside of the tubes, and heat is transferred to water at a lower pressure [75 atm (7.6MPa)] on the outside (shell side) of the tubes.

The water in the shell boils at the lower pressure and produced moist steam. Entrained moisture is separated in the upper part of the steam generator and steam at a temperature of about 290˚C proceeds to the turbine system. After passage through the steam generator tubes, the high pressure water is pumped back to the reactor vessel.

Coarse control of a PWR is achieved by the neutron poison (i.e. absorber) boron as boric acid, dissolved in the reactor water. The boron compensates for the extra fuel present initially, and this is used up during reactor operations, the basic acid concentration is decreased.

The controlled rods, referred to earlier, which can be moved in or out of the core, are used to start up the reactor and shut it down and for automatic fine adjustments during normal operation. Another used of the control rods is to make the heat (or power) distribution ad uniform as possible throughout the core. Completed insertion of the rods will always cause the reactor to shutdown.

Advantages

1. Steam supplied to the turbine is completely free from contamination
2. The reactor is compact in size as compared with some other type (such as gas cooled reactor GCR).
3. Light water is the cheapest coolant and moderator.
4. Cooling system is simple
5. Fission products remain contained in the reactor and are not circulated
6. High power density
7. Possibility of breeding plutonium by providing a blanket of U^{238}.

Limitations

1. High pressure requires a costly reactor vessel and leak proof primary coolant circuit.
2. High pressure and high temperature water at rapid flow rates increase corrosion an erosion problems.
3. Steam is produced at relatively low temperature and pressure and consequently needs super heating.

3.3.3 CANada Deuterium-Uranium reactor (CANDU)

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. The CANDU reactor was developed (and is used extensively) in Canada, where a full scale commercial reactor of this type first started operation in 1967.

A few CANDU reactors are operating or under construction in some other countries. These reactors are more economical to those countries which do not produced enriched uranium, as the enrichment of uranium is very costly. In this type of reactors the natural uranium (0.7% U^{235}) is used as fuel and heavy water as moderator.

A basic design difference between the CANDU (heavy water) reactor and light-water reactors (LWRS) is that in the latter the same water serves as 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 in the reactor core.

General Description

Reactor vessel and core: The arrangement of the different components of CANDU type reactor is shown in Fig 3.6. The reactor vessel is a steel cylinder with a horizontal axis. (Length and diameter of a typical cylinder are 6m x 8m respectively). The vessel is penetrated by some

380 horizontal channels called pressure tubes because they are designed to withstand a high internal pressure.

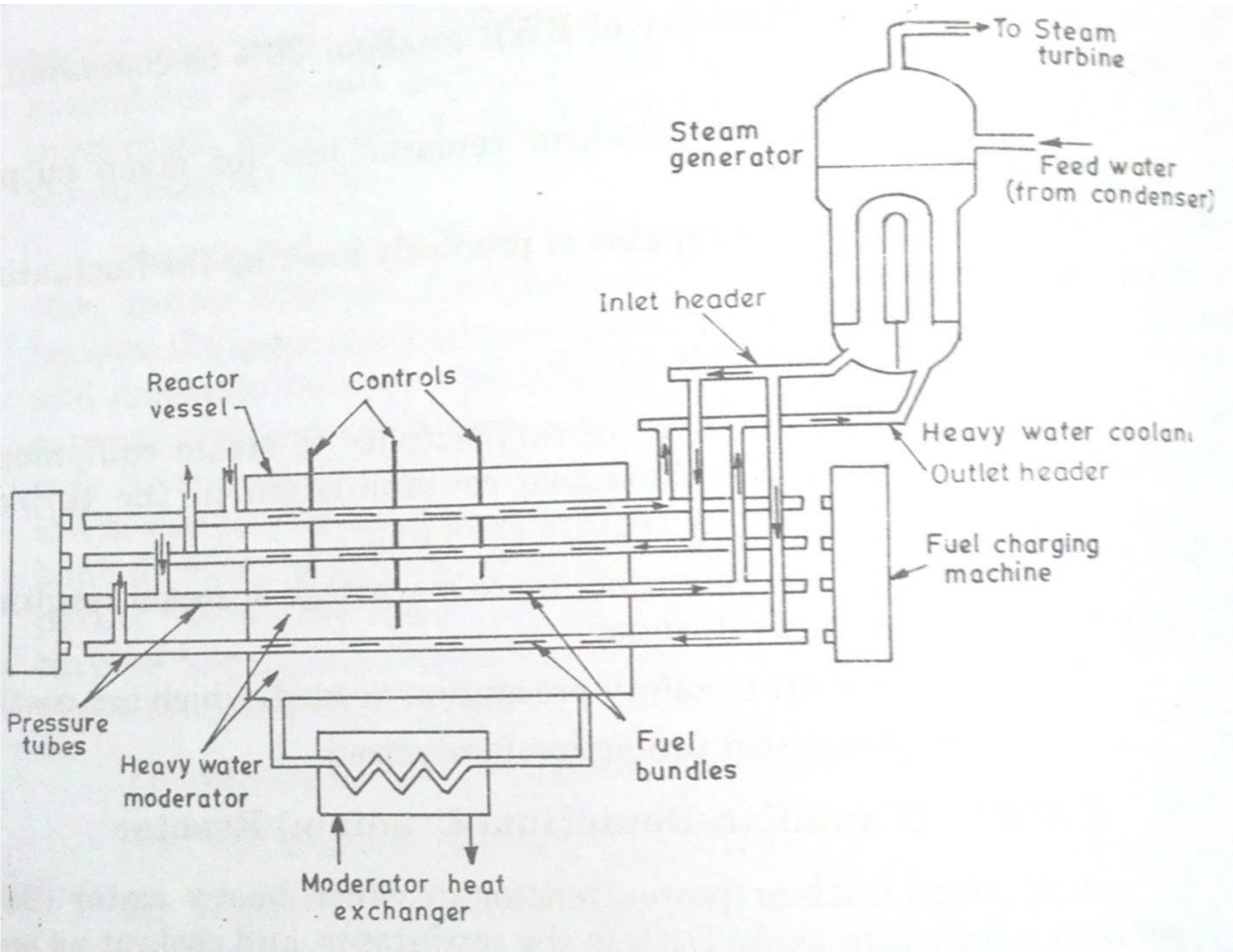


Fig 3.6 CANDU (Canadian Deuterium-Uranium) Reactor

The channels contain the fuel elements and the pressurized coolant flows along the channels and around the fuel elements to remove the heat generated by fission. Coolant flow is in the opposite directions in adjacent channels.

The high temperature (310˚C) and high pressure 100 atm (10Mpa) coolants leaving the reactor core enters the steam generator, as described below. Roughly 5% of the fission heat is generated by fast neutrons escaping into the moderator, and this is removed by circulation through a separate heat exchanger.

The fuel in the CANDU reactor is normal (i.e. unenriched) uranium oxide as small cylindrical pellets. The pellets are packed in corrosion—resistance zirconium alloy (zircaloy) tube, nearly 0.5m long and 1.3 cm diameter, to form a fuel rod. The relatively short rods are combined in bundles of 37 rods, and 12 bundles are placed end to end in each pressure tube. The total mass of fuel in the core to about 97,000 kg.

The CANDU reactor is unusual in that refueling (i.e. removal of spent fuel and replacement by fresh fuel) is conducted while the reactor is operating. A refueling machine inserts a fresh fuel bundle into one end at a horizontal pressure tube which is temporarily disconnected from the main coolant circuit.

A spent fuel bundle is thus displaced at the other end and is removed. This procedure is carried out, like the coolant flow, in opposite directions in adjacent channels.

Control and protection system. The CANDU reactor has several types of vertical control elements. T hey includes a number of strong neutron absorber (i.e. poison) rods of cadmium which are used mainly for reactor shutdown and start up.

In addition there is other less strongly, absorbing rods to control power variations heat (power) distribution throughout the core. In an emergency situation, the shut down rods would immediately drop into the core, followed if necessary by the injection of a gadolinium nitrate solution into the moderator (Gadolinium is a very strong absorber of thermal neutrons)

Steam System. The respective ends of the pressure tubes are all connected into inlet and outlet headers (manifolds). The high temperature coolant leaving the reactor passes out the outlet header to a steam generator of the conventional inverted U tube (as in pressurized water reactor) and is then pumped back to the reactor by way of the inlet header.

Steam is generated at a temperature of above 265˚C. There are two coolant outlet (and two inlet) headers, one at each end of the reactor vessel, corresponding to the opposite direction of coolant flow through the core. Each inlet (and outlet) header is connected to a separate steam generator and pump loop. A single pressurizer, of the type used in pressurized-water reactors, maintains an essentially constant coolant system pressure.

Safety features. A break in a single pressure tube would result in some loss of coolant, but the particular tube could be disconnected and reactor operation would proceed with the other tubes. A mere loss of coolant accident, with possible damage to the fuel and release of radioactive fission products would develop from a break in one of the coolant header or in the pipes to or from the steam generators.

An emergency core-cooling system would then supply additional coolant. The separate moderate system would also provide a substantial heat sink.

A concrete containment structure encloses the reactor vessel and the steam generator system. 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:

1. Enriched fuel is not required.

2. The reactor vessel does not have to withstand a high pressure as vessel of PWR and BWR. Only the heavy water coolant circuit (fuel tubes) has to be pressurized to inhibit boiling in the reactor core, therefore, the cost of the vessel is less?
3. The moderator can be kept at low temperature which increases its effectiveness in slowing down neutrons.
4. Heavy water is used as moderator, which has higher multiplication factor and low fuel consumption.
5. Site construction requires lesser time as compared with PWR and BWR.

Disadvantages

1. Heavy water is very costly
2. Leakage problems.
3. Very high standard of design, manufacture and maintenance are needed.
4. The reactor size is extremely large as power density is low as compared with PWR and BWR.

3.3.4 Breeder

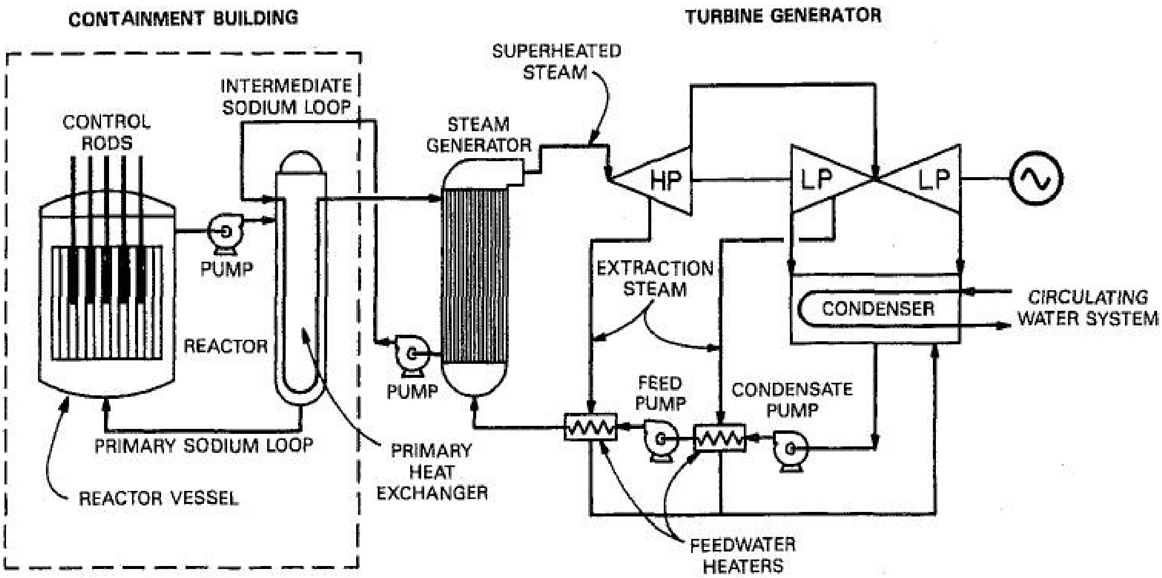


Fig 3.7 Schematic for a breeder reactor

The breeder reactor has the capability of producing more fuel than it consumes through the breeding of uranium. The reactor core is surrounded by fertile material $^{238}{}_{92}$, which captures the neutrons not used for fashioning, and through a series of nuclear decays produces $^{239}{}_{94}$, a fissile fuel.

Breeder reactors operate in the fast neutron energy range to take advantage of the higher number of neutrons produced take advantage of the higher number of neutrons produced per fission in uranium and plutonium fuel which result from the absorption of the high-energy neutrons.

Breeder reactors can produce additional plutonium fuel to support several light water reactors, and thus have the potential to increase nuclear fuel reserves.

Fig 3.7 shows a simplified schematic of a breeder reactor. Liquid sodium is used as the coolant to remove the reactor fission energy and transfer the energy to steam generators. Sodium is used because of its good heat transfer properties, low neutron moderating characteristics, and low operating pressures. Since liquid sodium becomes radioactive in passing through the reactor, a primary heat exchanger (sodium to sodium) is used to prevent leakage of radioactive sodium into the steam cycle.

An additional advantage of the primary heat exchanger is to prevent water getting into the nuclear core. The breeder core consists of a number of fuel assemblies of stainless steel fuel rods that are packed with pellets of $^{238}{}_{92}$ dioxide and $^{239}{}_{94}$ dioxide material.

The mixture is approximately 80% $^{238}{}_{92}$ and 20% $^{239}{}_{94}$. The core is also surrounded by a radial blanket of $^{238}{}_{92}$ dioxide. Sodium passes through the breeder core and radial blanket, where it removes the fission energy and then flows to the primary heat exchanger, transferring the fission energy to the intermediate sodium coolant.

The intermediate coolant passes to a steam generator (sodium to water exchanger) that produces superheated steam at 1,535 psig (10.6MPag), 906˚F (486˚C). Superheated steam expands through the high and low pressure section of the turbine generator, is condensed, and then returned to the sodium/water steam generator. The steam cycle is similar to a conventional steam cycle utilizing a 3,600 rpm non reheat turbine generator.

3.3.5 Gas Cooled Reactors

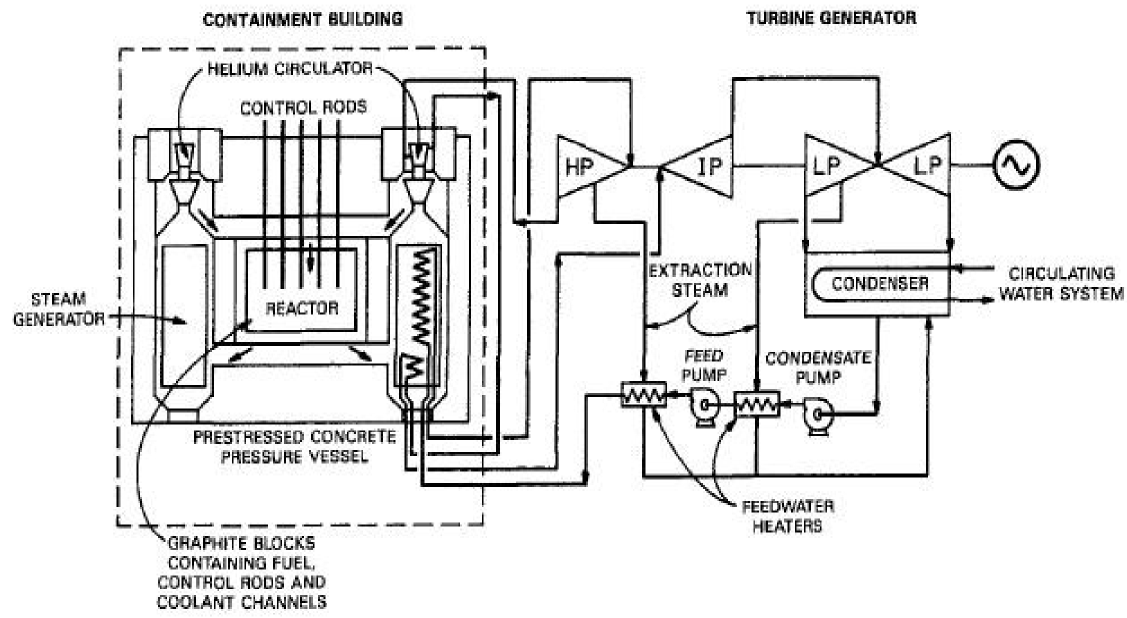


Fig 3.8 schematic for high temperature gas cooled reactor

The largest program involving commercial gas-cooled reactors (GCRs) was developed in England. The first series of GCRs used graphite as a moderator and carbon dioxide as the coolant. The reactor consisted of a large number of graphite blocks housed in a steel pressure vessel. Numerous channels ware drilled through the graphite blocks.

The channels either contained fuel elements or were used for control rod insertion. The fuel elements consisted of natural uranium metal clad with Magnox, an alloy of magnesium. Carbon dioxide passed through the fuel channels, removing the fission heat. The gas was then circulated to heat exchangers that produced steam, and then returned to the reactor.

The steam from the steam generators was expanded through a turbine generator, condensed, and returned to the steam generators. The Magnox series operated successfully but had low thermal efficiency and low fuel lifetime because of the low operating temperature (780˚F, 420˚C) and radiation damage limits due to the metallic uranium fuel. Later designs integrated the heat exchangers around the core inside the pressure vessel which consisted of a prestressed concrete structure.

The advanced gas-cooled reactor (AGR) was developed to overcome the limitations of the Magnox except that the reactor fuel consisted of enriched uranium dioxide fuel pins clash with stainless steel and housed in fuel elements. Each fuel channel contained several fuel elements. Because of the high operating gas coolant temperature of 1,210˚F(654˚C) at the reactor outlet, superheat and reheat steam were produced.

High-temperature Gas-Cooled Reactors

The high-temperature gas-cooled reactor (HTGR) is an American design that produces a higher gas temperature, and thus, a higher steam temperature and higher thermal efficiencies than those of the LWR and HWR. Thermal efficiencies are similar to those for modern pulverized coal plants.

The HTGR, shown schematically in Fig 3.8, uses helium gas as the coolant and graphite as the neutron energy moderator. This reactor consists of hexagonal graphite blocks in which cylindrical fuel rods containing small spherical fuel particles of enriched uranium and thorium are housed within fuel holes interspersed with coolant holes for helium flow.

The graphite blocks are stacked vertically to form the reactor core. Helium flows through the graphite blocks, removing the fission hear, and then passes to one or more steam generators that produced superheated and reheated steam.

Superheated steam at 2400 psig(15.4Mpag), 950˚F(510˚C) is sent to a high-pressure turbine where the steam exhaust is then reheated in the steam generators at 550 psia (3.8MPa), 950˚F (510˚C) and sent back to the intermediate pressure turbine. The balance-of-plant systems

(e.g., steam turbine generator, condensers, and feed water heaters) are very similar to those of a modern pulverized coal plant.

The graphite core, steam generators, and helium circulators are located in a prestressed concrete pressure vessel. Control is provided by control rods of boron carbide, which enter from the top of the reactor core through channels in the graphite blocks.

3.3.6 Liquid Metal Cooled Reactors or Liquid metal Fast Breeder Reactor

Fast breeder reactors are designed to create or breed new fissile material, while producing useful electric power. Most produced fissile plutonium from fertile uranium 238. The fuel rods in the core region thus contain a mixture of fissile pu-239 and U-238. The active core region is surrounded by a blanket of fertile U-238.

This blanket region captures neutrons that would otherwise be lost through leakage, thus producing additional fissile material. A fast neutron reaction with U-238 producing Pu-239 shown as follows.

$$\left.\begin{array}{l} {}_{92}U^{238} + {}_{0}n^{1} \rightarrow {}_{92}U^{239} + \gamma \\ {}_{92}U^{239} \xrightarrow[\beta]{24min} {}_{93}Np^{239} + {}_{-1}e^{0} \\ {}_{93}Np^{239} \xrightarrow[B]{23\ days} {}_{94}Pu^{239} + {}_{-1}e^{0} \end{array}\right\} \quad (1)$$

When a neutron is absorbed in the fuel, it produces ŋ neutrons, the number depending on the kind of fuel. One of these neutrons must be reserved for further absorption to keep the reaction going (steady state). Let L be the number of neutrons lost by parasitic capture in reactor coolant etc. and by leakage. The rest of the neutrons per neutron absorbed is available for the breeding reaction, Eq(1), and are called the conversion or breeding ration C, or

$$C = ŋ-1-L \qquad (2)$$

The maximum possible C, C_{max}, will occur if L=0, or

$$C_{max} = ŋ-1 \qquad (3)$$

Depending upon ŋ and L, C can be much less than unity, and the reactor are called a burner. A reactor with a low C is called a converter, and one with a high C but less than 1.0 is called an advanced converter. When C=1, the reactor produces as much fissionable nuclei as it consumes. When C>1, it breeds more nuclei than what it consumes. A reactor with C>1 is a breeder. Breeder gain G is the gain in fissionable nuclei per fissionable nucleus consumed, or

$$G = C-1 = h-2-L \qquad (4)$$

And the maximum gain is

$$G_{max} = C_{max} - 1 = \eta - 2 \qquad (5)$$

The doubling time is the time required to produce fissionable nuclei twice the number of fissionable nuclei consumed.

The high concentration of fissile fuel and the absence of moderator make the cores of a fast reactor smaller than a thermal reactor of the same power. With a high power density, thin fuel pins are used to minimize the temperature drop through the fuel.

A coolant with excellent heat transfers properties is required to minimize the temperature drop from the fuel surface to the coolant and also it must be non-moderating. These rules out water, and the best coolants for fast reactors are liquid metals such as sodium.

Liquid metals have the additional advantage that their boiling points at atmospheric pressure are very high, so most of them can be used unpressurized in a reactor. Sodium is the most common coolant for fast reactors. However, it becomes radioactive as a result of a non-fission reaction

$$_{11}Na^{23} + {}_{0}n^{1} \rightarrow {}_{11}Na^{24}$$

$$_{11}Na^{24} \xrightarrow[B]{14.8h} {}_{12}Mg^{24} + {}_{-1}e^{0} \qquad (6)$$

Where Na^{24} is a highly radioactive isotope that emits 2.76 MeV γ radiations and 1.3 MeV β decays with a 14.8 h half-life to stable Mg^{24}

Because of this indeed radioactivity of liquid sodium, an intermediate loop also using Na or NaK as coolant is used between the primary radioactive coolant the steam cycle (Fig 3.9)

There are two primary loop designs: (a) the pool type system, and (b) the loop type system. In the pool type system (3.10(a)) the reactor core, primary pumps and intermediate heat exchangers are all place in a large pool of liquid sodium contained in the reactor vessel.

The liquid sodium is discharged from the intermediate heat exchanger to the pool. It is then pumped upward through the core and re-enters the heat exchangers. In the loop type system Fig(3.10(b)), the intermediate heat exchanger is located outside the reactor vessel. The pool type configuration is widely used in europe, while the loop system is used in the USA.

www.BrainKart.com

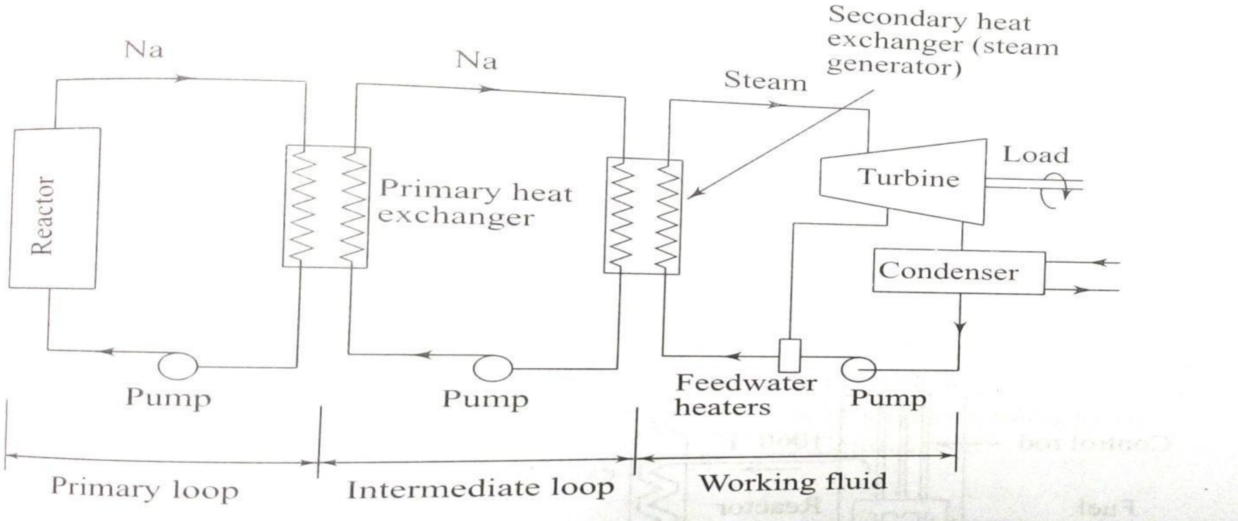


Fig 3.9 Schematic of a liquid metal fast breeder reactor (LMFBR) power plant

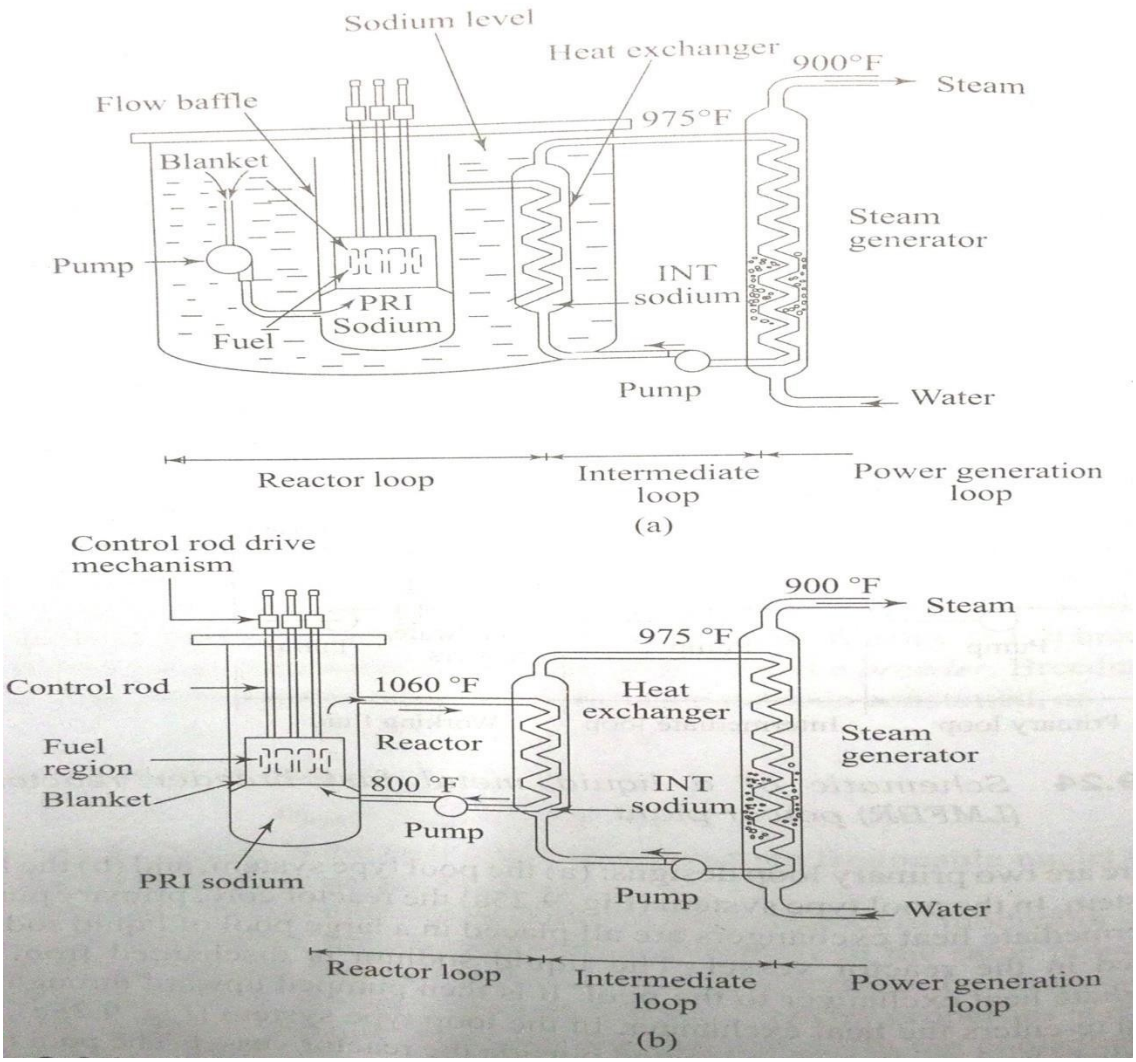


Fig 3.10 Liquid metal fast breeder reactor (a) Pool type, (b) Loop type

3.4 Safety measures for Nuclear Power plants

The radioactivity of the fission products which accumulate in the fuel during reactor operation has an important influence on the design of nuclear reactors of all types. Because radioactive material in the air or water constitutes a potential health hazard, special precautions are taken to ensure that any unavoidable releases to environmental during normal operation or at the lowest reasonably achievable levels. In addition so called “engineered safety features are provided to minimize the escape of radioactivity in the event of a severe malfunction.

The engineering safety features are designed to prevent or minimize the escape of radioactive fission products to the environment as the result of a severe transient that persists or develops after a reactor trip. Among the more important of these features are the emergency cores cooling system and the containment structure.

After a reactor is shutdown, either deliberately or as the result of an emergency, heat continues to be generated by radioactive decay of the fission products present in the fuel. For a reactor which has been operating for some time, the rate of decay heat regeneration after shutdown is initially about 7% of the full reactor heat power. This decreases with time but is still significant after several days.

Consequently, to avoid damage to the fuel by overheating, with the accompanying release of fission products, adequate cooling must be maintained for some time after the reactor is shutdown.

Safety considerations also dictate that the neutron detection and electronic gear by provided in duplicate such that, if one circuit fails, control can still be maintained. During normal operation the reactor control system must be able to maintain the power level at a constant value, change power level as load demand changes, and be able to handle short and long-term transients.

A variety of signals are used during steady-state operation to actuate control devices. Load demand, temperature, pressure, flow rate, and neutron flux signals are fed to appropriate discriminating and integrating circuits to provided the signals which adjust control rods, change moderator level, change fuel concentration, close or open valves, change motor speeds, etc. Either manual or automatic control can be used with a tendency toward greater reliance on automatic systems.

The use of safety devices, such as fuses to prevent overheating and relief valves to prevent over pressures, is common in industry. Safety devices on reactor differ in two important aspects—speed of action and range of operation.

Geothermal Power Plants

Geothermal Energy - geothermal energy is the heat from high pressure steam coming the earth. It is a renewable source of energy derived from the rain water in the earth heated to over 180^0C by hot rocks, The fig. below shows a schematic diagram of depicting how hot springs are produced through hot magma (molten mass), the fractured crystalline rocks, the permeable rocks and percolating ground water. (geothermal sources show up hot water springs with temperature of steam up to 150^0C, these are widely distributed over the globe).

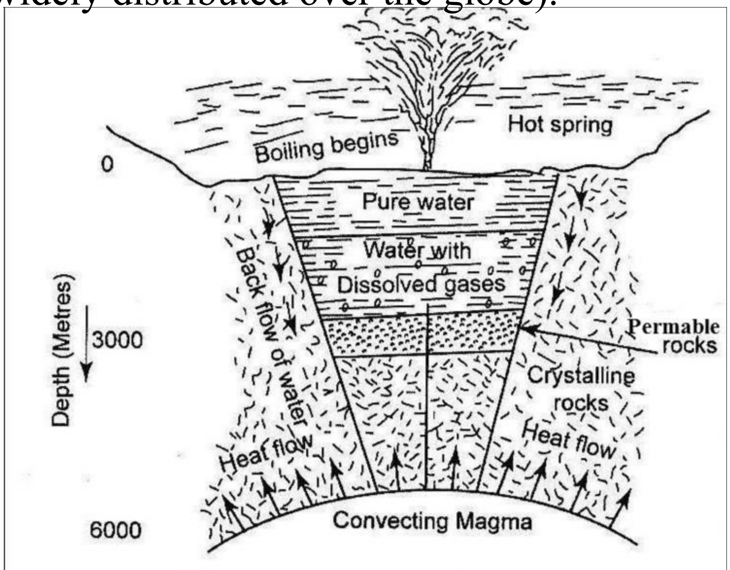


Fig. ***Hot spring system structure.***

Geothermal sources -

The categories of geothermal sources are: -
1 . Hydrothermal convective systems
2. Geopressure resources
3. Petro-thermal or hot dry rocks
4. Magma resources
5 Volcanoes

1. **Hydrothermal convective system:** Hydrothermal convective systems are classified into

a) Vapour-dominated or dry steam fields
b) Liquid-dominated or wet stream fields.
c) Hot-water fields.

a) Vapour-dominated or dry steam fields: - lf dry steam is available in the geothermal source, the field is called vapour dominated or dry steam field.

b) Liquid-dominated or wet steam fields: - The hot water deposits without much steam content are called liquid dominated or wet steam fields. The temperature of water in such deposits is usually in the range of 100^0C to 310^0C.

c) Hot water-field: Hot water geothermal energy deposits are present in several nations around the earth. Underground water collects heat from surrounding hot rocks. Such hot water reserves are with small content of steam.

2. **Geo-pressure sources: -** These are hydro-geothermal resources at greater depths 3km to 40km. The water is stored in underground cavities. Geo-pressure deposits are located at different levels and at different places, The stored water is at relatively low temperature (about 170^0C and at very high pressure (about $135kg/cm^2$).

3. **Petro-thermal or hot dry rocks:** The hard rock surrounding the magma is at high temperature. The known temperatures of hot rocks, at useful depths upto 3000m, are between 150^0C to 290^0C. The extraction of thermal energy from dry hard rock is shown in fig. below

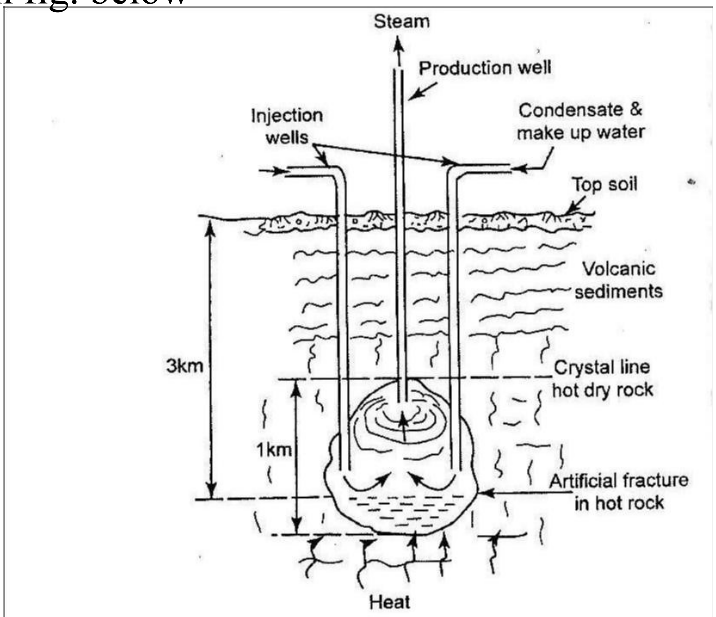


Fig. Extraction of petro-geothermal energy through Hot Dry Rock *(HDR)*

4. Magma Resources: - The magma in the temperature ranges from 1250^0C to 1500^0C. The liquid magma in the upper mantle approaches earth's surface at some points resulting in higher thermal gradients and higher heat flows through surface of the earth.

5. Volcanoes: - Eruption of geothermal energy in large quantities releasing hot lava, rocks, ash, mud, forming a. typical conical hill or mountain.

The types of geothermal fluids and corresponding type of turbines are listed below: -

Geothermal-fluid	Type of turbine cycle
1. Dry steam	--- Steam-turbine cycle
2. Hot water, temperature < 150^0C	--- Binary-cycle
3. Hot water, temperature > 180^0C	--- Steam-turbine cycle
4. Hot brine (Pressurised)	--- Binary cycle
5. Hot brine (flashed)	--- Special turbines - Impact turbine - Screw expander - Bladeless turbine

Application of geothermal energy: - geothermal energy is being used for many electrical power generation and non-electrical applications. the non-electrical applications include

1 . Space heating
2. Green house heating
3. Medical therapy
4. Air conditioning
5. Process heat
6. Mineral extraction

Geothermal water is used for heating green houses, heating houses, agricultural water, aquaculture water, mineral extraction, desalination plants, etc.

Geothermal power estimates: - geothermal power estimates vary widely. The rough estimate is given below: -

Depth	Total stored energy (approximately)
3 km	-- 8 x 10^{21} joules
10 km	-- 4 x 10^{22} joules

The energy stored in hot springs is 10 % of the above quantities.

If the above mentioned energy is extracted from a 3 km belt, with 1% thermal energy recovery factor, at a uniform rate of over 50 year period, Thermal power of 50GW is obtained.

Environmental problems:

1. Geothermal power plants create some environment problems which are peculiar to them alone.
2. The effluent will be salty and may contain sodium and potassium compounds.
3. Some effluents contain boron, fluorine and arsenic.

All the above said effluents are very harmful to plants and animal life in concentrations as low as two parts per million.

suitable waste treatment plants to prevent degradation of water quality will have to be installed to treat these new and increased sources of pollution.

Basic aspects regarding various types of geothermal plants:

The basic aspects of various geothermal power plants are shown table below:

Sl.No	Feature	Data
01	Type of Geothermal Fluids used as input to power plant. .	Alternatives: - Hot water > 180^0C - Hot water < 150^0C - steam - Hot brine (liquid with higher content of dissolved solids) - Mixture of above
02	Type of Geothermal Resource	Alternatives: - Hydro thermal vapour dominated - Hydro thermal liquid dominated - Petro thermal - Hot-dry rock
03	Type of thermodynamic cycle - - Steam cycle - Working fluid binary cycle - - Geothermal fluid total flow concept	alternatives: - With steam are primary energy source. - With hot water above 180^0C as primary energy source. - with warm water (<150^0C) as primary energy source. - With hot geothermal brine as a primary energy source.
04	Types of turbines for driving generator rotor.	Alternatives: - Steam turbines. - Gas turbine driven by vapour of working fluid (ammonia, organic fluid) - Impact turbine driven by brine. - Helical screw expander - bladeless turbine
05	Type of generator	- 3 phase, AC, synchronous generator driven by turbine. Alternative unit ratings. - 5 MW,- 8.5 MW,- 10 MW,- 15 MW. - 50MW,-100MW,-200MW,- 400MW.
06	Unit rating of turbine generator unit.	
07	Rating of power station	

Classification and types of geothermal power plants:

The geothermal electric power plants are classified on the basis of

- The type of geothermal fluid.
- The type of thermodynamic cycle

- The type of turbine.

Types of Geothermal Electric Power Plants are shown below in the table.

Sl.No	Type of plant	Geothermal fluid	Type of turbines
01	Vapour dominated geothermal power plants (Dry steam type power plant)	Dry steam at temperature 200^0 C	Steam turbine
02	Liquid dominated flashed steam type geothermal power plant	Hot water and wet Steam at temperature greater than 10^0C. Steam flashed from the geothermal fluid.	Steam turbine
03	Liquid dominated binary cycle geothermal power plant.	Hot geothermal brine at temperature less than 150^0C.	Organic fluid gas turbine Special turbine driven by geothermal brine.
04	Petro-thermal (Hot dry rock) geothermal power plant.	Hot geothermal fluid (brine)	
05	Petro-thermal (Hot dry rock) geothermal power plant.	Hoi water plus Steam from conduction well 280^0C. Cold water injected into fractured cavity in hot dry rock.	Steam turbine.
06	Hybrid geothermal fossil fueled power Plants.	Hot water of temperature 70^0C to 150^0C used for pre-heating the feed water or air	- Conventional steam thermal Power plant. - Conventional gas turbine Power plant.

a) **Vapour dominated (Steam) geothermal electrical power plant: -** the geothermal fluid for such plants is dry steam at temperatures between 180^0C to 240^0C with low content of particulate impurities and dissolved solid impurities. Steam from the geothermal reservoir (1) flows upwards through the production well (2) and is admitted in the centrifugal separator (4).

The temperatures and pressures of the steam at the bottom of the well are approximately 280^{0}C and 35bar. Temperature and pressure at the well head above ground are about 250^{0}C and 8 bar. As the steam flows towards the ground surface, it expands and cools.

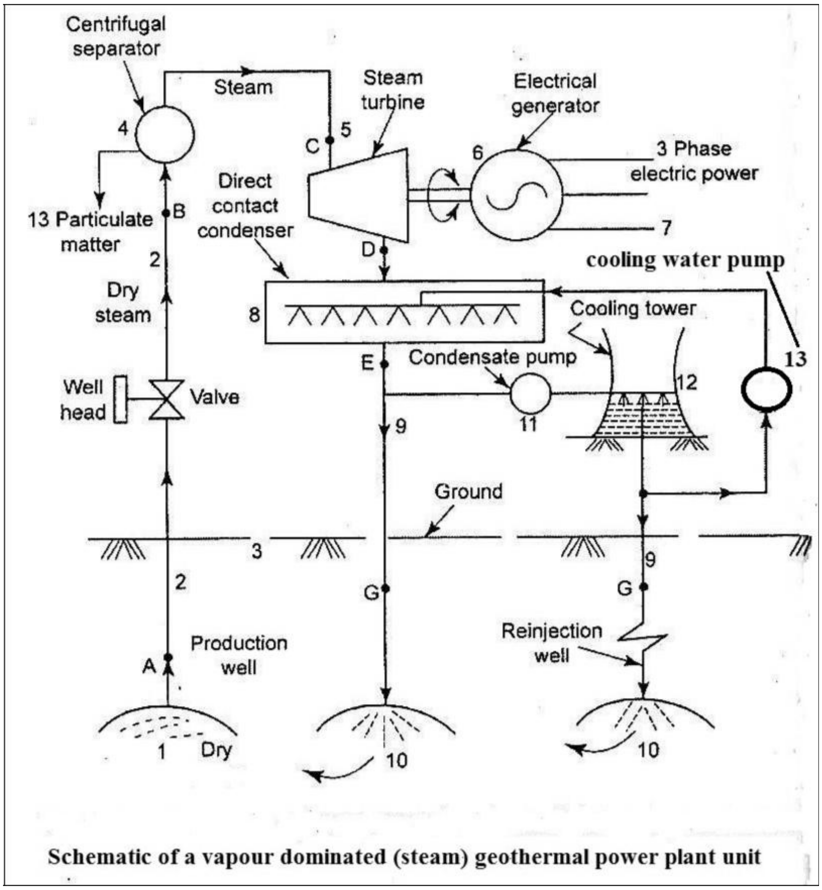
The centrifugal separator (4) removes particulate matter (13) from the steam. Then the steam is admitted into the steam turbine (5). the steam expands in the turbine and produces the rotary kinetic energy.

The low pressure exhaust steam from the turbine is condensed in the condenser (8). After the condensation of steam in the condenser, it is reinjected into the earth via the reinjection well (9).

Cooling water is circulated through the cooling tower (12) to condensate the steam in the condenser. The water pump (13) is used to supply the water from the sump to the cooling tower,

Geothermal energy in the form of dry steam (1) is converted into mechanical energy by the turbine (5). The mechanical energy is converted into electrical energy by the generator (6).

The schematic diagram of vapour dominated (steam) geothermal power plant is shown in fig. below:



Schematic of a vapour dominated (steam) geothermal power plant unit

b) **Liquid dominated geothermal electric power plants: -** In this type of power plant, the geothermal fluid is the mixture of water and steam. There are two types of power plants in liquid dominated geothermal electric power plants.

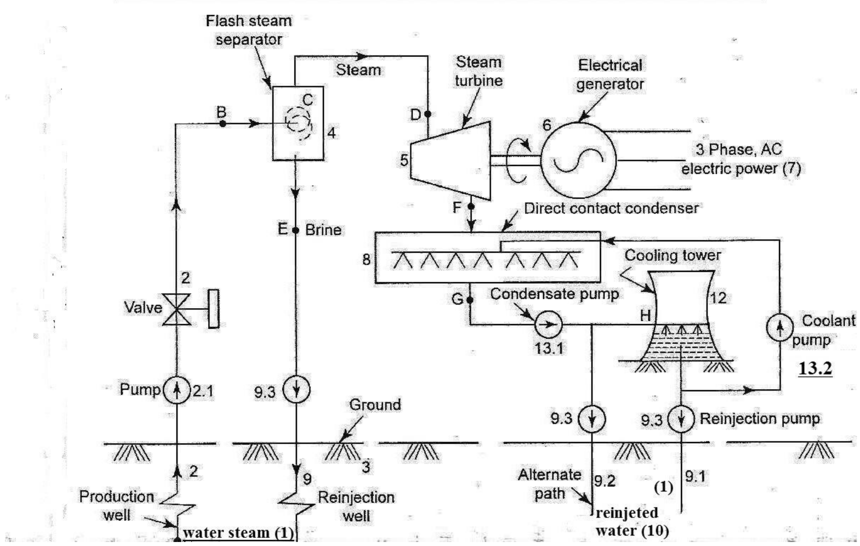
1 . Flashed steam system.

2. Binary system.

b.1) Flashed steam system: - Geothermal fluid (1) is a mixture of hot water and steam in temperature range of above 150^0C. In Geopressure system the geothermal fluid rises through the production well (2) by the geothermal pressure (around 35 bar).

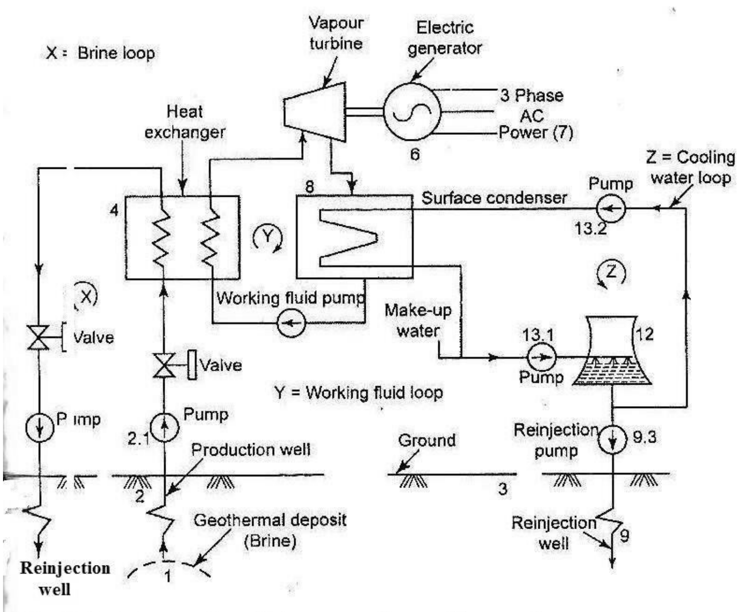
In low pressure geothermal systems, the geothermal fluid is pumped up through the production well (2) by means of the fluid pump (2.1). Cold fluid (9.1) is injected in hot dry rock (because geothermal source is hot dry rock) fracture by means of fluid pump (9.2) via injection well (9,3). Production well (2) delivers the mixture of hot water and steam to flash steam separator (4). Separated steam from this is supplied to steam turbine (5). After expanding in the steam turbine, the exhaust steam is condensed in the condenser (8). part of the condensate is circulated through cooling tower (12) by means of the condensate pump (13.1) and the coolant pump (13.2) reinjection wells (9, 9.1 , 9.2) inject discharge fluid back into the ground.
The fig. below shows the liquid dominated flashed steam geothermal power plant.

Schematic of a liquid dominated single flashed system geothermal power plant



b.2) Binary system: - Binary cycle has two cycles with a common heat exchanger. Geothermal (brine and steam) extracted by production well circulated through the heat exchanger (cycle X) working fluid cycle (cycle Y) has fluid of low boiling point.

Example: - 1. lsobutane ($C_4 H_{10}$); 2. Freon (12); 3. Ammonia; 4. Propane
The fig below shows the binary cycle geothermal power plant.



Schematic of binary cycle geothermal power plant

The energy conversion chain in liquid dominated binary cycle is

geothermal heat in two phase mixture brine + steam → heat exchanger → vapouriztion of working fluid → gas turbine converts thermal energy into rotary kinetic energy → electric generator produces electric energy

The major process loops involved in this system are: -

1 . Brine-loop (x)

2. Hydrocarbon loop (y)

3. Cooling water loop (z)

The working fluid is circulated through a closed loop comprising heat exchanger (4), gas turbine (5), condenser (8), back to heat exchanger.

The liquid working fluid extracts heat from the heat exchanger and gas converted into super heated vapour. This vapour expands through gas turbine and is condensed in the condenser. The condensed fluid is pumped to the heat exchanger. In the heat exchanger, the working fluid does not mix with the geothermal fluid.

Only heat is transferred.

Merits of binary cycle geothermal power plant:

1 . No problems of corrosion or scaling in the working fluid loop.

2. The geothermal fluid is returned to the earth. Therefore, there are no environmental powers associated with hydrogen sulphide emission.

3. There is no contact between geothermal fluid and the working fluid.

Advantages of geothermal energy over other energy forms:

1 . Geothermal energy is cheaper.

2. It is versatile in its use.

3. It delivers greater amount of net energy from its system as compared to other alternative or conventional systems.

4. It is least polluting as compared to other conventional energy sources.

5. Geothermal energy from the earth's interior is almost as inexhaustible as solar or wind energy, so long as its sources are actively sought and economically tapped.

Disadvantages of geothermal energy over other energy forms:

1 . Drilling operation is noisy.

2. Large areas are needed for exploitation of geothermal energy.

3. Low overall power production efficiency (about 15% as compared to 35 to 40% for fossil fuel plants).

OTEC (Ocean Thermal Energy Conversion)

Ocean Thermal Energy Conversion Plants (OTEC) convert thermal energy from Ocean water to electrical power. OTEC cogeneration plants deliver electrical energy and fresh water. The unit size of turbine generators is in the range of 10MW to 50MW. The plant ratings are of 50MW and 100MW.

Ocean Thermal Energy Conversion technologies are costly and difficult.

OTEC (Ocean Thermal Energy Conversion) projects are being financed by various authorities such as department of non-conventional and renewable energy. **Principle of OTEC:** - the Ocean water gets heated up naturally due to solar radiation, The temperature of water near surface is higher than that of deep water, Ocean thermal Gradient principle of thermodynamics is used to extract the heat energy from the Ocean.

Types of OTEC system: The types of OTEC systems are: -

l . Open cycle (Claude cycle, steam cycle)

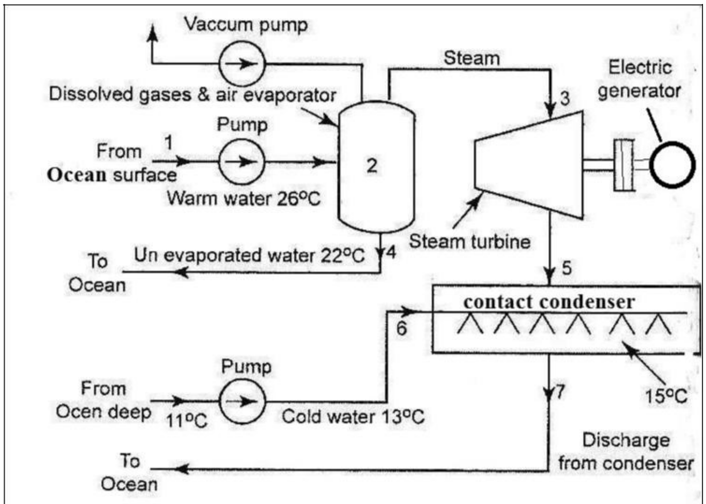
2. Closed cycle (Anderson cycle, Vapour cycle)

1. Open cycle: In open cycles, the warm ocean water is converted into steam in an evaporator. The steam drives steam-turbine generator to deliver electrical energy.

2. Closed cycle: In closed cycles, the ocean thermal energy is given to liquid working fluid (Ammonia, Butane or Freon). Vapour of the working fluid drives vapour-turbine generator to electrical energy.

Open cycle (Steam Cycle OIEC):

Warm Ocean water is converted into flashed steam in an evaporator. Specially designed steam turbine drives electrical generator. Steam is condensed in a contact condenser. Condensate is discharged into sea in an open cycle.



Schematic of an open cycle OTEC power plant

In this OTEC warm water from ocean surface (1) (at about 26^0C is admitted into the evaporator (2). The evaporator is maintained at vacuum pressure by means of vacuum pump. At low vacuum pressures, the boiling point of water reduces and more steam is generated.

Steam generated in evaporator enters into a special steam turbine and the remaining water from evaporator is discharged into the sea.

Steam-turbine converts thermal energy into mechanical energy. Steam at (3) is comparatively at low pressure and high specific volumes as compared with conventional power plants.

The steam admitted in steam turbine (3) drives the steam turbine rotor and is exhausted (5) in condenser.

Exhaust steam from turbine is condensed and discharged into the ocean at 7^0C. Cold water from deep sea is admitted into the condenser at (6). The temperature of cold water is about 15^0C.

Limitations of open cycle OTEC system: -

1 . Turbine is physically large.
2. Cost of plant is high.
3. Very large flow of ocean water in terms of mass and volume.
4. Plant is subjected to ocean storms high waves, etc.

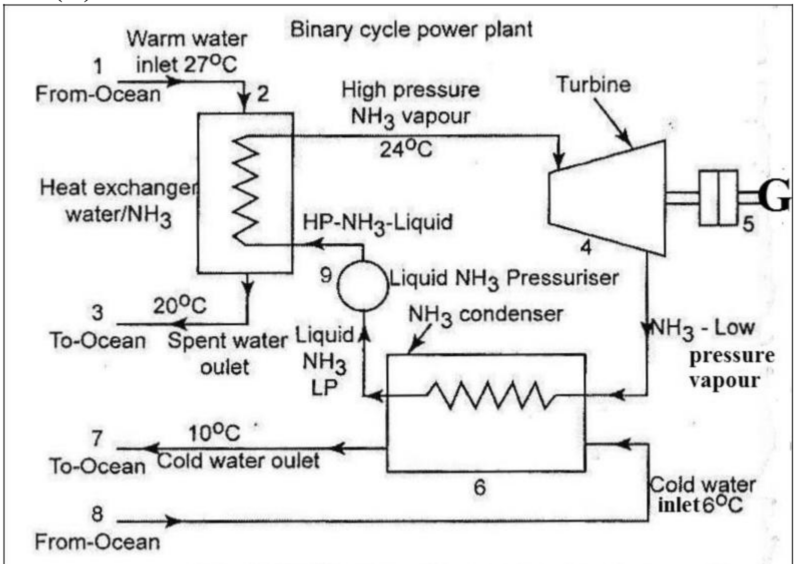
Closed cycle OTEC:

In a closed cycle OTEC plant, working fluid of low boiling point circulates in a closed cycle comprising of heat exchanger, vapour turbine, surface condenser and liquid vapour pressuriser.

Working fluids in closed cycle OTEC are Ammonia, Freon, Butane.

working: - In this type, working fluid (say Ammonia) is circulated through the closed cycle comprising of

l . Heat exchanger (3) .
2. Vapour turbine (4)
3. Vapour condenser (6)
4. Liquid pressuriser (9)



Closed cycle *OTEC plant schematic*

The working fluid extracts heat from the warm ocean water and is vapourised. The vapours having thermal energy are expanded in the vapour turbine (4). This vapour turbine drives electrical generator rotor (5) and the power is produced.

The expanded vapours from the turbine is condensed in condenser. Liquefied working fluid is passed through pressuriser (9) into the heat exchanger (2). The working fluid is circulated again and again through the closed cycle.

Tidal Power Plants - the periodic. rise and fall of the water level of sea which are by the action of the sun and moon on water of the earth is called the ***TIDE***.

Tidal energy can furnish a significant portion of all such energies which are renewable in nature. The difference in potential energy during high-tide and during low-tide is Tidal Energy.

Tidal Energy is a form of hydro energy recurring with every tide. The rise and fall of tidal water is maximum near sea shore and river mouths. The main feature of the tidal cycle is the difference in water surface elevations at the high tide and at the low tide. lf this differential head could be utilized in operating a hydraulic turbine, the tidal energy could be converted into electrical energy by means of an attached generator.

Components of tidal power plants: - The followings are the components of a tidal power plant.

1 . The dam to form the pool or basin.

2. Sluice ways from the basins to the sea.

3. The power house.

1.Dam: The function of dam is to form a barrier between the sea and the basin.

2.Sluice ways: those are used to fill the basin during the high tide or empty the staring the low tide, as per operational requirement.

3. Power house: It consists of turbines, electric generators and other auxiliary equipments

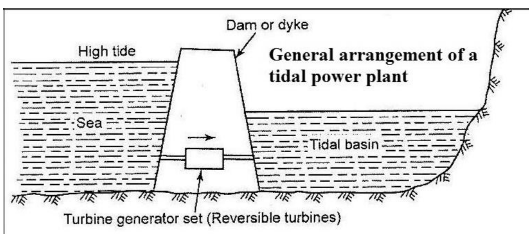
Tidal power plant types: Tidal power plants are classified into: -

1. Single basin arrangement
   a) Single tide - cycle system .
   b) Double cycle system
   c) Single ebb - cycle system
2. Double basin arrangement

1) Single basin arrangement: The single basin schemes have only one basin. Power generation is intermittent and mostly during off-peak load periods on daily load curves. The tidal basin and the sea are separated by a dam or dyke. The rise and fall of tidal water levels provide the potential head. .

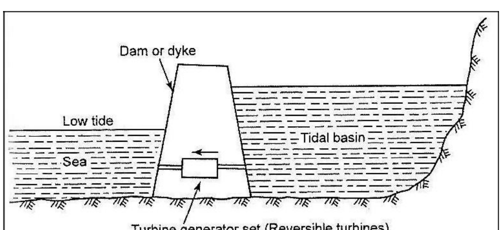
Working: .

Fig below shows a general arrangement of single basin tidal power plant (double cycle system)



(a) High Tide

such plants generally use reverse water turbines so that power is generated on low tide as well high tide. The turbine-generator units are mounted within the ducts inside the dam or dyke.



(b) Low Tide

General arrangement of tidal power plant

When there is incoming tide, sea level and tidal-basin are equal, the turbine conduit is closed. When the sea level raises, the turbine valves are opened and the sea water flows into the basin through the turbine runner and generates power.

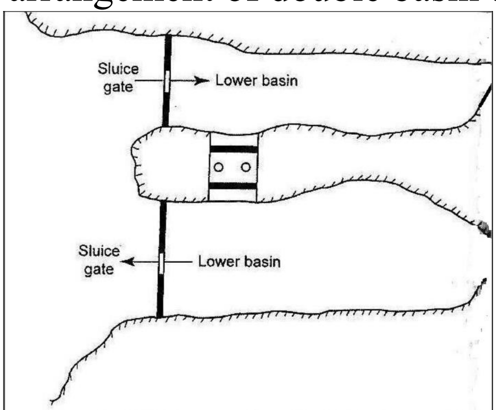
The turbine continues to generate power until the tide passes through its high point and beings to drop. The water head then quickly diminishes till it is not enough to supply the no-load losses.

To gain maximum water level into the basin, by pass valve quickly opens and the water comes into the basin. When sea and basin water level are again equal, the valves are closed as well as the turbine conduits.

The basin level then stays constant while the tide continues to go out. The turbine valves are again opened after getting sufficient water head, the water now flows from basin to the sea thereby generating power.

2) **Double basin arrangement: -** A single basin plant cannot generate power continuously, though it might do so by using a pumped storage plant, if the load it supplies fluctuates considerably. A double basin scheme can provide power continuously or on demand which is a great advantage. In the simplest double-basin scheme, there must be a dam between each basin and the sea, and also a dam between the basins containing the power house

Fig, below shows a general arrangement of double basin tidal power plant.



Tidal power plant-double basin operation

In this type the two basins are located apart and their waters are never exchanged. The turbine is set up between the two basins. One basin is intermittently filled by the flood tide and other is intermittently drained by the ebb tide. Water flow from high basin to low basin is through turbines. This flow is controlled such that continuous power is obtained from the plant without waiting for tidal sequence.

advantages of tidal power plants:

1 . It is free from pollution as it does not use any fuel.

2. Large area of valuable land is not required.

3. It does not produce any unhealthy waste like gases and ash.

4. It has an unique capacity to meet the peak power demand effectively when it works in combination with thermal or hydroelectric system.

5. It is much superior to hydropower plants as it is totally independent of rain which always fluctuates year to year.

disadvantages of tidal power plants:

1 . Due to variation in tidal range, the output is not uniform.

2. There is a fear of machinery being corroded due to corrosive sea water.

3. It is difficult to carry out construction in sea.

4. As compared to other sources of energy, the tidal power plant is costly.

5. The power transmission cost is high because the tidal power plants are located away from load centers.

4. **Pumped Storage** - Whenever old and inefficient thermal stations are available, they generally used to take up peak loads. If suitable plants are not available to take load, it is desirable to develop pumped storage plant for the purpose.

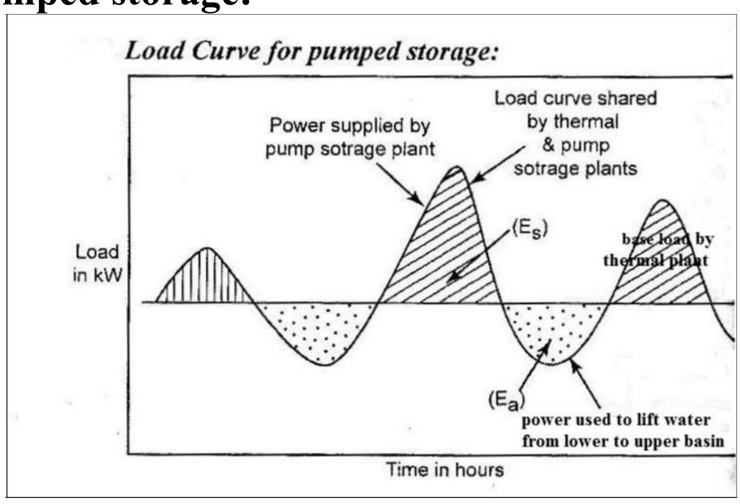
Pumped storage plant possesses the following advantages: -
Thermal plants are loaded more economically

A pumped storage plant stores the energy using off-peak energy of thermal plant and the same is supplied when demand arises.
The wastage of off-peak energy of thermal plants is reduced.

The pumped storage power plant essentially consists of a head water pond and a tail water pond. During the off-peak period of an interconnected power plants system (steam + pump-storage), the water from the tail water pond is pumped. During off-peak period, surplus available energy (E_a) is stored in the form of hydraulic energy by lifting the water from tail to upper basin.

During the peak toad period, the same stored hydraulic energy is used by supplying the water from the upper basin to the water turbine through the penstocks.

Load Curve for pumped storage: -



Operating modes of a pumped storage plant:

Sl.No	Duration	Mode	Conversion
1	off-peak hours	Motor-pump	Electrical-Hydro
2	peak-load hours	Turbine-generator	Hydro-electrical

Types of-operating cycles of pumped storage plants:

1. Daily peak load operation: plant operates in discharge mode every day during peak load hours

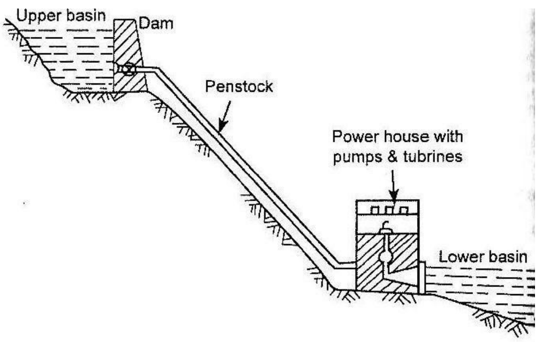
2. Weekly operation: plant operates in charging mode during week-end low load hours

3. Yearly operation: plant operated in charging mode during rainy season and in discharge mode during summer.

Types of pumped storage plant: the pumped storage plants are classified into:-

1. Over ground High Head/ medium head/ Low head.
2. Underground High Head/ Medium Head/ Low Head.

over ground pumped storage plants: fig below shows the pumped storage hydro plant above the ground.



Arrangement of different components of pump storage hydro-electric power plant

components of this system are 1 . Upper basin 2. Dam 3. Penstock 4. Power house with pumps and turbines 5. Lower basin

The pumped storage plant is installed in the power house and it is nearer to the low level reservoir (lower basin). The high level tank (upper basin) is located at higher level and away from the power plant

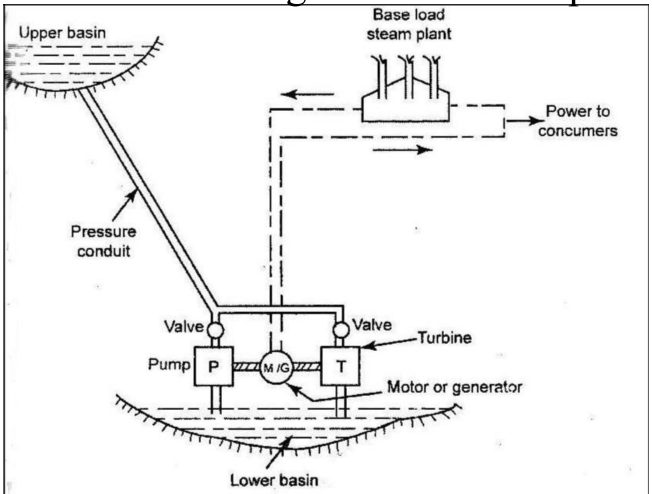
Working: - During off-peak hours of the day, the synchronous machine in the plant operates as a motor and the hydro machine as a pump. electrical energy from the network is taken and the unit operation in the motoring mode.

The purpose of motoring mode is to drive the motor and hydro-pump and water from low level main reservoir is pumped up to the high level storage reservoir.

During peak load hours, the synchronous machine is operated as a generator and the hydro machine as a turbine. The unit is operated in generating mode. stored hydro energy is converted to electrical form and fed into the electrical network/ grid.

Over head pumped storage plant in combination with steam power plant: -

fig below shows the pumped storage plant in combination with steam power plant. The main components in this system are 1 . Upper basin 2. Pressure conduit 3. Base load steam plant 4. Turbine 5. Motor or generator 6. Pump



Pumped storage power plant for peak load in conjunction with steam plant as base load plant

Working: - During the off-peak period the water from the lower basin is pumped by the pump to the upper basin. The pumping power is taken from the steam power plant.

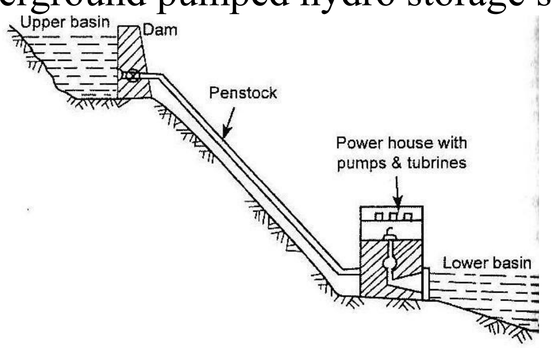
During peak load period the water from the upper basin is fed to the turbine and produces the power. It is combined with steam power and it goes to the consumer.

2. **Underground pumped storage plants:** The concept is similar to conventional over ground pumped hydro storage system except that

1 . The upper reservoir is at ground level, and

2. The lower reservoir and the power plant are underground

Fig. below shows the underground pumped hydro storage system.



Arrangement of different components of pump storage hydro-electric power plant

Such a scheme is preferred for sites having large underground caverns or salt solution mines which can store the water of lower reservoir. The underground pumped hydro plant site does not require the topology with high and low level reservoirs. The operating principle is same with that of over ground pumped hydro systems.

Advantages of pumped storage system

1 . The pumped storage plants can be constructed near load centers more easily than conventional hydro or thermal plant.

2. lts capacity is not controlled or limited by river flow and seasonal variations in the flow..

3. By seasonal storage through pumping, the stream flow in other rivers could be used which would otherwise run to waste

4. Since the storage is done usually on a daily or at the most weekly basis. Therefore, the size of the reservoirs required is only a fraction of that required for conventional hydro-plants where seasonal storage has to be provided.

5. The cost of electricity during high demand period is much more than during off-peak periods, Thus pumping the water back, the potential for high cost energy is increased at the cost of low value energy.

6. By adopting pumped storage plant in conjunction with thermal plant the storage capacity is reduced, the thermal plant is allowed to operate at almost 100% load factor. There is also no need to start-stop of thermal plants.

Disadvantages of pumped storage system

1 , Every pumped storage scheme suffers from the requirement of dual energy conversion system.

2. It requires minimum 200 metres of water head,

Solar Thermal Central Receiver System - large solar Thermal Power Plants in the range of 50MW to 200 MW comes under Central Receiver Schemes. Such systems are economical in MW range for network connected plants.

In the central receiver scheme several heliostats are located on the ground level. A heliostat is a nearly flat mirror with the provision to track the Sun in two planes. The reflected rays are pointed towards a central receiver mounted on a tall tower.

A large central receiver plant is usually built with modular concept. Each plant may have 2 to 10 modules and rated at 10MWe to 100MWe.

Description of the system: This system can be subdivided into the following:

1. The tower with the central receiver on top of it

2. The heat conversion sub system.

3. The heat storage device.

4. The field of oriented mirrors.

1. Central receiver system: The central receiver at the top of the tower has a heat absorbing surface by which the heat-transport fluid is heated. There are two basic receiver configurations have been proposed. They are:

a) cavity receiver type

b) External receiver pipe type

In the Cavity type, pipe line, the solar radiation reflected by the heliostats enters through an aperture at the bottom of the cavity.

In the external receiver pipe type, the absorber surface are on the exterior of a roughly cylindrical structure.

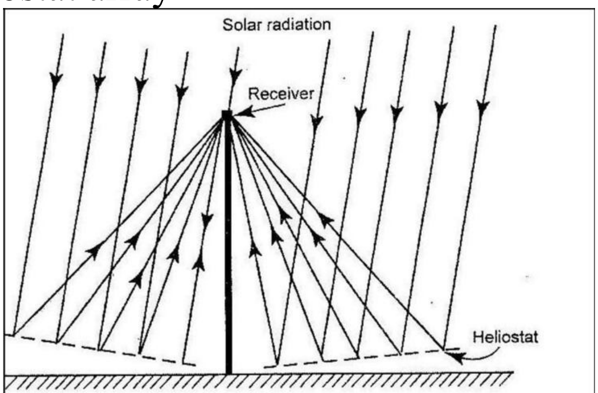
2. Heat conversion sub system: Liquid water under pressure enters the receiver,

absorbs the heat energy, and leaves as superheated steam. Typical steam conditions might be a temperature of 500^0C and a pressure of about 100atm. The steam is piped to ground level where it drives a conventional turbine generator system.

3. The heat storage device: Short steam storage of heat can be provided by fire bricks, ceramic oxides, fused salts, sulphur. The choice of a conventional storage material is determined by its energy density, thermal conductivity, corrosion characteristic, cost and convenience of use, as well as by the operating temperature of the working fluid.

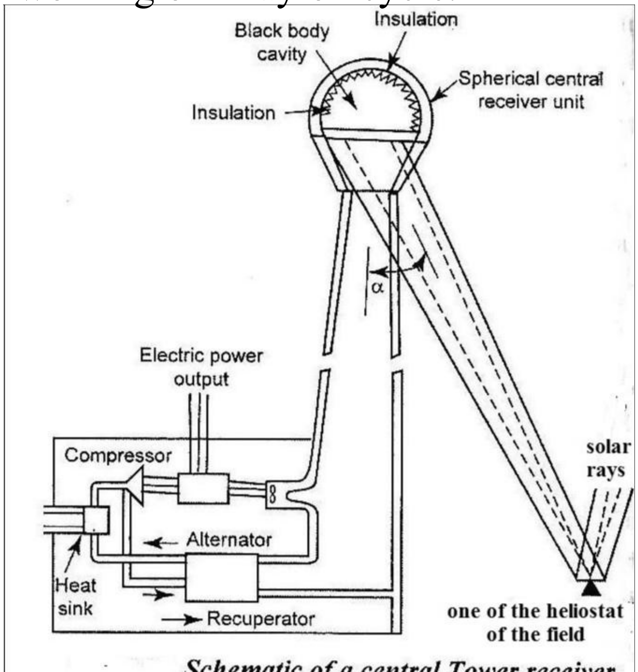
4.Mirrors: The flat mirror surface can be manufactured by metallization of float glass or flexible plastic sheets. The mirror must be steerable. The glass mirrors would not be capable of withstanding the wind loads that often occur in arid lands without any supporting structure.

Working: - The inclining solar radiation is focused to a central receiver or a boiler mounted on a tall tower using thousands of plane reflectors which are steerable about two axes and are called heliostats. Fig. below shows a schematic arrangement of a central receiver heliostat array



Schematic arrangement of central receiver heliostat array

Fig. below shows a schematic view of an electric power plant using gas turbine or gas turbine power plant working on Brayton cycle.

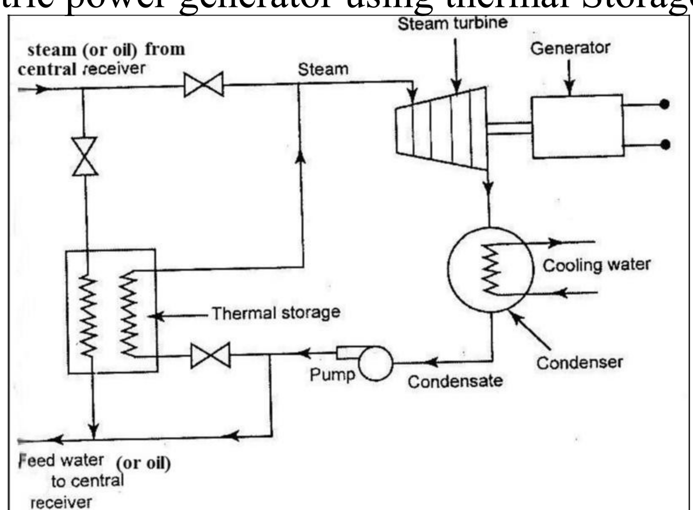


Schematic of a central Tower receiver system

The mirrors are installed on the ground are oriented so as to reflect the direct beam radiation into an absorber or receiver which is mounted on the top of a tower located near the center of the field of mirrors to produce high temperature.

Beam radiation incident in boiler absorbed by black pipes in which working fluid circulates and is heated. The working fluid is drive a turbine and produce mechanical energy.

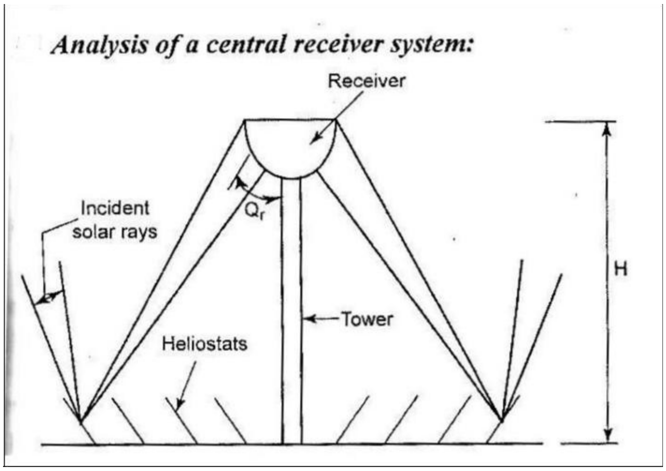
The turbine which is coupled to an alternator produce energy. Suitable heat storage is also provided to supply the heat energy during the period of cloudiness. . Fig. below shows the electric power generator using thermal Storage.



Electric power generation using thermal storage

Analysis of a central receiver system:

the mirror field in a central receiver system is to be laid such that both in winter season and summer season. There is no shade of the mirror on the other mirror.



Therefore, heliostats are put apart and only a fraction of the ground (ϕ) is covered. The value of (ϕ) is calculated by $\varphi = \frac{NA_M}{A_G}$ 4)

Where,

N= No. of mirrors (Heliostats)

A_m = Area of each mirror

A_g = Total ground area used around the tower.

The total ground area, $A_G = \frac{4H^2}{\tan^2 \theta_R}$

Where, H= Tower height ; Θ_r = Rim half angle

The energy absorbed by the receiver is = q_a

therefore, $q_a = I_b A_g \phi \dot{p} \eta_0 \alpha$

Where, I_b = beam radiation incident on A_g

$\dot{p}$= Mirror utilization factor ($\dot{p}$ = 0.78 in midsummer; $\dot{p}$ = 2.0 in winter afternoon) η_0 = Fraction of solar radiation

α = Absorbance of the receiver.

The concentration ratio is defined as $C = \frac{NA_M}{A_R} = \frac{\Phi A_G}{A_R}$

where, A_r = Receiver surface area

* wind is an indirect form of solar energy.

* It is produced by the uneven heating of the Earth's surf by the energy from the sun. The poles of the earth receive les energy from the sun than the equator.

* Since the earth's surface is made of different types of land and water, uneven heating of the earth's surface occurs.

* The rising and sinking of air in the atmosphere makes the plow pressure due to rising and where it sinks we get high pressure.

* wind is the horizontal movement of air, due to the pressure difference between two places.

characteristics of wind Energy:

-> It do not pollute the atmosphere

-> Fuel requirement and transportation are not not required

-> It is a renewable source of energy

-> when wind energy is produced on small scale, it is cheap, but it is competitive with conventional ... produced on a large scale.

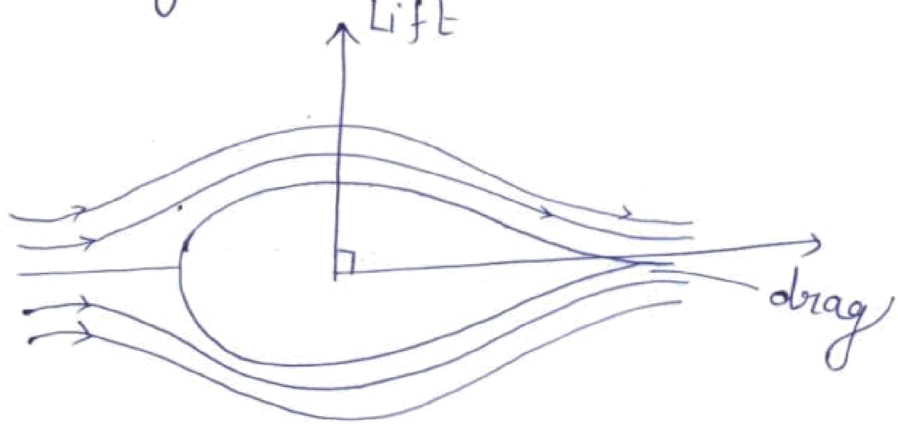
Principle of wind Energy Conversion:

The wind energy can be extracted from lift fo[rce] alone or drag force alone or lift and drag forces.

Lift force acts perpendicular to the air flo[w] direction and drag force acts parallel to the wind direction.

Lift is produced by change in velocity of ai[r] which speeds up the air flow, therefore it creates pressure drop.

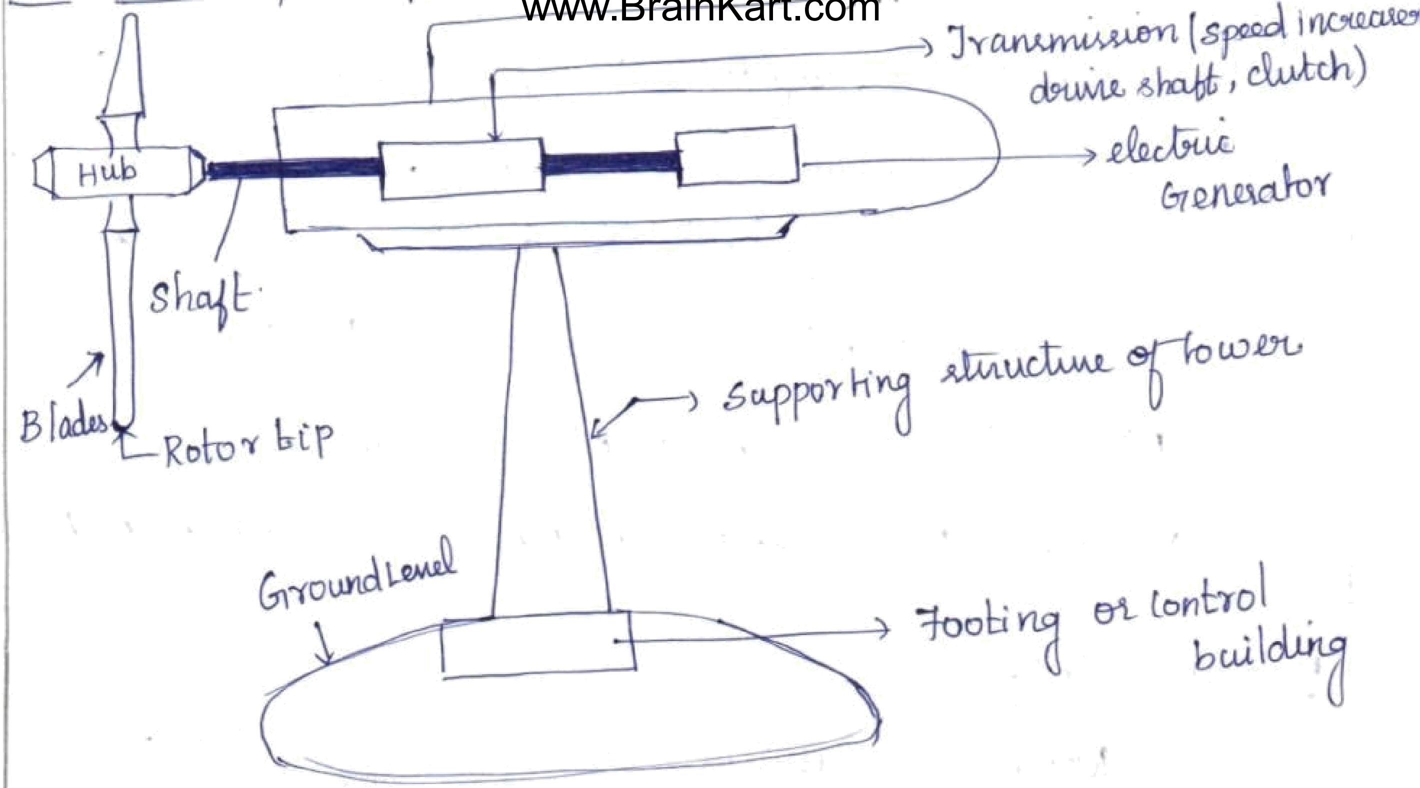
If the air pressure increases, on the low press[ure] side, enormous turbulence is produced which reduces lift force and it leads to increase the drag significa[ntly], called "stalling"



Basic features

* Drag is the direction of air flow
* Lift is perpendicular to the direction of airflow
* ... always causes drag to be developed

Wind electric power plant



Wind Turbine or windmill:

wind turbine is a rotating machine which converts Kinetic energy into mechanical energy.

If the mechanical energy is converted into electric energy, the machine is called a wind generator, wind turbine, wind power unit, or aero generator.

Various components of wind turbine are as follows.

1) Nacelle:

It includes gearbox, low-high speed shafts, generator controller and brake. It is placed on top of the tower and it is connected to the rotor.

Rotor :

* Hub and blades together compose the rotor.

* Most of the horizontal axis turbine use two or three blades in an upwind design. Blades are manufactured from steel or aluminium, Fibre glass - Reinforced Polyester (FRP).

FRP blade is comparatively lighter.

vertical axis wind turbine uses aluminium blades.

Hub and shaft.

Rotor is attached to shaft and hub.

Hub is infront of the shaft which faces the wind direction. It is normally of conical shape.

The end of the shaft is attached to the transmission system.

Anemometer :

It is a device used for the measurement of speed. The wind speed is also feed to the controller as it is one of the variables for controlling pitch angle and yaw.

Transmission system :

The mechanical power is transmitted to electric generator by a transmission system located in the nacelle.

It contains gearbox, clutch and braking system to

The purpose of gearbox is to increase the speed of the rotor, typically from 20 to 50 rpm or from 1000 to 1500 rpm.

Electric Generator :

- Asynchronous (Induction) or synchronous generators are used. Most of the wind turbines uses Asynchronous Generator. These turbines have to be connected to the electricity grid before they can generate electricity. The major drawback of this motor is they draw reactive power from the grid system But synchronous generator do not require reactive power.

Yaw control system :

It is used to continuously orient the rotor in the direction of the wind. The HAWT has a yaw control that turns the nacelle according to the actual wind direction. A slow closed loop control system is used to control the yaw drives.

Storage

Storage systems are used to store energy when there is excess power developed and to discharge it when there is a lack in power. The most common storage device is the lead - acid - battery.

Energy Convertors

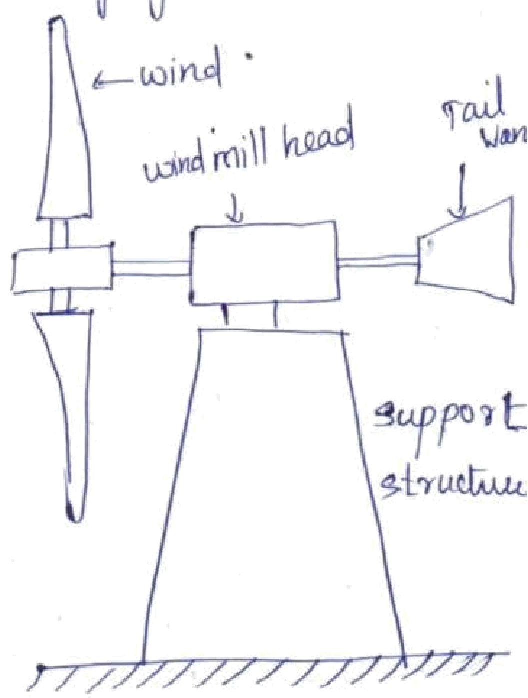
The electricity produced from wind energy is direct current (DC). and it should be converted into ~~at~~ alternating current (AC) using an alternator before supplying it ~~to~~ the transmission grid for industrial and household appliances

Towers :

Wind turbines are kept on high towers due to light in weight. Towers are basically made up of steel or stell lattice.

Horizontal Axis Turbine :

The Axis of rotation is horizontal with respect to ground. The rotating shaft is parallel to ground and blades are Perpendicular to the ground. It is highly developed than Vertical axis turbine



HAWT have the main components such as main rotor shaft and generator at the top of tower and it must be pointed into the wind. Blades are ~~produced at~~ placed at considerable distance in front of the tower and they are sometimes tilted up a small amount.

Vertical Axis wind Turbine

The main rotor shaft arranged vertically and the axis of rotation is vertical with respect to the ground.

The advantage of this arrangement is that turbine does not need to be pointed into the wind streams to be effective because their operation is independent of wind direction and these vertical machines are called "panemones"

With this, generator and gearbox can be placed near the ground so the tower does not need to support it and it is more accessible for maintenace. The main drawback is that they produce pulsating Torque.

Various types of vertical axis wind turbines are

* Darrieus rotor
* Savonius rotor (turbo machine)
* Multiple blade rotor
* Musgrove rotor
* Evans rotor.

The main consideration for selecting a site for wind turbine

Wind turbines are located away from main cities to avoid resistance to air movement created by buildings

A stable ground is selected

→ The land cost should be favourable.

Wind direction is also considered for the site selection

→ Topography helps to channelise and speed up winds.

→ Small trees and grasses are avoided under wind mill.

Advantages:

→ Wind power does not emit greenhouse gases.

→ There is no fuel concern, wind is obtained free of cost.

→ Wind turbines can be placed in a variety of inhospitable pla

→ Wind is helpful in supplying power to remote areas

→ Wind turbines can be virtually in any size. They can be fixed at rooftops or smaller version can be placed in garden

Disadvantages:

* Wind power needs wind but wind is not always availabl
* Wind turbines are quite expensive, it needs storage devi
* Wind power can affect national security
* They produce ample of noise
* It affect migration of birds and make bats 'lungs' explode.
* ~~It~~ Aesthetics: It is one really down to personal taste but it should be included because farms have often been banned for exactly this reason.

SOLAR PHOTOVOLTAIC SYSTEMS:

⇒ Solar photovoltaic systems convert solar energy directly into electrical energy by mean of using solar photo voltaic or solar cell.

⇒

Solar light or energy	→	PV cells	→	electrical energy

CONVERSION PROCESS

The photovoltaic cell works on the basis of photovoltaic effect

PHOTOVOLTAIC EFFECT:

* "It is defined as generation of an emf (electromotive force) by the absorption of ionizing radiation"

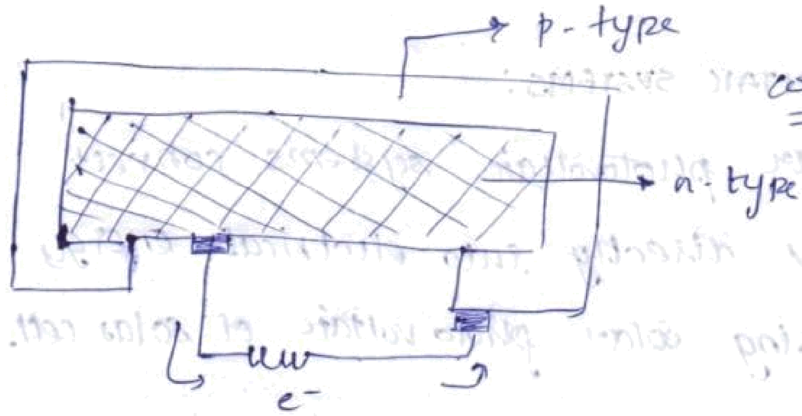
* photo electric effect was first noticed by French physicist Edmund Bequerel in 1839.

* when solar rays falls on a two layer of semiconductor device, a potential difference between 2 layer is produced, which causes flow of e⁻ & produces electricity when connected by an external circuit.

CONSTRUCTION

The solar cell ~~consu~~ is made of a p-type semiconductor (Si doped with B) and n-type semiconductor (Si doped with P) which are in close contact with each other.

construction

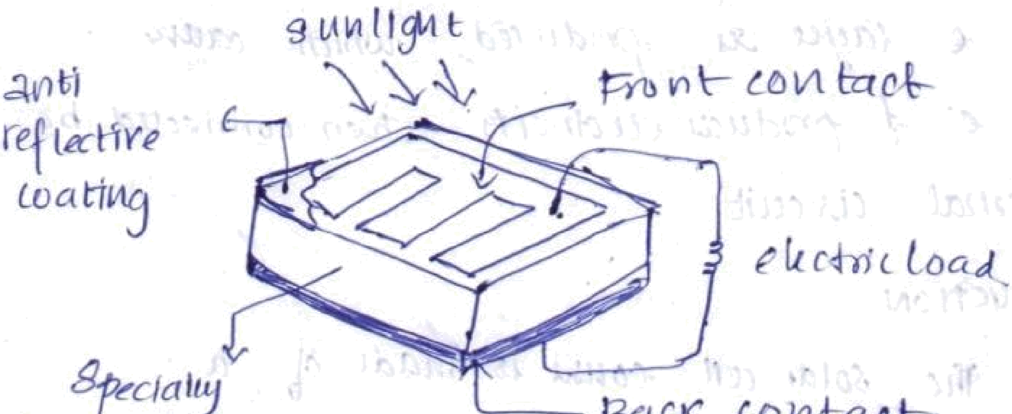


WORKING:

* when solar rays falls on top-layer of semiconductor, a potential difference is set-up between two layers and free electrons (which are formed upon excitation by light) flows from n to p-type

* conventional current flow is p to n-type when connected by means of external conductor and can be used to / utilised to power a load such as light

* The potential difference & current increases with increase in incident solar light (I ∝ intensity of solar light)



treated semiconductor material (a thin semiconductor wafer specially treated to form an electric field)

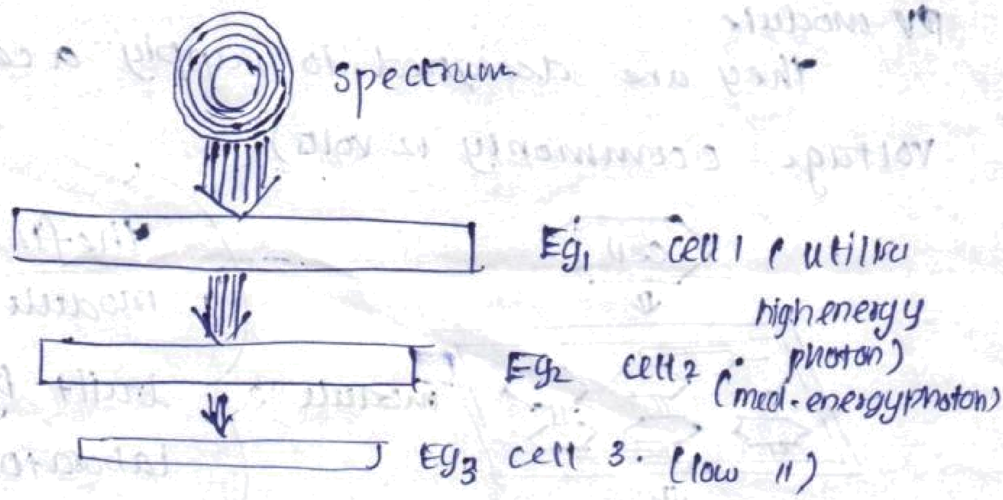
www.BrainKart.com

* Most commonly used one is single junction device.

* The disadvantage in single-junction device is that only the spectrum or photon, which has energy greater than bandgap energy can only free an electron.

∴ lower energy spectrum is not utilised here.

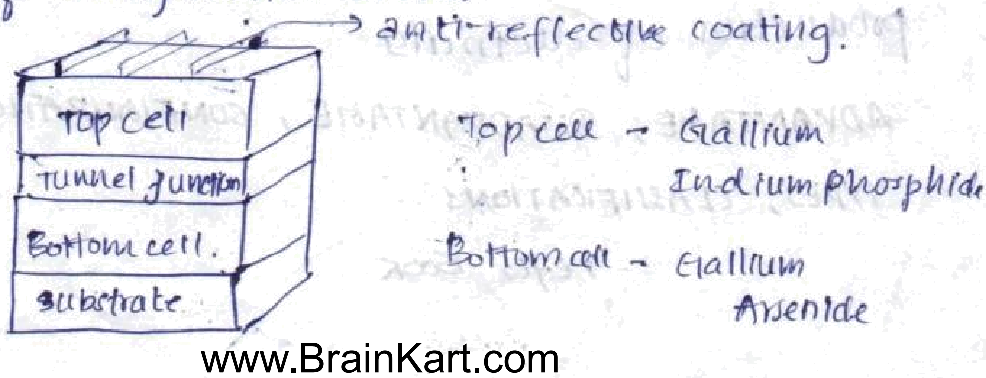
* To overcome this, multi-junction device is used.



$Eg_1 > Eg_2 > Eg_3$.

* Multijunction device can achieve higher conversion efficiency because they can convert more energy spectrum to electrons.

Construction of multijunction device



Tunnel junction aids the flow of electrons.

When we use GaAs as one of the component the efficiency is 35% under concentrated light.

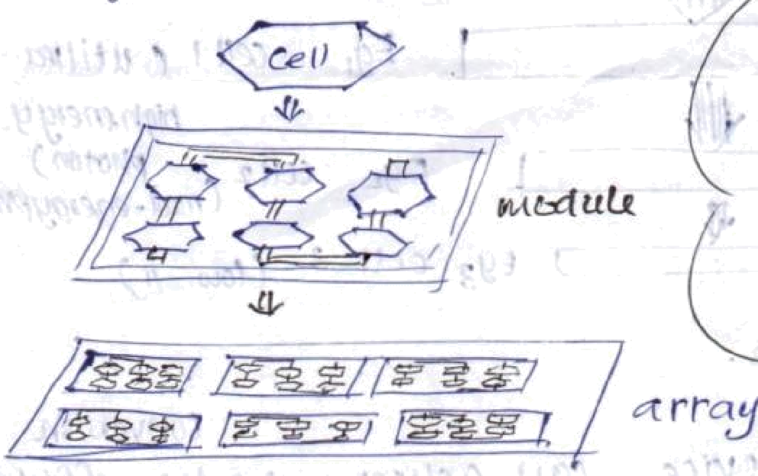
other materials used

⇒ amorphous Si, copper indium diselenide, etc

PV module:

A no. of solar cells electrically connected to each other & maintained in support is called PV module.

They are designed to supply a certain voltage (commonly 12 volts).



The first PV module was built by Bell laboratories in 1954.

Multiple modules are wired together to form an array & can be connected in series or ||el & is installed in large areas for production of electricity

ADVANTAGE, DISADVANTAGE, CONFIGURATION, TYPES, CLASSIFICATIONS

– refer BOOK.

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.

5.1 INTRODUCTION

In all fields of industry economics plays an important role. In power plant engineering economics of power system use certain well established techniques for choosing the most suitable system. The power plant design must be made on the basis of most economical condition and not on the most efficient condition as the profit is the main basis in the design of the plant is to bring the cost of energy produced to minimum.

Among many factors, the efficiency of the plant is one of the factors that determine the energy cost.

5.2 TERMS AND DEFINITIONS

1. **Connected Load.** The connected load on any system, or part of a system, is the combined continuous rating of all the receiving apparatus on consumer's premises, which is connected to the system, or part of the system, under consideration.

2. **Demand.** The demand of an installation or system is the load that is drawn from the source of supply at the receiving terminals averaged over a suitable and specified interval of time. Demand is expressed in (kW), kilo volt-amperes (kVA), amperes (A), or other suitable units.

3. **Maximum demand or peak load.** The maximum demand of an installation or system is the greatest of all the demands that have occurred during a given period. It is determined by measurement, according to specifications, over a prescribed interval of time.

4. **Demand factor.** The demand factor of any system, or part of a system, is the ratio of maximum demand of the system, a part of the system, to the total connected load of the system, or of the part of the system, under consideration~~, expressing the defi~~nition mathematically,

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}}$$

5. **Load factor**. The load factor is the ration of the average power to the maximum demand. In such cases, the interval of maximum load and the period over which the average is taken should be definitely specified, such as a "half-hour monthly" load factor. The proper interval and period are usually dependent upon load conditions and upon the purpose for which the load factor is to be used. Expressing the definition mathematically,

=

6. **Diversity factor.** The diversity factor of any system, or part of a system, is the ratio of the maximum power demands of the subdivisions of the system, or part of a system, to the maximum demand of the whole system, or part of the system, under consideration, measured at the point of supply. Expressing the definition mathematically,

7. **Utilization factor.** The utilization factor is defined as the ration of the maximum generator demand to the generation capacity.

8. **Plant capacity factor.** It is defined as the ratio of actual energy produced in kilowatt hours 9kWh) to the maximum possible energy that could have been produced during the same period. Expressing the definition mathematically,

$=$ $\times$

Where E = energy produced (kWh) in a given period.

C = capacity of the plant in kW, and

t =total number of hours in the given period.

9. Plant use factor. It is defined as the ration of energy produced in a given time to the maximum possible energy that could have been produced during the actual number of hours the plant was in operation. Expressing the definition mathematically,

$=$ $\times'$

Where t' = actual number of hours the plant has been in operation.

10. Types of load.

(i) **Residential load.** This type of load includes domestic lights, power needed for domestic appliances such as radios, television, water heaters, refrigerators, electric cookers and small motors for pumping water.

(ii) **Commercial load.** It includes lighting for shops, advertisements and electrical appliances used in shops and restaurants etc.

(iii) **Industrial load.** It consists of load demand of various industries.

(iv) **Municipal load**. It consists of street lightning, power required for water supply and drainage purposes.

(v) **Irrigation load**. This type of load includes electrical power needed for pumps driven by electric motors to supply water to fields.

(vi) **Traction load.** It includes trams, cars, trolley, buses and railways.

11. **Load curve**. A load curve (or load graph) is a graphic record showing the power demands for every instant during a certain time interval. Such a record may cover 1 hour, in which case it would be an hourly load graph; 24 hours, in which case it would be a daily load graph; a month in which case it would be a monthly load graph; or a year (8760 hours), in which case it would be a yearly load graph.

12. **Load Duration curve.** A load duration curve and the corresponding chronological load curve in order of descending magnitude. This curve is derived from chronological load curve.

13. **Dump Power.** This term is used in hydroplants and it shows the power in excess of the load requirements and it is made available by surplus water.

14. **Firm Power.** It is the power which should always be available even under emergency conditions.

15. Prime Power. It is the power which may be mechanical, hydraulic or thermal that is always available for conversion into electric power.

16. **Cold reserve.** It is that reserve generating capacity which is not in operation but can be available for service.

17. **Hot reserve.** It is that reserve generating capacity which is in operation but not in service.

18. **Spinning reserve.** It is that generating capacity which is in connected to the bus and is ready to take the load.

5.3 POWER TARIFF TYPES

INTRODUCTION

The cost of generation of electrical energy consists of fixed cost and running cost. Since the electricity generated is to be supplied to the consumers, the total cost of generation has to be recovered from the consumers. Tariffs or energy rates are the different methods of charging the consumers for the consumption of electricity.

It is desirable to charge the consumer according to the maximum demand (kW) and the energy consumed (kWh). The tariff chosen should recover the fixed cost, operating cost and profit etc. incurred in generating the electrical energy.

OBJECTIVES

1. Recovery of cost of capital investment in generating equipment, transmission and distribution system.
2. Recovery of the cost of operation, supplies and maintenance of the equipment.
3. Recovery of cost of material, equipment, billing and collection cost as well as for miscellaneous services.
4. A net return on the total capital investment must be ensured.

REQUIREMENTS

1. It should be easier to understand.
2. It should provide low rates for high consumption
3. It should be uniform over large population.
4. It should encourage the consumers having high load factors.
5. It should take into account maximum demand charges and energy charges.
6. It should provide incentive for using power during off-peak periods.
7. It should provide fewer charges for power connecting than lighting.
8. It should have a provision of penalty for low power factors.
9. It should have a provision for higher demand charges for high loads demanded at system peaks.
10. It should apportion equitably the cost of service to the different categories of consumers.

GENERAL TARIFF FORM

A large number of tariffs have been proposed from time to time and are in use. They are all derived from the following general equation:

$$= \;.+\;. \qquad +$$

Where,

z = total amount of bill for the period considered,

x =maximum demand in kW,

y =energy consumed in kWh during the period considered,

a =Rate per kW of maximum demand, and

b =energy rate per kWh.

c = constant amount charged to the consumer during each billing period. This charge is independent of demand or total energy because a consumer that remains connected to the line incurs expenses even if he does not use energy.

VARIOUS TYPES OF TARIFFS:

The various types of tariffs are:

1. Flat demand rate.
2. Straight meter rate.
3. Block meter rate.
4. Hopkinson demand rate (two-part tariff)
5. Doherty rate (three-part tariff)
6. Wright demand rate

FLAT DEMAND RATE:

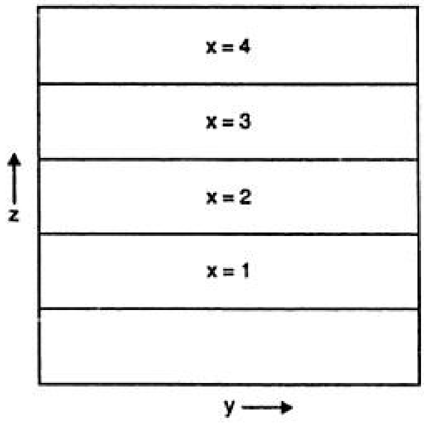


Fig 5.1 Flat demand rate

The flat demand rate is expressed as follows:

$$Z=ax$$

i.e., the bill depends only on the maximum demand irrespective of the amount of energy consumed. It is based on the customer's installation of energy consuming devices which is generally denoted by so many kW per month or per year. It is probably one of the early systems of charging energy rates. It was based upon the total number of lamps installed and a fixed number of hours of use per year. Hence the rate could be expressed as a price per lamp or unit of installed capacity.

Now-a-days the use of this tariff is restricted to signal system. street lighting etc., where the number of hours are fixed and energy consumption can be easily predicted. Its use is very common to supplies to irrigation tubewells, since the numbers of hours for which the tubewell feeders are switched on are fixed. The charge is made according to horse power of the motor installed.

In this form of tariff the unit energy cost decreases progressively with an increased energy usage since the total cost remains constant. The variation in total cost and unit cost are given in Fig 5.1

By the use of this form of tariff the cost of metering equipment and meter reading is eliminated.

STRAIGHT METER RATE

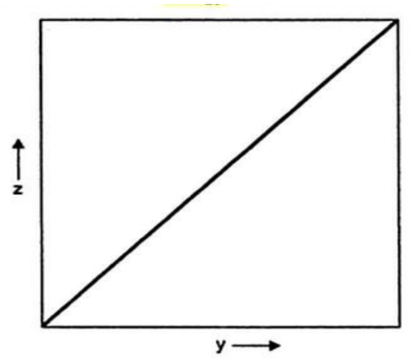


Fig 5.2 Straight meter rate

The straight meter rate can be expressed in the form:

$$Z=b.y$$

This is the simplest form of tariff. Here the charge per unit is constant. The charges depend on the energy used. This tariff is sometimes used for residential and commercial consumer. The variation of bill according to the variation of energy consumed in shown in Fig 5.2

Advantage. Simplicity

Disadvantages.

1. The consumer using no energy will not pay any amount although he has incurred some expenses to the power station.
2. This method does not encourage the use of electricity unless the tariff is very low.

BLOCK METER RATE

In order to remove the inconsistency of straight meter rate, the block meter rate charges the consumers on a sliding scale. The term 'block' indicates that a certain specified price per

unit is charged for all or any part of such units. The reduced prices per unit are charged for all or any part of succeeding block of units, each such reduced price per unit applying only to particular block or portion thereof.

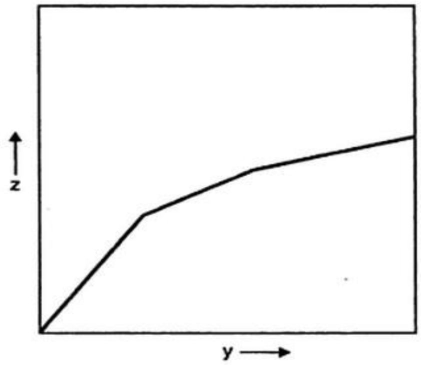


Fig 5.3 Block meter rate

The variation of bill according to this method is shown in Fig 5.3.

The block meter rate accomplishes the same purpose of decreasing unit energy charges with increasing consumption as the step meter rate without its defect. Its main defect is that is lacks a measure of the customer’s demand.

This tariff is very commonly used for residential and commercial customers. In many states of India, a reverse form of this tariff is being used to restrict the energy consumption. In this reverse form the unit energy charge increases with increase in energy consumption.

HOPKINSON DEMAND RATE (two-part tariff)

This method charges the consumer according to his maximum demand and energy consumption. This can be expressed as,

$Z=a+by$

This method requires two meters to record the maximum demand and energy The consumption of the consumer. variation of z with respect to y taking x as parameter is shown in Fig 5.4

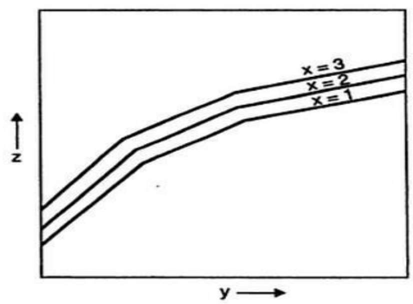


Fig 5.4 Hopkinson demand rate (two-part tariff)

This form of tariff is generally used for industrial customers.

DOHERTY RATE (three-part tariff)

When the Hopkinson demand rate is modified by the addition of a customer charge, it becomes a three charge rate or Doherty rate. It was first introduced by Henry L.Deoherty at the beginning of 20^{th} century. It consists of a customer or meter charge, plus demand charge plus any energy charge. This is expresses as follows:

$$Y=ax+by+c$$

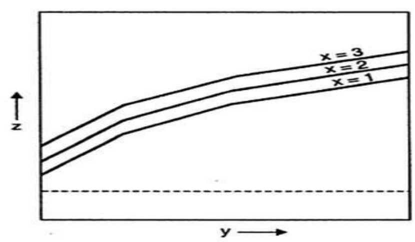


Fig 5.5 Doherty rate (three-part tariff)

Many people consider that theoretically this is an ideal type of rate. As it required two meters, is it better suited for industrial than for residential customers.

The Doherty rate is sometimes modified by specifying the minimum demand and the minimum energy consumption that must be paid for, if they are less than the minimum values specified. In this manner the customer charge is incorporated with the demand and energy component.

WRIGHT DEMAND RATE

This tariff was introduced by Arthur Wright (of England) in 1896. This rate intensifies the inducements by lowering both the demand and energy charge for a reduction in maximum demand or other words an improvement in load factor. This rate is usually specified for industrial consumers who have some measure of control over their maximum demands.

The rate is modified by stating a minimum charge which must be paid if the energy for the billing period falls below the amount by such charge. For allowing fair returns some adjustment in the rate forms are provided. Some of them are:

(i) Higher demand charges in summer
(ii) Fuel price adjustment to provide a rate change when fuel prices deviate from the standard.
(iii) Wage adjustment
(iv) Tax adjustment
(v) Power factor adjustment
(vi) Discount to be given to the customers for prompt payment of bills.

5.4 LOAD DISTRIBUTION PARAMETERS (Types of load)

A device which taps electrical energy from the electric power system is called a load on the system. The load may be resistive (e.g., electric lamp), inductive (e.g., induction motor), capacitive or some combination of them. The various types of load on the power system are:

(i) Domestic load
(ii) Commercial load
(iii) Industrial load
(iv) Municipal load
(v) Irrigation load
(vi) Traction load

Domestic load. Domestic load consists of lights, fans, refrigerator, heaters, television, small motors for pumping water etc. Most of the residential load occurs only for some hours during the day (i.e., 24 hours) e.g., lighting load occurs during night time and domestic appliance load occurs for only a few hours. For this reason, the load factor is low (10% to 12%).

Commercial load. Commercial load consists of lighting for shops, fans and electric appliances used in restaurants etc. This class of load occurs for more hours during the day as compared to the domestic load. The commercial load has seasonal variations due to the extensive use of air conditioners and space heaters.

Industrial Load. Industrial load consists of load demand by industries. The magnitude of industrial load depends upon the type of industry. Thus small scale industry requires load up to 25kW, medium scale industry between 25kW and 100kW and large-scale industry requires load above 500kW. Industrial loads are generally not weather dependent.

Municipal Load. Municipal load consists of street lighting, power required for water supply and drainage purposes. Street lighting load is practically constant throughout the hours of the night. For water supply, water is pumped to overhead tanks by pumps driven by electric

motors. Pumping is carried out during the off-peak period, usually occurring during the night. This helps to improve the load factor of the power system.

Irrigation load. This type of load is the electric power needed for pumps driven by motors to supply water to fields. Generally this type of load is supplied for 12 hours during night.

Traction load. This type of load includes tram cars, trolley buses, railways etc. This class of load has wide variation. During the morning hour, it reaches peak value because people have to go to their work place. After morning hours, the load starts decreasing and again rises during evening since the people start coming to their homes.

5.5 LOADCURVE

The curve showing the variation of load on the power station with respect to time is known as a load curve.

The load on a power station is never constant; it varies from time to time. These load variations during the whole day (i.e., 24 hours) are recorded half-hourly or hourly and are plotted against time on the graph. The curve thus obtained is known as daily load curve as it shows the variations of load w.r.t time during day. Fig 5.6 shows a typical daily load curve of a power station. It is clear that load on the power station is varying, being maximum at 6 P.M in this case. It may be seen that load curve indicates at a glance the general character of the load that is being imposed on the plant. Such a clear representation cannot be obtained from tabulated figures.

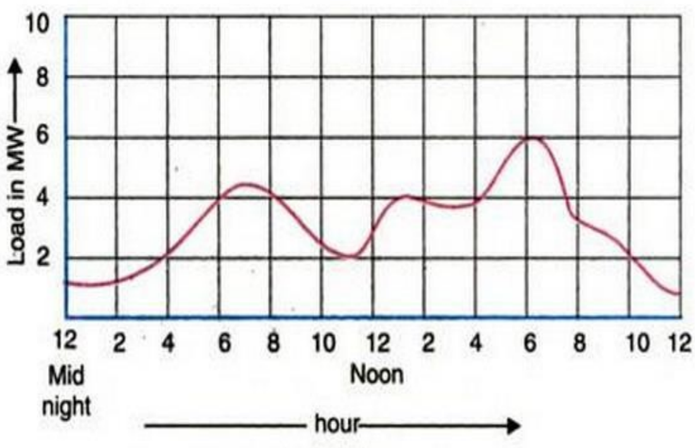


Fig 5.6

The monthly load curve can be obtained from the daily load curves of that month. For this purpose, average * values of power over a month at different times of the day are calculated and then plotted on the graph. The monthly load curve is generally used to fix the rates of

energy. The yearly load curve is obtained by considering the monthly load curves of that particular year. The yearly load curve is generally used to determine the annual load factor.

Importance. The daily load curves have attained a great importance in generation as they supply the following information readily:

(i) The daily load curve shows the variations of load on the power station during different hours of the day.

(ii) The area under the daily load curve gives the number of units generated in the day.
Units generated/day = Area (in kWh) under daily load curve.

(iii) The highest point on the daily load curve represents the maximum demand on the station on that day.

(iv) The area under the daily load curve divided by the total number of hours gives the average load on the station in the day.

(h)
24 h

(v) The ratio of the area under the load curve to the total area of rectangle in which it is contained gives the load factor.

× 24 . ×

24

h h h (h)

(vi) The load curve helps in selecting * the size and number of generating units

(vii) The load curve helps in preparing the operation schedule ** of the station. *For instance, if we consider the load on power station at mid-night during the various day of the month. It may vary slightly. Then the average will give the load, mod-night on the monthly curve.

*It will be shown in that number and size of the generating units are selected to fit the load curve. This helps in operating the generating units or near the point of maximum efficiency.

* It is the sequence and time for which the various generating units (i.e. alternators) in the plant will be put in operation.

5.6 COMPARISON OF SITE SELECTION CRITERIA

PRINCIPLES OF POWER PLANT DESIGN

The following factors should be considered while designing a power plant:

1. Simplicity of design

2. Low capital cost
3. Low cost of energy generated.
4. High efficiency
5. Low maintenance cost
6. Low operating cost
7. Reliability of supplying power
8. Reserve capacity to meet future power demand.

LOCATION OF POWER PLANT

Some of the considerations on which the location of a power plant depends are:

1. Centre of electrical load
2. Nearness to the fuel source
3. Availability of water
4. Type of soil available and land cost.

Centre of electrical load

The plant should be located where there are industries and other important consumption places of electricity. There will be considerable advantages in placing the power station nearer to the center of the load.

- There will be saving in the cost of copper used for transmitting electricity as the distance of transmission line is reduced.
- The cross-section of the transmission line directly depends upon the maximum current to be carried. In case of alternating current the voltage to be transmitted can be increased thus reducing the current and hence the cross-section of the transmission line can be reduced. This will save the amount of copper.
- It is desirable now to have a national grid connecting all power stations. This provides for selecting site which has other advantages such as nearer to fuel supply, condensing water available.

Nearness to the fuel source

The cost of transportation of fuel may be quite high if the distance of location of the power plant is considerable. It may be advisable to locate high thermal power plants at the mouth of the coal mines.

Lignite coal mines should have centralized thermal power station located in the mines itself as this type of coal cannot be transported.

Such type of power stations could be located near oil fields if oil is to be used as a fuel and near gas wells where natural gas is available in abundance.

In any case it has been seen that it is cheaper to transmit electricity than to transport fuel. Hence the power plant should be located neared the fuel supply source.

Availability of water

The availability of water is of greater importance than all other factors governing station location. Water is required for a thermal power station using turbines for the following two purposes:

(i) To supply the make-up water this should be reasonably pure water.

(ii) To cool the exhaust system. This cooling process is done in case of diesel engines too. For bigger power stations the quantity of this cooling water is tremendous and requires some natural source of water such as lake, river or even sea. Cooling towers could be used economically as the same cooling water could be used again and again.

Only a part of make-up water for cooling will then be required. For small plants spray pounds could sometimes be used. It is economical to limit the rise in cooling-water temperature to a small value (between 6º and 12ºC), and to gain in cycle efficiency at the expense of increased cooling water pumping requirement.

Type of soil available and land cost.

While selecting a site for a power plant it is important to know about the character of the soil. If the soil is loose having low bearing power the pile foundations have to be used.

Boring should be made at most of the projected site to have an idea of the characters of the various strata as well as of the bearing power of the soil. The best location is that for which costly and special foundation is not required.

In case of power plants being situated near metropolitan load centers, the land there will be very costly as compared to the land at a distance from the city.

LAYOUT OF POWER PLANT BUILDING

The following points should be taken care of which deciding about power plant building and its layout:

1. The power plant structure should be simple and rugged with pleasing appearance.
2. Costly materials and ornamental work should be avoided.
3. The power plant interior should be clean, airy and attractive.
4. The exterior of the building should be impressive and attractive.
5. Generally the building should be single storeyed.

6. The layout of the power plant should first be made on paper, the necessary equipment well-arranged and then design the covering structure. In all layouts, allowances must be made for sufficient clearances and for walkways. Good clearance should be allowed around generators, boilers, heaters, condensers etc. Walkway clearances around hot objects and rapidly moving machinery should be wider than those just necessary to allow passage. Also the galleries in the neighborhood of high tension bus bars should be sufficient as the space will permit.
7. Provision for future extension of the building should be made.
8. The height of the building should be sufficient so that overhead cranes could operate well and the overhauling of the turbines etc. is no problem. Sufficient room should be provided to lift the massive parts of the machines.
9. Each wall should receive a symmetrical treatment in window openings etc.
10. The principal materials used for building the power plant building are brick, stone, hollow tiles, concrete and steel.
11. In case of a steam power plant, there are distinct parts of the buildings viz., boiler room, turbine room and electrical bays. Head room required in the boiler room should be greater than in the other. Ventilation in boiler room presents greater difficulty because of heat liberated from the boiler surfaces. The turbine room is actually the show room of the plant. Mezzanine flooring should be used in the power plant. The chimney height should be sufficient so as to release the flue gases sufficiently high so that the atmosphere is not polluted and the nearby buildings are not affected.
12. The foundation of a power plant is one of the most important considerations. For this the bearing capacity of the sub-soil, selection of a working factor of safety and proportioning the wall footing to economical construction should be well thought of and tested. The pile foundations may have to be used where the soils have low bearing values.
13. In any power plant machines foundation plays an important part. The machine foundation should be able to distribute the weight of the machine, be plate and its own height over a sage subsoil area. It must also provide sufficient mass to absorb machine vibrations.
14. Sufficient room for storage of fuel should be provided indoor as well as outdoor so as to ensure against any prolonged breakdown.

5.7 CAPITAL AND OPERATING COST OF DIFFERENT POWER PLANTS (COST ANALYSIS)

The cost of a power system depends upon whether:

(i) An entirely new power system has to be set up, or
(ii) An existing system has to be replaced, or
(iii) An extension has to be provided to the existing system. The cost interalia includes:

1. Capital or Fixed cost. It includes the following:

(i) Initial cost
(ii) Interest
(iii) Depreciation cost
(iv) Taxes
(v) Insurance

2. Operational cost. It includes the following:
(i) Fuel cost
(ii) Operating labour cost
(iii) Maintenance cost
(iv) Supplies
(v) Supervision
(vi) Operating taxes.

CAPITAL COST OF FIXED COST

Initial cost

Some of the several factors on which cost of a generating station or a power plant depends are:

(i) Location of the plant
(ii) Time of construction
(iii) Size of units
(iv) Number of main generating units
(v) Overhead charges which will include the transportation cost, stores and storekeeping charges, interest during construction etc.

- To reduce the cost of building, it is desirable to eliminate the superstructure over the boiler house and as far as possible on turbine house also.
- The cost on equipment can be reduced by adopting unit system where one boiler is used for one turbo-generator. Also by simplifying the piping system, and elimination of duplicate system such as steam headers and boiler feed headers. The cost can be further reduced by eliminating duplicate or stand-by auxiliaries.
- When the power plant is not situated in the proximity to the load served, the cost of a primary distribution system will be a part of the initial investment.

Interest

All enterprises need investment of money and this money may be obtained as loan, through bonds and shares or from owners of personal funds. Interest is the difference between money borrowed and money returned. It may be charge at a simple rate expressed as % per

annum or may be compounded, in which case the interest is reinvested and adds to the principal, thereby earning more interest in subsequently years.

Even if the owner invests his own capital the charge of interest is necessary to cover the income that he would have derived from it through an alternative investment or fixed deposit with a bank. Amortization in the periodic repayment of the principal as a uniform annual expense.

Depreciation

Depreciation accounts for the deterioration of the equipment and decrease in its value due to corrosion, weathering and wear and tear with use. It also covers the decrease in value of equipment due to obsolescence. With rapid improvements in design and construction of plants, obsolescence factor is of enormous importance. Availability of better models with lesser overall cost of generation makes it imperative to replace the old equipment earlier than its useful life is spent. The actual life span of the plant has, therefore, to be taken as shorter than what would be normally expected out of it.

The following methods are used to calculate the depreciation cost:

(i) Straight line method
(ii) Percentage method
(iii) Sinking fund method
(iv) Unit method

(i) **Straight line method.** It is the simplest and commonly used method. The life of the equipment or the enterprise is first assesses as also the residual or salvage value of the same after estimated life span. This salvage value is deducted from the initial capital cost and the balance is divided by the life as assessed in years. Thus, the annual value of decrease in cost of equipment is found and is set aside as depreciation annually from the income. Thus, the rate of depreciation is uniform throughout the life of the equipment. By the time the equipment has lived out its useful life an amount equivalent to its net cost is accumulated which can be utilized for replacement of the plant.

(ii) **Percentage method**. In this method the deterioration in value of equipment from year to year is taken into account and the amount of depreciation calculated upon actual residual value for each year. It thus, reduces for successive years.

(iii) **Sinking fund method**. This method is based on the conception that the annual uniform deduction from income for depreciation will accumulate to the capital value of the plant at the end of life of the plant or equipment. In these methods, the amount set aside per year consists of annual installments and the interest earned on all the installments.

Let, A = Amount set aside at the end of each year for n years,
n = Life of plant in years,
S = Salvage value at the end of plant life,
i = Annual rate of compound interest on the invested capital, and
P = Initial investment to install the plant.

Then, amount set aside at the end of first year = A

Amount at the end of second year

$$= A + \text{interest on } A = A + Ai = A(1 + i)$$

Amount at the end of third year

$$= A(1 + i) + \text{interest on } A(1 + i)$$
$$= A(1 + i) + A(1 + i)i$$
$$= A(1 + i)^2$$

$\therefore$ Amount at the end of nth year = $A(1 + i)^{n-1}$

Total amount accumulated in n years (say x)

= Sum of the amounts accumulated in n years

i.e.,
$$x = A + A(1 + i) + A(1 + i)^2 + \ldots\ldots + A(1 + i)^{n-1}$$
$$= A\,[1 + (1 + i) + (1 + i)^2 + \ldots\ldots + (1 + i)^{n-1}] \quad \ldots(i)$$

Multiplying the above equation by $(1 + i)$, we get

$$x(1 + i) = A\,[(1 + i) + (1 + i)^2 + (1 + i)^3 + \ldots\ldots + (1 + i)^n] \quad \ldots(ii)$$

Subtracting equation (i) from (ii), we get

$$x.i = [(1 + i)^n - 1]\,A$$

$$\therefore \quad x = \left[\frac{(1+i)^n - 1}{i}\right] A$$

where, $x = (P - S)$

$$\therefore \quad P - S = \left[\frac{(1+i)^n - 1}{i}\right] A \quad \ldots(9.6)$$

or,
$$A = \left[\frac{i}{(1+i)^n - 1}\right] (P - S) \quad \ldots(9.7)$$

(iv) **Unit method.** In this method some factor is taken as a standard one and depreciation is measured by that standard. In place of years equipment will last, the number of hours that equipment will last is calculated. This total number of hours is then divided by the capital value of the equipment. This constant is then multiplied by the number of actual working hours each year to get the value of depreciation for that year. In place of number of hours, the number of units of production is taken as the measuring standard.

OPERATING COST

The elements that make up the operating expenditure of power plant include the following costs:

(i) Cost of fuels
(ii) Labour cost
(iii) Cost of maintenance and repairs
(iv) Cost of stores (other than fuel)
(v) Supervision
(vi) Taxes

Cost of fuels. In a thermal station fuel is the heaviest item of operating cost. The selection of the fuel and the maximum economy in its use are, therefore, very important considerations in thermal plant design. It is desirable to achieve the highest thermal efficiency for the plant so that fuel charges are reduced. The cost of the fuel includes not only its price at the sire of purchase but its transportation and handling costs also.

In the hydroplants the absence of fuel factor in cost is responsible for lowering the operating cost. Plant heat rate can be improved by the use of better quality of fuel or by employing better thermodynamic conditions in the plant design.

The cost of fuel varies with the following:

(i) Unit price of the fuel
(ii) Amount of energy produced.
(iii) Efficiency of the plant

Labour cost. For plant operation labour cost is another item of operating cost. Maximum labour is needed in a thermal power plant using coal as a fuel. A hydraulic power plant or a diesel power plant of equal capacity requires a lesser number of persons. In case of automatic power station the cost of labour is reduced to a great extent. However labour cost cannot be completely eliminated even with fully automatic station as they will still require some manpower for periodic inspection etc.

Cost of maintenance and repairs. In order to avoid plant breakdown maintenance is necessary. Maintenance includes periodic cleaning, greasing, adjustments and overhauling of equipment. The material used for maintenance is also charged under this head. Sometimes an arbitrary percentage is assumed as maintenance cost. A good plan of maintenance would keep the sets in dependable condition and avoid the necessity of too many stand-by-plants.

Repairs are necessitated when the plant breaks down or stops due to faults developing in the mechanism. The repairs may be minor, major or periodic overhauls and are charged to the depreciation fund of the equipment. This item of cost is higher for thermal plants than for hydro-plants due to complex nature of principal equipment and auxiliaries in the former.

Cost of stores. The items of consumable stores other than fuel include such articles as lubricating oil and greases, cotton waste, small tools, chemicals, paints and such other things. The incidence of this cost is also higher in thermal stations than in hydro-electric power stations.

Supervision. In this head the salary of supervising staff is included. A good supervision is reflected in lesser breakdowns and extended plant life. The supervising staff includes the station superintendent, chief engineer, chemist, engineers, supervisors, store in-charges, purchase officer and other establishment. Again, thermal stations, particularly coal fed, have a greater incidence of this cost than the hydro-electric power stations.

Taxes. The taxes under operating head include the following:

(i) Income tax
(ii) Sales tax

(iii) Social security and employee's security.

5.8 POLLUTION CONTROL TECHNOLOGIES INCLUDING WASTE DISPOSAL OPTIONS FOR COAL AND NUCLEAR POWER PLANTS. (POLLUTION AND ITS CONTROL)

INTRODUCTION

All power production plants, invariably, pollute the atmosphere and the resulting imbalance on ecology has a bad effect. The pollution is inevitable in some cases and has to be minimized to the extent possible. This is being achieved by effective legislations all over the world.

The power plant pollutants of major concern are:

A. From fossil power plants:
   (i) Sulphur oxide.
   (ii) Nitrogen oxide
   (iii) Carbon oxide
   (iv) Thermal pollution
   (v) Particulate matter
B. From nuclear power plants
   (i) Radioactivity release
   (ii) Radioactivity wastes
   (iii) Thermal pollution
   Besides this, pollutants such as lead and hydrocarbons are contributed by automobiles.

POLLUTION FROM THERMAL-POWER PLANTS

The environment is polluted to a great extent by thermal power plants. The emission from the chimney throws unwanted gases and particles into the atmosphere while the heat is thrown into the atmosphere and rivers. Both these aspects pollute the environment beyond tolerable limits and now are being controlled by appropriate regulations. The types of emissions, effects and methods of minimizing these pollutions are discussed below.

The air pollution in a large measure is caused by the thermal-power plants burning conventional fuels (coal,oil or gas). The combustible elements of the fuel are converted to gaseous products and non-combustible elements to ash. Thus the emission can be classified as follow:

(1) Gaseous emission
(2) Particulate emission
(3) Solid waste emission

(4) Thermal pollution (or waste heat)

Gaseous emission and its control

The various gaseous pollutants are:

(i) Sulphur di-oxide
(ii) Hydrogen sulphide
(iii) Oxides of nitrogen
(iv) Carbon monoxide etc.

The effects of pollutants on environment are as follows:

S. No.	Pollutant	Effects		
		On man	On vegitation	On materials/animals
1.	SO_2	Suffocation, irritation of throat and eyes, respiration system.	Destruction of sensitive crops and reduced yield.	Corrosion.
2.	NO_2	Irritation, bronchitis, oedema of lungs.	—	—
3.	H_2S	Bare disease, repiratory diseases.	Destruction of crops.	Flourosis in cattle grazing.
4.	CO	Poisoning, increased accident-liability.	—	—

Removal of Sulphur dioxide (SO_2):

SO2 is removed by wet scrubbers as shown in Fig 5.7

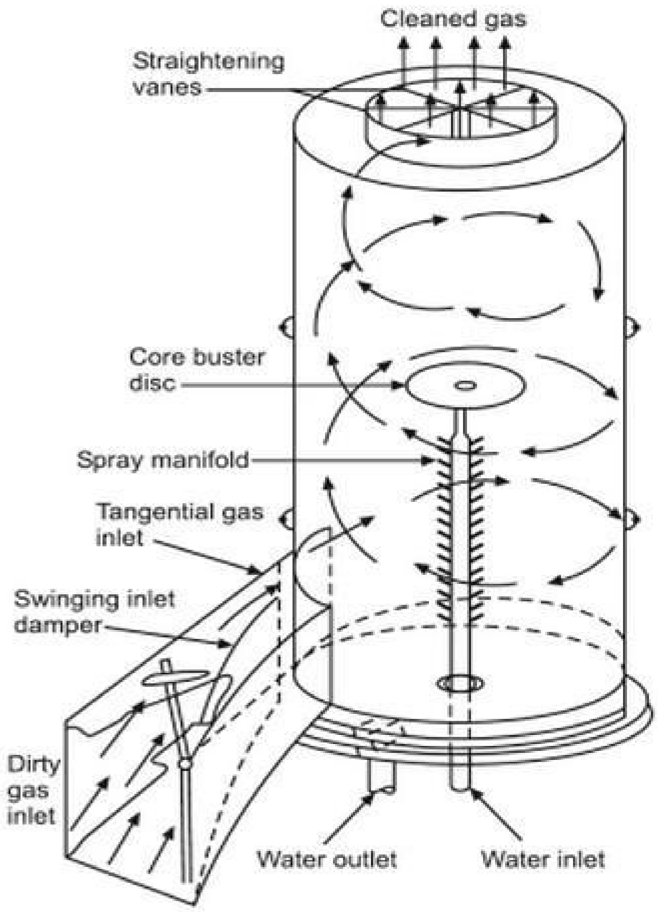


Fig 5.7 Wet scrubbers

- The gases to be cleaned are admitted tangentially into the scrubber which will also help in separating the particulate matters. Water spray absorbs these gases, and particulate matters which collect on the surface of the scrubber, are washed down by the water and this water is further treated, filtered and reused.
- The wet scrubbers also find application in chemical and grain milling industries
- The collection efficiency of scrubber is about 90%.

The following are disadvantages of using wet scrubbers:

1. The gases are cooled to such an extent that they must be reheated before being sent to the stack.
2. The pressure drops are very high.
3. Water used, after dissolving Sulphur oxides, will contain sulphuric and sulphurous acids which may corrode the pipelines and the scrubber itself, this water cannot be let out into the rivers for obvious reasons.

In power plants where high Sulphur content coal is the only source available, it is preferable to remove the Sulphur from the coal before it is burnt. This is done by coal washing which reduces the flyash as well as some Sulphur oxides in the flue gases. But the power plants employ "flue-gas desulphurization" (FGD) system similar to wet scrubber system. FGD can be of the following types:

1. The recovery or regenerative system.
2. Throw away or non-regenerative system. In this system the reactants are not recovered and the final products are Sulphur salts of calcium and magnesium.

Regenerative system:

Some of the regenerative systems are:

1. FW-Bergbau process
2. Wellman-Lord process
3. Wet magnesium oxide process

- In the fig 5.8 is shown the FW-Bergbau process. In this process, SO2 is removed by adsorption and Sulphur is collected as molten Sulphur.

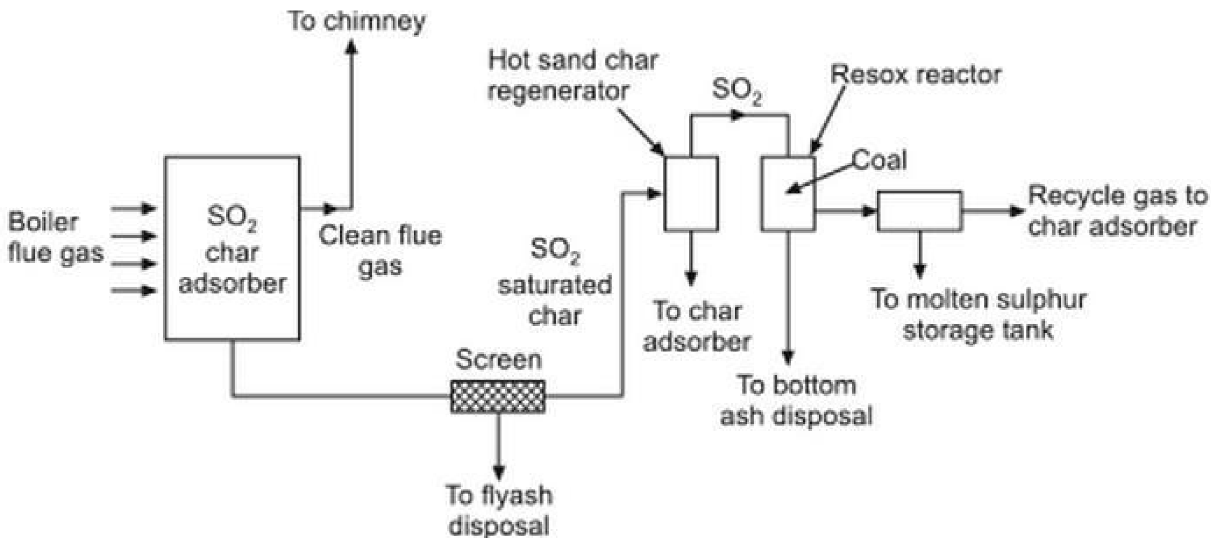


Fig 5.8 F.W Bergbau Forshung adsorption FGD regenerative system

- Fig 5.9 shows the Wellman-Lord FGD system. This system removes SO2 by absorption in sodium carbonate and SO2 is recovered as Sulphur or sulphuric acid products.

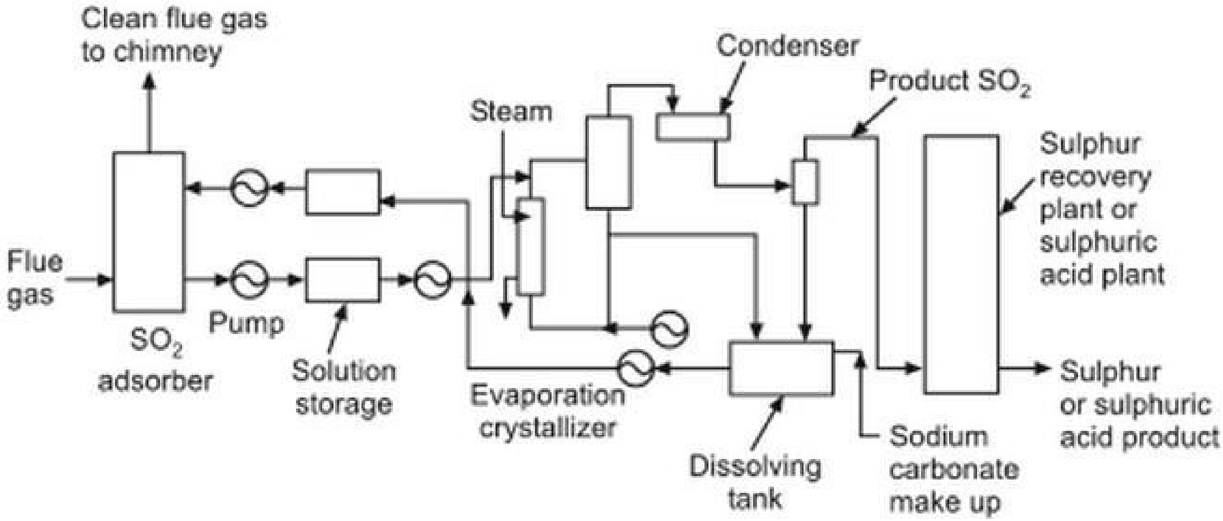


Fig 5.9 Wellman-Lord absorption FGD regenerative system

In non-regenerative systems the principal reactant is either lime or limestone. The slurry is made into sludge by adding flyash and other proprietary sludge additives and the sludge is disposed. These methods could prove a bit more expensive since no Sulphur or Sulphur product is recovered and the reactant is not generated as in the case of FB Bergbau process.

Emission of NO_x:

Nitrogen oxides are compounds of the elements nitrogen and oxygen, both of which are present in air. The combustion of fossil fuels in air is accompanied by the formation of nitric oxide (NO) which is subsequently partly oxidized to nitrogen dioxide (NO_2). The resulting mixture of variable combustion is represented by the symbol NO_x, where x has a value between 1 and 2. Nitro gen oxides are present in stack gases from coal, oil and gas furnaces (and also in the exhaust gases from internal combustion engines and gas turbines).

The following methods are commonly used to reduce the emission of NO_X from thermal (and gas turbine) power plants:

1. Reduction of temperature in combustion zone.
2. Reduction of residence period in combustion zone.
3. Increase in equivalence ratio in the combustion zone.

Particulate Emission and its control

The particulate emission, in power plants using fossil fuels, is easiest to control. Particulate matter can be either dust (particles having a diameter of 1 micron) which do not settle down or particles with a diameter of more than 10 microns which settle down to the ground. The particulate emission can be classified as follows:

Smoke: It composes of stable suspension of particles that have a diameter of less than 10 microns and are visible only in the aggregate.

Fumes. These are very small particles resulting from chemical reactions and are normally composed of metals and metallic oxides.

Flyash. These are ash particles of diameters of 100 microns or less.

Cinders. These are ash particles of diameters of 100 microns or more.

The above particulates, in any system of controlling the particulate emission, are to be effectively collected from the flue gases. The performance parameters for any particulate remover are called the collection efficiency defined as:

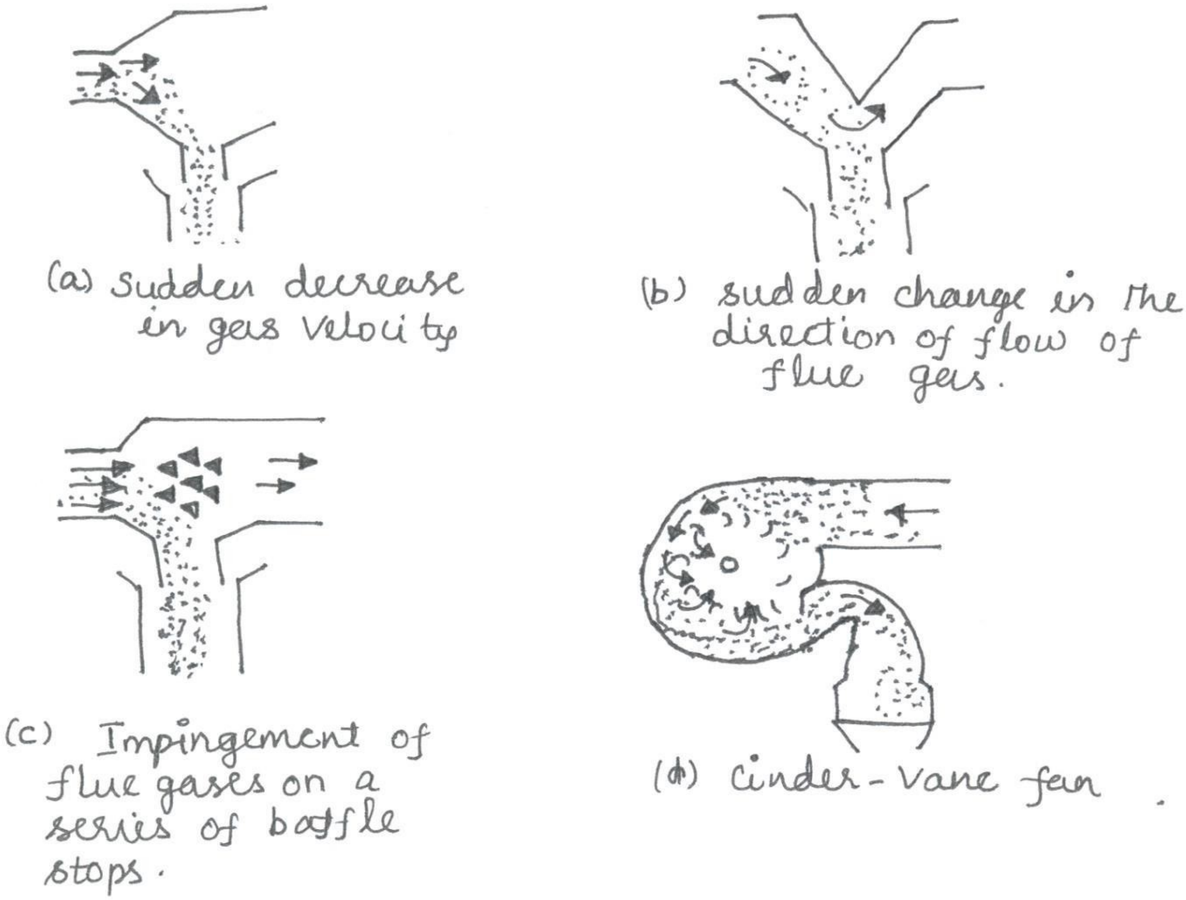
$$= \frac{\qquad}{\qquad} \times 100$$

For different system the collector efficiency varies from 50 to 99%; for an electrostatic precipitator it is more than 90%.

Some collector systems, their efficiencies and their adaptability, are discussed in the following paragraphs:

a. Cinder catchers

The cinder catchers are shown in fig 5.10



- Refer fig 5.10(a) sudden decrease in gas velocity makes the particulates separates and fall.
- Refer fig 5.10(b) a sudden change in the direction of flow of flue gas throws the particulates away and can be collected.
- Refer fig 5.10 (c) Impingement of flue gases on a series of baffle stops the particulate matter as shown. These are commonly used in stoker and small cyclone furnaces where crushed coal is burned rather than the very fine pulverized coal. The collection efficiencies of cinder catchers are from 50 to 75%.
- Refer Fig 5.10(d) the cinder vane fan uses the fan which imparts centrifugal force to the particulates and they are collected as shown. The efficiency is from 50 to 75%.

b. Wet scrubbers

- Wet scrubbers as described for removal of gases can also be used for removal of particulate matter; but the gases will have to be reheated before they are sent to the stack.
- The wet scrubbers are not commonly used to remove particulate matters,

c. Electrostatic precipitator

- An electrostatic precipitator is shown in fig 5.11. In this device a very high voltage of 30kV to 60kV is applied to the wires suspended in a gas-flow passage between two grounded plates.

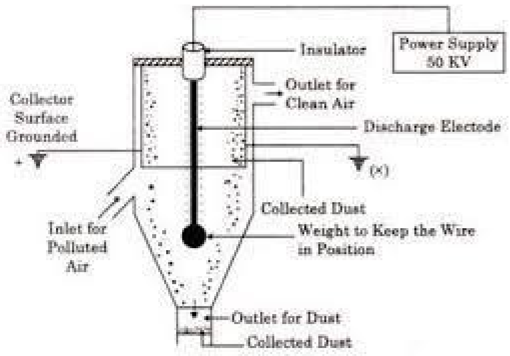


Fig 5.11 Electrostatic precipitator

- The particles in the gas stream acquire a charge from the negatively charged wires and are then attracted to the ground plates. The grounded plates are periodically rapped by a steel plug which is raised and dropped by an electromagnet and dust is collected in the hopper below:
- In this type of collector, care must be taken to see that large quantity of unburnt gases do not enter the precipitator. If such a mixture enters, power should be turned off; otherwise there could be explosion because of constant sparking between wires and plates.
- The collection efficiency is about 99%.
- Electrostatic precipitators are suitable for power plants where fly-ash content is high. Fly-ash having high electrical resistivity does not separate in the electrostatic precipitator. This problem can be solved by injecting Sulphur trioxide into the exhaust gas which improves the conductivity of fly-ash. This again poses a problem of discharging objectionable Sulphur trioxide into the atmosphere; this needs a wet scrubber after the electrostatic precipitator.

d. Baghouse filters

- Fig 5.12 shows a baghouse filter. Baghouse filters are found useful in removing the particulate matters where low Sulphur coal is used.

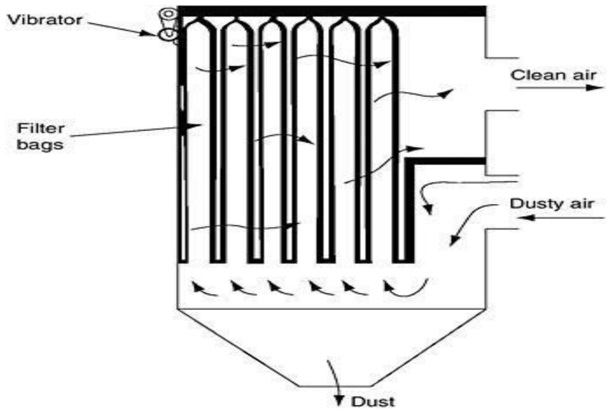


Fig 5.12 Baghouse filter

- The cloth filters cost about 20% of installation cost and last for 1.5 to 3 years.
- The baghouse filter is usually cleaned by forcing air in the reversed direction. They need large filter areas of about 6.5m2/MW of power generation. Hence the installation cost could be high.
- Although baghouse filters are expensive, yet they are being widely used in coal-fired systems.

Solid waste disposal

From the fossil fuel fired power plants considerable amount of solids in the form of ash is discharged. This ash is removed as bottom ash or slug from the furnace. The fossil fuel fired system also discharges solid wastes such as calcium and magnesium salts generated by absorption of SO_2 and SO_3 by reactant like lime stone.

Thermal pollution

Discharge of thermal energy into waters in commonly called “Thermal Pollution”.

Thermal power stations invariably will have to discharge enormous amounts of energy into water since water is one medium largely used to condense steam. If this heated water from condensers is discharged into lakes or rivers, the water temperature increases.

At about 35°C, the dissolved oxygen will be so low that the aquatic life will die. But in very cold regions, letting out hot water into the lakes or rivers helps in increasing the fish growth. But, in our country, such places are not many and hence, it is necessary that we minimize this thermal pollution of water. One of the regulations stipulates that a maximum temperature of water let out cab be 1°C above the atmospheric temperature. Thus the thermal power plants or any other industry has to resort to various methods of adhering to this regulation.

a. Thermal discharge index(TDI)

Thermal discharge index (TDI) is the term usually used in connection with the estimation of the amount of thermal energy released to environment from a thermal power plant. TDI of any power plant is the number of thermal energy units discharged to the environment of every unit of electrical energy generated.

$= h \quad h \quad h$

This index cannot be zero or else the plant violates the second law of thermodynamics; but this index should be as low as possible to improve the efficiency of the plant as well as to keep the pollution level low.

The thermal discharge index (TDI) is strongly dependent on the thermal efficiency of the plant.

b. How to reduce thermal pollution?

While considering the efficiency of the thermal plant, it is desirable that the water from a river or lake is pumped through the condenser and fed back to the source. The rise of temperature will be about 10°C which is highly objectionable from the pollution point of view. Hence, this waste heat which is removed from the condenser will have to be thrown into the atmosphere and not into the water source; in this direction following methods can be adopted:

1. Construction of a separate lake
2. Cooling pond
3. Cooling towers

Construction of a separate lake

Sufficientlylarge water storage in the form of a lake can be built and once-through cooling the condenser can be adopted. If the natural cooling of water from the lake is not sufficient, floating spray pumps can be employed.

This method improves the thermal efficiency of the plant but can prove expensive. Also, it may not always be possible to have a large enough lake artificially built.

Cooling pond

A cooling pond with continuously operating fountains can be adopted for smaller power plants. This will also serve as a beautifying feature of the power plant side.

Cooling towers

In order to throw heat into the atmosphere most power stations adopt the cooling towers. The hyperbolic shape given to the tower automatically induces air form the bottom to flow upwards and the water is cooled by coming in direct contact with the air. This is a natural convection cooling and is also called ‘wet-cooling tower’.

The overall efficiency of such plants will be lower than those of the plants adopting once-through cooling system. There will be considerable vapor flumes escaping from the cooling towers. Sometime, make-up cooling water may be scarce. In such cases, dry cooling tower can be adopted. Dry cooling towers are much more expensive than wet cooling towers.

All cooling towers, whether dry or wet, are expensive and add to the initial investment of the plant. Small plants can adopt mechanical-draft systems using induced or forced draft systems. This helps in avoiding height to the cooling towers. Thus, the initial cost is reduced but the maintenance costs of mechanical-draft systems are high.

POLLUTION FROM NUCLEAR POWER PLANTS

The various types of pollution from nuclear power plants are:

1. Radioactive pollution
2. Waste from reactor (solid, liquid, gases)
3. Thermal pollution

Radioactive pollution. This is the most dangerous and serious type of pollution. This is due to radioactive elements and fissionable products in reactor. The best way to abate is the radioactive shield around the reactor.

Waste from reactor. Due to nuclear reactor reaction nuclear wastes (mixtures of various Beta and Gamma emitting radioactive isotopes with various half-lives) are produced which cannot be neutralized by any chemical method.

If the waste is discharged in the atmosphere, air and water will be contaminated beyond the tolerable limits. Some methods of storage or disposal of radioactive waste materials are discussed below:

1. **Storage tanks.** The radioactive wastes can be buried underground (very deep below the surface) in corrosion resistance tanks locates in isolated areas. With the passage of time these will become stable isotopes.
2. **Dilution.** After storing for a short time, low energy wastes are diluted either in liquid or gaseous materials. After dilution, they are disposed off in sewer without causing hazard.
3. **Sea disposal.** This dilution can be used be adequately diluting the wastes and this method is being used by the British.

4. **Atmospheric dilution.** This method can be used for gaseous radioactive wastes. But solid particles from the gaseous wastes must be filtered out thoroughly since they are the most dangerous with higher half-lives.
5. **Absorption by the soil**. Fission products are disposed off by this method. The radioactive particles are absorbed by the soil particles. But this is expensive.
6. **Burying in sea.** Solid nuclear wastes can be stored is concrete blocks which are buried in the sea. This method is expensive but no further care is needed.