BHUBANANANDA ODISHA SCHOOL OF ENGINEERING, CUTTACK

DEPARTMENT OF MECHANICAL ENGINEERING

LECTURE NOTE

SUB- POWER STATION ENGINEERING

SEMESTER-6TH

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POWER STATION ENGINEERING (Th.-3)

COURSE OBJECTIVES:

At the end of the course the students will be able to:

- Understand the generation of power by utilizing various energy sources.
- Understand the use of steam, its operation in thermal power stations.
- Understand the nuclear energy sources and power developed in nuclear power station.

COURSE CONTENTS:

1.0 INTRODUCTION:

1.1 Describe sources of energy.

1.2 Explain concept of Central and Captive power station.

1.3 Classify power plants.

1.4 Importance of electrical power in day today life.

1.5 Overview of method of electrical power generation.

2.0 THERMAL POWER STATIONS:

2.1 Layout of steam power stations.

2.2 Steam power cycle. Explain Carnot vapour power cycle with P-V, T-s diagram and determine thermal efficiency.

2.3 Explain Rankine cycle with P-V, T-S & H-s diagram and determine thermal efficiency, Work done, work ratio, and specific steam Consumption.

2.4 Solve Simple Problems.

2.5. List of thermal power stations in the state with their capacities.

2.6 Boiler Accessories: Operation of Air pre heater, Operation of Economiser, Operation of Electrostatic precipitator and Operation of super heater. Need of boiler mountings and operation of boiler

2.7 Draught systems (Natural draught, Forced draught & balanced draught) with their advantages & disadvantages.

2.8 Steam prime movers: Advantages & disadvantages of steam turbine, Elements of steam turbine, governing of steam turbine. Performance of steam turbine: Explain Thermal efficiency, Stage efficiency and Gross efficiency.

2.9 Steam condenser: Function of condenser, Classification of condenser. Function of condenser auxiliaries such as hot well, condenser extraction pump, air extraction pump, and circulating pump.

2.10 Cooling Tower: Function and types of cooling tower, and spray ponds

2.11 Selection of site for thermal power stations.

3.0 NUCLEAR POWER STATIONS:

3.1 Classify nuclear fuel (Fissile & fertile material)

3.2 Explain fusion and fission reaction.

3.3 Explain working of nuclear power plants with block diagram .

3.4 Explain the working and construction of nuclear reactor .

3.5 Compare the nuclear and thermal plants.

3.6 Explain the disposal of nuclear waste.

3.7 Selection of site for nuclear power stations.

3.8 List of nuclear power stations.

4.0 DIESEL ELECTRIC POWER STATIONS:

4.1 State the advantages and disadvantages of diesel electric power stations.

4.2 Explain briefly different systems of diesel electric power stations: Fuel storage and fuel supply system, Fuel injection system, Air supply system, Exhaust system, cooling system, Lubrication system, starting system, governing system.

4.3 Selection of site for diesel electric power stations.

4.4 Performance and thermal efficiency of diesel electric power stations.

5.0 HYDEL POWER STATIONS:

5.1 State advantages and disadvantages of hydroelectric power plant.

5.2 Classify and explain the general arrangement of storage type hydroelectric project and explain its operation.

5.3 Selection of site of hydel power plant.

5.4 List of hydro power stations with their capacities and number of units in the state.

5.5 Types of turbines and generation used.

5.6 Simple problems.

6.0 GAS TURBINE POWER STATIONS

6.1 Selection of site for gas turbine stations.

6.2 Fuels for gas turbine

6.3 Elements of simple gas turbine power plants

6.4 Merits, demerits and application of gas turbine power plants

LEARNING RESOURCES:

Sl.No.	Name of Authors Title of the Book Name of the Publisher
1	R.K Rajput Power Plant Engineering Laxmi Publication
2	P.K.NAG Power Plant Engineering TMH
3	Nag pal G,R Power plant Engineering Khanna Publisher
4	P.C.SHARMA Power Plant Engineering S.K KATARIA &SONS

CHAPTER-1

1.0 INTRODUCTION

1.1 Describe sources of energy.

1.2 Explain concept of Central and Captive power station.

1.3 Classify power plants.

1.4 Importance of electrical power in day today life.

1.5 Overview of method of electrical power generation.

1.1 Describe sources of energy

The various sources of energy are :

1. Fuels :- Solids- Coal, coke anthracite ete.

Liquids- Petroleum and its derivates

Gases- Natural gas blast furnace gas etc.

2. Energy stored in water

3. Nuclear energy

4. Solar enengy

5. Wind power

6. Tidal power

7. Geothermal energy

8. Thermoelectric power.

1. Fuels:

Fuel is defined as any material that combines chemically with oxygen and liberates heat.

Fuels may be chemical or nuclear. A chemical fuel is a substance which releases heat energy on combustion.

Classification of fuels:

Fuels can be classified according to whether

1. They occur in nature called **primary fuels** or are prepared called **secondary fuels**.

2. They are in **solid, liquid or gaseous state**.

Type of fuel	**Natural (Primary)**	**Prepared (Secondary)**
1. Solid	Wood, Peat, Lignite coal	Coke ,Charcoal, Briquettes
2. Liquid	Petroleum	Gasoline, Kerosene, Fuel oil, Alcohol
3. Gaseous	Natural gas	Petroleum gas, Producer gas, Coal gas, Blast furnace gas

1. <u>Solid fuels:</u>

Coal:

- Its main constituents are carbon, hydrogen, oxygen, nitrogen, sulphur, moisture and passes through different stages during its formation from vegetation.
- These stages are:

Plant debris→Peat→Lignite andBrown coal→Bituminous coal→Anthracite coal→graphite.

Peat.

- It is the first stage in the formation of coal from wood.
- It contains huge amount of moisture and therefore it is dried for about 1 to 2 months before it is put to use. The high moisture content greatly reduces its calorific value, to about 730 kcal/kg and has 3000 to 5600 kcal/kg when it is dried, and therefore is not suitable for power plants and mostly used for domestic and other purposes.

Lignites and brown coals.

- These are intermediate stages between peat and coal.
- It also contains high percentage of moisture (30 to 45%) but can be dried by exposing to air, and can bring down the moisture upto 6%.
- It is brown in colour and exhibits a woody structure.
- It can be used as fuel in pulverised form.
- Its heat value range from 7000 to 11500 kJ/kg.

Bituminous coal.

- This is the real cool formed from lignite, variety and is most popular form of coal used for all purposes.
- It has low moisture content and has high caking power.
- Bituminous coal is a black coloured, brittle substance.
- Bituminous coals show carbon from 40 to 90%, mois ture from 5 to 20%, ash from 6 to 12%, and volatile constituents from 10 to 45%.
- Its heat value varies from 9,500 to 16,000 kJ/kg.

Anthracite.

- Anthracite is the last stage in the process of transformation of buried vegetation into coal
- It contains highest percentage of carbon 92-98% and the percentage of volatile matter is below 8%.
- It burns only at high temperature with little or no flame and pulverization of anthracite is very difficult, therefore, it is used only on the grate with forced draft. The anthracite is clean, dense, hard, non-caking. It burns freely uniformly and smoke lessly.
- Its heating value is between 14,500 to16,000 kJ/kg.

Coke:

- It consists of carbon, mineral matter with about 2% sulphur and small hydrogen, quantities of nitrogen and phosphorus.
- It is smokeless.
- It is mainly used in blast furnace to produce heat and at the same time to reduce the iron ore.

Briquettes:

- These are prepared from fine coal or coke by compressing the material under high pressure.

2. Liquid Fuels

The chief source of liquid fuels is petroleum and its derivatives. Petroleum is obtained from wells under the earth's crust. Other liquid fuels are kerosene, fuels oils, colloidal fuels and alcohol.

These fuels have more advantages in comparison to solid fuels in the following respect

Advantages

1. fuels Require less space for storage.
2. Higher calorific value.
3. Easy control of consumption.
4. Staff economy
5. Absence of danger from spontaneous combustion.

6 easy handling and transportation

7. Cleanliness
8. No ash problem

3. Gaseous Fuels

The gaseous fuels are of two types, namely, natural gas, and manufactured gas. Since manufactured gas is costly, only natural gas is used for steam generation. Manufacture gases are: blast furnace gas, coal gas, producer gas, water gas etc.

Natural gas

The main constituents of natural gas are methane (CH,) and ethane (C,H).

It has calorific value nearly 21000 kJ/m3. Natural gas is used alternately or simultaneously with oil for internal combustion engine.

Commonly used manufactured gases are:

Blast furnace gas:

This gas is obtained as a by-product from blast furnace used for producing pig iron. It has low calorific value.

Coal gas:

Coal gas is a by-product obtained during the destructive distillation of coal. Its calorific value is 7600 kcal/cu metre. It is used in boilers.

Producer gas.

Producer gas is produced during incomplete combustion of coke in current of air. Its main constituents are nitrogen and carbon monoxide.

Water gas:

Water gas is obtained by passing steam through a bed of red hot coke.

- Gageous fuels have following advantages

Advantages:

1. Better control of combustion.
2. Higher calorific value
3. Much less excess air is needed for complete combustion
4. Economy in fuel and more efficiency of furnace operation.
5. Easy maintenance of oxidizing or reducing atmosphere.
6. Cleanliness.
7. No problem of storage if the supply is available from public supply line.

2. Energy stored in water

- The energy contained in flowing streams of water is a form of mechanical energy. It may exist as the kinetic energy of a moving stream or as potential energy of water at some elevation with respect to a lower datum level, such as the water held behind a dam.
- When water strikes the blades fixed on the periphery of the turbine wheel, wheel starts rotating due to the force of the water. Thus, hydraulic turbines are the devices which convert hydraulic energy into mechanical energy. Mechanical energy thus produced is used for running the electric generator, which are coupled to the turbine shaft. The electric power thus produced is known as hydro-electric power or water power.
- Initial cost of the hydroelectric plant is very high, but operating costs are too low. Thus, if the water is available in large quantity at a suitable head, hydroelectric plants are very advantageous.

3. Nuclear energy

A large amount of energy can be liberated from a small amount of active material like, uranium, Plutonium etc. by the nuclear fission of materials. It has been found that complete fission of one kilogram of U can produce as much energy as can be produced by burning about 4000 tonnes of coal or 2,000 tonnes of oil.

The nuclear power isn't only available in abundance but it is cheaper than the power generated by conventional sources.

In a nuclear power station instead of a furnace, there is a nuclear reactor, in which heat is generated by fission of U or Pu, is used to heat water to generate steam which is used for running turbo-generators.

4. Solar energy

Solar energy has the greatest potential of all the sources of renewable energy. Sun is regarded as an inexhaustible source of useful energy.
The 'solar power (solar power is referred to the electricity generated by solar energy would eliminate most of the serious environmental problems associated with fossil fuel and nuclear power.

For developing solar energy two ways have been explored viz., the glass lens and the reflector. These devices concentrate the solar rays to a focal point and there by generates a high degree of heat which can be utilized to boil water and generate steam.

There are certain major limitations to the extensive application of solar energy such as

(i) The intermittent and variable manner in which it arrives at the earth's surface.

(ii) The large area required to collect the energy.

(iii) The solar energy is effective only during the day time and Solar energy cannot be used during cloudy weather and rainy season.

5. Wind power

Winds arise primarily from temperature difference of the earth's surface resulting from unequal exposure to (or absorption of) solar radiation. Wind energy is thus a form of solar energy. Like direct solar energy, wind energy is also highly variable.

Wind power is the conversion of kinetic energy of the wind into mechanical energy, by installing wind mills, that can be utilized to perform useful work or to generate electricity. Wind energy is a renewable source of energy.

- Some characteristics of wind energy are as under

1. It is a free and inexhaustible renewable source of energy
2. Wind power systems are non-polluting, and has no adverse influence on the environ ment
3. It avoid fuel provision and transport
4. These are economical to the rural areas.

However, limitations of wind power are:

1. Wind energy available is unpredictable and f1uctuating in nature
2. Wind energy systems are noisy in operation
3. Large areas are needed to install wind farms of electrical power generators
4. Wind mills usually kill the birds.

6. Tidal power

The water level in a sea rises and falls during tides, caused mainly by gravitational attraction of the moon and the sun on the water of solid earth and the oceans.

The potential energy developed by the water head created during high tide can be used to run the turbines, to generate electricity. Electricity produced by these tides is called tidal power.

During high tide, the sea water flows towards the land reservoir through the openings in the dam or the barrage, and turns the turbines, generating electricity. During the low tide, as the seawater levels falls, the water from the upstream reservoir flows towards the downstream in seaward direction, again turning the turbine blades, to generate electricity.

Characteristic of tidal power are the tidal are periodical phenomenon and two tides in any cycle are alike. Moreover the mean tidal range varies from place to place. Therefore very few sites are available where tidal energy can be economically harnessed.

6. Geothermal energy

Geothermal energy is the energy which lies embedded within the earth as heat in the earth's crust.

From the extremely hot interior of the earth, a continuous upward current of heat flows towards the upper crust of the earth.

There are two ways of electric power production from geothermal energy

i) Heat energy is transferred to a working fluid which operates the power cycle. This may be particularly useful at places of fresh volcanic activity where the molten interior mass of earth vents to the surface through fissures and substantially high temperatures, such as between 450 to 550°C can be found. By embedding coil of pipes and sending water through them steam can be raised.

(ii) The hot geothermal water and/or steam is used to operate the turbines directly. Water separators are usually employed to separate moisture and solid particles from steam.

8. Thermo-electric Power

According to Seebeck effect, when the two ends of a loop of two dissimilar metals are held at different temperatures, an electromotive force is developed and the current flows in loop. This method, by selection of suitable materials, can also be used for power generation.

This method involves low initial cost and negligible operating cost.

1.2 Explain concept of Central and Captive power station

Power plants may be classified as follows:

1. Central stations.

2. Industrial power stations or cáptive power stations.

1. Central stations

The electrical energy available from these stations is meant for general sale to the customers who wish to purchase it.

Generally, these stations are condensing type where the exhaust steam is discharged into a condenser instead of into the atmosphere.

In the condenser the pressure is maintained below the atmospheric pressure and the exhaust steam is condensed. The steam which has been condensed into water in the condenser, can be recirculate to the boilers with the help of pumps

2. Industrial power stations or captive power stations.

This type of power station is run by a manufacturing company for its own use and its output is not available for general sale.

Normally these plants are non-condensing because a large quantity of steam (low pressure) is for different required manufacturing operations. In non-condensing steam power plants a continuous supply of fresh feed water is require which becomes a problem at places where there is a shortage of pure water.

1.3 CLASSIFICATION OF POWER PLANTS

Power plant may be classified as under:

1. On the basis of service rendered:

(i) Stationary (ii) Mobile.

2. On the basis of source of energy

(i) Steam power plants: (a) condensing (b) non-condensing

(ii) Diesel power plants

(iii)Hydro electric power plant

(iv) Nuclear power plants

(v)Gas turbine power plant

(vi) Tidal power plants

(vii)solar power plant

(viii) Wind power plants

(ix) Geo-thermal power plants

3. On the basis of location:

(i) Central power station

(ii) Isolated power station

4. On the basis of nature of load:

(i) Poak load plant (ii) Base load plant (iii) Stand-by plant

5. On the basis of conventional or non-conventional sources:

(i) Conventional sources

(a) Thermal power plants (Steam, Diesel, and Gas)

(6) Hydro power plants

(c) Nuclear power plants

(ii) Non-conventional sources

(a) Tidal

b) Solar

(c) Wind

(d) Geo-thermal

6. On the basis of Renewable or Non-renewable energy resources

i) Renewable energy resources

(a) Hydro (b) Solar (c) Wind (d) Tidal (e) Geothermal

(ii) Non-Renewable energy resources

(a) Coal (b) Oil (c) Gas (d) Nuclear

CHAPTER-2

THERMAL POWER STATIONS

2.1 Layout of steam power stations

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

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

1. Coal and ash circuit

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

2. Air and Gas circuit

- Air is supplied to the combustion chamber of the boiler either through F.D or I.D or by using both. The dust from the air is removed before supplying to the combustion chamber.
- The exhaust gases carrying sufficient quantity of heat and ash are passed through the air-heater where the exhaust heat of the gases is given to the air and then it is passed through the dust collectors where most of the dust is removed before exhausting the gases to the atmosphere through chimney.

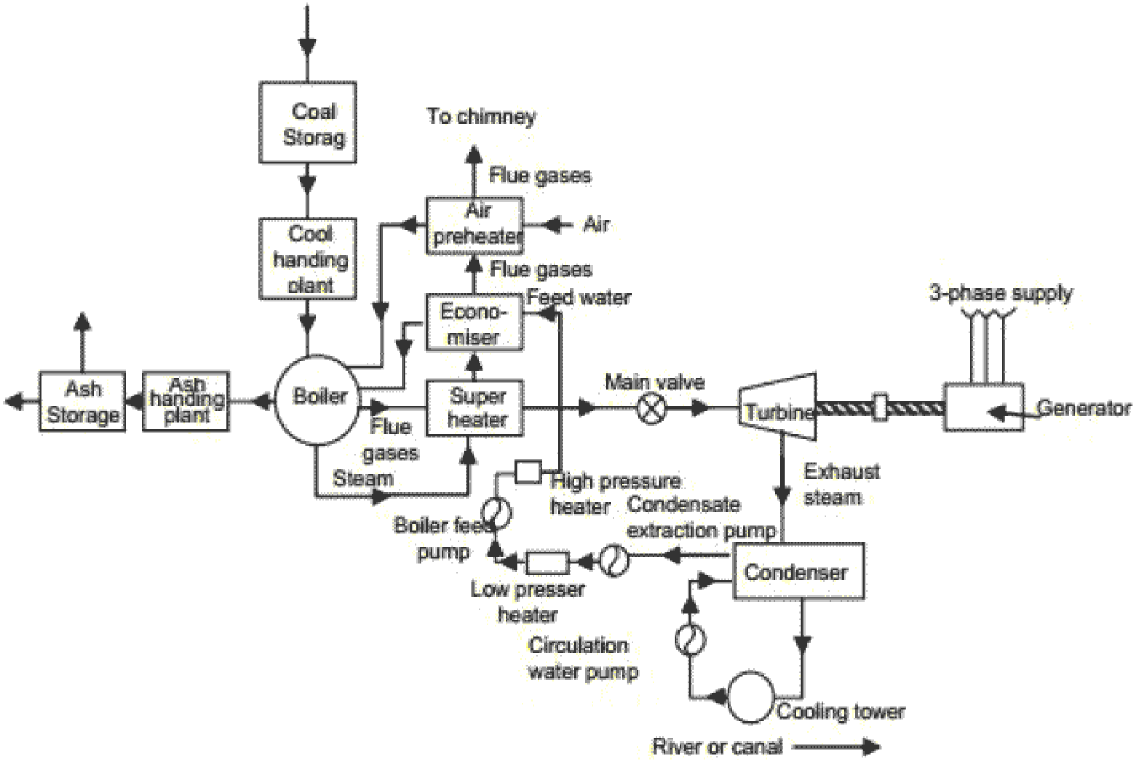


Fig- layout of steam power plant

3. Feed water and Steam flow circuit

- The steam generated in the boiler is fed to the steam prime mover to develop the power.
- The steam coming out of prime mover is condensed in the condenser. The condensate is heated in the feed-heaters using the steam tapped from different points of the turbine. The feed heaters may be of mixed type or indirect heating type. Then it is fed into the boiler through economiser with the help of the pump.

- In the boiler drum and tubes, water circulates due to the density difference between the water in the lower temperature and the higher temperature section of the boiler. Wet steam from the drum is further heated up in the super heater before being supplied to the prime mover.

4. **Cooling water circuit**

- The quantity of cooling water required to condense the steam is considerably large and it is taken either from lake, river or sea.
- The cooling water is taken from the upper side of the river, it is passed through the condenser and heated water is discharged to the lower side of the river. Such system of cooling water supply is possible if adequate cooling water is available throughout the year. This system is known as open system.
- When the adequate water is not available, them the water coming out from the condenser is cooled either in cooling pond or cooling tower. The cooling is effected by partly evaporating the water. When the cooling water coming out of the condenser is cooled again and supplied to the condenser then the system is known as closed system. When the water coming out from the condenser is discharged to river downward side directly, the system is known as open system.
- Open system is economical than closed system provided adequate water is available throughout the year.

<u>Components of modern steam power plant</u>

1. Boiler – superheater, economizer, reheater, air-preheater
2. Steam turbine
3. Generator
4. Condenser
5. Cooling tower
6. Circulating water pump

7. Boiler feed pump
8. Coal mill
9. Induced draught fan
10. Forced draught fan
11. Ash precipitator
12. Boiler chimney
13. Water treatment plant
14. Control room

Working of the thermal power

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

Merits:

(i) Higher efficiency

(ii) Lower cost

(iii) Ability to burn coal especially of high ash content, and inferior coals.

(iv) Reduced environmental impact in terms of air pollution

(v) Reduced water requirement

(vi) Higher reliability and availability

Demerits:

(i) There are more chances of explosion as coal burns like a gas

(ii) Coal transportation is quite complicated.

2.6 Boiler Accessories: Operation of Air pre heater, Operation of Economiser, Operation of Electrostatic precipitator and Operation of super heater. Need of boiler mountings and operation of boiler

BOILER ACCESSORIES

Accessories are the auxiliary plants required for steam boilers for their proper operation and for the increase of their efficiency.

Commonly used accessories are discussed as follows:

Air Preheater

The function of the air pre-heater is to increase the temperature of air before it enters the furnace. It is generally placed after the economiser; so the flue gases pass through the economiser and then to the air preheater.

Location-

Air preheater is usually placed after the economiser and before the gases enters the chimney.

Thus, with the heating of air supplied for the combustion of fuel. The use of hot **air makes the** combustion process more efficient by making it more stable and reducing the energy losses due to incom. **plete combustion and unburnt carbon.**

An air-preheater consists of plates or tubes with hot gases on one side and air on the other. It preheats the air to be supplied to the furnace. Preheated air accelerates the combustion and facilitates the burning of coal.

- Degree of preheating depends on
- Type of fuel,
- Type of fuel burning equipment, and
- Rating at which the boiler and furnace are operated.

- There are three types of air preheaters

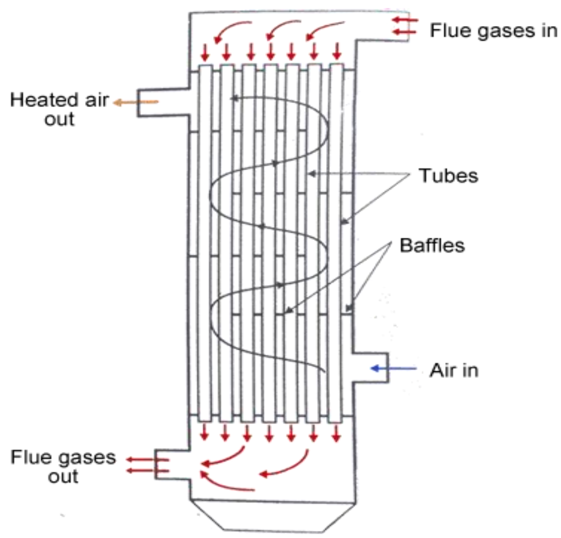
1. Tubular type

2. Plate type
3. Regenerative type.

1.Tubular type-

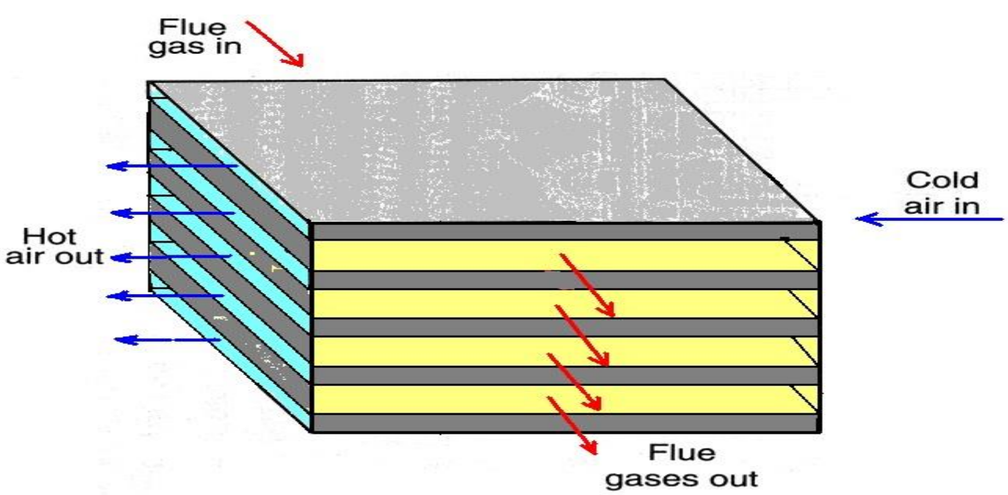
Fig. shows a tubular type air preheater. After leaving the boiler or economiser the gaseous products of combustion travel through the inside of the tubes of air preheater in a direction opposite to that of air travel and transfer some of their heat to the air to be supplied to the furnace. Thus the air gets initially heated before being supplied to the furnace. The horizontal baffles are provided as shown in the figure to increase time of contact which will help for higher heat transfer.

The gases reverse their direction near the bottom of the air heater, and a soot hopper is fitted to the bottom of air heater casing to collect soot.



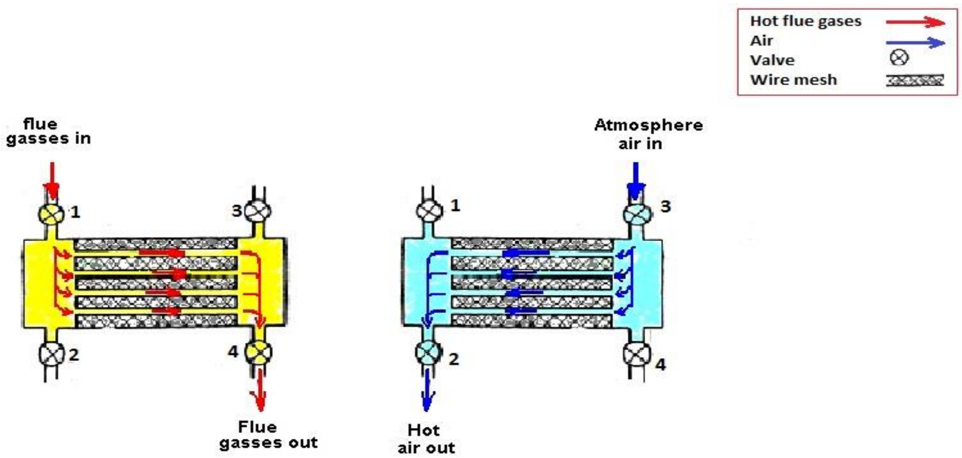
2. Plate type-

In plate type air preheater the air absorbs heat from the hot gases being swept through the heater at high velocity plates spaced from 1.5 to 2.5 cm apart leaving alternate air and gas passages. This type of air-preheater is not used in modern installations, as it is more expensive both as to initial cost and maintenance cost and also in efficiency as compared with tubular air preheater.



3.Regenerative type:

The hot flue gas and air are made to flow alternatively through the same path consisting wire mesh as shown in Fig. The hot flue gasses are made to pass through wire mesh by opening valves 1 & 4 and closing valves 2 & 3. While passing through wire mesh, the hot flue gasses reject and store their heat into wire mesh. In the alternate pass, when the atmosphere air is passed through wire mesh by opening valves 2 & 3 and closing valves 1 & 4, it receives heat from wire mesh and as a result the air gets heated.



Advantages of preheating of air:

(1) Waste heat from the flue gases is recovered for heating air and causes a fuel saving of about 1.5% for each 100°C drop in gas temperature.

(2) Inferior grades of coal can be burnt efficiently with preheated air.

(3) Less excessive air is required to burn fuel and thus cost of producing draught will be less.

(4) Combustion can be more efficient and an intense flame can be achieved in the furnace. This increases the evaporation rate of the boiler.

Disadvantages:

(i) Increase in the capital and running cost of the preheater as induced draft fan for removing gases and forced fan for forcing cold air through the air preheater are used.

Super heater

The function of a superheater is to increase the temperature of the steam above its saturation point. The superheater is very important accessory of a boiler and can be used both on fire tube and water-tube boilers. The small boilers are not commonly provided with a superheater.

Location

Superheaters are located in the path of the furnace gases so that heat is recovered by the superheater from the hot gases.

Construction and operation:

It consists of a set of tubes through which wet or saturated dry steam flows and hot combustion gases pass around these tubes. By this way, the wet or saturated dry steam takes heat from the flue gases and become superheated.

Classification of Superheaters:

According to the mode of heat reception:

(i) Convective superheaters,

(ii) Radiant superheaters and

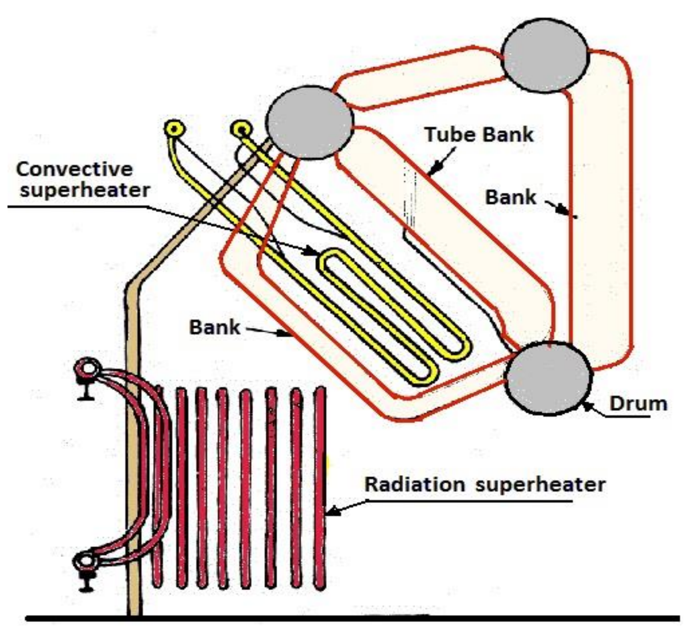
(iii) Combination superheaters

As shown in Fig.

(i) Convective superheaters: In the convective superheaters, the superheaters are placed between or near the water tubes where the superheater tubes receive heat by convection from combustion gases.

(ii) Radiant type superheaters: In the radiation superheaters, the superheaters are placed in the walls of the furnace of a steam boiler where the superheater tubes receive heat by direct radiation from fire and re-radiation from refractory walls.

(iii) Combination type: In combined superheaters, the steam first enters the radiant superheater and then the convective superheater. In this heat of combustion is transferred to the superheater tubes by radiation and then convection.



- **According to the arrangement of the superheater tubes:**

(i) Overdeck. This is placed in the space over the water tubes.

(ii) Interdeck. This is placed between the water tubes which are located near the furnace.

(iii) Intertubes. This is placed between bank or row of water tubes

- Sugden Superheater Fig. shows sugden's super heater used in a Lancashire boiler. This super heater uses two steel headers to which are attached solid drawn 'U' tubes of steel. These tubes are arranged in groups of four and one pair of the headers generally carries ten of these groups or total of forty tubes. The steam from the boiler enters and leaves the headers as shown by the arrows. It shows how the steam pipes may be arranged so as to pass the steam through the superheater or direct to the main steam pipe.

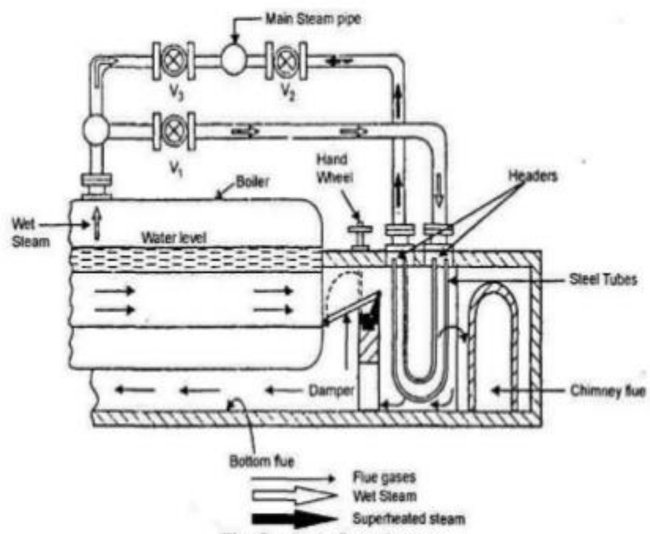


Fig. Sugden's Superheater

Economiser

An economiser is a device in which the waste heat of the flue gases is utilised for heating the feed water.

Location: It is placed in the path of the flue gases in between the exit from the boiler and entry into air preheater/chimney.

Types of economiser

-**Based on part of steam generation**

There are steaming economisers in which the water is raised to the boiling point and partially (10-20%) evaporates and non-steaming economisers in which the temperature of water is below the boiling point by 20 -30°C.

- **Based on location of economiser**

They are of the two types: (i) Independent type, and (ii) Integral type.

Independent type- economiser is installed in chamber apart from the boiler setting. The chamber is situated at the passage of the flow of the flue gases from the boiler or boiler to the chimney.

Integral Type- Economiser is a part of the boiler heating surface and is installed within the boiler setting.

Construction

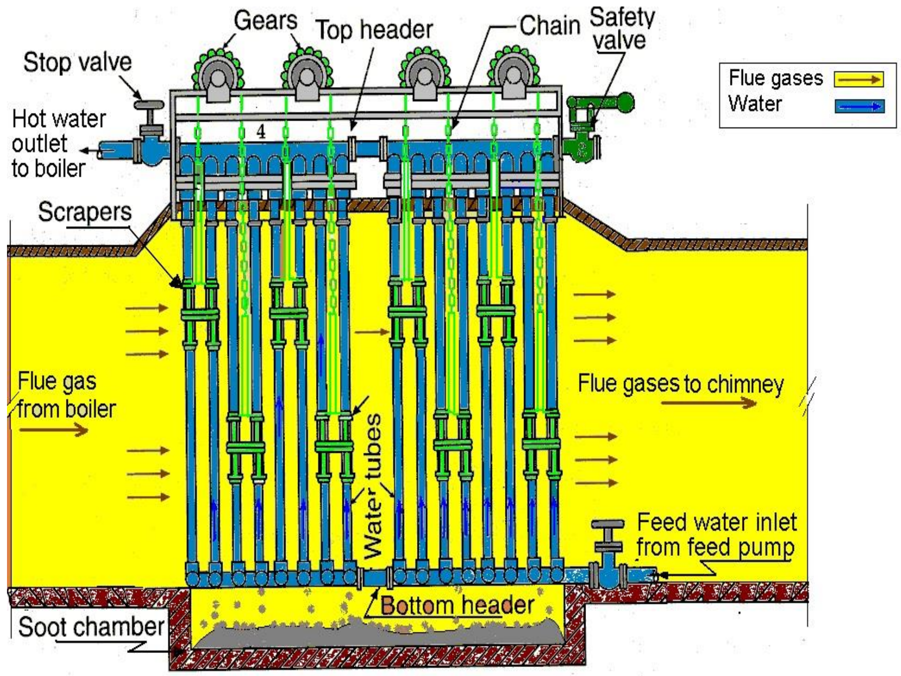
Fig. shows an independent type vertical tube economiser (called Green's economiser). It is employed for boilers of medium pressure range upto about 25 bar. It consists of a large number of vertical cast iron pipes P which are connected with two horizontal pipes, one at the top header and the other at the bottom header.

For safety against high pressure, a safety valve is mounted on the top of the header. Like boiler, it has blow off cock valve fitted at the bottom to discharge sediments collected at the bottom of economizer. Scrapers are provided on the tubes to remove the soot of flue gas deposited on the tubes of the economiser. The soot thus removed from the tubes is collected in a chamber provided at the bottom of economizer. The two stop valves, one at the bottom header and other at the top header, are provided to stop or allow water into and out of the economizer, respectively.

Operation:

The feed water from the feed pump first enters into the bottom header of economizer before it enters into the boiler. From the bottom header the water then passes through the vertical tubes and reaches into the top header, from where it finally leads into the boiler. At the same time the flue gas moves around the tubes and gives off their heat to the water flowing inside the vertical tubes and water is thereby heated in the economizer.

While economizer in operation of water heating, the scrapers provided on the tubes are moved up and down continuously with the help of chain and gear arrangement so that soot deposited on the pipes may be removed and maximum efficiency of the economizer may be achieved as the soot deposit on pipes reduce the heat transfer to water.



The use of an economiser entails the following advantages-

1. The temperature range between various parts of the boiler is reduced which results in reduction of stresses due to unequal expansion.
2. Longer life of the boiler as this reduces the temperature difference between different parts of the boiler
3. A large quantity of scale forming impurities may be removed by precipitation due to pre-heating the feed water.
4. Evaporative capacity of the boiler is increased.
5. Overall efficiency of the plant is increased.

Electrostatic precipitator

An electrostatic precipitator (ESP) is defined as a filtration device that is used to remove fine particles like smoke and fine dust from the flowing gas. It is the commonly used device for air pollution control. They are used in industries like steel plants, thermal energy plants.

In the year 1907, chemistry professor Frederick Gardner Cottrell patented the first electrostatic precipitator that was used to collect sulphuric acid mist and lead oxide fumes that were emitted from various acid-making and smelting activities.

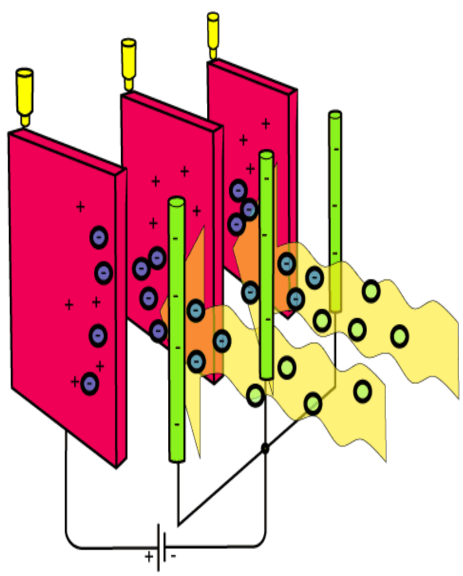
Working Principle of Electrostatic Precipitator

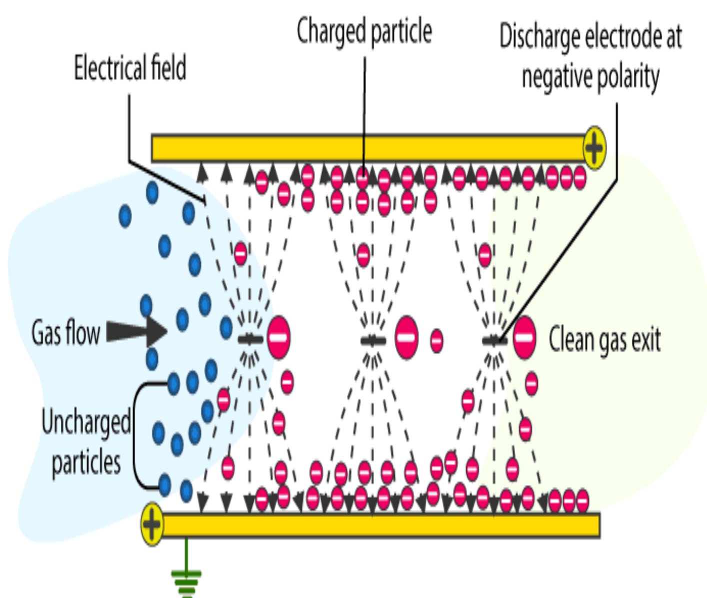
The working principle of the electrostatic precipitator is moderately simple. It consists of two sets of electrodes: positive and negative. The negative electrodes are in the form of a wire mesh and the positive electrodes are in the form of plates. These electrodes are vertically placed and are alternate to each other.
The gas borne particles such as ash are ionised by the high voltage discharge electrode by the corona effect. These particles are ionised to a negative charge and are attracted to positively charged collector plates

The negative terminal of high voltage DC source is used to connect the negative electrodes and the positive terminal of the DC source is used to connect the positive plates. To ionize the medium between the negative and the positive electrode, a certain distance is maintained between the positive, negative electrode and the DC source resulting in a high voltage gradient.

The medium that is used between the two electrodes is air. There might be corona discharge around the electrode rods or the wire mesh due to high negativity of negative charges. The entire system is enclosed in a metallic container consisting of an inlet for flue gases and an outlet for filtered gases. There are plenty of free electrons as the electrodes are ionized which interact with the dust particles of the gas making them negatively charged. These particles move towards positive electrodes and fall off due to gravitational force. Now the flue gas is free from the dust particles as it flows through the electrostatic precipitator and is discharged to the atmosphere through the chimney.

ELECTROSTATIC PRECIPITATOR DIAGRAM





Types of Electrostatic Precipitator

There are different electrostatic types, and Following are the three types of ESPs:

Plate precipitator: This is the most basic precipitator type that consists of rows of thin vertical wires and stack of vertically arranged large flat metal plates that are placed at a distance of 1cm to 18cm apart. The air stream is passed horizontally through the vertical plates and then through the large stack of plates. In order to ionize the particles, a negative voltage is applied between the wire and the plate. These ionized particles are then diverted towards the grounded plates using electrostatic force. As the particles get collected on the collection plate, they are removed from the air stream.

Dry electrostatic precipitator: This precipitator is used to collect pollutants like ash or cement in a dry state. It consists of electrodes through which the ionized particles are made to flow through and a hopper through which the collected particles are extracted out. The dust particles are collected from a stream of air by hammering the electrodes.

Wet electrostatic precipitator: This precipitator is used to remove resin, oil, tar, paint that are wet in nature. It consists of collectors that are continuously sprayed with water making the collection of ionized particles from the sludge. They are more efficient than dry ESPs.

Tubular precipitator: This precipitator is a single-stage unit consisting of tubes with high voltage electrodes that are arranged parallel to each other such that they are running on their axis. The arrangement of the tubes could either be circular or square or hexagonal honeycomb with gas either flowing upwards or downwards. The gas is made to pass through all the tubes. They find applications where sticky particles are to be removed.

- **Advantages and Disadvantages**

Advantages of electrostatic precipitator:

- The durability of the ESP is high.
- It can be used for the collection of both dry and wet impurities.
- It has low operating costs.
- The collection efficiency of the device is high even for small particles.
- It can handle large gas volumes and heavy dust loads at low pressures.

Disadvantages of electrostatic precipitator:

- Can’t be used for gaseous emissions.
- Space requirement is more.
- Capital investment is high.
- Not adaptable to change in operating conditions.

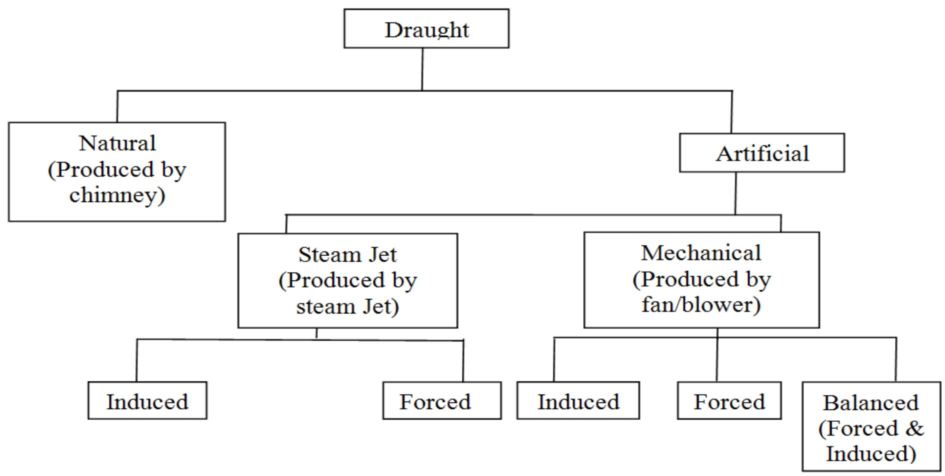
2.7 Draught systems (Natural draught, Forced draught & balanced draught) with their advantages & disadvantages.

Definition and Classification of Draught

The small pressure difference which causes a flow of gas to take place is termed as a draught.

The function of the draught, in case of a boiler, is to force air to the fire and to carry away the gaseous products of combustion. In a boiler furnace proper combustion takes place only when sufficient quantity of air is supplied to the burning fuel.

The draught may be classified as:



1. Natural Draught

Natural draught is obtained by the use of a chimney.

The chimney in a boiler installation performs one or more of the following functions:

(i) It produces the draught whereby the air and Gas are forced through the fuel bed, furnace, boiler passes and settings;

(ii) It carries the products of combustion to such a height before discharging them that they will not be objectionable or injurious to surroundings.

A chimney is vertical tubular structure built either of masonry, con crete or steel. The draught produced by the chimney is due to the density difference between the column of hot gases inside the chimney and the cold air outside.

Advantages

(1) It does not require any external power for producing the draught.

(2) The capital investment is less. The maintenance cost is nil as there is no mechanical part.

(3) Chimney keeps the flue gases at a high place in the atmosphere which prevents the contamination of atmosphere.

(4) It has long life.

Limitations

(1) The maximum pressure available for producing natural draught by chimney is hardly 10 to 20 mm of water under the normal atmospheric and flue gas temperatures.(2) The available draught decreases with increase in outside air temperature and for producing sufficient draught, the flue gases have to be discharged at comparatively high temperatures resulting in the loss of overall plant efficiency. And thus maximum utilization of heat is not possible.

(3) The chimney has no flexibility to create more draught under peak load conditions because the draught available is constant for a particular height of chimney and the draught can be increased by allowing the flue gases to leave the combustion chamber at higher temperature. thereby refuces the overall plant efficiency.

(4)Due to low velocity of air, there is no thorough mixing of air and fuel in the combus tion chamber resulting into poor consumption.

(5) Nearly 20% heat released by the fuel is lost to the flue gases.

2. Artificial Draught

In the boiler installations of today the total static draught required may vary from 30 to 35 Mm of water column.

It may not be possible to build a chimney high enough to produce draught of such a large magnitude. To meet this requirement artificial draught system should be used. It may be a mechanical draught or a steam jet draught. The former is used for central power stations and many other boiler installations while the latter is employed for small installations and in locomotives.

(i) Forced Draught

In a mechanical draught system, the draught is produced by a fan.

In a forced draught system, a blower or a fan is installed near or at the base of the boiler to force the air through the cool bed and other passages through the furnace, flues, air preheater, economiser etc. It is a positive pressure draught. The enclosure for the furnace etc. has to be very highly sealed so that gases from the furnace do not leak out in the boiler house.

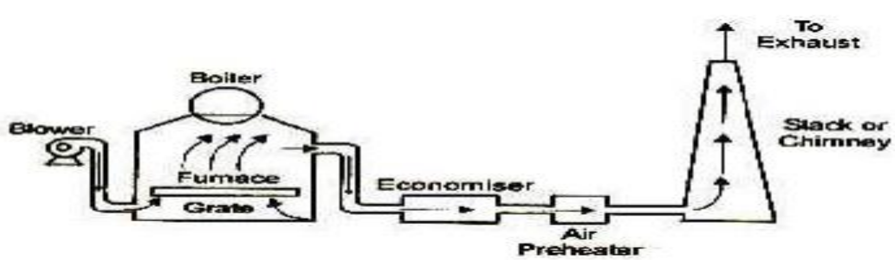


Figure: Forced draught

ii. Induced Draught

In this system a fan or blower is located at or near the base of the chimney.

The pressure over the fuel bed is reduced below that of the atmosphere. By creating a partial vacuum in the furnace and flues, the products of combustion are drawn from the main flue and they pass up the chimney.

This draught is used usually when economisers and air preheaters are incorporated in the system. The draught is similar in action to the natural draught.

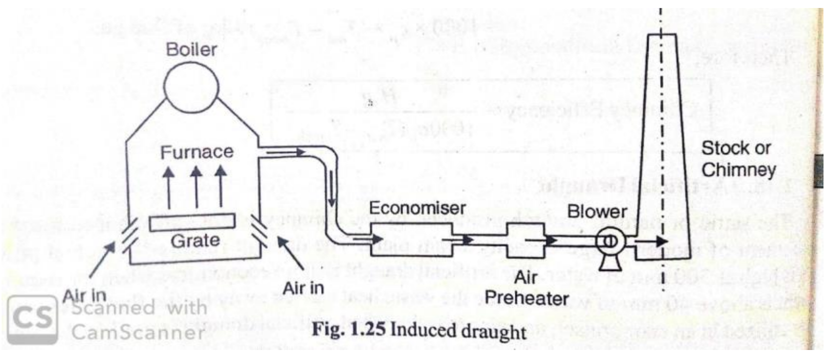


Fig. 1.25 Induced draught

iii. Balanced Draught

It is a combination of the forced and induced draught systems.

In this system, the forced draught fan overcomes the resistance in the air preheater and chain grate stoker while the induced draught fan overcomes draught losses through boiler, economiser, air preheater and connecting flues.

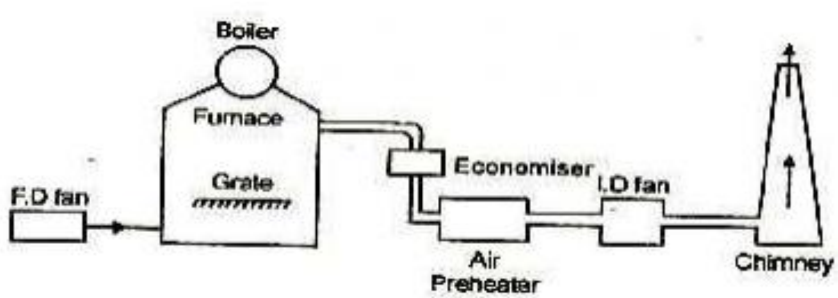


Figure: Balanced draught

The forced draught entails following advantages over induced draught:

Forced draught fan does not require water-cooled bearings.

Tendency to air leak into the boiler furnace is reduced.

loss due to inrush of cold air through the furnace doors when they are opened for fire and cleaning fires.

size and power required for the same draught are 1/5 to ½ of that required for an induced draught fan installation because forced draught fan handles cold air.

Advantages of Mechanical Draught

The mechanical draught possesses the following advantages:

Easy control of combustion and evaporation.

Increase in evaporative power of a boiler.

Improvement in the efficiency of the plant.

Reduced chimney height.

Prevention of smoke.

Capability of consuming low grade fuel.

Low grade fuel can be used as the intensity of artificial draught is high.

Rapid start of the boiler is possible.

Comparatively less number of operators are required.

2.8 Steam prime movers: Advantages & disadvantages of steam turbine, Elements of steam turbine, governing of steam turbine. Performance of steam turbine: Explain Thermal efficiency, Stage efficiency and Gross efficiency.

Steam prime movers/steam turbines

Definition –

The steam turbine is a prime-mover in which the potential energy of the steam is trans formed into kinetic energy, and latter in its turn is transformed into the mechanical energy of rotation of the turbine shaft. The turbine shaft, directly or with the help of a reduction gearing, is connected with the driven mechanism. Depending on the type of the driven mechanism a steam turbine may be utilised in most diverse fields of industry, for power generation and for transport.

Classification of Steam Turbines

There are several ways in which the steam turbines may be classified. The most important and common division being

- **With respect to the action of the steam, as :**

- Impulse turbine
- Reaction turbine
- Combination of impulse and reaction

- According to the number of pressure stages:

- Single-stage turbines with one or more velocity stages usually of small-power capaci ties; these turbines are mostly used for driving centrifugal compressors, blowers and other similar machinery.
- Multi-stage impulse and reaction turbines; they are made in a wide range of power capacities varying from small to large.

- According to the direction of steam flow :

- Axial turbines in which steam flows in a direction parallel to the axis of the turbine. Turbine; one or more low-pressure stages in such turbines are made axial.
- Radial turbines in which steam flows in a direction perpendicular to the axis of the

- According to the number of cylinders:

- Single-cylinder turbines.

- Double-cylinder turbines.
- Three-cylinder turbines.
- Four-cylinder turbines.
- Multi-cylinder turbines which have their rotors mounted on one and the same shaft and coupled to a single generator are known as single shaft turbines; turbines with separate rotor shafts for each cylinder placed parallel to each other are known as multiaxial turbines.

- According to the method of governing:

- Turbines with throttle governing in which fresh steam enters through one or more (depending on the power developed) simultaneously operated throttle valves.
- Turbines with nozzle governing in which fresh steam enters through two or more con secutively opening regulators.

Advantages of Steam Turbine over the Steam Engines

The following are the principal advantages of steam turbine over steam engines

1. The thermal efficiency of a steam turbine is much higher than that of a steam engine.

2 The power generation in a steam turbine is at a uniform rate, therefore necessity to use. A flywheel (as in the case of steam engine) is not felt.

3 Much higher speeds and greater range of speed is possible than in case of a steam engine.

4 In large thermal stations where we need higher outputs, the steam turbines prove very suitable as these can be made in big sizes.

5 With the absence of reciprocating parts (as in steam engine) the balancing problem is minimised.

6 No internal lubrication is required as there are no rubbing parts in the steam turbine.

7 In a steam turbine there is no loss due to initial condensation of steam..

8 It can utilise high vacuum very advantageously.

9 Considerable overloads can be carried at the expense of slight reduction in overall efficiency.

The main parts of s steam turbine are as follows:

(i) A rotor on the circumference of which a series of blades or buckets are attached. To a great extent of performance of the turbine depends upon the design and construction of blades.

- The blades should be so designed that they are able to withstand the action of steam

and the centrifugal force caused by high speed.

- As the steam pressure drops the length and size of blades should be increased in order

to accommodate the increase in volume. The various materials used for the construction of blades materials used for the construction of blades depend upon the conditions under which they operated steel or alloys are the materials generally used.

(ii) Bearing to support the shaft.

(iii) Metallic casing which surrounds blades, nozzles, rotor etc.

(iv) Governor to control the speed.

(v) Lubricating oil system.

- Steam from nozzles is directed against blades thus causing the rotation. The steam attains

high velocity during its expansion in nozzles and this velocity energy of the steam is converted into mechanical energy by the turbine.

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

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

Compounding

In 'simple impulse turbine' that if the steam is expanded from the boiler pressure to condenser pressure in one stage the speed of the rotor becomes tremendously high which crops up practical complicacies. There are several methods of reducing this speed to lower value; all these methods utilise a multiple system of rotor in series, keyed on a common shaft and the steam pressure of jet velocity is absorbed in stages as the steam flows over the blades. This is known as ‘compounding.

- The different methods of compounding are:

  - Velocity compounding.
  - Pressure compounding.
  - Pressure velocity compounding.
  - Reaction turbine.

- **Velocity compounding:**

Steam is expanded through a stationary nozzle from the boiler or inlet pressure to con denser pressure. So the pressure in the nozzle drops, the kinetic energy of the steam increases due to increase in velocity.

- A portion of this available energy is absorbed by a row of moving blades. The Steam (whose velocity has decreased while moving over the moving blades) then flows through the second row of blades which are fixed.
- The function of these fixed blades is to redirect the steam flow without altering its velocity to the following next row moving blades where again work is done on them and steam leaves the turbine with a low velocity. Fig. shows a cut away section of such a stage and changes in pressure and velocity as the steam passes through the nozzle, fixed and moving blades.
- Though this method has the advantage that the initial cost is low due to lesser number of Stages yet its efficiency is low.

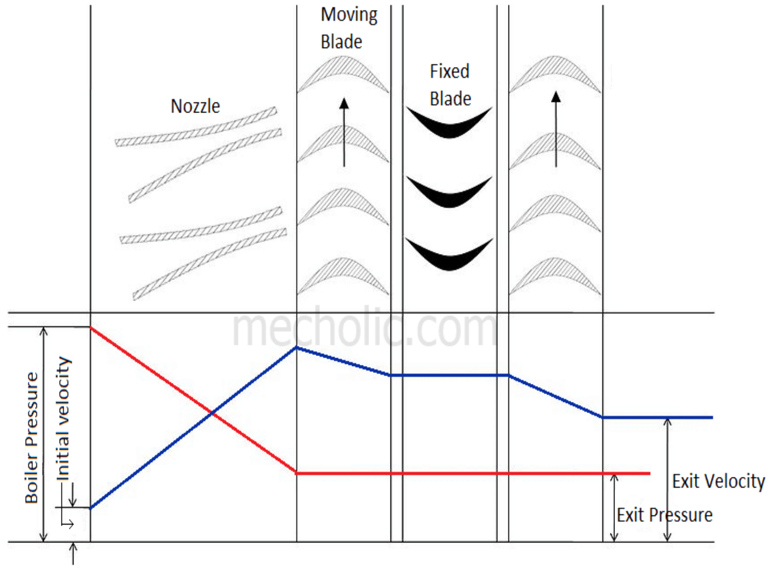


Fig- velocity compounding

- **Pressure compounding :**

➢ Fig. shows rings of fixed nozzles incorporated between the rings of moving blades.
➢ The steam at boiler pressure enters the first set of nozzles and expands partially. The kinetic energy of the steam thus obtained is absorbed by the moving blades (stage 1).
➢ The steam then expands partially in the second set of nozzles where its pressure again falls and the velocity increases; the Kinetic energy so obtained is absorbed by the second ring of moving blades (stage 2).
➢ This is repeated in stage 3 and steam finally leaves the turbine at low velocity and pressure.
➢ The number of stages (or pressure reductions) depends on the number of rows of nozzles through which the steam must pass.

This method of compounding is used in Rateau and Zoelly turbine. This is most efficient turbine since the speed ratio remains constant but it is expensive owing to a large number of stages.

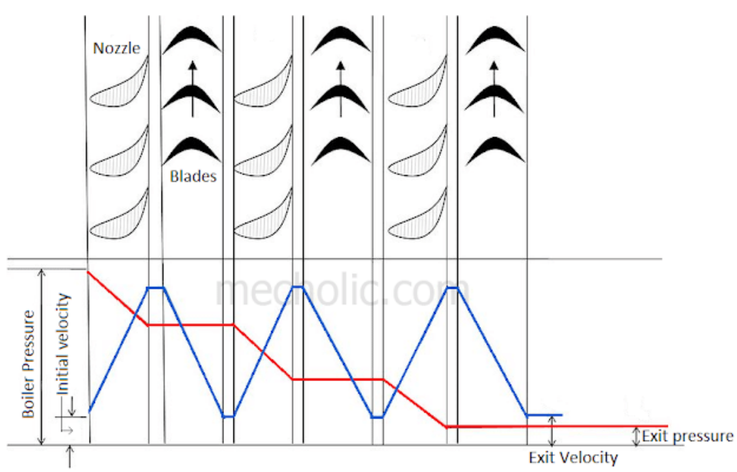


Fig – pressure compounding

- **Pressure velocity compounding:**

This method of compounding is the combination of two previously discussed method. The total drop in steam pressure is divided into stages and the velocity obtained in each stage is also compounded. The rings of nozzles are fixed at the beginning of each stage and pressure remains constant during each stage. The changes in pressure and velocity are shown in Fig. 3.87.

This method of compounding is used in Curits and Moore turbine.

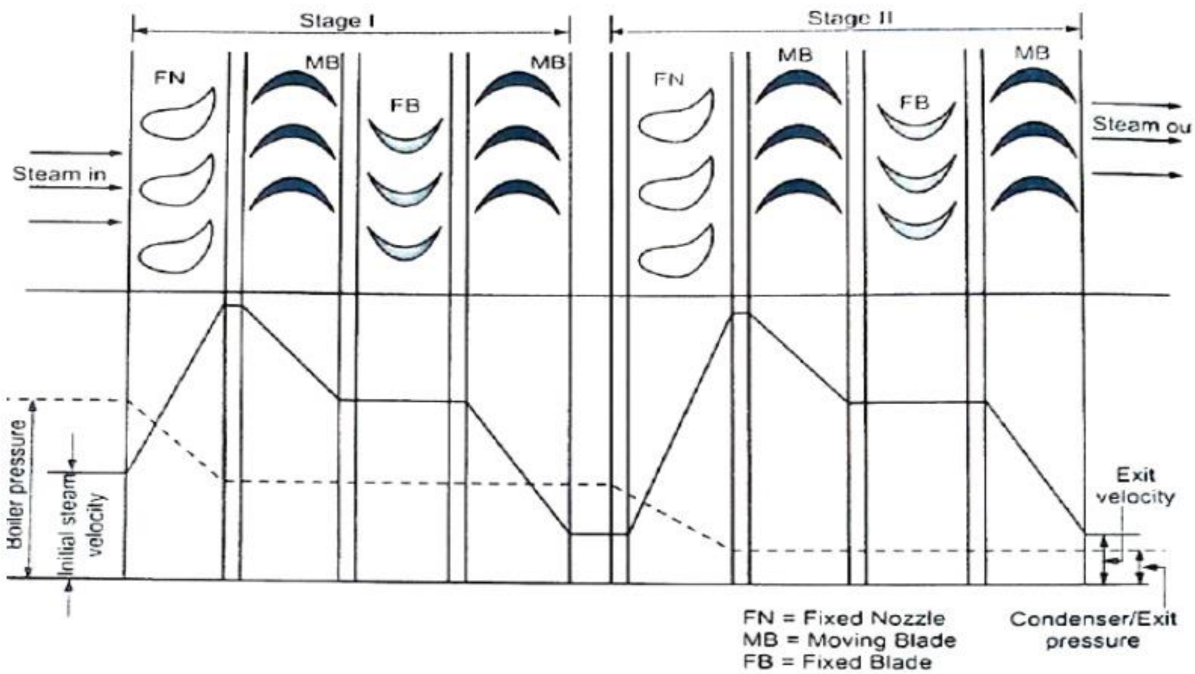


Figure: Pressure and Velocity compounding

Performance of steam turbine

Velocity triangle diagram for moving blade-

Cbl=linear velocity of moving blade

C_1 Absolute velocity of steam entering moving blade (m/s)

Co Absolute velocity of steam leaving moving blade (m/s)

Cw1= Velocity of whirl at the entrance of moving blade = tangential component of C_1

Cw0= Velocity of whirl at exit of the moving blade = tangential component of Co

Cf1= Velocity of flow at entrance of moving blade= axial component of C_1

C_{f0}= Velocity of flow at exit of the moving blade = axial component of Co

C_{r1}= Relative velocity of steam to moving blade at entrance

C_{r0}= Relative velocity of steam to moving blade at exit

α= Angle with the tangent of the wheel at which the steam with velocity C1 enters. This is also called nozzle angle.

β=Angle which the discharging steam makes with the tangent of the wheel at the exit of moving blade

θ= entrance angle of moving blade

ϕ= exit angle of moving blade

The steam jet issuing from the nozzle at a velocity of C_1 impinges on the blade at an angle α . The tangential component of this jet (Cw1,) performs work on the blade

The axial component (Cf1) however does no work but causes the steam to flow through the turbine.

As the blades move with a tangential velocity of Cbl, the entering steam jet has a relative velocity

Cr1(with respect to blade) which makes an angle θ with the wheel tangent.

The steam then glides over the blade without any shock and discharges at a relative velocity of Cr0, at an angle with the tangent of the Blades.

The relative velocity at the inlet (Cr1) is the same as the relative velocity at the outlet (Cro) if there is no frictional loss at the blade.

The absolute velocity (Co) of leaving steam makes an angle β to the tangent at the wheel.

To have convenience in solving the problems on turbines it is a common practice to combine the two vector velocity diagrams on a common base which represents the blade velocity (C) as shown in Fig. This diagram has been obtained by superimposing the inlet velocity diagram on the outlet diagram in order that the blade velocity lines Cbl coincide.

- **Work done on the blade**

The work done on the blade may be found out from the change of momentum of the steam jet during its flow over the blade. As earlier discussed, it is only the velocity of whirl which per forms work on the blade since it acts in its (blade) direction of motion.

From Newton's second law of motion,

Force (tangential) on the wheel= Mass of steam x acceleration

= Mass of steam/sec. X change of velocity

= m(Cw1-Cw0)

The value of Cwo is actually negative as the steam is discharged in the opposite direction to the blade motion, therefore, due consideration should be given to the fact that the values of Cw1 and Cw0 are to be added while doing Work done on blades/sec.

Work done on the blade

= Force x distance travelled/sec.

= m(Cw1+Cw0)*Cbl

Power per wheel

= m. (Cw_1+C). Cbl /1000 Kw

Blade or diagram efficiency= work done on the blade/ energy supplied to the blade

= m(Cw1+Cw0)*Cbl/m$C1^2$

=2Cbl(Cw1+Cw0)/$C1^2$

If h, and h, be the total heats before and after expansion through the nozzles, then (h_1-h_2) is the heat drop through a stage of fixed blades ring and moving blades ring.

Stage efficiency= work done on the blade per kg of steam/Toptal energy supplied per kg of steam

= Cbl(Cw1+Cw0)/(h1-h2)

Nozzle efficiency= $C1^2$/2(h1-h2)

Stage efficiency= blade efficiency × nozzle edfficiency

= $\{2\mathrm{Cbl}(\mathrm{Cw1}+\mathrm{Cw0})/\mathrm{C12}\}$× $C1^2$/2(h1-h2)

= Cbl(Cw1+Cw0)/(h1-h2)

- The axial thrust on the wheel is due to difference between the velocities of flow at entrance and outlet.

Axial force on the wheel= Mass of steam x axial acceleration= $m(Cf1_1\text{-}Cf2)$

The axial force on the wheel must be balanced or must be taken by a thrust bearing.

Energy converted to heat by blade friction

= Loss of kinetic energy during flow over blades

$=m(Cr1^2\text{-}Cr0^2)$

- Blade velocity coefficient

...(3.44)

In an impulse turbine, if friction is neglected the relative velocity will remain unaltered as it passes over blades. In practice the flow of steam over the blades is resisted by friction. The effect of the friction is to reduce the relative velocity of steam as it passes over the blades. In general, there is a loss of 10 to 15 per cent in the relative velocity. Owing to friction in the blades, Cr, is less than C, and we may write

$Cr_1 = K.\ Cr_1$

Where K is termed as blade velocity coefficient

Steam Turbine Governing

The objective of governing is to keep the turbine speed fairly constant irrespective of load.

The principal methods of steam turbine governing are as follows:

- Throttle governing
- Nozzle governing
- By-pass governing
- Combination of 1 and 2 and 1 and 3.

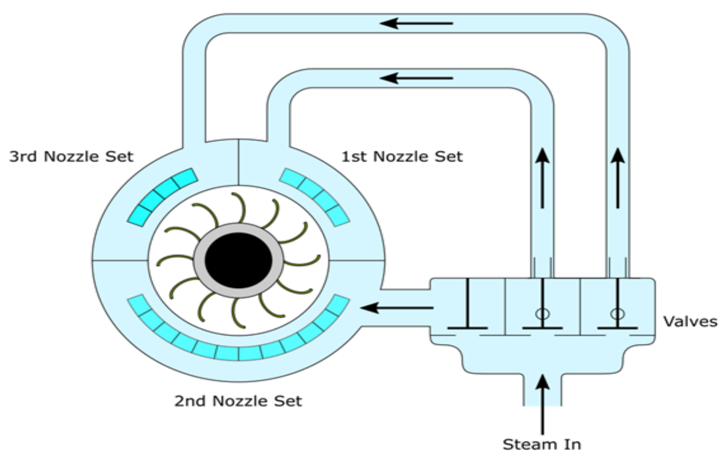
Throttle governing :

Throttle governing is the most widely used particularly on small turbines, because its initial cost is less and the mechanism is simple. The object of throttle governing is to throttle the steam, whenever, there is a reduction of load compared to economic or design load for maintaining speed and vice versa.

Fig. shows a simple throttle arrangement. To start the turbine for full load running valve A is opened. The operation of double beat valve B is carried out by an oil servomotor which is controlled by a centrifugal governor. As the steam turbine gains speed the valve B closes to throttle the steam and reduces the supply to the nozzle.

Nozzle governing

The efficiency of a steam turbine is considerably reduced if throttle governing is carried out at low loads. An alternative, and more efficient form of governing is by means of nozzle control. Fig. 3.100 shows a diagrammatic arrangement of typical nozzle control governing. In this method of governing, the nozzles are grouped together 3 to 5 or more groups and supply of steam to each group is controlled by regulating valves. Under full load conditions the valves remain fully open.



When the load on the turbine becomes more or less than the design value, the supply of steam to a group of nozzles may be varied accordingly so as to restore the original speed.

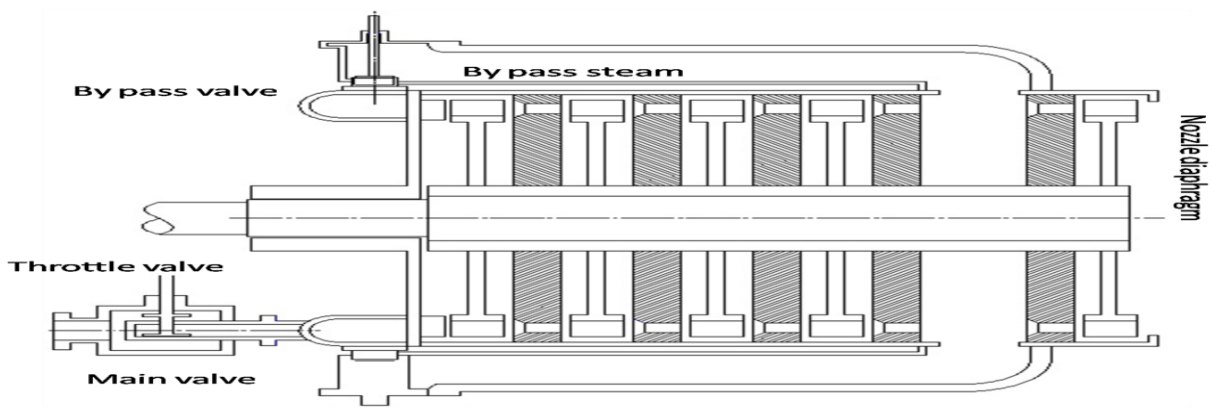
Nozzle control can only be applied to the first stage of a turbine. It is suitable for simple impulse turbine and larger units which have an impulse stage followed by an impulse-reaction turbine. In pressure compounded impulse turbines, there will be some drop in pressure at entry to second stage when some of the first stage nozzles are cut out.

By-pass governing :

The steam turbines which are designed to work at economic load it is desirable to have full admission of steam in the high pressure stages. At the maximum load, which is greater than the economic load, the additional steam required could not pass through the first stage since additional nozzles are not available.

By-pass regulation allows for this in a turbine which is throttle governed, by means of a second by-pass valve in the first stage nozzle . This valve opens when throttle valve has opened a definite amount. Steam is by-passed through the second valve to a lower stage in the turbine. When by-pass valve operates it is under the control of the turbine governor. The secondary and tertiary supplies of steam in the lower stages increase the work output in these stages.

In reaction turbines, because of the pressure drop required in the moving blades, nozzles control governing is not possible, and throttle governing plus by-pass governing, is used.



Steam condensers

Steam condensers are devices in which the exhaust steam from the steam turbine is condensed by means of cooling water. Condensation can be done by removing heat from exhaust steam using circulating cooling water. During condensation, the working substance (steam) changes its phase from vapour to liquid and rejects latent heat.

The primary object of a condenser is to maintain a low pressure on the exhaust side of the rotor of steam turbine. This enables the steam to expand to a greater extent which results in an increase in available energy for conversation into mechanical work.

The secondary object of condenser is to supply to the boiler pure and hot feed water, as the condensed steam which is discharged from the condenser and collect in a hot well can be used over again as feed water for the boiler.

The use of a condenser in a power plant is to improve the efficiency of the power plant by decreasing the exhaust pressure of the steam below atmospheric pressure.

Another advantage of the condenser is that the steam condensed may be recovered to provide a source of pure feed water to the boiler and reduce the water softening capacity to a considerable extent.

- **Advantages of a condenser in a steam power plant**

The main advantages of incorporating a steam condenser in a steam power plant are as follows:

• It increases the efficiency of the power plant due to increased enthalpy drop.

• It reduces back pressure of the steam which results in more work output.

• It reduces temperature of the exhaust steam which also results in more work output.

• The condensed steam can be reused as feed water for boiler which reduces the cost of power generation.

• The temperature of the condensate is higher than that of the fresh water which reduces the heat supplied per Kg of steam produced.

- **Function of condenser**

The main function of condenser is to convert gaseous form of exhaust steam into liquid form at a pressure of below atmosphere. Cooling medium is used water to convert steam into water. Others important functions of condensers:

• Function of the condenser is to create a vacuum by condensing steam

• Remove dissolved non - condensable gases from the condensate.

• Providing a leak tight barrier between the high grade condensate contained within the shell and the untreated cooling water.

➢ Providing leak tight barrier against air ingress, preventing excess back pressure on the turbine.

Elements of a steam condensing plant

The main elements of a steam condensing plants are:

• A condenser in which the exhaust steam is condensed

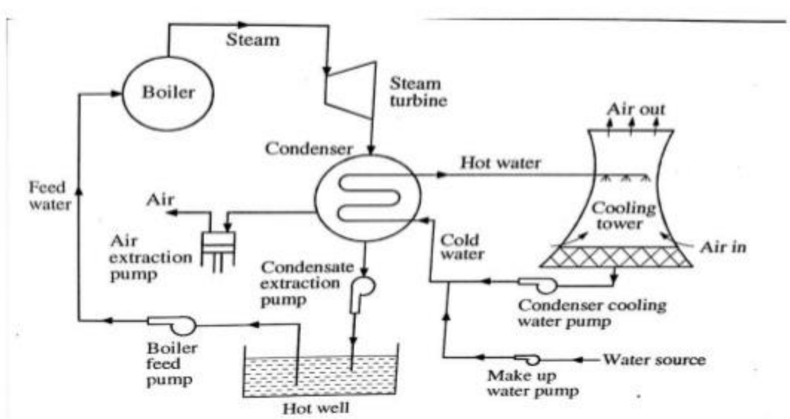
• Supply of cooling water for condensing exhaust steam

• A pump to circulate the cooling water in case of a surface condenser

• A pump called the wet air pump to remove the condensed steam (condensate) the air, and uncondensed water vapour and gases from the condenser (separate pump may be used to remove air and condensed steam)

• A hot well where the condensed steam can be discharged and from which the boiler feed water is taken
• An arrangement (cooling pond or cooling tower) for cooling the circulation water when a surface condenser is used and the supply of water is limited

Steam condensing plant



Types of condensers

The steam condensers are classified as follows:

1. Jet condensers (mixing type condensers)

a. Parallel flow jet condenser

b. Counter flow jet condenser (low level)

c. Barometric or high level jet condenser

d. Ejector condenser

2. Surface condensers (non mixing type condensers)

a. Down flow surface condenser

b. Central flow surface condenser

c. Regenerative surface condenser

d. Evaporative condenser

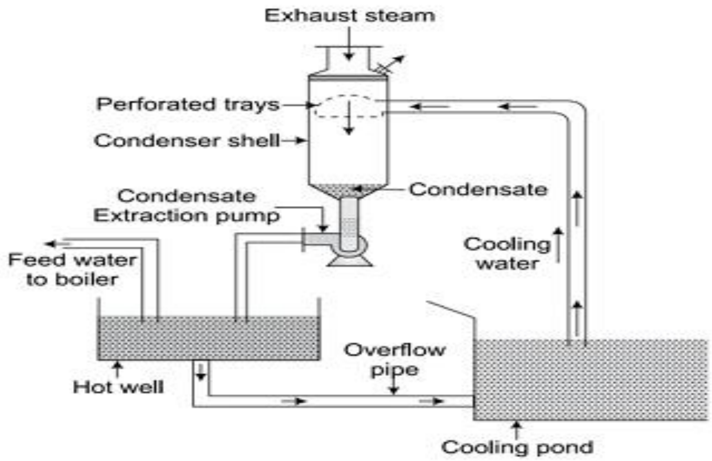
- . In jet condensers, the exhaust steam and water come in direct contact with each other and temperature of the condensate is the same as that of cooling water leaving the condenser. The cooling water is usually sprayed into the exhaust steam to cause rapid condensation.
- In surface condensers, the exhaust steam and water do not come into direct contact. The steam passes over the outer surface of tubes through which a supply of cooling water is maintained. There may be single-pass or double-pass. In single-pass condensers, the water flows in one direction only through all the tubes, while in two-pass condenser the water flows in one direction through the tubes and returns through the remainder.
- A jet condenser is simpler and cheaper than a surface condenser. It should be installed when the cooling water is cheaply and easily made suitable for boiler feed or when a cheap source of boiler and feed water is available. A surface condenser is most commonly used because the condensate obtained is not thrown as a waste but returned to the boiler.

Jet condenser-

(i) **Parallel flow jet condenser**

In parallel flow jet condenser both the steam and the water enters from the top and flows in the same direction as shown in Figure .

The exhaust steam is condensed when it mixes up with water. The condensate and the cooling water are delivered to the hot well from where surplus water flows to the cooling pond through an overflow pipe. Sometimes a single pump know as wet air pump is used to remove both air and the condensate but generally separate air pump is used to remove air as it gives a great vacuum.

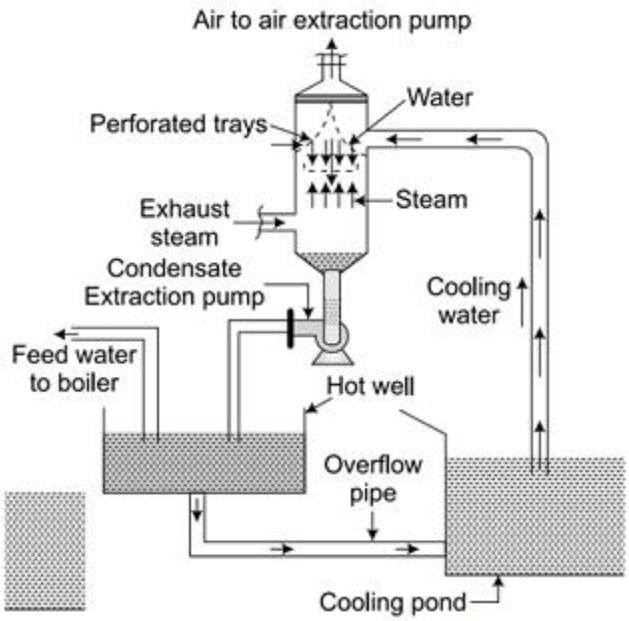


Parallel Flow Jet Condenser

(ii) **Counter flow or low level jet condenser**

In counter flow or low level jet condenser, the exhaust steam enters from bottom and mixes with the down coming cooling water as shown in Figure .

The air pump mounted at the top of the condenser shell creates vacuum as it suck air. This draws the supply of cooling water which falls from a large number of jets through perforated conical plate. The water then falls in the trays and flows through second series of jets and mixes with the exhaust steam entering at the bottom. This cause rapid condensation after which the condensate and the cooling water are delivered to the hot well by the condensate extraction pump.



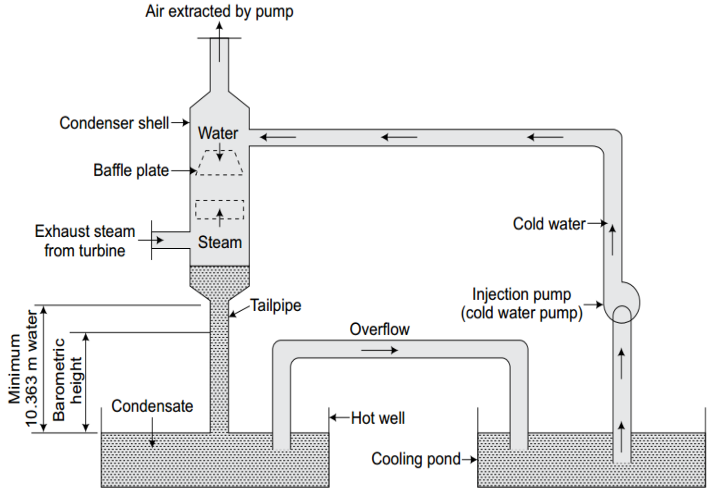
Counter Flow Jet Condenser

(iii) **Barometric or high level jet condenser**

This type of condenser is provided at a high level as shown in Figure having a long tail pipe.

The exhaust steam enters from the bottom and flows upwards. This steam then mixes with cooling water which falls from the top through various baffles.

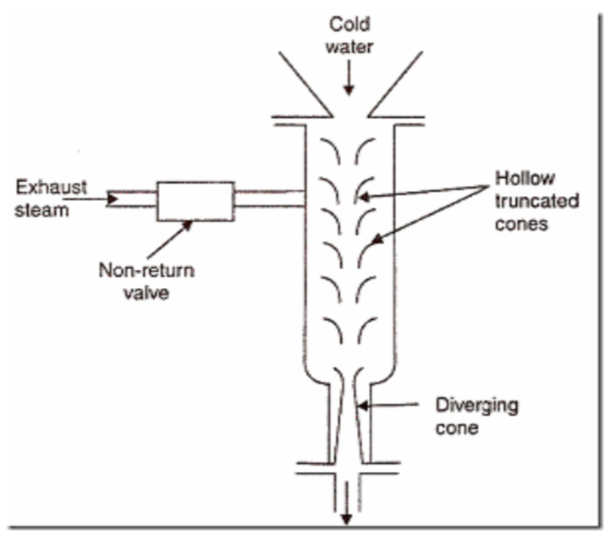
The vacuum is created by the air pump placed at the top of the condenser shell. The condensate and the cooling water flows downwards through a vertical tail pipe to the hot well without the aid of any pump. The surplus water from the hot well flows to the cooling pond through an overflow pipe.



Barometric or High Level Jet Condenser

(iv) **Ejector condenser**

In ejector condenser, the steam and water mix-up while passing through a series of metal cones as shown in Figure . Water enters from the top through a number of guide cones. The exhaust steam enters the condenser through a non return valve. The steam and air then pass through the hollow truncated cones. After that it passes through the diverging cone where its kinetic energy is partly transformed into pressure energy. The condensate and the cooling water are then discharged to the hot well. The high exit pressure in the diverging cone allow discharged of water automatically into the hot well at atmospheric pressure.



(2) **Surface condenser**

In surface condenser, the condensate does not mix up with the cooling water. So the whole condensate can be reused in the boiler. This type of condenser is used where is only limited quantity of fresh water is available like ships..

It consists of a horizontal cylindrical vessel made of cast iron packed with tubes for cooling water. The cooling water flows in one direction through the lower half of the tubes and in opposite direction through the upper half. The water tubes are fixed into vertical perforated type plates at the ends so that leakage of water should not occur into the central condensing space. The steam enters from top end. The extraction pump at the bottom sucks the condensate resulting in the downwards flow of steam over the water tubes.

(i) **Down flow surface condenser**

In down flow surface condenser, the steam enters from the top as shown in Figure . The exhaust steam is forced to flow downwards over the water tubes due to suction of the extraction pump at the bottom. The suction pipe of the dry air pump is provided near the bottom and is covered by a baffle so that the condensed steam does not enter into it. As the steam flow perpendicular to the direction of flow of cooling water, it is also called cross flow surface condenser.

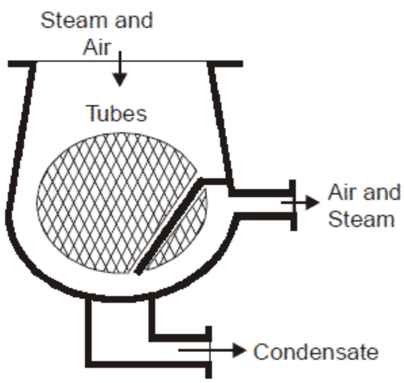


Fig. 1

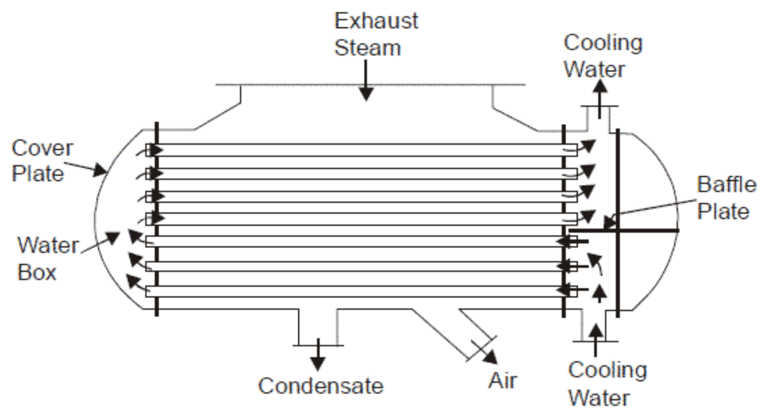
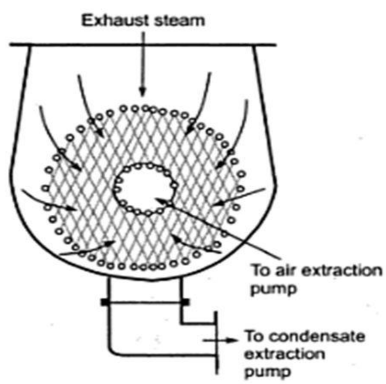


Fig. 2

(ii) **Central flow surface condenser**

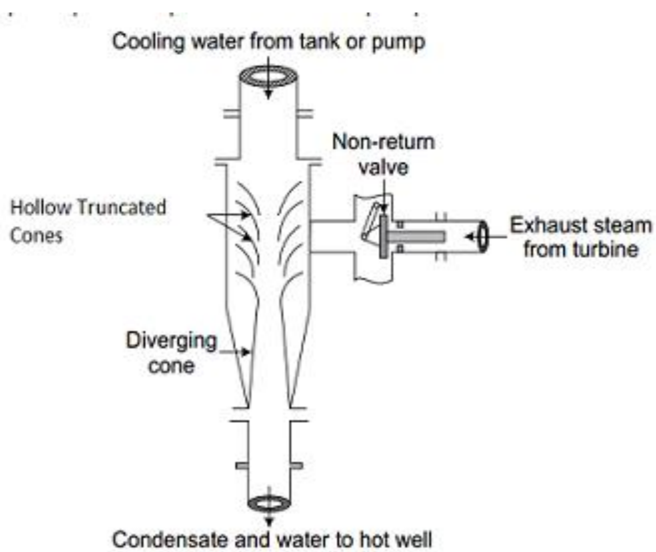
In this type of surface condenser the suction pipe of the air extraction pump is placed in the center of the tube nest as shown in Figure 7. The exhaust steam from turbine enters from the top and flows radially inwards over the tubes. The condensate is collected at the bottom. The advantage of central flow type surface condenser over the down flow type is that the steam flows over the whole periphery of the water tubes as the steam flows radially inwards.

Central flow surface condenser



(iii)**Evaporative condenser**

In evaporative condenser the steam flows enters the gilled pipes and flows backwards and forwards in a vertical plane as shown in Figure . The water pump sprays water on the pipes which condenses the steam. The main advantage of this type of condenser is that the quantity of cooling water needed to condense the steam can be reduced by causing the circulating water to evaporate which decrease the temperature. The remaining water is collected in the cooling pond.



Ejector Condenser

Cooling tower

Cooling pond

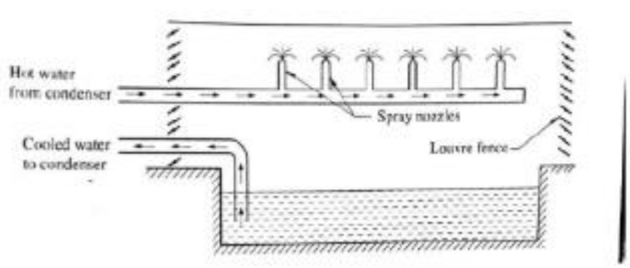
The simplest system of removing heat from the cooling water consists of cooling it in an open pond. The effectiveness of this method depends upon a very long surface area of the pond and hence it is used mostly for small condenser only. In this system sufficient amount of water is lost by evaporation and windage. The factors which affect the rate of heat dissipation from cooling pond are area and depth of pond, temperature of water entering the pond and wind velocity, atmospheric temperature, shape and size of water spray nozzle and relative humidity.

Cooling ponds are of two types namely: 1. Non directed flow type 2. Direct flow type

Spray pond

For a given cooling capacity, the size of pond in this case is much less than that of open pond. Hot water coming out from power plant is sprayed into the atmosphere, through many nozzles. Tiny particles of sprayed water loose the sensible heat to air and get cooled and are finally collected into a reservoir from which cold water is supplied to the power plant for reuse. In this case cooling achieved is more effective.

Spray pond with louver fence



Cooling towers

The place where acquisition of land is very expensive, we may use cooling tower for cooling purposes. A cooling tower requires smaller area than a spray pond. It is an artificial device used to cool the hot cooling water coming out of condenser effectively. The cooling tower is a semi – enclosed device made of steel or concrete structure and corrugated surfaces or trough or baffles are provided inside the tower for uniform distribution and better atomization of water in the tower. The hot water coming out from the condenser falls down in radial sprays from height and the atmospheric air enters from the base of the tower. The partial evaporation of water takes place which reduces the temperature of circulating water. This cooled water is collected in the pond at the base of the tower and pumped into the condenser. Draft eliminators are provided at the top of the tower to prevent the escaping of water particles with air.

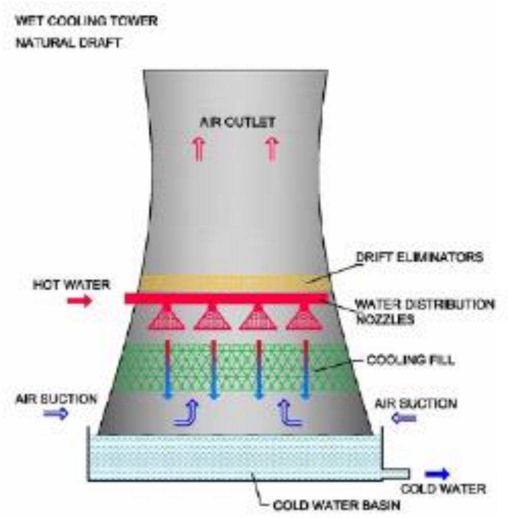
According to the method of air circulation, cooling towers are classified as:

1. Natural draught type cooling tower

2. Mechanical draught type cooling tower a. Forced draught type b. Induced draught type

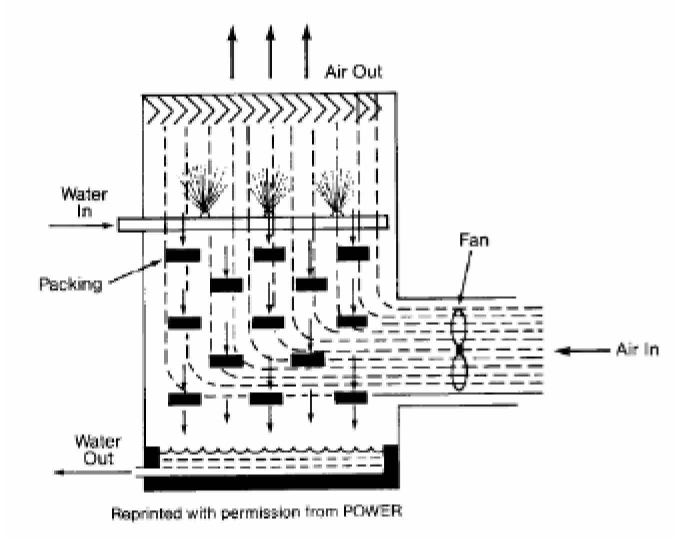
Natural draught type cooling tower

In this hot water from condenser is pumped at the top where water sprays through a series of spray nozzles. Then waterfalls over decks, the decks also increase the amount of wetted surface in the tower and breaks up the water into droplets. The air flowing across in transverse direction cools the falling water. These towers are used for small capacity power plants such as diesel power plants.



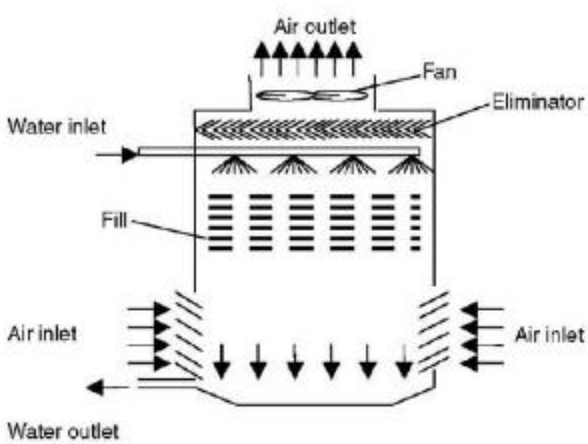
Forced draught cooling tower

In this tower draught air fan is installed at the bottom of tower. The hot water from the condenser enters the nozzles. The water is sprayed over the tower filling slats and the rising air cools the water. The entrained water is removed by eliminators located at the top.

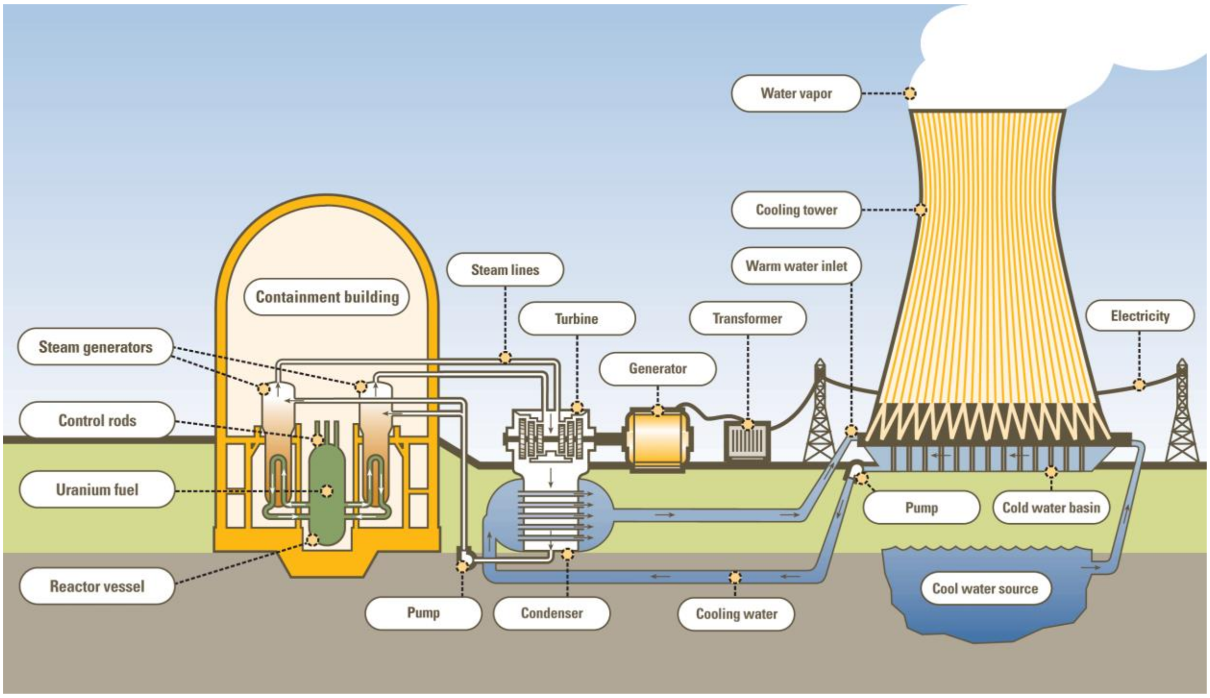


Induced draught cooling tower

The difference here is in the supply of air. The drought fans installed at the top of tower draw air thought the tower. The hot water is allowed to pass thought the tower bellow the eliminators. The air moving in the upward direction cools the down coming hot water particles issued from spray nozzles some percentage (1%) of total water goes into air in the form of water vapour.



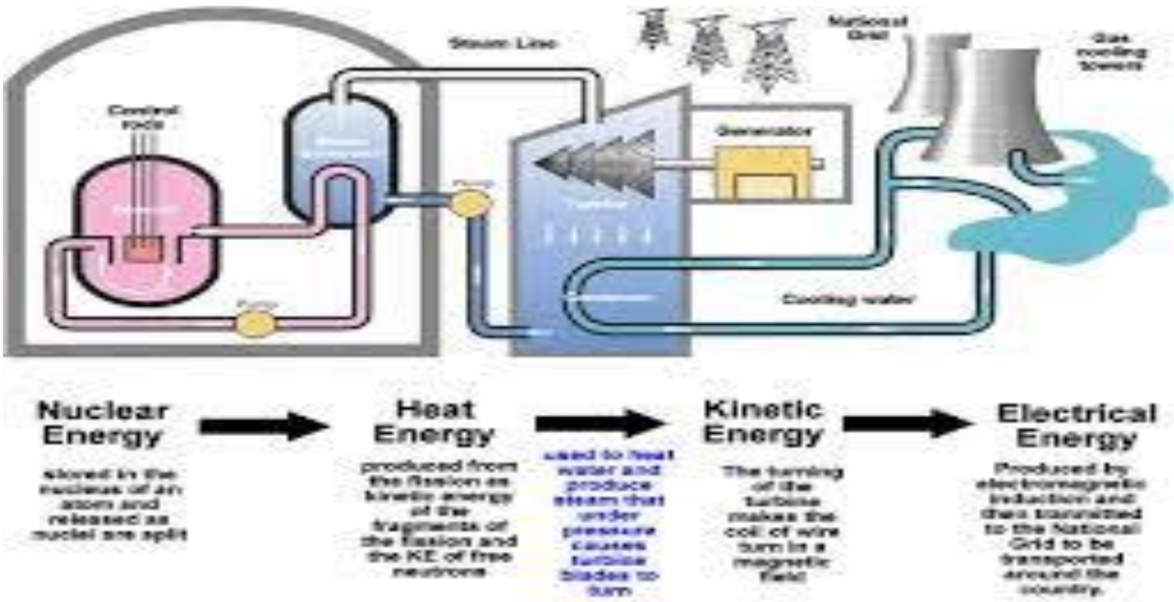
NUCLEAR POWER PLANT



Definition of Nuclear Power Plant:

The Power Plant which converts the nuclear energy of radioactive material into Electrical Energy is known as Nuclear Power Plant.

Basic Principle of Nuclear Power Plant:



Nuclear material:

1.fissile material
2.fertile material

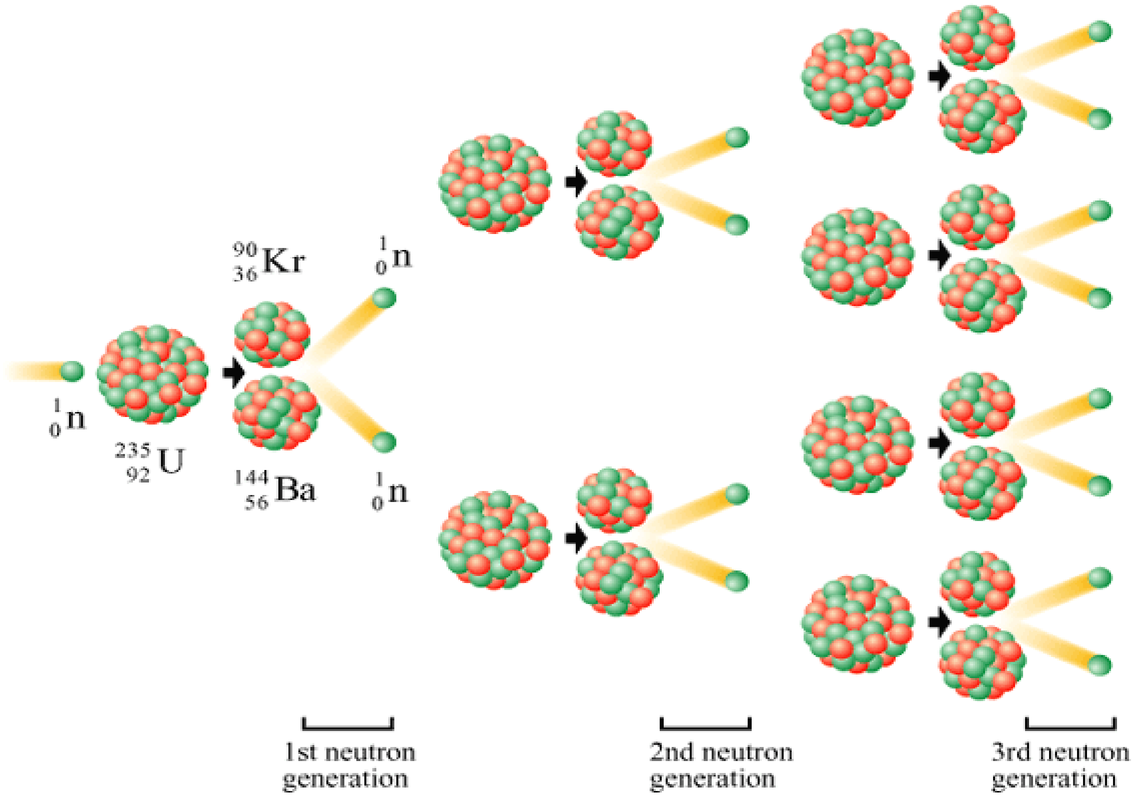
Fissile material:

it is a material that is capable of undergoing of fission reaction after absorbing thermal neutron.
Fissile materials undergo fission reaction after absorption of the binding energy of thermal neutron.they do not require additional kinetic energy for fission.
Fissile material consists of fissionable isotopes that are capable of undergoing nuclear fission only after capturing a thermal neutron.
Example-U235,U233,PU239,PU241

Fertile material:

it has been found that some materials are not fissionable by themselves but they can be converted to the fissionable materials,these are known as fertile material.
Example-u238,th232

Nuclear chain reaction:



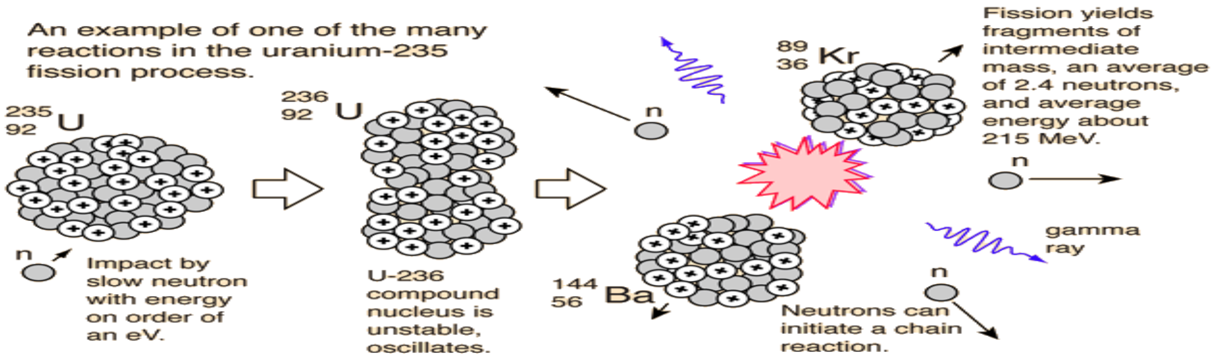
NUCLEAR CHAIN REACTION

A chain reaction is that process in which the number of neutrons keeps on multiplying rapidly during fission till whole of the fissionable material is disintegrated.the chain reaction will become self sustaining or self propagating only if,for every neutron absorbed ,at least one fission neutron becomes available for causing fission of another nucleus.this condition can be expressed in the form of multiplication factor(k) of the system.

K=no of neutrons in any particular generation/no of neutrons in the preceding generation

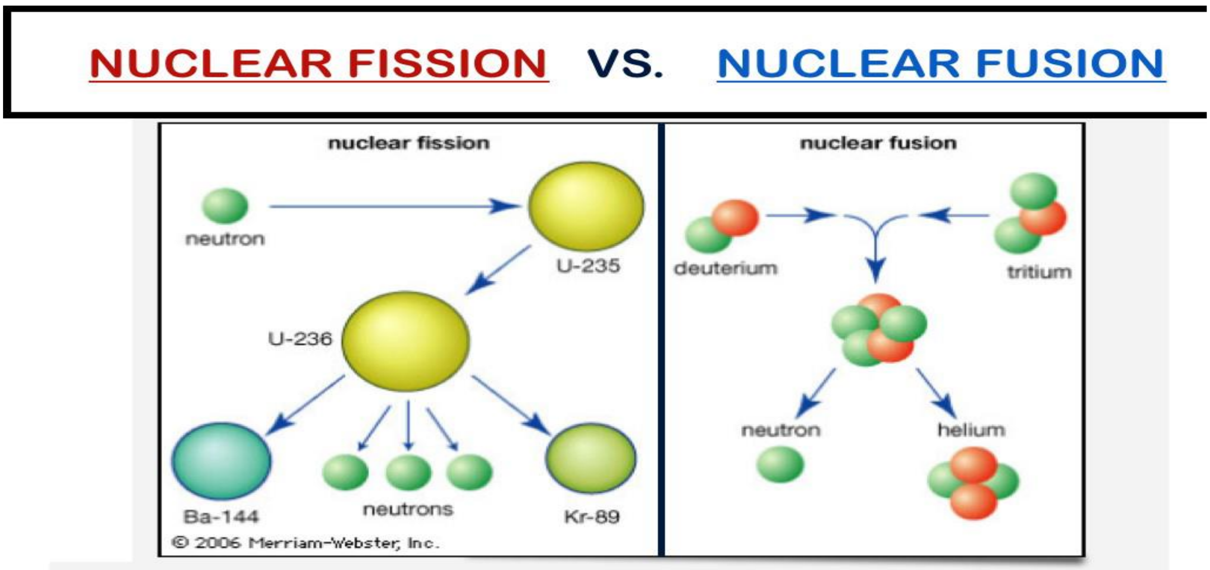
If k >1 chain reaction will continue

K<1 chain reaction can not be maintained.



Nuclear fission: when the nucleus is excited too much ,it splits into two mostly equal masses.this particular reaction is suited only to the heavy nucleus such as U235,U233 AND Pu239etc.this transformation is known as fission.

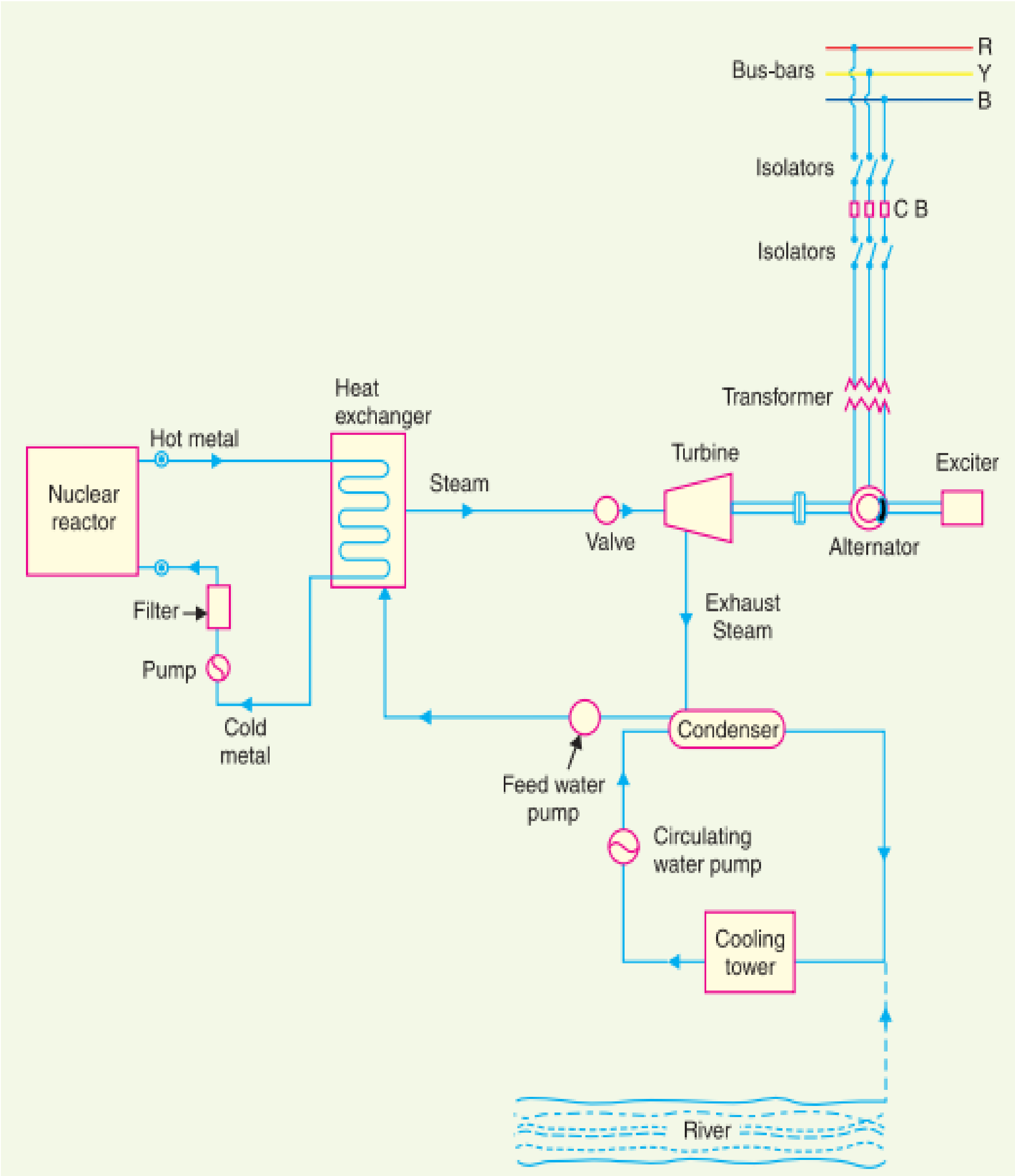
Nuclear Fusion: it is the process of making a single heavy nucleus from two lighter nuclei which releases large amount of energy.

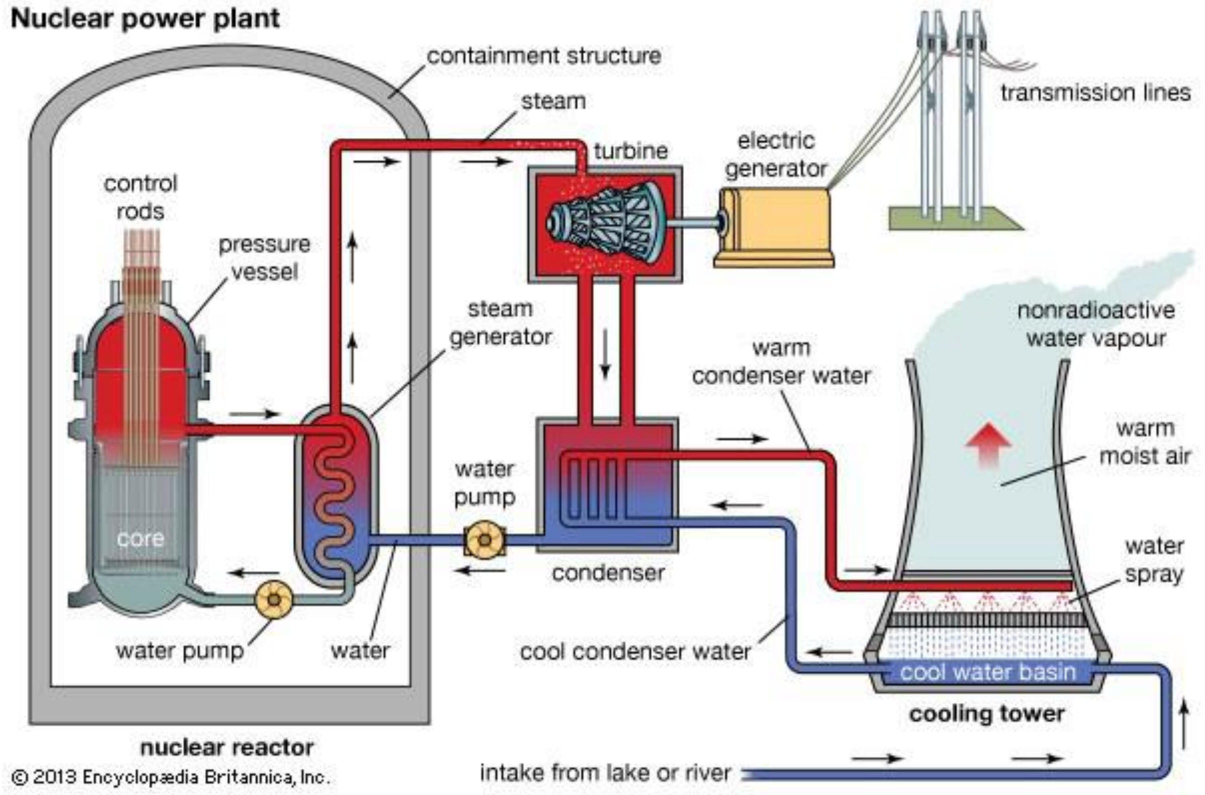


Top: Uranium-235 combines with a neutron to form an unstable intermediate, which quickly splits into barium-144 and krypton-89 plus three neutrons in the process of nuclear fission. Bottom: Deuterium and tritium combine by nuclear fusion to form helium plus a neutron.

NUCLEAR FISSION	NUCLEAR FUSION
A heavy nucleus breaks up to form two lighter nuclei.	Two light nuclei combine to form a heavy nucleus.
It involves a chain reaction.	Chain reaction is not involved.
The heavy nucleus is bombarded with neutrons.	Light nuclei are heated to an extremely high temperature.
We have proper mechanisms to control fission reaction for generating electricity.	Proper mechanisms to control fusion reaction are yet to be developed.
Disposal of nuclear waste is a great environmental problem.	Disposal of nuclear waste is not involved.
Raw material is not easily available and is costly.	Raw material is comparatively cheap and easily available.

Schematic Arrangement of Nuclear Power Plant

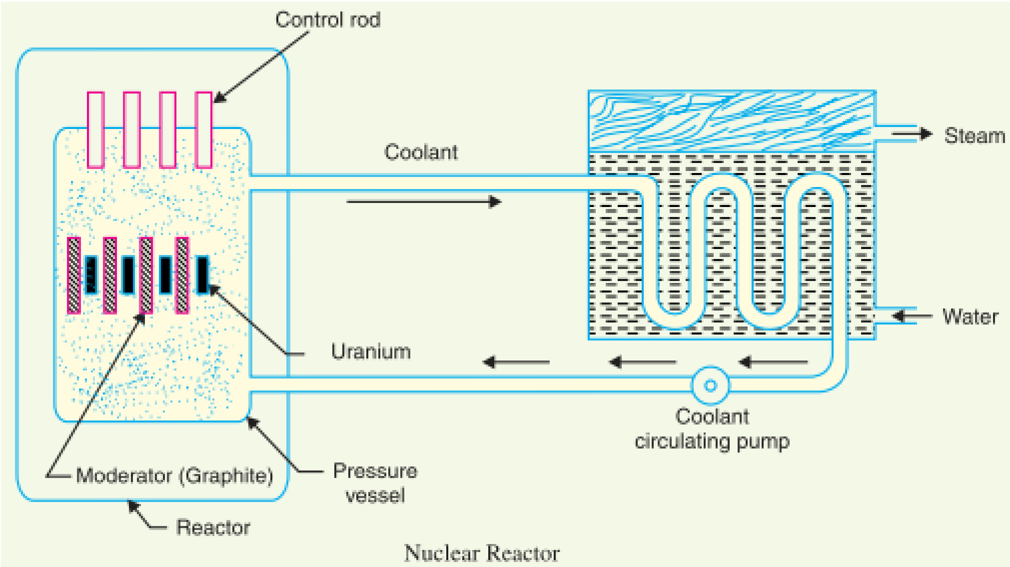




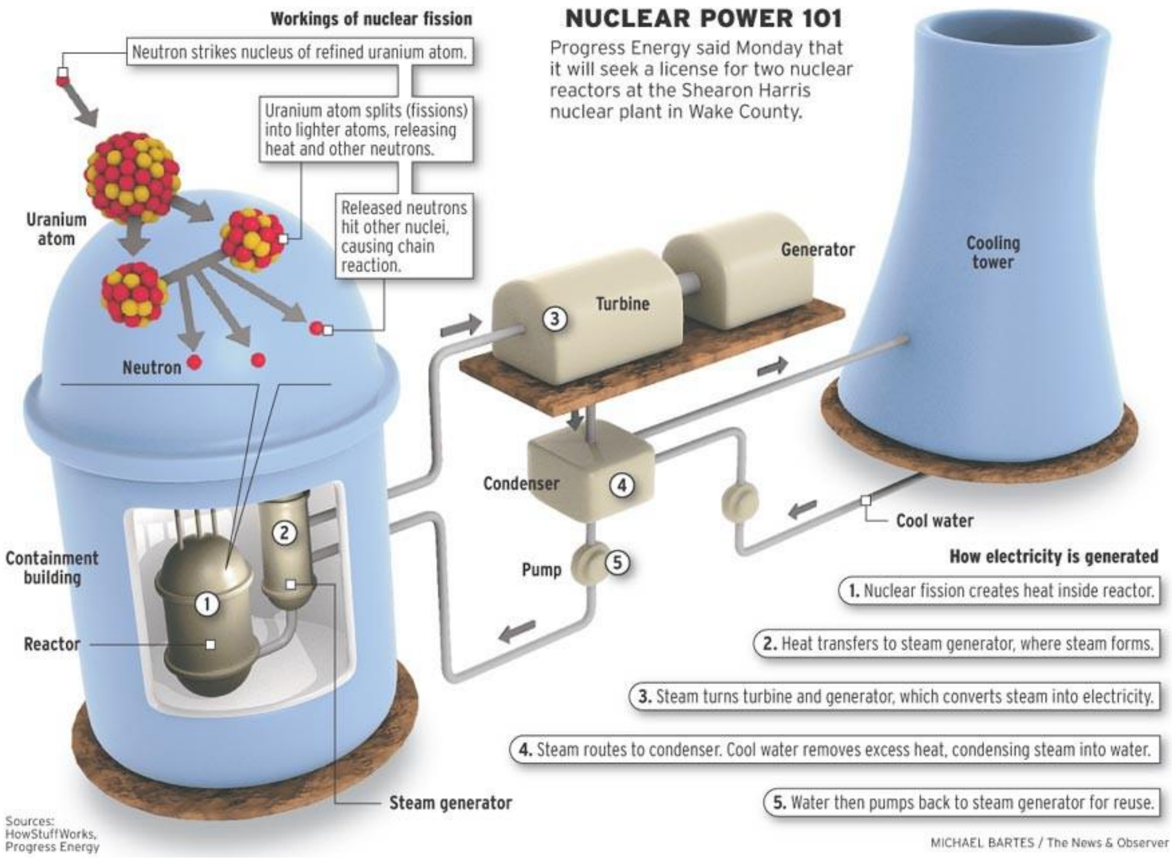
The above figure shows, the schematic arrangement of nuclear power plant. Every nuclear power plant consists of following main parts, which are mentioned below:

1. Nuclear Reactor
2. Heat Exchanger
3. Steam Turbine
4. Condenser & Cooling Tower
5. Feed Water Heater

NUCLEAR REACTOR



Nuclear Reactor



3D View of Nuclear Reactor

Main Parts & Its Explanation of Nuclear Reactor:

1. Fuel rods
Hundreds of 12-foot uranium rods undergo a fission reaction, releasing substantial heat.

2. Reactor
A steel pressure vessel contains the uranium rods, surrounding water and other reactor components.

3. Control rods
Operators can speed up or slow down the fission reaction by raising and lowering neutron-absorbing rods between the fuel rods.

4. Pump
A water pump keeps water circulating, which transfers heat away from the reactor core.

5. Pressuriser
The pressuriser contains water, air, and steam. By adding or releasing air in the pressuriser, operators can control the pressure of the coolant water around the reactor.

6. Heat exchanger
A pipe carries hot water from the reactor to a separate reservoir of water.

7. Steam generator
The hot pipe leading from the reactor heats a separate reservoir of water to the boiling point, generating steam.

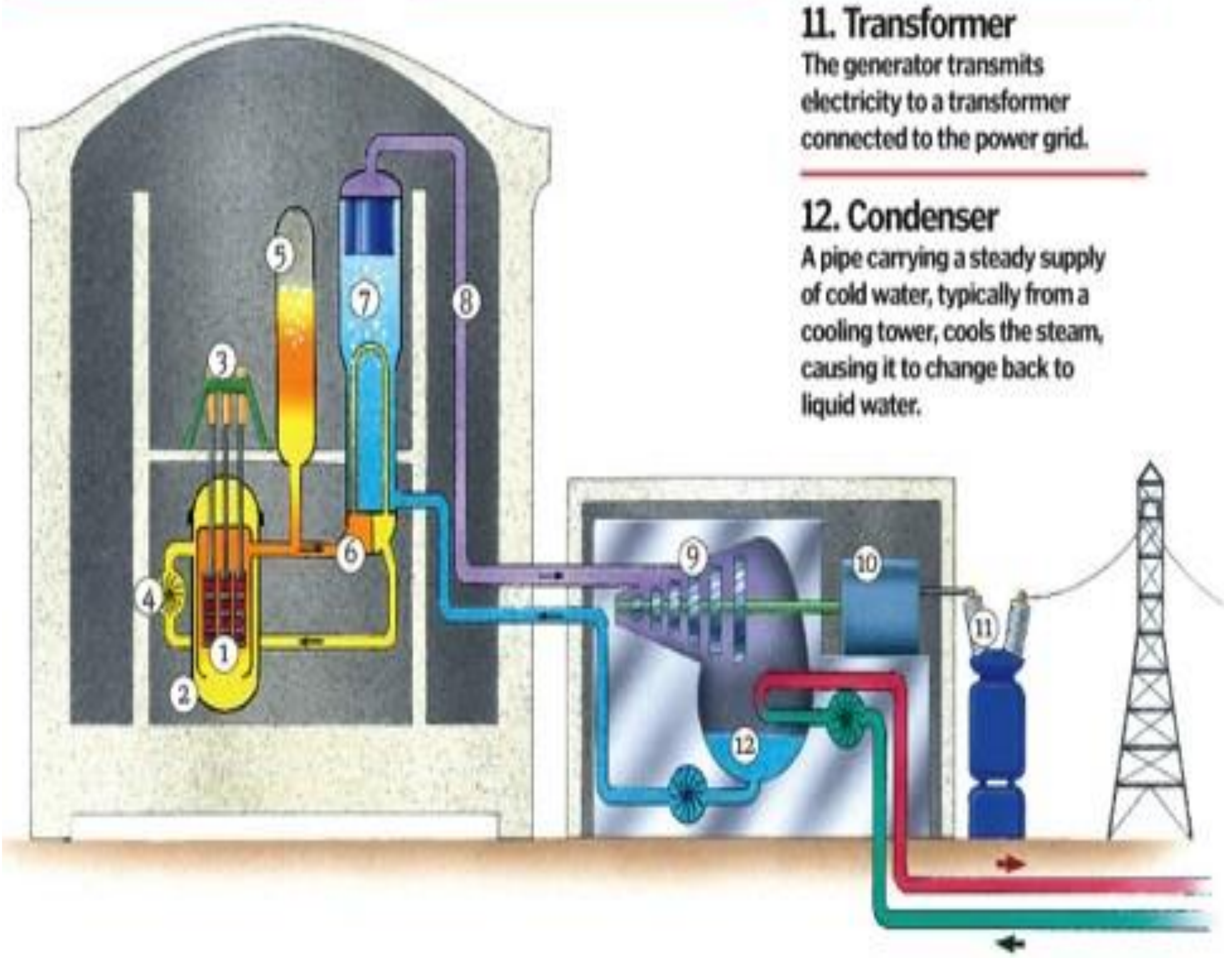
8. Steam line
Steam travels from the steam generator to the turbine.

9. Turbine
Rushing steam spins the turbine.

10. Generator
The turbine spins a rotor that sits in a magnetic field in a generator, inducing an electric current.

11. Transformer
The generator transmits electricity to a transformer connected to the power grid.

12. Condenser
A pipe carrying a steady supply of cold water, typically from a cooling tower, cools the steam, causing it to change back to liquid water.



Essential components of Nuclear Reactor:

1. reactor core
2. Reflector
3. Control mechanism.
4. Moderator
5. coolants
6. measuring instruments
7. shielding

1.reactor core:

The reactor core is that part of a nuclear power plant where fission chain reaction is made to occur and where fission energy is liberated in the form of heat for operating power conversion equipment.the core consists of fuel elements,control rods,coolant and moderator.it has generally a shape to a right circular cylinder with diameter ranging from 0.5m to 15m.the fuel elements are made of plates or rods of uranium metal.

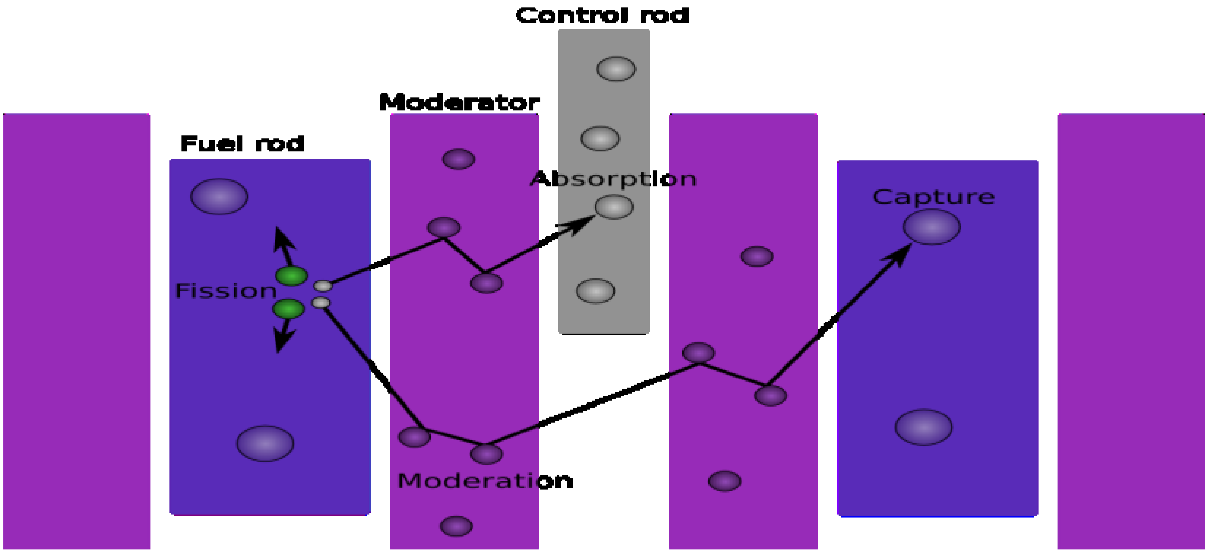
2. Reflector:

A reflector is placed round the core to reflect back some of the neutrons that leak out from the surface of the core.it is generally made of the same material as moderator.

3.control mechanism:

It is essential part of the reactor and serves the following purposes.
1.for starting the reactor
2.for maintaining at that level
3.for shutting the reactor down under normal and emergency condition.

4 .MODERATOR



The function of moderator is to slow down the neutrons from the high velocities which have been released from the fission process.neutrons are slowed down most effectively in scattering collisions with nuclei of the light elements such as hydrogen ,graphite,beryllium etc.it does not absorb the neutrons.

5.coolant

The function of coolant is to remove the intense heat produced in the reactor and to bring out for being utilised.

6.measuring instruments:

It is used to measure the thermal neutron flux which determines the power developed by the reactor.

7.shielding:

Shielding is necessary to protect the walls of the reactor vessel from radiation damage and also to protect the operating personnel from exposure of radiation.

10. Types of Nuclear Reactor:

The nuclear reactors are classified into four types. These are mentioned below:

1. Pressurised Water Reactor (PWR).
2. Boiling Water Reactor (BWR).
3. Advanced Gas Cooled Reactor (AGCR).
4. Fast Breeder Reactor (FBR).

1. PRESSURISED WATER REACTOR (PWR).

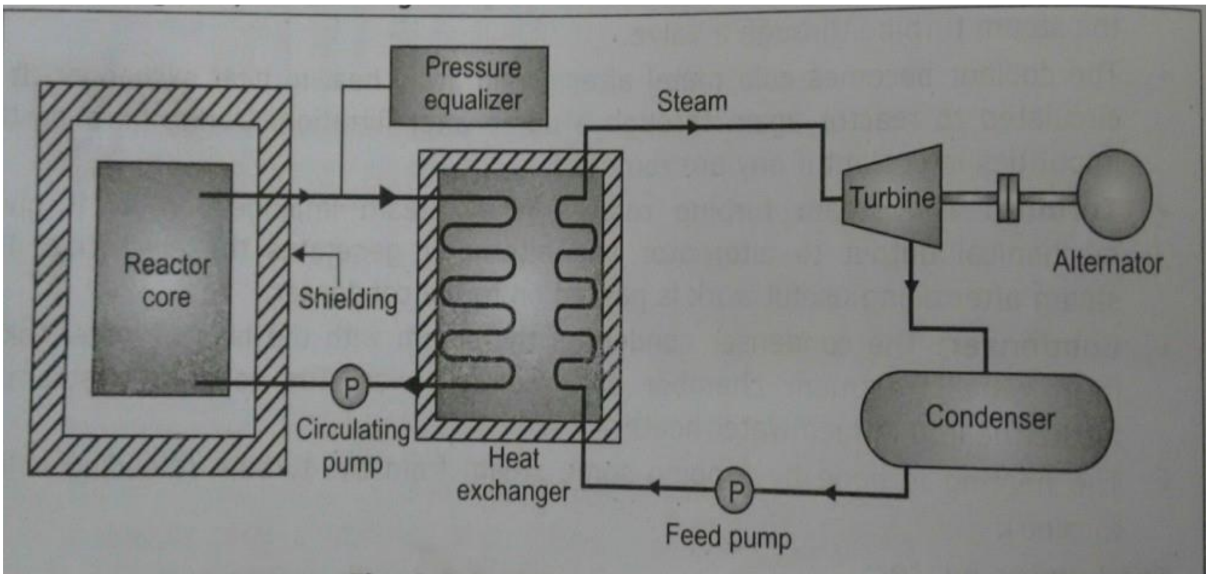
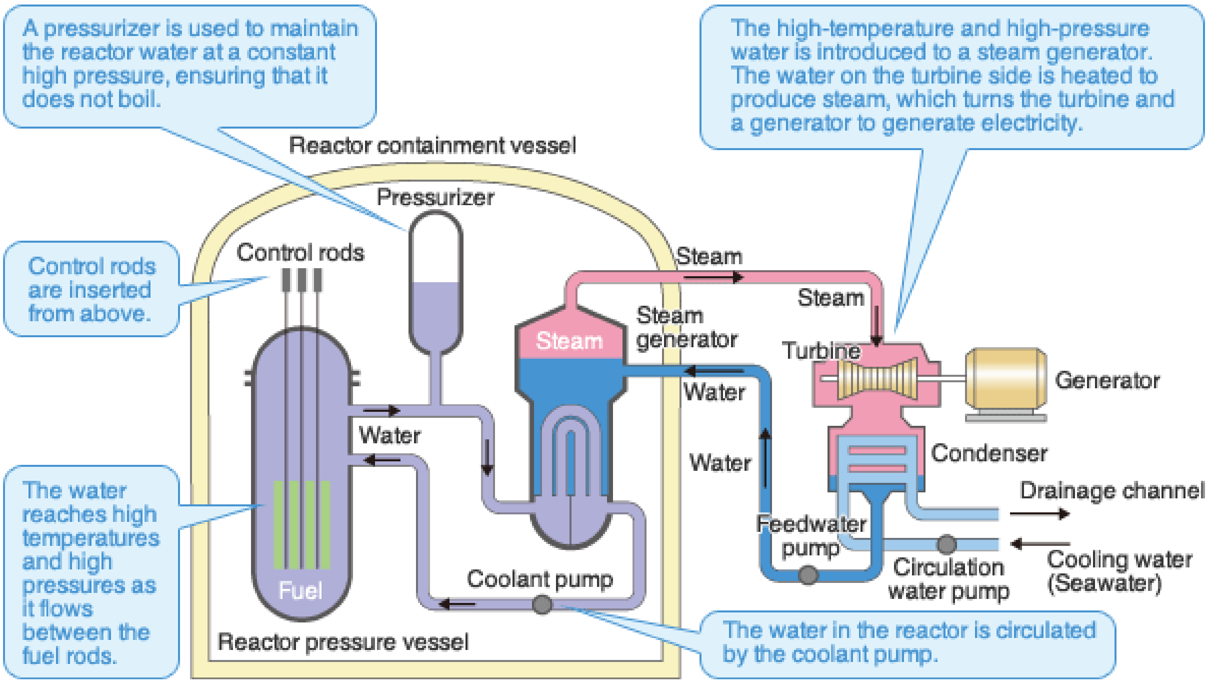


Fig. 4.4: Pressurised water reactor

Pressurized water reactor (PWR)

The interior of the reactor is maintained at a high pressure to prevent water from boiling despite its high temperature; a steam generator produces steam using water other than the water flowing inside the reactor.



In PWR there are two circuits of water ,one primary circuit which passes through the fuel core and is radioactive.this primary circuit then produces steam in a secondary circuit which consists of heat exchanger or the boiler and the turbine.the steam in turbine is not radioactive so it need not be shielded.the pressure in the primary circuit should be high so that the boiling of water takes place at high pressure.electric heating coils in the pressuriser boils some of the water to form steam tha is collected in the dome.as more steam is forced into the dome by boiling its pressure rises and pressurises the entire circuit.the pressure may be reduced by providing cooling coils or spraying water on the steam.water acts both as coolant as well as moderator.either heavy water or the light water may be used for the above purpose.a pressurised water reactor can produce only saturated steam.by providing a separate fournace the steam formed from the reactor can be superheated.

ADVANTAGES:

1.water used in reactor is cheap and easily available.
2.the reactor is compact and power density is high.
3.fission products are not circulated.
4.a small no of control rods are required.
5.easy inspection.
6.fuel cost is reduced by extracting more energy per unit weight of fuel.

DISADVANTAGES:

1.capital cost is high.
2.reprocessing of fuel is difficult because it suffers radiation damage.
3.corrosion problems.
4.fuel element fabrication is expensive.
5.in the secondary circuit the thermodynamic efficiency is low.

2. BOILING WATER REACTOR (BWR)

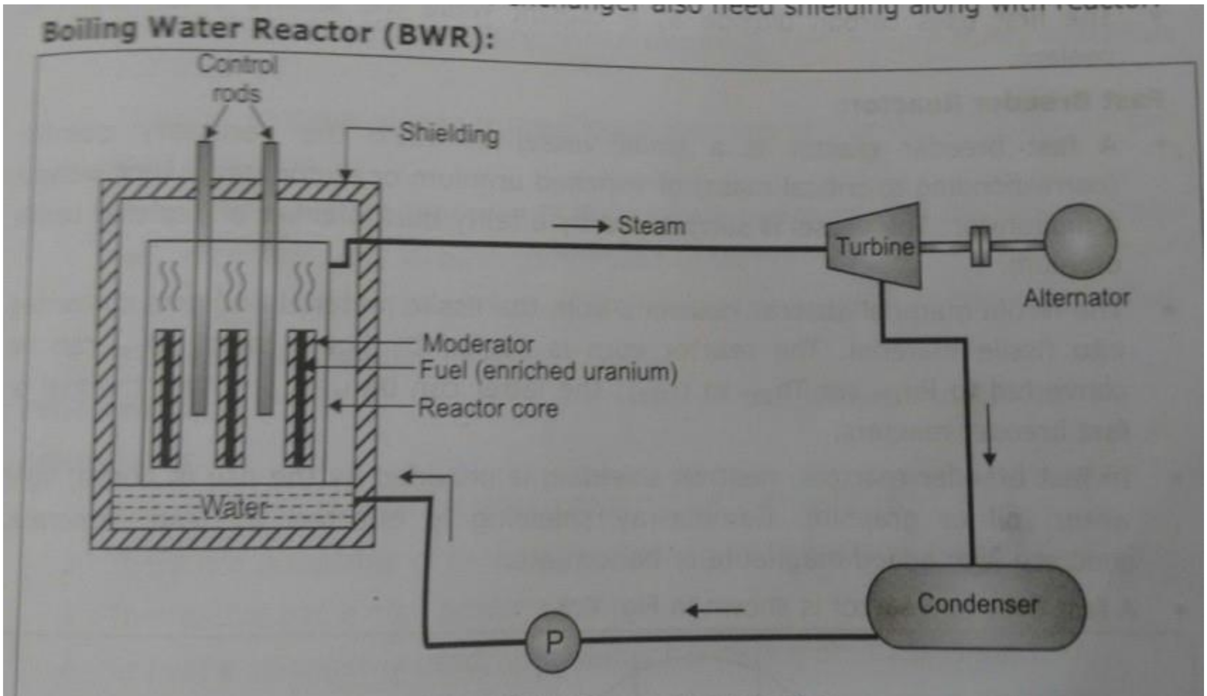
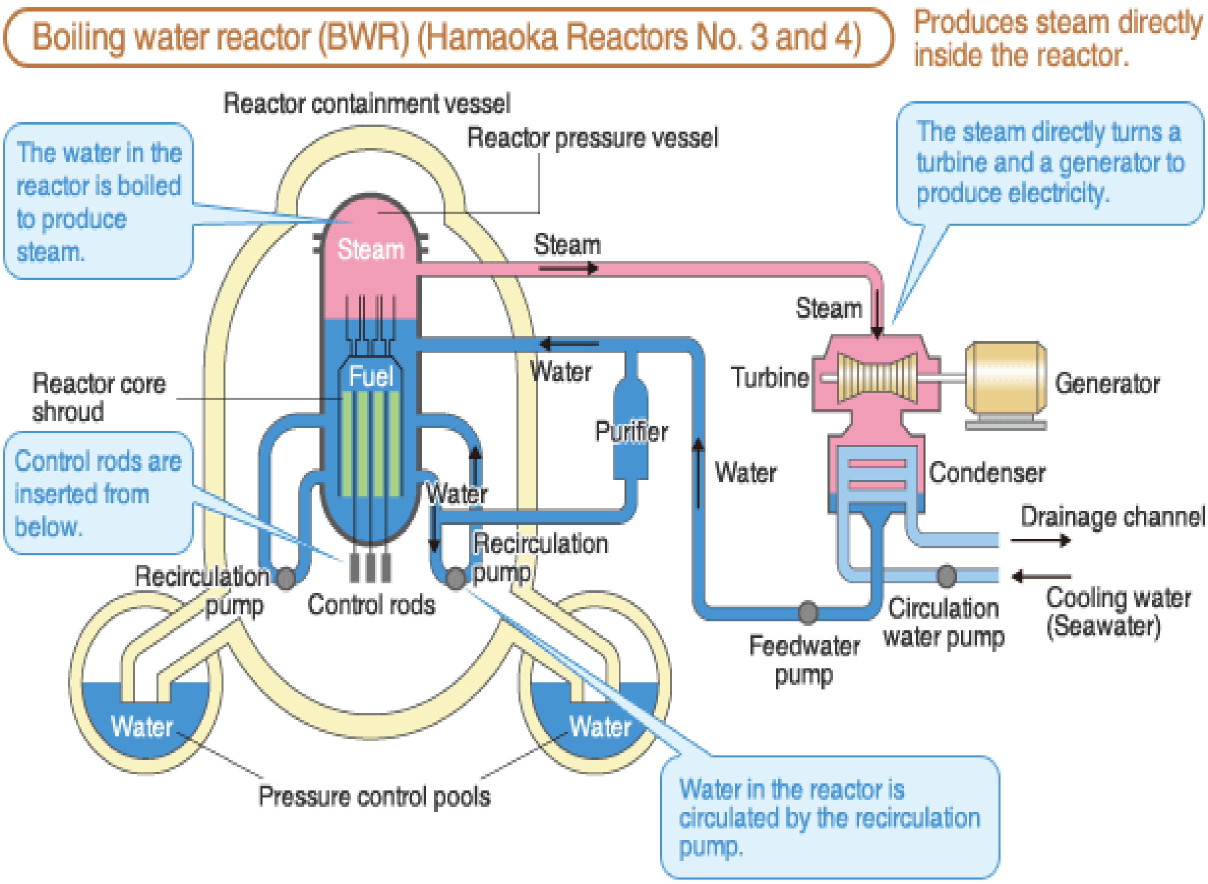


Fig. 4.5: Boiling water reactor



In BWR, the enriched uranium fuel is used in reactor. In this type of reactor water is directly passes to the bottom of reactor core. When the chain reaction starts, the reactor core produces a heat energy, which produces steam and that goesv to the turbine for generation of power.

As compared to PWR the arrangement of BWR plant is simple.

The plant can be safely operated using natural convection within the core .for the safe operation of the reactor the pressure in the forced circulation must be maintained constant irrespective of the load.

ADVANTAGES:

1.more thermal efficiency.

2.use of lower pressure vessel for the reactor reduces cost.

3.metal temperature remains low for given output condition.

4.the cycle for BWR is more efficient than PWR.

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

DISADVANTAGES:

1.more safety precautions needed which are costly.

2.wastage of steam results in lowering the thermal efficiency on part load operion.

4.the possibility of burn out of fuel is more in this reactor than PWR.

Nuclear Waste Management:

Classification of nuclear (Radioactive) Wastage:

1. Low Level Waste (LLW)
2. Intermediate Level Waste (ILW)
3. High Level Wastage (HLW)

1. LLW (Low Level Waste):

In case of low level waste, the (% Content of Radioactivity) radioactive level is very less. Normally, this type of waste comes from industries, hospitals, small nuclear plant. At the time of handling & transport the low level waste, it does not require shielding. The low level waste are buried in land with suitable depth at the time of disposal.

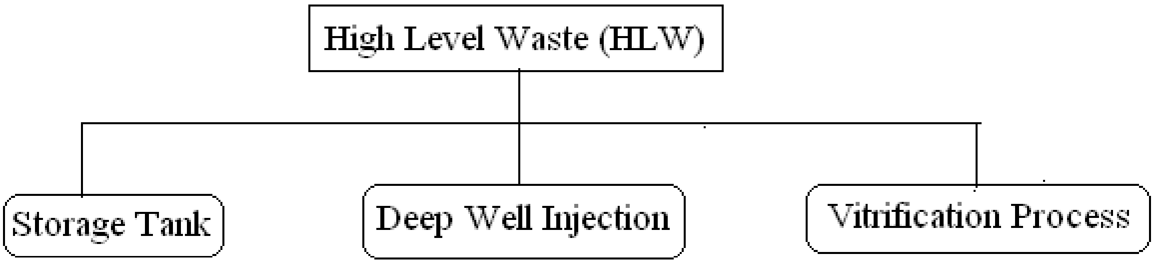
2. ILW (Intermediate Level Waste):

The percentage of radioactivity is higher as compared with low level waste. At the time of handling & transportation shielding is required because it is more radioactive. It will affect the human health. At the time of ILW disposal it is placed in concrete container, after that it is well sealed. Finally the ILW is buried in underground .

3. HLW (High Level Waste):

As compared with LLW & ILW, the HLW is very dangerous to handle . Most of accidents in nuclear power plants are occurred due to this HLW. At the time of handling it requires shielding as well as cooling. The HLW mainly comes from reprocessing of nuclear fuel in the reactor. The HLW is obtained in liquid form & the heat % is very high.

There are three ways to dispose the HLW.



1. With the help of Storage Tank:

The agitator is placed, which is rotating type. In that agitator the high temperature liquid waste is kept. Due to its continuous rotation, & outer cooling, temperature reduces. For the protection & leak proof purpose the closed vessel surrounded by stainless steel tank & concrete layer. Whenever the tank is full, it will be well sealed & buried underground.

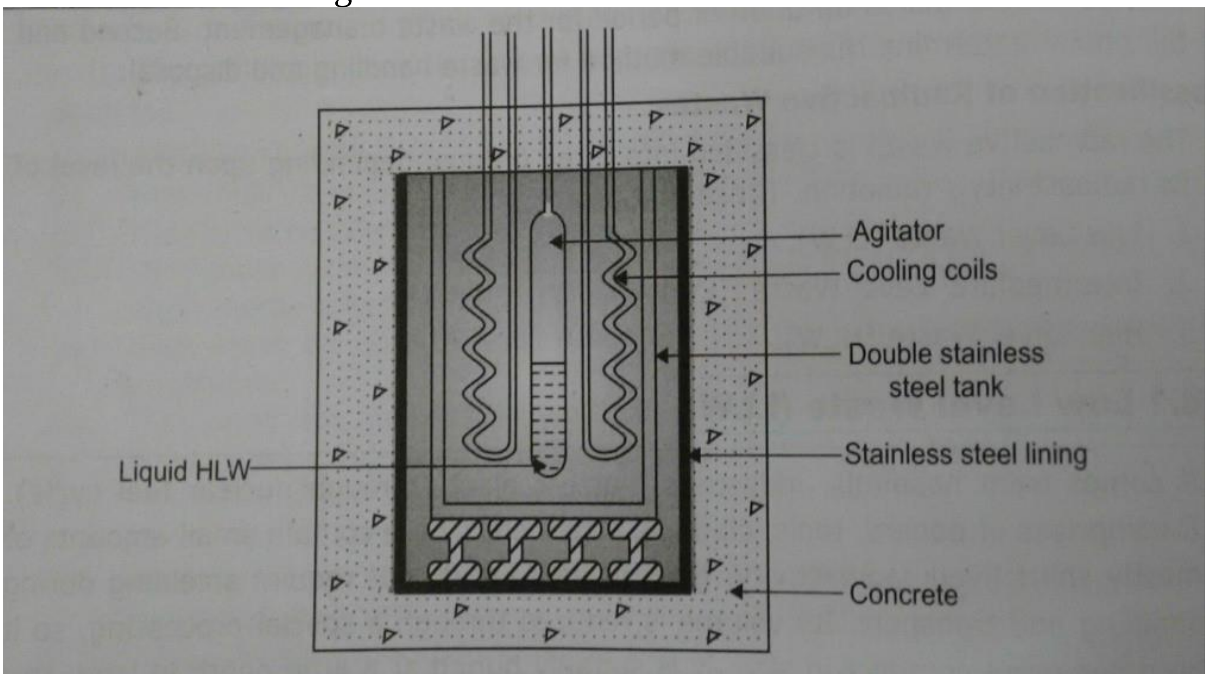


Fig. 4.7: Tank for storing high level liquid waste

2. Disposal through Deep Well Injection:

In this method, the high temperature liquid HLW is kept in storage tank. Then with the help of pumps these liquid HLW is sent to ground at high pressure. Its depth is normally 3500 to 16000 feet.

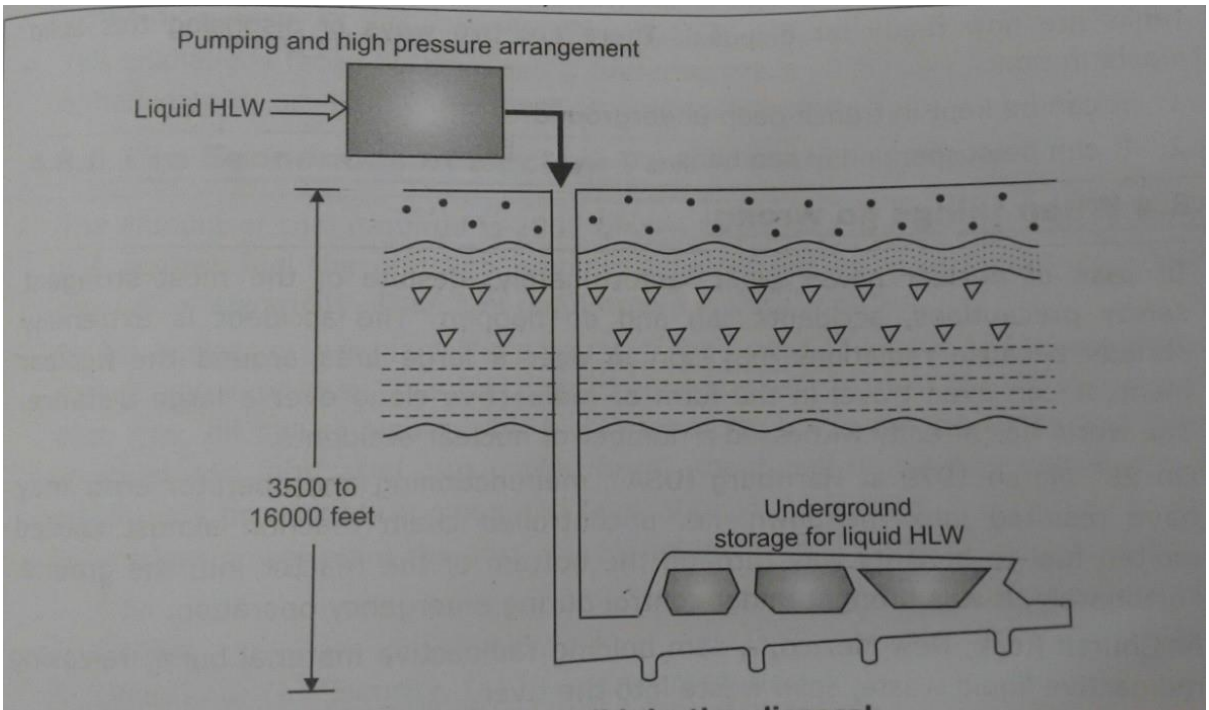


Fig. 4.8: Deep well injection disposal

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3.Vitrification Process:

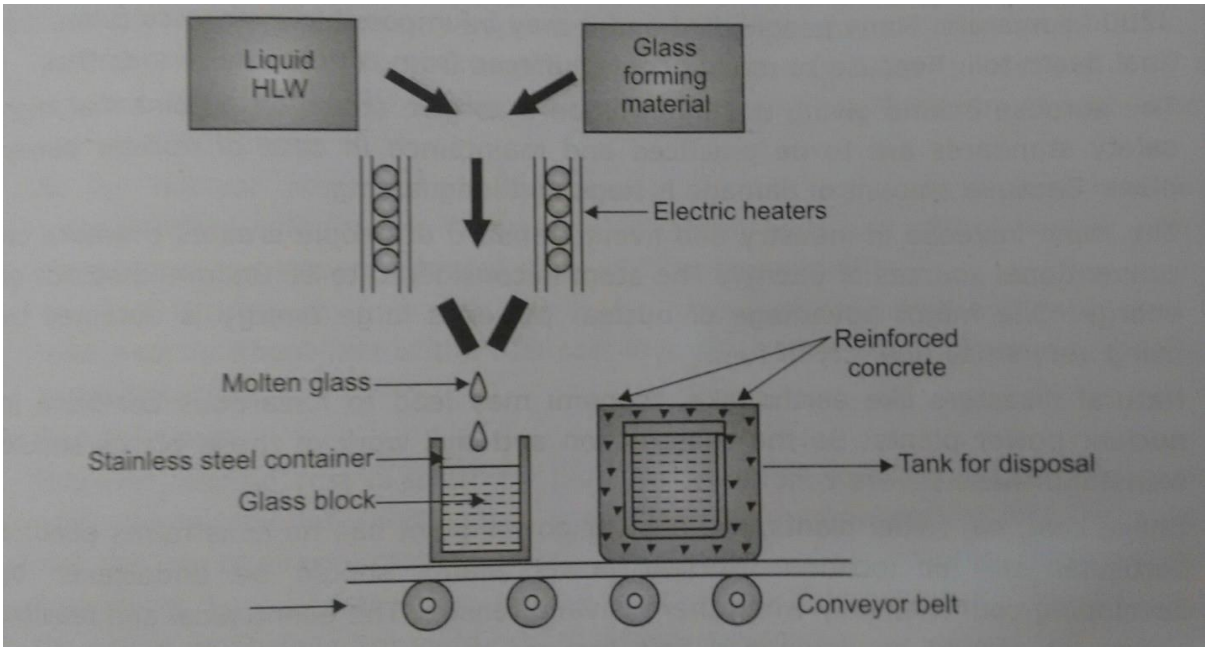

Fig. 4.9: Vitrification process

7. Advantages & Disadvantages of Nuclear Power Plant.

Advantages of Nuclear Power Station:

1. A nuclear power station occupies much smaller space compared to other conventional power station of same capacity.

2. This station does not require plenty of water; hence it is not essential to construct plant near natural source of water.

3. This also does not require huge quantity of fuel; for e.g. 1 kg of uranium produces a heat which is equivalent to 4300 tonnes of coal.

4. It is possible to locate the plant near to load center

5. If bulk power is produced it is economical.

6. Clean operation, no ash is produced.

7. Area required is very less.

8. Independent of geographical conditions.

9. Saving of natural resources such as coal, oil, gas etc.

Disadvantages of Nuclear Power Plant

1. The fuel is not easily available and it is very costly.

2. Initial cost for constructing nuclear power station is quite high.

3. Erection and commissioning of this plant is much complicated.

4. The fission by products is radioactive in nature, and it may cause high radioactive pollution.

5. The maintenance cost is higher and the man power required to run a **nuclear power plant** is quite higher since specialty trained people are required.

6. Sudden fluctuation of load cannot be met up efficiently by nuclear plant.

7. It is very big problem for disposal of this by products. It can only be disposed deep inside ground or in a sea away from sea share.

8. Enrichment technology is essential for fuel processing & fabrication.

9. Maintenance cost is very high.

10. Waste disposal is problematic.

11. For variable load it is not suitable.

12. Construction is complicated.