KALAIGNAR KARUNANIDHI INSTITUTE OF TECHNOLOGY

Kannampalayam Post, Coimbatore -641 402

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

Course Material on

ME6701- POWER PLANT ENGINEERING

Regulation : 2013

Semester : V

Prepared by

S.Rathinamala

Assistant Professor / EEE

ME6701 POWER PLANT ENGINEERING L T P C
3 0 0 3

OBJECTIVES:

- Providing an overview of Power Plants and detailing the role of Mechanical Engineers in their operation and maintenance.

UNIT I COAL BASED THERMAL POWER PLANTS 10

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

UNIT II DIESEL, GAS TURBINE AND COMBINED CYCLE POWER PLANTS 10

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.

UNIT III NUCLEAR POWER PLANTS 7

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

UNIT IV POWER FROM RENEWABLE ENERGY 10

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

UNIT V ENERGY, ECONOMIC AND ENVIRONMENTAL ISSUES OF POWER 8

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.

TOTAL : 45 PERIODS

OUTCOMES:

- Upon completion of this course, the Students can able to understand different types of power plant, and its functions and their flow lines and issues related to them.
- Analyse and solve energy and economic related issues in power sectors.

TEXT BOOK:

1. P.K. Nag, Power Plant Engineering, Tata McGraw – Hill Publishing Company Ltd., Third Edition, 2008.

REFERENCES:

1. M.M. El-Wakil, Power Plant Technology, Tata McGraw – Hill Publishing Company Ltd., 2010.
2. Black & Veatch, Springer, Power Plant Engineering, 1996.
3. Thomas C. Elliott, Kao Chen and Robert C. Swanekamp, Standard Handbook of Power Plant Engineering, Second Edition, McGraw – Hill, 1998.
4. Godfrey Boyle, Renewable energy, Open University, Oxford University Press in association with the Open University, 2004.

INTRODUCTION

A **power plant** or a **power generating station**, is basically an industrial location that is utilized for the generation and distribution of electric power in mass scale, usually in the order of several 1000 Watts. These are generally located at the sub-urban regions or several kilometers away from the cities or the load centers, because of its requisites like huge land and water demand, along with several operating constraints like the waste disposal etc.

For this reason, a power generating station has to not only take care of efficient generation but also the fact that the power is transmitted efficiently over the entire distance. And that's why, the transformer switch yard to regulate transmission voltage also becomes an integral part of the **power plant**. At the center of it, however, nearly all power generating stations has an A.C. generator or an alternator, which is basically a rotating machine that is equipped to convert energy from the mechanical domain (rotating turbine) into electrical domain by creating relative motion between a magnetic field and the conductors. The energy source harnessed to turn the generator shaft varies widely, and is chiefly dependent on the type of fuel used.

UNIT I
COAL BASED THERMAL POWER PLANTS

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

1.RANKING CYCLE

The **Rankine cycle** is a thermodynamic cycle. Like other thermodynamic cycle, the maximum efficiency of the Ranking cycle is given by calculating the maximum efficiency of the carnot cycle.

In a real Rankine cycle, the compression by the pump and the expansion in the turbine are not isentropic. In other words, these processes are non-reversible and entropy is increased during the two process (indicated in the figure). This somewhat increases the power required by the pump and decreases the power generated by the turbine. It also makes calculations more involved and difficult.

Process of the Rankine Cycle

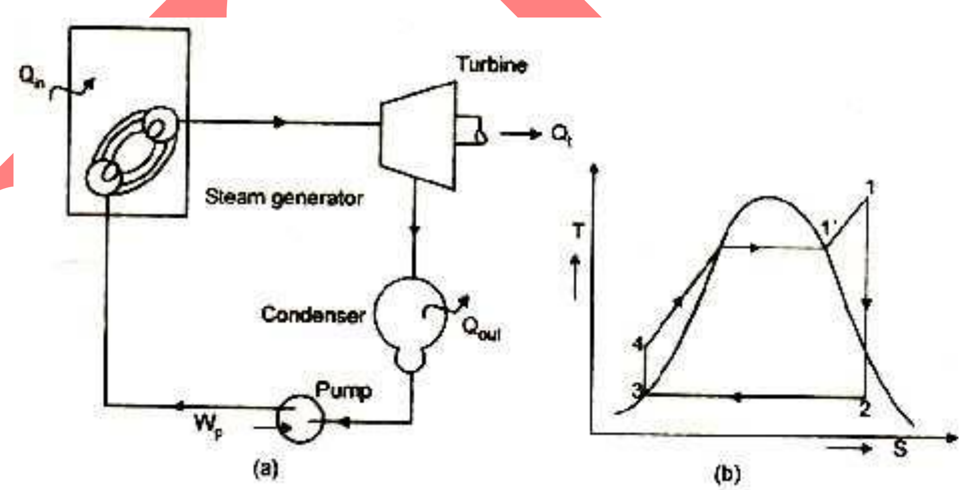


Figure: Schematic representation and T-S diagram of Rankine cycle

There are four processes in the Rankine cycle, each changing the state of the working fluid. These states are identified by number in the diagram above.

Process 3-4:

First, the working fluid (water) is enter the pump at state 3 at saturated liquid and it is pumped (ideally isentropically) from low pressure to high (operating) pressure of boiler by a pump to the state 4. During this isentropic compression water temperature is slightly increased. Pumping requires a power input (for example, mechanical or electrical). The conservation of energy relation for pump is given as

Wpump = m (h4 - h3)

Process 4-1:

The high pressure compressed liquid enters a boiler at state 4 where it is heated at constant pressure by an external heat source to become a saturated vapour at statel' which in turn superheated to state 1 through super heater. Common heat source for power plant systems are coal (or other chemical energy), natural gas, or nuclear power. The conservation of energy relation for boiler is given as

Qin =m (h1 - h4)

Process 1 – 2:

The superheated vapour enter the turbine at state 1 and expands through a turbine to generate power output. Ideally, this expansion is isentropic. This decreases the temperature and pressure of the vapour at state 2. The conservation of energy relation for turbine is given as

Wturbine = m (h1 –h2)

Process 2 – 3:

The vapour then enters a condenser at state 2. At this state, steam is a saturated liquid-vapour mixture where it is cooled to become a saturated liquid at state 3. This liquid then re-enters the pump and the cycle is repeated. The conservation of energy relation for condenser is given as

Qout = m (h2 – h3)

The exposed Rankine cycle can also prevent vapour overheating, which reduces the amount of liquid condensed after the expansion in the turbine.

Description

Rankine cycles describe the operation of steam heat engines commonly found in power generation plants. In such vapour power plants, power is generated by alternatively vaporizing and condensing a working fluid (in many cases water, although refrigerants such as ammonia may also be used.)

The working fluid in a Rankine cycle follows a closed loop and is re-used constantly. Water vapour seen billowing from power plants is evaporating cooling water, not working fluid. (NB: steam is invisible until it comes in contact with cool, saturated air, at which point it condenses and forms the white billowy clouds seen leaving cooling towers). or

Variables

Qin- heat input rate (energy per unit time)

m= mass flow rate (mass per unit time)

W= Mechanical power used by or provided to the system (energy per unit time)

η = thermodynamic efficiency of the process (power used for turbine per heat input, unit less).

The thermodynamic efficiency of the cycle as the ratio of net power output to heat input.

$W_{net} = (W_{turbine} - W_{pump})$ or $(Q_{in} - Q_{out})$

$\eta = W_{net} / Q_{in}$

Improvisation of the Basic Rankine Cycle:

Two main variations of the basic Rankine cycle to improve the efficiency of the steam cycles are done by incorporating Reheater and Regenerator in the ideal ranking cycle.

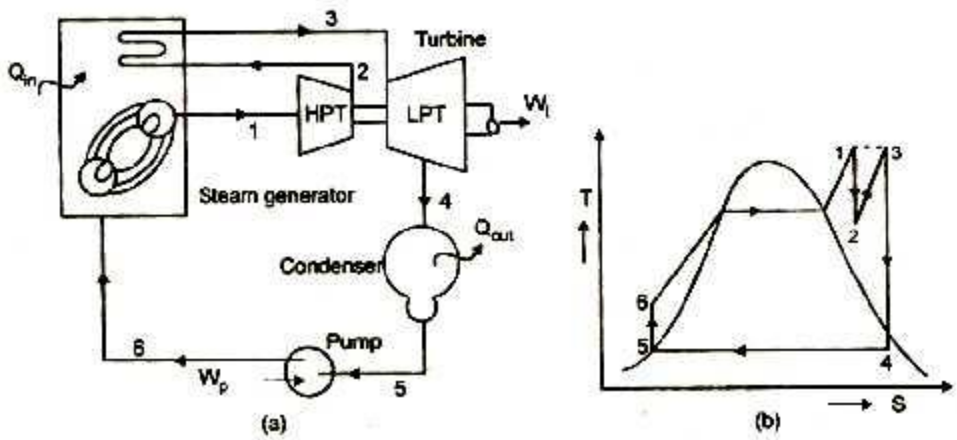
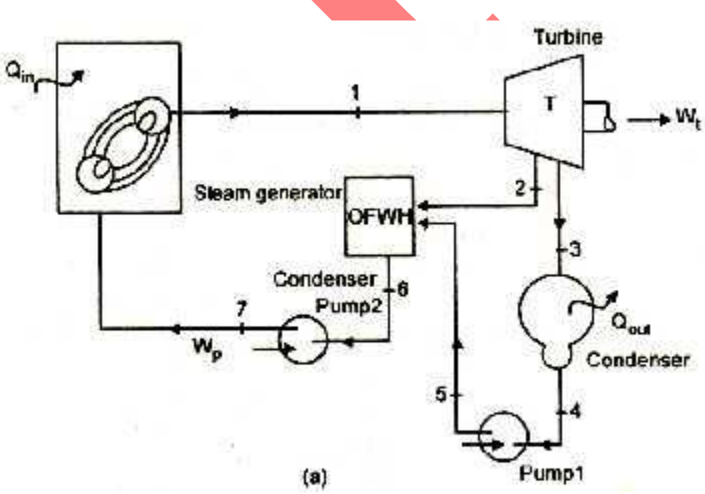


Figure: Schematic diagram and T-S diagram of Rankine cycle with reheat.

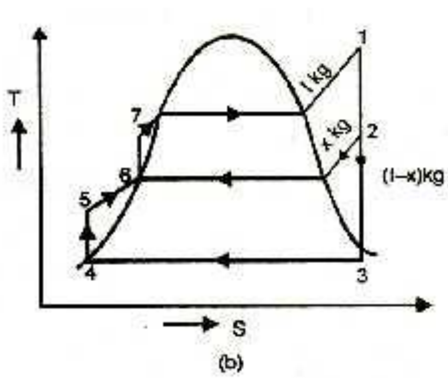
In this variation, two turbines work in series. The first accepts vapour from the boiler at high pressure. After the vapour has passed through the first turbine, it re-enters the boiler and is reheated before passing through a second, lower pressure turbine. Among other advantages, this prevents the vapour from condensing during its expansion which can seriously damage the turbine blades.

Regenerative Ranking cycle

The regenerative Ranking cycle is so named because after emerging from the condenser (possibly as a sub cooled liquid) the working fluid heated by steam tapped from the hot portion of the cycle and fed in to Open Feed Water Heater(OFWH). This increases the average temperature of heat addition which in turn increases the thermodynamics efficiency of the cycle.



2.



Layout of Coal (steam) power plant:

Introduction:
Steam is an important medium for producing mechanical energy. Steam is used to drive steam engines and steam turbines. Steam has the following advantages.

1. Steam can be raised quickly from water which is available in plenty.
2. It does not react much with materials of the equipment used in power plants.
3. It is stable at temperatures required in the plant.

Equipment of a Steam Power Plant:
A steam power plant must have the following equipment

1. A furnace for burning the fuel.
2. A steam generator or boiler for steam generation.
3. A power unit like an engine or turbine to convert heat energy into mechanical energy.
4. A generator to convert mechanical energy into electrical energy.
5. Piping system to carry steam and water.

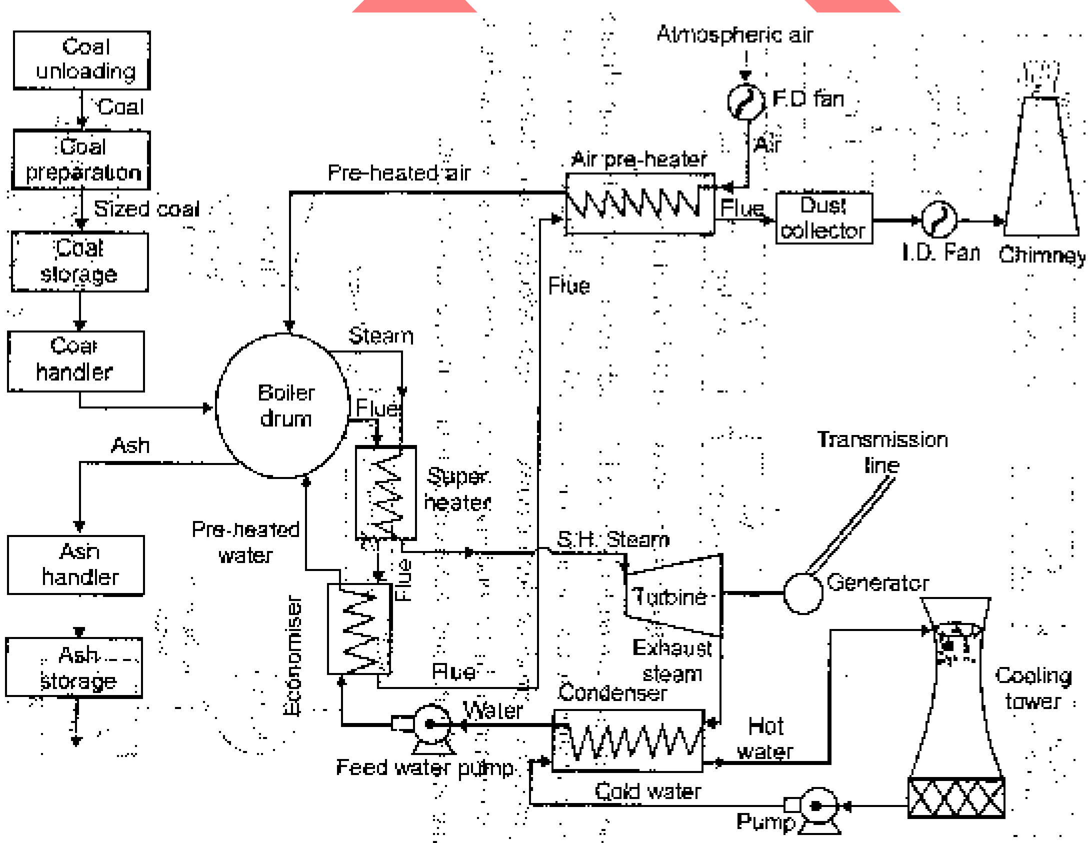


Figure: Layout of a steam power plant

Figure: shows a schematic layout of a steam power plant. The working of a steam power plant can be explained in four circuits.

1. Fuel (coal) and ash circuit
2. Air and flue gas circuit
3. Feed water and steam flow circuit
4. Cooling water flow circuit

1. Coal and Ash circuit:

This includes coal delivery, preparation, coal handling, boiler furnace, ash handling and ash storage. The coal from coal mines is delivered by ships, rail or by trucks to the power station. This coal is sized by crushers, breakers etc. The sized coal is then stored in coal storage (stock yard). From the stock yard, the coal is transferred to the boiler furnace by means of conveyors, elevators etc.

The coal is burnt in the boiler furnace and ash is formed by burning of coal, Ash coming out of the furnace will be too hot, dusty and accompanied by some poisonous gases. The ash is transferred to ash storage. Usually, the ash is quenched to reduced temperature corrosion and dust content.

There are different methods employed for the disposal of ash. They are hydraulic system, water jetting, ash sluice ways, pneumatic system etc. In large power plants hydraulic system is used. In this system, ash falls from furnace grate into high velocity water stream. It is then carried to the slumps. A line diagram of coal and ash circuit is shown separately in figure.

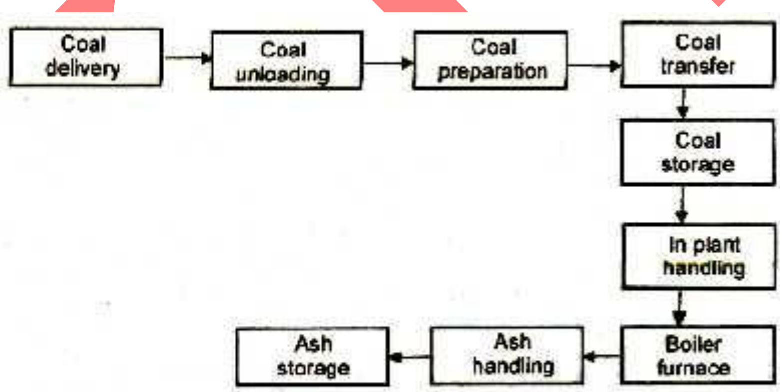


Figure: Fuel (coal) and ash circuit

2. Water and Steam circuit

It consists of feed pump, economizer, boiler drum, super heater, turbine condenser etc. Feed water is pumped to the economizer from the hot well. This water is preheated by the flue gases in the economizer. This preheated water is then supplied to the boiler drum. Heat is transferred to the water by the burning of coal. Due to this, water is converted into steam.

The steam raised in boiler is passed through a super heater. It is superheated by the flue gases. The superheated steam is then expanded in a turbine to do work. The turbine drives a generator to produce electric power. The expanded (exhaust) steam is then passed through the condenser. In the condenser, the steam is condensed into water and recirculated. A line diagram of water and steam circuit is shown separately in figure.

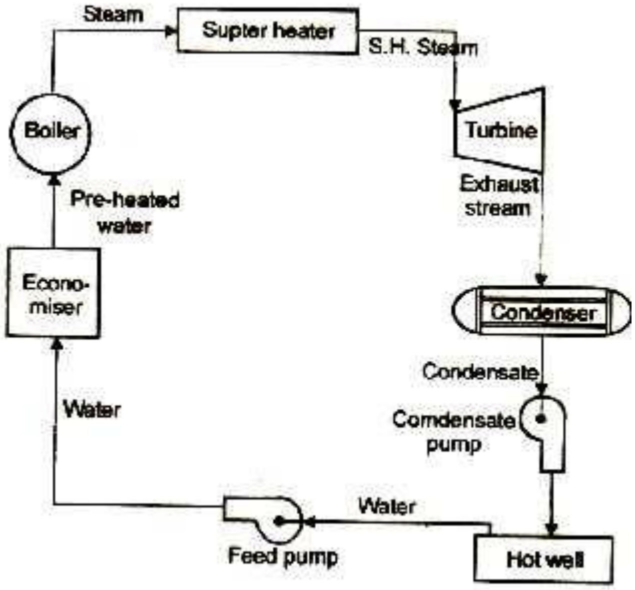


Figure: Water and Steam circuit

3. Air and Flue gas circuit

It consists of forced draught fan, air pre heater, boiler furnace, super heater, economizer,
dust collector, induced draught fan, chimney etc. Air is taken from the atmosphere by the action of a forced draught fan. It is passed through an air pre-heater. The air is pre-heated by the flue gases in the pre-heater. This pre-heated air is supplied to the furnace to aid the combustion of fuel. Due to combustion of fuel, hot gases (flue gases) are formed.

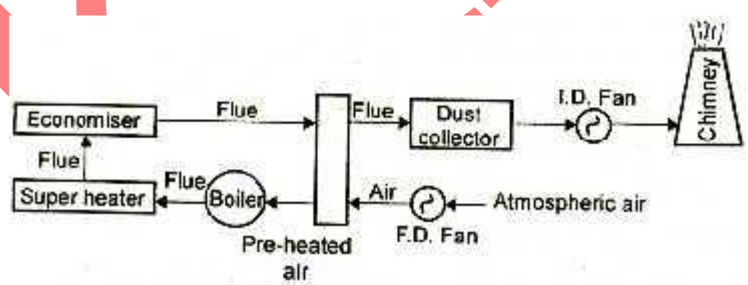


Figure: Air and flue gas circuit

The flue gases from the furnace pass over boiler tubes and super heater tubes. (In boiler,wet steam is generated and in super heater the wet steam is superheated by the flue gases.) Then the flue gases pass through economizer to heat the feed water. After that, it passes through the air pre-heater to pre-heat the incoming air. It is then passed through a dust catching device (dust collector). Finally, it is exhausted to the atmosphere through chimney. A line diagram of air and flue gas circuit is shown separately in figure.

4. Cooling water circuit:

The circuit includes a pump, condenser, cooling tower etc. the exhaust steam from the turbine is condensed in condenser. In the condenser, cold water is circulated to condense the steam into water. The steam is condensed by losing its latent heat to the circulating cold water.

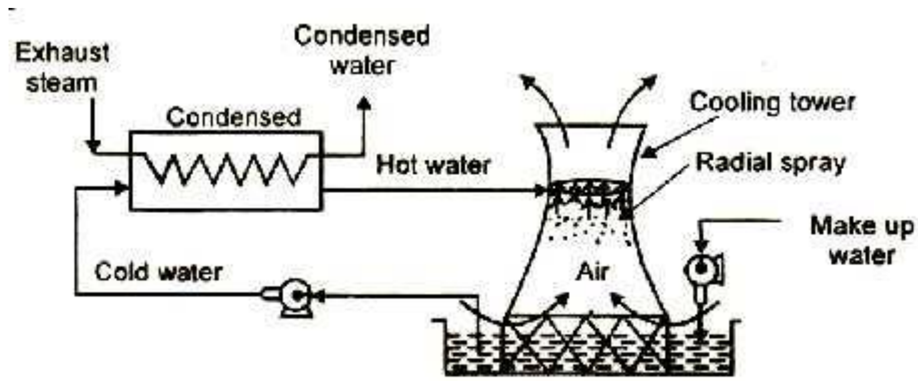


Figure: Cooling water circuit

Thus the circulating water is heated. This hot water is then taken to a cooling tower, In cooling tower, the water is sprayed in the form of droplets through nozzles. The atmospheric air enters the cooling tower from the openings provided at the bottom of the tower. This air removes heat from water. Cooled water is collected in a pond (known as cooling pond). This cold water is again circulated through the pump, condenser and cooling tower. Thus the cycle is repeated again and again. Some amount of water may be lost during the circulation due to vaporization etc. Hence, make up water is added to the pond by means of a pump. This water is obtained from a river or lake. A line diagram of cooling water circuit is shown in figure separately.

Merits (Advantages) of a Thermal Power Plant

1. The unit capacity of a thermal power plant is more.
2. The cost of unit decreases with the increase in unit capacity.
3. Life of the plant is more (25-30 years) as compared to diesel plant (2-5 years).
4. Repair and maintenance cost is low when compared with diesel plant.
5. Initial cost of the plant is less than nuclear plants. Suitable for varying load conditions.
6. No harmful radioactive wastes are produced as in the case of nuclear plant.
7. Unskilled operators can operate the plant.
8. The power generation does not depend on water storage.
9. There are no transmission losses since they are located near load centres.

Demerits of thermal power plants

1. Thermal plant are less efficient than diesel plants
2. Starting up the plant and bringing into service takes more time.
3. Cooling water required is more.
4. Space required is more
5. Storage required for the fuel is more
6. Ash handling is a big problem.

7. Not economical in areas which are remote from coal fields
8. Fuel transportation, handling and storage charges are more
9. Number of persons for operating the plant is more than that of nuclear power plant increases operation cost.
10. For large units, the capital cost is more. Initial expenditure on structural materials, piping, storage mechanisms is more.

3. BOILERS

Fluidized Bed Combustion (FBC) Boiler

https://www.youtube.com/watch?v=P8YXdJbx20M

Fluidization is a method of mixing fuel and air in a specific proportion, for obtaining combustion. A **fluidized bed** may be defined as the bed of solid particles behaving as a fluid. It operates on the principal that when an evenly distributed air is passed upward through a finely divided bed of solid particles at low velocity, the particles remain undisturbed, but if the velocity of air flow is steadily increased, a stage is reached when the individual particles are suspended in the air stream. If the air velocity is further increased, the bed becomes highly turbulent and rapid mixing of particles occur which appear like formation of bubbles in a boiling liquid and the process of combustion as a result is known as **fluidized bed combustion** .

benefits – compact boiler design, fuel flexibility, higher combustion efficiency and reduced emission of noxious pollutants such as SOx and NOx. The fuels burnt in these boilers include coal, washery rejects, rice husk, bagasse & other agricultural wastes. The fluidized bed boilers have a wide capacity range- 0.5 T/hr to over 100 T/hr.

When an evenly distributed air or gas is passed upward through a finely divided bed of solid particles such as sand supported on a fine mesh, the particles are undisturbed at low velocity. As air velocity is gradually increased, a stage is reached when the individual particles are suspended in the air stream – the bed is called "fluidized".

With further increase in air velocity, there is bubble formation, vigorous turbulence, rapid mixing and formation of dense defined bed surface. The bed of solid particles exhibits the properties of a boiling liquid and assumes the appearance of a fluid – "bubbling fluidized bed".

If sand particles in a fluidized state is heated to the ignition temperatures of coal, and coal is injected continuously into the bed, the coal will burn rapidly and bed attains a uniform temperature. The fluidized bed combustion (FBC) takes place at about 840 OC to 950 OC. Since this temperature is much below the ash fusion temperature, melting of ash and associated problems are avoided.

The lower combustion temperature is achieved because of high coefficient of heat transfer due to rapid mixing in the fluidized bed and effective extraction of heat from the bed through in-bed heat transfer tubes and walls of the bed. The gas velocity is maintained between minimum fluidisation velocity and particle entrainment velocity. This ensures stable operation of the bed and avoids particle entrainment in the gas stream.

Atmospheric Fluidized Bed Combustion (AFBC) Boiler

Most operational boiler of this type is of the Atmospheric Fluidized Bed Combustion. (AFBC). This involves little more than adding a fluidized bed combustor to a conventional shell boiler. Such systems have similarly being installed in conjunction with conventional water tube boiler.

Coal is crushed to a size of 1 – 10 mm depending on the rank of coal, type of fuel fed to the combustion chamber. The atmospheric air, which acts as both the fluidization and combustion air, is delivered at a pressure, after being preheated by the exhaust fuel gases. The in-bed tubes carrying water generally act as the evaporator. The gaseous products of combustion pass over the super heater sections of the boiler flow past the economizer, the dust collectors and the air preheater before being exhausted to atmosphere.

Pressurized Fluidized Bed Combustion (PFBC) Boiler

In Pressurized Fluidized Bed Combustion (PFBC) type, a compressor supplies the Forced Draft (FD) air and the combustor is a pressure vessel. The heat release rate in the bed is proportional to the bed pressure and hence a deep bed is used to extract large amount of heat. This will improve the combustion efficiency and sulphur dioxide absorption in the bed. The steam is generated in the two tube bundles, one in the bed and one above it. Hot flue gases drive a power generating gas turbine. The PFBC system can be used for cogeneration (steam and electricity) or combined cycle power generation. The combined cycle operation (gas turbine & steam turbine) improves the overall conversion efficiency by 5 to 8%.

Atmospheric Circulating Fluidized Bed Combustion Boilers (CFBC)

In a circulating system the bed parameters are so maintained as to promote solids elutriation from the bed. They are lifted in a relatively dilute phase in a solids riser, and a down-comer with a cyclone provides a return path for the solids. There are no steam generation tubes immersed in the bed. Generation and super heating of steam takes place in the convection section, water walls, at the exit of the riser.

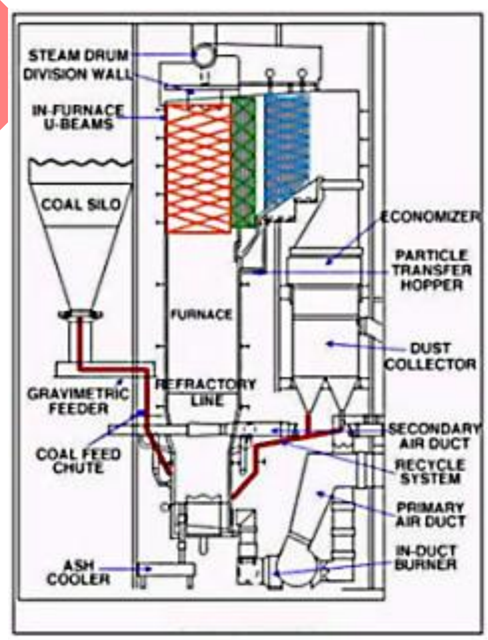


Fig: CFBC Boiler

Reference: http://www.tbwindia.com/boiler/cfbc_system.asp

CFBC boilers are generally more economical than AFBC boilers for industrial application requiring more than 75 – 100 T/hr of steam. For large units, the taller furnace characteristics of CFBC boilers offers better space utilization, greater fuel particle and sorbent residence time for efficient combustion and SO2 capture, and easier application of staged combustion techniques for NOx control than AFBC steam generators.

Advantages :

1) High thermal efficiency.
2) Easy ash removal system, to be transferred for made cement .
3) Short commissioning and erection period.
4) Fully automated and thus ensures safe operation, even at extreme temperatures.
5) Efficient operation at temperatures down to 150° C (i.e. well below the ash fusion temperature).
6) Reduced coal crushing etc.(pulverised coal is not a necessity here).
7) The system can respond rapidly to changes in load demand, due to quick establishment of thermal equilibrium between air and fuel particles in the bed.
8) The operation of fluidized bed furnace at lower temperature helps in reducing air pollution. The low temperature operation also reduces the formation of nitrogen oxides. By adding either dolomite (a calcium-magnesium carbonate) or lime stone (calcium carbonate) to the furnace the discharge of sulphur oxides to the atmosphere can also be reduced if desired.

Super Critical Boiler

The term "supercritical" refers to main steam operating conditions, being above the critical pressure of water (221. bar). o Above the critical pressure there is no distinction between steam and water, i.e. above 221. bar, water is a fluid.

Supercritical Pressure Pressure range

o Sub critical : Below 221 bar-a

o Super critical : 221bar-a and above STATES OF WATER : Critical Pt.= 221BAR,374 deg C

Benefit of supercritical technology

I) Higher cycle efficiency means o Primarily ν less fuel consumption ν less per MW infrastructure investments ν less emission ν less auxiliary power consumption ν less water consumption

II) Operational flexibility ν Better temp. control and load change flexibility ν Shorter start-up time ν More suitable for widely variable pressure operation

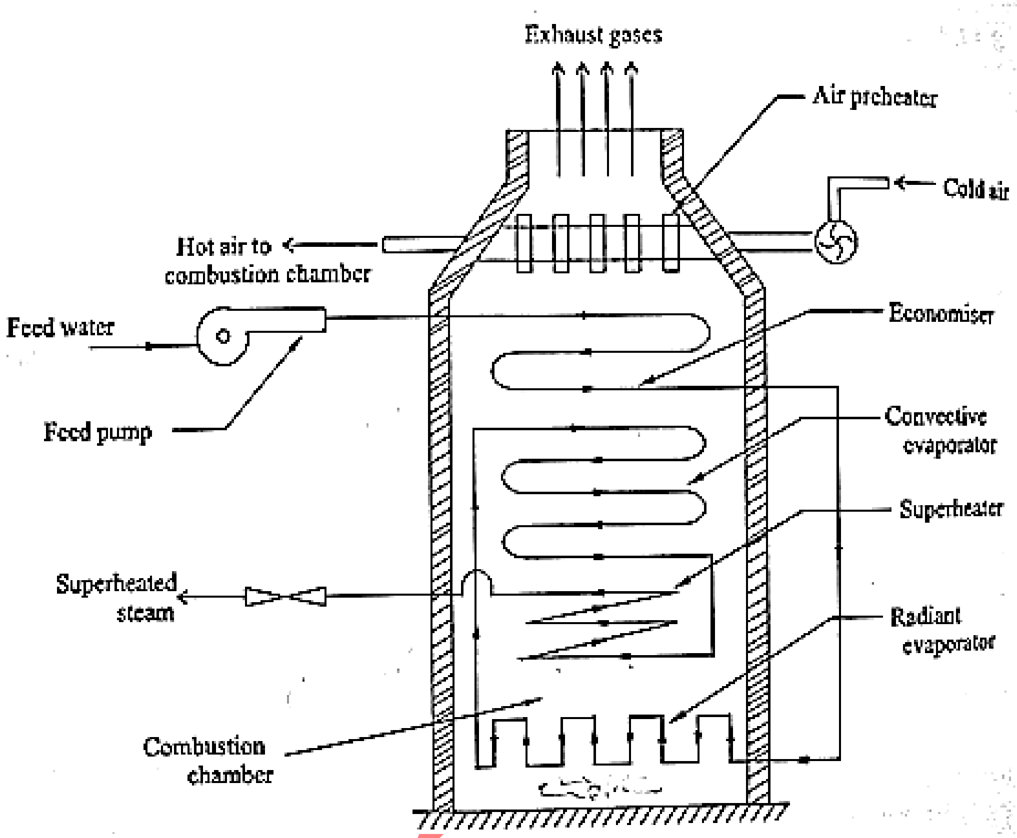
Similarities-subcritical & supercritical

- Basic operation of cycle is same i.e. Rankine Cycle.
- Constructional Features are also same except supercritical is drumless Boiler.

- The equipments & philosophy of working are similar in both the cases like: Air preheater , Economiser , PA, SA & ID fans,Electrostatic precipitator,Boiler feed pump , Feed water heaters, Turbine andCondenser

BENSON BOILER (SUPERCRITICAL BOILER)

The main difficulty experienced in the La Mont boiler is the formation and attachment of ubbles on the inner surfaces of the heating tubes. The attached bubbles reduce the heat flow and steam generation as it offers higher thermal resistance compared to water film. Benson of siemens- West Germany in 1922 argued that if the boiler pressure was raised to critical pressure(225 atm.), the steam and water would have the same density and therefore the danger of bubble formation can be completely removed.



Important Components

1. Economiser – The feed water from the well passes through the economiser where it is pre-heated by the pre-heat of exhaust hot flue gases.
2. Radiant evaporator – The feed water after circulation through the economiser flow sthrough the radiant evaporator tubes. Water is heated up by the radiation heat from the combustion chamber. Here, part of the water is converted to steam directly.

3. Convective evaporator – The mixture of water and steam coming out from the radiant evaporator enters the convective evaporator tubes. The hot flue gases passing over the evaporator tubes transfer a large portion of heat to the water by convection. Thus, water becomes steam in the convective evaporator.
4. Superheater – The steam from the convective evaporator enters the superheater tubes where it is superheated by the hot flue gases passing over them. The superheated steam then enters the steam turbine to develop power.
5. Air pre-heater – The hot flue gases then passes through the air pre-heater where the air required for combustion is pre-heated.

Advantages

1. As there is no drum, the total weight of Benson boiler is 20% less than other boilers.
This reduces the cost of the boiler.
2. Floor space requirements of Benson boiler are very less.
3. Transportation of Benson boiler parts and its erection is very easy as there are no drums.
4. Natural circulation boilers require expansion joints in pipes but the pipes in Benson boilers are welded.

Disadvantages

1. As the Benson boiler operates at high pressure and temperature, special alloy materials are required.
2. Maintenance costs are very high.
3. This is more efficient, resulting in slightly less fuel use.

The term "boiler" should not be used for a supercritical pressure steam generator, as no "boiling" actually occurs in this device.

4. TURBINES :

- **A steam turbine is a prime mover in which potential energy is converted into kinetic energy and then to Mechanical energy.**

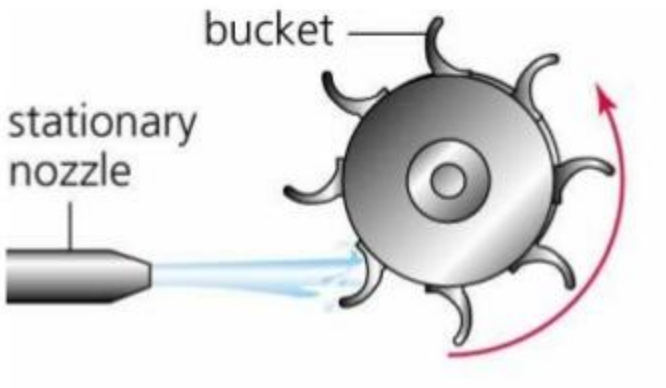
Types of Turbine

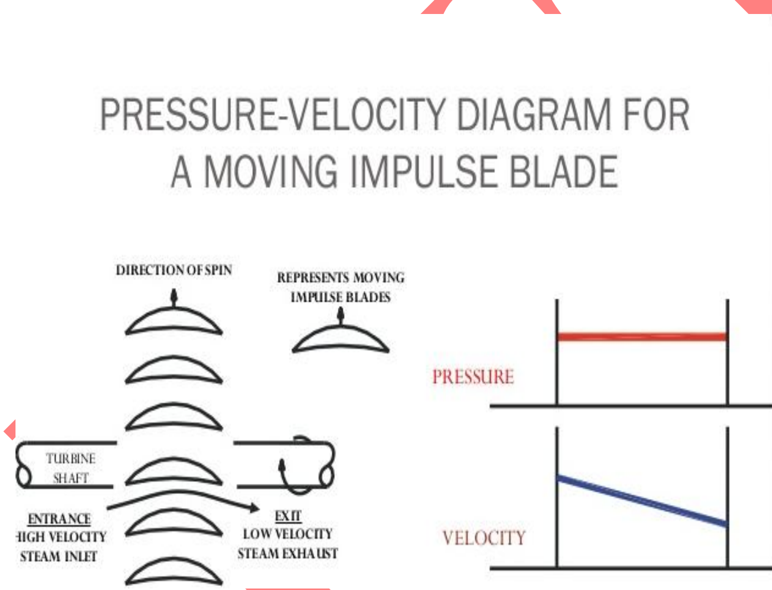
1. Impulse Turbine.
2. Reaction Turbine.

- The main difference between these two turbines lies in the way of expanding the steam while it moves through them.
- In the impulse turbine, the steam expands in the nozzles and it's pressure does not alter as it moves over the blades. In the reaction turbine the stea m expanded
- continuously as it passes over the blades and thus there is gradually fall in the pressur e during expansion below the atmospheric pressure.

Impulse Turbine

- It the impulse turbine, the steam expanded within the nozzle and there is no any change in the steam pressure as it passes over the blades



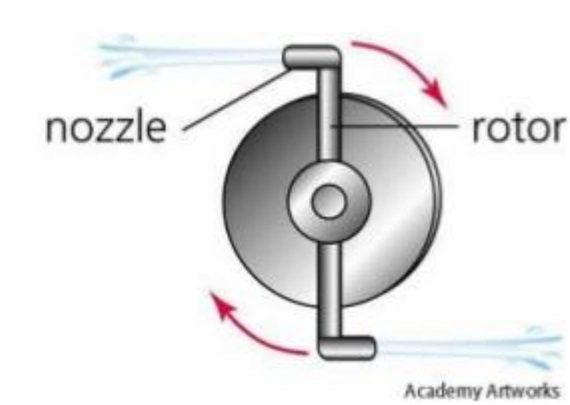


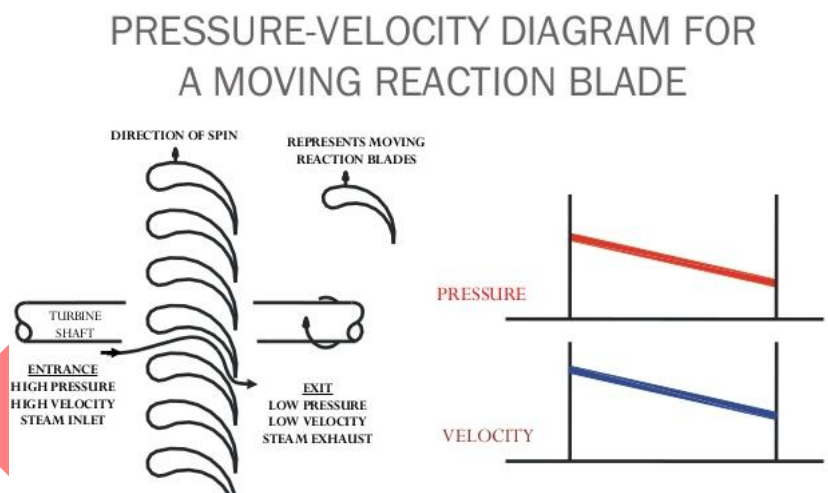
- **Reaction Turbine:**

In this type of turbine, there is a gradual pressure drop and takes place continuously over the fixed and moving blades. The rotation of the shaft and drum, which carrying the blades is the result of both impulse and reactive force in the steam. The reaction turbine consist of a row of stationary blades and the following row of moving blades

The fixed blades act as a nozzle which are attached inside the cylinder and the moving blades are fixed with the rotor as shown in figure When the steam expands over the blades there is gradual increase in volume and decrease in pressure. But the velocity decrease in the moving blades and increases in fixed blades with change of direction.

Because of the pressure drops in each stage, the number of stages required in a reaction turbine is much greater than in a impulse turbine of same capacity. It also concluded that as the volume of steam increases at lower pressures therefore the diameter of the turbine must increase after each group of blade rings.





4.CONDENSER :

The heat transfer device in which the exhaust steam of a turbine or an engine is condensed by means of cooling water at pressure below atmospheric, is called Steam Condenser.

Condensate:

The condensed Steam is called Condensate and can be again returned to Boiler. It saves the cost of water.

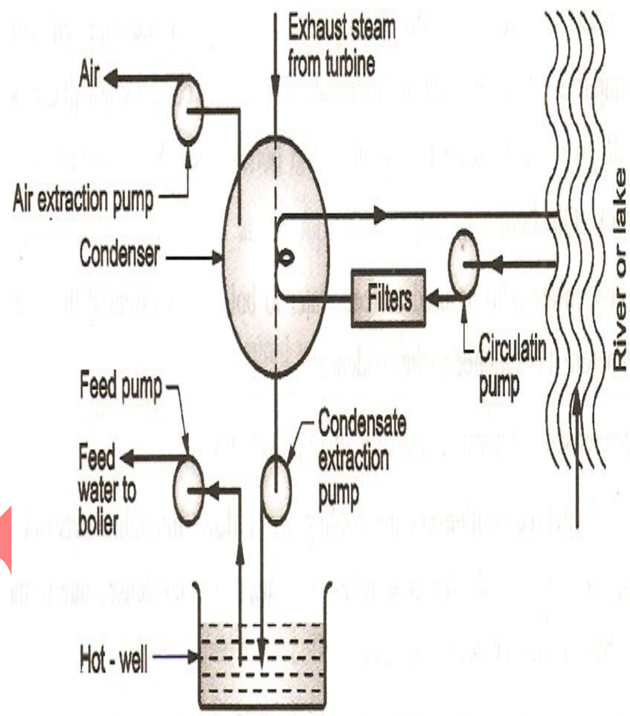
Advantages :

- It increases the work output per kg of steam supplied to the power plant.
- Reduces the specific steam consumption.
- Reduces the size of power plant of given capacity.
- Improves the thermal efficiency of power plant.

• Saves the cost of water to be supplied to boiler.

ELEMENTS OF CONDENSING PLANT:

- **CONDENSER**: In which the exhaust steam of the turbine is condensed by circulating cooling water.
- **CONDENSATE EXTRACTION PUMP:** to remove the condensate from the condenser and feed it into the hot-well. The feed water from hot-well is further pumped to boiler.



- **AIR EXTRACTION PUMP**: to remove air from the condenser, such a pump is called dry air pump. If air and condensate both are removed, it is called as wet air pump.
- **CIRCULATING PUMP**: used to supply feed water either from river or from the cooling tower pond to the condenser.
- **COOLING TOWER:**
- The Ferro concrete made device (hyperbolic shape) in which the hot water from the condenser is cooled by rejecting heat to current of air passing in the counter direction.
- Ring troughs are placed 8-10m above the ground level.

TYPES OF CONDENSERS:

Jet Condensers :

In jet condensers, there is direct contact between the cooling water and the steam which is to be condensed.

Surface Condensers :

In surface condensers, there is no direct contact between the cooling water and the steam which is to be condensed.

S.No	Jet condensers	Surface condensers
1.	Steam and water comes in direct contact.	Steam and water does not come in direct contact.
2.	Condensation is due to mixing of coolant.	Condensation is due to heat transfer by conduction and convection.
3.	Condensate is not fit for use as boiler feed until the treated cooling water is supplied.	Condensate is fit for reuse as boiler feed.
4.	It is cheap. Does not affect plant efficiency.	It is costly. Improves the plant efficiency.
5.	Maintenance cost is low.	Maintenance cost is high.
6.	Vacuum created is up to 600 mm of Hg.	Vacuum created is up to 730 mm of Hg.

CLASSIFICATION OF JET CONDENSERS:

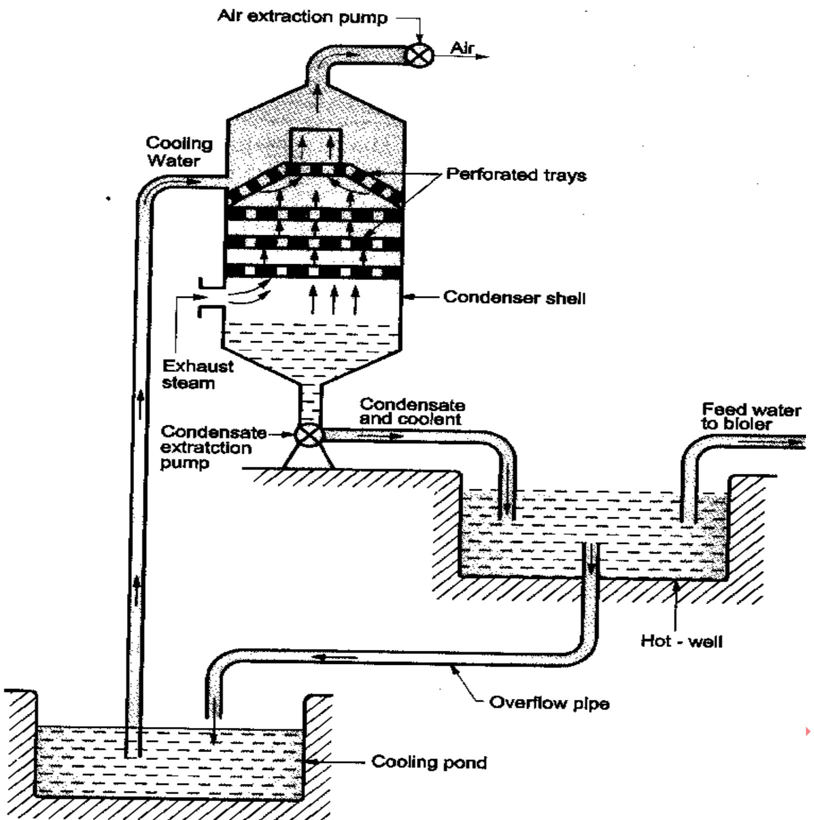
1. **1.Low level jet condensers**
   i) *Counter flow type*
   ii) *Parallel flow type*

2. High level jet injectors

3. Ejector jet condensers

1.(i). LOW LEVEL COUNTER FLOW JET INJECTOR :

- The cooling water to be lifted into the condenser up to a height of 5.5m.
- It is having disadvantage of flooding the steam turbine if the condensate extraction pump fails.



1.*(ii)* LOW LEVEL PARALLEL FLOW JET INJECTOR

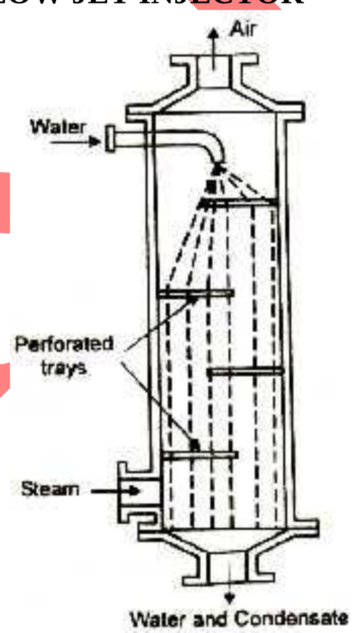


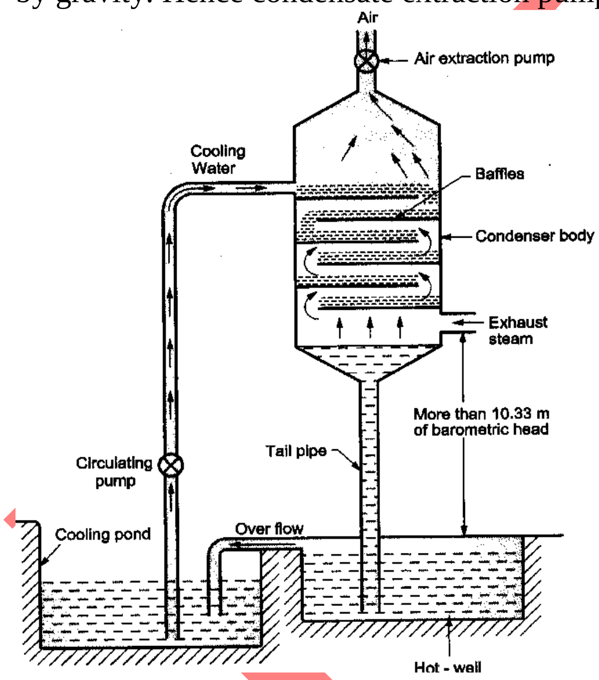
Figure: Low level jet condenser

A low level counter flow jet condenser is shown in figure. In this condenser, the cooling water enters at the top and sprayed through jets. The steam enters at the bottom and mixes with the fine spray of cooling water. The condensate is removed by a separate pump. The air is removed by an air pump separately from the top.

In a parallel flow type of this condenser, the cooling water and steam to be condensed move in the same direction. [i.e., from top to bottom].

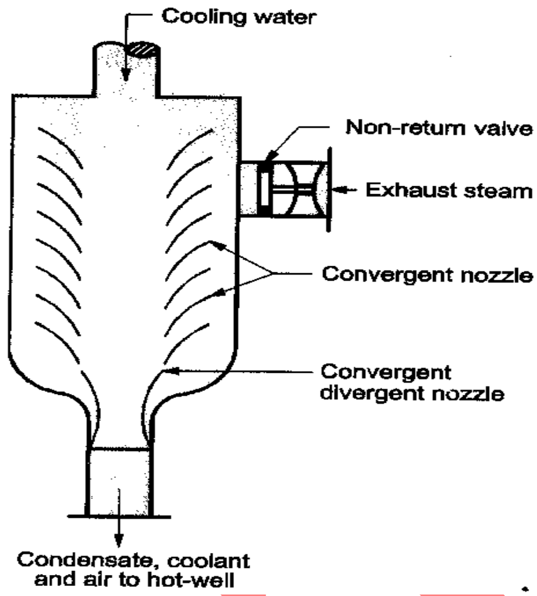
2. HIGH LEVEL JET CONEDNSER/ BAROMETRIC JET CONDENSER :

- It is also called Barometric jet condenser since it is placed above the atmospheric pressure equivalent to 10.33 m of water pressure. Condensate extraction pump is not required because tail pipe has incorporated in place of it.
- A high level jet condenser is shown in figure. This is similar to a low level condenser,
- except that the condenser shell is placed at a height of 10.36 m [barometric height] above the hot well. The column of water in the tail pipe forces the condensate into the hot well by gravity. Hence condensate extraction pump is not required.



3. EJECTOR JET CONDENSER:

An ejector condenser is shown in figure. In this condenser cooling water under a head of 5 to 6 m enters at the top of the condenser. It is passed through a series of convergent nozzles. There is a pressure drop at the throat of the nozzle. The reduction is pressure draws exhaust steam into the nozzle through a non-return valve. Steam is mixed with water and condensed. In the converging cones, pressure energy is partly converted into kinetic energy. In diverging cones, the kinetic energy is partly converted into pressure energy. The pressure obtained is higher than atmospheric pressure and this forces the condensate to the hot well.



Merits and Demerits of jet condensers

Merits

1. Intimate mixing of steam and cooling water.
2. Quantity of cooling water required is less.
3. Simple equipment and cost is low.
4. Less space is required.
5. Cooling water pump is not needed in low level jet condenser. Condensate extraction pump is not required for high level and ejector condensers

Demerits

1. Condensate is wasted.
2. The cooling water should be clean and free from harmful impurities.
3. In low level jet condensers, the engine may be flooded, if condensate extraction pump fails

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 a 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 b 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:

1. Down flow condenser
2. Central flow condenser
3. Evaporative condenser

Down flow condenser

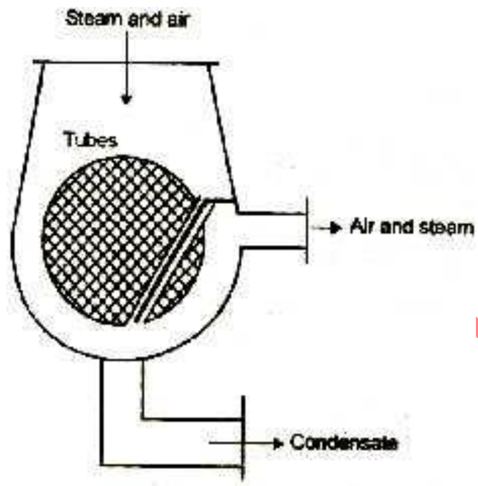


Figure: Sectional views of down flow condenser.

Figure 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. In this type of condenser, the cooling water and exhaust steam do not come in direct contact with each other as in case of jet condensers. This is generally used where large quantities of inferior water are available and better quantity of feed water to the boiler must be used most economically. The arrangement of the surface condenser is shown in figure. It consists of cast iron airtight cylindrical shell closed at each end as shown in figure. A number of water tubes are fixed in the tube plates which are located between each cover head and shell.

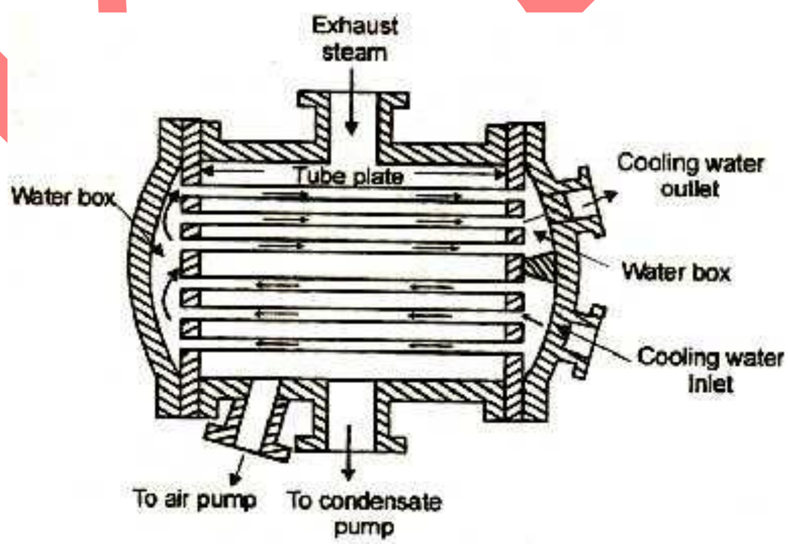


Figure: Surface condenser

The exhaust steam from the prime mover enters at the top of the condenser and surrounds the condenser tubes through which cooling water is circulated under force. The steam gets condensed as it comes in contact with cold surface of the tubes. The cooling water flows in one direction through the first set of the tubes situated in the lower half of condenser and returns in the opposite direction through the second set of the condenser is discharged into the river or pond. The condensed steam is taken out from the condenser by a separate extraction pump and air is removed by an air pump.

2. Central flow condenser.

Figure 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 centre of the condenser. The condensate moves radially towards the centre of the tube next. Some of the exhaust steam which moving towards the centre meets the under cooled condensate and pre-heats it thus reducing under cooling.

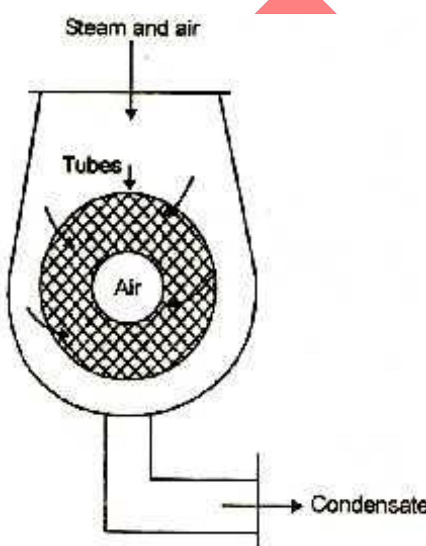


Figure: Central flow condenser

3. Evaporative condenser

In this condenser steam to be condensed in passed through a series of tubes and the cooling water falls over these tubes 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.These condensers are more preferable where acute shortage of cooling water exists. The arrangement of the condenser is shown in figure. Water is sprayed through the nozzles over the pipe carrying exhaust steam and forms a thin film over it. The air is drawn over the surface of the coil with the help of induced fan as shown in figure. The air passing over the coil carries the water from the surface of condenser coil in the form of vapour.

The latent heat required for the evaporation of water vapour is taken from the water film formed on the condenser coil and drops the temperature of the water film and this helps for heat transfer from the steam to the water. This mode of heat transfer reduces the cooling water requirement of the condenser to 10% of the requirement of surface condensers. The water particles carried with air due to high velocity of air are removed with the help of eliminator as shown in the figure. The make-up water (water vapour and water particles carried with air) is supplied from outside source.

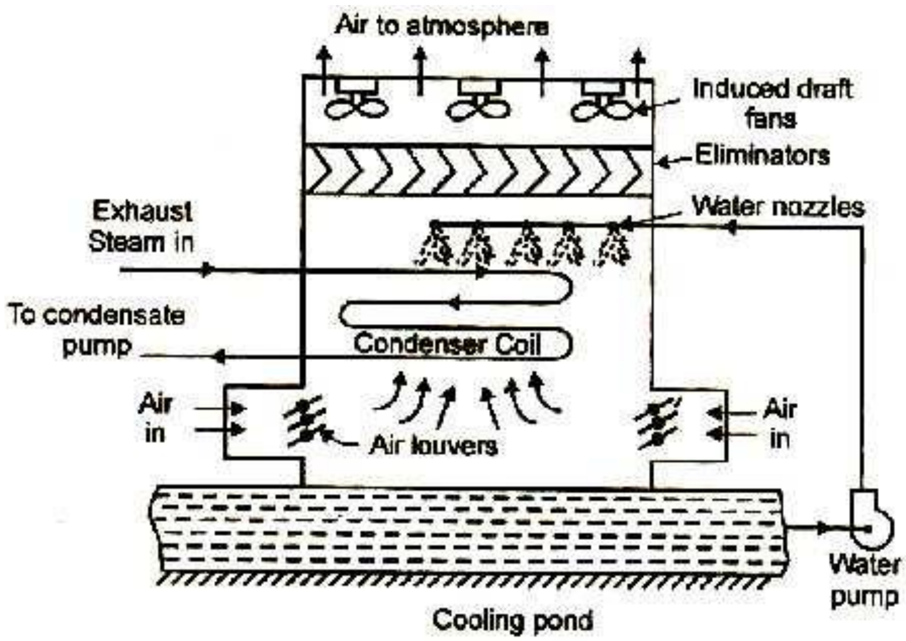


Figure: Evaporative condenser

The quantity of water sprayed over the condenser coil should be just sufficient to keep the condenser coil thoroughly wetted. The water flow rate higher than this will only increase the power requirement of water pump without materially increasing the condenser capacity. This type of condenser works better in dry weather (low WBT) compared with wet weather as the water vapour carrying capacity of dry air is higher than wet air at the same temperature. The arrangement of this type of condenser is simple and cheap in first cost. It does nor require large quantity of water therefore needs a small capacity cooling water pump. The vacuum maintained in this condenser is not as high as in surface condensers therefore the work done per kg of steam is less with this condenser compared with surface condenser. These condensers are generally preferred for small power plants and where there is acute shortage of cooling water.

Advantages and disadvantages of a surface condenser:

The various advantages of a surface condensers are as follows:

(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 cm of Hg) can be obtained in the surface condenser. This increases the thermal efficiency of the plant.

The various disadvantages of the surface condenser are as follows:

i)The capital cost is more.

ii)The maintenance cost and running cost of this condenser is high.

iii)It is bulky and required more space.

6. STEAM & HEAT RATE

Heat rate is the common measure of system efficiency in a steam power plant. It is defined as "the energy input to a system, typically in Btu/KWh, divided by the electricity generated, in kW." Mathematically:

Heat Rate = Input Energy (Btu/Hr) / Output Energy (KW)

Efficiency is "a ratio of the useful energy output by the system to the energy input to the system." Mathematically:

Efficiency = Useful Output Energy / Input Energy

Steam rate is defined as the rate of rate of steam flow(Kg/hr) required for producing unit shaft output (1KW) therefore,

Steam rate = $3600\ .Q1/\ W_{net}$ (kg/kwhr)

7. COAL (FUEL) HANDLING

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

1. Coal delivery.
2. Unloading
3. Preparation
4. Transfer Outdoor storage
5. Covered storage
6. Inplant handling
7. Weighing and measuring
8. Feeding the coal into furnace.

i) Coal delivery

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. The transportation of coal by trucks is used if the railway facilities are not available.

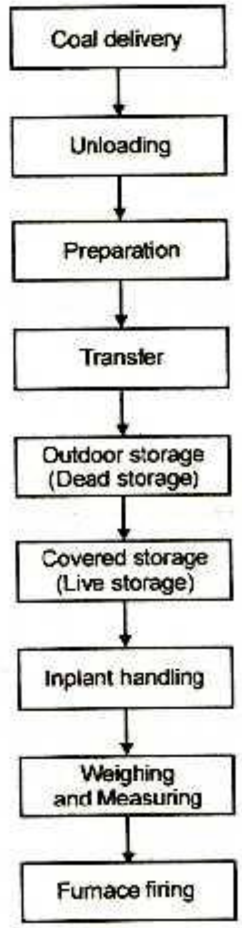


Figure: Steps involved in fuel handling system

ii) 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 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 railways 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.

(iii) 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.

iv)Transfer

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

1. Belt conveyors
2. Screw conveyors
3. Bucket elevators
4. Grab bucket elevators
5. Skip hoists
6. Flight conveyor

Belt Conveyor

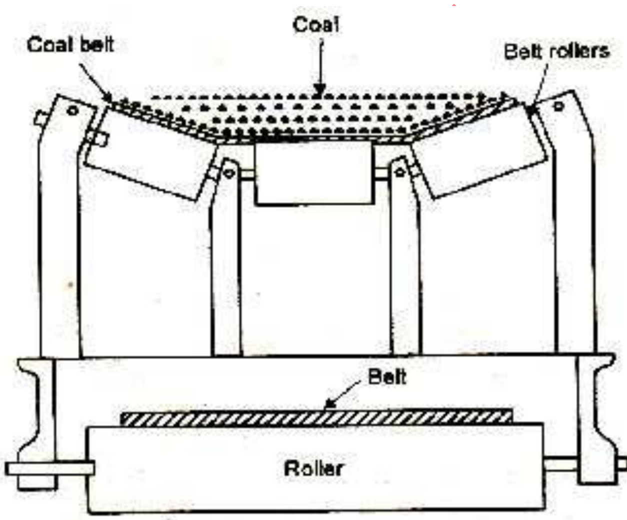


Figure: Belt Conveyor

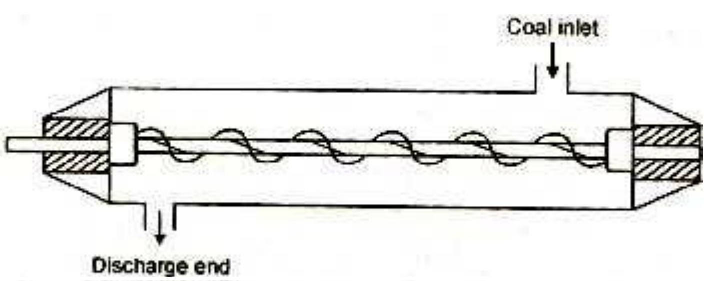
Figure shows a belt conveyor. It consists of an endless belt moving over a pair of end drums (rollers). At some distance a supporting roller is provided at the centre. The belt is made up of rubber or canvas. Belt conveyor is suitable for the transfer of coal over long distances. It is used in medium and large power plants. The initial cost of 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^o. Average speed 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. Material can be transported on moderate inclines.

2. Screw Conveyor

It consists of an endless helicoid screw fitted to a shaft (figure). 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 consumption is high and there is considerable wear o screw. Rotation of screw varies between 75-125 r.p.m

3. Bucket elevator

It consists of buckets fixed to a chain (figure). The chain moves over two wheels. The coal is carried by the bucket from bottom and discharged at the top.

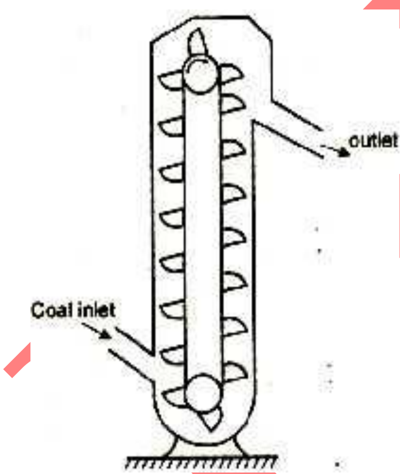


Figure: Bucket elevator

4. 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 figure . Although the initial cost of this system is high but operating cost is less.

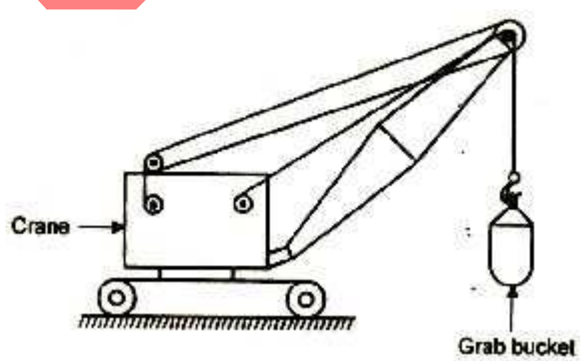
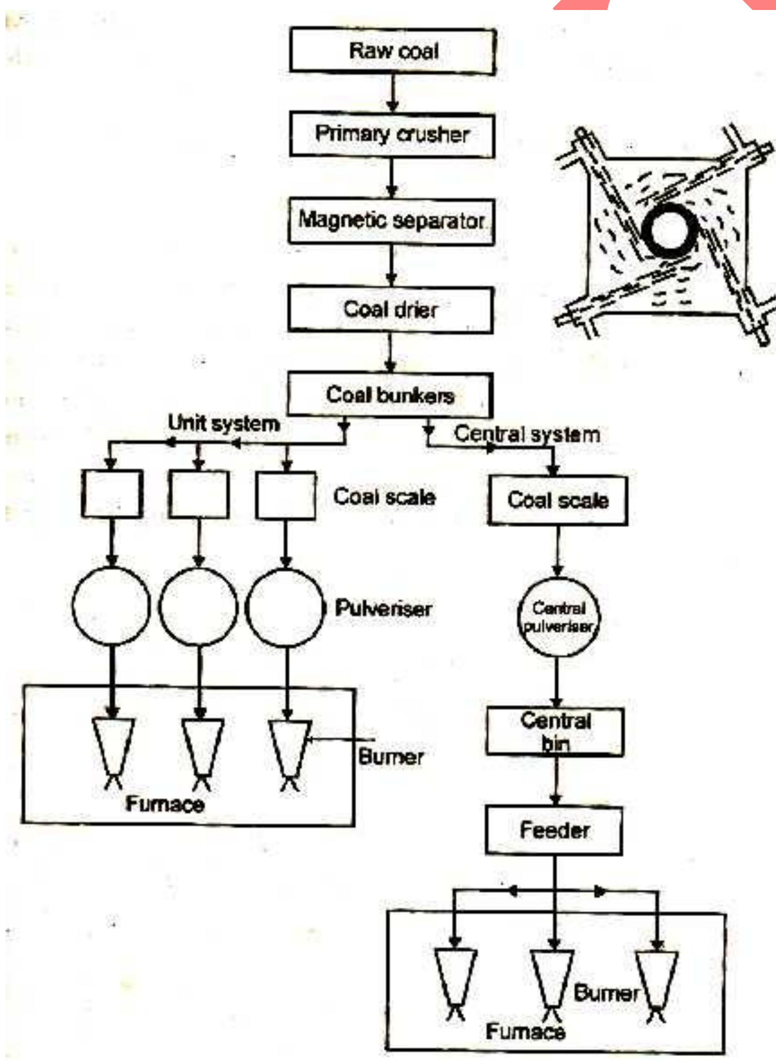


Figure: Grab bucket elevator

Storage of Coal

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 strike 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 one month operation of power plant is stored in case of power stations are 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.

Pulverized Fuel Handling System:



Two methods are in general use to feed the pulverized fuel to the combustion chamber of the power plant. First is ‘Unit System’ and second is ‘Central or Bin System ‘. In unit system, each burner of the plant is fired by one or more pulverizers connected to the burners, while in the central system, the fuel is pulverized in the central plant and then disturbed to each furnace with the help of high pressure air current. Each type of fuel handling system consists of crushers, magnetic separators, driers, pulverizing mills, storage bins, conveyors and feeders.

Figure: Pulverized coal handling plant showing all required equipment for unit and central system.

The arrangement of different equipment required in both systems is shown in figure. With the help of a block diagram.The coal received by the plant from the mine may vary widely in sizes. It is necessary tomake the coal of uniform size before passing the pulverizer for efficient grinding. The coal received from the mine is passed through a preliminary crusher to reduce the size to allowable limit (30 mm). The crushed coal is further passed over magnetic separator which removes pyrites and tramp iron. The further equipment through which coal is passed before passing to pulverizer are already shown in figure.

8. ASH HANDLING SYSTEM:

Boilers burning pulverized coal (PC) have 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 baghouse. 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 figure. Pyrites, which are the rejects from the pulverizers, are disposed of with the bottom ash system. Three major factors should be considered for ash disposal systems.

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

Needs for water and land are important considerations for many ash handling systems. Ash quantities to be disposed of depend on the king of fuel source. Ash storage and disposal sites are guided by environmental regulations.

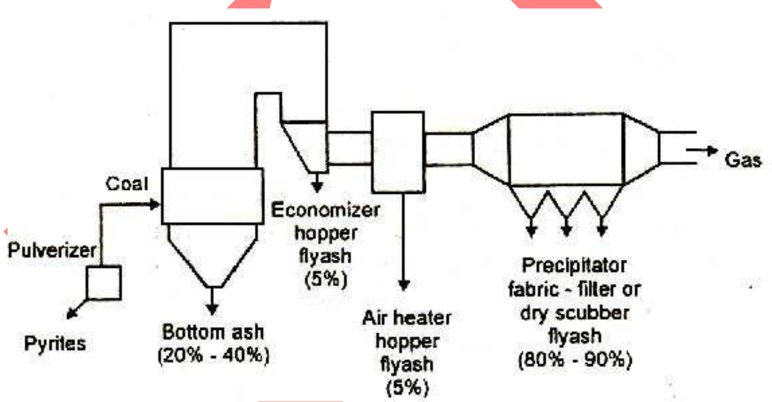


Figure: Layout of ash collection and transportation

The sluice conveyor system is the most widely used for bottom ash handling, while the hydraulic vaccum conveyor (figure) is the most frequently used for fly systems.

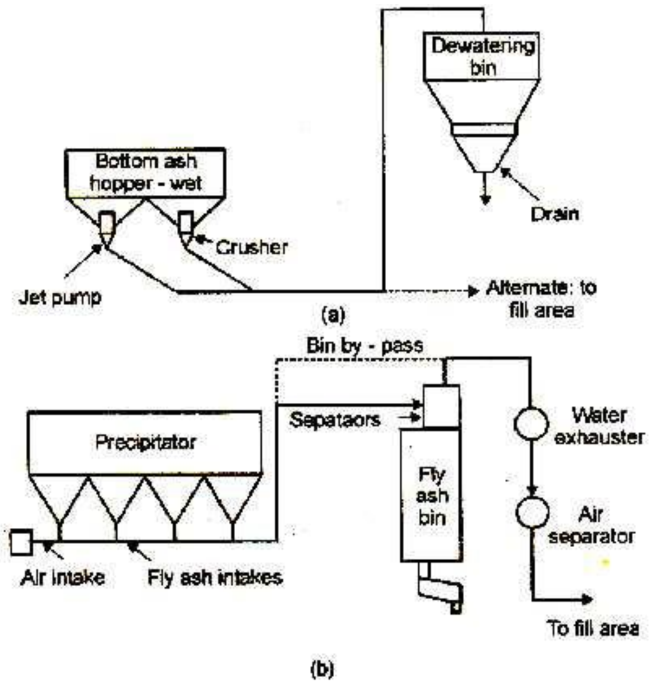


Figure: Layout of ash handling system.

Bottom 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.

Ash Handling Equipment:

Mechanical means are required for the disposal of ash. The handling equipment should perform the following functions: 1. Capital investment, operating and maintenance charges of the equipment should be low. 2. It should be able to handle large quantities of ash. 3. Clinkers, shoot, dust etc. create troubles. The equipment should be able to handle them smoothly. 4. The equipment used should remove the ash from the furnace, load it to the conveying system to deliver the ash to dumping site or storage and finally it should have means to dispose of the stored ash. 5. The equipment should be corrosion and wear resistant.

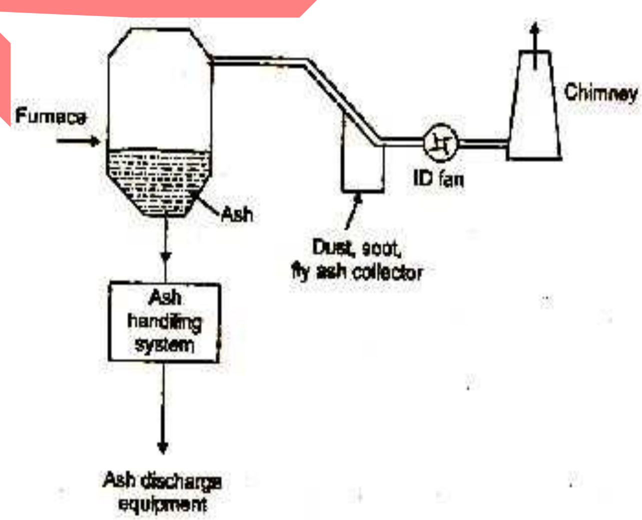


Figure: Ash handling equipment

Classification of Ash Handling System:

i) Hydraulic system

ii) Pneumatic system

iii) Mechanical system

The commonly used ash discharge equipment is as follows:

i) Rail road cars ii) Motor truck iii) barge

Hydraulic System

In this system, ash from the furnace grate falls into a system of water possessing high velocity and is carried to the sumps. It is generally used in large power plants. Hydraulic system is of two types, namely, low pressure hydraulic system used for intermittent ash disposal figure. Figure shows hydraulic system.

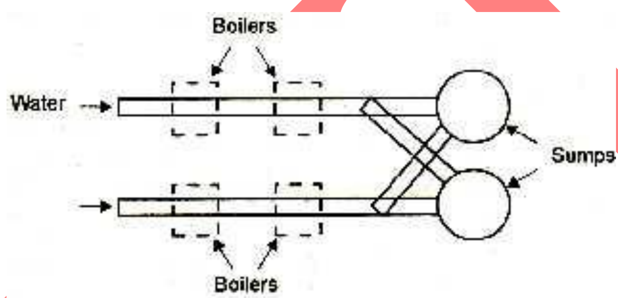


Figure: Hydraulic system

In this method water at sufficient pressure is used to take away the ash to sump. Where water and ash are separated. The ash is then transferred to the dump site in wagons, rail cars to trucks. The loading of ash may be through a belt conveyor, grab buckets. If there is an ash basement with ash hopper the ash can fall, directly in ash car or conveying system.

Water-Jetting System

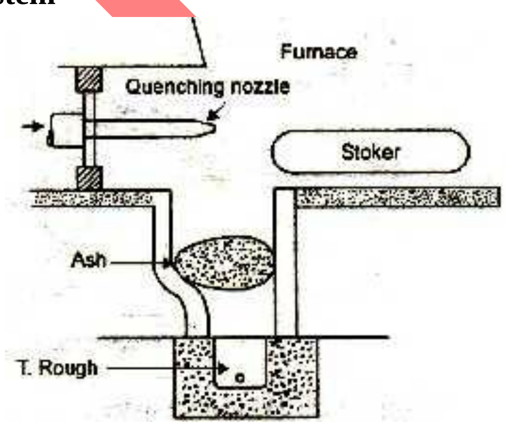


Figure: Water jetting

Water jetting of ash is shown in figure. In this method a low pressure jet of water coming out of quenching nozzle is used to cool the ash. The ash falls into trough and is then removed.

Pneumatic System

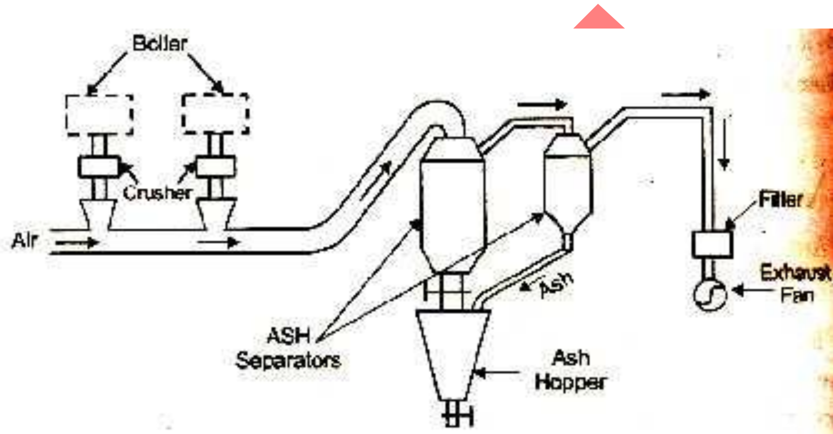


Figure: Pneumatic system

Mechanical system

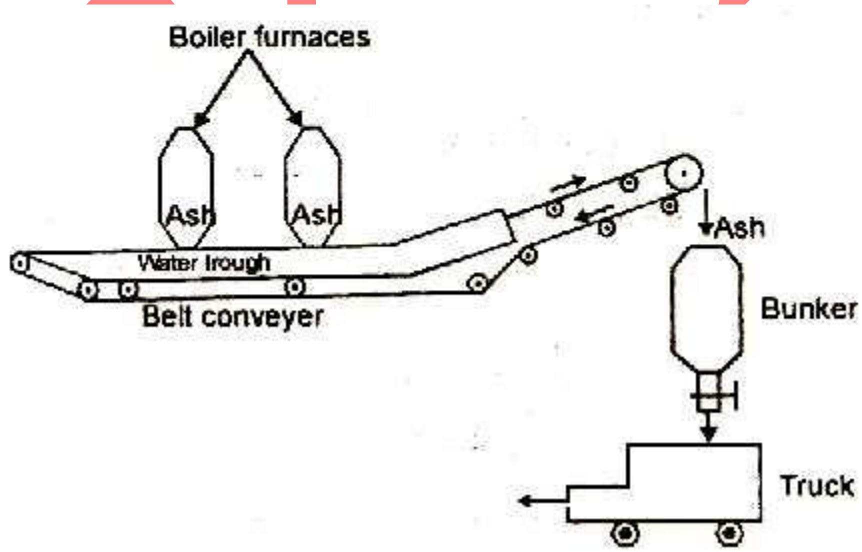


Figure: Mechanical system

Figure shows a mechanical ash handling system. In this system ash cooled by water seal falls on the belt conveyor and is carried out continuously to the bunker. The ash is then removed to the dumping site from the ash banker with the help of trucks.

9. DRAUGHT:

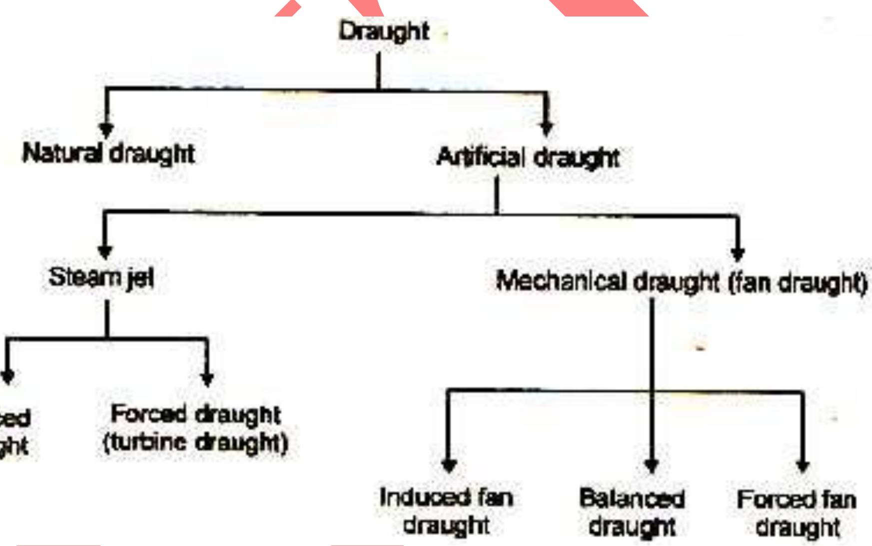
Draught is defined as the difference between absolute gas pressure at any point in a gasflow passage and the ambient (same elevation) atmospheric pressure. Draught is plus if Patm < Pgas and it is minus Patm > Pgas. Draught is achieved by small pressure difference which causes the flowof air or gas to take place. It is measured in milimetre (mm) or water.

The purpose of draught is as follows:

i)To supply required amount of air to the furnace for the combustion of fuel. The amount of fuel that can be burnt per square root of grate area depends upon the quantity of air circulated through fuel bed.

ii)To remove the gaseous products of combustion.

Classification of DRAUGHT:



If only chimney is used to produce the draught, it is called natural draught.

Artificial Draught

If the draught is produced by steam jet or fan it is known as artificial draught

Steam jet Draught:

It employs steam to produce the draught

Mechanical draught

It employs fan or blowers to produce the draught.

Induced draught

The flue is drawn (sucked) through the system by a fan or steam jet

Forced draught

The air is forced into system by a blower or steam jet.

Natural Draught:

Natural draught system employs a tall chimney as shown in figure. The chimney is a vertical tubular masonry structure or reinforced concrete. It is constructed for enclosing a column of exhaust gases to produce the draught. It discharges the gases high enough to prevent air pollution. The draught is produced by this tall chimney due to temperature difference of hotgases in the chimney and cold external air outside the chimney.

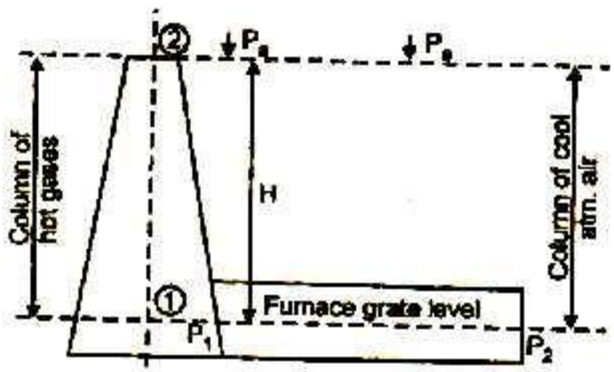


Figure: Natural draught

Where H- Height of the Chimney (m)pa – Atmospheric pressure (N/m)

p1 – Pressure acting on the grate from chimney side (N/m2)

p2 – Pressure acting on the grate from atmospheric (N/m2)

Due to this pressure difference (p), the atmospheric air flows through the furnace grate and the flue gases flow through the chimney. The pressure difference can be increased by increasing the height of the chimney or reducing the density of hot gases.

Merits of Natural Draught

1. No external power is required for creating the draught.
2. Air pollution is prevented since the flue gases are discharged at a higher level
3. Maintenance cost is practically nil since there are no mechanical parts.
4. It has longer life.
5. Capital cost is less than that of an artificial draught

Demerits of natural draught

1. Maximum pressure available for producing draught by the chimney is less.
2. Flue gases have to be discharged at high temperature since draught increases with the increase in temperature of flue gases.
3. Heat cannot be extracted from the flue gases for economizer, superheater, air pre-heater, etc. since the effective draught will be reduced if the temperature of the flue gases is decreased.
4. Overall efficiency of the plant is decreased since the fluid gases are discharged at higher temperatures.
5. Poor combustion and specific fuel consumption is increased since the low velocity of air affects thorough mixing of air and fuel.
6. Not flexible under peak loads since the draught available for a particular height of a chimney is constant.
7. A considerable amount of heat released by the fuel (about 20%) is lost due to flue gases.

Applications
Natural draught system is used only in small capacity boilers and it is not used in high capacity thermal plants.

Forced Draught

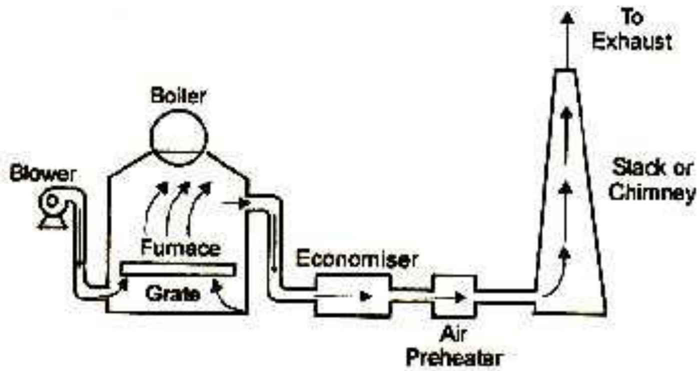


Figure: Forced draught

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

Induced Draught:

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

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

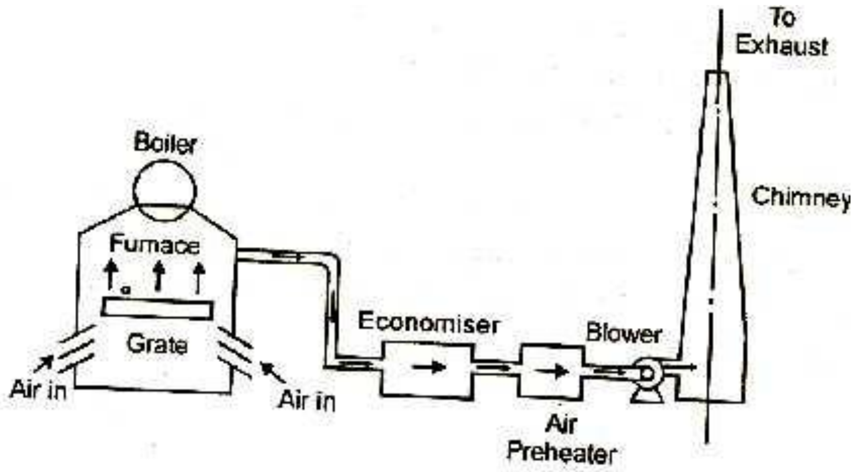


Figure: Induced draught

Balanced Draught:

It is always preferable to use a combination of forced draught and induced draught instead of forced or induced draught alone. If the forced draught is used alone, then the furnace cannot be opened either for firing or inspection because the high pressure air inside the furnace will try to blow out suddenly and thereis every chance of blowing out the fire completely and furnace stops. If the induced draught is used alone, then also furnace cannot be opened either for firing or inspection because the cold air will try to rush into the furnace as the pressure inside the furnace is below atmospheric pressure. This reduces the effective draught and dilutes the combustion.

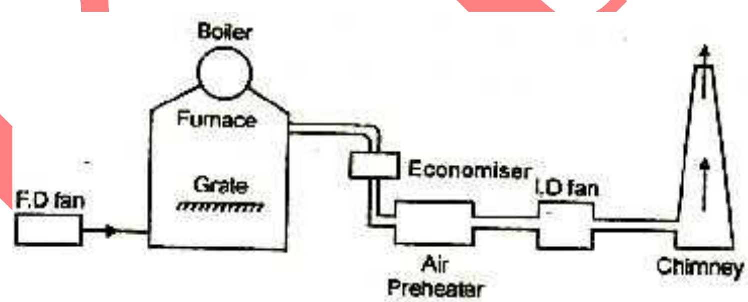


Figure: Balanced draught

To overcome both the difficulties mentioned above either using forced draught or induced draught alone, a balanced draught is always preferred. The balanced draught is a combination of forced and induced draught. The forced draught overcomes the resistance of the fuel bed there fore sufficient air is supplied to the fuel bed for proper and complete combustion. The induced draught fan removes the gases from the furnace maintaining the pressure in the furnace just below atmosphere. This helps to prevent the blow – off of flames when the doors are opened as the leakage of air is inwards.

The arrangement of the balanced draught is shown in figure. Also the pressure inside the furnace is near atmospheric therefore there is no danger of blowout or there is no danger of inrushing the air into the furnace when the doors are opened for inspection.

S.No	Forced Draught	Induced Draught
1	The size and power required by the F.D. fan is less.	The size and power required by I.D. fan is more.
2	Volume of gas handled is less. Water cooled bearings are not required.	Volume of gas handled is more. Water cooled bearings are required to withstand high temperature flue gas.
3	There is no chance of air leakage as the pressure inside the furnace is above atmospheric.	Continuous air leakage is possible as the pressure inside the furnace is less than atmosphere.
4	The flow of air through the grate and furnace is uniform.	Flow of air is not uniform
5	The heat transfer efficiency will be increased.	There may a chance of reduction in heat transfer efficiency.

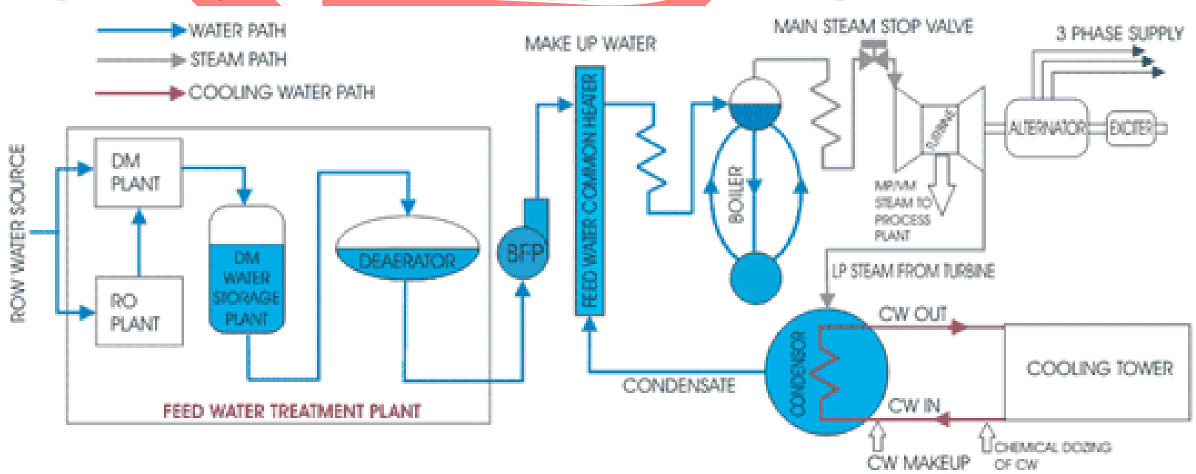
10. FEED WATER TREATMENT

For continuous supply of feed water to boiler, after removing impurities, there are two types of plant generally incorporated. These are:
(1) **Demineralization plant** (**D M plant**) (2) **Reverse Osmosis plant** (**R O plant**)

Demineralization plant employs a chemical method to separate out the dissolved salt in raw water. But **reverse osmosis plant** employs a simple physical method to separate the dissolved salts. Before feeding the raw water to these plants sand filtration is done by different filters.

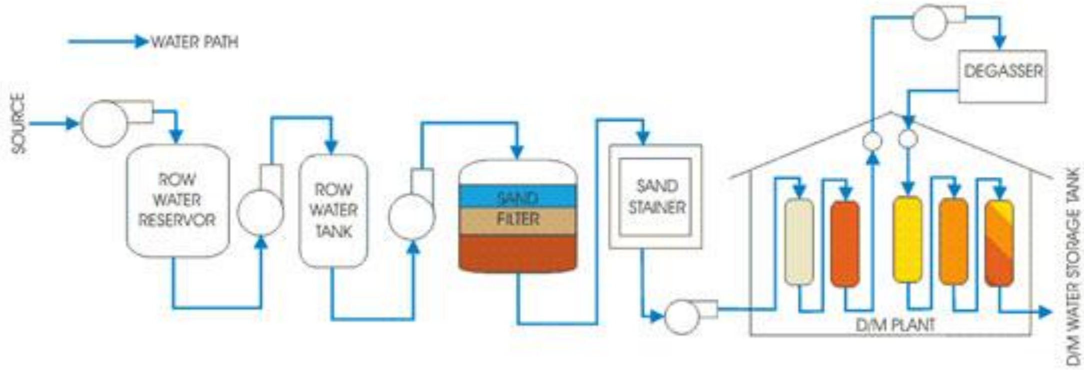
Along with these plants there are two **deaerators**, which remove dissolved oxygen in the feed water, as traces of oxygen may react with boiler tubes and thereby corrode those.

Complete arrangements and inside equipment of these plants are described below.



Demineralization Plant

The function of demineralization plant is to remove dissolved salt by ion exchange method (chemical method) and there by producing pure feed water for boiler.



The salts which make the water hard are generally-chloride, carbonates, bi-carbonates, silicates & phosphates of sodium, potassium, iron, calcium and magnesium.

In **D M plant** there are three types of resin used for **boiler feed water treatment process** -

(1) Cation exchange resin (2) Anion exchange resin (3) Mixed Bed resin

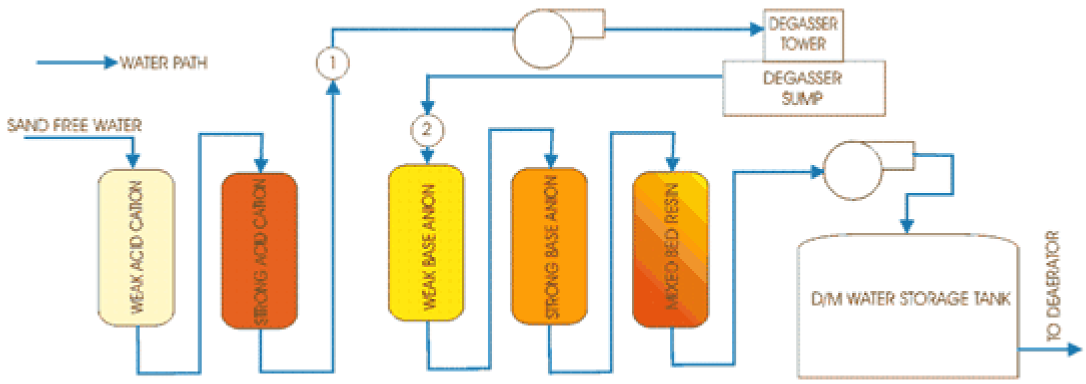
1. Resins are chemical substances (usually polymers of high molecular weight) used to react with salts & eliminates them by chemical process.
2. As the name suggests, the cation exchange resin, exchanges the cation & anion exchange resin, exchanges anions with the salts dissolved in hard-water.

Cation Exchange Resin

$NaCl + RSO_3H = RSO_3^- Na^+ + HCl$ Thus H_2SO_4, H_2CO_3 are also produced. We have removed Na^+ but the water has become acidic.

Anion Exchange Resin

$HCl + R_4NOH = R_4NCl + H_2O$ This way we have eliminated Cl^- and thus acidity of the water. Similar Reaction for H_2SO_4 also.



Mixed Bed Resins

These mixed bed resins are used in Demineralization plant of boiler feed water treatment, to remove the ions (especially Na^+ and SO_3^{2-}) which may further present in the water after foregoing process of purification.

Degasser

The function of degasser tower is to remove carbonate ions by forming carbon-di-oxide. In degasser tower stream of water is poured from top & air is blown from bottom to top. In the pressure of air the carbonic acid (H_2CO_3) present in the water dissociates into H_2O and CO_2.

$H_2CO_3 = H_2O + CO_2$

This CO_2 is free to mix with air.

Benefits of using degasser are:

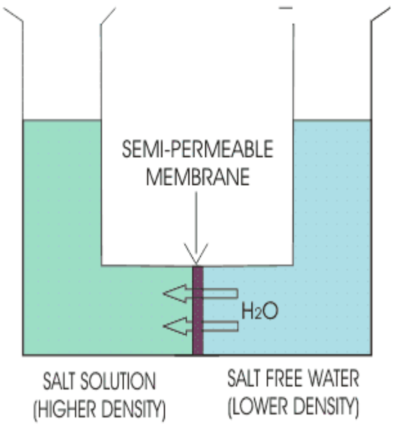
(1) It removes the carbonic acid and other gases mixed with water by simple physical method & thereby reduce the chances of corrosion.

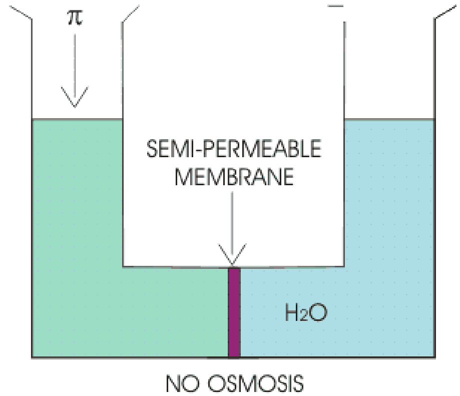
(2) It saves the resins which are very costly chemicals and thereby improves the economy of boiler feed water treatment process.

The H_2CO_3 free water is now collected in degasser sump and then pumped to anion exchange resin inlet.

Reverse Osmosis Plant (RO Plant)

Like demineralization plant there is another stage of water treatment which is known as **reverse osmosis plant**. **RO plant** uses the process known as reverse osmosis to produce salt-free water. The theoretical aspect is described below:-





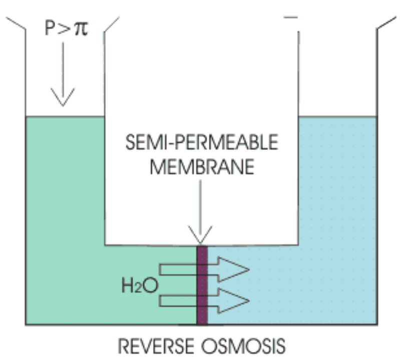
Osmosis is a process in which only the solvent molecules pass through a semi-permeable membrane from higher solvent density to lower solvent density (i.e. from solution of lower density to the solution of higher density). Osmotic pressure:- It is the minimum pressure that should be applied on the higher density solution so that no osmosis takes place through the semi-permeable membrane is called the osmotic pressure (π).

$\pi = iCRT$ Where, C is concentration of solution,

R is universal gas constant,

T is temperature in Kelvin scale,

i is van't Hoff's factor, different for different solutions. i = 1 for infinitely dilute



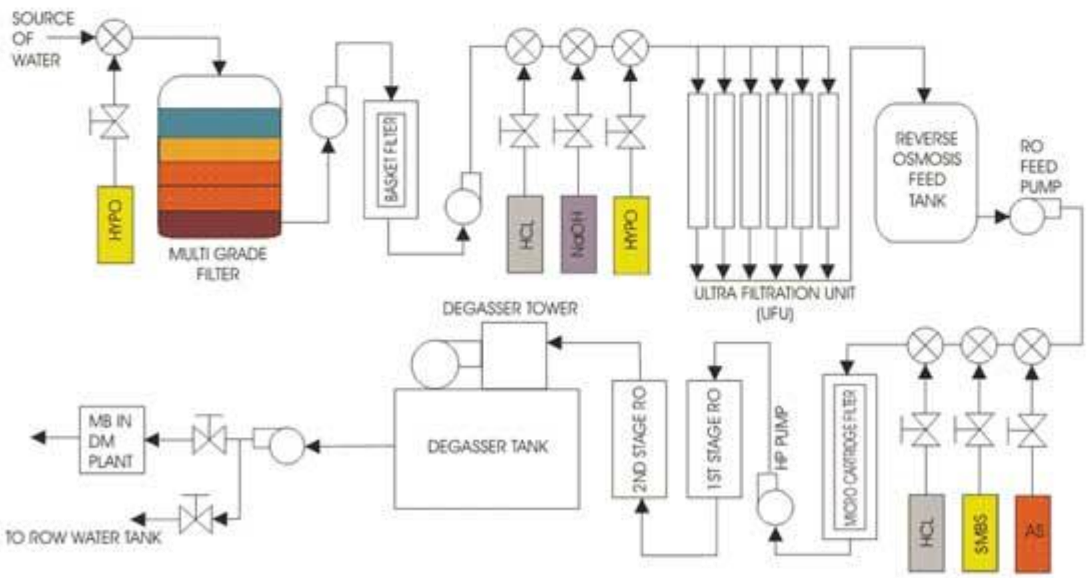
solution.

Reverse Osmosis

On the higher density solution (lower density solvent) if a pressure (P), greater than osmotic pressure (π) is applied then the solvent molecules pass through the semi-permeable membrane from higher density solution to lower density solution. This phenomenon is called reverse osmosis. This one important stage for boiler feed water treatment process.

Reverse Osmosis Plant

In RO plant using reverse osmosis phenomenon salt-free water is taken out from raw water after the sand filtration. Purity of the salt-free water depends on effectiveness of the permeable membrane. The layout of a typical **Reverse Osmosis Plant** is given below



Steam air pre-heater require some steam which will reduce the efficiency of the power plant. The procedure is described below: (1) Sodium hypochlorite(NaOCl) is injected to raw water to kill the algae or bacteria present in the raw water. Otherwise they may cause harm to the multi grade-filter (MGF).

(2) The multi-grade filter is the primitive type of filter where sand, stone-chips, stones are used in stacks to remove the large size suspended particles from the raw water.

(3) The net filter again removes medium-size suspended particles, where the raw water passes through the net minute vents.

(4) Then by ultra-filtration very small suspended particles are removed. After long usage of ultra-filtration unit, it requires back-wash, and then it is back-washed with water & three chemicals, viz. HCL, NaOH & NaOCl (Sodium Hypochlorite). HCl Removes iron by dissolving it. It also removes the basic salts those are rejected on UFU. NaOH ← It helps to remove acidic salt. NaOCl ← To kill algae and bacteria inside the UFU.

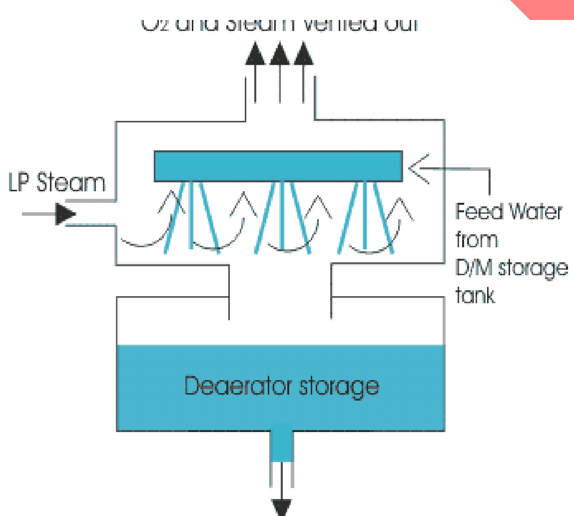
(5) After ultra-filtration the water is stored into RO feed tank & then pumped with RO feed pump of Reverse Osmosis Plant. In the channel the water is mixed with HCL (for pH controlling, as the water coming from RO plant or RO permeate water should have pH around 6.0) and SMBS (sodium meta bi-sulphate) [$Na_2S_2O_5$]. Due to the presence of sodium hypochlorite the water is chlorinated. To remove excess chlorine SMBS is used. If excess chlorine is not removed then the semi-permeable membrane may get damaged. It is also mixed with anti-scaling reagent (AS), which reacts with those chemicals which form scale inside the channel.

(6) Then the water is passed through micro-cartridge filter (MCF) which removes the other suspended particles & the precipitate formed by the reaction of anti-scaling reagent with the scaling chemicals.

(7) In the this stage of boiler feed water treatment the water is fed to RO unit by H/P pump, where after successive filtration by 1^{st} & 2^{nd} stage RO it is fed to degasser unit.

(8) After degasification the water is passed through D/M plant MB (mixed bed) resin & stored into D/M water storage tank.

Deaerator



Deaerator is a contact type open heater in which dissolved oxygen in the feed water is removed as much as possible by mechanical means. Gases move from higher partial pressure to lower partial pressure. Partial pressure of oxygen in air is high (as air contains almost 21% oxygen by volume) than the partial pressure of dissolved oxygen in feed water. Hence, by simple mechanical means it is not possible to eliminate the dissolved oxygen from water.
Hence, in **deaerator** the feed water is heated by LP or VB steam (pressure: 2.5 – 3.5kg/cm^2, temperature: 1400°C). Due to heating the partial pressure of dissolved oxygen in feed water increases and solubility decreases to considerable amount. Then by mechanical means dissolved oxygen is released in air. Hence Deaerator is another very important part of boiler feed water treatment plant.

The mechanical means is same as that of in degasser. But instead of air, LP steam is blown from bottom to top and feed water is poured from top to bottom.

Deaerator also serves as header, to provide a net positive suction head (NPSH) to the boiler feed pumps (BFP) and here by protects the BFPs from any damage due to vapor lock and cavitations.

11. COGENERATION

Cogeneration is also called as **combined heat and power** or **combine heat and power**. As it name indicates **cogeneration** works on concept of producing two different form of energy by using one single source of fuel. Out of these two forms one must be heat or thermal energy and other one is either electrical or mechanical energy.

Cogeneration is the most optimum, reliable, clean and efficient way of utilizing fuel. The fuel used may be natural gas, oil, diesel , propane, wood, bassage, coal etc. It works on very simple principle i.e the fuel is used to generate electricity and this electricity produces heat and this heat is used to boil water to produce steam , for space heating and even in cooling buildings. In conventional power plant , the fuel is burnt in a boiler , which in turn produces high pressure steam. This high pressure steam is used to drive a tribune, which is in turn is connected to an alternator and hence drive an alternator to produce electric energy. The exhaust steam is then sent to the condenser, where it gets cool down and gets converted to water and hence return back to boiler for producing more electrical energy. The efficiency of this conventional power plant is 35% only.

In **cogeneration plant** the low pressure steam coming from turbine is not condense to form water, instead of it its used for heating or cooling in building and factories, as this low pressure steam from turbine has high thermal energy. The **cogeneration plant** has high efficiency of around 80 - 90 %. In India, the potential of power generation from cogeneration plant is more than 20,000 MW. The first commercial cogeneration plant was built and designed by Thomas Edison in New York in year 1882.

Need for Cogeneration

a) Cogeneration helps to improve the efficiency of the plant.
b) Cogeneration reduce air emissions of particulate matter, nitrous oxides, sulphur dioxide, mercury and carbon dioxide which would otherwise leads to greenhouse effect.
c) It reduces cost of production and improve productivity.
d) Cogeneration system helps to save water consumption and water costs.
e) Cogeneration system is more economical as compared to conventional power plant

Types of Cogeneration Power Plants

In a typical Combined heat and power plant system there is a steam or gas turbine which take steam and drives an alternator. A waste heat exchanger is also installed in cogeneration plant, which recovers the excess heat or exhaust gas from the electric generator to in turn generate steam or hot water.

There are basically two types of cogeneration power plants, such as-

• Topping cycle power plant

• Bottoming cycle power plant

Topping cycle power plant-

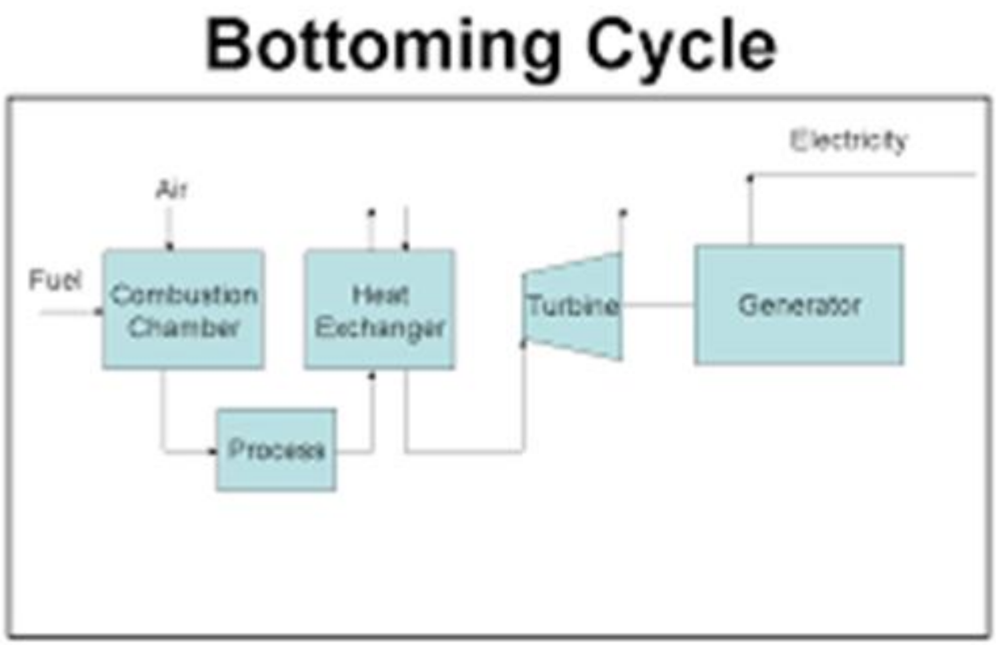
In this type of **Combine Heat and Power** plant electricity is generated first and then waste or exhaust steam is used to heating water or building . There are basically four types of topping cycles.

a) Combined-cycle topping CHP plant - In this type of plant the fuel is firstly burnt in a steam boiler . The steam so produced in a boiler is used to drive turbine and hence synchronous generator which in turn produces electrical energy . The exhaust from this turbine can be either used to provide usable heat, or can be send to a heat recovery system to generate steam, which maybe further used to drive a secondary steam turbine.

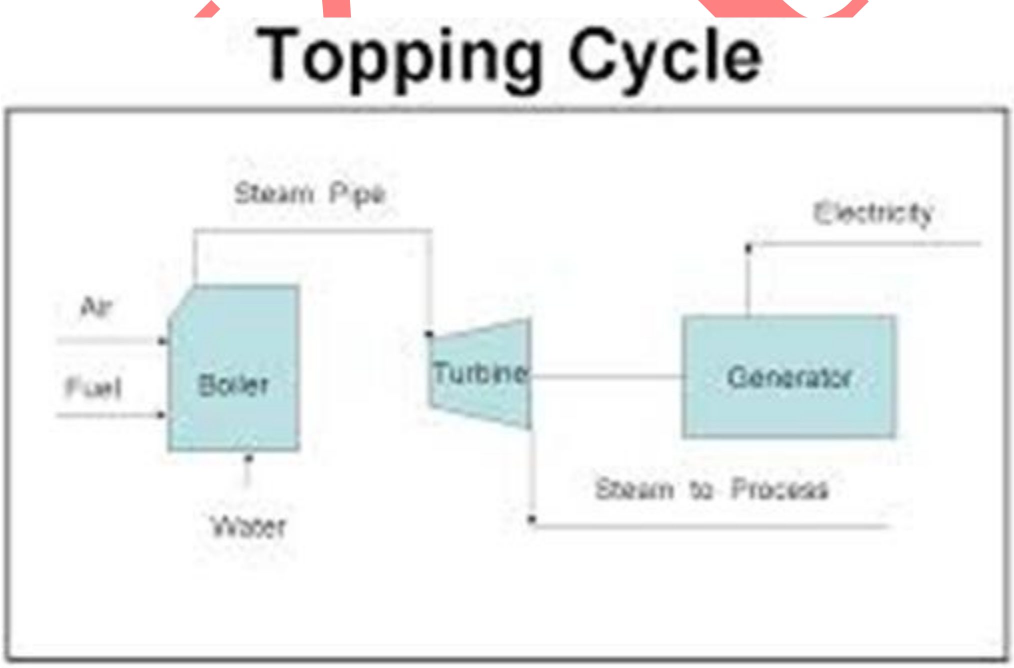
b) Steam-turbine topping CHP Plant- In this the fuel is burned to produce steam, which generates power. The exhaust steam is then used as low-pressure process steam to heat water for various purposes.

c) Water- turbine topping CHP Plant- In this type of CHP plant a jacket of cooling water is run through a heat recovery system to generate steam or hot water for space heating.

d) Gas turbine topping CHP plant- In This topping plant a natural gas fired turbine is used to drives a synchronous generator to produce electricity. The exhaust gas is sent to a heat recovery boiler where it is used to convert water into steam, or to make usable heat for heating purposes.



Bottoming cycle power plant - As its name indicate bottoming cycle is exactly opposite of topping cycle. In this type of CHP plant the excess heat from a manufacturing process is used to generate steam, and this steam is used for generating electrical energy. In this type of cycle no extra fuel is required to produce electricity, as fuel is already burnt in production process.



Economizer:

An economizer pre – heats (raise the temperature) the feed water by the exhaust flue gases. This pre – heated water is supplied to the boiler from the economizer. An economizer is placed in the path of the flue gases in between the boiler and the air pre - heater or chimney.

Air pre-heater

Air pre-heater pre-heats (increases the temperature) the air supply to the furnace with the help of hot the gases.It is installed between the economizer and the chimney.

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.

1. OTTO CYCLE

The Otto cycle is a set of processes used by spark ignition internal combustion engines (2-stroke or 4-stroke cycles). These engines a) ingest a mixture of fuel and air, b) compress it, c) cause it to react, thus effectively adding heat through converting chemical energy into thermal energy, d) expand the combustion products, and then e) eject the combustion products and replace them with a new charge of fuel and air. The different processes are shown in Figure.

1. Intake stroke, gasoline vapor and air drawn into engine ($5 \rightarrow 1$).
2. Compression stroke, p, T increase ($1 \rightarrow 2$).
3. Combustion (spark), short time, essentially constant volume ($2 \rightarrow 3$). Model: heat absorbed from a series of reservoirs at temperaturesT2 to T3.
4. Power stroke: expansion ($3 \rightarrow 4$).
5. Valve exhaust: valve opens, gas escapes.
6. ($4 \rightarrow 1$) Model: rejection of heat to series of reservoirs at temperaturesT_4 to T_1.
7. Exhaust stroke, piston pushes remaining combustion products out of chamber ($1 \rightarrow 5$).

We model the processes as all acting on a fixed mass of air contained in a piston-cylinder arrangement, as shown in Figure .

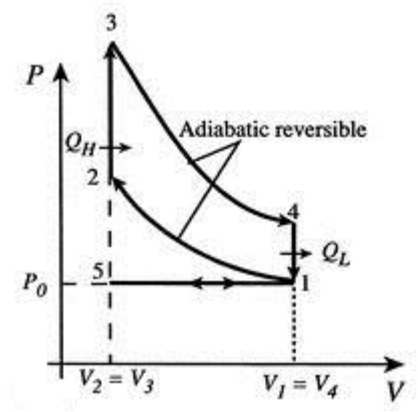


Figure: The ideal Otto cycle

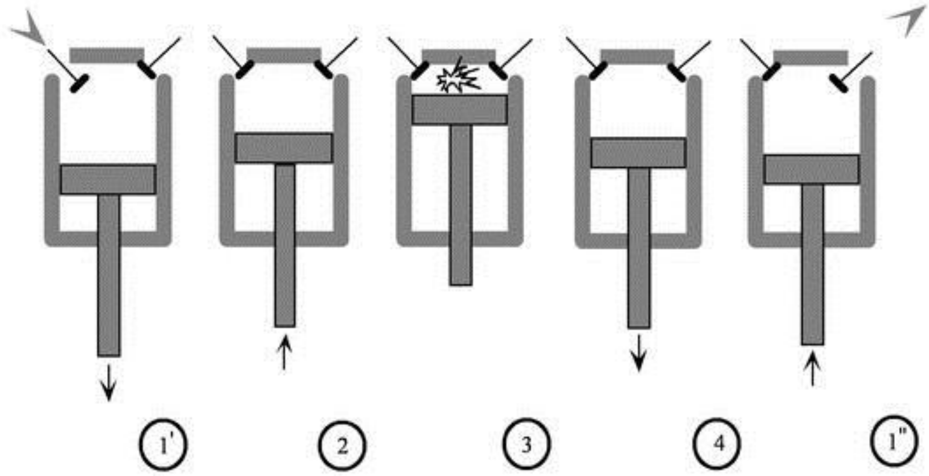


Figure: Piston and valves in a four-stroke internal combustion engine

The actual cycle does not have the sharp transitions between the different processes that the ideal cycle has, and might be as sketched in Figure

Efficiency of an ideal Otto cycle

The starting point is the general expression for the thermal efficiency of a cycle:

$$\eta = \frac{\text{work}}{\text{heat input}} = \frac{Q_H + Q_L}{Q_H} = 1 + \frac{Q_L}{Q_H}.$$

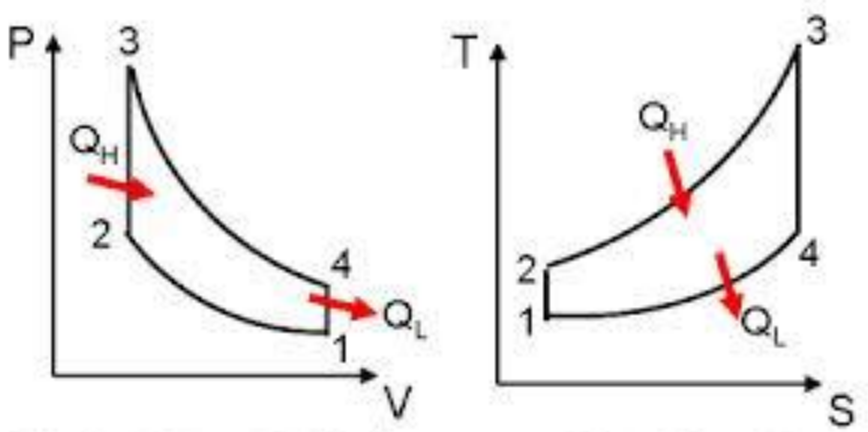


Fig.2. P-V and T-S diagrams of Ideal Otto Cycle

The processes are described by:

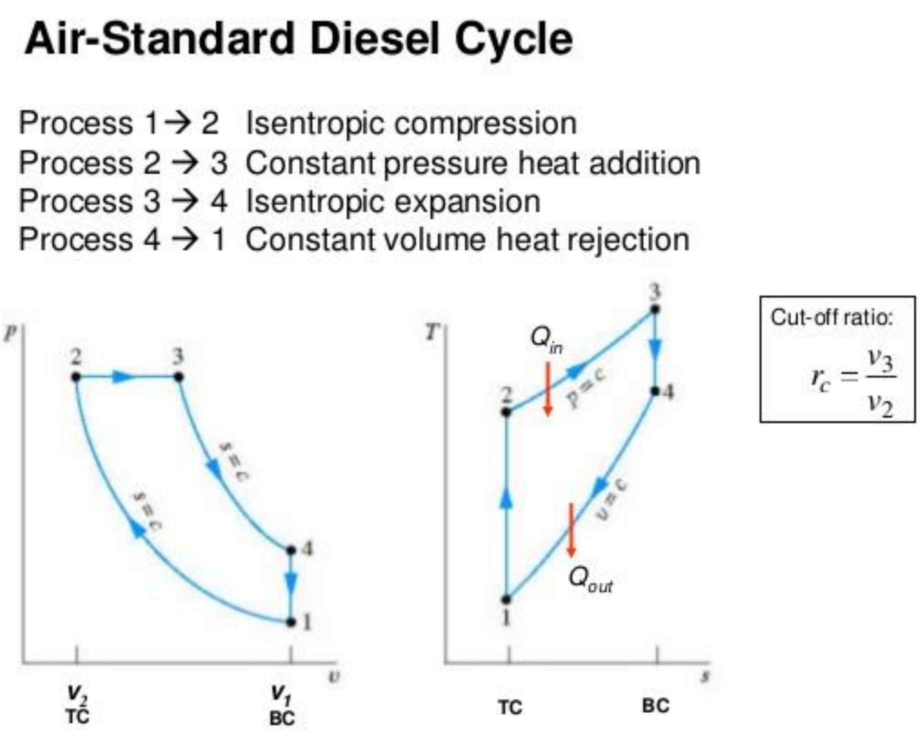
- Process 0-1 a mass of air is drawn into piston/cylinder arrangement at constant pressure.
- Process 1-2 is an adiabatic (isentropic) compression of the air as the piston moves from bottom dead centre (BDC) to top dead centre (TDC).

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

2.DIESEL CYCLE

The is a combustion process of a reciprocating internal combustion engine. In it, fuel is ignited by heat generated during the compression of air in the combustion chamber, into which fuel is then injected. This is in contrast to igniting the fuel-air mixture with a spark plug as in the Otto cycle (four-stroke/petrol) engine. Diesel engines are used in aircraft, automobiles, power generation, diesel-electric locomotives, and both surface ships and submarines.[dubious – discuss]

The Diesel cycle is assumed to have constant pressure during the initial part of the "combustion" phase. This is an idealized mathematical model: real physical diesels do have an increase in pressure during this period, but it is less pronounced than in the Otto cycle. In contrast, the idealized Otto cycle of a gasoline engine approximates a constant volume process during that phase.



p-V diagram for the ideal Diesel cycle; where p is pressure and V the volume or the specific volume if the process is placed on a unit mass basis. The ideal Diesel cycle follows the following four distinct processes:

- Process 1 to 2 is isentropic compression of the fluid (blue)
- Process 2 to 3 is reversible constant pressure heating (red)
- Process 3 to 4 is isentropic expansion (yellow)
- Process 4 to 1 is reversible constant volume cooling (green)

The Diesel engine is a heat engine: it converts heat into work. During the bottom isentropic processes (blue), energy is transferred into the system in the form of work, but by definition (isentropic) no energy is transferred into or out of the system in the form of heat. During the constant pressure (red, isobaric) process, energy enters the system as heat. During the top isentropic processes (yellow), energy is transferred out of the system in the form of, but by definition (isentropic) no energy is transferred into or out of the system in the form of heat. During the constant volume (green, isochoric) process, some of energy flows out of the system as heat through the right depressurizing process. The work that leaves the system is equal to the work that enters the system plus the difference between the heat added to the system and the heat that leaves the system; in other words, net gain of work is equal to the difference between the heat added to the system and the heat that leaves the system.

- Work in (W in) is done by the piston compressing the air (system)
- Heat in (Qin) is done by the combustion of the fuel
- Work out (Wout) is done by the working fluid expanding and pushing a piston (this produces usable work
- Heat out (Qout) is done by venting the air
- Net work produced = Q in- Qout

The net work produced is also represented by the area enclosed by the cycle on the P-V diagram. The net work is produced per cycle and is also called the useful work, as it can be turned to other useful types of energy and propel a vehicle (kinetic energy) or produce electrical energy. The summation of many such cycles per unit of time is called the developed power. The Woutis also called the gross work, some of which is used in the next cycle of the engine to compress the next charge of air.

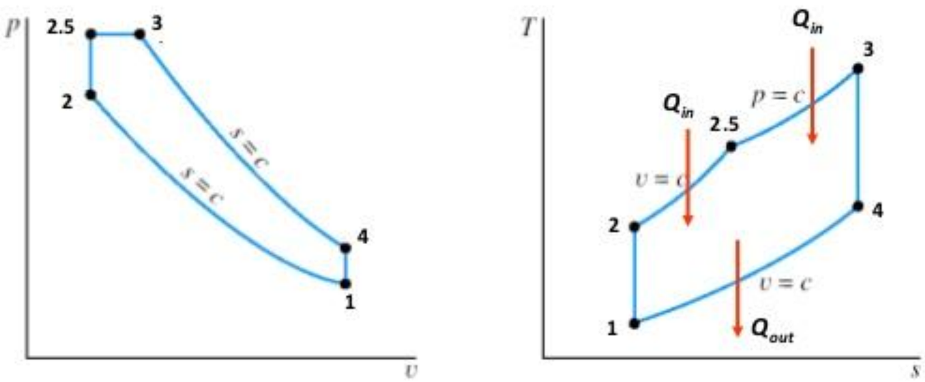
3. DUAL CYCLE (LIMITED PRESSURE CYCLE)

This cycle is also called as the dual cycle, which is shown in Fig.4.6. Here the heat addition occurs partly at constant volume and partly at constant pressure. This cycle is a closer approximation to the behavior of the actual Otto and Diesel engines because in the actual engines, the combustion process does not occur exactly at constant volume or at constant pressure but rather as in the dual cycle.

The dual combustion cycle (also known as the limited pressure or mixed cycle, Trinkler cycle, Seiliger cycle or Sabathe cycle) is a thermal cycle that is a combination of the Otto cycle and the Diesel cycle, first introduced by Russian-German engineer Gustav Trinkler. Heat is added partly at constant volume and partly at constant pressure, the advantage of which is that more time is available for the fuel to completely combust. Because of lagging characteristics of fuel this cycle is invariably used for diesel and hot spot ignition engines. The P-V diagram is given below:

Dual Cycle

Process 1 → 2 Isentropic compression
Process 2 → 2.5 Constant volume heat addition
Process 2.5 → 3 Constant pressure heat addition
Process 3 → 4 Isentropic expansion
Process 4 → 1 Constant volume heat rejection



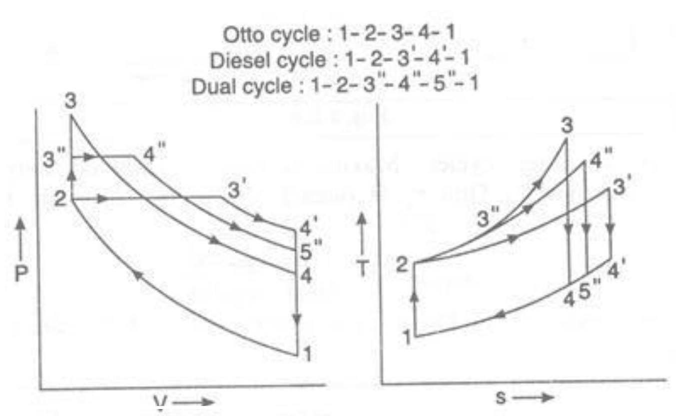
$$\frac{Q_{in}}{m} = (u_{2.5} - u_2) + (h_3 - h_{2.5}) = c_v(T_{2.5} - T_2) + c_p(T_3 - T_{2.5})$$

Comparison of Otto, Diesel and Dual Cycles

The **comparison of Otto, Diesel and Dual cycles** can be made on the basis of compression ratio, maximum pressure, maximum temperature, heat input, work output etc.

(a) **For same compression ratio and same heat input:**

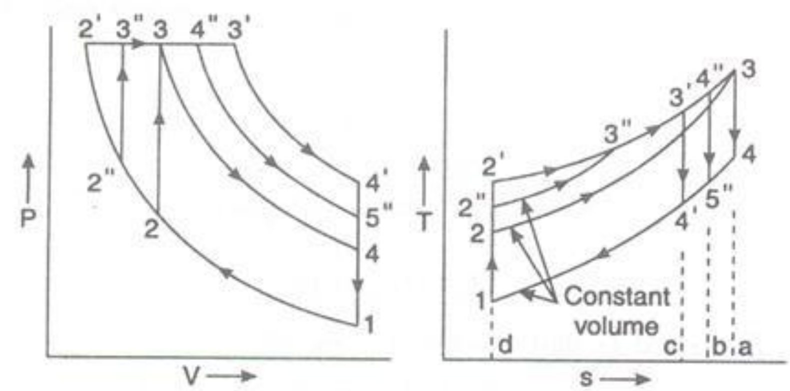
When compression ratio is kept constant process (1-2) remains the same for all the three cycles. But process (2-3), which shows the heat addition is different for those cycle. If same heat is transferred in all three cycles, the temperature attained is maximum for Otto cycle and minimum for Diesel cycle.



The work done during the cycle is proportional to the area inside the bounded region. The area is maximum for Otto cycle and minimum for Diesel cycle. Thus, for same heat input, efficiency of Otto cycle will be the maximum while that of Diesel cycle will be the minimum.

(b) For same maximum pressure and same heat input:

For the same maximum pressure 3.3'. and 3" must be on same pressure line and for the same heat input the area 2-3-a-d-2, 3' -3' –c-d-2 and 2"3"4" b – d – 2" should be equal. It is obvious from figure that heat rejected by otto cycle 1-4 – a – d – 1 is more than 1-5" – b – d – 1 and 1 – 4' – c – d – 1.

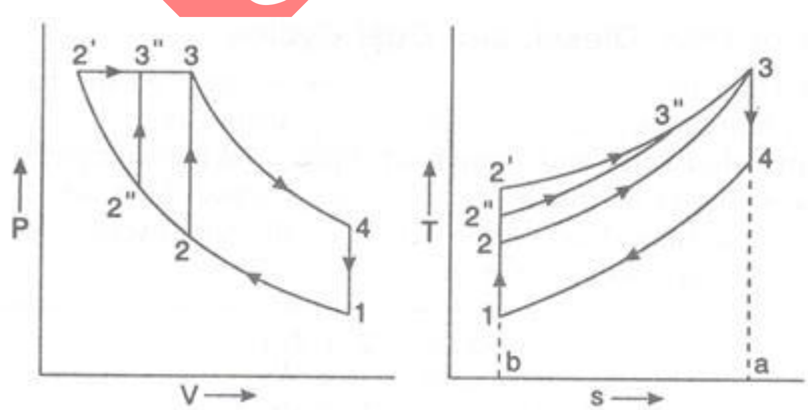


Since $\prod_{thermal} = Q_s - Q_R / Q_s$

The Diesel cycle is more efficient that Dual cycle, which in term is more efficient that Otto cycle.

(iii) For same pressure and temperature:

It is clear from the figure that the heat rejected by all three cycles, Otto, Diesel and Dual cycle remains the same (area 4-a – b - 1 - 4). But the heat supplied is



different for all three cycles. Maximum heat is supplied during diesel cycle (area 2’-3-a-b-2’) and minimum for Otto cycle (area 2 – 3 – a – b - 2) while for Dual cycle it is in between the two (area 2’ – 3” – 3 – a – b – 2”)

since, $\prod_{thermal}$ = 1 – Heat rejected / Heat supplied

Hence, for the above conditions the Diesel cycle is more efficient than Dual cycle, which in turn is more efficient than Otto cycle.

ŋ Diesel >ŋ Dual> ŋOtto

4. DIESEL ENGINE POWER PLANT

The diesel engine power plant consists of the following auxiliary systems:

Fuel Supply System

It consists of fuel tank for the storage of fuel, fuel filters and pumps to transfer and inject the fuel. The fuel oil may be supplied at the plant site by trucks, rail, road, tank, cars, etc.

Air Intake and Exhaust System

It consists of pipe for the supply of air and exhaust of the gases. Filters are provided to remove dust etc. from the incoming air. In the exhaust system silencer is provided to reduce the noise. Filters may be of dry type (made up of cloth, felt, glass, wool etc.) or oil bath type. In oil bath type of filters the air is swept over or through a bath of oil in order that the particles of dust get coated. The duties of the air intake systems are as follows:

i) To clean the air intake supply.

ii) To silence the intake air.

iii) To supply air for super charging.

The intake system must cause a minimum pressure loss to avoid reducing engine capacity and raising the specific fuel consumption. Filters must be cleaned periodically to prevent pressure losses from clogging. Silencers must be used on some systems to reduce high velocity air noises.

3. Cooling Systems

This system provides a proper amount of water circulation all around the engines to keep the temperature at reasonable level. Pumps are used to discharge the water inside and the hot water leaving the jacket is cooled in cooling ponds or other devices and is recirculated again.

4. Lubrication System

Lubrication is essential to reduce friction and wear of the rubbing parts. It includes lubricating oil tank, pumps, filters and lubricating oil cooler.

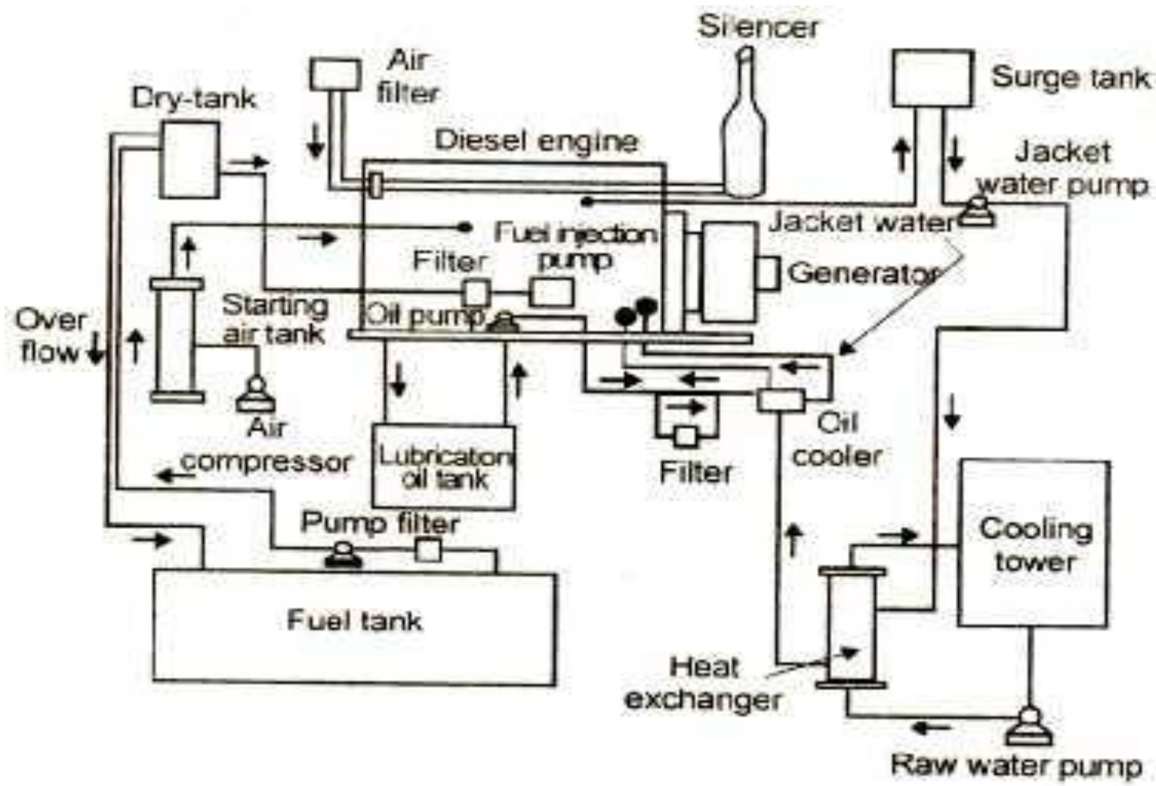


Figure : Schematic representation of a diesel engine power plant.

5. Starting System

For the initial starting of engine the various devices used are compressed air, battery, electric motor or self-starter. The auxiliary equipment of diesel engine power plant.

Advantages of diesel power plant:

1. Plant layout is simple. Hence it can be quickly installed and commissioned, while the erection and starting of a steam power plant or hydro-plant takes a fairly long time.
2. Quick starting and easy pick-up of loads are possible in a very short time.
3. Location of the plant is near the load center.
4. The load operation is easy and requires minimum labors.
5. Efficiency at part loads does not fall so much as that of a steam plant.
6. Fuel handling is easier and no problem of ash disposal exists.
7. The plant is smaller in size than steam power plant for same capacity.
8. Diesel plants operate at high overall efficiency than steam.

Disadvantages of diesel power plant:

1. Plant capacity is limited to about 50 MW of power.
2. Diesel fuel is much more expensive than coal.
3. The maintenance and lubrication costs are high.
4. Diesel engines are not guaranteed for operation under continuous, while steam can work under 25% of overload continuously.

Applications of diesel power plant

1. Diesel power plant's is in the range of 2 to 50 MW capacity. They are used as central station for small or medium power supplies.
2. They can be used as stand-by plants to hydro-electric power plants and steam power plants for emergency services.
3. They can be used as peak load plants in combinations with thermal or hydro-plants.
4. They are quite suitable for mobile power generation and are widely used in transportation systems such as automobiles, railways, air planes and ships.
5. Now-a-days power cut has become a regular feature for industries. The only solution to tide over this difficulty is to install diesel generating sets.

5. BRAYTON CYCLE

The Brayton cycle (or Joule cycle) represents the operation of a gas turbine engine. The ideal Brayton cycle is made up of four internally reversible processes.

- 1-2 Isentropic compression (in a compressor)
- 2-3 Constant pressure heat addition
- 3-4 Isentropic expansion (in a turbine)
- 4-1 Constant pressure heat reject

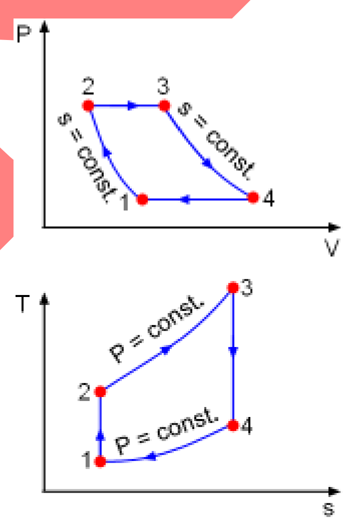


Figure. P-v and T-s Diagrams of Ideal Brayton Cycle

The P-v and T-s diagrams of an ideal Brayton cycle are shown on the left. In an ideal Brayton cycle, heat is added to the cycle at a constant pressure process (process 2-3).

$$q_{in} = h_3 - h_2 = c_P(T_3 - T_2)$$

Heat is rejected at a constant pressure process (process 4 -1).

$$q_{out} = h_4 - h_1 = c_P(T_4 - T_1)$$

Then the thermal efficiency of the ideal Brayton cycle under the cold air-standard assumption is given as

$$\eta_{th,\,Brayton} = 1 - \frac{c_P(T_4 - T_1)}{c_P(T_3 - T_2)} = 1 - \frac{T_1}{T_2}\,\frac{T_4/T_1 - 1}{T_3/T_2 - 1}$$

Process 1-2 and process 3-4 are isentropic processes, thus,

$$\frac{T_1}{T_2} = \left(\frac{P_1}{P_2}\right)^{(k-1)/k} \quad \text{and} \quad \frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{(k-1)/k}$$

Since $P_2 = P_3$ and $P_4 = P_1$,

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

Considering all the relations above, the thermal efficiency becomes,

$$\eta_{th,Brayton} = 1 - \frac{T_1}{T_2} = 1 - \left(\frac{P_1}{P_2}\right)^{(k-1)/k} = 1 - \frac{1}{r_P^{(k-1)/k}}$$

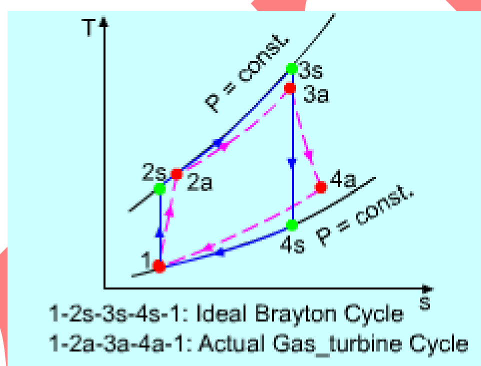
where $r_P = P_2/P_1$ is the pressure ratio and k is the specific heat ratio. In most designs, the pressure ratio of gas turbines range from about 11 to 16.

Actual Gas-turbine Cycle

The actual gas-turbine cycle is different from the ideal Brayton cycle since there are irreversibilities. Hence, in an actual gas-turbine cycle, the compressor consumes more work and the turbine produces less work than that of the ideal Brayton cycle. The irreversibilities in an actual compressor and an actual turbine can be considered by using the adiabatic efficiencies of the compressor and turbine. They are:

$$\eta_C = \frac{h_1 - h_{2s}}{h_1 - h_{2a}}$$

$$\eta_T = \frac{h_3 - h_{4a}}{h_3 - h_{4s}}$$



T-s Diagram of Actual Gas-turbine Cycle

6. GAS TURBINE PLANT

A gas turbine plant may be defined as one "in which the principal prime-mover is of the turbine type and the working medium is a permanent gas".

A simple gas turbine plant consists of the following:

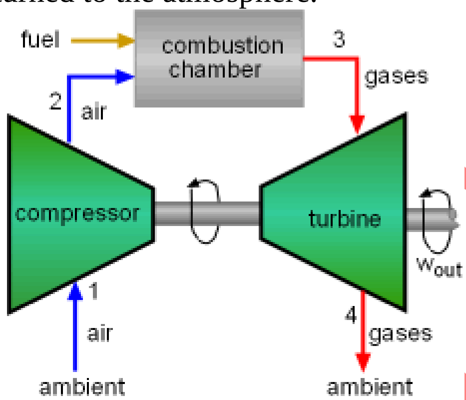
i)Turbine
ii)Compressor
iii) Combustor
iv) Auxiliaries.

A modified plant may have in addition and intercooler, a regenerator, a reheater etc.

Open cycle gas turbine

In the open cycle gas turbine, air is drawn into the compressor from atmosphere and is compressed. The compressed air is heated by directly burning the fuel in the air at constant pressure in the combustion chamber. Then the high pressure hot gases expand in the turbine and mechanical power is developed.

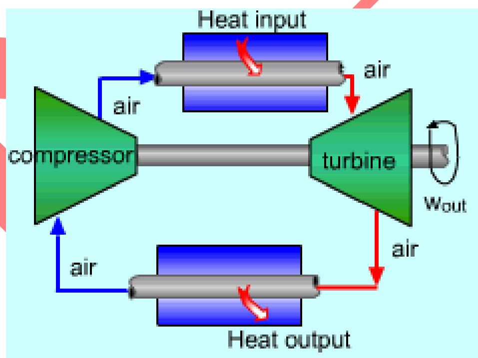
Part of the power developed by the turbine (about 66%) is used for driving the compressor. The remaining is available as useful output. The working fluid, air and fuel, must be replaced continuously as they are exhausted into the atmosphere. Thus the entire flow comes from the atmosphere and is returned to the atmosphere.



Closed cycle gas turbine

In this, the compressed air from the compressor is heated in a heat exchange (air heater) by some external source of heat (coal or oil) at constant pressure. Then the high pressure hot gases expand passing through the turbine and mechanical power is developed. The exhaust gas is then cooled to its original temperature in a cooler before passing into the compressor again.

The main difference between the open and closed cycles is that the working fluid is continuously replaced in open cycle whereas it is used again and again in a closed cycle. The open cycle plant is much lighter than the closed cycle. Hence it is widely used.



Some of the important terms used to measure performance of a gas turbine are defined as follows:

1. Pressure ratio. It is the ratio of cycle's highest to its lowest pressure, usually highest pressure-compressor discharges to the lowest-pressure-compressor inlet pressures.

2. Work ratio. It is the ratio of network output to the total work developed in the turbine or turbines.

3. Air ratio. Kg of air entering the compressor inlet per unit of cycle net output, for example, kg/kWh.

4. Compression efficiency It is the ratio of work needed for ideal air compression through a given pressure range to work actually used by the compressor.

5. Engine efficiency. It is the ratio of work actually developed by the turbine expanding hot power gas through a given pressure range to that would be yielded for ideal expansion conditions.

6. Machine efficiency. It is the collective term meaning both engine efficiency and compressor efficiency of turbine and compressor efficiency of turbine and compressor, respectively.

7. Combustion efficiency. It is the ratio of heat actually released by 1 kg of fuel to heat that would be released by complete perfect combustion.

8. Thermal efficiency. It is the percentage of total energy input appearing as net work output of the cycle.

Methods for improvement of thermal efficiency of open cycle gas turbine plant are :

i)Inter cooling

ii) Reheating

iii)Regeneration

Gas turbine cycle with Reheater

Reheat gas

C : Compressor
CC: Combustion chamber
G : Generator
f : Fuel
HPT: High Pressure turbine
LPT: Low pressure turbine
RCC: Reheat combustion chamber

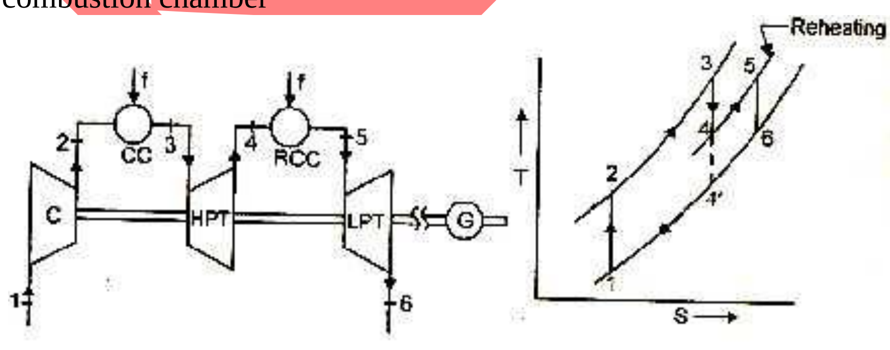


Figure: Reheat gas turbine cycle.

Reheat gas turbine cycle arrangement is shown in figure. In order to maximize the work available from the simple gas turbine cycle one of the option is to increase enthalpy of fluid entering gas turbine and extend its expansion upto the lowest possible enthalpy value. This can also be said in terms of pressure and temperature values i.e., inject fluid at high pressure and temperature into gas turbine and expand upto lowest possible pressure value. Upper limit at inlet to turbine is limited by metallurgical limits while lower pressure is limited to near atmospheric pressure in case of open cycle. For further increasing in net work output the positive work may be increased by using multistage expansion with reheating in between. In multistage expansion is divided into parts and after part expansion working fluid may be reheated for getting larger positive work in left out expansion. For reheating another combustion chamber may be used.

Here in the arrangement shown ambient air enters compressor and compressed air at highpressure leaves at 2. Compressed air is injected into combustion chamber for increasing its temperature upto desired turbine inlet temperature at state3. High pressure and high temperature fluid enters high pressure turbine (HPT) for first phase of expansion and expanded gases leaving at 4 are sent to reheat combustion chamber (reheater) for being further heated. Thus reheating is a kind of energizing the working fluid. Assuming perfect reheating (in which temperature after reheat is same as temperature attained in first combustion chamber), the fluid leaves at state 5 and enters low pressure turbine (LPT) for remaining expansion upto desired pressure value. Generally temperature after reheating at state 5, is less than temperature at state 3. In the absence of reheating the expansion process within similar pressure limits goes upto state 4'. Thus reheating offers an obvious advantage of work output increase since constant pressure lines T-S diagram diverge slightly with increasing entropy, the total work of the two stage turbine is greater that that of single expansion from state 3 to state 4', i.e., $(T3 - T4) + (T5 - T6) > (T3 - T4')$.

Here it may be noted that the heat addition also increases because of additional heat supplied for reheating. Therefore, despite the increase in network due to reheating the cycle thermal efficiency would not necessarily increases. Let us now carry out air standard cycle analysis.

Network output in reheat cycle, W net, reheat $= W_{HPT} + W_{LPT} - W_C$

$W_{HPT} = m\,(h_3 - h_4)$,
$W_{LPT} = m(h_5 - h_6)$,
$WC = m(h_2 - h_1)$
$W_{net,\,reheat} = m\,\{(h_3 - h_4) + (h_5 - h_6) - (h_2 - h_1)\}$
$W_{net,\,reheat} = m\,cp\,\{(T_3 - T_4) + (T_5 - T_6) - (T_2 - T_1)\}$

Assuming, $T_3 = T_5$

$W_{net,\,reheat} = m\,cp\,\{(2T3 - T4) - T6 - (T2 - T1)\}$
$Qin = m\,cp\,\{(T3 - T2) + (T5 - T4)$

$$\eta\ reheat = \frac{W_{net}}{Q_{in}}$$

Gas turbine cycle with Regenerator.

In earlier discussion it is seen that for the maximization of specific work output the gas turbine exhaust temperature should be equal to compressor exhaust temperature. The turbine exhaust temperature is normally much above the ambient temperature. Thus their exist potential for tapping the heat energy getting lost to surroundings with exhaust gases. Here it is devised to use this potential by means of a heat exchanger called regenerator, which shall preheat the air leaving compressor before entering the combustion chamber, thereby reducing the amount of fuel to be burnt inside combustion chamber (combustor).

Regenerative air standard gas turbine cycles shown ahead in figure (a) has a regenerator (counter flow heat exchanger) through which the hot turbine exhaust gas and comparatively cooler air coming from compressor flow in opposite directions. Under ideal conditions, no frictional pressure drop occurs in either fluid stream while turbine exhaust gas gets cooled from 4 to 4' while compressed air is heated from 2 to 2'. Assuming regenerator effectiveness as 100% the temperature rise from 2 – 2' and drop from 4 to 4' is shown on T-S diagram.

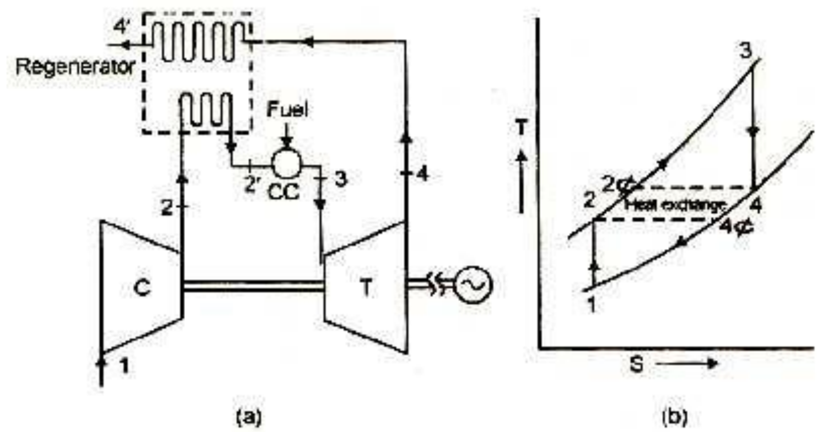


Figure: Regenerative air standard gas turbine cycle.

Regenerator effectiveness, $\varepsilon = \frac{h_{2'} - h_2}{h_4 - h_2}$, where 'h' refers to specific enthalpy values.

Thus thermodynamically the amount of heat now added shall be

$$Q_{add,\ regen} = m(h_3 - h_{2'})$$

Whereas without regenerator the heat added; $Q_{add} = m(h_3 - h_2)$ Here it is obvious that, $Q_{add,\ regen} < Q_{add}$'

This shows an obvious improvement in cycle thermal efficiency as every thing else remains same. Network produced per unit mass flow is not altered by the use of regenerator.

Air standard cycle thermal efficiency

$$\eta_{regen} = \frac{(h_3 - h_4) - (h_2 - h_1)}{h_3 - h_2}$$

$$\eta_{regen} = \frac{C_P(T_3 - T_4) - C_P(T_2 - T_1)}{C_P(T_3 - T_4)}$$

Gas turbine cycle with inter cooling.

Net work output from gas turbine cycle can also be increased by reducing negative work i.e., compressor work. Multistaging of compression precess with intercooling in between is one of the approaches for reducing compression work. It is based on the fact that for a fixed compression ratio is higher is the inlet temperature higher shall be compression work requirement and viceversa. Schematic for inter cooled gas turbine cycle is give in figure.

Thermodynamic processes involved in multistage inter cooled compression are shown in figure. First stage compression occurs in low pressure compressor (LPC) and compressed air leaving LPC at '2' is sent to intercooler where temperature of compressed air is lowered down to state 3 at constant pressure. In case of perfect intercooling the temperature after intercooling is brought down to ambient temperature i.e., temperature at 3 and 1 are same. Intercooler is a kind of heat exchanger where heat is picked up from high temperature compressed air. The amount of compression work saved due to intercooling is obvious from p-V diagram and shown by area 2342'. Area 2342' gives the amount of work saved due to intercooling between compression.

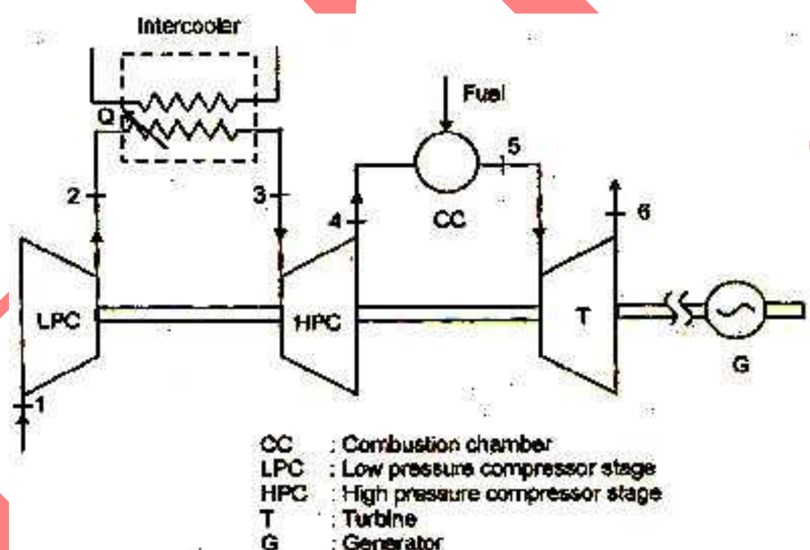


Figure: Gas turbine cycle with intercooling

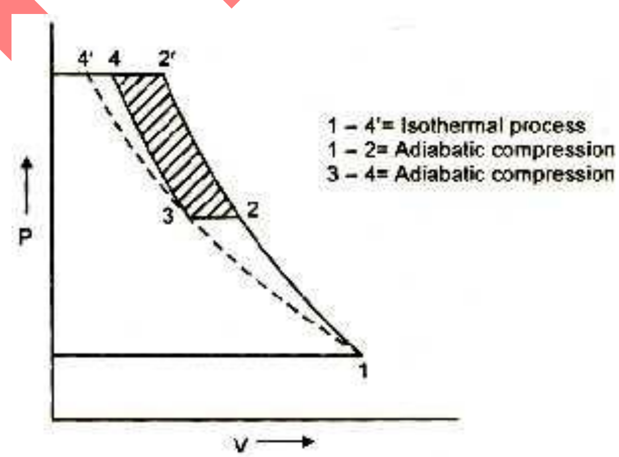


Figure : Intercooled compression

Some large compressors have several stages of compression with intercooling between stages. Use of multistage compression with intercooling in a gas turbine power plant increases the network produced because of reduction in compressor work. Inter cooled compression results in reduced temperature at the end of final compression. T-S diagram for gas turbine cycle with intercooling shows that in the absence of intercooling within same pressure limits the state at the end of compression would be 2' while with perfect intercooling this state is at 4 i.e., T2' > T4. The reduced temperature at compressor exits leads to additional heat requirement in combustion chamber i.e., more amount of fuel is to be burnt for attaining certain inlet temperature as compared to simple cycle without intercooling.

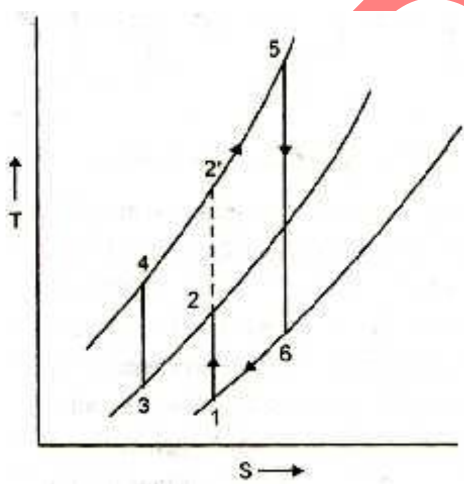


Figure: T-S diagram for gas turbine cycle with intercooling

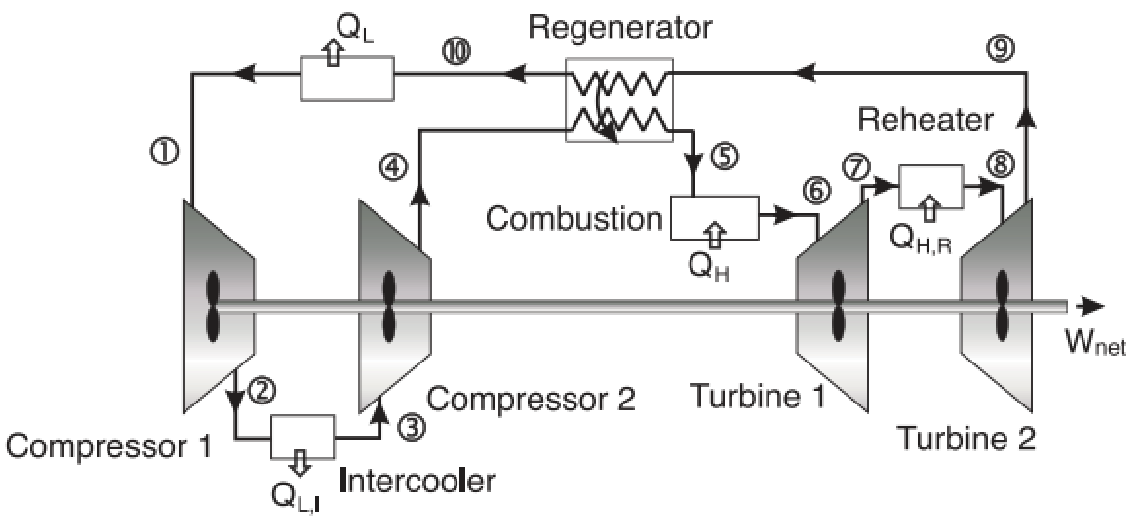
Thus intercooled cycle thermal efficiency may not increase with intercooling because of simultaneous increase in heat addition requirement. The lower temperature at compressor exit enhances the potential for regeneration so when intercooling is used in conjunction with regeneration an appreciable increase in thermal efficiency can result.
Net work output in gas turbine cycle with intercooling;

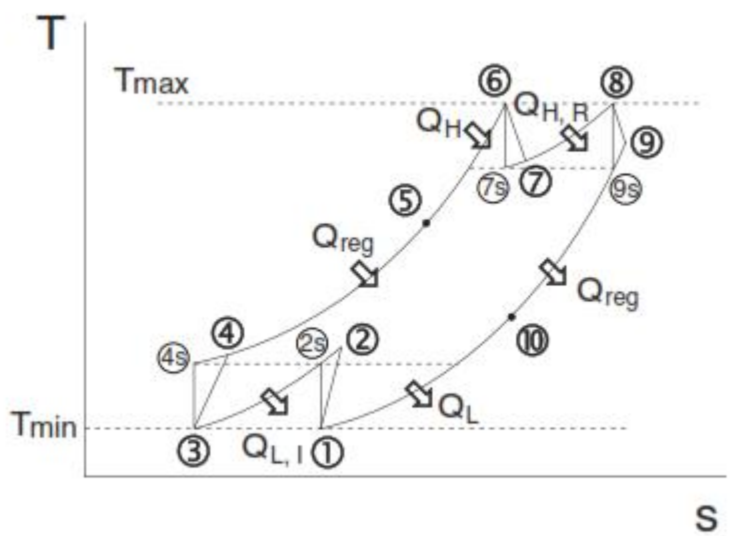
$$W_{net, intercool} = m\{(h_5 - h_6) - (h_4 - h_3) - (h_2 - h_1)\}$$
$$W_{net, intercool} = m\, c_p \{(T_5 - T_6) - (T_4 - T_3) - (T_2 - T_1)\}$$

Cycle thermal efficiency;

$$\eta_{intercool} = \frac{\{(h_5 - h_6) - (h_4 - h_3) - (h_2 - h_1)\}}{(h_5 - h_4)}$$

Brayton Cycle With Intercooling, Reheating and Regeneration





Advantages of Gas Turbine Power Plant

1. They are small in size, weigh less and have low initial cost per unit output.
2. They are easy to install within short periods.
3. They are quick-starting and smooth running.
4. They offer flexibility by supplying electricity for power generation as well as by supplying compressed air for process needs.
5. They are capable of using a range of liquid and gaseous fuels including synthetic fuels.
6. They are subjected (put) to fewer environmental restrictions than other prime movers.
7. Water consumption is less compared to steam power plant.

Disadvantages

1. An electric motor or an I.C. engine is necessary for starting the plant. The starting motor must bring the compressor well towards the operating speed. So, starting is not simple as in the case of other power plants.
2. Gas turbine plants have less vibrations when compared with reciprocating engines of the same speed. However the high frequency noise from the compressor is objectionable.
3. High temperatures impose severe restriction on the servicing conditions of the plant.
4. Overall efficiency is low since two-thirds of the total power output is used for driving the compressor.
5. The blades of the turbine require special cooling methods due to the severity of operating temperatures and pressures. In practice, the temperatures at the entry of the turbine are as high as 1100^{o}C - 1260^{o}C. Hence they should be made of special metals and alloys.
6. They are incompatible with solid fuels.

7.COMBINED CYCLE POWER PLANT

The Combined Cycle Power Plant or ***combined cycle gas turbine***, a gas turbine generator generates electricity and waste heat is used to make steam to generate additional electricity via a steam turbine. The gas turbine is one of the most efficient one for the conversion of gas fuels to mechanical power or electricity. The use of distillate liquid fuels, usually diesel, is also common as alternate fuels.

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

This system is known as a ***Combined Cycle***. The basic principle of the Combined Cycle is simple: burning gas in a gas turbine (GT) produces not only power – which can be converted to electric power by a coupled generator – but also fairly hot exhaust gases.

Routing these gases through a water-cooled heat exchanger produces steam, which can be turned into electric power with a coupled steam turbine and generator.

This type of power plant is being installed in increasing numbers round the world where there is access to substantial quantities of natural gas.

A Combined Cycle Power Plant produces high power outputs at high efficiencies (up to 55%) and with low emissions. In a Conventional power plant we are getting ***33% electricity only*** and remaining 67% ***as waste***.

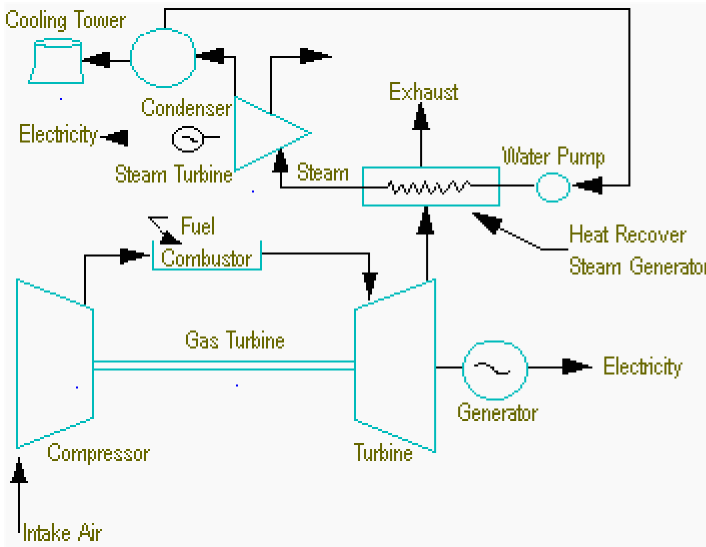


Figure - Combined cycle power plant scheme

By using combined cycle power plant we are getting ***68% electricity***. It is also possible to use the ***steam from the boiler for heating purposes*** so such power plants can operate to deliver electricity alone or in combined heat and power (CHP) mode.

Working principle of CCTG plant

First step is the same as the simple cycle gas turbine plant. An open circuit gas turbine has a compressor, a combustor and a turbine. For this type of cycle the input temperature to turbine is very high. The output temperature of flue gases is also very high. This is therefore high enough to provide heat for a second cycle which uses steam as the working medium i.e. thermal power station.

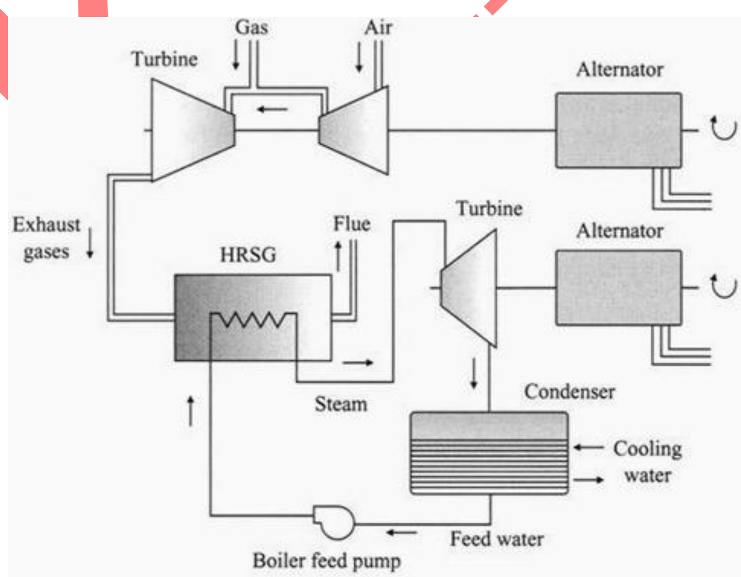


Figure - Working principle of combined cycle gas turbine (CCTG) plant

Air Inlet

This air is drawn though the large air inlet section where it is cleaned cooled and controlled. Heavy-duty gas turbines are able to operate successfully in a wide variety of climates and environments due to inlet air filtration systems that are specifically designed to suit the plant location. Under normal conditions the inlet system has the capability to process the air by removing contaminants to levels below those that are harmful to the compressor and turbine.

Turbine Cycle

The air which is purified then compressed and mixed with natural gas and ignited, which causes it to expand. The pressure created from the expansion spins the turbine blades, which are attached to a shaft and a generator, creating electricity. In second step the heat of the gas turbine's exhaust is used to generate steam by passing it through a heat recovery steam generator (HRSG) with a live steam temperature *between 420 and 580 °C.*

Heat Recovery Steam Generator

In Heat Recovery Steam Generator highly purified water flows in tubes and the hot gases passes a around that and thus producing steam .The steam then rotates the steam turbine and coupled generator to produce Electricity. The hot gases leave the HRSG at around 140 degrees centigrade and are discharged into the atmosphere.

The steam condensing and water system is the same as in the steam power plant.

Merits

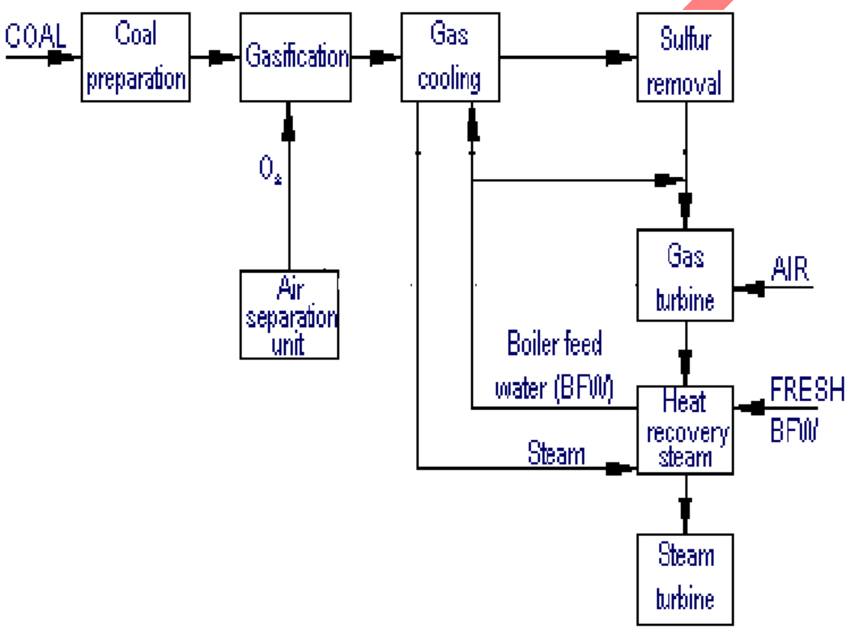
- Fuel efficiency conversion of *50% or more,*
- Low capital costs
- Combined cycle units are commercially available from suppliers anywhere in the world. They are easily manufactured, shipped and transported.
- Abundant fuel sources
- Reduced emission and fuel consumption

Demerits

1. The gas turbine can only use Natural gas or high grade oils like diesel fuel.
2. Because of this the combined cycle can be operated only in locations where these fuels are available and cost effective.

8. INTEGRATED GASIFICATION COMBINED CYCLE (IGCC)

The integrated gasification combined cycle (IGCC) produces electricity from a solid or liquid fuel. First, the fuel is converted to syngas which is a mixture of hydrogen and carbon monoxide. Second, the syngas is converted to electricity in a combined cycle power block consisting of a gas turbine process and a steam turbine process which includes a heat recovery steam generator (HRSG). The combined cycle technology is similar to the technology used in modern natural gas fired power plants.



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

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

UNIT III
NUCLEAR POWER PLANTS

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

1. BASICS OF NUCLEAR ENGINEERING

A nuclear power plant is similar to a conventional steam power plant except how that energy is evolved. The heat is produced in the nuclear power plant by fission, whereas in steam and gas turbine plants, the heat is produced by combustion in the furnace. The nuclear reactor acts as a furnace where nuclear energy is evolved by splitting or fissioning of the nucleus of fissionable material like Uranium U-235. It is claimed that 1 kg U-235 can produce as much heat energy that can be produced by burning 4500 tones of high grade coal or 1700 tons of oil.

Fission Energy:

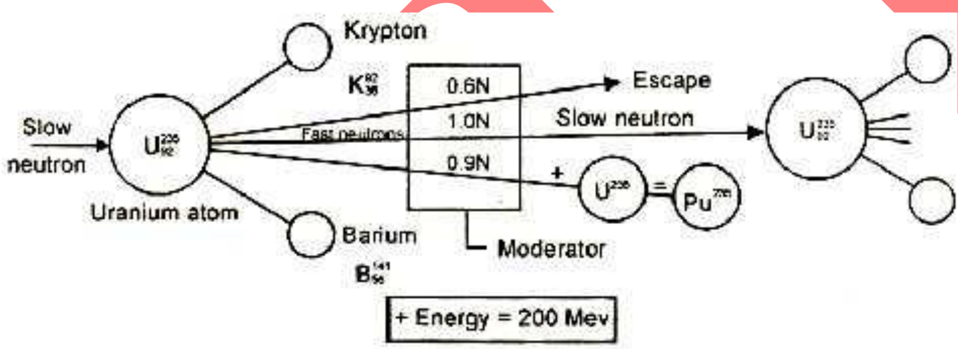


Figure : Nuclear fission

Nuclear energy is divided from splitting (or)fissioning of the nucleus of fissionable material like Uranium U-235. Uranium has several isotopes (Isotopes are atoms of the same element having different atomic masses) such as U-234, U-235 and U-238. Of the several isotopes, U-235 is the most unstable isotope, which is easily fissionable and hence used as fuel in an atomic reactor. When a neutron enters the nucleus of an unstable U-235, the nucleus splits into two equal fragments (Krypton and Barium) and also releases 2.5 fast moving neutrons with a velocity of 1.5×10m/sec and along with this produces a large amount of energy, nearly 200 million electrovolts. This is called nuclear fission.

1. Chain reaction

The neutrons released during fission are very fast and can be made to initiate the fission of other nuclei of U-235, thus causing a chain reaction. When a large number of fission occurs, enormous amount of heat is generated, which is used to produce steam.

The chain reaction under controlled conditions can release extremely large amount of energy causing "atomic explosion" Energy released in chain reaction, according to Einstein law is

$$E = mc^2$$

Where E = Energy liberated (J)

m= Mass (kg)

c = Velocity of light (3×10^8m/sec).

Out of 2.5 neutrons released in fission of each nucleus of U-235, one neutron is used to sustain the chain reaction, about 0.9 neutron is captured by U-238, which gets converted into fissionable material Pu-239 and about 0.6 neutron is partially absorbed by control rod materials, coolant and moderator.

If thorium is used in the reactor core, it gets converted to fissionable material U-233.

Thorium 232 + Neutron → U-233

Pr-239 and U-233 so produced are fissionable materials are called secondary fuels. They can be used as nuclear fuels. U-238 and Th-232 are called fertile materials.

2. Fusion energy

Energy is produced in the sun and stars by continuous fusion reactions in which four nuclei of hydrogen fuse in a series of reactions involving other particles that continually appear and disappear in the course of the reaction, such as He , nitrogen, carbon, and other nuclei, but culminating in one nucleus of helium of two positrons.

$$\rightarrow 4\,{}_1H \rightarrow {}_2He + 2\,{}_{+1}e^{o}$$

To cause fusion, it is necessary to accelerate the positively charged unclei to high kinetic energies, in order to overcome electrical repulsive forces, by raising their temperature to hundreds of millions of degrees resulting in plasma. The plasma must be prevented from contacting the walls of the container, and must be confined for a period of time (of the order of a second) at a minimum density. Fusion reactions are called thermonuclear because very high temperatures are required to trigger and sustain them. Table lists the possible fusion reactions and the energies produced by them. n, p, D, and T are the symbols for the neutron, proton, deuterium (H2), and tritium (H3), respectively.

Number	Fusion reaction		Energy perreaction MeV
	Reactants	Products	
1	D + D	T + p	4
2	D + D	He^3 + n	3.2
3	T + D	He^4 + n	17.6
4	He^3 + D	He^4 + p	18.3

Many problems have to be solved before an artificially made fusion reactor becomes a reality. The most important of these are the difficulty in generating and maintaining high temperatures and the instabilities in the medium (plasma), the conversion of fusion energy to electricity, and many other problems of an operational nature.

2.LAYOUT OF NUCLEAR POWER PLANT

Main components of nuclear power plants:

i) Moderators

In any chain reaction, the neutrons produced are fast moving neutrons. These are less effective in causing fission of U235 and they try to escape from the reactor. It is thus implicit that speed of these neutrons must be reduced if their effectiveness is carrying out fission is to be increased. This is done by making these neutrons collide with lighter nuclei of other materials, which does not absorb these neutrons but simply scatter them. Each collision causes loss of energy and thus the speed of neutrons is reduced. Such a material is called a 'Moderator'. The neutrons thus slowed down are easily captured by the fuel element at the chain reaction proceeds slowly.

ii) Reflectors

Some of the neutrons produced during fission will be partly absorbed by the fuel elements, moderator, coolant and other materials. The remaining neutrons will try to escape from the reactor and will be lost. Such losses are minimized by surrounding (lining) the reactor core with a material called a reflector which will reflect the neutrons back to the core. They improve the neutron economy. Economy: Graphite, Beryllium.

iii) Shielding

During Nuclear fission α, β, γ particles and neutrons are also produced. They are harmful to human life. Therefore it is necessary to shield the reactor with thick layers of lead, or concrete to protect both the operating personnel as well as environment from radiation hazards.

iv) Cladding

In order to prevent the contamination of the coolant by fission products, the fuel element is covered with a protective coating. This is known as cladding. Control rods are used to control the reaction to prevent it from becoming violent. They control the reaction by absorbing neutrons. These rods are made of boron or cadmium. Whenever the reaction needs to be stopped, the rods are fully inserted and placed against their seats and when the reaction is to be started the rods are pulled out.

v) Coolant

The main purpose of the coolant in the reactor is to transfer the heat produced inside the reactor. The same heat carried by the coolant is used in the heat exchanger for further utilization in the power generation.

Some of the desirable properties of good coolant are listed below

1. It must not absorb the neutrons.
2. It must have high chemical and radiation stability
3. It must be non-corrosive.
4. It must have high boiling point (if liquid) and low melting point (if solid)
5. It must be non-oxidising and non-toxic.

The above-mentioned properties are essential to keep the reactor core in safe condition as well as for the better functioning of the content.

6. It must also have high density, low viscosity, high conductivity and high specific heat.

These properties are essential for better heat transfer and low pumping power.The water, heavy water, gas (He, CO_2), a metal in liquid form (Na) and an organic liquid are used as coolants. The coolant not only carries large amounts of heat from the core but also keeps the fuel assemblies at a safe temperature to avoid their melting and destruction.

vi) Nuclear reactor

A nuclear reactor may be regarded as a substitute for the boiler fire box of a steam power plant. Heat is produced in the reactor due to nuclear fission of the fuel U235. The heat liberated in the reactor is taken up by the coolant circulating through the core. Hot coolant leaves the reactor at top and flows into the steam generator (boiler).

vii) Steam generator

The steam generator is fed with feed water which is converted into steam by the heat of the hot coolant. The purpose of the coolant is to transfer the heat generated in the reactor core and use it for steam generation. Ordinary water or heavy water is a common coolant.

viii) Turbine

The steam produced in the steam generator is passed to the turbine and work is done by the expansion of steam in the turbine.

ix) Radiation hazards and Shieldings

The reactor is a source of intense radioactivity. These radiations are very harmful to human life. It requires strong control to ensure that this radioactivity is not released into the atmosphere to avoid atmospheric pollution. A thick concrete shielding and a pressure vessel are provided to prevent the escape of these radiations to atmosphere

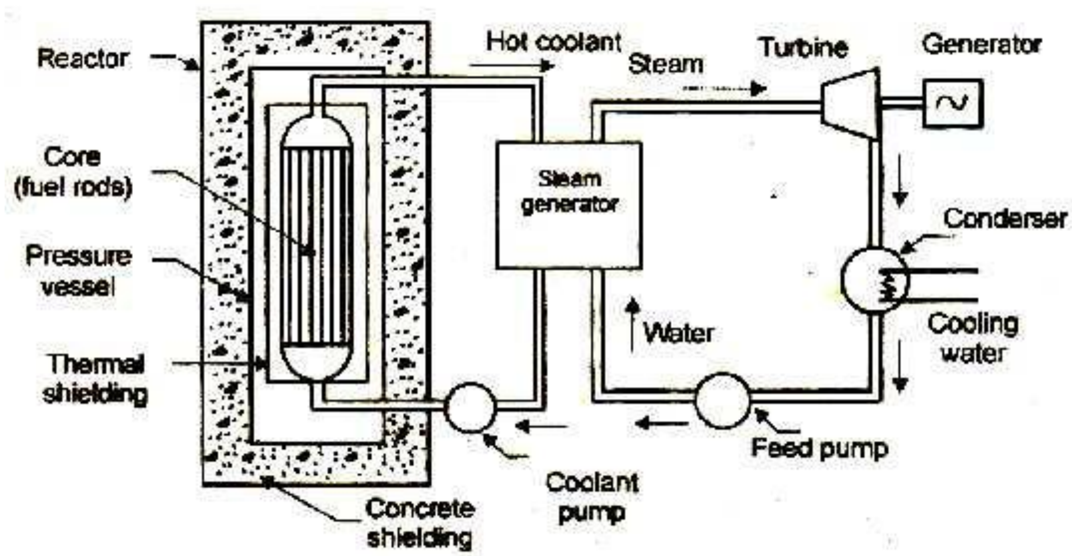


Figure : Nuclear Power Plant (PWR)

ix) Coolant pump and Feed pump

The steam from the turbine flows to the condenser where cooling water is circulated.

Coolant pump and feed pump are provided to maintain the flow of coolant and feed water respectively.

Advantages of nuclear power plant

1. It can be easily adopted where water and coal resources are not available.
2. The nuclear power plant requires very small quantity of fuel. Hence fuel transportation cost is less.
3. Space requirement is less compared to other power plants of equal capacity.
4. It is not affected by adverse weather conditions.
5. Fuel storage facilities are not needed as in the case of the thermal power plant.
6. Nuclear power plants will converse the fossils fuels (coal, petroleum) for other energy needs.
7. Number of workmen required at nuclear plant is far less than thermal plant.
8. It does not require large quantity of water.

Disadvantages

1. Radioactive wastes, if not disposed of carefully, have adverse effect on the health of workmen and the population surrounding the plant.
2. It is not suitable for varying load condition.
3. It requires well-trained personnel.
4. It requires high initial cost compared to hydro or thermal power plants.

Classifications of Nuclear Reactors

The nuclear reactors are classified on the following basis:

1. On the basis of neutron energy

a) Fast reactors

In these reactors, the fission is effected by fast neutrons without any use of moderators.

b) Thermal reactors

In these reactors, the fast neutrons are slowed with the use of moderators. The slow neutrons are absorbed by the fissionable fuel and chain reaction is maintained. The moderator is the most essential component in these reactors.

2. On the basis of fuel used

a) Natural fuel

In this reactor, the natural uranium is used as fuel and generally heavey water or graphite is used as moderator.

b) Enriched uranium

In this reactor, the Uranium used contains 5 to 10% U and ordinary water can be used as moderator.

3. On the basis of moderator used

a) Water moderated

b) Heavy water moderated

c) Graphite moderated

d)Beryllium moderated

4. On the basis of coolant used

a) Water cooled reactors (ordinary or heavy),

b) Gas cooled reactors

c) Liquid metal cooled reactors

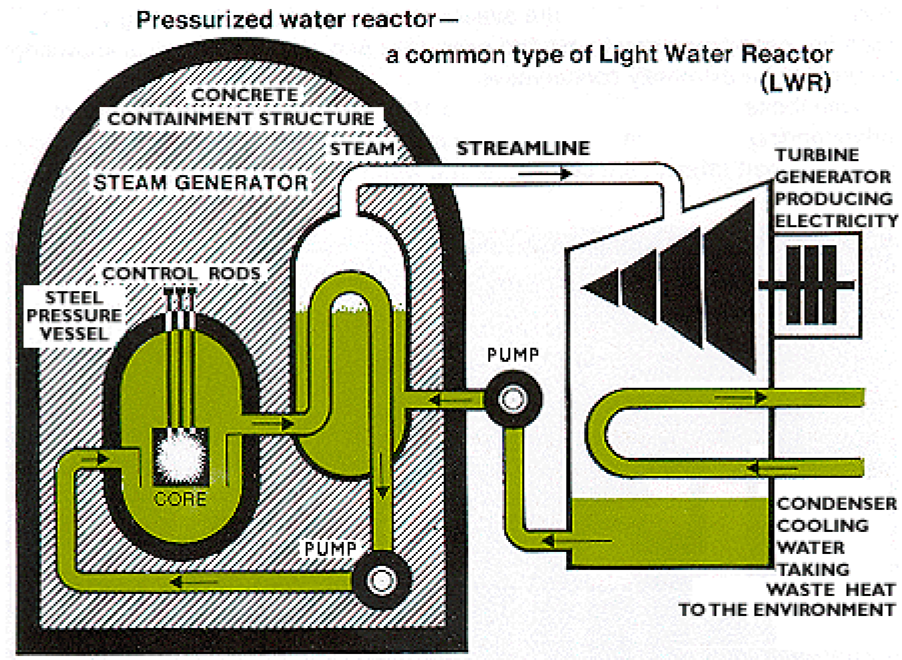
d) Organic liquid cooled reactors

3.PRESSURIZED WATER REACTOR (PWR):

Working principle:

A nuclear power plant differs from a conventional steam power plant only in the steam generating part. There is no change in the turbo-alternator and the condensing system. The nuclear fuel which is at present in commercial use is Uranium. Heat energy evolved by the fission reaction of one kg of Ucan produce as much energy as can be produced by burning 4500 tons of high grade coal.

Uranium exists in the isotopic form of U235 which is unstable. When a neutron enters the nucleus of U235 , the nucleus splits into two equal fragments and also releases 2.5 fast moving neutrons with a velocity of 1.5×10^7 metres / sec producing a large amount of energy, nearly 200millions electron-volts. This is called “nuclear fission”.



A PWR has fuel assemblies of 200-300 rods each, arranged vertically in the core, and a large reactor would have about 150-250 fuel assemblies with 80-100 tonnes of uranium.

Water in the reactor core reaches about 325°C, hence it must be kept under about 150 times atmospheric pressure to prevent it boiling. Pressure is maintained by steam in a pressuriser (see diagram). In the primary cooling circuit the water is also the moderator, and if any of it turned to steam the fission reaction would slow down. This negative feedback effect is one of the safety features of the type. The secondary shutdown system involves adding boron to the primary circuit.

The secondary circuit is under less pressure and the water here boils in the heat exchangers which are thus steam generators. The steam drives the turbine to produce electricity, and is then condensed and returned to the heat exchangers in contact with the primary circuit.

4.BOILING WATER REACTOR (BWR)

Construction

i) Moderators

In any chain reaction, the neutrons produced are fast moving neutrons. These a material is called a 'Moderator' thus slowed down the neutrons are easily captured by the fuel element at the chain reaction proceeds slowly.

ii) Reflectors

Some of the neutrons produced during fission will be partly absorbed by the fuel elements, moderator, coolant and other materials. The remaining neutrons will try to escape from the reactor and will be lost. Such losses are minimized by surrounding (lining) the reactor core with a material called a reflector which will reflect the neutrons back to the core. They improve the neutron economy. Economy: Graphite, Beryllium.

iii) Shielding

During Nuclear fission α,β,γ particles and neutrons are also produced. They are harmful to human life. Therefore it is necessary to shield the reactor with thick layers of lead, or concrete to protect both the operating personnel as well as environment from radiation hazards.

iv) Cladding

In order to prevent the contamination of the coolant by fission products, the fuel element is covered with a protective coating. This is known as cladding. Control rods are used to control the reaction to prevent it from becoming violent. They control the reaction by absorbing neutrons. These rods are made of boron or cadmium. Whenever the reaction needs to be stopped, the rods are fully inserted and placed against their seats and when the reaction is to be started the rods are pulled out.

v) Coolant

The main purpose of the coolant in the reactor is to transfer the heat produced inside the reactor. The same heat carried by the coolant is used in the heat exchanger for further utilization in the power generation. The light water used as coolants in BWR. The

vi) Nuclear reactor

A nuclear reactor may be regarded as a substitute for the boiler fire box of a steam power plant. Heat is produced in the reactor due to nuclear fission of the fuel U235. The heat liberated in the reactor is taken up by the coolant circulating through the core. Hot coolant leaves the reactor at top and flows into the steam generator (boiler).

Working

Figure shows a simplified BWR. Light water, which acts as the coolant and moderator, passes through the core where boiling takes place in the upper part of the core. The wet steam then passes through a bank of moisture separators and steam dryers in the upper part of the pressure vessel. The water that is not vaporized to steam is recirculated through the core with the entering feed water using two recirculation pumps coupled to jet pumps (usually 10 to 12 per recirculation pump). The steam leaving the top of the pressure vessel is at saturated conditions of 7.2 MPa and 278^{o}C.

The steam then expands through a turbine coupled to an electrical generator. After condensing to liquid in the condenser, the liquid is returned to the reactors as feedwater. Prior to entering the reactor, the feedwater is preheated in several stages of feedwater heaters. The balance of plant systems (Example: Turbine generator, feedwater heaters) are similar for both PWR and BWRs.

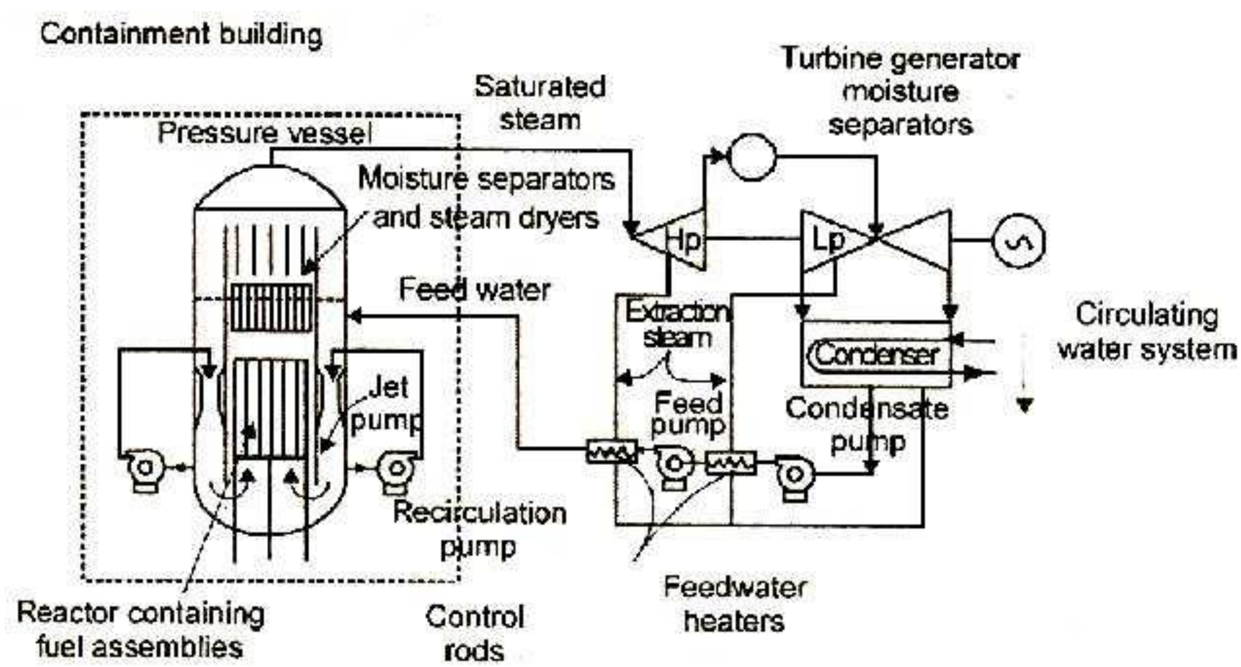


Figure: Schematic for a boiling water reactor.

The BWR reactor core, like that in a PWR, consists of a large number of fuel rods housed in fuel assemblies in a nearly cylindrical arrangement. Each fuel assembly contains an 8×8 or 9×9 square array of 64 or 81 fuel rods (typically two of the fuel rods contain water rather than fuel) surrounded by a square Zircaloy channel box to ensure no coolant crossflow in the core. The fuel rods are similar to the PWR rods, although larger in diameter. Each fuel rod is a zirconium alloy clad tube containing pellets of slightly enriched uranium dioxide (2% to 5% U-235) stacked end-to end. The reactor is controlled by control rods housed in a cross-shaped, or cruciform, arrangement called a control element. The control elements enter from the bottom of the reactor and move in spaces between the fuel assemblies.

The BWR reactor core is housed in a pressure vessel that is larger than that of a PWR. A typical BWR pressure vessel, which also houses the reactor core, moisture separators, and steam dryers, has a diameter of 6.4 m, with a height of 22 m. Since a BWR operators at a nominal pressure of 6.9 MPa, its pressure vessel is thinner that of a PWR.

5. HEAVY WATER COOLED REACTOR (HWR) (OR) CANDU TYPE REACTOR (CANDU – CANADIUM, DEUTRIUM, URANIUM).

Construction

i) Moderators

In any chain reaction, the neutrons produced are fast moving neutrons. These a material is called a 'Moderator' thus slowed down the neutrons are easily captured by the fuel element at the chain reaction proceeds slowly.

ii) Reflectors

Some of the neutrons produced during fission will be partly absorbed by the fuel elements, moderator, coolant and other materials. The remaining neutrons will try to escape from the reactor and will be lost. Such losses are minimized by surrounding (lining) the reactor core with a material called a reflector which will reflect the neutrons back to the core. They improve the neutron economy. Economy: Graphite, Beryllium.

iii) Shielding

During Nuclear fission α, β,γ particles and neutrons are also produced. They are harmful to human life. Therefore it is necessary to shield the reactor with thick layers of lead, or concrete to protect both the operating personnel as well as environment from radiation hazards.

iv) Cladding

In order to prevent the contamination of the coolant by fission products, the fuel element is covered with a protective coating. This is known as cladding. Control rods are used to control the reaction to prevent it from becoming violent. They control the reaction by absorbing neutrons. These rods are made of boron or cadmium. Whenever the reaction needs to be stopped, the rods are fully inserted and placed against their seats and when the reaction is to be started the rods are pulled out.

v) Coolant

The main purpose of the coolant in the reactor is to transfer the heat produced inside the reactor. The same heat carried by the coolant is used in the heat exchanger for further utilization in the power generation. The light water used as coolants in BWR.

vi) Nuclear reactor

A nuclear reactor may be regarded as a substitute for the boiler fire box of a steam power plant. Heat is produced in the reactor due to nuclear fission of the fuel U235. The heat liberated in the reactor is taken up by the coolant circulating through the core. Hot coolant leaves the reactor at top and flows into the steam generator (boiler).

These reactors are more economically to those nations which do not produce enriched uranium as the enrichment of uranium is very costly. In this type of reactors, the natural uranium (0.7% U235) is used as fuel and heavy water as moderator. This type of reactor was first designed and developed in Canada. The first heavy water reactor in Canada using heavy water as coolant and moderator of 200 MW capacity with 29.1% thermal efficiency was established at Douglas (Ontario known as Douglas power station. The arrangement of the different components of CANDU type reactor is shown in figure.

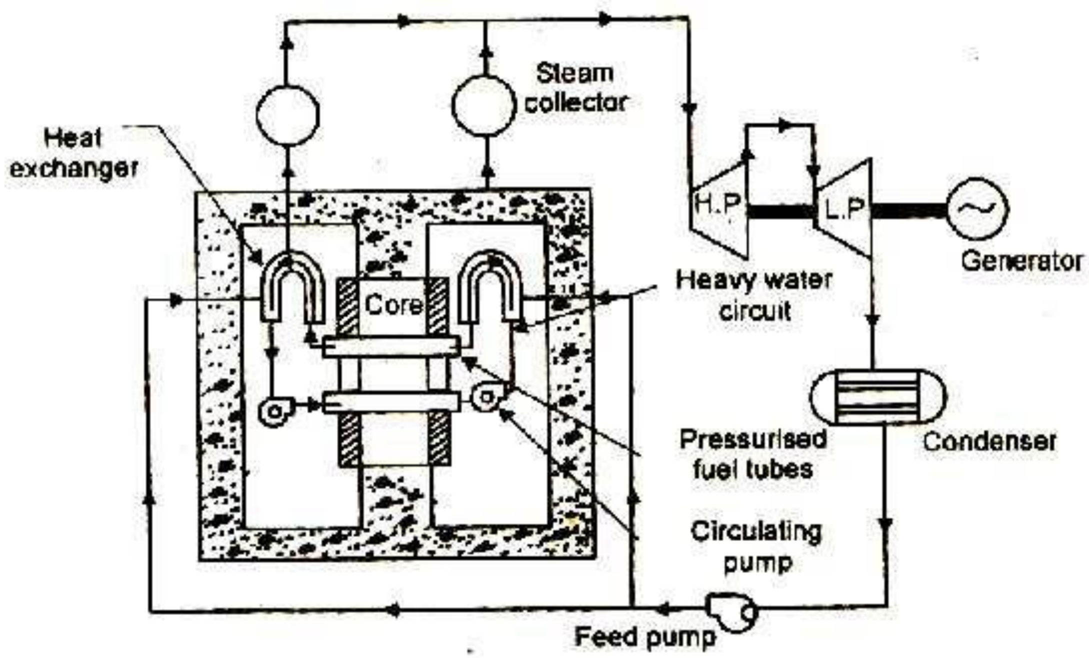


Figure: Douglas-point candu type heavy water moderated and cooled nuclear reactor power plant

The coolant heavy water is passed through the fuel pressure tubes and heat-exchanger. The heavy water is circulated in the primary circuit in the same way as with a PWR and the steam is raised in the secondary circuit transferring the heat in the heat exchanger to the ordinary water. The control of the reactor is achieved by varying the moderator level in the reactor and, therefore, control rods are not required. For rapid shutdown purpose, the moderator can be dumped through a very large area into a tank provided below the reactor.

Advantages

1. The major advantage of this reactor is that the fuel need not be enriched.
2. The reactor vessel may be built to withstand low pressure, therefore, the cost of the vessel is less.
3. No control rods are required, therefore, control is much easier than other types.
4. The moderator can be kept at low temperature which increases its effectiveness in slowing down neutrons.
5. Heavy water being a very good moderator, this type of reactor has higher multiplication factor and low fuel consumption.
6. A shorter period is required for the site construction compared with PWR and BWR.

Disadvantages

1. The cost of heavy water is extremely high (Rs. 300/kg).
2. The leakage is a major problem as there are two mechanically sealed closures per fuel channel. Canadian designs generally are based on recovering high proportion of heavy water leakages as absolute leak-tightness cannot be assured.
3. Very high standard of design, manufacture inspection and maintenance are required.
4. The power density is considerably low (9.7 kW/litre) compared with PWR and BWR, therefore, the reactor size is extremely large.

Even though CANDU-type reactors look promising in future, light water reactors all over the world proved more efficient than heavy water and in fact only 36 out of 529 power reactors in the world are based on heavy water.

6.FAST BREEDER REACTOR

Figure shows a fast breeder reactor system. In this reactor the core containing U235 In surrounded by a blanket (a layer of fertile material placed outside the core) of fertile material U238.In this reactor no moderator is used. The fast moving neutrons liberated due to fission of U235 are absorbed by U238 which gets converted into fissionable material Pu239 which is capable of sustaining chain reaction. Thus this reactor is important because it breeds fissionable material from fertile material U239 available in large quantities. Like sodium graphite nuclear reactor this reactor also uses two liquid metal coolant circuits. Liquid sodium is used as primary coolant when circulated through the tubes of intermediate heat exchange transfers its heat to secondary coolant sodium potassium alloy. The secondary coolant while flowing through the tubes of steam generator transfers its heat to feed water.

Fast breeder reactors are better than conventional reactors both from the point of view of safety and thermal efficiency. For India which already is fast advancing towards self reliance in the field of nuclear power technology, the fast breeder reactor becomes inescapable in view of the massive reserves of thorium and the finite limits of its uranium resources. The research and development efforts in the fast breeder reactor technology will have to be stepped up considerably if nuclear power generation is to make any impact on the country's total energy needs in the not too distant future.

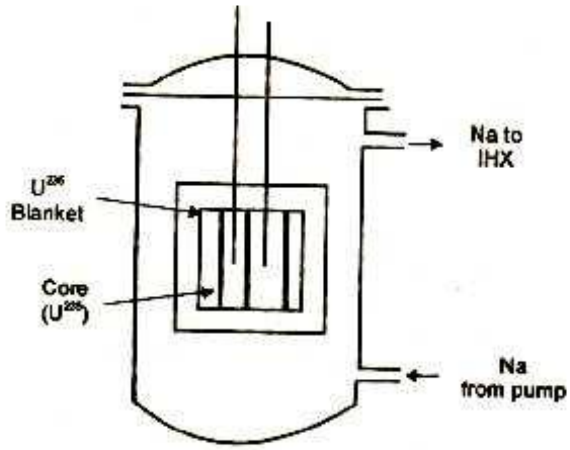
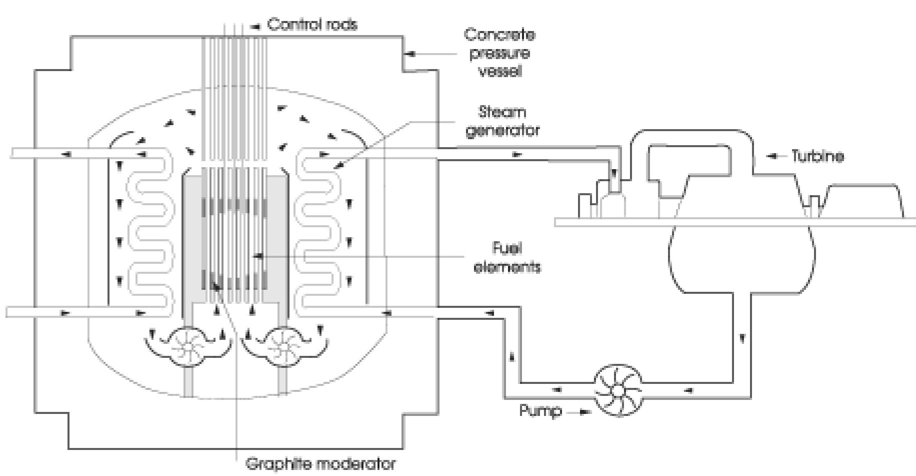


Figure: Fast breeder reactor.

The commonly used coolants for fast breeder reactors are as follows:
i) Liquid metal (Na or NaK).
ii)Helium (He)iii) carbon dioxide.
Sodium has the following advantages:
i) It has very low absorption cross-sectional area.
ii) It possesses good heat transfer properties at high temperature and low pressure.
iii)It does not react on any of the structural materials used in primary circuits.

7. ADVANCED GAS-COOLED REACTOR (AGR)

These are the second generation of British gas-cooled reactors, using graphite moderator and carbon dioxide as coolant. The fuel is uranium oxide pellets, enriched to 2.5-3.5%, in stainless steel tubes. The carbon dioxide circulates through the core, reaching 650°C and then past steam generator tubes outside it, but still inside the concrete and steel pressure vessel. Control rods penetrate the moderator and a secondary shutdown system involves injecting nitrogen to the coolant.



8. SODIUM GRAPHITE REACTOR (SGR) - LIQUID METAL COOLED REACTORS:

The reactor shown in figure uses two liquid metal coolants. Liquid sodium (Na) serves as the primary coolant and an alloy of sodium potassium (NaK) as the secondary coolant. Sodium melts at 208^{o}C and boils at 885^{o}C. This enables to achieve high outlet coolant temperature in the reactor at moderate pressure nearly atmospheric which can be utilized in producing steam of high temperature, thereby increasing the efficiency of the plant. Steam at temperature as high as 540^{o}C has been obtained by this system. This shows that by using liquid sodium as coolant more electrical power can be generated for a given quantity of the fuel burn up.

Secondly low pressure in the primary and secondary coolant circuits, permits the use of less expensive pressure vessel and pipes etc. Further sodium can transfer its heat very easily. The only disadvantage in this system is that sodium becomes radioactive while passing through the core and reacts chemically with water. So it is not used directly to transfer its heat to the feed water, but a secondary coolant is used. Primary coolant while passing through the tubes of intermediate heat exchanges (I.H.X) transfers its heat to the secondary coolant. The secondary coolant then flows through the tubes of steam generator and passes on its heat to the feed water.
Graphite is used as heat transfer media have certain advantages of using liquids used for heat transfer purposes. The various advantages of using liquid metals as heat transfer media are that they have relatively low melting points and combine high densities with low vapour pressure at high temperatures as well as with large thermal conductivities.

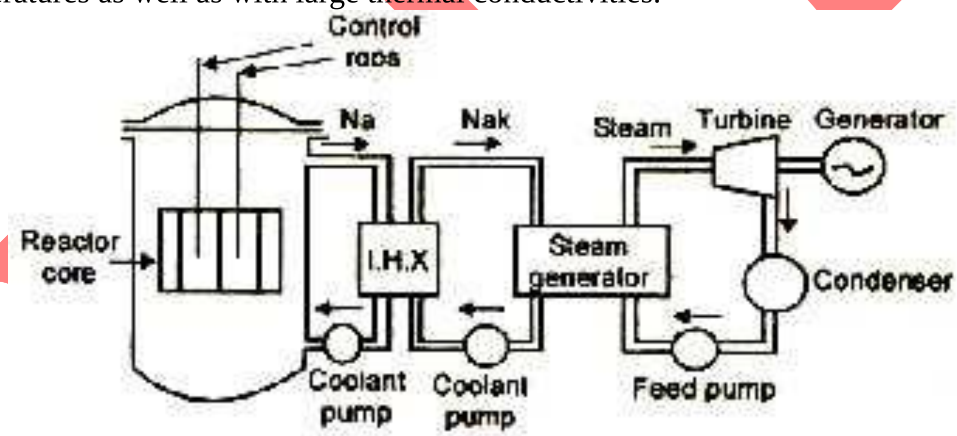


Figure: Sodium graphite reactor

9. SAFETY FOR NUCLEAR POWER PLANTS:

Nuclear power plants should be located far away from the populated area to avoid the radioactive hazard. A nuclear reactor produces α and β particles, neutrons and γ- quanta which can disturb the normal functioning of living organisms. Nuclear power plants involve radiation leaks, health hazard to workers and community, and negative effect on surrounding forests.
At nuclear power plants there are three main sources of radioactive contamination of air.
1. Fission of nuclei of nuclear fuels.
2. The second source is due to the effect of neutron fluxes on the heat carrier in the primary

cooling system and on the ambient air.
3. Third source of air contamination is damage of shells of fuel elements.

This calls for special safety measures for a nuclear power plant. Some of the safety measures are as follows.
1. Nuclear power plant should be located away from human habitation.
2. Quality of construction should be of required standards.
3. Waste water from nuclear power plant should be purified.
The water purification plants must have efficiency of water purification and satisfy rigid requirements as regards the volume of radioactive wastes disposed to burial.
4. An atomic power plant should have an extensive ventilation system. The main purpose of this ventilation system is to maintain the concentration of all radioactive impurities in the air below the permissible concentrations.
5. An exclusion zone of 1.6 km radius around the plant should be provided where no public habitation is permitted.
6. The safety system of the plant should be such as to enable safe shut down of the reactor whenever required.

UNIT IV

POWER FROM RENEWABLE ENERGY

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

1.LAYOUT OF HYDRO POWER PLANT

Introduction

Hydro-electric power plant utilizes the potential energy of water stored in a dam built

across the river. The potential energy of water is used to run water turbine to which the electric generator is coupled. The mechanical energy available at the shaft of the turbine is converted into electrical energy means of the generator.

ELEMENTS OF HYDEL POWER PLANT

The schematic representation of a hydro-electric power plant is shown in figure.

i) Water reservoir

Continuous availability of water is the basic necessity for a hydro-electric plant. Water

collected from catchment area during rainy season is stored in the reservoir. Water surface in the storage reservoir us known as head race.

ii) Dam

The function of a dam is to increase the height of water level behind it which ultimately

increases the reservoir capacity. The dam also helps to increase the working heat of the power plant.

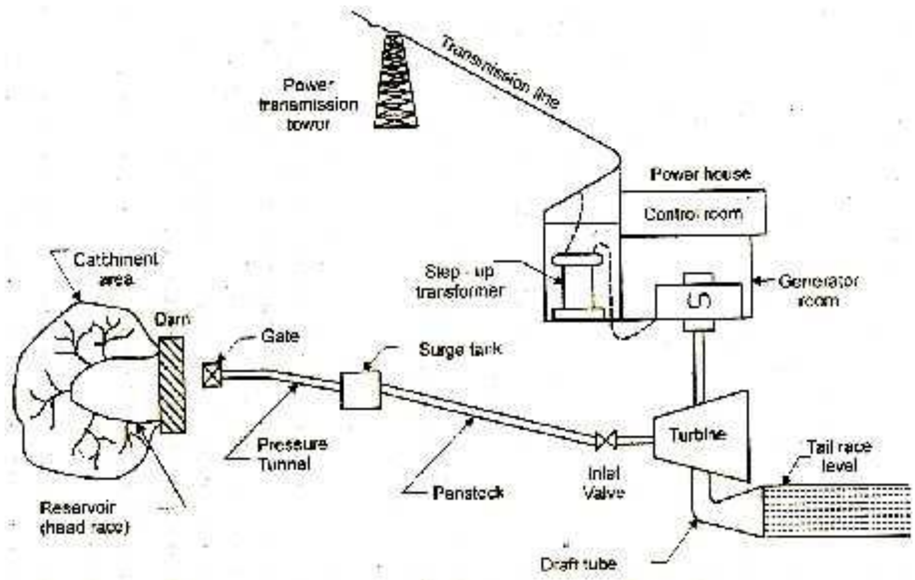


Figure: Layout of hydro-electric power plant.

iii) Spillway

Water after a certain level in the reservoir overflows through spillway without allowing the increase in water level in the reservoir during rainy season

iv) Pressure tunnel

It carries water from the reservoir to surge tank.

v) Penstock

Water from surge tank is taken to the turbine by means of penstocks, made up of reinforced concrete pipes or steel.

vi) Surge tank

There is sudden increase of pressure in the penstock due to sudden backflow of water, as load on the turbine is reduced. The sudden rise of pressure in the penstock is known as water hammer. The surge tank is introduced between the dam and the power house to keep in reducing the sudden rise of pressure in the penstock. Otherwise penstock will be damaged by the water hammer.

vii) Water turbine

Water through the penstock enters into the turbine through and inlet valve. Prime movers which are in common use are Pelton turbine, Francis turbine and Kaplan turbine. The potential energy of water entering the turbine is converted into mechanical energy. The mechanical energy available at the turbine shaft is used to run the electric generator. The water is then discharged through the draft tube.

viii) Draft tube

It is connected to the outlet of the turbine. It allows the turbine to be placed over tail race level.

ix) Tail race

Tail race is a water way to lead the water discharged from the turbine to the river. The water held in the tail race is called tail race water level.

x) Step-up transformer

Its function is to raise the voltage generated at the generator terminating before transmitting the power to consumers.

xi) Power house

The power house accommodates the turbine, generator, transformer and control room.

2. CLASSIFICATION OF HYDRO-POWER PLANTS

Hydro-plants are classified according to the head of water under which they work.

- When the operating head of water exceeds 70 metres, the plant is known as "high headpower plant". Pelton turbine is used as prime mover in such power plants.

- When the head of water ranges from 15 to 70 metres then the power plant is known as "medium head plant". It uses Francis turbine.
- When the head is less than 15 metres the plant is named as "low head plant". It uses Francis or Kaplan turbine as prime mover.

3. CLASSIFICATION OF HYDRO TURBINES

Hydraulic turbines are classified as follows:

1. According to the head and quantity of water available.

2. According to the name of the originator.

3. According to the action of water on the moving blades.

4. According to the direction of flow of water in the runner.

5. According to the disposition of the turbine shaft.

6. According to the specific speed N.

1. According to the head and Quality of water available

i) Impulse turbine: It requires high head and small quantity of flow.

ii) Reaction turbine: It requires low head and high rate of flow.

Actually there are two types of reaction turbines, one for a medium head and medium flow and the other for a low head and large flow.

2. According to the name of the originator

i) Pelton turbine, named after Lester Allen Pelton of California (U.S.A). It is an impulse

type of turbine and is used for high head and low discharge.

ii) Francis turbine, named after James Bichens Francis. It is a reaction type of turbine from medium high to medium low heads and medium small to medium large quantities of water.

iii) Kaplan turbine, named after Dr. Victor Kaplan. It is a reaction type of turbine for low

heads and large quantities of flow.

3. According to action of water on the moving blades

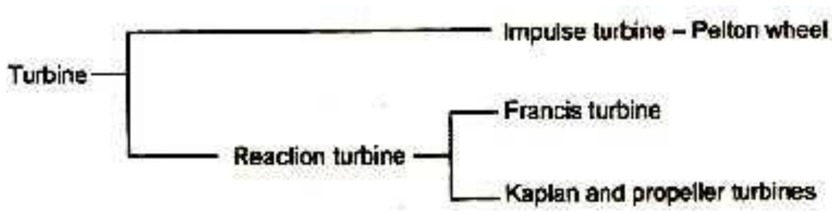


Figure: According to action of water.

4. According to direction of flow of water in the runner.

i) Tangential flow turbines (Pelton turbine).

ii) Radial flow turbine (no more used).

iii) Axial flow turbine (Kaplan turbine).

iv) Mixed (radial and axial flow turbine (Francis turbine).

a tangential flow turbine of the Pelton type the water strikes the runner tangential to the path of rotation.

In an axial flow turbine water flows parallel to the axis of the turbine shaft. The Kaplan turbine is an axial flow turbine. In the Kaplan turbine the runner blades are adjustable and can be rotated about pivots fixed to the boss of runner. If the runner blades of the axial flow turbines are fixed, these are called “propeller turbines”.

In mixed flow turbines the water enters the blades radially and comes out axially, parallel to the turbine shaft. Modern Francis turbines have mixed flow runners.

5. According to the disposition of the turbine shaft

A turbine shaft may be either vertical or horizontal. In modern practice, Pelton turbines usually have horizontal shafts whereas the rest, especially the large units, have vertical shafts.

6. According to specific speed.

The specific speed of a turbine is defined as the speed of a geometrically similar turbine that would develop 1 kW under 1 m head.

Turbines with low specific speed work under a high head and low discharge conditions, while high specific speed turbines work under a low head and high discharge conditions.

PELTON WHEEL

This is a commonly used impulse type of turbine. It is named after an American engineer Lester. A. Pelton (1829-1908), who developed this turbine. The Pelton wheel is suitable for very high heads and it requires a lesser quantity of water. A pelton wheel is shown in figure. It consists of a runner, buckets, a nozzle, a guide mechanism, a hydraulic brake and casing.

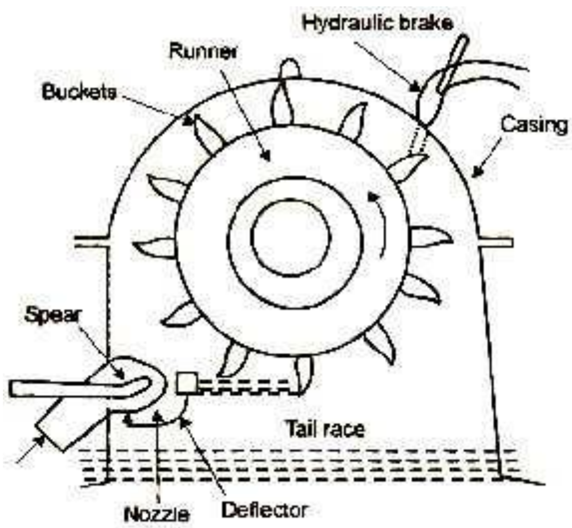


Figure : Pelton wheel

Runner and Buckets

The runner is a circular disc. It consists of a number of semi-ellipsoidal buckets evenly spaced around its periphery. The buckets are divided into two hemi-spherical cups by a sharpedged ridge known as a splitter. This arrangement avoids the axial thrust and end thrust on bearings. (The axial thrusts being equal and opposite, neutralize each other). Generally, the buckets are bolted to the periphery of the runner. In some cases, to the periphery of the runner. In some cases, the buckets and the wheel are cast integral as one piece. In the case of the bolted type, broken or damaged buckets can be replaced economically. For low heads, the bucket is made of case iron and for high heads, they are made of bronze or stainless steel to withstand heavy impact.

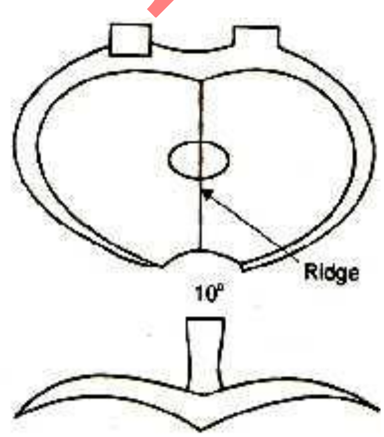


Figure: Bucket of pelton wheel.

Nozzle and Guide mechanism:

A nozzle is fitted to the end of the penstock near the turbine. The nozzle is provided with a conical needle or spear to regulate the quantity of water coming out of the nozzle, thereby control the speed of the runner. The spear may be operated manually by a hand wheel (for small units) or automatically by a governing mechanism (for larger units).

Hydraulic brake:

When the turbine has to be brought to rest by closing the inlet valve of the turbine, the runner generally takes a very long time to come to rest due to its inertia. To bring it to rest quickly, a small brake nozzle is provided. This nozzle is opened and it directs a jet of water at the back of the buckets. This acts as a brake to bring revolving runner quickly to rest.

Casing

The casing is made up of cast-Iron or fabricated steel plates. It is provided for the following purposes:

- To prevent splashing of water,
- To lead the water to the tail race and
- To act as a safeguard (cover) against any accidents.

Working principle

The water is conveyed to the power house from the head race through penstocks. The nozzle is fitted to the end of the penstock (power house end) delivers a high velocity water jet into the bucket. One or more jets of water are arranged to impinge on the buckets tangentially. The impact of water jet on the bucket causes the wheel to rotate, thus producing mechanical work. An electric generator is coupled to the runner shaft and mechanical energy is converted into electrical power. After leaving the turbine wheel, water falls into the tail race. The Pelton wheel is located above the tail race so that, the buckets do not splash the tail race water.

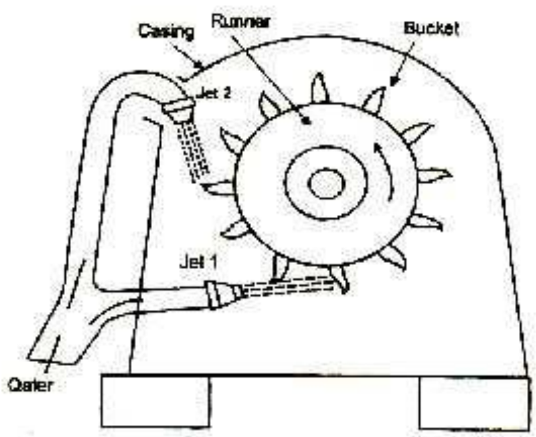


Figure : Multiple jet pelton wheel

The velocity of jet, velocity of wheel and the jet ratio (the ratio of pitch circle diameter of runner and jet diameter) are restricted in the case of a single jet Pelton wheel. Hence, a single jet Pelton wheel cannot develop high power. However the power can be increased by arranging more than one jet (usually 2, 3, 4 or 6)spaced evenly around the same runner. The maximum number of jets with a single runner is six.

Sometimes, for increasing the power, a number of runners mounted on a common shaft may be used. In certain cases, a combination of the above two systems may be preferred.

Construction and working principle of Francis turbine

Reaction turbines

Reaction turbines operate under pressure of water. Only a part of the total head of water is converted into a kinetic head before it reaches the runner. The water completely fills all the passages in the runner (turbine runs full). Water enters the wheel due to the head of water at inlet and flows through the vanes. When flowing through the vanes, both the pressure and velocity change. The water leaves the turbine to the tail race at a reduced pressure and velocity.

Reaction turbines may be: 1) Radially inward flow turbines, 2) Outward flow turbines, 3)Axial flow turbines, 4) Mixed flow turbines.

FRANCIS TURBINE

The modern Francis turbine is a mixed flow type of reaction turbine. In this, water under pressure enters the runner towards the centre in a radial direction and leaves the runner axially. It operates under medium heads and requires a moderate quantity of water. Figure shows the parts of a Francis turbine. It consists of a scroll casing, stay ring, guide mechanism, runner and draft tube.

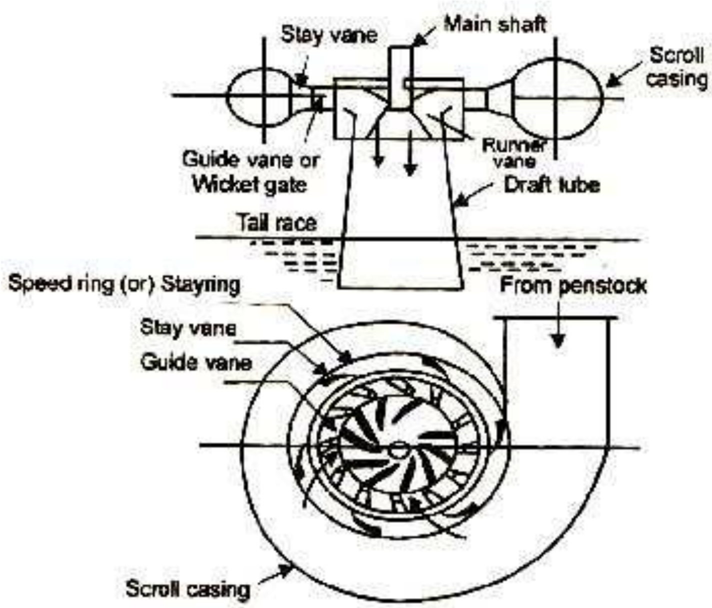


Figure Francis Turbine

a) Scroll Casing

Water from the penstock is received by a scroll casing. The scroll casing (also called spiral casting) surrounds the guide wheel and runner. The cross-sectional area of the casing decreases uniformly to distribute the water around the guide ring evenly. Also, this prevents eddy formation. In bigger units, stay vanes are provided inside the casing to direct the water to the guide vanes. The casing has inspection holes and provision for connecting a pressure gauge. The casing is made of welded steel plates or cast steel.

b) Speed ring or Stay ring

The speed ring or stay ring consists of two rings held together by a series of fixed vanes called stay vanes. This ring directs water from the scroll casing to the guide vanes. It also transfers the loads (caused by the water pressure, weight of turbine and the weight of the generator) to the foundation. It is made of cast iron, cast steel or fabricated plate steel.

c) Guide mechanism

The guide blades (wicket gates) are fitted between two rings in the form of a wheel known vas a guide wheel. The guide vanes guide the water to enter tangentially to the runner blades. The air foil shape of the vanes prevent eddy formation and reduces frictional losses. Each guide vane is pivoted and it can be rotated about its pivot by a system of levers and links. This rotation of guide vanes alters the width of the water passage between them. Thus, water flowing into the runner is varied accordingly to the requirement. The guide vanes are generally made of case steel or stainless steel.

d) Runner

The runner consists of series of curved vanes. The vanes (16 to 24) are evenly arranged around the circumference in the annualar space between two plates. The vanes are properly shaped to receive the water without a shock. The runner is keyed to the shaft which may be vertical or horizontal. The runner is made of cast iron for small turbines. In large turbines, the runner is made of cast steel or stainless steel.

e) Draft tube

This is a pipe or passage which leads the water exhausted from the turbine into the tail race. Its cross-section increases gradually towards the outlet. The bottom enlarged end is submerged in a tail race water level. It is made of cast steel, welded plate steel or concrete.

f) Working principle

The water from the reservoir is carried to the turbine through penstocks and enters the scroll casing. The casing distributes water evenly around the circumference of the turbine runner. From the scroll casing, the water passes through the stay ring. This ring directs water to the guide vanes or wicket gates. These guide vanes regulate the quantity of water supplied to the runner.

The air foil shape of the guide vanes allows the water to flow smoothly without a shock. The water enters the runner with a low velocity and considerable pressure. As the water flows through the runner, the direction of flow of waters changed from axial to radial. The pressure energy is gradually converted into kinetic energy and the runner is rotated at high speed. This torque is transmitted to the generator which is coupled to the runner shaft. After passing through the runner water enters the tail race through a draft tube.

KAPLAN TURBINE

The Kaplan turbine is an axial flow reaction turbine. It is suitable for relatively low heads. Hence, it requires a large quantity of water to develop high power. It operates in an entirely closed conduct from the head race to the rail race.

The main components of a Kaplan turbine are shown in figure. It consists of a scroll case, staring, guide vane mechanism and draft tube which are similar to those of a Francis turbine. The runner blade arrangement in a Kaplan turbine differs from a Francis turbine.

a) Runner

The runner has 4 to 6 blades attached to a hub or boss. It resembles a ship's propeller and hence a Kaplan turbine is a type of propeller turbine. The blades are so shaped that water flows axially through the runner. The blades of the runner can also be adjusted to any desired angle and the area of flow passage can be varied. This adjustment can be carried automatically by a servomotor governor mechanism. Thus, in a Kaplan turbine, both the guide vane angle, and runner blade angle may be varied, resulting in higher efficiency. Even at a part load, when alower quantity of water is flowing through the turbine high efficiency can be obtained.

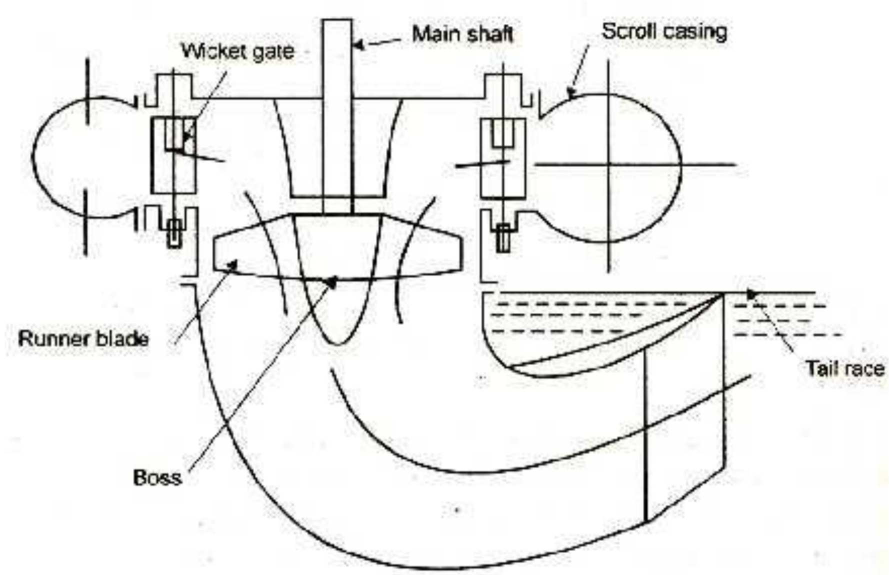


Figure: Kaplan turbine

b) Working principle

The water from the scroll casing flows over the guide vanes. It is deflected through 90^{O} between guide vanes and runner. Then, it flows axially into the runner. The blades are shaped such that water flows axially in the runner. The force exerted on the blades causes the runner shaft to rotate. This rotation is transmitted to the generator which is couple to the runner shaft. After passing through the runner, the water enters the tailrace through a draft tube.

Compare Impulse and reaction turbines

S.No.	**Impulse turbine**	**Reaction turbine**
1	**Head:** The machine is suitable for high installation. (H=100 + 200 m).	The machines can be used for medium heads (H=50 to 500 m) and low heads (less than 50 m)
2	**Nature of input energy to the runner:** The nozzle converts the entire hydraulic energy into kinetic energy before water strikes the runner.	The head is usually inadequate to produce high velocity jet. Hence water is supplied to the runner in the forms of both pressure and kinetic energy.
3	**Method of energy transfer:** The buckets of the runner are so shaped that they extract almost all the kinetic energy of the jet.	The wicket gates accelerate the flow a little and direct the water to runner vanes to which energies of water are transferred.
4	**Operating pressure:** The turbine works under atmospheric pressure. Which is the difference between the inlet and exit points of the runner.	The runner works is a closed system under the action of reaction pressure.

5	**Admission of water to the wheel:** Only a few buckets comprising a part of the wheel are exposed to the water jet.	The entire circumference of the wheel receives water and all passages between the runner blades are always full of water.
6	**Discharge:** They are essential low discharge turbines.	Since power is a product of head and weight of the rate of flow, these turbines consume large quantities of water in order to develop a reasonable power under a relatively low head.
7	**Speed of operation:** The speed are invariably high.	Although the specific speeds of these turbines is high, their actual running speeds are comparatively low.
8	**Size :** These are generally small size.	The turbines sizes is much larger than impulse wheels, in order to accommodate heavy discharge.
9	**Casing:** It prevents splashing of water. It has no hydraulic function to serve.	The spiral casing has an important role to play; it distributes water under the available pressure uniformly around the periphery of the runner.
10	**Turbine setting:** The head between the wheel and race is lost.	The draft tube ensures that the head of water below tail race level is not lost.
11	**Maximum efficiency:** The highest efficiency (=88%) is less than that of reaction turbine.	The maximum efficiency (=95%) of design output is higher than that of impulse wheels.
12	**Part load operation:** From about 20% to 100% of design output, the efficiency remains nearly the same. Hence the machine is ideal for generating small loads over long periods of time.	With the exception of a Kaplan turbine, all reaction turbines give poor part load performance i.e., appreciably low efficiency at less than design output.
13	**Cavitation:** These machine are not susceptible to cavitation.	Runner blades and draft tube invariably undergo cavitation on damage.
14	**Civil engineering works:** Civil works like excavation and concreting are much simpler and economical.	Civil works are more expensive on account of spiral casing and draft tube.

Pumped storage plants

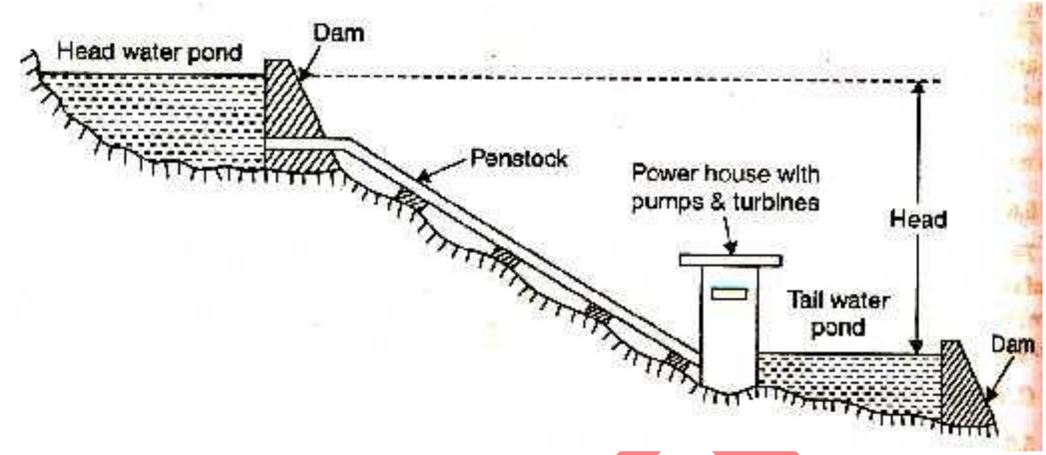


Figure: Pumped storage plant.

Components

i) Water reservoir

Continuous availability of water is the basic necessity for a hydro-electric plant. Water

collected from catchment area during rainy season is stored in the reservoir. Water surface in the storage reservoir us known as head race.

ii) Dam

The function of a dam is to increase the height of water level behind it which ultimately increases the reservoir capacity. The dam also helps to increase the working heat of the power plant.

iii) Penstock

Water from surge tank is taken to the turbine by means of penstocks, made up of reinforced concrete pipes or steel.

iv) Water turbine

Water through the penstock enters into the turbine through and inlet valve. Prime movers which are in common use are Pelton turbine, Francis turbine and Kaplan turbine. The potential energy of water entering the turbine is converted into mechanical energy. The mechanical energy available at the turbine shaft is used to run the electric generator. The water is then discharged through the draft tube.

v) Draft tube

It is connected to the outlet of the turbine. It allows the turbine to be placed over tail race level.

vi) Tail race

Tail race is a water way to lead the water discharged from the turbine to the river. The water held in the tail race is called tail race water level.

vii) Power house

The power house accommodates the turbine, generator, transformer and control room.

Pumped storage plants are employed at the places where the quantity of water available for power generation is inadequate. Here the water passing through the turbines is store in 'tail race pond'. During low load periods this water is pumped back to the head reservoir using the extra energy available. This water can be again used for generating power during peak load periods. Pumping of water may be done seasonally or daily depending upon the conditions of the site and the nature of the load on the plant. Such plants are usually interconnected with steam or diesel engine pants so that off peak capacity of interconnecting stations is used in pumping water and the same is used during peak load periods. Of course, the energy available from the quantity of water pumped water the power available is reduced on account of losses occurring in prime movers.

Advantages:

The pump storage plants entail the following advantages :

1. There is substantial increase in peak load capacity of the plant at comparatively low capital cost.
2. Due to load comparable to rated load on the plant, the operating efficiency of the plant is high.
3. There is an improvement in the load factor of the plant.
4. The energy available during peak load periods is higher than that of during off peak periods so that inspite of losses incurred in pumping there is over-all gain.
5. Load on the hydro-electric plant remains uniform.
6. The hydro-electric plant becomes partly independent of the stream flow conditions.

Under pump storage projects almost 70 percent power used in pumping the water can be recovered. In this field the use of "Reversible Turbine Pump" units is also worth noting. These units can be used as turbine while generating power and as pump while pumping water to storage. The generator in this case works as motor during reverse operation. The efficiency in such case is high and almost the same in both the operations. With the use of reversible turbine pump sets, additional capital investment on pump and its motor can be saved and the scheme can be worked more economically.

4. WIND-ELECTRIC GENERATING POWER PLANT

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

1. Wind turbine or rotor.

2. Wind mill head – it houses speed increaser, drive shaft, clutch, coupling etc.

3. Electric generator.

4. Supporting structure.

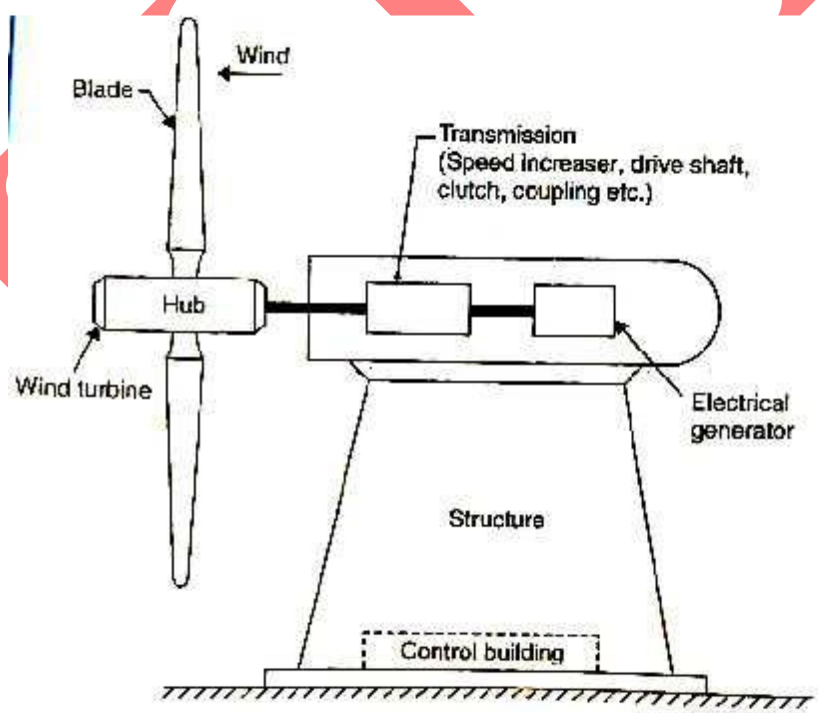


Figure: Wind-Electric generating power plant

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

The wind mill head performs the following functions:
(i) It supports the rotor housing and the rotor bearings.
(ii) It also houses any control mechanism incorporated like changing the pitch of the blades for safety devices and tail vane to orient the rotor to face the wind, the latter is facilitated by mounting it on the top of the supporting structure on suitable bearings.

The wind turbine may be located either unwind or downwind of the power. In the unwind location the wind encounters the turbine before reaching the tower. *Downwind rotors are generally preferred especially for the large aerogenerators.*

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

Types of Wind Machines

Wind machines (aerogenerators) are generally classified as follows:

1. Horizontal axis wind machines.

2. Vertical axis wind machines.

Horizontal axis wind machines.

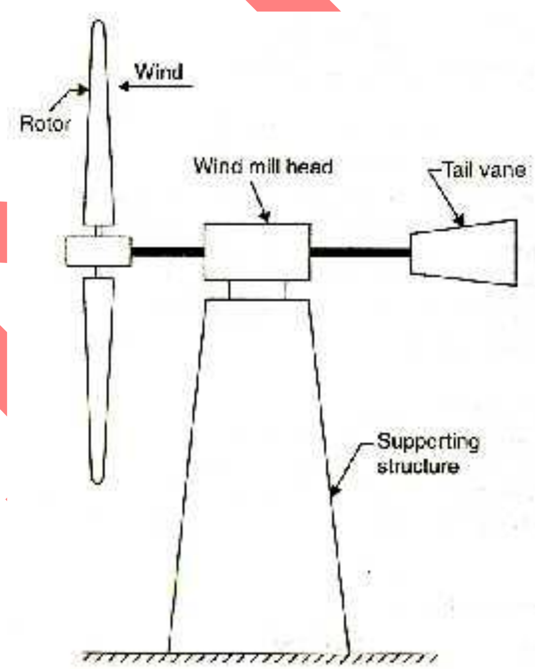


Figure: Horizontal axis wind machine.

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

Vertical axis wind machines.

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

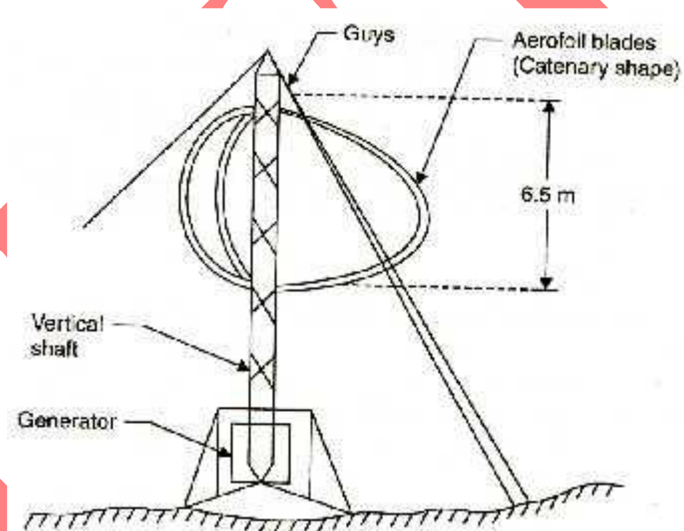


Figure: Vertical axis wind machine

5.TIDAL POWER PLANTS

Principle

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

Working

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

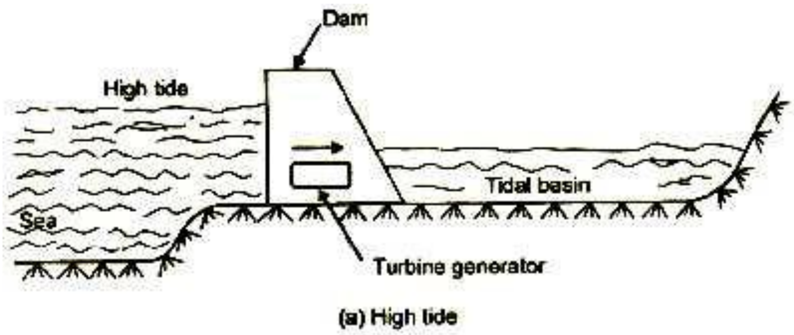


Figure: High tide

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

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

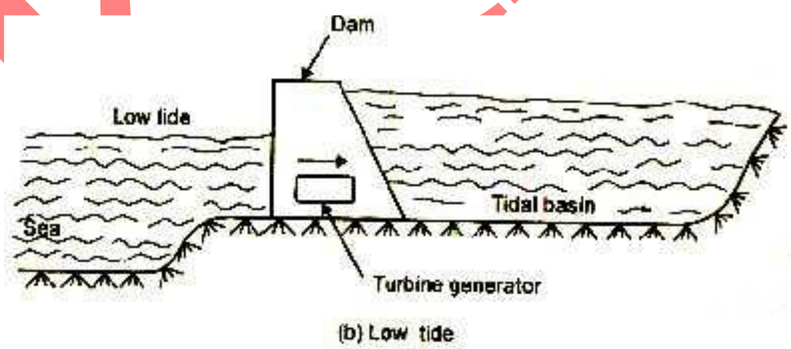


Figure : Low tide

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

Advantages of tidal power plants.

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

2. It is superior to hydro-power plant as it is totally independent of rain.

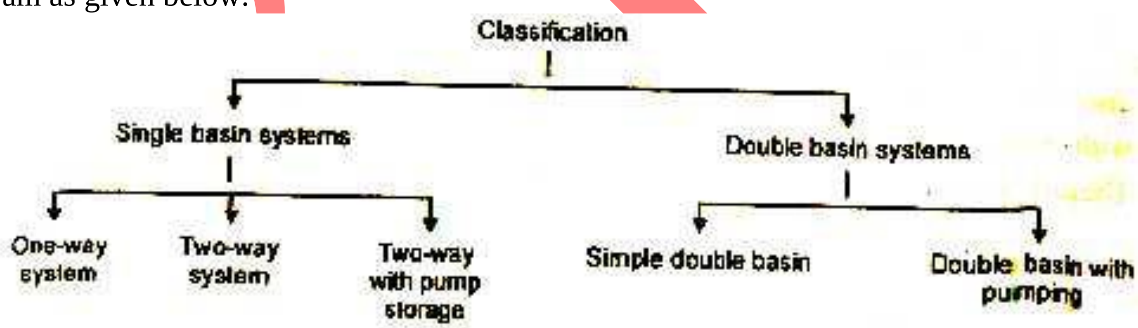
3. It improves the possibility of fish farming in the tidal basins and it can provide recreational to visitors and holiday makers.

Disadvantages

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

Different tidal power plants

The tidal power plants are generally classified on the basis of the number of basins used for the power generation. They are further subdivided as one-way or two-way system as per the cycle of operation for power generation. The classification is represented with the help of a line diagram as given below.



Working of different tidal power plants

1. Single basin-one-way cycle

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

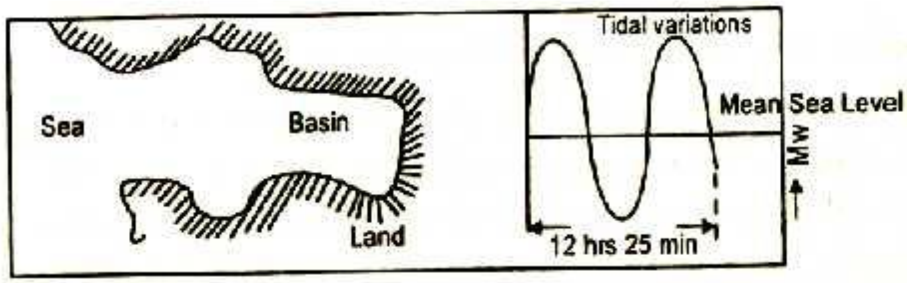


Figure: (a) Tidal region before construction of the power plant and tidal variation

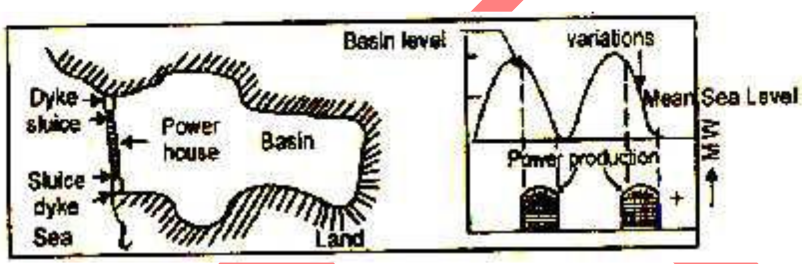


Figure: (b) Single basin, one –way tidal power plant

Figure (a) shows a single tide basin before the construction, of dam and figure (b) shows the diagrammatic representation of a dam at the mouth of the basin and power generating during the falling tide.

2. Single-basin two-way cycle

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

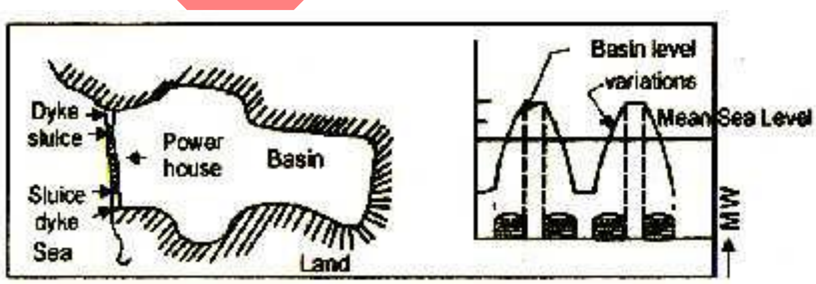


Figure: Single –basin two-way tidal power plant

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

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

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

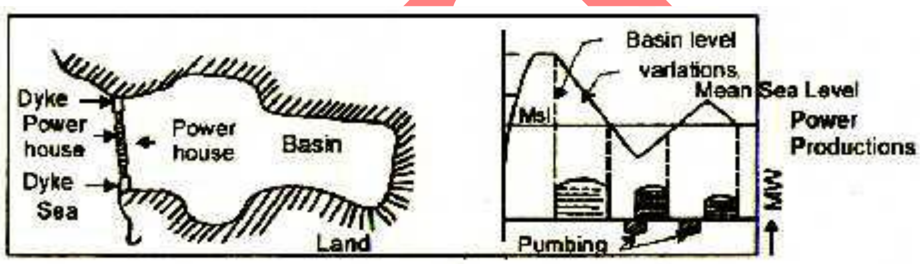


Figure: Single-basin, two-way tidal plant coupled with pump storage system.

4. Double basin type

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

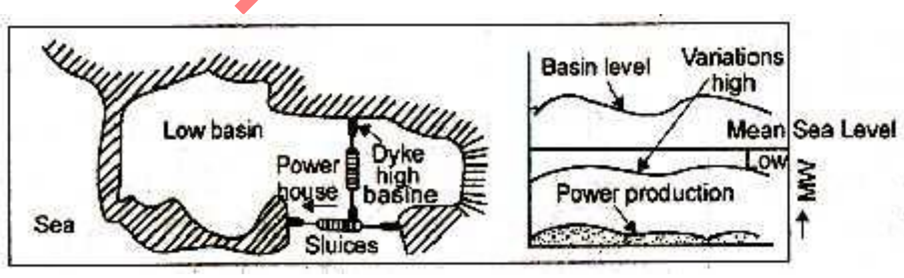


Figure: Double basin, one-way tidal plant.

5. Double basin with pumping

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

Advantages:

1. Tidal power is completely independent of the precipitation (rain) and its uncertainty besides being inexhaustible.
2. Large area of valuable land is not required.
3. When a tidal power plant works in combination with thermal or hydro-electric system peak power demand can be effectively met with.
4. Tidal power generation is free from pollution.

Limitations:

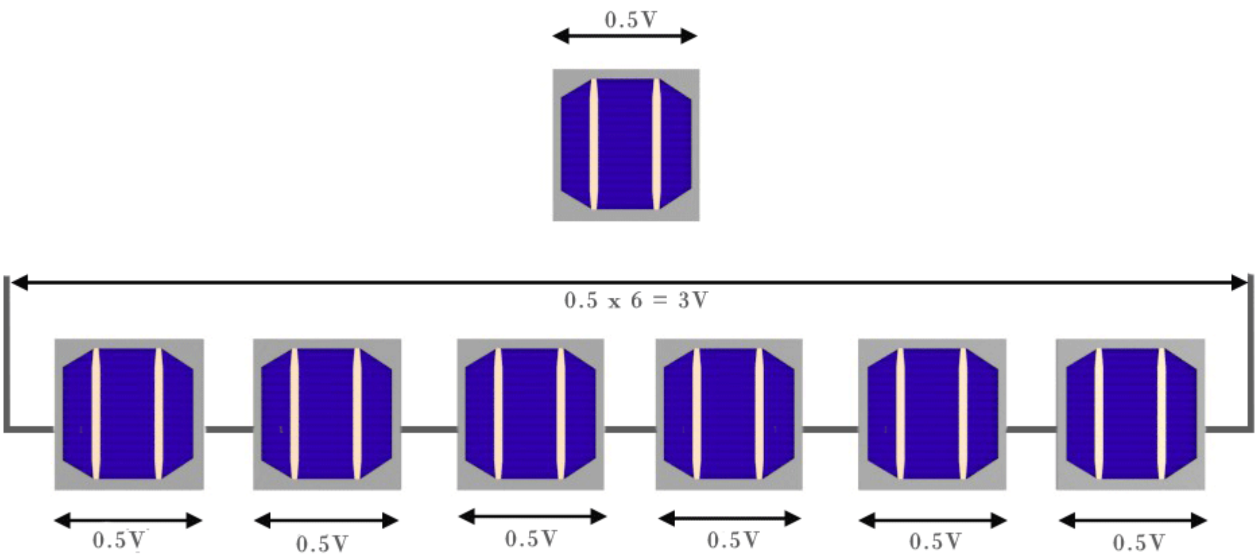
1. Due to variation in tidal range the output is not uniform.
2. Since the turbines have to work on a wide range of head variation (due to variable tidal range) the plant efficiency is affected.
3. There is a fear of machinery being corroded due to corrosive sea water.
4. It is difficult to carry out construction in sea.
5. As compared to other sources of energy, the tidal power plant is costly.
6. Sedimentation and silteration of basins are the problems associated with tidal power plants.
7. The power transmission cost is high because the tidal power plants are located away from load centres.

6.SOLAR PHOTO VOLTAIC (SPV)

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

A single solar cell cannot provide required useful output. So to increase output power level of a PV system, it is required to connect number of such PV solar cells. A solar module is normally series connected sufficient number of solar cells to provide required standard output voltage and power. One solar module can be rated from 3 watts to 300 watts. The solar modules or PV modules are commercially available basic building block of a solar electric power generation system.

Actually a single solar PV cell generates very tiny amount that is around 0.1 watt to 2 watts. But it is not practical to use such low power unit as building block of a system. So required number of such cells are combined together to form a practical commercially available solar unit which is known as solar module or PV module. In a solar module the solar cells are connected in same fashion as the battery cell units in a battery bank system. That means positive terminals of one cell connected to negative terminal voltage of solar module is simple sum of the voltage of individual cells connected in series in the module.



Series Connected Solar Module

The normal output voltage of a solar cell is approximately 0.5 V hence if 6 such cells are connected in series then the output voltage of the cell would be 0.5 × 6 = 3 Volt.

7. SOLAR THERMAL

Figure shows a solar power plant with a low temperature solar engine using heated water from flat plate solar collector and Butane as the working fluid. This was developed t o lift water for irrigation purposes.

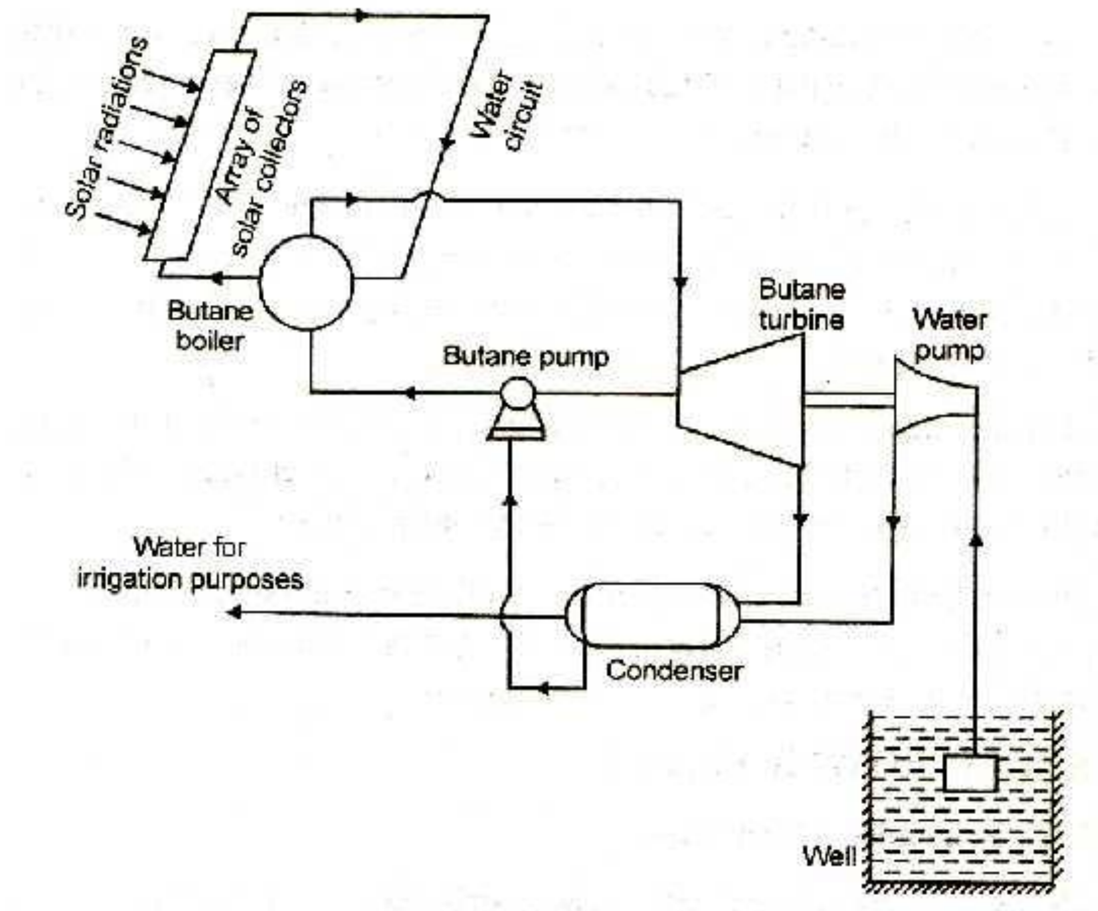
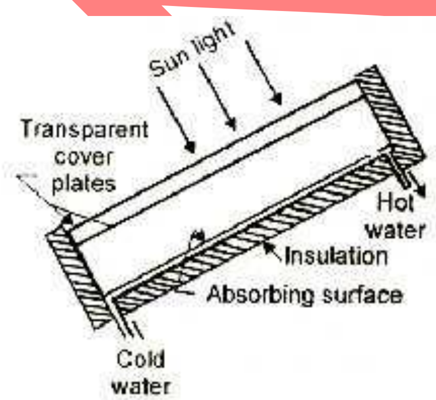


Figure : Solar power plant

1. Solar collectors
a) Flat plate collector



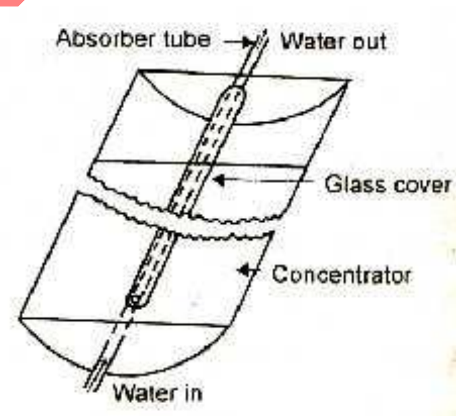


Figure: Flat plate collector Figure: Cylindrical parabolic concentrator collector

In a flat plate collector (figure), the radiation energy of the sun falls on a flat surface coated with black paint having high absorbing capacity. It is placed facing the general direction of the sun. The materials used for the plate may be copper, steel aluminium. The thickness of the plate is 1 to 2 mm. Tubing of copper is provided in thermal contact with the plate.

Heat is transferred from the absorbed plate to water which is circulated in the copper tubes through the flat plate collection. Thermal insulation is provided behind the absorber plate to prevent heat losses from the rear surface. Insulating material is generally fibre glass or mineral wool. The front cover is made up of glass and it is transparent to the incoming solar radiations.

b) Cylindrical parabolic concentrator collector

Concentrator collectors (figure) are of reflecting type utilizing mirrors. The reflecting surface may be parabolic mirror. The solar energy falling on the collector surface is reflected and focused along a line where the absorber tube is located. As large quantity of energy falling on the collector surface is collected over a small surface, the temperature of the absorber fluid is very much higher than in flat plate collector. While flat place collectors may be used to heat water upto $80^{o}C$ (low temperature), the concentrating type of collectors are designed to heat water to medium and high temperature ranges.

c) Butane boiler

The water heated in flat plate solar collector to $80^{o}C$ is used for boiling butane at high pressure in the butane boiler. Boiling point of butane is about $50^{o}C$.

d) Turbine

The butane vapour generated at high pressure in the boiler is used to run the vapour turbine which drives the electrical generator. The vapour coming out of the turbine at low pressure is condensed in a condenser using water. The condensed liquid butane is fed back to the butane boiler using feed pump.

Tower concept for power generation

The tower concept consists of an array of plane mirrors or heliostats which are individually controlled to reflect radiations from the sun into a boiler mounted on a 500 metres high tower. Steam in generated in the boiler, which may attain a temperature upto $2000^{\circ}K$. Electricity is generated by passing steam through the turbine coupled to a generator.

Advantages

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

Disadvantages

1. It is available in a dilute and is at low potential. The intensity of solar energy on a sunny day in India is about 1.1 kW/square meter area. Hence very large collecting areas are required.
2. Also the dilute and diffused nature of the solar energy needs large land area for the power plant for instance, about 30 square kilometers area is required for a solar power station to replace a nuclear plant on a 1 square kilometer site. Hence capital cost is more for the solar plant.
3. Solar energy is not available at night or during cloudy or rainy days.

Applications of Solar Energy:

Applications of solar energy enjoying most success today are:

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

9. GEO THERMAL POWER PLANT

<u>Kinds of Geothermal Sources</u>

Hydrothermal systems

Hydrothermal systems are those in which water is heated by contact with the hot rock, as explained above. Hydrothermal systems are in turn subdivided into 1) Vapor-dominated and 2)Liquid-dominated systems.

Vapor-dominated systems

In these systems the water is vaporized into steam that reaches the surface in relatively dry Condition at about 205°C and rarely above 8 bar. This steam is the most suitable for use in turboelectric power plants with the least cost. It does, however, suffer problems similar to those encountered by all geothermal systems, namely, the presence of corrosive gases and erosive material and environmental problems. Vapor-dominated systems, however, are a rarity; there are only five known sites in the world to date. These systems account for about 5 per cent of all U.S. geothermal resources. Example: Geysers plant (United States)and Larderello (Italy).

Liquid-dominated systems

In these systems the hot water circulating and trapped underground is at a temperature range of 174 to 315°C. When tapped by wells drilled in the right places and to the right depths the water flows either naturally to the surface or is pumped up to it. The drop in pressure, usually to 8 bar or less, causes it to partially flash to a two-phase mixture of low quality, i.e., liquid dominated.

It contains relatively large concentration of dissolved solids ranging between 3000 to 25,000 ppm and sometimes higher. Power production is adversely affected by these solids because they precipitate and cause scaling in pipes and heat-exchange surfaces, thus reducing flow and heat transfer. Liquid-dominated systems, however, are much more plentiful than vapor dominated systems and next to them, require the least extension of technology.

Geopressured systems

Geopressured systems are sources of water, or brine, that has been heated in a manner similar to hydrothermal water, except that geopressured water is trapped in much deeper underground acquifers, at depths between 2400 to 9100 m. This water is thought to be at the relatively low temperature of about 160^{o}C and is under very high pressure, from the overlying formations above, of more than 1000 bars. It has a relatively high salinity of 4 to 10 percent and is often referred to as brine. In addition, it is saturated with natural gas, mostly methane CH4, thought to be the result of decomposition of organic matter.

Such water is thought to have thermal and mechanical potential to generate elect ricity. The temperature however, is not high enough and the depth so great that there is little economic justification of drilling this water for its thermal potential alone.

Petrothermal systems

Magma lying relatively close to the earth's surface heats overlying rock as previously explained. When no underground water exists, there is simply hot, dry rock (HDR). The known temperatures of HDR vary between 150 to 290^{o}C. This energy, called petrothermal energy, represents by far the largest resource base of the United States. Other estimates put the ratio of steam: hot water: HDR at 1: 10: 1000.

Much of the HDR occurs at moderate depths, but it is largely impermeable. In order to extract thermal energy out of it, water (or other fluid, but water most likely) will have to be pumped into it and back out to the surface. It is necessary for the heat transport mechanism that a way be found to render the impermeable rock into a permeable structure with a large heat transfer.

A large surface is particularly necessary because of the low thermal conductivity of the rock. Rendering the rock permeable is to be done by fracturing it. Fracturing methods that have been considered involve drilling wells into the rock and then fracturing by 1) High-pressure water or 2) Nuclear explosives.

High-pressure water

Fracturing by high-pressure water is done by injecting water into HDR at very high pressure. This water widens existing fractures and creates new ones through rock displacement. This method is successfully used by the oil industry to facilitate the path of underground oil.

Nuclear explosives

Fracturing by nuclear explosives is a scheme that has been considered part of a programme for using such explosives for peaceful uses, such as natural gas and oil stimulation, creating cavities for gas storage, canal and harbor construction, and many other applications. This method would require digging in shafts suitable for introducing and sealing nuclear explosives and the detonation of several such devices for each 200-MW plant. The principle hazards associated with this are ground shocks, the danger of radioactivity releases to the environment, and the radioactive material that would surface with the heater water and steam.

Geothermal power plant

It is also a thermal power plant, but the steam required for power generation is available naturally in some part of the earth below the earth surface. According to various theories earth has a molten core. The fact that volcanic action taken place in many places on the surface of earth supports these theories.

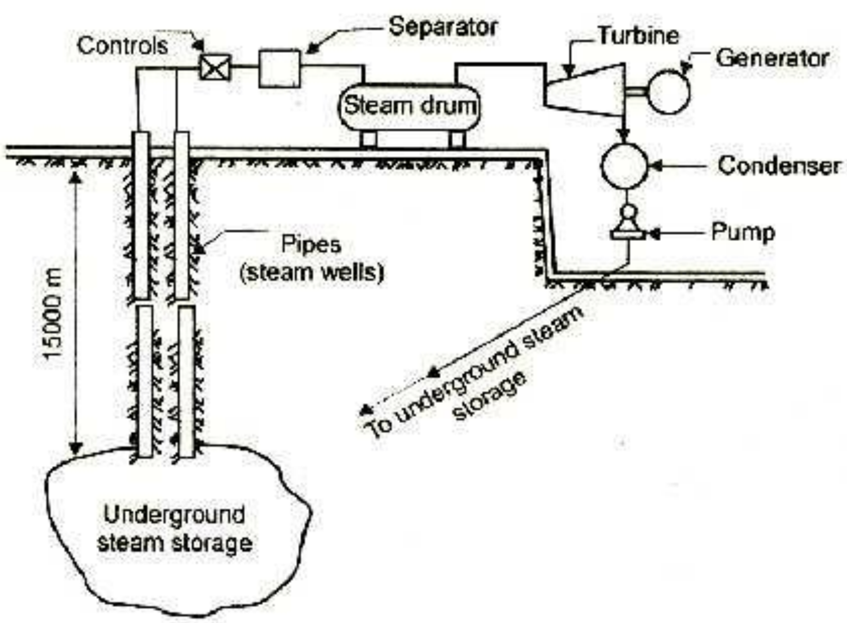


Figure: Geo-thermal power plant

Steam well

Pipes are embedded at places of fresh volcanic action called steam wells, where the molten internal mass of earth vents to the atmospheric with very high temperatures. By sending water through embedded pipes, steam is raised from the underground steam storage wells to the ground level.

Separator

The steam is then passed through the separator where most of the dirt and sand carried by the steam are removed.

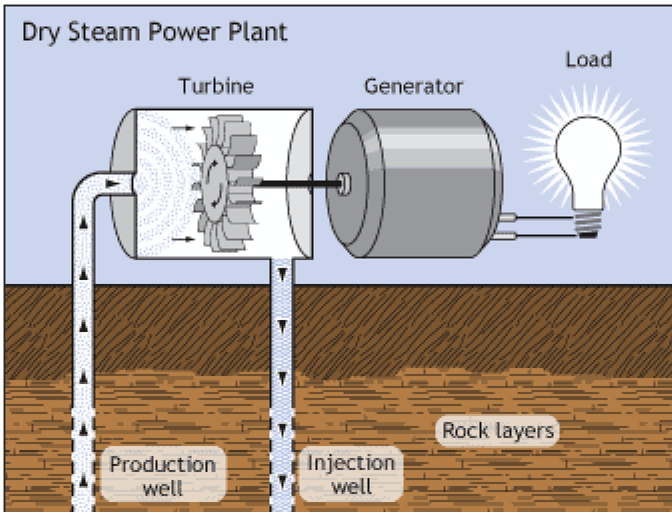
Turbine

The steam from the separator is passed through steam drum and is used to run the turbine which in turn drives the generator. The exhaust steam from the turbine is condensed. The condensate is pumped into the earth to absorb the ground heat again and to get converted into steam.

Location of the plant, installation of equipment like control unit etc., within the source of heat and the cost of drilling deep wells as deep as 15,000 metres are some of the difficulties commonly encountered.

Types of Geo thermal Plant

Direct Dry Steam

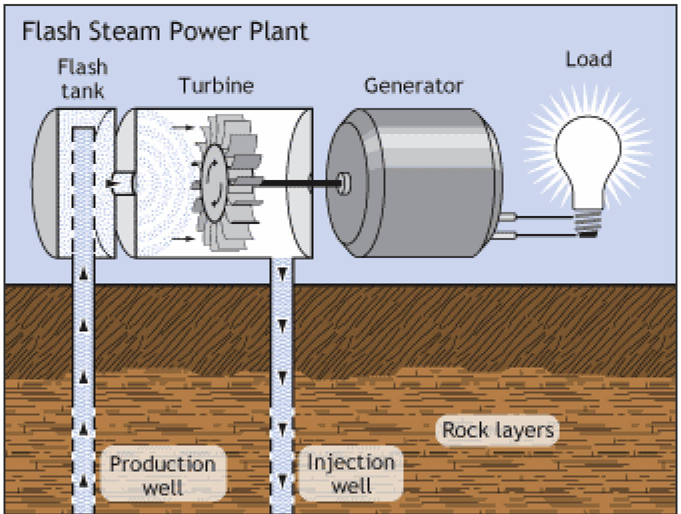


Steam plants use hydrothermal fluids that are primarily steam. The steam goes directly to a turbine, which drives a generator that produces electricity. The steam eliminates the need to burn fossil fuels to run the turbine. (Also eliminating the need to transport and store fuels!)

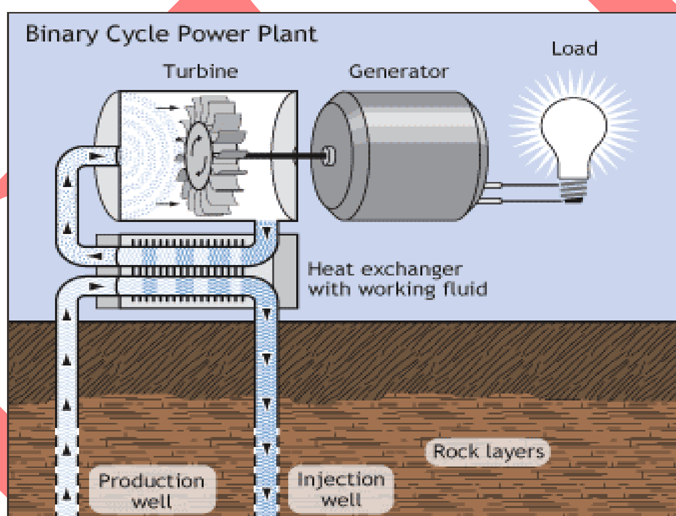
This is the oldest type of geothermal power plant. It was first used at Lardarello in Italy in 1904. Steam technology is used today at The Geysers in northern California, the world's largest single source of geothermal electricity. These plants emit only excess steam and very minor amounts of gases.

Flash and Double Flash Cycle

Hydrothermal fluids above 360°F (182°C) can be used in flash plants to make electricity. Fluid is sprayed into a tank held at a much lower pressure than the fluid, causing some of the fluid to rapidly vaporize, or "flash." The vapor then drives a turbine, which drives a generator. If any liquid remains in the tank, it can be flashed again in a second tank (double flash) to extract even more energy.



Binary Cycle



Most geothermal areas contain moderate-temperature water (below 400°F). Energy is extracted from these fluids in binary-cycle power plants.

Hot geothermal fluid and a secondary (hence, "binary") fluid with a much lower boiling point than water pass through a heat exchanger. Heat from the geothermal fluid causes the secondary fluid to flash to vapor, which then drives the turbines.

Because this is a closed-loop system, virtually nothing is emitted to the atmosphere. Moderate-temperature water is by far the more common geothermal resource, and most geothermal power plants in the future will be binary-cycle plants.

10. FUEL CELL

A Fuel cell is an electrochemical device in which the chemical energy of a conventional fuel is converted directly and efficiently into low voltage, direct-current electrical energy. One of the chief advantages of such a device is that because the conversion, atleast in theory, can be carried out isothermally, the Carnot limitation on efficiency does not apply. A fuel cell is often described as primary battery in which the fuel and oxidizer are stores external to the battery and fed to it as needed.

Fig. shows a schematic diagram of a fuel cell. The fuel gas diffuses through the anode and is oxidized, thus releasing electrons to the external circuit; the oxidizer diffuses through the cathode and is reduced by the electrons that have come from the anode by way of the external circuit.

The fuel cell is a device that keeps the fuel molecules from mixing with the oxidizer molecules, permitting, however, the transfer of electrons by a metallic path that may contain a load. Of the available fuels, hydrogen has so far given the most promising results, although cells consuming coal, oil or natural gas would be economically much more useful for large scale applications.

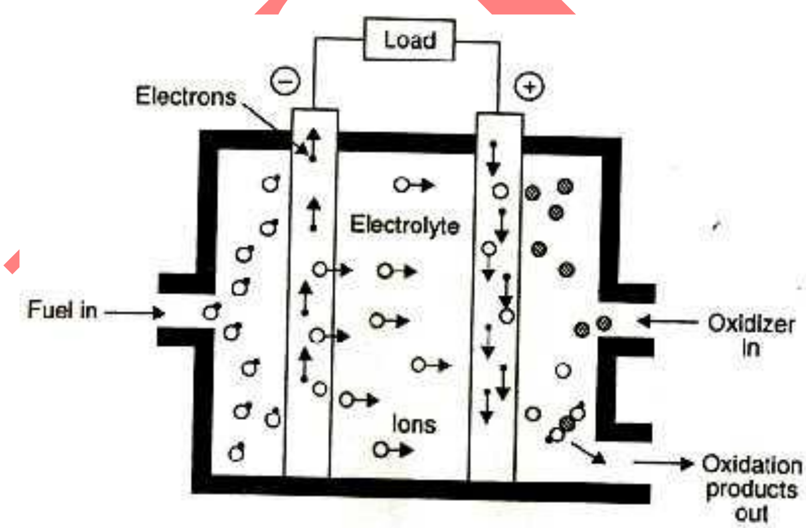


Figure: Schematic of a fuel cell.

Some of the possible reactions are :

Hydrogen/oxygen	1.23 V	$2H_2 + O_2 \rightarrow 2\ H_2O$
Hydrazine	1.56 V	$N_2H_4 + O_2 \rightarrow 2H_2O + N_2$
Carbon (coal)	1.02 V	$C + O_2 \rightarrow CO_2$
Methane	1.05 V	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Hydrogen-oxygen cell :

The hydrogen-oxygen devices shown in figure is typical of fuel cells. It has three chambers separated by two porous electrodes, the anode and the cathode. The middle chamber between the electrodes is filled with a strong solution of potassium hydroxide. The surfaces of the electrodes are chemically treated to repel the electrolyte, so that there is minimum leakage of potassium hydroxide into the outer chambers. The gases diffuse through the electrodes, undergoing reactions are show below:

$4KOH \rightarrow 4K^+ + f(OH)^-$

Anode: $2H2 + 4\,(OH)^- \rightarrow 4H_2O + 4e^-$

Cathode: $O2 + 2H_2O + 4e^- \rightarrow 4\,(OH)^-$

Cell reaction $2H_2 + {}_{O2} \rightarrow 2H_2O$

The water formed is drawn off from the side. The electrolyte provides the (OH) ions needed for the reaction, and remains unchanged at the end, since these ions are generated. The electrons liberated at the anode find their way to the cathode through the external circuit. This transfer is equivalent to the flow of a current from the cathode to the anode.

Such cells when properly designed and operated, have an open circuit voltage of about 1.1volt. Unfortunately, their life is limited since the water formed continuously dilutes the electrolyte. Fuel efficiencies as high as 60%-70% may be obtained.

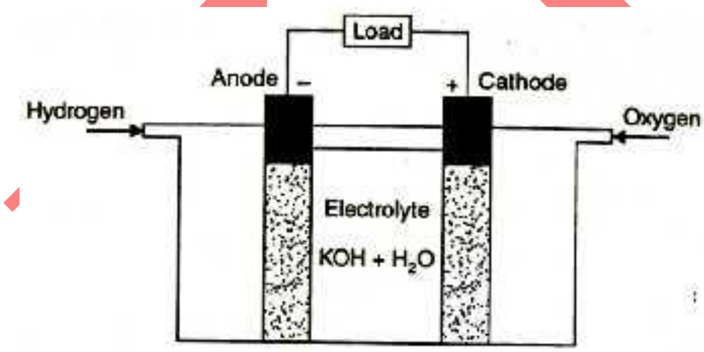


Figure: Hydrogen-oxygen fuel cell.

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.

1. TARIFF

The rate at which electrical energy is supplied to a consumer is known as tariff.

Cost of Producing Electricity depends upon the magnitude of Electricity consumed by used and his load

Objectives of tariff

(*i*) Recovery of cost of producing electrical energy at the power station.

(*ii*) Recovery of cost on the capital investment in transmission and distribution systems.

(*iii*) Recovery of cost of operation and maintenance of supply of electrical energy *e.g.*, metering equipment, billing etc.

(*iv*) A suitable profit on the capital investment

1. Simple tariff.

When there is a fixed rate per unit of energy consumed, it is called a **simple tariff** *or* **uniform rate tariff.**

Disadvantages

(*i*) There is no discrimination between different types of consumers since every consumer has to pay equitably for the fixed* charges.

(*ii*) The cost per unit delivered is high.

(*iii*) It does not encourage the use of electricity.

2. Flat rate tariff.

When different types of consumers are charged at different uniform per unit rates, it is called a flat rate tariff.

Disadvantages

(*i*) Since the flat rate tariff varies according to the way the supply is used, separate meters are required for lighting load, power load etc. This makes the application of such a tariff expensive and complicated.

(*ii*) A particular class of consumers is charged at the same rate irrespective of the magnitude of energy consumed. However, a big consumer should be charged at a lower rate as in his case the fixed charges per unit are reduced.

3. Block rate tariff. When a given block of energy is charged at a specified rate and the succeeding blocks of energy are charged at progressively reduced rates, it is called a **block rate tariff**.

The advantage of such a tariff is that the consumer gets an incentive to consume more electrical energy. This increases the load factor of the system and hence the cost of generation is reduced.

4. Two-part tariff. When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed, it is called a **two-part tariff**.

- In two-part tariff, the total charge to be made from the consumer is split into two components viz., fixed charges and running charges.
  - Total charges = Rs ($b \times$ kW + $c \times$ kWh)
    where, b = charge per kW of maximum demand

    c = charge per kWh of energy consumed consumer.

Advantages

(*i*) It is easily understood by the consumers.

(*ii*) It recovers the fixed charges which depend upon the maximum demand of the consumer but are independent of the units consumed.

Disadvantages

(*i*) The consumer has to pay the fixed charges irrespective of the fact whether he has consumed or not consumed the electrical energy.

(*ii*) There is always error in assessing the maximum demand of the consumer.

5. Maximum demand tariff. It is similar to two-part tariff with the only difference that the maximum demand is actually measured by installing maximum demand meter in the premises of the consumer. This removes the objection of two-part tariff where the maximum demand is assessed merely on the basis of the rateable value. This type of tariff is mostly applied to big consumers.

However, it is not suitable for a small consumer (*e.g.*, residential consumer) as a separate maximum demand meter is required.

6. Power factor tariff. The tariff in which power factor of the consumer's load is taken into consideration is known as **power factor tariff**.

In an a.c. system, power factor plays an important role. A low* power factor increases the rating of station equipment and line losses.

- **(i) k VA maximum demand tariff :** It is a modified form of two-part tariff. In this case, the fixed charges are made on the basis of maximum demand in kVA and not in kW. As kVA is inversely proportional to power factor, therefore, a consumer having low power factor has to contribute more towards the fixed charges. This type of tariff has the advantage that it encourages the consumers to operate their appliances and machinery at improved power factor.
- **(ii) Sliding scale tariff :** This is also know as average power factor tariff. In this case, an average power factor, say 0·8 lagging, is taken as the reference. If the power factor of the consumer falls below this factor, suitable additional charges are made. On the other hand, if the power factor is above the reference, a discount is allowed to the consumer.
  (iii) kW and kVAR tariff : In this type, both active power (kW) and reactive power (kVAR) supplied are charged separately. A consumer having low power factor will draw more reactive power and hence shall have to pay more charges.

7. Three-part tariff. When the total charge to be made from the consumer is split into three parts viz., fixed charge, semi-fixed charge and running charge, it is known as a **three-part tariff**. i.e.

- Total charge = Rs (a + b × kW + c × kWh)

where a = fixed charge made during each billing period.

b = charge per kW of maximum demand,

c = charge per kWh of energy consumed.

- It may be seen that by adding fixed charge or consumer's charge (*i.e.*, *a*) to two-part tariff, it becomes three-part tariff. The principal objection of this type of tariff is that the charges are split into three components. This type of tariff is generally applied to big consumers.

2. **PARAMETERS - DEFINITIONS:**

Maximum demand:
Maximum demand is the greatest of all demands which have occurred during a given period of time.

Average load:
Average load is is the average load on the power station in a given period (day/month or year)

Base load:
Base load is the minimum load over a given period of time.

Connected load:
Connected load of a system is the sum of the continuous ratings of the load consuming apparatus connected to the system.

Peak load:
Peak load is the maximum load consumed or produced by a unit or group of units in a stated period of time. It may be the maximum instantaneous load or the maximum average load over a designated interval of time.

Demand factor:
Demand factor is the ratio of maximum demand to the connected load of a consumer.

Diversity factor:
Diversity factor is the ratio of sum of individual maximum demands to the combined maximum demand on power stations

Load factor:
Load factor is the ratio of average load during a specified period to the maximum load occurring during the period.
Load factor = Average Load / Maximum demand

Station load factor:
Station load factor is the ratio of net power generated to the net maximum demand on a power station.

Plant factor:
Plant factor is the ratio of the average load on the plant for the period of time considered, to the aggregate rating of the generating equipment installed in the plant.

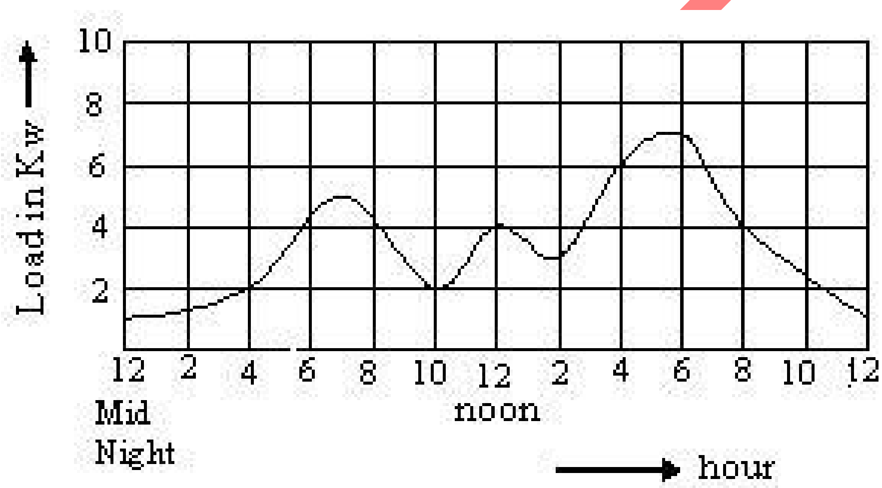
Capacity factor:
Capacity factor is the ratio of the average load on the machine for a period of time considered, to the rating of the machine.

Demand factor:
Demand factor is the ratio of maximum demand of system or part of system, to the total connected load of the system, or part of system, under consideration.

3.LOAD CURVE:
Load curve is plot of load in kilowatts versus time usually for a day or a year.

Definition:

The curve showing the variation of load on the power station with respect to time.

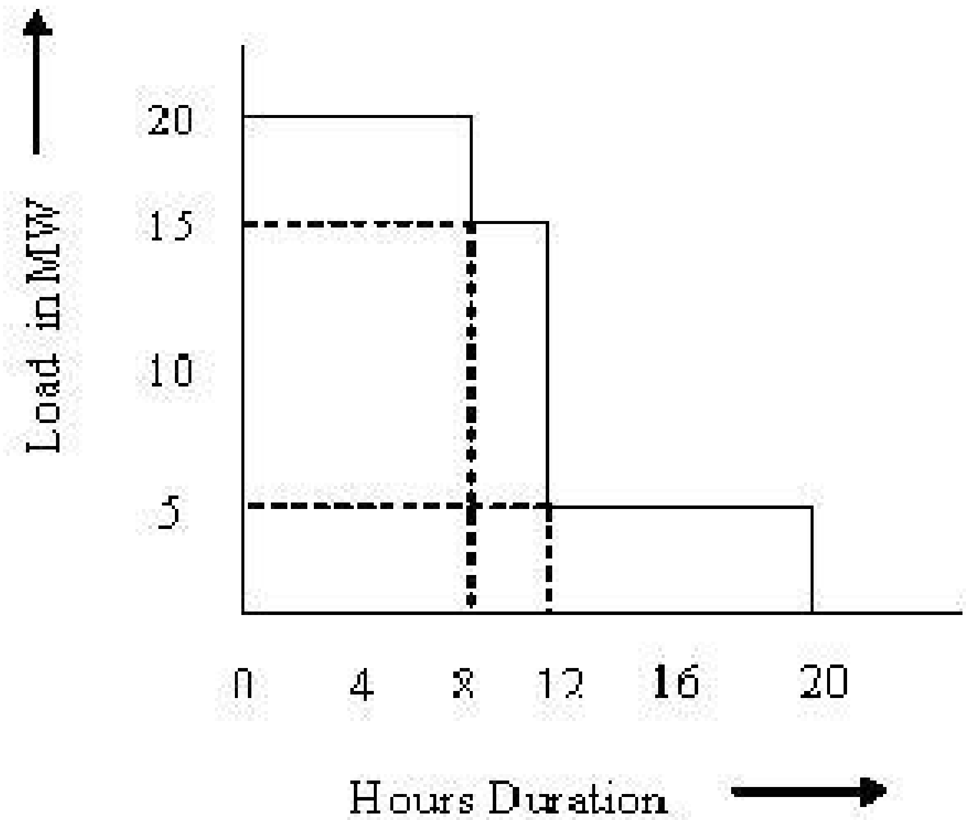


Types of load curves:
1. Daily load curve–Load variations during the whole day
2. Monthly load curve–Load curve obtained from the daily load curve
3. Yearly load curve-Load curve obtained from the monthly load curve

Load Characteristics:
- Connected load
- Maximum demand Average load
- Load factor
- Diversity factor
- Plant capacity factor
- Plant use factor

LOAD DURATION CURVE:
Load duration curve is the plot of load in kilowatts versus time duration for which it occurs. When the elements of a load curve are arranged in the order of descending magnitudes.
The load demand on a power system is governed by the consumers and for a system supplying industrial and domestic consumers, it varies within wide limits. This variation of load can be considered as daily, weekly, monthly or yearly. Such load curves are termed as "**Chronological load Curves**".

If the ordinates of the chronological load curves are arranged in the descending order of magnitude with the highest ordinates on left, a new type of load curve known as **“load duration curve”** is obtained. If any point is taken on this curve then the abscissa of this point will show the number of hours per year during which the load exceeds the value denoted by its ordinate. The lower part of the curve consisting of the loads which are to be supplied for almost the whole number of hours in a year, represents the “Base Load”, while the upperpart, comprising loads which are required for relatively few hours per year, represents the “Peak Load”.



4. COMPARISON OF SITE SELECTION CRITERIA FOR POWER PLANTS

Site selection for Thermal Power Plant

1.**Availability of Fuel** - Availability of huge amount of fuel at reasonable cost is one of the major criterion for choosing plant location.

2.**Geology and Soil Type** - The soil should be such that it should provide good and firm foundation of plant and buildings

3.Availability of Water - A large quantity of cooling water is required for the condensers etc of **thermal power generation plant**, hence the plant should preferably situated beside big source of natural water source such as big river.

4.Availability of Land - the cost of land is quite reasonable. The land should be such that the acquisition of private property must be minimum. The plant should be established on plane land

5.Distance from Populated Areas - The **thermal power plant** location should not be very nearer to dense locality as there are smoke, noise steam, water vapors etc.

6.Transportation Facilities - good railways and road ways availabilities are required

7.Nearness to Load Centers - Power plant should be set up near the load centre, this will reduce the cost of maintenance of transmission line.

Site Selection of Nuclear Power Station

1. **Availability of water :** Although very large quantity of water is not regulated as hydro-electric power plant, but still sufficient supply of neutral water is obvious for cooling purposes in nuclear power station. That is why it is always preferable to locate this plant near a river or sea side.
2. **Disposal of Water :** The by products or wastes of nuclear power station are radioactive and may cause severe health hazards. Because of this, special care to be taken during disposal of wastes of nuclear power plant. The wastes must be buried in sufficient deep from earth level or these must be disposed off in sea quite away from the sea share. Hence, during selecting the location of nuclear plant, these factor must be taken into consideration.
3. **Distance from Populated Area :** As there is always a probability of radioactivity, it is always preferable to locate a nuclear station sufficiently away from populated area.
4. **Transportation Facilities :** During commissioning period, heavy equipments to be erected, which to be transported from manufacturer site. So good railways and road ways availabilities are required. For availability of skilled manpower good public transport should also be present at the site.

Site Selection of Hydroelectric power plant

1. **Availability of water** – All other designs are based on it. – Estimate should be made about the average quantity of water available throughout the year and also about maximum and minimum quantity of water available during the year. – These details are necessary to decide the capacity of the hydropower plant, and – It also provide adequate spillways or gate relief during flood period.

2**. Water storage** – Since there a is wide variation in rainfall during the year, therefore it is necessary to store the water for continuous generation of power. The storage capacity can be calculated with the help of mass curve. – The two types of storages in use are 1. The storage is so constructed that it can make water available for power generation for one year only. 2. Water is available in sufficient quantity even during the worst dry periods.

3. **Water head** – In order to generate a requisite quantity of power it is necessary that a large quantity of water at sufficient head should be available. – An increase in effective head for a given output, reduces the quantity of water required to be supplied to the turbines.

4. **Accessibility of site** – The site where hydro-electric plant is to be constructed should be easy accessible. This is important if the electric power generated is to be utilised at or near the plant site. – The site selected should have transportation facilities of rail and road.

5. **Distance from the load centre** – Power plant should be set up near the load centre, this will reduce the cost of maintenance of transmission line.

6. **Type of the land of the site** – The land to be selected for the site should be cheap and rocky. – The ideal site will be one where the dam will have largest catchment area to store water at high head and will be economical in construction. – Necessary requirement of the foundation rocks for masonry dam . The rock should be strong enough to withstand the stresses transmitted from the dam structure as well as the thrust of the water when the reservoir is full. The rock in the foundation of the dam should be reasonably impervious. The rock should remain stable under all conditions.

Economics of Power Generation

The art of determining the per unit (i.e., one kWh) cost of production of electrical energy is known as **economics of power generation.**

(*i*) Interest. *The cost of use of money is known as* **interest.**

(*ii*) Depreciation. *The decrease in the value of the power plant equipment and building due to constant use is known as* **depreciation.**

5. COST OF ELECTRICAL ENERGY

The **total annual expenditure** of the plant can be classified into several subheadings namely, 1) Fixed Charges 2) Semi fixed Charges 3) Running Charges These are all important parameters pertaining to the **Economics of power generation.** and are considered in details below.

Fixed Charges of Power Generation

Fixed charges, as the name suggest does not vary either with the capacity of the plant or with plant operation. These costs remain fixed under all circumstances. These mainly include the salaries of higher officials of the central organization and the rent of the land reserved for future expansion.

Semi Fixed Charges of Power Generation

These charges mainly depend on the installed capacity of the plant and are independent of the electrical energy output of the plant. These charges include the following :

1) Interest and depreciation on the capital cost of the generating plant, transmission and distribution network, buildings and other civil engineering works etc. Capital cost of the plant also includes the interest paid during the construction of the plant, salaries of engineers and other employees, development and construction of the power station. It also includes cost incurred on account of transportation, labor etc. to bring the equipment on site and installing the same, all of which are involved for the overall economics of power generation. It is particularly note worthy, that in nuclear stations the capital cost of the station also includes the cost of initial charges of the nuclear fuel minus the salvage value paid at the end of its useful life.

2) It also includes all types of taxes, insurance premiums pain on policies to cover the risk of accidental breakdown.

3) Rent paid for the land being actually used for the construction purpose. The cost due to starting and shutting down of plants are also included in this category , when the power plant operates on one or two shift basis.

Running Charges of Power Generation

The running charges or running cost of a power plant, is probably one of the most important parameters while considering the economics of power generation as it depends upon the number of hours the plant is operated or upon the number of units of electrical energy generated. It essentially comprises of the following costs incurred mentioned below.

1) Cost of the fuel delivered coupled with the fuel handling cost in the plant. Coal is the fuel used in a thermal power plant, and diesel oil in case of a diesel station. In case of a hydro-electric plant there is no fuel cost as water is the free gift of nature. But a hydro-plant requires higher installation cost and their mega Watt output of power generation is also lower compared to the thermal power plants.

2) Wastage of the operational and maintenance stuff and salaries of supervisor staffs engaged in running the plant.

3) In case of a thermal power plant, power generation economics includes the cost of feed water for the boiler, like the cost of water treatment and conditioning.

4) As the amount of wear and tear of the equipment depends on the extent to which the plant is being used, so the lubricating oil cost and repair and maintenance charges of the equipment are also included in the running charges.

So, we can conclude saying, that the total annual charges incurred in the power generation, and the overall power generation economics can be represented by the equation,

E = a + b KW + c kWH

1. Where ‘a’ represents the total fixed cost of the plant, and has no relation with the total output of the plant or the number of hours for which the plant is running.
2. ‘b’ represents the semi-fixed cost, which mainly depends on the total output of the plant and not on the number of hours for which the plant is being operated. The unit for ‘b’ is thus ideally chosen to be in k-Watt.
3. ‘c’ essentially represents the running cost of the plant, and depends on the number of hours for which the plant is running to generate a certain mega watt of power. Its unit is given in K-Watt-Hr.

NUCLEAR POLLUTION CONTROL & MEASURES OF NUCLEAR PLANTS

a. Laboratory generated nuclear wastes should be disposed off safely and scientifically.

b. Nuclear power plants should be located in areas after careful study of the geology of the area, tectonic activity and meeting other established conditions.

c. Appropriate protection against occupational exposure.

d. Leakage of radioactive elements from nuclear reactors, careless use of radioactive elements as fuel and careless handling of radioactive isotopes must be prevented.

e. Safety measure against accidental release of radioactive elements must be ensured in nuclear plants.

f. Unless absolutely necessary, one should not frequently go for diagnosis by x-rays.

g. Regular monitoring of the presence of radioactive substance in high risk area should be ensured.

CONTROL OF THERMAL POLLUTION:

Control of thermal pollution is necessary as its detrimental effects on aquatic ecosystem may be detrimental in the future. Viable solutions to chronic thermal discharge into water bodies are as follows:

(1) Cooling Ponds:

Cooling ponds or reservoirs constitute the simplest method of controlling thermal discharges. Heated effluents on the surface of water in cooling ponds maximize dissipation of heat to the atmosphere and minimize the water area and volume. This is the simplest and cheapest method which cools the water to a considerable low temperature. However, the technique alone is less desirable and inefficient in terms of air-water contact.

(2) Cooling Towers:

Using water from water sources for cooling purposes, with subsequent return to the water body after passing through the condenser is termed as cooling process. In order to make the cooling process more effective, cooling towers are designed to control the temperature of water. In-fact, cooling towers are used to dissipate the recovered waste heat so as to eliminate the problems of thermal pollution.

(3) Artificial Lake:

Artificial lakes are man-made bodies of water which offer possible alternative to once through cooling. The heated effluents may be discharged into the lake at one end and the water for cooling purposes may be withdrawn from the other end. The heat is eventually dissipated through evaporation.

These lakes have to be rejuvenated continuously. A number of methods have been suggested and developed for converting the thermal effluents from power plants into useful heat resources for maximing the benefits.

6. WASTE DISPOSAL OF NUCLEAR POWER PLANT:

Waste disposal problem is common in every industry. Wastes from atomic energy installations are radioactive, create radioactive hazard and require strong control to ensure that radioactivity is not released into the atmosphere to avoid atmospheric pollution. The wastes produced in a nuclear power plant may be in the form of liquid, gas or solid and each is treated in a different manner:

1. Liquid Waste

The disposal of liquid wastes is done in two ways:

i) Dilution

The liquid wastes are diluted with large quantities of water and then released into the ground. This method suffers from the drawback that there is a chance of contamination of underground water if the dilution factor is not adequate.

ii) Concentration to small volumes and storage

When the dilution of radioactive liquid wastes is not desirable due to amount or nature of isotopes, the liquid wastes are concentrated to small volumes and stored in underground tanks.

The tanks should be of assured long term strength and leakage of liquid from the tanks should not take place otherwise leakage or contents, from the tanks may lead to significant underground water contamination.

2. Gaseous Waste

Gaseous wastes can most easily result in atmospheric pollution. Gaseous wastes are generally diluted with air, passed through filters and then released to atmosphere through large stacks (chimneys).

3. Solid Waste

Solid wastes consist of scrap material or discorded objects contaminated with radioactive matter. These wastes if combustible are burnt and the radio active matter. These wastes if concrete, are drummed and shipped for burial. Non-combustible solid wastes, are always buried deep in the ground.

Effects of nuclear radiation:

Biological damage

Biological effects upon living tissues exposed to a radiation field result from the interaction of the radiation and the tissue. The interaction between radiation and tissue is manifested in three ways, ionization, and displacement of atoms and absorption of neutrons by nuclei of tissue.

1. Ionization

The formation of ion-pair in tissue requires 32.5 eV of energy. About 3100 ion-pairs are formed when a single 1 MeV beta particle is stopped by tissue. If one cm^2 area of tissue surface is subjected to a beam of β-radiation of 100 β -articles/cm^2/sec, about 31×10^6 ion-pairs are formed each second. This absorption results in complete damage of tissues in the body of man of beast or bird. α, β □and γ-radiations all ionize tissues into which they penetrate.

2. Displacement

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

3. Absorption

Absorption of neutron by a tissue nucleus results in forming a radioactive nucleus and change the chemical nature of the nucleus. This severe alteration of the tissue causes malfunctioning of the cell and cell damage may have severe biological effects including genetic modification.

The inhalation of radioactive materials in air, water or food also presents a radiation hazard. Some body elements are eliminated from the body rapidly, others become chemically involved in such a way as to give serious long time problems. Strontium-90 has an affinity for bones and if it is absorbed by the bones through water, air or food, it will have a serious effect as bone marrow.

7. DISPOSAL OF FLY ASH

Coal-based thermal power plants have been a major source of power generation in India where about 57% of the total power obtained is from coal-based thermal power plants [1]. Fly Ash is a by-product material being generated by thermal power plants from combustion of Pulverised coal. High ash content is found to be in range of 30% to 50% in Indian coal [2]. The quantum of Fly Ash produced depends on the quality of coal used and the operating conditions of thermal power plants.

In the past, Fly Ash produced from coal combustion in thermal power plants was simply dispersed into the atmosphere. At thermal power plants, Fly Ash is presently collected or disposed by using either dry or wet systems. Worldwide, more than 65% of Fly Ash is disposed in landfills and ash ponds [8]. The Fly Ash is a resource material, if not managed well, this may pose environmental and health problems.

A. Dry Fly Ash Disposal system

In dry disposal system, electrostatic precipitation (ESP) is the most popular and widely used method of emission control today which enables collection of dry Fly Ash. After collecting the Fly Ash in ESP, it is then transported by trucks or conveyors at the sight and disposed of by constructing a dry embankment.

B. Wet Fly Ash Disposal System

In wet disposal system, the Fly Ash is mixed with water and transported as slurry through pipe and disposed of in ash ponds or dumping areas near the plants. Being cheaper than any other manner of Fly Ash removal, it is widely used method at present in India.

UTILIZATION OF FLY ASH

Fly ash bricks

The Central Fuel Research Institute, Dhanbad has developed a technology for the utilization of fly ash for the manufacture of building bricks. Fly ash bricks have a number of advantages over the conventional burnt clay bricks. Unglazed tiles for use on footpaths can also be made from it. Awareness among the public is required and the Government has to provide special incentives for this purpose.

Fly ash in manufacture of cement

Fly ash is suitable for use as pozzolana. In the presence of moisture, it reacts chemically with calcium hydroxide at room temperature to form compounds possessing cementitious properties. Fly ash has a high amount of silica and alumina in reactive form. These reactive elements complement the hydration chemistry of cement.

Fly ash as fertilizer

Fly ash provides the uptake of vital nutrients/minerals (Ca, Mg, Fe, Zn, Mo, S and Se) by crops and vegetation, and can be considered as a potential growth improver. It serves as a good fertilizer.

Fly ash in road construction

The use of fly ash in large quantities making the road base and surfacing can result in low value–high volume utilization.

Advantages of Fly Ash utilization

- Saving of space for disposal
- Saving of scare of natural resources
- Energy saving, firstly because the material is automatically produced as a by-product and no energy is consumed
- for its generation and secondly because it can replace material which otherwise would need to be produced by consuming energy
- Protection of environment, as in construction it can partly replace cement, production of which entails energy consumption and CO_2 emissions.