LECTURE NOTES

ON

Power Plant Engineering

IV B. Tech II Semester (JNTUA-R15)

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UNIT-I
INTRODUCTION TO POWER PLANTS

1.1. ENERGY

- **Energy** probably was the *original stuff or creation*. It appears in many forms, but has one thing in common— *energy is possessed of the ability to produce a dynamic, vital effect.* It shows itself by *excited animated state* assumed by material which receives energy.
- Energy exists in various forms, *e.g., mechanical, thermal, electrical* etc. One form of energy can be converted into other by the use of suitable arrangements.
- **Electric energy** is an essential gradient for the industrial and all-around development of any country. It is preferred one to the following *advantages* :
  (*i*) Can be generated centrally in bulk.
  (*ii*) Can be easily and economically transported from one place to another over long distances.
  (*iii*) Losses in transport are minimum.
  (*iv*) Can be easily sub-divided.
  (*v*) Can be adapted easily and efficiently to domestic and mechanical work.
- **Electric energy** is obtained, conventionally, by *conversion from fossil fuels (coal, oil, natural gas), the nuclear and hydro sources.* Heat energy released by burning fossil fuels or by fusion of nuclear material is converted to electricity by first converting heat energy to the mechanical form through a thermocycle and then converting mechanical energy through generators to the electrical form. Thermo-cycle is basically a low efficiency process—highest efficiencies for modern large size plants range upto 40%, while smaller plants may have considerably lower efficiencies. The *earth has fixed non-replenishable resources of fossil fuels and nuclear materials. Hydro-energy*, though replenishable, is also *limited in terms of power.*
- In view of the ever increasing per capita energy consumption and exponentially rising population, the earth's non-replenishable fuel resources are not likely to last for a long time. Thus a coordinated world-wide action plan is, therefore, necessary to ensure that energy supply to humanity at large is assured for a long time and at low economic cost. The following factors needs to considered and actions to be taken accordingly : (*i*) *Energy consumption curtailment* ; (*ii*) *To initiate concerted efforts to develop alternative sources of energy including unconventional sources like solar, tidal, geothermal energy etc.* ; (*iii*) Recycling of *nuclear wastes* ; (*iv*) *Development and application of antipollution technologies.*

1.2. POWER

- Any physical unit of energy when divided by a unit of time automatically becomes a *unit of power*. However, it is in connection with the mechanical and electrical forms of energy that the term "*power*" is generally used. The rate of production or consumption of heat energy and, to a certain extent, of radiation energy is not ordinarily thought of as power. *Power is primarily associated with mechanical work and electrical energy*. Therefore, **power** can be defined as the *rate of flow of energy* and can state that a *power plant* is a *unit built for production and delivery of a flow of mechanical and electrical energy.*
- In common usage, a machine or assemblage of equipment that produces and delivers a flow of mechanical or electrical energy is a **power plant.** Hence, an internal combustion engine is a power plant, a water wheel is a power plant, etc. However, what we generally mean by the term is that assemblage of equipment, permanently located on some chosen site which receives raw energy in the form of a substance capable of being operated on in such a way as to produce electrical energy for delivery from the power plant.

1.3. SOURCES OF ENERGY

The various sources of energy are :

1. Fuels
   - Solids—Coal, coke anthracite etc.
   - Liquids—Petroleum and its derivatives
   - Gases—Natural gas, blast furnace gas etc.

   } Conventional

2. Energy stored in water
3. Nuclear energy
4. Wind power
5. Solar energy
6. Tidal power
7. Geothermal energy
8. Thermoelectric power.

} Non-conventional

1.3.1. Fuels

Fuels may be chemical or nuclear. Here we shall consider chemical fuels only.

***A chemical fuel** is a substance which releases heat energy on combustion.* The principal combustible elements of each fuel are *carbon* and *hydrogen*. Though *sulphur* is a combustible element too but its presence in the fuel is considered to be *undesirable*.

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*.

The detailed classification of fuels can be given in a summary form as below :

Type of fuel	*Natural (Primary)*	*Prepared (Secondary)*
Solid	Wood	Coke
	Peat	Charcoal
	Lignite coal	Briquettes.
Liquid	Petroleum	Gasoline
		Kerosene
		Fuel oil
		Alcohol
		Benzol
		Shale oil.
Gaseous	Natural gas	Petroleum gas
		Producer gas
		Coal gas
		Coke-oven gas
		Blast furnace gas
		Carburetted gas
		Sewer gas.

1.3.1.1. Solid fuels

Coal. Its main constituents are carbon, hydrogen, oxygen, nitrogen, sulphur, moisture and ash. Coal passes through different *stages* during its formation from vegetation. These stages are enumerated and discussed below :

Plant debris-Peat-Lignite-Brown coal-Sub-bituminous coal-Bituminous coal-Semi-bituminous coal-Semi-anthracite 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. It is used as a domestic fuel in Europe and for power generation in Russia. In India it does not come in the categories of good fuels.

Lignites and brown coals. These are intermediate stages between peat and coal. They have a woody or often a clay like appearance associated with high moisture, high ash and low heat contents. Lignites are usually amorphous in character and impose transport difficulties as they break easily. They burn with a smoky flame. Some of this type are suitable for local use only.

Bituminous coal. It burns with long yellow and smoky flames and has high percentages of volatile matter. The average calorific value of bituminous coal is about 31350 kJ/kg. It may be of two types, namely *caking* or *non-caking*.

Semi-bituminous coal. It is softer than the anthracite. It burns with a very small amount of smoke. It contains 15 to 20 per cent volatile matter and has a tendency to break into small sizes during storage or transportation.

Semi-anthracite. It has less fixed carbon and less lustre as compared to true anthracite and gives out longer and more luminous flames when burnt.

Anthracite. It is very hard coal and has a shining black lustre. It ignites slowly unless the furnace temperature is high. It is non-caking and has high percentage of fixed carbon. It burns either with very short blue flames or without flames. The calorific value of this fuel is high to the tune of 35500 kJ/kg and as such is *very suitable for steam generation*.

Wood charcoal. It is obtained by destructive distillation of wood. During the process the volatile matter and water are expelled. The physical properties of the residue (charcoal) however, depends upon the rate of heating and temperature.

Coke. It consists of carbon, mineral matter with about 2% sulphur and small quantities of hydrogen, nitrogen and phosphorus. It is solid residue left after the destructive distillation of certain kinds of coals. It is smokeless and clear fuel and can be produced by several processes. 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.

Analysis of coal :

The following two types of analysis is done on the coal :

1. Proximate analysis.
2. Ultimate analysis.

1. **Proximate analysis.** In this analysis, *individual elements are not determined ; only the percentage of moisture, volatile matters, fixed carbon and ash are determined.*

Example. Moisture = 4.5%, volatile matter = 5.5%, fixed carbon = 20.5%.

This type of analysis is easily done and is for *commercial purposes* only.

2. **Ultimate analysis.** In the ultimate analysis, the percentage of various elements are determined.

Example. Carbon = 90%, hydrogen = 2%, oxygen = 4%, nitrogen = 1%, sulphur = 15% and ash = 1.5%.

This type of analysis is useful for *combustion calculations.*

Properties of coal :

Important properties of coal are given below :

1. Energy content or heating value.
2. Sulphur content.
3. Burning characteristics.
4. Grindability.
5. Weatherability.
6. Ash softening temperature.

A *good coal should have* :

(*i*) Low ash content and high calorific value.

(*ii*) Small percentage of sulphur (less than 1%).

(*iii*) Good burning characteristics (*i.e.* should burn freely without agitation) so that combustion will be complete.

(*iv*) High grindability index (in case of ball mill grinding).

(*v*) High weatherability.

Ranking of coal :

ASME and ASTM have accepted a specification based on the fixed carbon and heating value of the mineral matter free analysis.

- **Higher ranking** is done on the basis of fixed carbon percentage (*dry basis*).
- **Lower ranking** is done on the heating value on the *moist basis.*

Example. 62% C and a calorific value of 5000 kcal/kg is ranked as (62—500) rank.

Rank is an inherent property of the fuel depending upon its relative progression in the classification process.

Grading of coal :

Grading is done on the following basis :

(*i*) Size
(*ii*) Heating value
(*iii*) Ash content
(*iv*) Ash softening temperature
(*v*) Sulphur content.

Example. A grade written as 5—10 cm, 5000-A8-F24-S1.6 indicate the coal as having :

—a size of 5–10 cm,

—heating value of 5000 kcal/kg,

—8 to 10% ash,

—ash softening temperature of 2400—2590°F, and

—a sulphur content of 1.4 to 1.6%.

A rank and grade of a coal gives a complete report of the material. Thus the following are the rank and grade of the coal described above :

(62—500), 5—10 cm, 500-A8-F24-S1.6.

1.3.1.2. Liquid fuels

The chief source of liquid fuels is petroleum which is obtained from wells under the earth's crust. These fuels have proved *more advantageous in comparison to sold fuels* in the following respects.

Advantages :

1. 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.
9. Non-deterioration of the oil in storage.

Petroleum. There are different opinions regarding the origin of petroleum. However, now it is accepted that petroleum has originated probably from organic matter like fish and plant life etc., by bacterial action or by their distillation under pressure and heat. It consists of a mixture of gases, liquids and solid hydrocarbons with small amounts of nitrogen and sulphur compounds. In India the main sources of petroleum are Assam and Gujarat.

Heavy fuel oil or crude oil is imported and then refined at different refineries. The refining of crude oil supplies the most important product called *petrol*. Petrol can also be made by polymerization of refinery gases.

Other liquid fuels are kerosene, fuels oils, colloidal fuels and alcohol.

The following table gives *composition* of some common liquid fuels used in terms of the elements in *weight percentage*.

Important properties of liquid fuels :

(1) Specific gravity
(2) Flash point
(3) Fire point
(4) Volatility
(5) Pour point
(6) Viscosity
(7) Carbon residue
(8) Octane number
(9) Cetane number
(10) Corrosive property
(11) Ash content
(12) Gum content
(13) Heating value
(14) Sulphur content.

The requisite properties vary from device to device which uses the fuel to generate power. For example, *higher the octane number, higher can be the compression ratio and the thermal efficiency will be higher.* Similarly, *the cetane number of a diesel oil should be as high as possible.*

In general the liquid fuels should have :

(*i*) Low ash content
(*ii*) High heating value
(*iii*) Low gum content
(*iv*) Less corrosive tendency
(*v*) Low sulphur content
(*vi*) Low pour point.

Viscosity and other properties vary from purpose to purpose to which the fuel is employed.

1.3.1.3. Gaseous fuels

Natural gas. The main constituents of natural gas are methane (CH_4) and ethane (C_2H_6). It has calorific value nearly 21000 kJ/m^3. Natural gas is used alternately or simultaneously with oil for internal combustion engines.

Coal gas. This gas mainly consists of hydrogen, carbon monoxide and hydrocarbons. It is prepared by carbonisation of coal. It finds its use in boilers and sometimes used for commercial purposes.

Coke-oven gas. It is obtained during the production of coke by heating the bituminous coal. The volatile content of coal is driven off by heating and major portion of this gas is utilised in heating the ovens. This gas must be thoroughly filtered before using in gas engines.

Blast furnace gas. It is obtained from smelting operation in which air is forced through layers of coke and iron ore, the example being that of pig iron manufacture where this gas is produced as by product and contains about 20% carbon monoxide (CO). After filtering it may be blended with richer gas or used in gas engines directly. The heating value of this gas is very low.

Producer gas. It results from the partial oxidation of coal, coke or peat when they are burnt with an insufficient quantity of air. It is produced in specially designed retorts. It has low heating value and in general is suitable for large installations. It is also used in steel industry for firing open hearth furnaces.

Water or Illuminating gas. It is produced by blowing steam into white hot coke or coal. The decomposition of steam takes place liberating free hydrogen and oxygen in the steam combines with carbon to form carbon monoxide according to the reaction :

$$C + H_2O \longrightarrow CO + H_2$$

The gas composition varies as the hydrogen content if the coal is used.

Sewer gas. It is obtained from sewage disposal vats in which fermentation and decay occur. It consists of mainly marsh gas (CH_4) and is collected at large disposal plants. It works as a fuel for gas engines which is turn drive the plant pumps and agitators.

Gaseous fuels are becoming popular because of following *advantages* they possess :

Advantages :

1. Better control of combustion.

2. Much less excess air is needed for complete combustion.

3. Economy in fuel and more efficiency of furnace operation.

4. Easy maintenance of oxidizing or reducing atmosphere.

5. Cleanliness.

6. No problem of storage if the supply is available from public supply line.

7. The distribution of gaseous fuels even over a wide area is easy through the pipe lines and as such handling of the fuel is altogether eliminated. Gaseous fuels give economy of heat and produce higher temperatures as they can be preheated in regenerative furnaces and thus heat from hot flue gases can be recovered.

Important properties of gaseous fuels :

1. Heating value or calorific value.
2. Viscosity.
3. Specific gravity.
4. Density.
5. Diffusibility.

Typical composition of some gaseous fuels is given below :

Fuel	H_2	CO	CH_4	C_2H_4	C_2H_6	C_4H_8	O_2	CO_2	N_2
Natural gas	—	1	93	—	3	—	—	—	3
Coal gas	53.6	9.0	25	—	—	3	0.4	3	6
Blast furnace gas	2	27	—	—	—	—	—	11	—

1.3.1.4. Calorific or heating values of fuels

The **calorific value** *of the fuel is defined as the energy liberated by the complete oxidation of a unit mass or volume of a fuel.* It is expressed in kJ/kg for solid and liquid fuels and kJ/m^3 for gases.

Fuels which contain hydrogen have two calorific values, the *higher* and the *lower*. The '*lower calorific value*' is the heat liberated per kg of fuel after deducting the heat necessary to vaporise the steam, formed from hydrogen. The '*higher or gross calorific value' of the fuel is one indicated by a constant-volume calorimeter in which the steam is condensed and the heat of vapour is recovered.*

The lower or net calorific value is obtained by subtracting latent heat of water vapour from gross calorific value. In other words, the relation between Lower Calorific Value (L.C.V.) and Higher Calorific Value (H.C.V.) can be expressed in the following way :

$$\text{L.C.V.} = (\text{H.C.V.} - 2465\ m_w) \qquad \ldots(1.1)$$

where m_w is the mass of water vapour produced by combustion of 1 kg of fuel and 2465 kJ/kg is the latent heat corresponding to standard temperature (saturation) of 15°C.

In MKS units:

$$\text{L. C. V.} = (\text{H. C. V.} - 588.76\, m_w)$$

where m_w is the mass of water vapour produced by combustion of 1 kg of fuel and 588.76 is the latent heat value in kcal as read from steam tables for 1 kg of water vapour

Dulong's formula (Solid/liquid fules). Dulong suggested a formula for the calculation of the calorific value of the solid or liquid fuels from their chemical composition which is as given below :

Gross calorific value,

$$\text{H.C.V.} = \frac{1}{100}\left[33800\,\text{C} + 144000\left(\text{H} - \frac{\text{O}}{8}\right) + 9270\,\text{S}\right] \text{ kJ/kg} \qquad \ldots(1.2)$$

$$\left[\begin{array}{l}\textbf{In MKS units:}\\ \text{H.C.V.} = \frac{1}{100}\left[8080\,C + 34500\left(H - \frac{O}{8}\right) + 2240\,S \text{ kcal / kg}\right]\end{array}\right]$$

where C, H, O and S are carbon, hydrogen, oxygen and sulphur in percentages respectively in 100 kg of fuel. In the above formula, the oxygen is assumed to be in combination with hydrogen and only extra surplus hydrogen supplies the necessary heat.

1.3.2. 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, an example of which would be the water held behind a dam. *Hydraulic plants* are slowly increasing in number, although the number of new plants of this type built is quite small compared with those which exploit heat energy. As a usual thing, the most desirable hydroelectric sites are the first to be utilized, consequently, as more hydroelectric plants are built, the owners must pay increasingly higher development costs.
- From the stand point of capitalistic economics, it is often hard to justify the development of hydroelectric power in comparison with steam power, but from the stand point of the conservation of a fixed natural resource, namely, its mineral fuels, it is obvious that every effort should be made to harness the water power of the country, since if unharnessed it goes to waste, whereas fuel, if unmined, remains intact and undiminished in value in the ground.
- Water power is quite cheap where water is available in abundance. Although *capital cost of hydroelectric power plants is higher as compared to other types of power plants yet their operating costs are quite low.*

1.3.3. Nuclear Energy

- One of the outstanding facts about nuclear power is the *large amount of energy that can be released from a small mass of active material.* Complete fission of one kg of uranium contains the energy equivalent of 4500 tonnes of coal or 2000 tonnes of oil. The *nuclear power is not only available in abundance but it is cheaper than the power generated by conventional sources.*

  The following factors go in *favour of nuclear energy :*

  (*i*) Practically independent of geographical factors.

  (*ii*) No combustion products.

  (*iii*) Clean source of power which does not contribute to air pollution.

  (*iv*) Fuel transportation networks and large storage facilities not required.
- The economic advantage of nuclear power can be realised only if one can ensure a guaranteed base load of about 75%. The number of electro-chemical processes (fertiliser plants), desalination of water and use of electricity for pumping water from tube wells assure a constant base load. Therefore, such type of power requirements must be developed before the adoption of nuclear power in the country.

1.3.4. Wind Power

- The man has been served by the power from winds for many centuries but the total amount of energy generated in this manner is *small.* The expense of installation and variability of operation have tended to *limit* the use of the windmill to intermittent services where *its variable output has no serious disadvantage.* The principal services of this nature are the *pumping of water into storage tanks and the charging of storage batteries.*

- Windmill power equipment may be *classified* as follows :
  1. *The multi-bladed turbine wheel.* This is the foremost type in use and its efficiency is about 10 per cent of the kinetic energy of the wind passing through it.
  2. *The high-speed propeller type.*
  3. *The rotor.*
- The propeller and rotor types are *suitable for the generation of electrical energy,* as both of them possess the ability to start in very low winds. The *Propeller type is more likely to be used in small units* such as the driving of small battery charging generators, whereas the *rotor,* which is rarely seen, is more practical *for large installations,* even of several hundred kilowatts' capacity.
- In india, the wind velocity along coastline has a range 10-16 kmph and a survey of wind power has revealed that wind power is capable of exploitation for pumping water from deep wells or for generating small amounts of electric energy.

Modern windmills are capable of working on velocities as low as 3-7 kmph while *maximum efficiency is attained at 10-12 kmph.*

- A normal working life of 20 to 25 years is estimated for windmills.
- The great advantage of this source of energy is that *no operator is needed and no maintenance and repairs are necessary for long intervals.*

Characteristics of wind power/energy. Some characteristics of wind energy are given below :

1. No fuel provision and transport are required in wind energy systems.
2. It is a renewable source of energy.
3. Wind power systems are non-polluting.
4. Wind power systems, upto a few kW, are less costly, but on a large scale, costs can be competitive with conventional electricity. Lower costs can be achieved by mass production.

Problems associated with wind energy :

1. Wind energy systems are *noisy in operation.*
2. *Large areas* are needed to install *wind farms* for electrical power generators.
3. Wind energy available is *dilute and fluctuating in nature.* Because of dilute form, conversion machines have to be necessarily large.
4. Wind energy *needs storage means* because of its irregularity.

1.3.5. Solar Energy

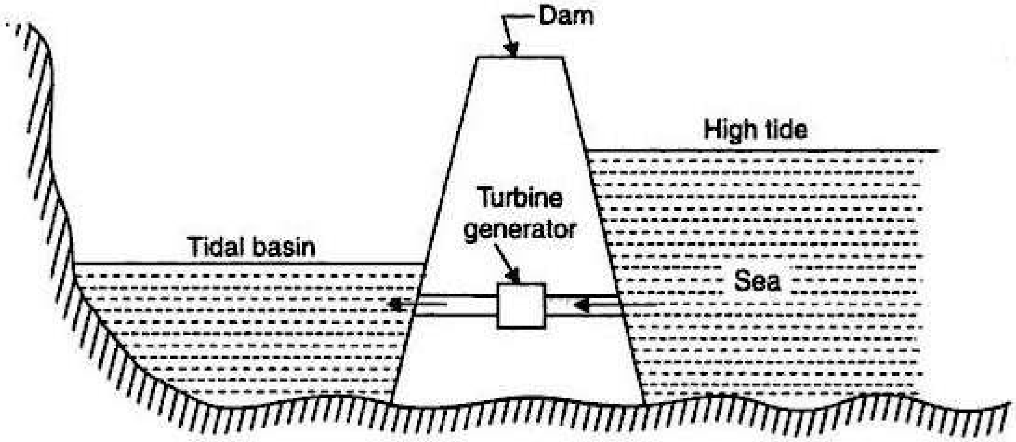
- A lot of work to utilise solar energy for generation of steam has been done in some countries, and it is likely that this could be developed on commercial scale.
- A serious fault of this source of energy is, of course, that it is *effective only during the day,* so that if a continuous output is needed, some large reservoir of energy, such as a storage battery or a heat accumulator tank, must be drawn upon at night. Also, the output is handicapped if there is cloudy weather. Nevertheless, there are some locations in the world where strong solar radiation is received very regularly, and where the sources of mineral fuel are either scanty or entirely lacking. Such locations offer more interest to the solar power plant builder than the more favoured regions of earth.
- 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 which is characterised by a high degree of heat which can be utilised to boil water and generate steam. The reflector is the better of the two methods due to the convenience with which it can be

manufactured in different shapes and sizes. If an arrangement is provided to turn the reflector with the sun, so that the rays can constantly concentrate at the focal point, a continuous supply of heat is made available during the hours of the day. However, a great deal of practical research is still necessary before the solar energy can be *commercially exploited at a cheaper rate.*

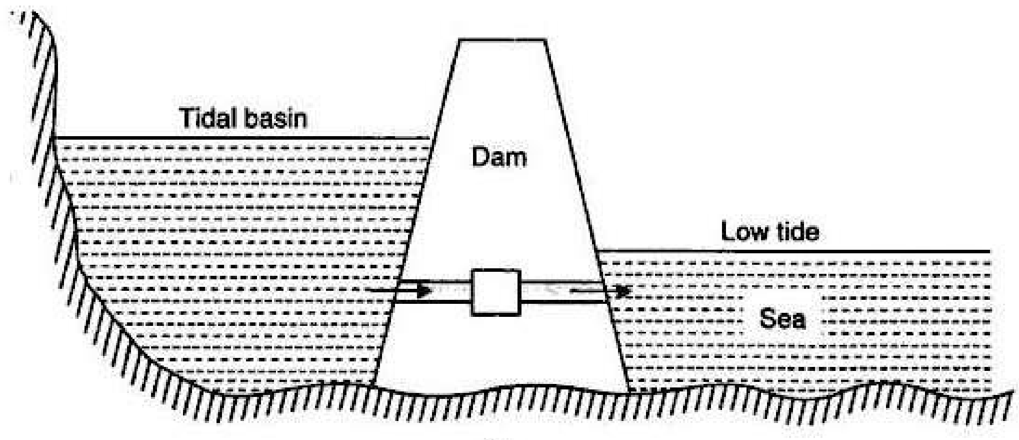
- Conditions for utilisation of solar energy, in India, are favourable since for nearly six months of the year sunshine is uninterrupted during the day, while in the other six months cloudy weather and rain provide conditions suitable for water power. Thus, a *coordination of solar energy with water power can provide a workable plan for most places in India.*

1.3.6. Tidal Power

- The rise and fall of tides offers a means for storing water at the rise and discharging the same at fall. Of course the head of water available under such cases is very low but with increased catchment area considerable amounts of power can be generated at a negligible cost.



(a)



(b)

Fig. 1.1. Generation of power by tides.

- The use of tides for electric power generation is practical in a few favourably situated sites where the geography of an inlet of bay favours the construction of a large scale hydroelectric plant. To harness the tides, a dam would be built across the mouth of the bay in which large gates and low head hydraulic turbines would be installed. At the time of high tide the gates are opened and after storing water in the tidal basin the gates are closed. After the tide has recided, there is a working hydraulic head between the basin water and open sea/ocean and the water is allowed to flow back to the sea through water turbines installed in the dam. With this type of arrangement, the generation of electric power is *not continuous*. However by using reversible water turbine the turbine can be run continuously as shown in Fig. 1.1.

1.3.7. Geothermal Energy

In many places on the earth natural steam escapes from surface vents. Such natural steam wells suggest the possibility of tapping terrestrial heat (or geothermal energy) in this form and using it for the development of power. Unfortunately, the locations where the steam-producing sub-strata seem to be fairly close to the surface are far removed from centres of civilization where the power could be usefully employed. Nevertheless, there are probably many places where, although no natural steam vent or hot springs are showing, deep drillings might tap a source of underground steam. The cost of such explorations and the great likelihood of an unsuccessful conclusion are not very conductive to exploitation of this source of energy.

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. From the well-head the steam is transmitted by pipelines upto 1 m in diameter over distances upto about 3 km to the power station. Water separators are usually employed to separate moisture and solid particles from steam.

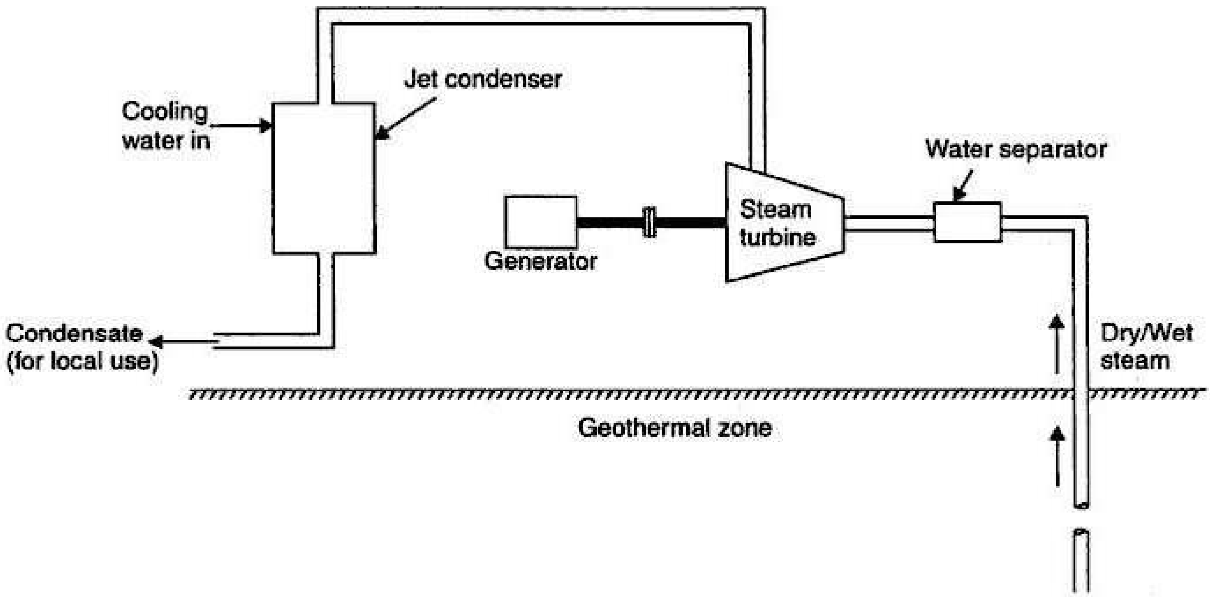


Fig. 1.2. Geothermal power plant.

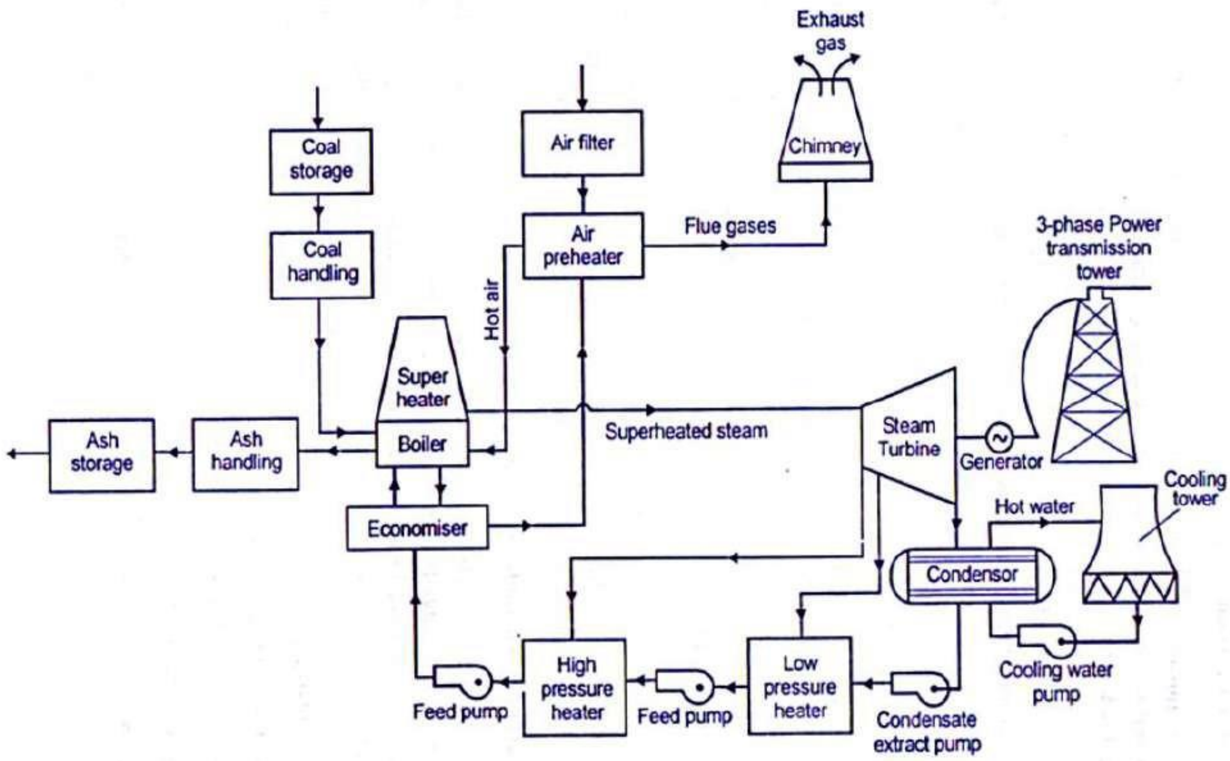
Presently, only steam coming out of the ground is used to generate electricity, the hot water is discarded, because it contains as much as 30% dissolved salts and minerals, and these cause serious rust damage to the turbine. The water, however, contains more than $\frac{1}{3}$rd of the available thermal energy.

1.3.8. 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*.

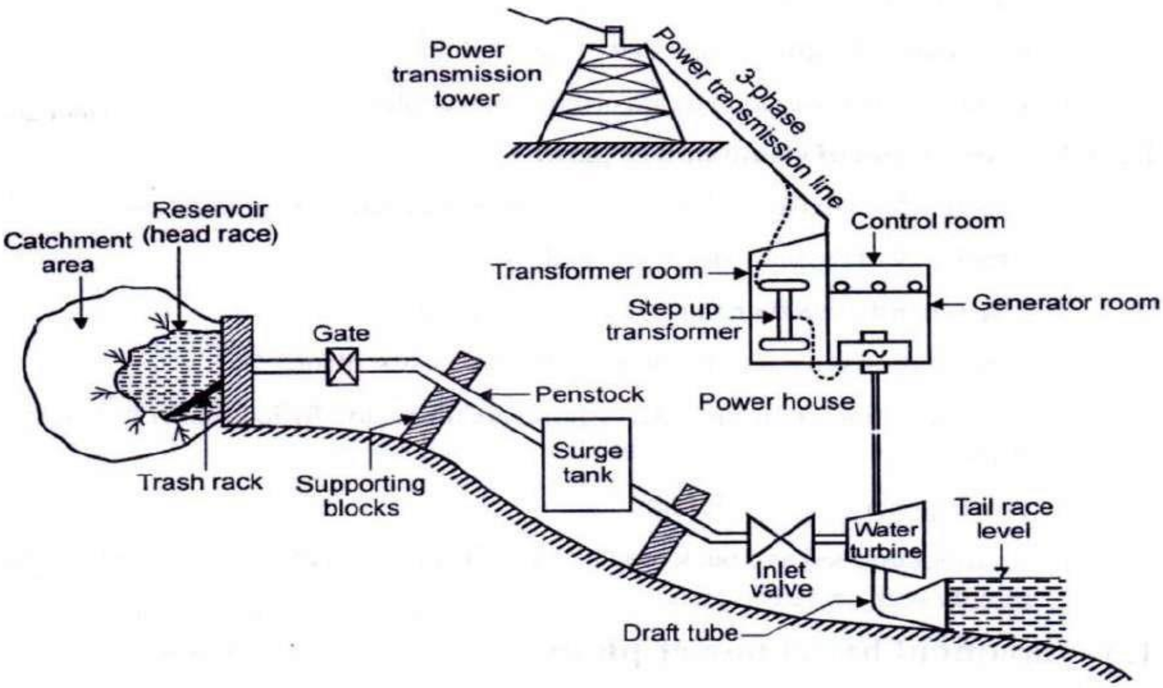
Layouts of power plants

1. Steam power plant



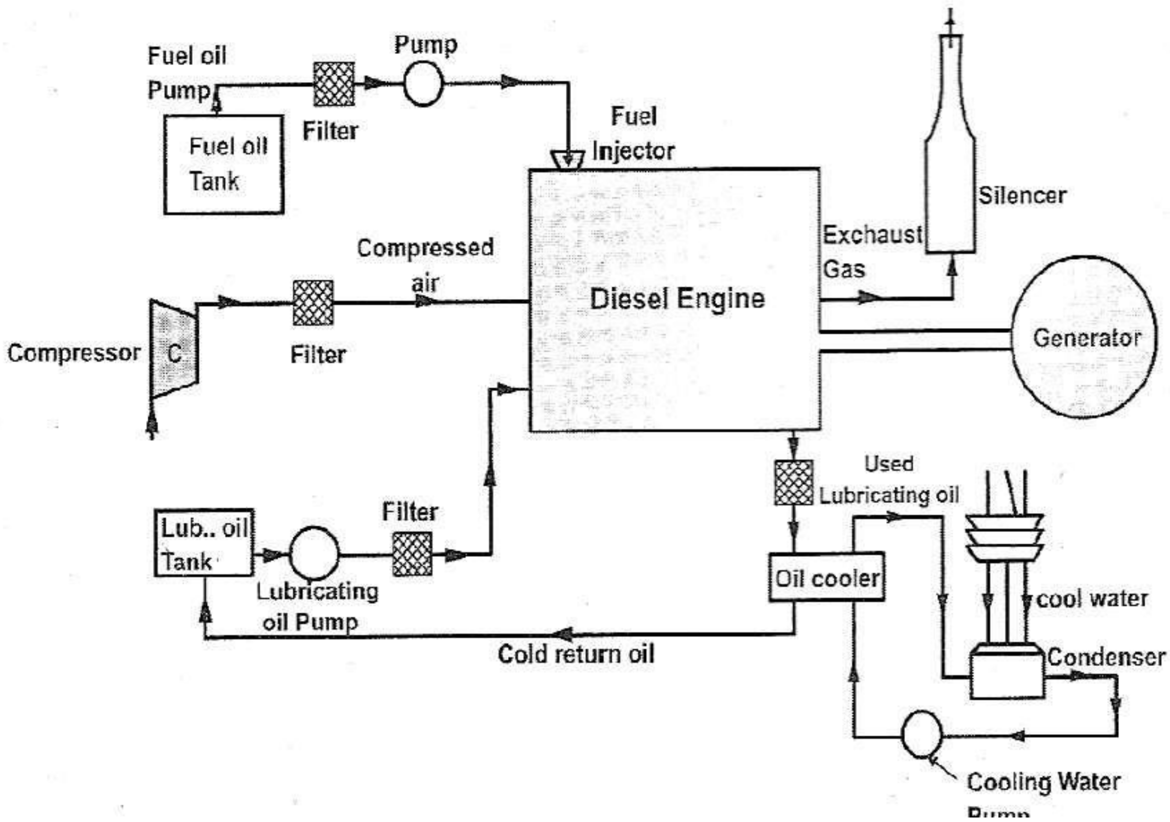
2. hydel power plant

sdfsd

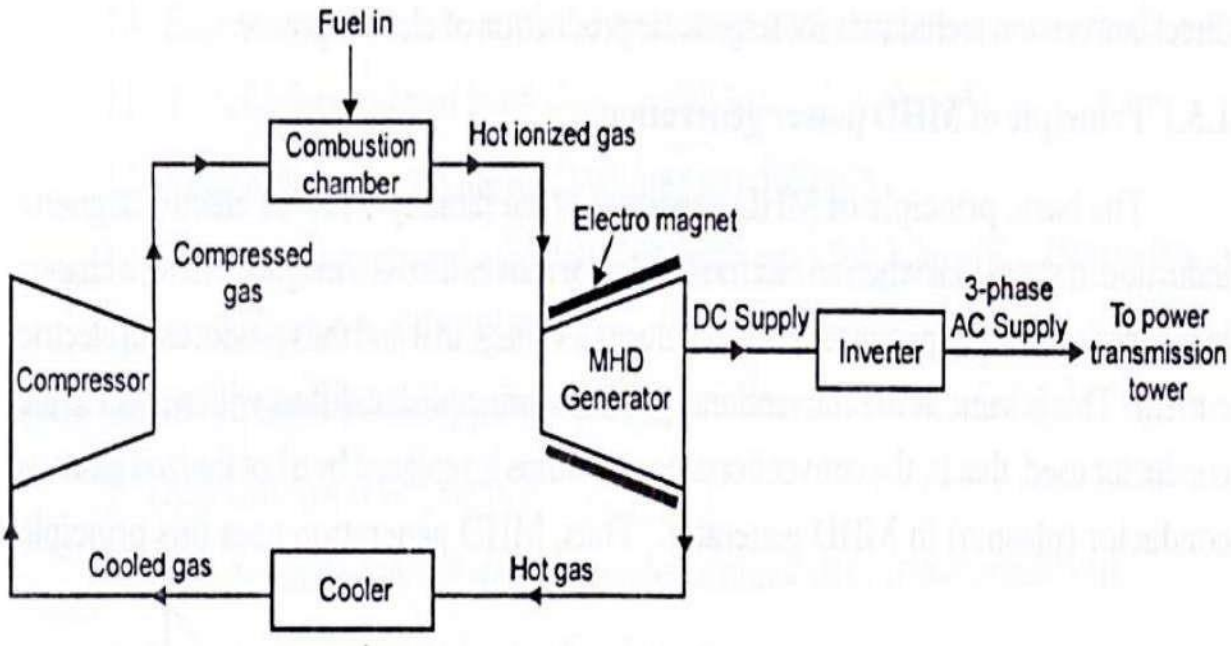


3. **Diesel power plant**

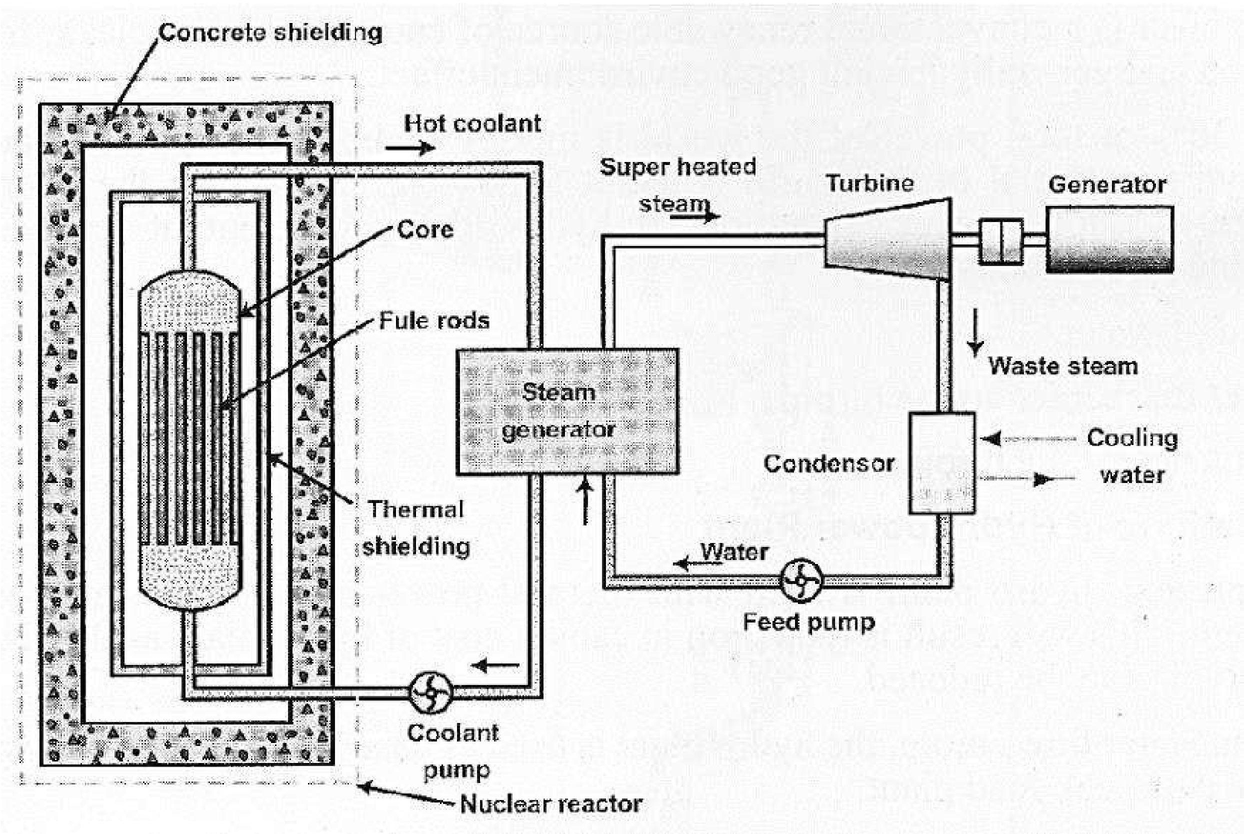
LAYOUT OF DIESEL POWER PLANT:



4 LAYOUT OF MHD POWER PLANT

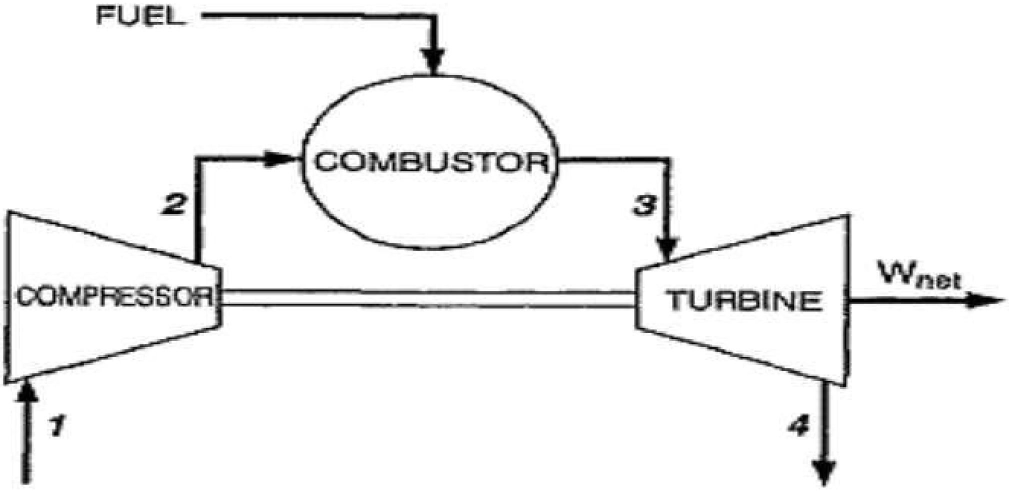


5. nuclear power plant



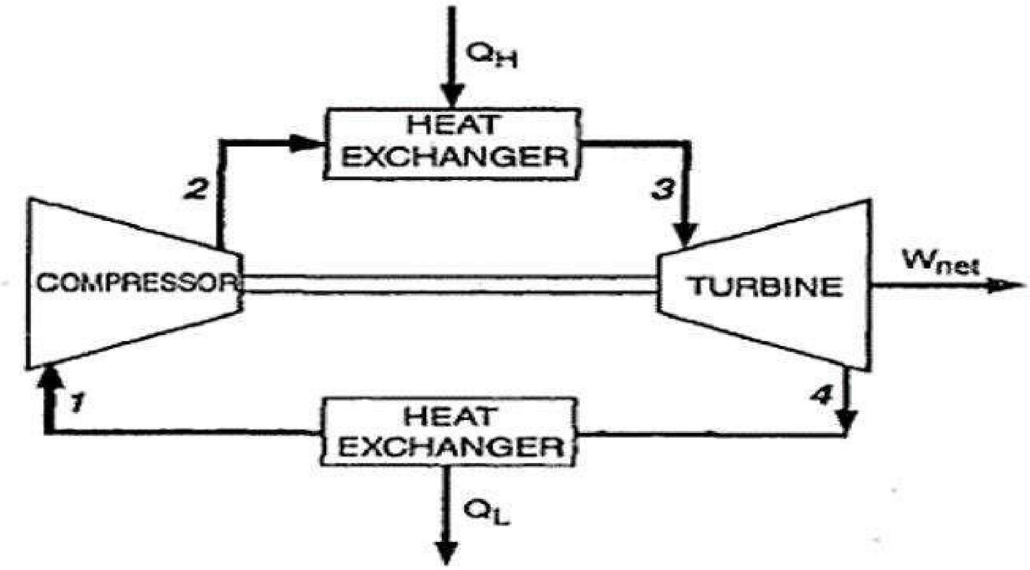
6 Open gas cycle

Open cycle gas turbine



1- Atmospheric Air
2- Compressed Atmospheric Air
3- Fuel air mixture after compression
4- Exhaust gases.

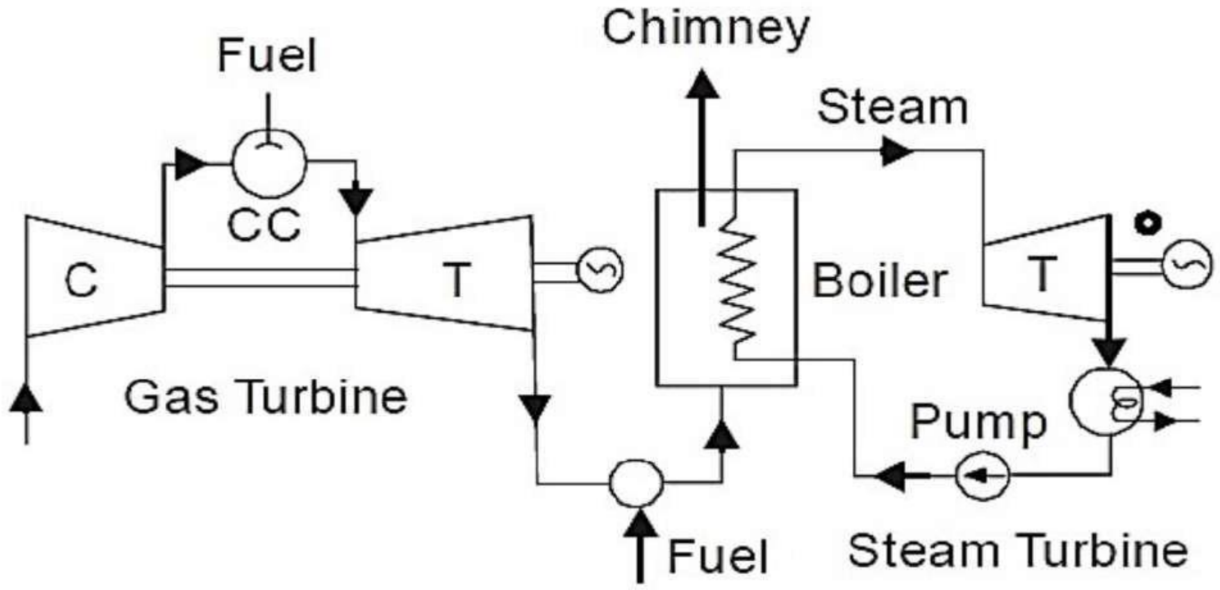
Closed gas turbine cycle



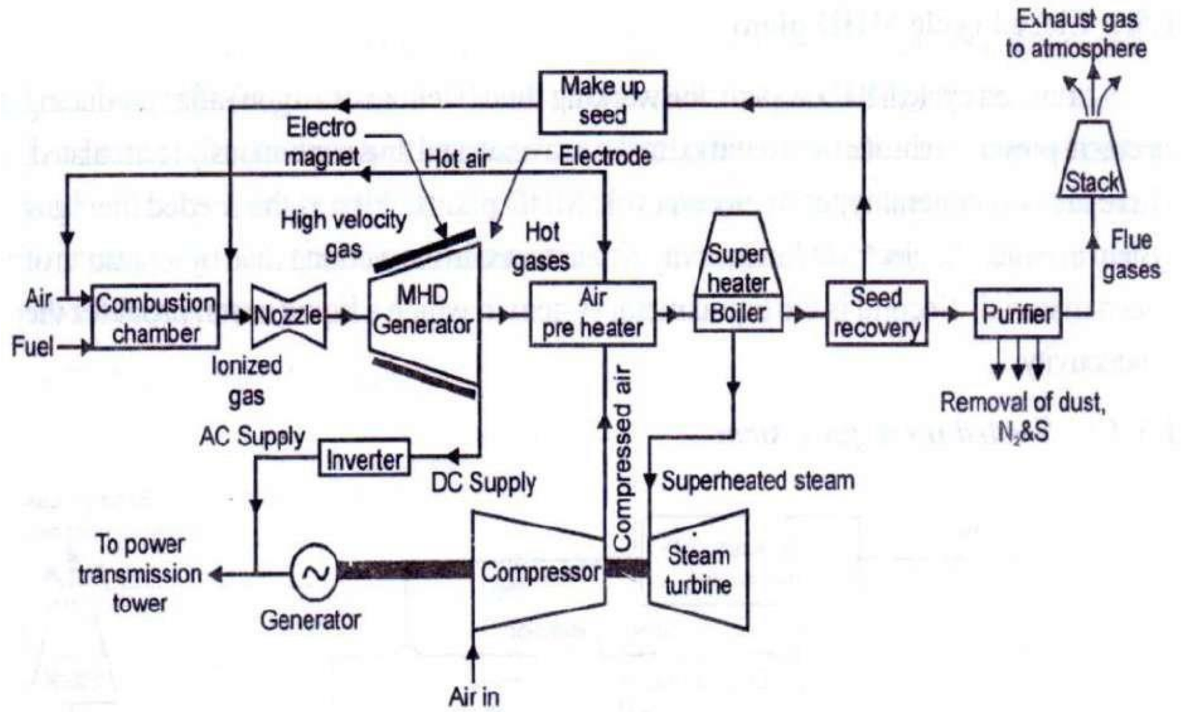
1- Low Pressure Working Fluid @ Low temperature
2- High Pressure Working Fluid
3- Fuel + Working Fluid mixture @ High Pressure and Temperature
4- Low Pressure Working Fluid @ Temperature T4 < Temperature T3

Combined cycles

GT-ST cycle



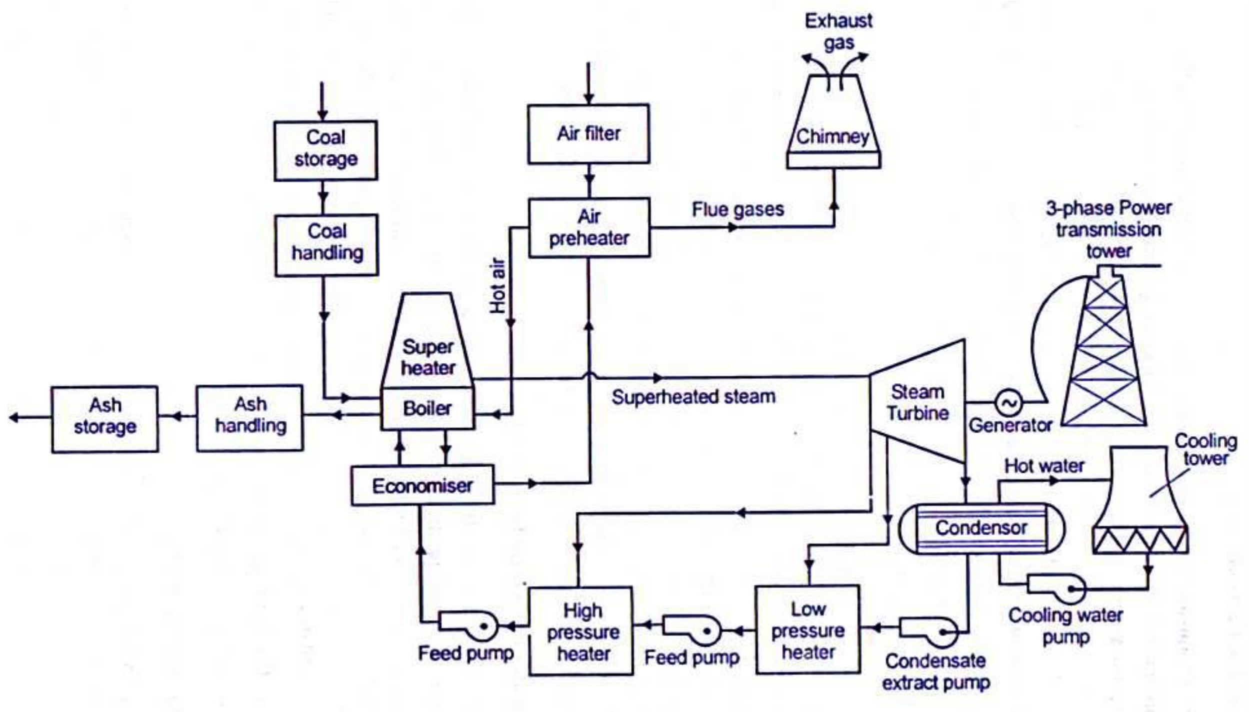
ST-MHD Cycle



STEAM POWER PLANTS:

A thermal power station is a power plant in which the prime mover is steam driven. Water is heated, turns into steam and spins a steam turbine which drives an electrical generator. After it passes through the turbine, the steam is condensed in a condenser and recycled to where it was heated; this is known as a **Rankine cycle**. The greatest variation in the design of thermal power stations is due to the different fuel sources. Some prefer to use the term *energy center* because such facilities convert forms of heat energy into electricity. Some thermal power plants also deliver heat energy for industrial purposes, for district heating, or for desalination of water as well as delivering electrical power. A large proportion of CO_2 is produced by the worlds fossil fired thermal power plants; efforts to reduce these outputs are various and widespread.

LAYOUT OF STEAM POWER PLANT:



The four main circuits one would come across in any thermal power plant layout are
- Coal and Ash Circuit
- Air and Gas Circuit
- Feed Water and Steam Circuit
- Cooling Water Circuit

Coal and Ash Circuit

Coal and Ash circuit in a thermal power plant layout mainly takes care of feeding the boiler with coal from the storage for combustion. The ash that is generated during combustion is collected at the back of the boiler and removed to the ash storage by scrap conveyors. The combustion in the Coal and Ash circuit is controlled by regulating the speed and the quality of coal entering the grate and the damper openings.

Air and Gas Circuit

Air from the atmosphere is directed into the furnace through the air preheated by the action of a forced draught fan or induced draught fan. The dust from the air is removed before it enters the combustion chamber of the thermal power plant layout. The exhaust gases from the combustion heat the air, which goes through a heat exchanger and is finally let off into the environment.

Feed Water and Steam Circuit

The steam produced in the boiler is supplied to the turbines to generate power. The steam that is expelled by the prime mover in the thermal power plant layout is then condensed in a condenser for re-use in the boiler. The condensed water is forced through a pump into the feed water heaters where it is heated using the steam from different points in the turbine. To make up for the lost steam and water while passing through the various components of the thermal power plant layout, feed water is supplied through external sources. Feed water is purified in a purifying plant to reduce the dissolve salts that could scale the boiler tubes.

Cooling Water Circuit

The quantity of cooling water required to cool the steam in a thermal power plant layout is significantly high and hence it is supplied from a natural water source like a lake or a river. After passing through screens that remove particles that can plug the condenser tubes in a thermal power plant layout, it is passed through the condenser where the steam is condensed. The water is finally discharged back into the water source after cooling. Cooling water circuit can also be a closed system where the cooled water is sent through cooling towers for re-use in the power plant. The cooling water circulation in the condenser of a thermal power plant layout helps in maintaining a low pressure in the condenser all throughout.

All these circuits are integrated to form a thermal power plant layout that generates electricity to meet our needs.

Advantages

- Generation of power is continuous.
- Initial cost low compared to hydel plant.
- Less space required.
- This can be located near the load centre so that the transmission losses are reduced.
- It can respond to rapidly changing loads.

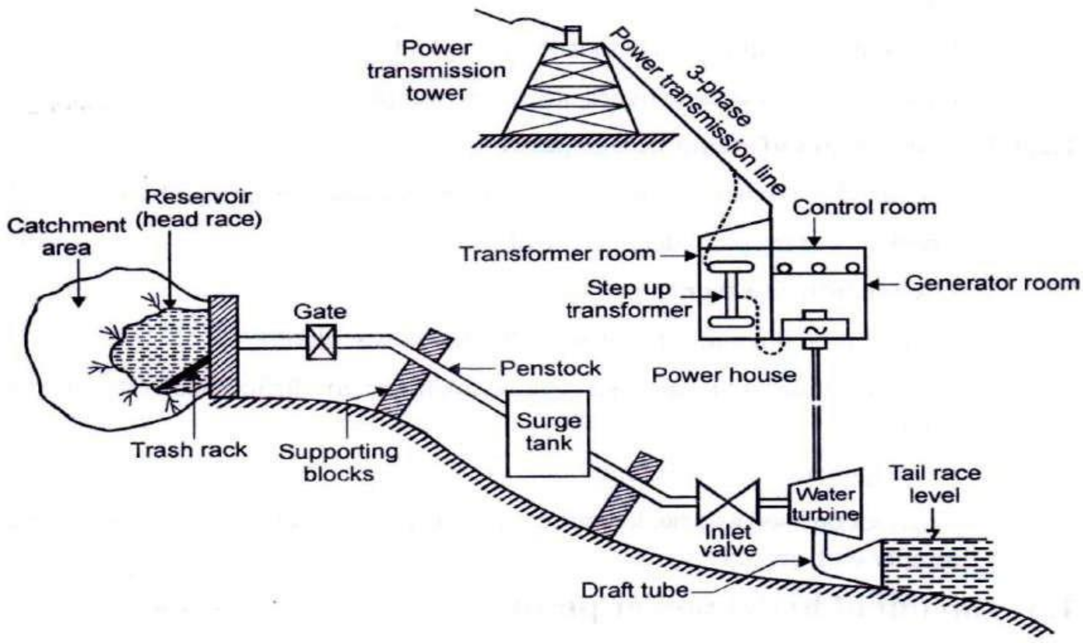
Disadvantages

- Long time required for installation.
- Transportation and handling of fuels major difficulty.
- Efficiency of plant is less.
- Power generation cost is high compared to hydel power plant.
- Maintenance cost is high.

HYDEL POWER PLANTS

Hydroelectric power plants convert the hydraulic potential energy from water into electrical energy. Such plants are suitable were water with suitable ***head*** are available. The layout covered in this article is just a simple one and only cover the important parts of hydroelectric plant.

LAYOUT OF HYDEL POWER PLANT:



(1) Dam

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

(2) Spillway

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

(3) Penstock and Tunnels

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

(4) Surge Tank

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

(5) Power Station

Power station contains a turbine coupled to a generator. The water brought to the power station rotates the vanes of the turbine producing torque and rotation of turbine shaft. This rotational torque is transferred to the generator and is converted into electricity.

The used water is released through the *tail race*. The difference between head race and tail race is called gross head and by subtracting the frictional losses we get the net head available to the turbine for generation of electricity.

Advantages

- Water the working fluid is natural and available plenty.
- Life of the plant is very long.
- Running cost and maintenance are very low.
- Highly reliable.
- Running cost is low.
- Maintenance and operation costs are very less.
- No fuel transport problem.
- No ash disposal problem.

Disadvantages

- Initial cost of plant is very high.
- Power generation depends on quantity of water available which depends on rainfall.
- Transmission losses are very high.
- More time is required for erection.

DIESEL POWER PLANTS

Diesel power plants produce power from a diesel engine. Diesel electric plants in the range of 2 to 50 MW capacities are used as central stations for small electric supply networks and used as a standby to hydroelectric or thermal plants where continuous power supply is needed. Diesel power plant is not economical compared to other power plants.

The diesel power plants are cheaply used in the fields mentioned below.

1. Mobile electric plants
2. Standby units
3. Emergency power plants
4. Starting stations of existing plants
5. Central power station etc.

LAYOUT OF DIESEL POWER PLANT:

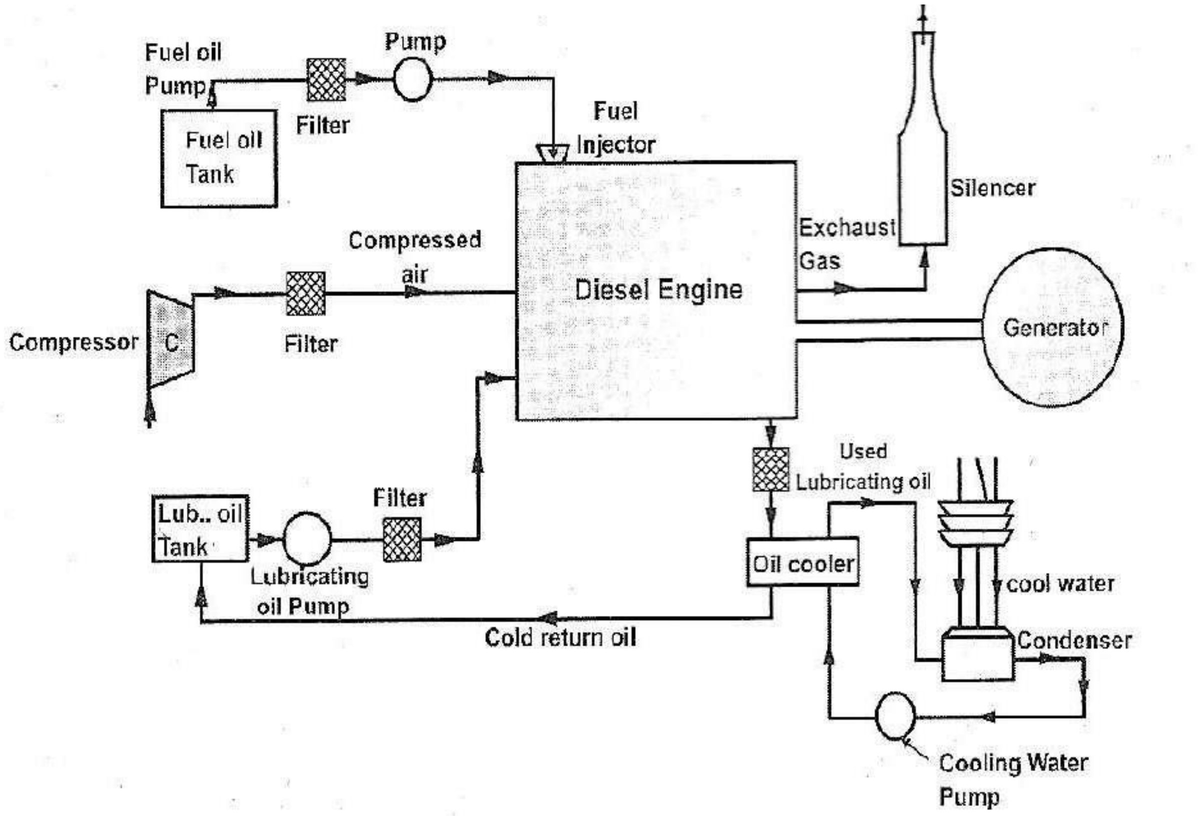


Figure shows the arrangements of the engine and its auxiliaries in a diesel power plant. The major components of the diesel power plant are:

1) Engine

Engine is the heart of a diesel power plant. Engine is directly connected through a gear box to the generator. Generally two-stroke engines are used for power generation. Now a days, advanced super & turbo charged high speed engines are available for power production.

2) Air supply system

Air inlet is arranged outside the engine room. Air from the atmosphere is filtered by air filter and conveyed to the inlet manifold of engine. In large plants supercharger/turbocharger is used for increasing the pressure of input air which increases the power output.

3) Exhaust System

This includes the silencers and connecting ducts. The heat content of the exhaust gas is utilized in a turbine in a turbocharger to compress the air input to the engine.

4) Fuel System

Fuel is stored in a tank from where it flows to the fuel pump through a filter. Fuel is injected to the engine as per the load requirement.

5) Cooling system

This system includes water circulating pumps, cooling towers, water filter etc. Cooling water is circulated through the engine block to keep the temperature of the engine in the safe range.

6) Lubricating system

Lubrication system includes the air pumps, oil tanks, filters, coolers and pipe lines. Lubricant is given to reduce friction of moving parts and reduce the wear and tear of the engine parts.

7) Starting System

There are three commonly used starting systems, they are;

1) A petrol driven auxiliary engine
2) Use of electric motors.
3) Use of compressed air from an air compressor at a pressure of 20 Kg/cm.

8) Governing system

The function of a governing system is to maintain the speed of the engine constant irrespective of load on the plant. This is done by varying fuel supply to the engine according to load.

Advantages

- Diesel power plants can be quickly installed and commissioned.
- Quick starting.
- Requires minimum labour.
- Plant is smaller, operate at high efficiency and simple compared to steam power plant.
- It can be located near to load centres.

Disadvantages

- Capacity of plant is low.
- Fuel, repair and maintenance cost are high.
- Life of plant is low compared to steam power plant.
- Lubrication costs are very high.
- Not guaranteed for operation under continuous overloads.
- Noise is a serious problem in diesel power plant.
- Diesel power plant cannot be constructed for large scale.

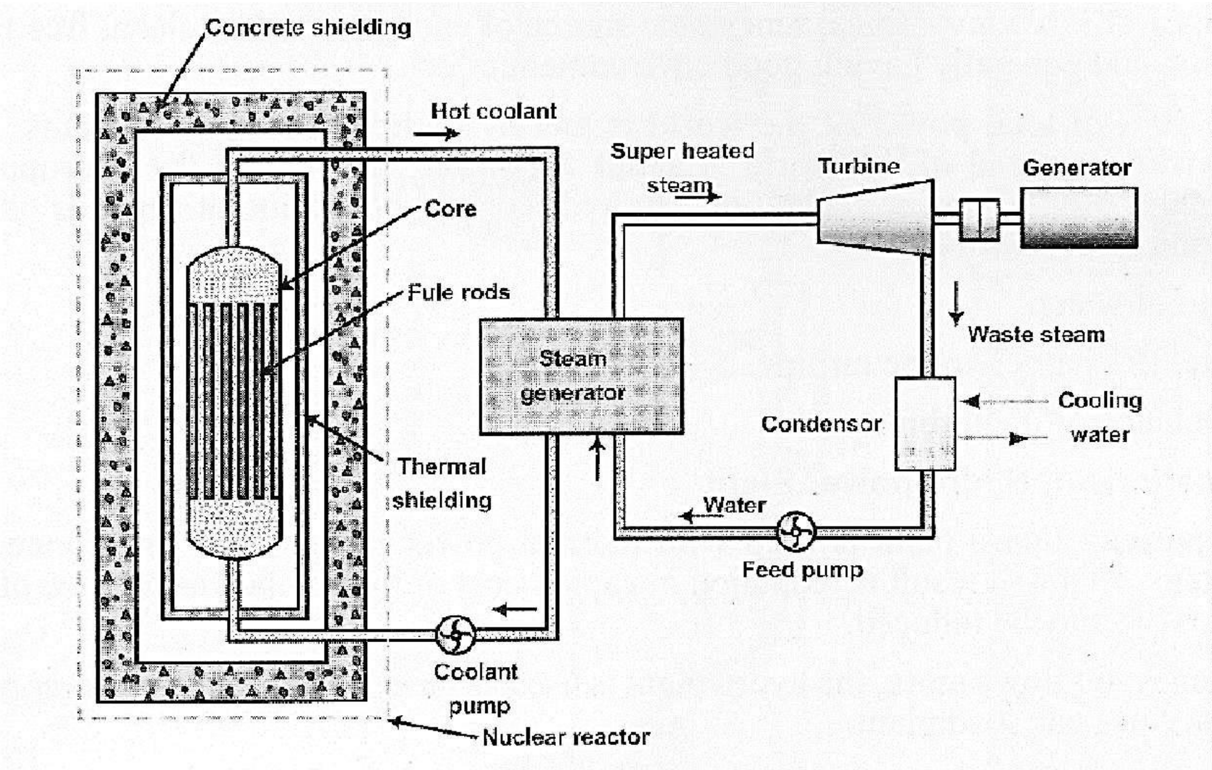
NUCLEAR POWER PLANTS

Nuclear power is the use of sustained or controlled **nuclear fission** to generate heat and do useful work. Nuclear Electric Plants, Nuclear Ships and Submarines use controlled nuclear energy to heat water and produce steam, while in space, nuclear energy decays naturally in a radioisotope thermoelectric generator. Scientists are experimenting with fusion energy for future generation, but these experiments do not currently generate useful energy.

Nuclear power provides about 6% of the world's energy and 13–14% of the world's electricity, with the U.S., France, and Japan together accounting for about 50% of nuclear generated electricity.

Also, more than 150 naval vessels using nuclear propulsion have been built. Just as many conventional thermal power stations generate electricity by harnessing the thermal energy released from burning fossil fuels, nuclear power plants convert the energy released from the nucleus of an atom, typically via nuclear fission.

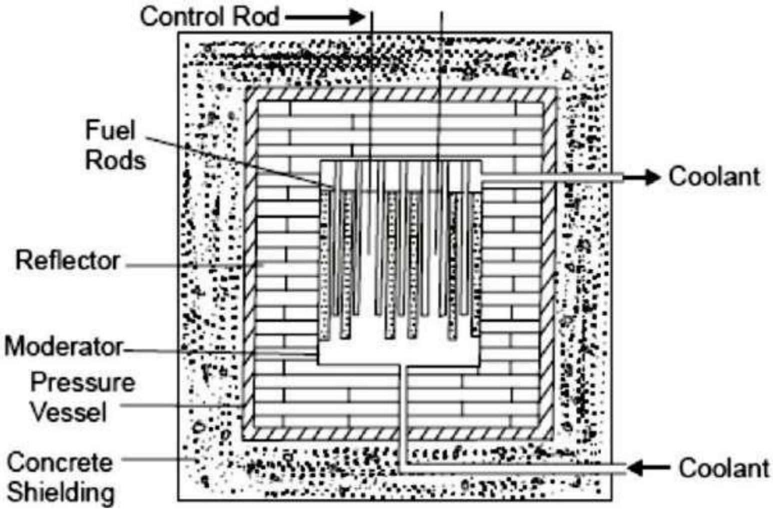
LAYOUT OF NUCLEAR POWER PLANT:



NUCLEAR REACTOR

A nuclear reactor is an apparatus in which heat is produced due to nuclear fission chain reaction. Fig. shows the various parts of reactor, which are as follows:

1. Nuclear Fuel
2. Moderator
3. Control Rods
4. Reflector
5. Reactors Vessel
6. Biological Shielding
7. Coolant.



Nuclear reactor

1. **Nuclear Fuel**

Fuel of a nuclear reactor should be fissionable material which can be defined as an element or isotope whose nuclei can be caused to undergo nuclear fission by nuclear bombardment and to produce a fission chain reaction. It can be one or all of the following U^{233}, U^{235} and Pu^{239}.

Natural uranium found in earth crust contains three isotopes namely U^{234}, $U2^{35}$ and U^{238} and their average percentage is as follows:

U^{238} - 99.3%

U^{235} - 0.7%

U^{234} - Trace

2. **Moderator**

In the chain reaction the neutrons produced are fast moving neutrons. These fast moving neutrons are far less effective in causing the fission of U235 and try to escape from the reactor. To improve the utilization of these neutrons their speed is reduced. It is done by colliding them with the nuclei of other material which is lighter, does not capture the neutrons but scatters them. Each such collision causes loss of energy, and the speed of the fast moving neutrons is reduced. Such material is called Moderator.

The slow neutrons (Thermal Neutrons) so produced are easily captured by the nuclear fuel and the chain reaction proceeds smoothly. Graphite, heavy water and beryllium are generally used as moderator

3. **Control Rods**

The Control and operation of a nuclear reactor is quite different from a fossil fuelled (coal or oil fired) furnace. The energy produced in the reactor due to fission of nuclear fuel during chain reaction is so much that if it is not controlled properly the entire core and surrounding structure may melt and radioactive fission products may come out of the reactor thus making it uninhabitable. This implies that we should have some means to control the power of reactor. This is done by means of control rods.

Control rods in the cylindrical or sheet form are made of boron or cadmium. These rods can be moved in and out of the holes in the reactor core assembly. Their insertion absorbs more neutrons and damps down the reaction and their withdrawal absorbs less neutrons. Thus power of reaction is controlled by shifting control rods which may be done manually or automatically.

4. **Reflector**

The neutrons produced during the fission process will be partly absorbed by the fuel rods, moderator, coolant or structural material etc. Neutrons left unabsorbed will try to leave the reactor core never to return to it and will be lost. Such losses should be minimized. It is done by surrounding the reactor core by a material called reflector which will send the neutrons back into the core. The returned neutrons can then cause more fission and improve the neutrons economy of' the reactor.

Generally the reflector is made up of graphite and beryllium.

5. **Reactor Vessel**

It is a. strong walled container housing the cure of the power reactor. It contains moderator, reflector, thermal shielding and control rods.

6. **Biological Shielding**

Shielding the radioactive zones in the reactor roan possible radiation hazard is essential to protect, the operating men from the harmful effects. During fission of nuclear fuel, alpha particles, beta particles, deadly gamma rays and neutrons are produced. Out of these gamma rays are of main significance. A protection must be provided against them. Thick layers of lead or concrete are provided round the reactor for stopping the gamma rays. Thick layers of metals or plastics are sufficient to stop the alpha and beta particles.

7. **Coolant**

Coolant flows through and around the reactor core. It is used to transfer the large amount of heat produced in the reactor due to fission of the nuclear fuel during chain reaction. The coolant either transfers its heat to another medium or if the coolant used is water it takes up the heat and gets converted into steam in the reactor which is directly sent to the turbine.

Advantages

- Need less space.
- Fuel consumption is small, hence transportation and storage charges are low.
- Well suited for large power demands.
- Less work men required.

Disadvantages

- Capital cost very high.
- Radioactive wastes, if not disposed properly have adverse effect on environment.
- Maintenance cost high.

GAS TURBINE POWER PLANTS

A gas turbine, also called a combustion turbine, is a type of internal combustion engine. It has an upstream rotating compressor coupled to a downstream turbine, and a combustion chamber in-between.

Energy is added to the gas stream in the combustor, where fuel is mixed with air and ignited. In the high pressure environment of the combustor, combustion of the fuel increases the temperature. The products of the combustion are forced into the turbine section. There, the high velocity and volume of the gas flow is directed through a nozzle over the turbine's blades, spinning the turbine which powers the compressor and, for some turbines, drives their mechanical output. The energy given up to the turbine comes from the reduction in the temperature and pressure of the exhaust gas.

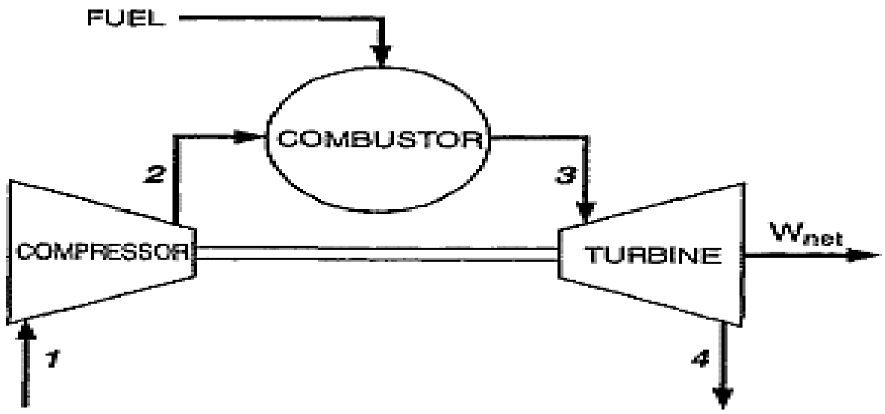
LAYOUT OF GAS TURBINE POWER PLANT

The gas turbine power plants which are used in electric power industry are classified into two groups as per the cycle of operation.

(1) Open cycle gas turbine.

(2) Closed cycle gas turbine.

Open cycle gas turbine



1- Atmospheric Air

2- Compressed Atmospheric Air

3- Fuel air mixture after compression

4- Exhaust gases.

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

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

Advantages

1. Warm-up time is very less.
2. Low weight and size.
3. Almost any hydrocarbon fuels can be used.
4. Open cycle plants occupy comparatively little space.
6. Very economical when compared to other plants.
7. Independent of separate cooling medium.

Disadvantages

1. The part load efficiency of the open cycle plant decreases rapidly as the considerable percentage of power developed by the turbine is used to drive the compressor.

2. The system is sensitive to the component efficiency; particularly that of compressor.

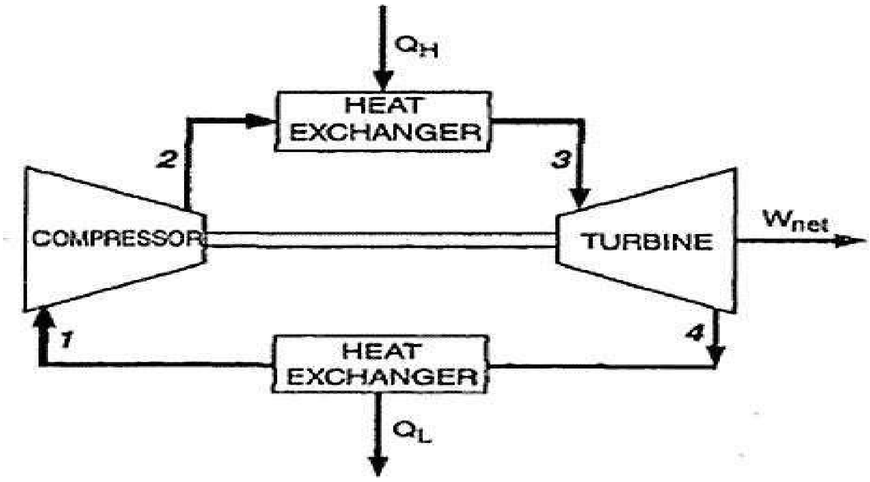
3. The open cycle plant is sensitive to changes in the atmospheric air temperature, pressure and humidity.

3. The open-cycle gas turbine plant has high air rate compared to the other cycles.

4. It is essential that the dust should be prevented from entering into the compressor.

5. The deposition of the carbon and ash on the turbine blades is not at all desirable as it also reduces the efficiency of the turbine.

Closed cycle gas turbine



1- Low Pressure Working Fluid @ Low temperature

2- High Pressure Working Fluid

3- Fuel + Working Fluid mixture @ High Pressure and Temperature

4- Low Pressure Working Fluid @ Temperature T4 < Temperature T3

In closed cycle gas turbine plant, the working fluid (air or any other suitable gas) coming out from compressor is heated in a heater by an external source at constant pressure.

The high temperature and high-pressure air coming out from the external heater is passed through the gas turbine. The fluid coming out from the turbine is cooled to its original temperature in the cooler using external cooling source before passing to the compressor.

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

Advantages

1. The closed cycle plant is not sensitive to changes in the atmospheric air temperature, pressure and humidity.
2. The closed cycle avoids erosion of the turbine blades due to the contaminated gases and fouling of compressor blades due to dust.
3. The need for filtration of the incoming air which is a severe problem in open cycle plant is completely eliminated.
4. Load variation is usually obtained by varying the absolute pressure and mass flow of the circulating medium, while the pressure ratio, the temperatures and the air velocities remain almost constant.
5. The density of the working medium can be maintained high by increasing internal pressure range, therefore, the compressor and turbine are smaller for their rated output. The high density of the working fluid further increases the heat transfer properties in the heat exchanger.
6. As indirect heating is used in closed cycle plant, the inferior oil or solid fuel can be used in the furnace and these fuels can be used more economically because these are available in abundance.
8. The maintenance cost is low and reliability is high due to longer useful life.

Disadvantages

1. The system is dependent on external means as considerable quantity of cooling water is required in the pre-cooler.
2. Higher internal pressures involve complicated design of all components and high quality material is required which increases the cost of the plant.
3. The response to the load variations is poor compared to the open-cycle plant.
4. It requires very big heat-exchangers as the heating of workings fluid is done indirectly.

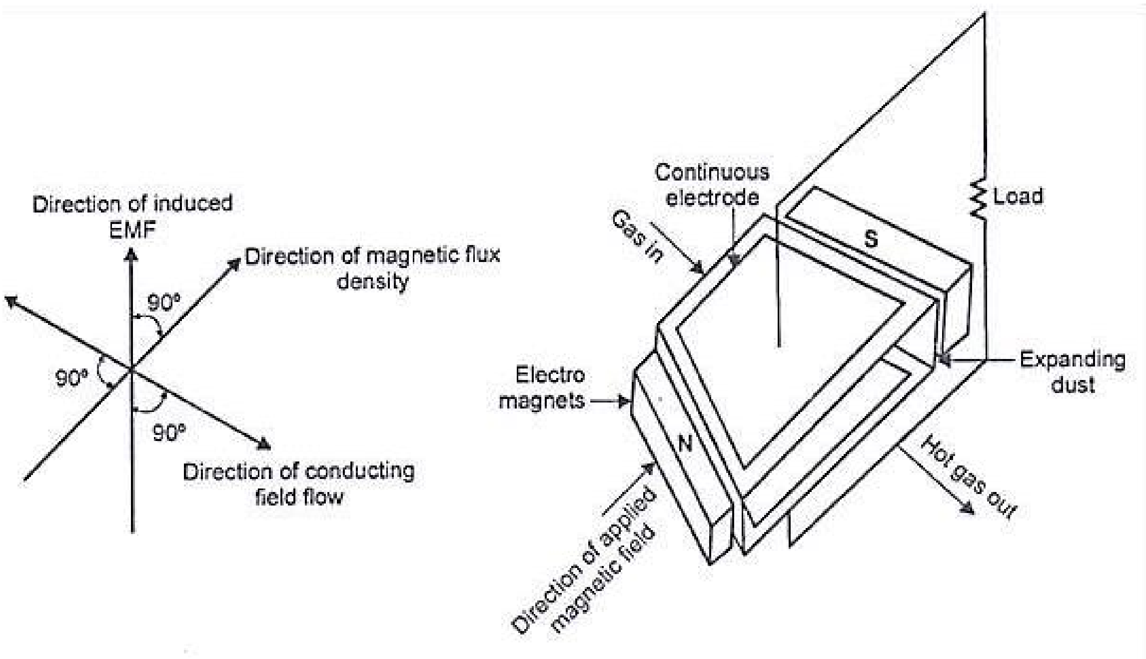
MAGNETO HYDRO DYNAMIC (MHD) POWER PLANTS

MHD power generation is a new system of electric power generation which is said to be of high efficiency and low pollution. In advanced countries MHD generator are widely used but in developing countries like India it is still under construction. This construction work is in progress at Tiruchirapalli in Tamilnadu under joint efforts of BARC (Bhabha Atomic Research Centre), BHEL, Associated Cement Corporation and Russian technologists.

As its name implies, magneto-hydro-dynamic (MHD) is concerned with the flow of conducting fluid in presence of magnetic and electric field. This fluid may be gas at elevated temperature or liquid metal like sodium or potassium.

A MHD generator is a device for converting heat energy of fuel directly into electric energy without a conventional electric generator. The basic difference between conventional generator and MHD generator is in the nature of conductor.

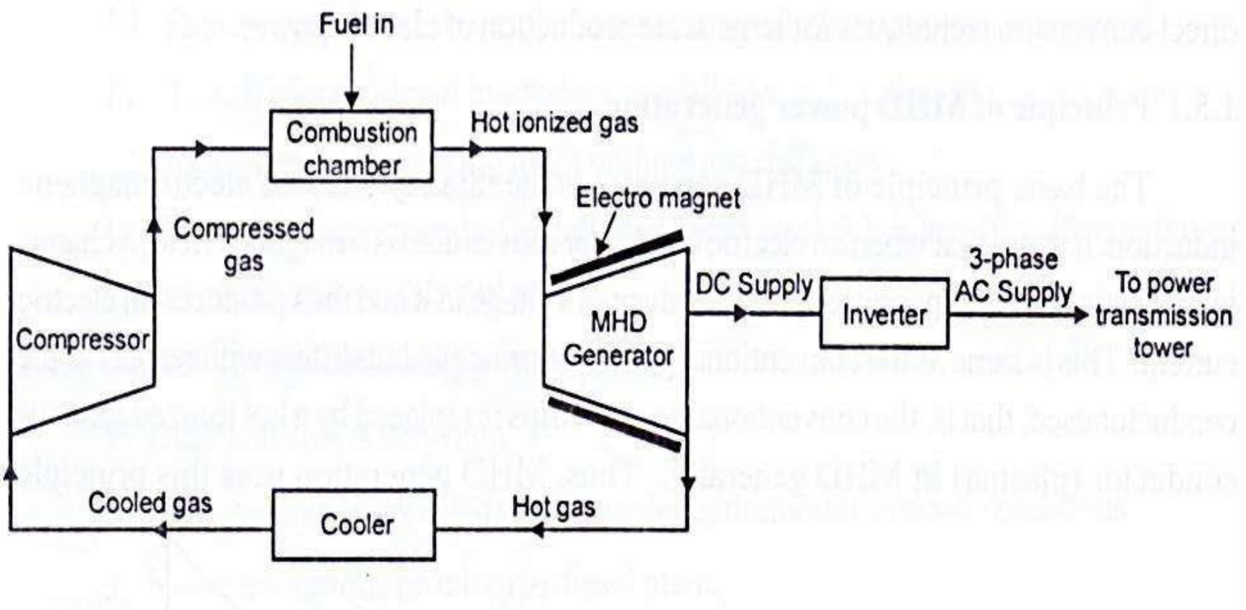
Principle of MHD Power Generation



When an electric conductor moves across a magnetic field; an emf is induced in it, which produced an electric current. This is the principle of the conventional generator also, where the conductors consists of copper strips.

In MHD generator the solid conductors are replaced by a gaseous conductor; i.e.an ionized gas. If such gas is passed at high velocity through a powerful magnetic field, a current is generated and can extract by placing electrodes in a suitable position in the stream.

LAYOUT OF MHD POWER PLANT



A MHD conversion is known as direct energy conversion because it produces electricity directly from heat source without the necessity of the additional stage of steam generation as in a steam power plant. An ionized gas is employed as a conducting field. Ionization is produced either by thermal means i.e. by an elevated temperature **or** by seeding with substance like cesium or potassium vapour which ionize at relatively low temperature.

The atom of seed element split off electrons. The presence of negatively charge electrons make the carrier gas an electrical conductor.

Advantages

1. Large amount of power is generated.
2. No moving parts, so more reliable.
3. Closed cycle system produces power, free of pollution.
4. Ability to reach its full power as soon as started.
5. Size of the plant is considerably small.
6. Low overall operation cost.
7. Better utilization of fuel.

Disadvantages

1. Needs very large magnets (high expensive).
2. Very high friction and heat transfer losses.
3. It suffers from the reverse flow of electrons through the conducting fluids around the ends of the magnetic field.

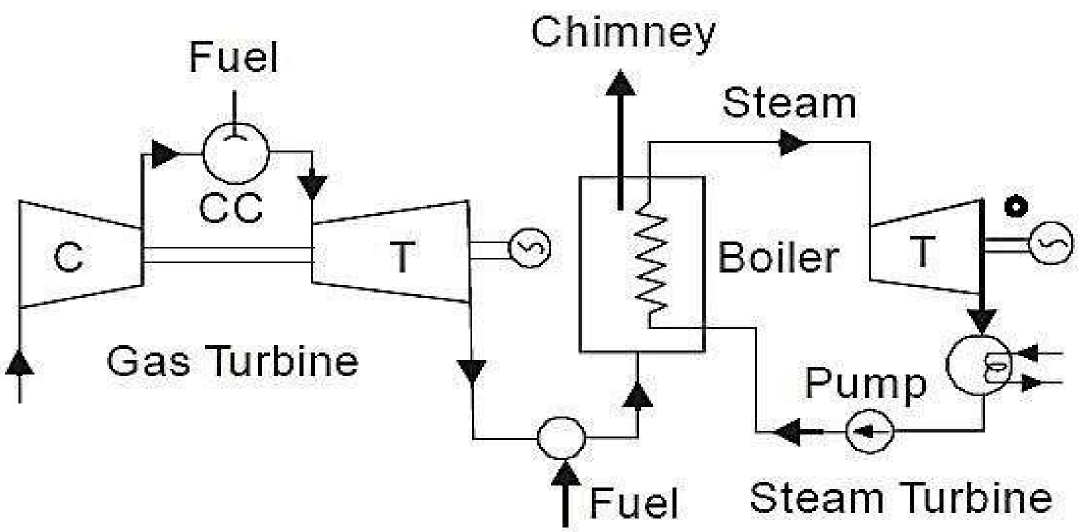
COMBINED POWER CYCLES

In electric power generation a **combined cycle** is an assembly of heat engines that work in tandem off the same source of heat, converting it into mechanical energy, which in turn usually drives electrical generators. The principle is that the exhaust of one heat engine is used as the heat source for another, thus extracting more useful energy from the heat, increasing the system's overall efficiency. This works because heat engines are only able to use a portion of the energy their fuel generates (usually less than 50%).

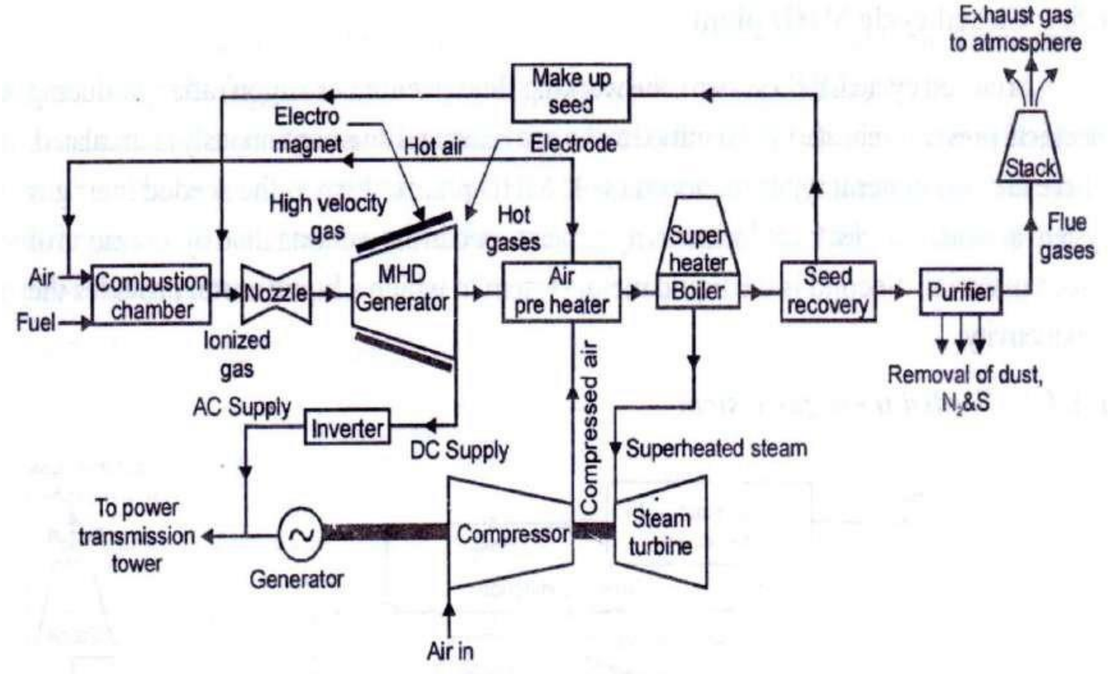
The objective of this approach is to use all of the heat energy in a power system at the different temperature levels at which it becomes available to produce work, or steam, or the heating of air or water, thereby rejecting a minimum of energy waste. The best approach is the use of combined cycles. There may be various combinations of the combined cycles depending upon the place or country requirements. Even nuclear power plant may be used in the combined cycles.

GT-ST Combined Power plants

It has been found that a considerable amount of heat energy goes as a waste with the exhaust of the gas turbine. This energy must be utilized. The complete use of the energy available to a system is called the total energy approach. The remaining heat (e.g., hot exhaust fumes) from combustion is generally wasted. Combining two or more thermodynamic cycle's results in improved overall efficiency, reducing fuel costs. In stationary power plants, a successful, common combination is the **Brayton cycle** (in the form of a turbine burning natural gas or synthesis gas from coal) and the **Rankine cycle** (in the form of a steam power plant). Multiple stage turbine or steam cylinders are also common.



ST-MHD Combined Power plants



Economics of Power Plant

Terms and Definitions

- **Connected load** – is the combined continuous rating of all the receiving apparatus on consumer's premises which is connected to the system or part of the system under consideration.
- **Demand** – It is the load expressed in (kW) that is drawn from the source of supply at the receiving terminals averaged over a suitable and specified interval of time.
- **Max demand or peak load** – is the greatest of all the demands that have occurred during a given period.
- **Load curve** – It is a graphic record showing the power demands for every instant during a certain time interval.

Reasons for fluctuations in load

- *Daily variation*
- *Weekly variation*
- *Season variation*
- *Random variation*
- *Long term growth.*

Load Profile

- ***A load profile is a graph of the variation in the electrical load versus time, and it will vary according to* customer type.** (residential, commercial and industrial)
- **Load curve** is a chart showing **the amount of electricity customers use over a period of time.** Generation companies use this information to **plan how much power** they will need to generate at any given time.
- **Load duration curve** is similar to a load curve. The information is the same but is presented in a different form. These curves are useful in the **selection of generator units** for supplying electricity.

- Load Curves
- Daily Demand Curves
- Load Variation

Factors of Performance and Variation

- Load factor (LF)
- Capacity factor (CF)
- Utility factor (UF)
- Diversity factor (DrF)
- Availability factor (AF)
- Demand factor (DF)
- Plant use factor (PuF)

Load Factor (LF)

Load factor is defined as ***"the ratio of the average load demanded to the peak load demanded during a certain prescribed period of time"***

LF is usually less than (1), however, HIGH LF is desirable for :

- That the total capacity of the plant is utilized for the max period of time.
- High LF means greater average load , which mean that more power units (kWhr) may be generated for a given max demand.
- The fixed cost which is proportional to the max demand can be distributed over a greater number of power units (kWhr) supplied.
- All of the above will lower cost of electricity being generated and supplied.
- *LF –applied to power users and consumers*

$$LF = \frac{\text{Average load demanded at } \Delta tx}{\text{Peak load demanded at } \Delta tx}$$

$$LF = \frac{\text{Energy consumed during } \Delta tx}{\text{Maximum demand x } \Delta tx}$$

Capacity Factor (CF)

- Capacity factor is *defined* as "the ratio of the actual o/p of a power plant over a period of time to it's o/p if it had operated at full rated capacity during the same period of time."
- CF –applied to power generation system.

Capacity Factor = $\frac{\text{Actual output during ti}}{\text{Output that could be produced at the rated plant operation during ti}}$

ACF = $\frac{\text{Annual kWhr produced}}{\text{Plant capacity (kW) x (hr/year)}}$

- ***Is capacity factor the same as efficiency?***

✓ ***No**, and they are not really related. Efficiency is the ratio of the useful output to the effort input –in this case, the input and the output are energy. The types of efficiency are thermal, mechanical and electrical efficiencies.*

✓ *These efficiencies account for losses, most of which turn into heat in the atmosphere and water. For instance, the average efficiency of the US electricity generation infrastructure is about 35% –this is because in most thermal plants, about two thirds of the input energy is wasted as heat into the environment. A higher capacity factor is not an indicator of higher efficiency or vice versa.*

➢ ***Is a higher capacity factor "better"?***

✓ *Yes, within a given technology or a given plant, you can generally say that a higher capacity factor is better and in particular, more economical.*

✓ *But it does not make sense to compare capacity factors across technologies, because the economics of both production and capacity are so different from one technology to the next –the capacity factor is just one of many factors in judging if a power plant is feasible. Instead, more useful is to compare the cost of producing energy among the various technologies.*

Reserve Capacity (RC)

- Reserve capacity (RC) is defined as "the difference between the total rated capacity of all the units in the grid network and the expected peak demand of the system"
- The plant reserve capacity can be approximated as in the following expression:

$$RC = LF - CF$$

- Where normal values of (RC) usually maintained at about 20%

Utility Factor (UF)

Utility Factor is defined as "the ratio of maximum demand of a plant to the rated capacity of the plant"

- **Utility Factor** = $\frac{\textbf{Maximum demand of the plant}}{\textbf{Rated capacity of the plant}}$
- **Maximum Demand = Maximum Load x LF**

Diversity Factor (DrF)

- Consider a group of consumers, each individual in the group had a max demand at a certain time.
- The max demand of the group individuals most probably may not occur at one time, but at different instant of time. So:

1. Each individual has his own max demand.

2. Selecting this max demand value of each individual and sum them up to get the total max demand value of the group, and let this be equal to (x)

3. Selecting the highest max demand value among the group individual, and let this be (y)

4. The diversity factor DrF is

$$\text{Diversity Factor} = \frac{\Sigma\ (\text{maximum demand})_1 + (\text{maximum demand})_2 + \text{etc}}{\text{Highest maximum demand among the group}}$$

- *DrF= x/y*
- Where (DrF> 1) always; High DrFis desirable, and it means “low max demand on the plant for a given number of consumers.

Availability Factor (AF)

- It is known as ‘the plant operating factor’ and it is defined as “the ratio of the time period in which the plant was in operation to the total time period considered.”
- This simply means that plant availability is plant available to be used for actual running or as stand-by.
- Stand-by is not really working status, it is nevertheless, available to be used instantly when being required.
- Therefore, total availability time is the sum of the running plus the stand-by time

$$\text{Availability Factor} = \frac{\text{Time period the plant in operation}}{\text{Total time intervals}}$$

$$\text{Availability Factor} = \frac{\text{Running time}}{\text{Time running + time standby + stoppage time}}$$

Demand Factor (DF)

- The ratio of the maximum real power consumed by a system to the maximum real power that would be consumed if the entire load connected to the system were to be activated at the same time.

- For a consumer, the demand factor is “the ratio of it’s max demand to the connected load.
- Max demand is the max load (in kW) which a consumer uses at any time.
- Connected load is the total rating (in kW) of the various electrical equipment installed in a consumer’s premises.

$$\text{Demand Factor} = \frac{\text{maximum demand of consumer}}{\text{connected load}}$$

- The actual max demand of a consumer is almost always less than his connected load from the grid, as all of his residential appliances may not be in operation at the same time.
- DF is usually less than (1), but can be equal to (1)
- $DF \leq 1$

Plant Use Factor (PuF)

- PuF is different from CF in that the actual operation power is considered.

$$\text{annual PuF} = \frac{\text{annual (kWhr) produced}}{\text{plant capacity} \times \text{hrs. of plant operation}}$$

Electricity Power Generation Cost

- This is the cost of new power plant to be constructed, where such costs are divided into three categories :

1.Capital cost

2.Operating & maintenance cost

3.Fuel cost

These costs are often expressed in **unit currency per kWh** of power produced.

The cost to the consumer for electric energy charge can be roughly approximated according to :

- Generation –60%
- Transmission –10%
- Distribution –20%
- Administrative/Profit –10%
- Capital Cost

Most difficult to compute due to the large expenditure and time period involved. However, for simplification, capital cost can be divided into two main categories :

A-initial costs

- *1.Land* *2.Buildings*
- *3. Equipment* *4. Installation*
- *5. Overall charges : 'transportation –stores -keeping –interest …etc'*

B - Economic charges

- *1. Interest rate*
- *2. Depreciation :physical → wear & tear –corrosion –aging …functional → change of process technical advancement.*
- *3. Taxes* *4. insurance*

Fuel Cost

- To produce a given amount of electricity can be determine Annual thermal heat required as : $E = \dot{m}f \times HHV \times \eta th$
- The annual fuel cost is determined from the amount of fuel used and it's cost per unit of such amount, i.e: **Fuel cost = ṁf x fuel cost**
- From above the fuel **cost of electricity** production can be expressed as :

  $ef = \text{fuel cost} / E = \dot{m}f \times \text{fuel cost} / \dot{m}f \times HHV \times \eta th = \text{cost} / HHV \times \eta th$

Where, **E** –power produced (kWh/yr); **HHV** –fuel heating value (kJ/kg);

ṁf – fuel annual consumption rate (ton/yr); **ηth** – plant thermal efficiency;

cost – cost of unit mass of fuel (INR/ton)

Operation & Maintenance Cost

Labor costs (wages & salaries): These will depend on the manning levels and degree of automation of the plant, as well as the living standard.

Maintenance charges: Maintenance costs as an average over the plant life (based on previous experience and guidance) should be sought from the manufacturer

Electric Power Produced (EPP): To simplify cost estimation, a new term "electric power produced" will be presented which is usually expressed per one year.

Therefore EPP for one year

- **EPP = Prt. CF . t (kWh)**

Prt – nominal power plant rating (kW); **CF** –plant capacity factor; **t** - hrs/yr = 8760 hrs/yr

The EPP is very useful term, as cost of power generation is related to it, and so the overall power generation cost (OPGC) is generally expressed as:

$$\mathbf{OPGC} = \frac{\textbf{Capital cost + O\&M + fuel cost}}{\textbf{EPP}}$$

UNTI-II

STEAM POWER PLANT

A **steam power plant** *converts the chemical energy of the fossil fuels (coal, oil, gas) into mechanical / electrical energy*. This is achieved by raising the steam in the boilers, expanding it through the turbines and coupling the turbines to the generators which convert mechanical energy to electrical energy as shown in Fig. 2.1.

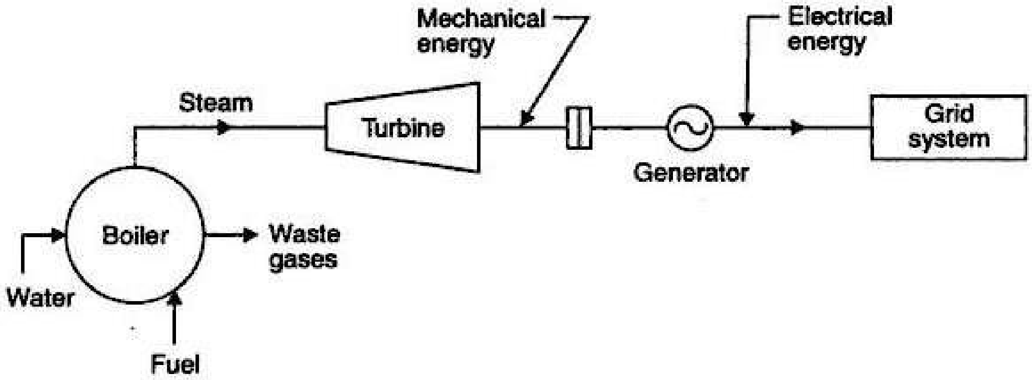


Fig. 2.1. Production of electric energy by steam power plant.

The following two purposes can be served by a steam power plant :

1. To produce electric power.

2. To produce steam for industrial purposes besides producing electric power. The steam may be used for varying purposes in the industries such as *textiles, food manufacture, paper mills, sugar mills* and *refineries* etc.

CLASSIFICATION OF STEAM POWER PLANTS

The steam power plants may be *classified* as follows :

1. Central stations.

2. Industrial power stations or captive 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.

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 required for different manufacturing operations.

In the *condensing steam power plants* the following *advantages* accrue :

(*i*) The amount of energy extracted per kg of steam is *increased* (a given size of the engine or turbine develops more power).

(*ii*) The steam which has been condensed into water in the condenser, can be recirculated to the boilers with the help of pumps.

In non-condensing steam power plants a continuous supply of fresh feed water is required which becomes a problem at places where there is a shortage of pure water.

2.3. LAYOUT OF A MODERN STEAM POWER PLANT

Refer Fig. 2.2. The layout of a modern steam power plant comprises of the following *four circuits* :

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

The brief descripation of these circuits is given below :

1. **Coal and ash circuit.** Coal arrives at the storage yard and after necessary handling, passes on to the furnaces through the *fuel feeding device.* Ash resulting from combustion of coal collects at the back of the boiler and is removed to the ash storage yard through *ash handling equipment.*

2. **Air and gas circuit.** Air is taken in from atmosphere through the action of a forced or induced draught fan and passes on to the furnace through the *air preheater*, where it has been heated by the heat of flue gases which pass to the chimney *via* the preheater. The flue gases after passing around boiler tubes and superheater tubes in the furnace pass through a *dust* catching device or precipitator, then through the economiser, and finally through the air preheater before being exhausted to the atmosphere.

3. **Feed water and steam flow circuit.** In the water and steam circuit condensate leaving the condenser is first heated in a closed feed water heater through extracted steam from the lowest pressure extraction point of the turbine. It then passes through the *deaerator* and a few more water heaters before going into the boiler through *economiser.*

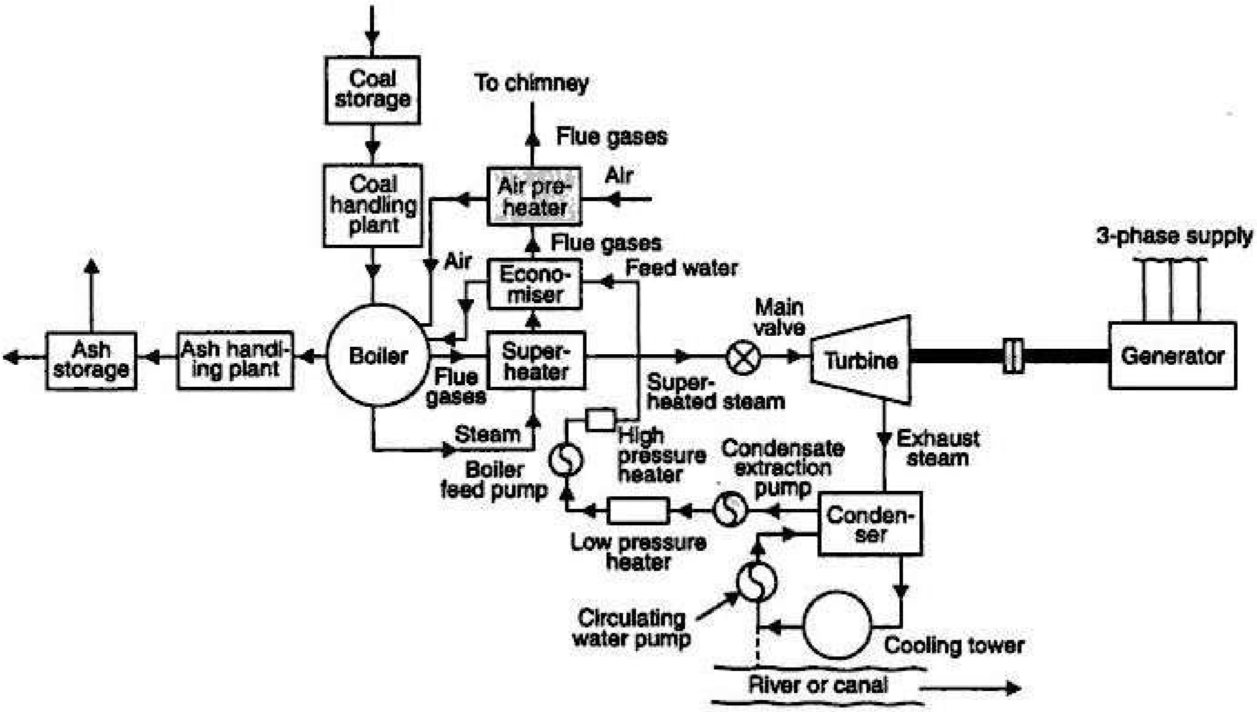


Fig. 2.2. Layout of a steam power plant.

In the boiler drum and tubes, water circulates due to the difference between the density of water in the lower temperature and the higher temperature sections of the boiler. Wet steam from the drum is further heated up in the superheater before being supplied to the primemover. After expanding in high pressure turbine steam is taken to the reheat boiler and brought to its original dryness or superheat before being passed on to the low pressure turbine. From there it is exhausted through the condenser into the hot well. The condensate is heated in the feed heaters using the steam trapped (bled steam) from different points of turbine.

A part of steam and water is lost while passing through different components and this is compensated by supplying additional feed water. This feed water should be purified before hand, to avoid the scaling of the tubes of the boiler.

4. **Cooling water circuit.** The cooling water supply to the condenser helps in maintaining a low pressure in it. The water may be taken from a natural source such as river, lake or sea or the same water may be cooled and circulated over again. In the later case the cooling arrangement is made through spray pond or cooling tower.

Components of a Modern Steam Power Plant :

A modern steam power plant consists of the following *components* :

1. Boiler
   - (*i*) Superheater
   - (*ii*) Reheater
   - (*iii*) Economiser
   - (*iv*) Air-heater
2. Steam turbine
3. Generator
4. Condenser
5. Cooling towers
6. Circulating water pump
7. Boiler feed pump
8. Wagon tippler
9. Crusher house
10. Coal mill
11. Induced draught fans
12. Ash precipitators
13. Boiler chimney
14. Forced draught fans
15. Water treatment plant
16. Control room
17. Switch yard.

ESSENTIAL REQUIREMENTS OF STEAM POWER STATION DESIGN

The *essential requirements of steam power station design are* :

1. Reliability.
2. Minimum capital cost.
3. Minimum operating and maintenance cost.
4. Capacity to meet peak load effectively.
5. Minimum losses of energy in transmission.
6. Low cost of energy supplied to the consumers.
7. Reserve capacity to meet future demands.

The above essential requirements depend to a large extent on the following :

(*i*) Simplicity of design.
(*ii*) Subdivision of plant and apparatus.
(*iii*) Use of automatic equipment.
(*iv*) Extensibility.

2.5. SELECTION OF SITE FOR STEAM POWER STATION

The following points should be taken into consideration while *selecting the site* for a steam power station :

1. Availability of raw material.
2. Nature of land.
3. Cost of land.
4. Availability of water.
5. Transport facilities.
6. Ash disposal facilities.
7. Availability of labour.
8. Size of the plant.
9. Load centre.
10. Public problems.
11. Future extensions.

2.8.4. Coal Handling

Refer to Fig. 2.8.

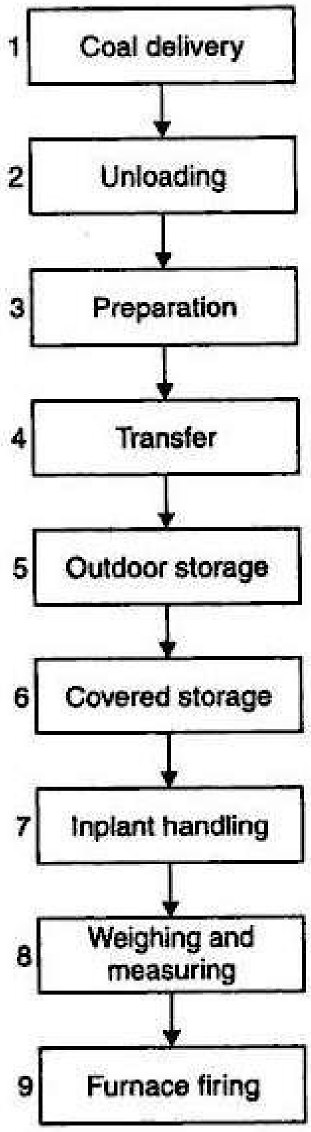


Fig. 2.8. Various stages in coal handling.

The following *stages / steps* are involved in handling the coal :

1. Coal delivery
2. Unloading
3. Preparation
4. Transfer
5. Storage of coal
6. In-plant handling
7. Weighing and measuring
8. Furnace firing.

Fig. 2.9 shows the outline of coal handling equipment.

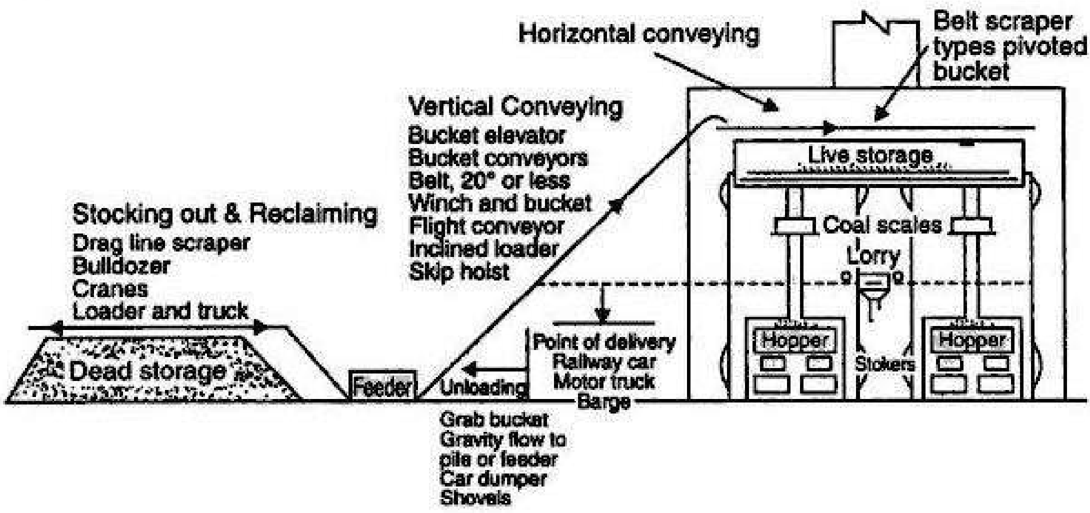


Fig. 2.9. Outline of coal handling equipment.

2.8.5. Layout of a Fuel Handling Equipment

Fig. 2.10 shows a schematic layout of a fuel handling equipment of a modern steam power plant where coal (a solid fuel) is used. Brief description is as follows :

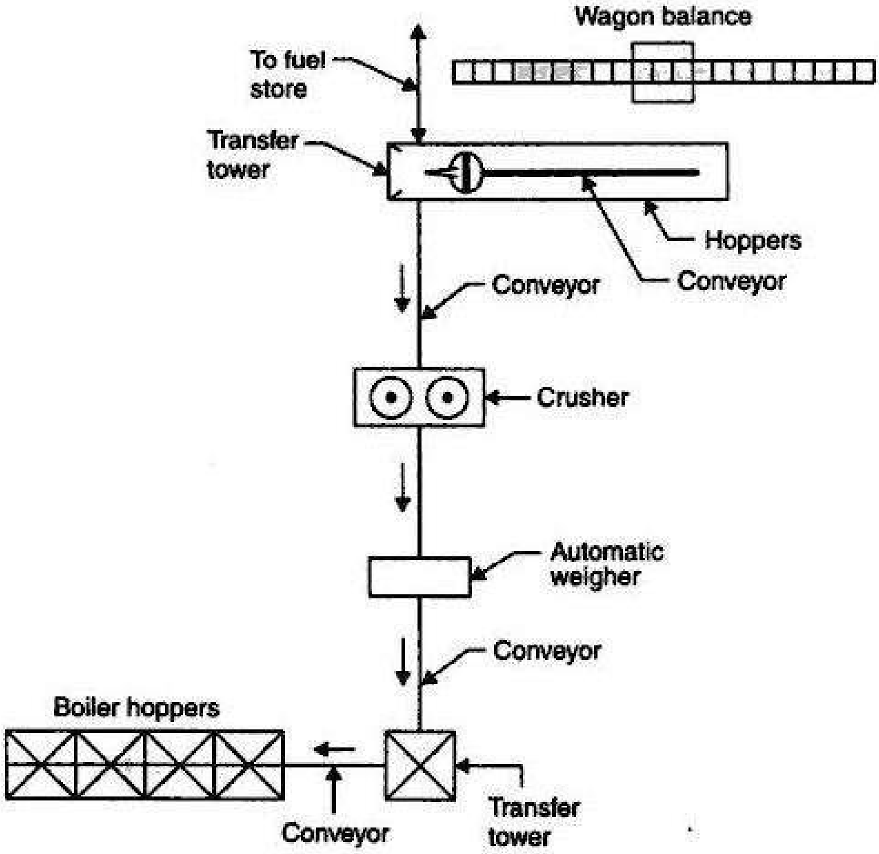


Fig. 2.10. Layout of a fuel handling equipment.

— Coal is supplied to the power plant in railway wagons.
— After weighing on wagon balance the coal is then unloaded into underground hoppers or bunkers. The wagon can be unloaded either manually or through rotary wagon tipplers.
— From the bunkers, the coal is lifted by conveyor to the transfer tower from where it can be delivered either to the fuel store or by a conveyor to a crusher.
— The coal is then passed through the magnetic separators and screens and crushed in crushers into pieces 25 to 30 mm in size for stoker firing and 10 to 20 mm when pulverished fuel is fired in boiler furnaces. The crushed coal in the later case is *milled to a fine powder* and then it is carried through automatic weigher to a transfer tower where fuel is lifted and distributed between boiler hoppers by a conveyor.

2.9. COMBUSTION EQUIPMENT FOR STEAM BOILERS

2.9.1. General Aspects

The combustion equipment is a component of the steam generator. Since the source of heat is the combustion of a fuel, a working unit must have, whatever, equipment is necessary to receive the fuel and air, proportioned to each other and to the boiler steam demand, mix, ignite, and perform any other special combustion duties, such as distillation of volatile from coal prior to ignition.

- *Fluid fuels are handled by burners ; solid lump fuels* by *stokers*.
- In boiler plants hand firing on grates is *practically unheard* of nowdays in new plants, although there are many small industrial plants still in service with hand firing.
- The fuels are mainly bituminous coal, fuel oil and natural gas mentioned in order of importance. All are composed of hydrocarbons, and coal has, as well, much fixed carbon and little sulphur. To burn these fuels to the desired end products, CO_2 and H_2O, requires (*i*) *air in sufficient proportions*, (*ii*) *a good mixing of the fuel and air*, (*iii*) *a turbulence* or *relative motion between fuel and air*. The combustion equipment *must fulfill these requirements and, in addition, be capable of close regulation of rate of firing the fuel, for boilers which ordinarily operate on variable load*. Coal-firing equipment *must also have a means for holding and discharging the ash residue*.

The basic requirements of combustion equipment :

1. Thorough mixing of fuel and air.
2. Optimum fuel-air ratios leading to most complete combustion possible maintained over full load range.
3. Ready and accurate response of rate of fuel feed to load demand (usually as reflected in boiler steam pressure).
4. Continuous and reliable ignition of fuel.
5. Practical distillation of volatile components of coal.
6. Adequate control over point of formation and accumulation of ash, when coal is the fuel.

Natural gas is used as a boiler fuel in gas well regions where fuel is relatively cheap and coal sources comparatively distant. The transportation of natural gas over land to supply cities with domestic and industrial heat has made the gas in the well more valuable and the gas-fired steam generator more difficult to justify in comparison with coal, or fuel cost alone. Cleanliness and convenience in use are other criteria of selection, but more decisive in small plants in central power stations.

Transportation costs add less to the delivery price of oil than gas ; also fuel oil may be stored in tanks at a reasonable cost, whereas, gas cannot. Hence although fuel oil is usually more costly than coal per kg of steam generated, many operators select fuel oil burners rather than stokers because of the simplicity and cleanliness of storing and transporting the fuel from storage to burner.

Depending on the type of combustion equipment, boilers may be *classified* as follows :

1. Solid fuels fired :

(*a*) Hand fired

(*b*) Stoker fired

(*i*) Overfeed stokers

(*ii*) Underfeed strokers.

(*c*) Pulverised fuel fired

(*i*) Unit system

(*ii*) Central system

(*iii*) Combination of (*i*) and (*ii*).

2. Liquid fuel fired :

(*a*) Injection system

(*b*) Evaporation system

(*c*) Combination of (*a*) and (*b*).

3. Gaseous fuel fired :

(*a*) Atmospheric pressure system

(*b*) High pressure system.

2.9.2. Combustion Equipment for Solid Fuels—Selection Considerations

While selecting combustion equipment for solid fuels the following *considerations* should be taken into account :

1. Initial cost of the equipment.
2. Sufficient combustion space and its ability to withstand high flame temperature.
3. Area of the grate (over which fuel burns)
4. Operating cost
5. Minimum smoke nuisance.
6. Flexibility of operation.
7. Arrangements for thorough mixing of air with fuel for efficient combustion.

2.9.3. Burning of Coal

The two most commonly used methods for the burning of coal are :

1. Stroker firing
2. Pulverised fuel firing.

The selection of one of the above methods depends upon the following *factors* :

(*i*) Characteristics of the coal available.

(*ii*) Capacity of the boiler unit.

(*iii*) Load fluctuations.

(*iv*) Station load factor.

(*v*) Reliability and efficiency of the various types of combustion equipment available.

2.9.3.1. Stoker Firing

A **"stoker"** *is a power operated fuel feeding mechanism and grate.*

Advantages of stoker firing :

1. A cheaper grade of fuel can be used.

2. A higher efficiency attained.
3. A greater flexibility of operations assured.
4. Less smoke produced.
5. Generally less building space is necessary.
6. Can be used for small or large boiler units.
7. Very reliable, maintenance charges are reasonably low.
8. Practically immune from explosions.
9. Reduction in auxiliary plant.
10. Capital investment as compared to pulverised fuel system is less.
11. Some reserve is gained by the large amount of coal stored on the grate in the event of coal handling plant failure.

Disadvantages :

1. Construction is complicated.
2. In case of very large units the initial cost may be rather higher than with pulverised fuel.
3. There is always a certain amount of loss of coal in the form of riddling through the grates.
4. Sudden variations in the steam demand cannot be met to the same degree.
5. Troubles due to slagging and clinkering of combustion chamber walls are experienced.
6. Banking and standby losses are always present.
7. Structural arrangements are not so simple and surrounding floors have to be designed for heavy loadings.
8. There is excessive wear of moving parts due to abrasive action of coal.

Classification of stoker firing :

Automatic stokers are *classified* as follows :

1. Overfeed stokers.
2. Underfeed stokers.

In case of overfeed stokers, the coal is fed into the grate *above* the point of air admission and in case of underfeed stokers, the coal is admitted into the furnace *below* the point of air admission.

1. Overfeed stokers :

Principle of operation. Refer to Fig. 2.11. The principle of an overfeed stoker is discussed below :

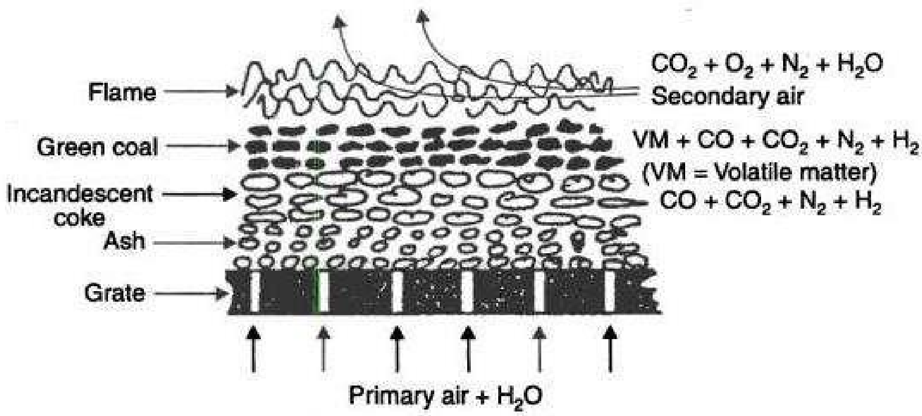


Fig. 2.11. Principle of overfeed stoker.

The fuel bed section receives fresh coal on top surface. The ignition plane lies between green coal and incandescent coke.

The air (with its water vapour content from atmosphere) enters the bottom of the grate under pressure. In flowing through the grate opening the air is heated while it cools the grate. The warm air then passes through a layer of hot ashes and picks up the heat energy.

The region immediately above the ashes contains a mixture of incandescent coke and ash, coke content increasing in upward direction. As the air comes in contact with incandescent coke, the oxygen reacts with carbon to form carbondioxide. Water vapour entering with the air reacts with coke to form CO_2, CO and free H_2. Upon further travel through the incandescent region some of the CO_2 reacts with coke to form CO. Hence no free O_2 will be present in the gases leaving the incandescent region.

Fresh fuel undergoing distillation of its volatile matter forms the top-most layer of the fuel bed. Heat for distillation and eventually ignition comes from the following *four sources* :

(*i*) By conduction from the incandescent coke below.

(*ii*) From high temperature gases diffusing through the surface of the bed.

(*iii*) By radiation from flames and hot gases in the furnace.

(*iv*) From the hot furnace walls.

The ignition zone lies directly below the raw fuel undergoing distillation.

To burn the combustible gases, additional secondary air must be fed into the furnace to supply the needed oxygen. The secondary air must be injected at considerable speed to create turbulence and to penetrate to all parts of the area above the fuel bed. The combustible gases then completely burn in the furnace.

Fuel, coke and ash in the fuel bed move in direction opposite to that of air and gases. Raw fuel continually drops on the surface of the bed. The rising air feed cools the ash until it finally rests in a plane immediately adjacent to the grate.

Types of overfeed stokers

The "overfeed stokers" are used for large capacity boiler installation where the coal is burnt with pulverisation.

These stokers are mainly of following two types :

(*i*) Travelling grate stoker

(*a*) Chain grate type (*b*) Bar grate type

(*ii*) Spreader stoker.

(i) Travelling grate stoker :

These stokers may be *chain grate type or bar grate type*. These two differ only in the details of grate construction.

Fig. 2.12 shows a **"Chain grate stoker"**.

A chain grate stoker consists of flexible endless chain which forms a support for the fuel bed. The chain travels over two sprocket wheels one at the front and one at the rear of furnace. The front sprocket is connected to a variable speed drive mechanism. The speed of the stroker is 15 cm to 50 cm per minute.

The coal bed thickness is shown for all times by an index plate. This can be regulated either by adjusting the opening of fuel grate or by the speed control of the stoker driving motor.

The air is admitted from the underside of the grate which is divided into several compartments each connected to an air duct. The grate should be saved from being overheated. For this, coal should have sufficient ash content which will form a layer on the grate.

Since there is practically no agitation of the fuel bed, non-coking coals are best suited for chain grate stokers.

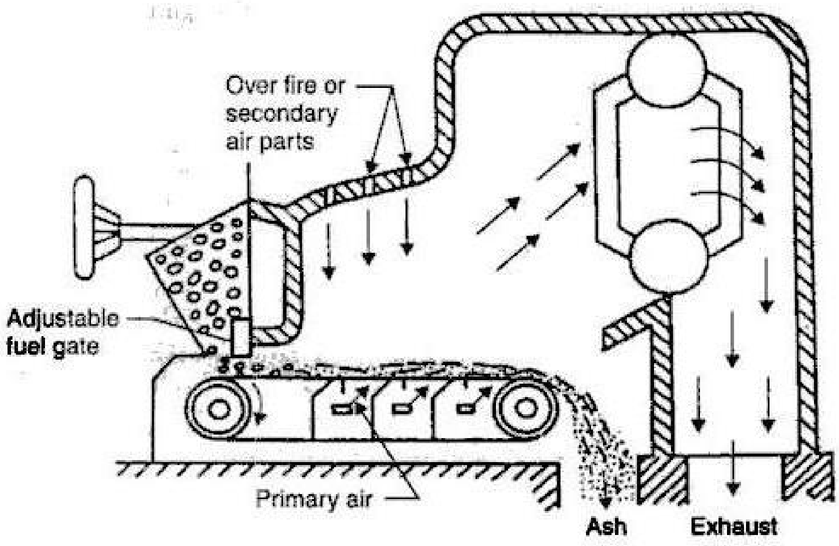


Fig. 2.12. Chain grate stoker.

The rate of burning with this stoker is 200 to 300 kg per m^2 per hour when forced draught is used.

Advantages of chain grate stoker :

1. Simple in construction.
2. Initial cost low.
3. Maintenance charges low.
4. Self-cleaning stoker.
5. Gives high release rates per unit volume of the furnace.
6. Heat release rates can be controlled just by controlling the speed of chain.

Disadvantages :

1. Preheated air temperatures are limited to 180°C maximum.
2. The clinker troubles are very common.
3. There is always some loss of coal in the form of fine particles through riddlings.
4. Ignition arches are required (to suit specific furnace conditions).
5. This cannot be used for high capacity boilers (200 tonnes/hr or more).

(ii) Spreader stoker. Refer to Fig. 2.13.

- In this type of stoker the coal is not fed into furnace by means of grate. The function of the grate is only to support a bed of ash and move it out of the furnace.
- From the coal hopper, coal is fed into the path of a rotor by means of a conveyer, and is thrown into the furnace by the rotor and is *burnt in suspension*. The *air for combustion* is supplied through the holes in the grate.
- The *secondary air* (or overfire *air*) to *create turbulence and supply oxygen for thorough combustion of coal* is supplied through *nozzles* located directly above the ignition arch.
- Unburnt coal and ash are deposited on the grate which can be moved periodically to remove ash out of the furnace.
- Spreader stokers *can burn any type of coal.*

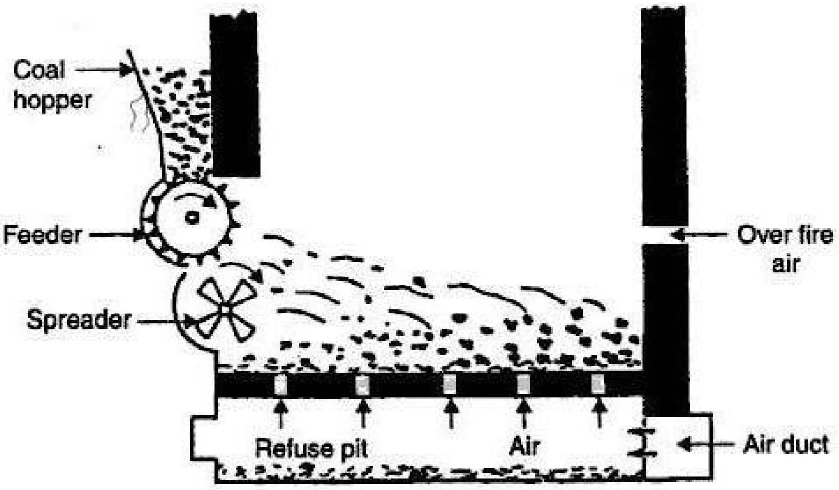


Fig. 2.13. Spreader stoker.

- This type of stoker can be used for boiler capacities from 70000 kg to 140000 kg of steam per hour. The heat release rate of 10×10^6 k cal/m^2-hr is possible with *stationary grate* and of 20×10^6 k cal/m^2-hr is possible with *travelling grate*.

Advantages :

1. A wide variety of coal can be burnt.
2. This stoker is simple to operate, easy to light up and bring into commission.
3. The use of high temperature preheated air is possible.
4. Operation cost is considerably low.
5. The clinking difficulties are reduced even with coals which have high clinkering tendencies.
6. Volatile matter is easily burnt.
7. Fire arches etc. are generally not required with this type of stokers.
8. As the depth of coal bed on the grate is usually limited to 10 to 15 cm only, fluctuating loads can be easily met with.

Disadvantages :

1. It is difficult to operate spreader with varying sizes of coal with varying moisture content.
2. Fly-ash is much more.
3. No remedy for clinker troubles.
4. There is a possibility of some fuel loss in the cinders up the stack because of the thin fuel bed and suspension burning.

2. Underfeed feeders :

Principle of operation. Refer to Fig. 2.14 (*a*).

- *The underfeed principle is suitable for burning the semi-bituminous and bituminous coals.*
- Air entering through the holes in the grate comes in contact with the raw coal (green coal). Then it passes through the incandescent coke where reactions similar to overfeed system take place. The gases produced then pass through a layer of ash. The secondary air is supplied to burn the combustible gases.

The underfeed stokers fall into two main groups, the *single retort* and *multi-retort stokers*.

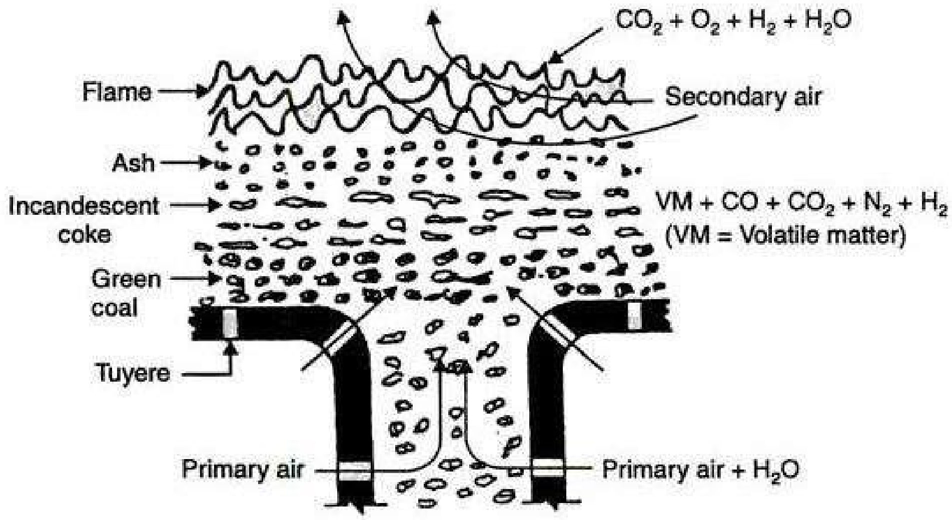


Fig. 2.14. (*a*) Principle of underfeed feeders.

Multi-retort underfeed stokers :

Refer to Fig. 2.14 (*b*).

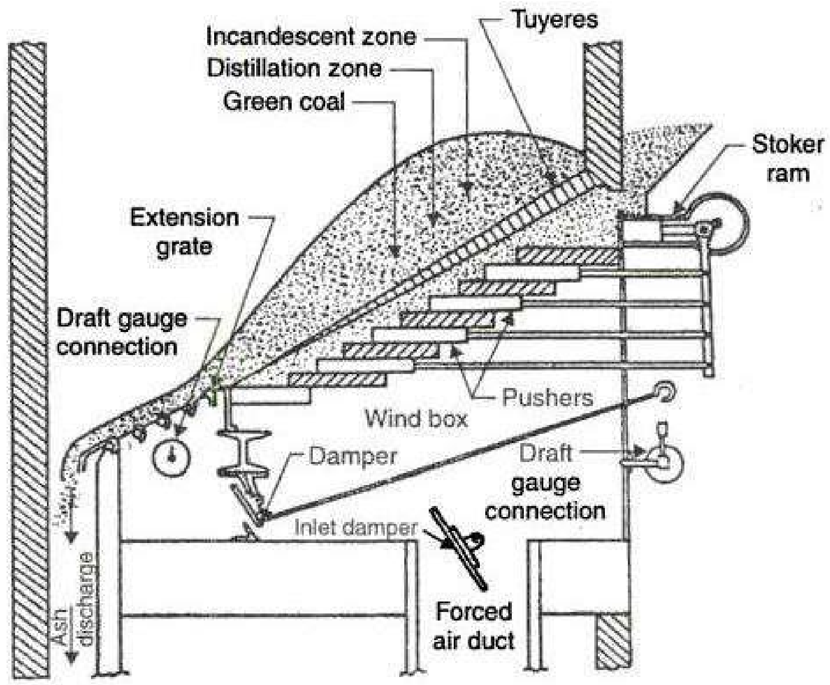


Fig. 2.14. (*b*) Multi-retort underfeed stokers.

- The stoker consists of a series of sloping parallel troughs formed by tuyere stacks. These troughs are called *retorts*. Under the coal hopper at the head end of the retorts, *feeding rams* reciprocate back and forth. With the ram in the outer position coal from the hopper falls into space vacated by the ram. On the inward stroke the ram forces the coal into the retort.

- The height and profile of the fuel bed is controlled by *secondary*, or *distributing rams*. These rams oscillate parallel to the retort axes, the length of their stokes can be varied as needed. They slowly move the entire fuel bed down the length of the stoker.
- At the rear of the stoker the partly burned fuel bed moves onto an *extension grate* arranged in sections. These sections also oscillate parallel to the fuel-bed movement. The sharp slope of the stoker aids in moving the fuel bed. Fuel-bed movement keeps it slightly agitated to break up clinker formation. From extension grate the ash moves onto ash dump plate. Tilting the dump plate at long intervals deposits the ash in the ashpit below.
- *Primary air* from the wind box underneath the stoker enters the fuel bed through holes in the vertical sides of the tuyeres. The extension grate carries a much thinner fuel bed and so must have a lower air pressure under it. The air entering from the main wind box into the extension-grate wind box is regulated by a *controlling air damper*.

In this stoker the number of retorts may vary from 2 to 20 with coal burning capacity ranging from 300 kg to 2000 kg per hour per retort.

Underfeed stokers are *suitable for non-clinkering, high voltatile coals having caking properties and low ash contents*.

Advantages :

1. High thermal efficiency (as compared to chain grate stokers).
2. Combustion rate is considerably higher.
3. The grate is self cleaning.
4. Part load efficiency is high particularly with multi-retort type.
5. Different varieties of coals can be used.
6. Much higher steaming rates are possible with this type of stoker.
7. Grate bars, tuyeres and retorts are not subjected to high temperature as they remain always in contact with fresh coal.
8. Overload capacity of the boiler is high as large amount of coal is carried on the grate.
9. Smokeless operation is possible even at very light load.
10. With the use of clinker grinder, more heat can be liberated out of fuel.
11. Substantial amount of coal always remains on the grate so that the boiler may remain in service in the event of temporary breakdown of the coal supply system.
12. It can be used with all refractory furnaces because of non-exposure of stoker mechanism to the furnace.

Disadvantages :

1. High initial cost.
2. Require large building space.
3. The clinker troubles are usually present.
4. Low grade fuels with high ash content cannot be burnt economically.

2.9.3.2. Pulverised fuel firing

In pulverised fuel firing system the *coal is reduced to a fine powder with the help of grinding mill and then projected into the combustion chamber with the help of hot air current*. The amount of air required (known as *secondary air*) to complete the combustion is supplied separately to the combustion chamber. The resulting turbulence in the combustion chamber helps for uniform mixing of fuel and air and thorough combustion. *The amount of air which is used to carry the coal and to dry* *it before entering into the combustion chamber is known as* **Primary air** *and the amount of air which is supplied separately for completing the combustion is known as* **Secondary air.**

The *efficiency* of the pulverised fuel firing system mostly *depends upon the size of the powder*. The fineness of the coal should be such as 70% of it would pass through a 200 mesh sieve and 90% through 50 mesh sieve.

Fig. 2.15 shows elements of pulverised coal system.

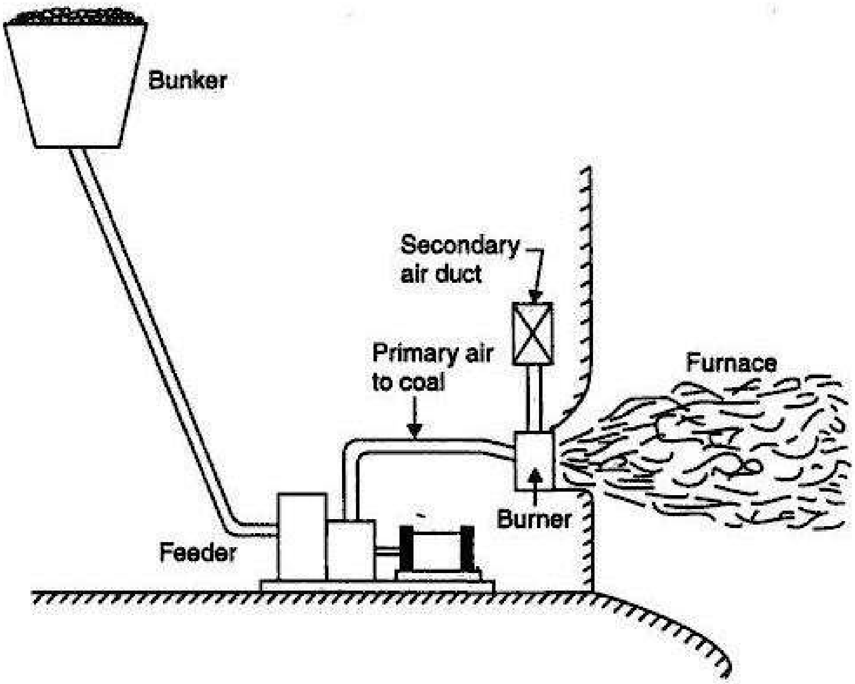


Fig. 2.15. Elements of pulverised coal system.

Advantages :

1. Any grade of coal can be used since coal is powdered before use.
2. The rate of feed of the fuel can be regulated properly resulting in fuel economy.
3. Since there is almost complete combustion of the fuel there is increased rate of evaporation and higher boiler efficiency.
4. Greater capacity to meet peak loads.
5. The system is practically free from sagging and clinkering troubles.
6. No standby losses due to banked fires.
7. Practically no ash handling problems.
8. No moving part in the furnace is subjected to high temperatures.
9. This system works successfully with or in combination with gas and oil.
10. Much smaller quantity of air is required as compared to that of stoker firing.
11. Practically free from clinker troubles.
12. The external heating surfaces are free from corrosion.
13. It is possible to use highly preheated secondary air (350°C) which helps for rapid flame propagation.
14. The furnace volume required is considerably less.

Disadvantages :

1. High capital cost.
2. Lot of fly-ash in the exhaust, which makes the removing of fine dust uneconomical.
3. The possibility of explosion is more as coal burns like gas.
4. The maintenance of furnace brickwork is costly.
5. Special equipment is needed to start this system.
6. The skilled operators are required.
7. A separate coal preparation plant is necessary.
8. High furnace temperatures cause rapid deterioration of the refractory surfaces of the furnace.
9. Nuisance is created by the emission of very fine particles of grit and dust.
10. Fine regular grinding of fuel and proper distribution to burners is usually difficult to achieve.

Pulverised Fuel Handling

Basically, pulverised fuel plants may be divided into the following *two systems* :

1. Unit system.
2. Central system.

Unit system :

A unit system is shown in Fig. 2.16.

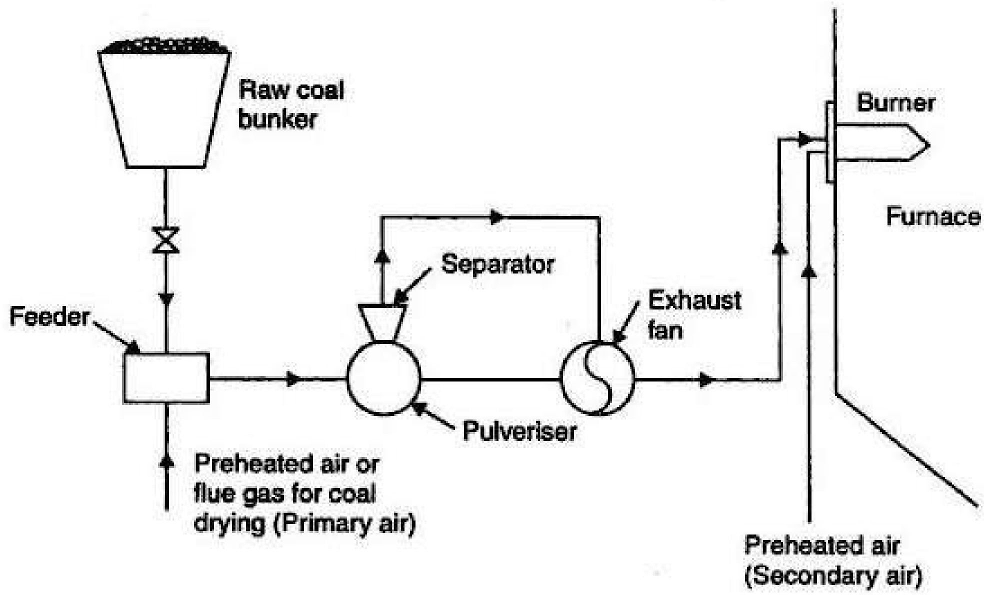


Fig. 2.16. Unit system.

Most pulverised coal plants are now being installed with unit pulveriser.

The *unit system* is so called from the fact that each burner or burner group and the pulveriser constitute a unit. Crushed coal is fed to the pulverising mill at a variable rate governed by the combustion requirements of the boiler and furnace. Primary air is admitted to the mill and becomes the transport air which carries the coal through the short delivery pipe to the burner. This air may be preheated if mill drying is desirable.

Advantages :

1. The layout is simple and permits easy operation.
2. It is cheaper than central system.
3. Less spaces are required.
4. It allows direct control of combustion from the pulveriser.
5. Maintenance charges are less.
6. There is no complex transportation system.
7. In a replacement of stokers, the old conveyor and bunker equipment may be used.
8. Coal which would require drying in order to function satisfactorily in the central system may usually be employed without drying in the unit system.

Disadvantages :

1. Firing aisle is obstructed with pulverising equipment, unless the latter is relegated to a basement.

2. The mills operate at variable load, a condition not especially conducive to best results.

3. With load factors in common practice, total mill capacity must be higher than for the central system.

4. Flexibility is less than central system.

Central system :

This system is illustrated in Fig. 2.17.

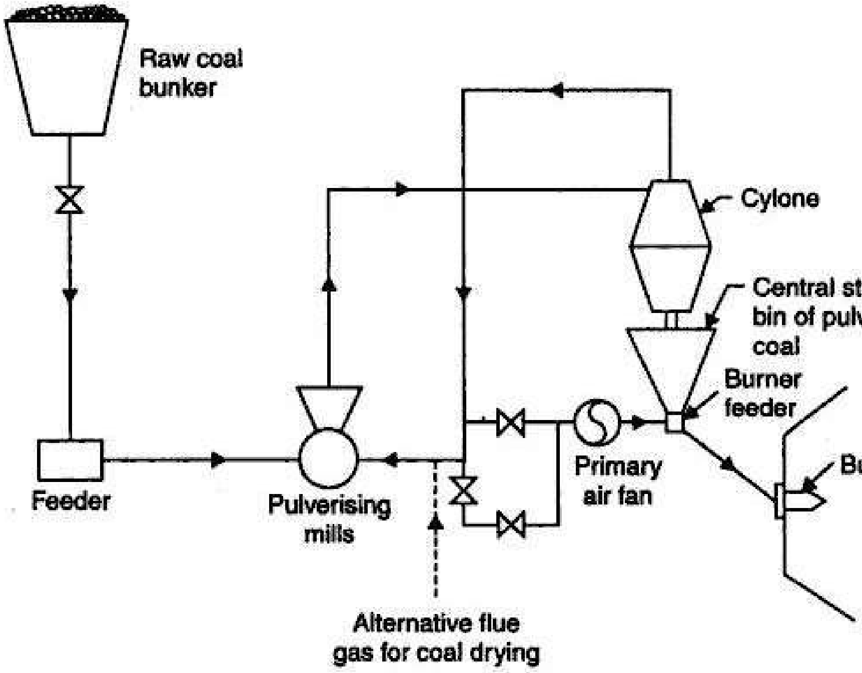


Fig. 2.17. Central system.

A central pulverising system employs a limited number of large capacity pulverisers at a central point to prepare coal for all the burners. Driers, if required, are conveniently installed at this point. From the pulverisers the coal is transported to a central storage bin where it is deposited and its transporting air vented from the bin through a *"cyclone"*. This bin may contain from 12 to 24 hours supply of pulverised coal. From the bin the coal is metered to the burners by motor-driven feeders of varied design. Primary air, added at the feeders, floats the coal to the burners.

Advantages :

1. Offers good control of coal fineness.
2. The pulverising mill may work at constant load because of the storage capacity between it and the burners.
3. The boiler aisels are unobstructed.
4. More latitude in the arrangement and number of burners is allowed to the designers.
5. The large storage is protection against interruption of fuel supply to the burners.
6. Less labour is required.
7. Power consumption per tonne of coal handled is low.
8. Burners can be operated independent of the operation of coal preparation plant.
9. Fans handle only air, as such, there is no problem of excessive wear as in case of unit system, where air and coal both are handled by the fan.

Disadvantages :

1. Driers are usually necessary.
2. Fire hazard of quantities of stored pulverised coal.
3. Central preparation may require a separate building.
4. Additional cost and complexity of coal transportation system.
5. Power consumption of auxiliaries is high.

Pulveriser. Coal is pulverised in order to increase its surface exposure, thus promoting rapid combustion without using large quantities of excess air. A pulveriser is the most important part of a pulverised coal system. Pulverisers (sometimes called *mills*) are classified as follows :

1. Attrition mills :
   (*i*) Bowl mills
   (*ii*) Ball and race mills.
2. Impact mills :
   (*i*) Ball mills
   (*ii*) Hammer mills.

Pulverisers are driven by electric motors with the feeders either actuated by the main drive or by a small d.c. motor, depending upon the control used.

2.9.4. Burners

Primary air that carries the powdered coal from the mill to the furnace is only about 20% of the total air needed for combustion. Before the coal enters the furnace, it must be mixed with additional air, known as *secondary air,* in burners mounted in the furnace wall. *In addition to the prime function of mixing, burners must also maintain stable ignition of fuel-air mix* and *control the flame shape and travel in the furnace.* Ignition depends on the rate of flame propagation. To prevent flash back into the burner, the coal-air mixture must move away from the burner at a rate equal to flame-front travel. *Too much secondary air can cool the mixture and prevent its heating to ignition temperature.*

The *requirements of a burner* can be summarised as follows :

(*i*) The coal and air should be so handled that there is stability of ignition.

(*ii*) The combustion is complete.

(*iii*) In the flame the heat is uniformly developed avoiding any superheat spots.

(*iv*) Adequate protection against overheating, internal fires and excessive abrasive wear.

2.9.4.1. Pulverised fuel burners

Pulverised fuel burners may be *classified* as follows :

1. Long flame burners.
2. Turbulent burners.
3. Tangential burners.
4. Cyclone burners.

2.9.4.2. Oil burners

Principle of oil firing. *The functions of an oil burner are to mix the fuel and air in proper proportion and to prepare the fuel for combustion.* **Fig.** 2.18 shows the principle of oil firing.

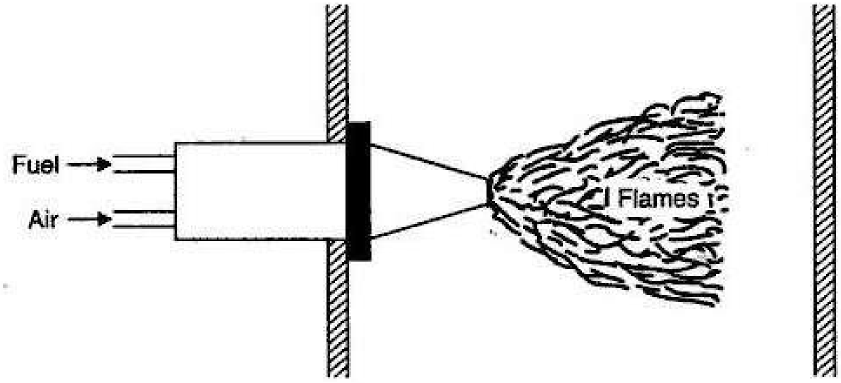


Fig. 2.18. Principle of oil firing.

Classification of oil burners. The oil burners may be *classified* as :

1. *Vapourising oil burners :*
   (*a*) Atmospheric pressure atomising burner
   (*b*) Rotating cup burner
   (*c*) Recirculation burner
   (*d*) Wick type burner.
2. *Atomising fuel burners :*
   (*a*) Mechanical or oil pressure atomising burner
   (*b*) Steam or high pressure air atomising burner
   (*c*) Low pressure air atomising burner.

2.9.4.3. Gas burners

Gas burning claims the following *advantages* :

(*i*) It is much simpler as the fuel is ready for combustion and requires no preparation.

(*ii*) Furnace temperature can be easily controlled.

(*iii*) A long slow burning flame with uniform and gradual heat liberation can be produced.

(*iv*) Cleanliness.

(*v*) High chimney is not required.

(*vi*) No ash removal is required.

For generation of steam, natural gas is invariably used in the following cases :

(*i*) Gas producing areas.

(*ii*) Areas served by gas transmission lines.

(*iii*) Where coal is costlier.

Typical gas burners used are shown in Fig. 2.19 to 2.20.

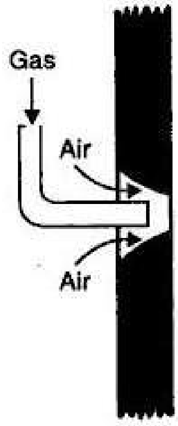


Fig. 2.19

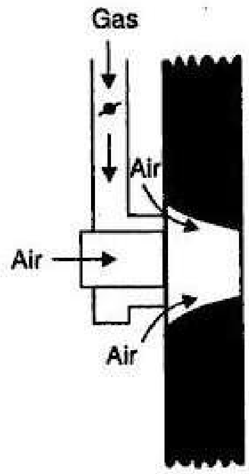


Fig. 2.20

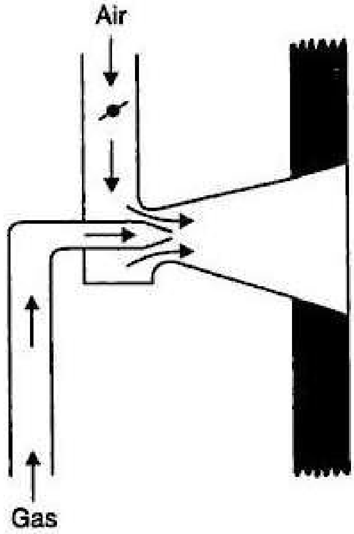


Fig. 2.21

Refer to Fig. 2.19. In this burner the mixing is poor and a fairly long flame results.

Refer to Fig. 2.20. This is a *ring type burner* in which a short flame is obtained.

Refer to Fig. 2.21. This arrangement is used when both gas and air are under pressure.

In order to prevent the flame from turning back the velocity of the gas should be more than the "*rate of flame propagation*".

2.10. FLUIDISED BED COMBUSTION (FBC)

A ***fluidised bed*** *may be defined as the bed of solid particles behaving as a fluid.* The *principle of FBC-system* is given below :

When a gas is passed through a packed bed of finely divided solid particles, it experiences a pressure drop across the bed. At low gas velocities, this pressure drop is small and does not disturb the particles. But if the gas velocity is increased further, a stage is reached, *when particles are suspended in the gas stream and the packed bed becomes a 'fluidised bed'*. With further increase in gas velocity, the bed becomes turbulent and rapid mixing of particles occurs. In general, the behavior of this mixture of solid particles and gas is like a fluid. Burning of a fuel in such a state is known as a *fluidised bed combustion.*

Fig. 2.22 shows the arrangement of the FBC system.

On the distributor plate are fed the fuel and inert material *dolomite* and from its bottom air is supplied. The high velocity of air keeps the solid feed material in suspending condition during burning. The generated heat is rapidly transferred to the water passing through the tubes immersed in the bed and generated steam is taken out. During the burning sulphur dioxide formed is absorbed by the dolomite and prevents its escape with the exhaust gases. The molten slag is tapped from the top surface of the bed.

The primary object of using the *inert material* is to control the bed temperature, it accounts for 90% of the bed volume. It is very necessary that the selection of an inert material should be done judiciously as it remains with the fuel in continuous motion and at high temperature to the tune of 800°C. Moreover, the inert material should not disintegrate coal, the parent material of the bed.

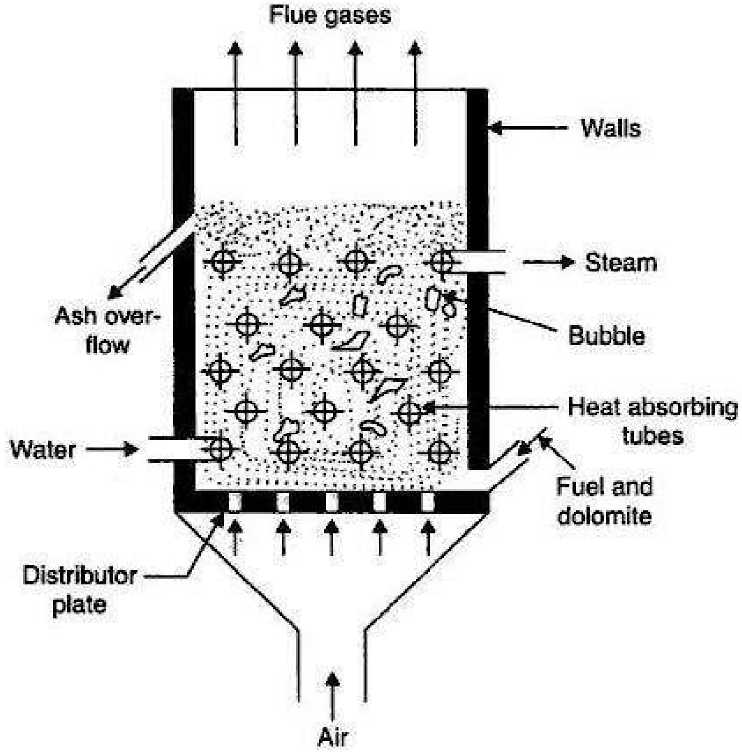


Fig. 2.22. Basic FBC system.

The cost economic shows that a saving of about 10% in operating cost and 15% capital cost could be achieved for a unit rating of 120 MW and it may be still higher for bigger units.

Advantages :

1. As a result of better heat transfer, the unit size and hence the *capital costs are reduced*.
2. It can respond rapidly to changes in load demand (since thermal equilibrium between air and coal particles in the bed is quickly established).
3. Low combustion temperatures (800 to 950°C) inhibits the formation of nitrogen oxides like nitric oxide and nitrogen dioxide.
4. Since combustion temperatures are low the fouling and corrosion of tubes is reduced considerably.
5. As it is not necessary to grind the coal very fine as is done in pulverised fuel firing, therefore, the cost of coal crushing is reduced.
6. Pollution is controlled and combustion of high-sulphur coal is possible.

7. FBC system can use solid, liquid or gaseous fuel or mix as well as domestic and industrial waste. Any variety of coal can be used successfully.
8. Combustion temperature can be controlled accurately.
9. The system can be readily designed for operation at raised combustion pressure, owing to the simplicity of arrangement, small size of the plant and reduced likelihood of corrosion or erosion of gas turbine blades.
10. The combustion in conventional system becomes unstable when the ash exceeds 48% but even 70% ash containing coal can be efficiently burned in FBC.
11. The large quantity of bed material acts as a thermal storage which reduces the effect of any fluctuation in fuel feed ratio.

2.11. ASH HANDLING

A huge quantity of ash is produced in central stations, sometimes being as much as 10 to 20% of the total quantity of coal burnt in a day. Hundreds of tonnes of ash may have to be handled every day in large power stations and mechanical devices become indispensable. A station using low grade fuel has to deal with large quantities of ash.

Handling of ash includes :

(*i*) Its removal from the furnace.

(*ii*) Loading on the conveyers and delivery to the fill or dump from where it can be disposed off by sale or otherwise.

Handling of ash is a problem because ash coming out of the furnace is too hot, it is dusty and irritating to handle and is accompanied by some poisonous gas. Ash needs to be *quenched* before handling due to following *reasons* :

(*i*) Quenching reduces corrosion action of the ash.

(*ii*) It reduces the dust accompanying the ash.

(*iii*) It reduces temperature of the ash.

(*iv*) Ash forms clinkers by fusing in large lumps and by quenching clinkers will disintegrate.

2.11.1. Ash Handling Equipment

A *good ash handling plant* should have the following *characteristics* :

1. It should have enough capacity to cope with the volume of ash that may be produced in a station.
2. It should be able to handle large clinkers, boiler refuse, soot etc., with little personal attention of the workmen.
3. It should be able to handle hot and wet ash effectively and with good speed.
4. It should be possible to minimise the corrosive or abrasive action of ashes and dust nuisance should not exist.
5. The plant should not cost much.
6. The operation charges should be minimum possible.
7. The operation of the plant should be noiseless as much as possible.
8. The plant should be able to operate effectively under all variable load conditions.
9. In case of addition of units, it should need minimum changes in original layout of plant.
10. The plant should have high rate of handling.

The *commonly used equipment for ash handling* in large and medium size plants may comprise of :

(*i*) Bucket elevator
(*ii*) Bucket conveyor
(*iii*) Belt conveyor
(*iv*) Pneumatic conveyor
(*v*) Hydraulic sluicing equipment
(*vi*) Trollies or rail cars etc.

Fig. 2.23 shows the outline of ash disposal equipment.

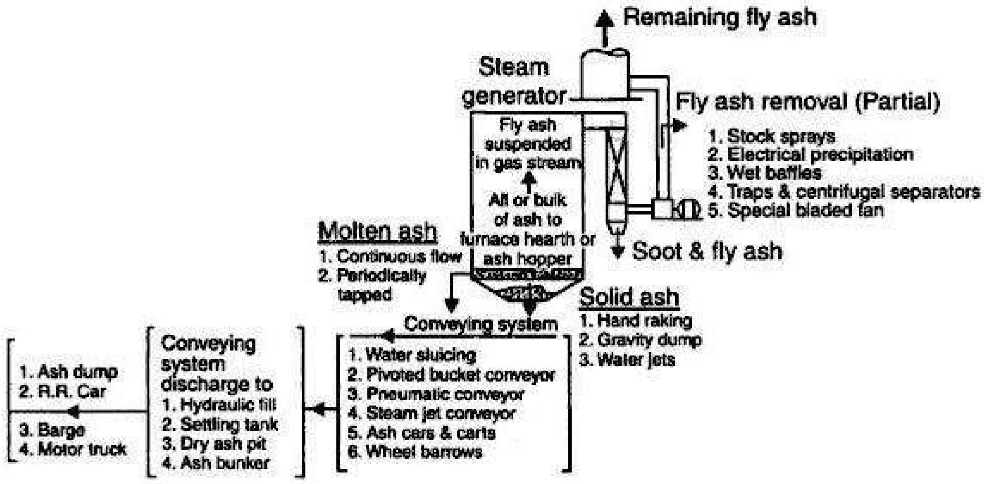


Fig. 2.23. Outline of ash disposal equipment.

2.11.2. Ash Handling Systems

The modern ash-handling systems are mainly *classified* into *four* groups :

1. Mechanical handling system
2. Hydraulic system
3. Pneumatic system
4. Steam jet system.

2.12. DUST COLLECTION

2.12.1. Introduction

The products of combustion of coal-fed fires contain particles of solid matter floating in suspension. This may be smoke or dust. If *smoke*, the indication is that combustion conditions are faulty, and the proper remedy is in the design and management of the furnace. If *dust*, the particles are mainly fine ash particles called "*Fly-ash*" intermixed with some quantity of carbon-ash material called "*cinder*". *Pulverised coal and spreader stoker firing units are the principle types causing difficulty from this source.* Other stokers may produce minor quantities of dust but generally not enough to demand special gas cleaning equipment. The two mentioned are troublesome because coal is burned in suspension—in a turbulent furnace atmosphere and every opportunity is offered for the gas to pick up the smaller particles and sweep them along with it.

UNIT-III

Diesel power plant

INTRODUCTION

- Diesel engine power plants are installed *where supply of coal and water is not available in sufficient quantity* or *where power is to be generated in small quantity* or *where standby sets are required for continuity of supply such as in hospitals, telephone exchanges, radio stations and cinemas.* These plants in the range of 2 to 50 MW capacity are used as *central stations* for supply authorities and works and they are universally adopted to supplement hydro-electric or thermal stations where standby generating plants are essential for starting from cold and under emergency conditions.
- In several countries, the demand for diesel power plants is increased for electric power generation because of difficulties experienced in construction of new hydraulic plants and enlargement of old hydro-plants. A long term planning is required for the development of thermo and hydro-plants which cannot keep the pace with many times the increased demand by the people and industries.
- The diesel units used for electric generation are *more reliable* and *long-lived piece of equipment* compared with other types of plants.

ADVANTAGES AND DISADVANTAGES OF DIESEL POWER PLANTS

The *advantages and disadvantages* of diesel power plants are listed below :

Advantages :

1. Design and installation are very simple.
2. Can respond to varying loads without any difficulty.
3. The standby losses are less.
4. Occupy less space.
5. Can be started and put on load quickly.
6. Require less quantity of water for cooling purposes.
7. Overall capital cost is lesser than that for steam plants.
8. Require less operating and supervising staff as compared to that for steam plants.
9. The efficiency of such plants at part loads does not fall so much as that of a steam plant.
10. The cost of building and civil engineering works is low.
11. Can burn fairly wide range of fuels.
12. These plants can be located very near to the load centres, many times in the heart of the town.
13. No problem of ash handling.
14. The lubrication system is more economical as compared with that of a steam power plant.
15. The diesel power plants are *more efficient than steam power plants* in the range of 150 MW capacity.

Disadvantages :

1. High operating cost.
2. High maintenance and lubrication cost.
3. Diesel units capacity is limited. These cannot be constructed in large size.
4. In a diesel power plant noise is a serious problem.
5. Diesel plants cannot supply overloads continuously whereas steam power plant can work under 25% overload continuously.
6. The diesel power plants are not economical where fuel has to be imported.
7. The life of a diesel power plant is quite small (2 to 5 years or less) as compared to that of a steam power plant (25 to 30 years).

3.3. APPLICATIONS OF DIESEL POWER PLANT

The diesel power plants find wide application in the following fields :

1. Peak load plant
2. Mobile plants
3. Standby units
4. Emergency plant
5. Nursery station
6. Starting stations
7. Central stations—where capacity required is small (5 to 10 MW)
8. Industrial concerns where power requirement is small say of the order of 500 kW, diesel power plants become more economical due to their higher overall efficiency.

3.4. SITE SELECTION

The following factors should be considered while *selecting the site for a diesel power plant* :

1. Foundation sub-soil condition. The conditions of sub-soil should be such that a foundation at a reasonable depth should be capable of providing a strong support to the engine.

2. Access to the site. The site should be so selected that it is accessible through rail and road.

3. Distance from the load centre. The location of the plant should be near the load centre. This reduces the cost of transmission lines and maintenance cost. The power loss is also minimised.

4. Availability of water. Sufficient quantity of water should be available at the site selected.

5. Fuel transportation. The site selected should be near to the source of fuel supply so that transportation charges are low.

3.5. HEAT ENGINES

Any type of engine or machine which derives heat energy from the combustion of fuel or any other sources and converts this energy into mechanical work is termed as a **heat engine.**

Heat engines may be classified into two main classes as follows :

1. External Combustion Engines.
2. Internal Combustion Engines.

1. External combustion engines (E.C. engines). In this case, *combustion of fuel takes place outside the cylinder* as in case of *steam engines* where the heat of combustion is employed to

3.8.3. Exhaust System

Refer to Fig. 3.3. The purpose of the exhaust system is to discharge the engine exhaust to the atmosphere outside the building. The exhaust manifold connects the engine cylinder exhausts outlets to the exhaust pipe which is provided with a muffler to reduce pressure in the exhaust line and eliminate most of the noise which may result if gases are discharged directly into the atmosphere.

The exhaust pipe leading out of the building should be short in length with minimum number of bends and should have one or two flexible tubing sections which take up the effects of expansion, and isolate the system from the engine vibration. Every engine should be provided with its independent exhaust system.

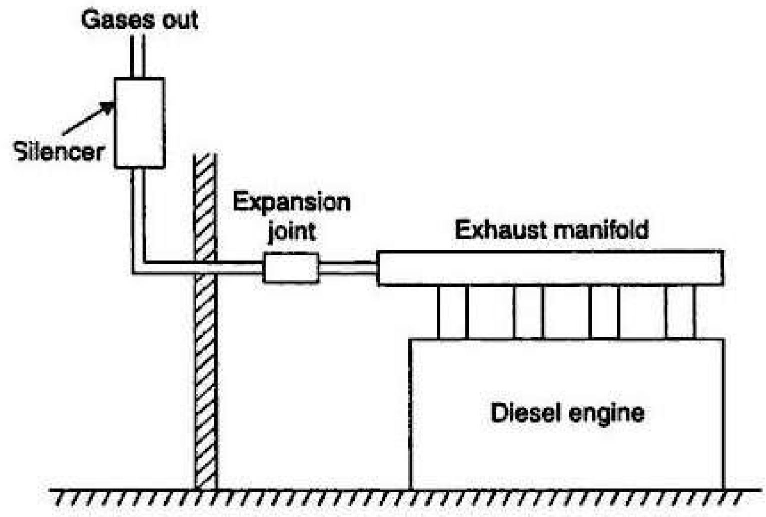


Fig. 3.3. Exhaust system.

The waste heat utilisation in a *diesel-steam* station may be done by providing waste-heat boilers in which most of the heat of exhaust gases from the engine is utilised to raise low pressure steam. Such application is common on *marine plants*. On the *stationary power plant* the heat of exhaust may be utilised to heat water in gas-to-water heat exchangers consisting of a water coil placed in exhaust muffler and using the water in the plant suitably. If air heating is required, the exhaust pipe from the engine is surrounded by the cold air jacket, and transfers the heat of exhaust gases to the air.

3.8.4. Fuel System

Refer to Fig. 3.4.

The fuel oil may be delivered at the plant site by trucks, railroad tank cars or barge and tankers. From tank car or truck the delivery is through the unloading facility to main storage tanks and then by transfer pumps to small service storage tanks known as *engine day tanks*. Large storage capacity allows purchasing fuel when prices are low. The main flow is made workable and practical by arranging the piping equipment with the necessary heaters, by passes, shut-offs, drain lines, relief valves, strainers and filters, flow meters and temperature indicators. The actual flow plans depend on type of fuel, engine equipment, size of the plant etc. The tanks should contain manholes for internal access and repair, fill lines to receive oil, vent lines to discharge vapours, overflow return lines for controlling oil flow and a suction line to withdraw oil. *Coils heated by hot water or steam reduce oil viscosity to lower pumping power needs.*

The minimum storage capacity of at least a month's requirement of oil should be kept in bulk, but where advantage of seasonal fluctuations in cost of oil is to be availed, it may be necessary to provide storage for a few month's requirements. *Day tanks* supply the daily fuel need of engines and may contain a minimum of about 8 hours of oil requirement of the engines. These tanks are usually placed high so that oil may flow to engines under gravity.

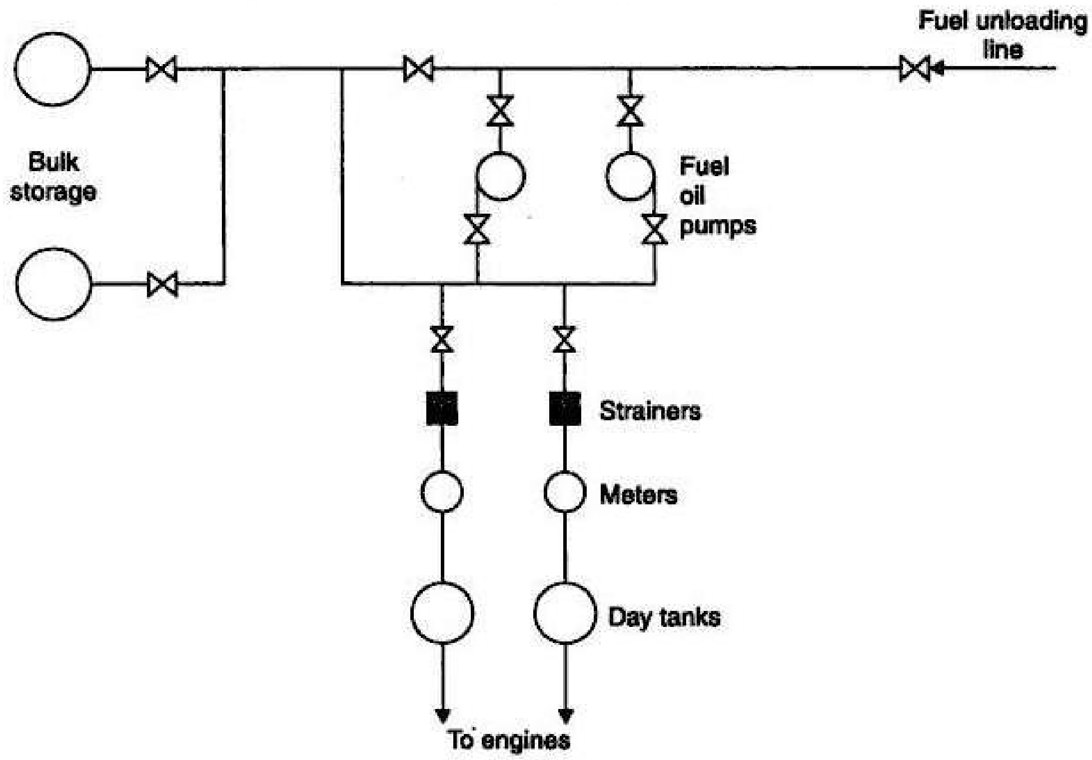


Fig. 3.4. System of fuel storage for a diesel power plant.

For satisfactory operation of a fuel oil supply system the following points should be taken care of :

1. There should be provisions for cleanliness and for changing over of lines during emergencies.
2. In all suction lines the pipe joints should be made tight.
3. Before being covered, all oil lines should be put under air pressure and the joints tested with soap solution. Small air leaks into the line can be the source of exasperating operating difficulties and are hard to remedy once the plant is in operation.
4. The piping between filter and the engine should be thoroughly oil flushed before being first placed in service.
5. Considerable importance should be given for cleanliness in handling bulk fuel oil. Dirt particles will ruin the fine lap of injection pumps or plug the injection nozzle orifices. So *high-grade filters* are of paramount importance to the diesel oil supply system.

3.8.4.1. Fuel injection system

The mechanical heart of the Diesel engine is the *fuel injection system*. The engine can perform no better than its fuel injection system. A very small quantity of fuel must be measured out, injected, atomised, and mixed with combustion air. The mixing problem becomes more difficult—the larger the cylinder and faster the rotative speed. Fortunately the high-speed engines are the small-bore automotive types ; however, special combustion arrangements such as precombustion chambers, air cells, etc., are necessary to secure good mixing. *Engines driving electrical generators have lower speeds and simple combustion chambers.*

3.8.4.2. Functions of a fuel injection system

1. Filter the fuel.
2. Meter or measure the correct-quantity of fuel to be injected.
3. Time the fuel injection.
4. Control the rate of fuel injection.
5. Automise or break up the fuel to fine particles.
6. Properly distribute the fuel in the combustion chamber.

The injection systems are manufactured with great accuracy, especially the parts that actually meter and inject the fuel. Some of the tolerances between the moving parts are very small of the order of *one micron*. Such closely fitting parts require special attention during manufacture and hence the injection systems are *costly*.

3.8.4.3. Types of fuel injection systems

The following fuel injection systems are commonly used in diesel power station :

1. Common-rail injection system.
2. Individual pump injection system.
3. Distributor.

Atomisation of fuel oil has been secured by (*i*) *air blast* and (*ii*) *pressure spray*. Early diesel engines used air fuel injection at about 70 bar. This is sufficient not only to inject the oil, but also to atomise it for a rapid and thorough combustion. The expense of providing an air compressor and tank lead to the development of "*solid*" injection, using a liquid pressure of between 100 and 200 bar which is sufficiently high to atomise the oil it forces through spray nozzles. Great advances have been made in the field of solid injection of the fuel through research and progress in fuel pump, spray nozzles, and combustion chamber design.

3.9. OPERATION OF A DIESEL POWER PLANT

When diesel alternator sets are put in parallel, "*hunting*" or "*phase swinging*" may be produced *due to resonance* unless due care is taken in the design and manufacture of the sets. This condition occurs *due to resonance between the periodic disturbing forces of the engine and natural frequency of the system.* The engine forces result from uneven turning moment on the engine crank which are corrected by the flywheel effect. *"Hunting" results from the tendency of each set trying to pull the other into synchronism* and is characterised by flickering of lights.

To ensure *most economical operation of diesel engines* of different sizes when working together and sharing load it is necessary that they should carry the same percentage of their full load capacity at all times as the fuel consumption would be lowest in this condition. For best operation performance the manufacturer's recommendations should be strictly followed.

In order to get good performance of a diesel power plant the following points should be taken care of :

1. It is necessary to maintain the *cooling temperature* within the prescribed range and use of very cold water should be avoided. The cooling water should be free from suspended impurities and suitably treated to be scale and corrosion free. If the ambient temperature approaches freezing point, the cooling water should be drained out of the engine when it is kept idle.

2. During operation the *lubrication system* should work effectively and requisite pressure and temperature maintained. The engine oil should be of the correct specifications and should be in a fit condition to lubricate the different parts. A watch may be kept on the consumption of lubricating oil as this gives an indication of the true internal condition of the engine.

3. *The engine should be periodically run even when not required to be used and should not be allowed to stand idle for more than 7 days.*

4. *Air filter, oil filters and fuel filters* should be periodically serviced or replaced as recommended by the manufacturers or if found in an unsatisfactory condition upon inspection.

5. Periodical checking of engine compression and firing pressures and also exhaust temperatures should be made.

- The engine exhaust usually provides a good indication of satisfactory performance of the engine. *A black smoke in the exhaust is a sign of inadequate combustion or engine overloading.*
- *The loss of compression resulting from wearing out of moving parts lowers the compression ratio causing inadequate combustion.* These defects can be checked by taking *indicator diagrams* of the engine after reasonable intervals.

3.10. TYPES OF DIESEL ENGINES USED FOR DIESEL POWER PLANTS

The diesel engines may be four-stroke or two stroke cycle engines. *The two-stroke cycle engines are favoured for diesel power plants.*

Efforts are being made to use "*dual fuel engines*" in diesel power plants for better economy and proper use of available gaseous fuels in the country. The gas may be a waste product as in the case of sewage treatment installations or oil fuels where the economic advantage is self evident. With the wider availability of natural gas, the dual fuel engines may become an attractive means of utilising gas as fuel at off-peak tariffs for the electric power generation.

Working of Dual Fuel Engines :

The various strokes of a dual fuel engine are as follows :

1. **Suction stroke.** During this stroke *air and gas are drawn* in the engine cylinder.

2. **Compression stroke.** During this stroke the pressure of the mixture drawn is increased. Near the end of this stroke the *'pilot oil' is injected into the engine cylinder. The compression heat first ignites the pilot oil* and then gas mixture.

3. **Working/power stroke.** During this stroke the gases (at high temperature) expand and thus power is obtained.

4. **Exhaust stroke.** The exhaust gases are released to the atmosphere during the stroke.

3.11. LAYOUT OF A DIESEL ENGINE POWER PLANT

Fig. 3.5 shows the layout of a diesel engine power plant.

The most common arrangement for diesel engines is with parallel centre lines, with some room left for extension in future. The repairs and usual maintenance works connected with such engines necessitate sufficient space around the units and consideration should be given to the need for dismantling and removal of large components of the engine generator set. The air intakes and filters as well as the exhaust mufflers are located outside the building or may be separated from the main engine room by a partition wall. The latter arrangement is not vibration free. Adequate space for oil storage and repair shop as well as for office should be provided close to the main engine room. Bulk storage of oil may be outdoor. The engine room should be well ventilated.

4.1. GAS TURBINES—GENERAL ASPECTS

Probably a windmill was the first turbine to produce useful work, wherein there is no pre-compression and no combustion. The characteristic features of a gas turbine as we think of the name today include a *compression process* and a *heat-addition* (or combustion) process. The gas turbine represents perhaps the *most satisfactory way of producing very large quantities of power in a self-contained and compact unit*. The gas turbine may have an ample future use in conjunction with the oil engine. For smaller gas turbine units, the inefficiencies in compression and expansion processes become greater and to improve the thermal efficiency it is necessary to use a heat exchanger. In order that a small gas turbine may compete for economy with the small oil engine or petrol engine it is necessary that a compact effective heat exchanger be used in the gas turbine cycle. The thermal efficiency of the gas turbine alone is still quite modest 20 to 30% compared with that of a modern steam plant 38 to 40%. It is possible to construct *combined plants* whose efficiencies are of the order of 45% or more. Higher efficiencies might be attained in future.

The following are the major fields of application of gas turbines :

1. Aviation
2. Power generation
3. Oil and gas industry
4. Marine propulsion.

The efficiency of a gas turbine is not the criteria for the choice of this plant. A gas turbine is used in *aviation* and marine fields because *it is self contained, light weight not requiring cooling water and generally fit into the overall shape of the structure.* It is selected for '*power generation*' because of its *simplicity, lack of cooling water, needs quick installation and quick starting*. It is used in *oil and gas industry* because of *cheaper supply* of *fuel and low installation cost*.

The gas turbines have the following ***"limitations"*** :

1. They are not self starting.
2. Low efficiencies at part loads.

3. Non-reversibility.

4. Higher rotor speeds.

5. Low overall plant efficiency.

In the last two decides, rapid progress has been observed in the *development and improvement of the gas turbine plants for electric power production*. The major progress has been observed in the following *directions* :

(*i*) Increase in unit capacities of gas turbine units.

(*ii*) Increase in their efficiency.

(*iii*) Drop in capital cost.

4.2. APPLICATIONS OF GAS TURBINE PLANTS

Gas turbine plants for the purpose of power plant engineering find the following *applications* :

1. To drive generators and supply peak loads in steam, diesel or hydroplants.
2. To work as combination plants with conventional steam boilers.
3. To supply mechanical drive for auxiliaries.

- These plants are well suited for *peak load service* since the fuel costs are somewhat higher and initial cost low. Moreover, *peak load operation permits use of water injection which increases turbine work by about 40% with an increase in heat rate of about 20%.* The short duration of increase in heat rate does not prove of any much harm.
- The combination arrangement of gas turbines with conventional boilers may be supercharging or for heat recovery from exhaust gases. In the *supercharging system* air is supplied to the boiler under pressure by a compressor mounted on the common shaft with turbine and gases formed as result of combination after coming out of the boiler pass through the gas turbine before passing through the economiser and the chimney.
- The application of the gas turbine to drive the auxiliaries is not strictly included under direct electric power generation by the turbines and would not be discussed.

4.3. ADVANTAGES AND DISADVANTAGES OF GAS TURBINE POWER PLANTS OVER DIESEL AND THERMAL POWER PLANTS

A. Advantages Over Diesel Plants :

1. The work developed per kg of air is large compared with diesel plant.
2. Less vibrations due to perfect balancing.
3. Less space requirements.
4. Capital cost considerably less.
5. Higher mechanical efficiency.
6. The running speed of the turbine (40,000 to 100,000 r.p.m.) is considerably large compared to diesel engine (1000 to 2000 r.p.m.).
7. Lower installation and maintenance costs.
8. The torque characteristics of turbine plants are far better than diesel plants.
9. The ignition and lubrication systems are simpler.
10. The specific fuel consumption does not increase with time in gas turbine plant as rapidly as in diesel plants.
11. Poor quality fuels can be used.

Disadvantages :

1. Poor part load efficiency.
2. Special metals and alloys are required for different components of the plants.
3. Special cooling methods are required for cooling the turbine blades.
4. Short life.

B. Advantages Over Steam Power Plant :

1. No ash handling problem.
2. Low capital cost.
3. The gas turbine plants can be installed at selected load centre as space requirement is considerably less where steam plant cannot be accommodated.
4. Fewer auxiliaries required/used.
5. Gas turbines can be built relatively quicker. They require much less space and civil engineering works and water supply.
6. The gas turbine plant as peak load plant is more preferable as it can be brought on load quickly and surely.
7. The components and circuits of a gas turbine plant can be arranged to give the most economic results in any given circumstances which is not possible in case of steam power plants.
8. For the same pressure and initial temperature conditions the ratio of exhaust to inlet volume would be only 3.95 in case of gas turbine plant as against 250 for steam plant.
9. Above 550°C, the thermal efficiency of the gas turbine plant increases three times as fast the steam cycle efficiency for a given top temperature increase.
10. The site of the steam power plant is dictated by the availability of large cooling water whereas an open cycle gas turbine plant can be located near the load centre as no cooling water is required. The cooling water required for closed cycle gas turbine is hardly 10% of the steam power plant.
11. The gas turbine plants can work quite economically for short running hours.
12. Storage of fuel is much smaller and handling is easy.

4.4. SITE SELECTION

While selectinig the site for a gas turbine plant. The following *points* should be given due consideration :

1. The plant should be located near the load centre to avoid transmission costs and losses.
2. The site should be away from business centres due to noisy operations.
3. Cheap and good quality fuel should be easily available.
4. Availability of labour.
5. Availability of means of transportation.
6. The land should be available at a cheap price.
7. The bearing capacity of the land should be high.

4.5. THE SIMPLE GAS TURBINE PLANT

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

Refer Fig. 4.1. A simple gas turbine plant consists of the following :

1. *Turbine.*
2. *A compressor* mounted on the same shaft or coupled to the turbine.
3. *The combustor.*
4. *Auxiliaries* such as starting device, auxiliary lubrication pump, fuel system, oil system and the duct system etc.

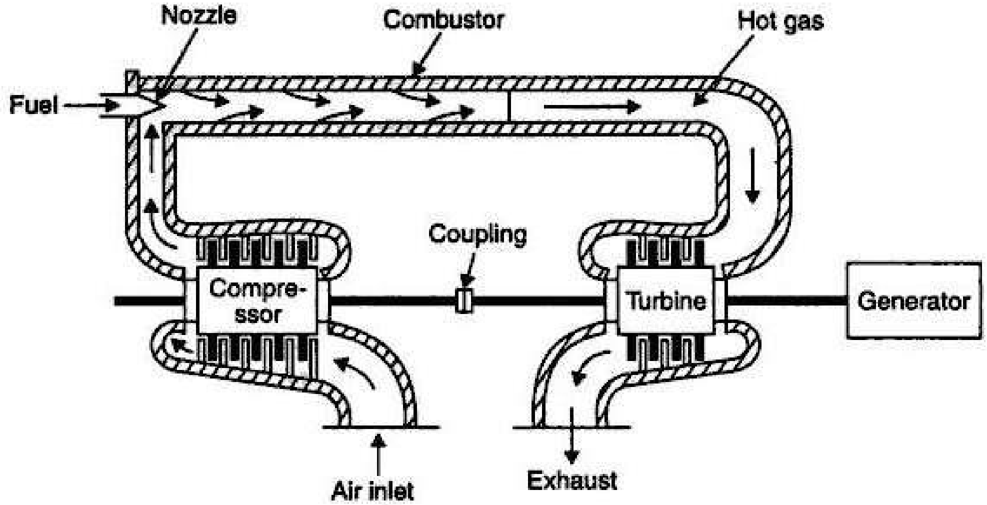


Fig. 4.1. Arrangement of a simple gas turbine plant.

A modified plant may have in addition to above an *intercooler, a regenerator, a reheater* etc.

The working fluid is compressed in a compressor which is generally rotary, multistage type. Heat energy is added to the compressed fluid in the chamber. This high energy fluid, at high temperature and presssure, then expands in the turbine unit thereby generating power. Part of the power generated is consumed in driving the generating compressor and accessories and the rest is utilised in electrical energy. The gas turbines work on open cycle, semi-closed cycle or closed cycle. In order to improve efficiency, compression and expansion of working fluid is carried out in multistages.

4.6. ENERGY CYCLE FOR A SIMPLE-CYCLE GAS TURBINE

Fig. 4.2 shows an energy-flow diagram for a simple-cycle gas turbine, the description of which is as follows :

- The air brings in minute amount of energy (measured above 0°C).
- Compressor adds considerable amount of energy.
- Fuel carries major input to cycle.
- Sum of fuel and compressed-air energy leaves combustor to enter turbine.
- In turbine smallest part of entering energy goes to useful output, largest part leaves in exhaust.

Shaft energy to drive compressor is about twice as much as the useful shaft output.

Actually the shaft energy keeps circulating in the cycle as long as the turbine runs. The important comparison is *the size of the output with the fuel input*. For the simple-cycle gas turbine the output may run about 20 per cent of the fuel input for pressure and temperature conditions at turbine inlet. This means 80% of the fuel energy is wasted. While the 20% thermal efficiency is not too bad, it can be improved by including *additional heat recovery apparatus.*

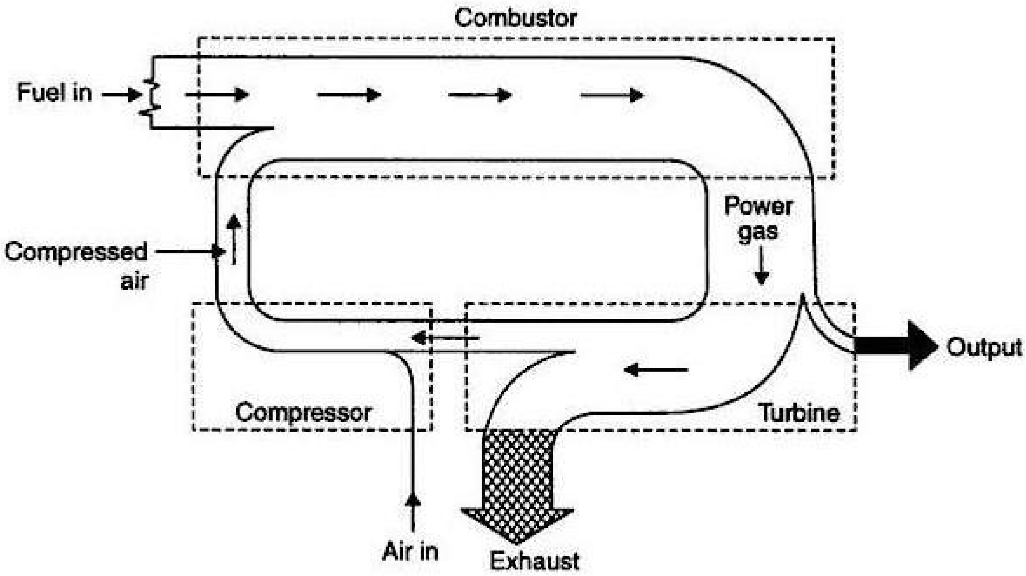


Fig. 4.2. Energy flow diagram for gas-turbine unit.

4.7. PERFORMANCE TERMS

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

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

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

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

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

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

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

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

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

4.8. CLASSIFICATION OF GAS TURBINE POWER PLANTS

The gas turbine power plants may be *classified* according to the following criteria :

1. By application :

(*i*) *In aircraft*

(*a*) Jet propulsion (*b*) Prop-jets

(*ii*) *Stationary*

(*a*) Peak load unit
(*b*) Standby unit
(*c*) End of transmission line unit
(*d*) Base load unit
(*e*) Industrial unit.

(*iii*) Locomotive

(*iv*) Marine

(*v*) Transport.

2. By cycle :

(*i*) Open cycle
(*ii*) Closed cycle
(*iii*) Semi-closed cycle.

3. According to arrangement :

(*i*) Simple
(*ii*) Single shaft
(*iii*) Multi-shaft
(*iv*) Intercooled
(*v*) Reheat
(*vi*) Regenerative
(*vii*) Combination.

4. According to combustion :

(*i*) Continuous combustion
(*ii*) Intermittent combustion.

5. By fuel :

(*i*) Solid fuel
(*ii*) Liquid fuel
(*iii*) Gaseous fuel.

4.9. CLASSIFICATION OF GAS TURBINES

The gas turbines are mainly divided into two groups :

1. **Constant pressure combustion gas turbine**

(*a*) Open cycle constant pressure gas turbine

(*b*) Closed cycle constant pressure gas turbine.

2. **Constant volume combustion gas turbine**

In almost *all the fields open cycle gas turbine plants are used. Closed cycle plants were introduced at one stage because of their ability to burn cheap fuel.* In between their progress remained slow because of availability of cheap oil and natural gas. Because of rising oil prices, now again, the attention is being paid to closed cycle plants.

4.10. COMBINATION GAS TURBINE CYCLES

4.10.1. Combined Turbine and Steam Power Plants

The characteristics of the gas turbine plants render these plants very well suited for use in combination with steam or hydro-plants. These plants can be quickly started for emergency or peak load service. The combination *'gas-turbine-steam cycles' aim at utilising the heat of exhaust gases from the gas turbine and thus, improve the overall plant efficiency.*

Three popular designs of combination cycle comprise of :

1. Heating feed water with exhaust gases.
2. Employing the gases from a supercharged boiler to expand in the gas turbine.
3. Employing the gases as combustion air in the steam boiler.

3. Employing the gases as combustion air in the steam boiler :

Refer Fig. 4.5. When exhaust gases are used as preheated air for combustion in the bo an improvement of about 5 percent in overall heat rate of the plant results. The boiler is fed supplementary fuel and air, and is made larger than the conventional furnace. If only the tur exhaust is used in the furnace without any supplementary fuel firing, the arrangement becom waste heat boiler.

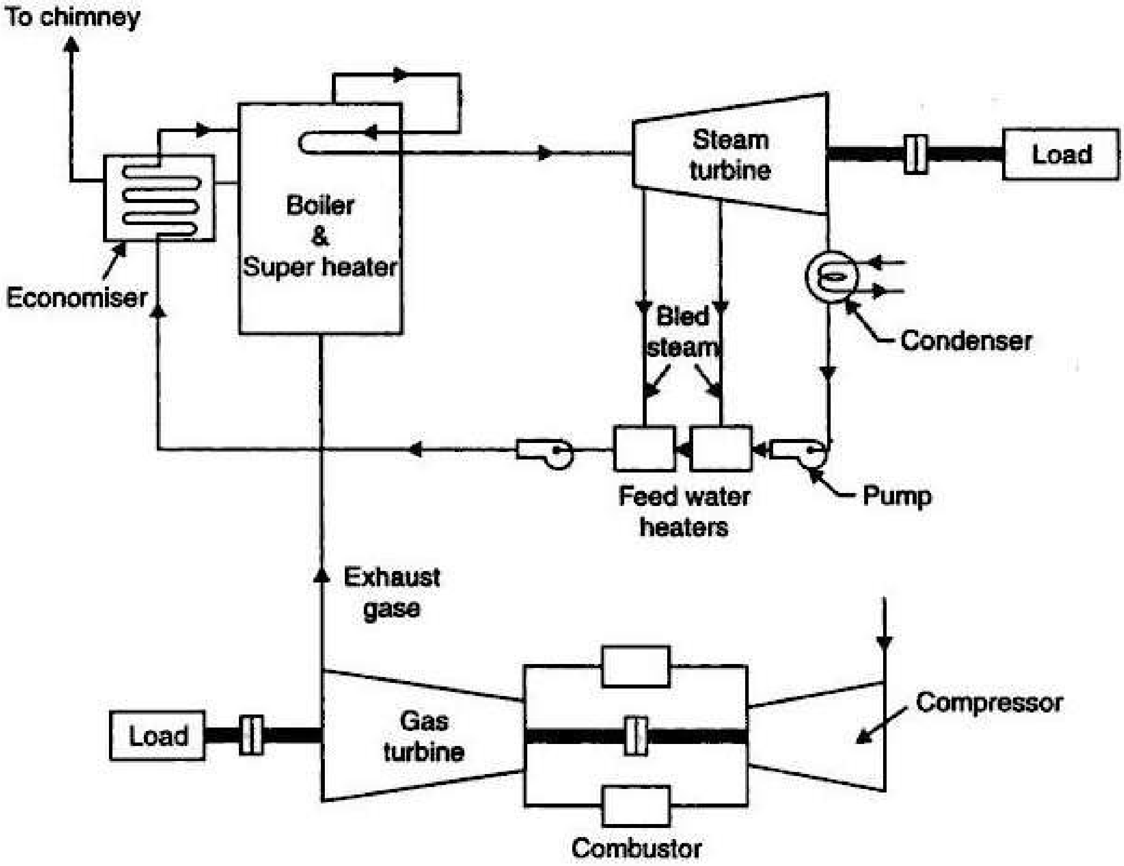


Fig. 4.5. Use of exhaust gases for combustion in the furnance of the steam plant.

- Fig. 4.6 shows the gain in heat rate due to combination cycle.
- Fig. 4.7 shows the comparison of a steam and closed cycle gas plant.

4.10.2. Combined Gas Turbine and Diesel Power Plants

The performance of a diesel engine can be improved by combining it with an exhaust driven gas turbine. It can be achieved by the following three combinations :

1. Turbo-charging.
2. Gas-generator.
3. Compound engine.

1. Turbo-charging :

Refer Fig. 4.8. This method is known as *supercharging*. Here the exhaust of the diesel engine is expanded in the gas turbine and the work output of the gas turbine is utilised to run a compressor which supplies the pressurised air to the diesel engine to increase its output. The load is coupled to the diesel engine shaft and the output of the gas turbine is just sufficient to run the compressor.

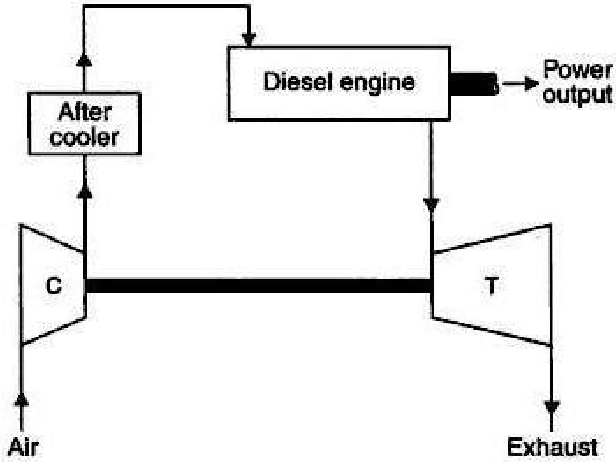


Fig. 4.8. Turbo-charging.

2. Gas-generator :

Fig. 4.9 shows the schematic arrangement. Here the compressor which supplies the compressed air to the diesel engine is not driven from gas turbine but from the diesel engine through some suitable drive. The output of the diesel engine is consumed in driving the air compressor and the gas turbine supplies the power.

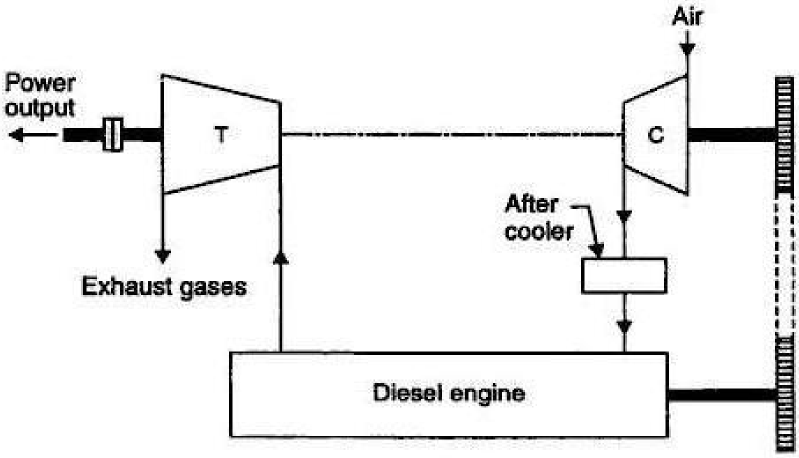


Fig. 4.9. Gas-generator.

4.13. COMPONENTS OF A GAS TURBINE POWER PLANT

The main components of a gas turbine power plant are enumerated and discussed as follows :

1. Gas turbines
2. Compressors
3. Combustor
4. Intercoolers and regenerators.

1. Gas turbines :

A turbine basically employs vanes or blades mounted on a shaft and enclosed in a casing. The flow of fluid through the turbine in *most design is axial and tangential to the rotor* at a nearly constant or increasing radius. The basic requirements of the turbines are : (*i*) *Light weight* (*ii*) *High efficiency* (*iii*) *Reliability in operation and* (*iv*) *Long working life*. Large work output can be obtained per stage with high blade speeds when the blades are designed to sustain higher stresses. *More stages of the turbine are always preferred in gas turbine power plant because it helps to reduce the stresses in the blades and increases the overall life of the turbine.*

It is essential to cool the gas turbine blades for long life as these are continuously subjected to high temperature gases. The blades can be cooled by different methods, the common method being the *air-cooling*. The air is passed through the holes provided through the blade.

The following **accessories** are fitted to the turbine :

(*i*) *Tachometer*. It shows the speed of the machine and also actuates the fuel regulator in case the speed shoots above or falls below the regulated speed, so that the fuel regulator admits less or more fuel into the combustor and varies the turbine power according to the demand. The tachometer is driven through a gear box.

(*ii*) *An overspeed governor*. The governor backs off fuel feed if exhaust temperature from the turbine exceeds the safe limit, thermal switches at the turbine exhaust acting on fuel control to maintain present maximum temperature.

(*iii*) *Lubricating oil pump*. It supplies oil to the bearings under pressure.

(*iv*) Starting motor or engine

(*v*) Starting set-up gear

(*vi*) Oil coolers

(*vii*) Filters

(*viii*) Inlet and exhaust mufflers.

2. Compressors :

The compressors which are commonly used are of the following two types :

1. Centrifugal type.
2. Axial flow type.

- The *'centrifugal compressor'* consists of an *impeller* and a *diffuser*. The *impeller imparts the high kinetic energy to the air* and *diffuser converts the kinetic energy into the pressure energy.* The pressure ratio of 2 to 3 is possible with single stage compressor and it can be increased upto 20 with 3-stage compressor. The compressors may have single or double inlet. The *single inlet* compressors are designed to handle

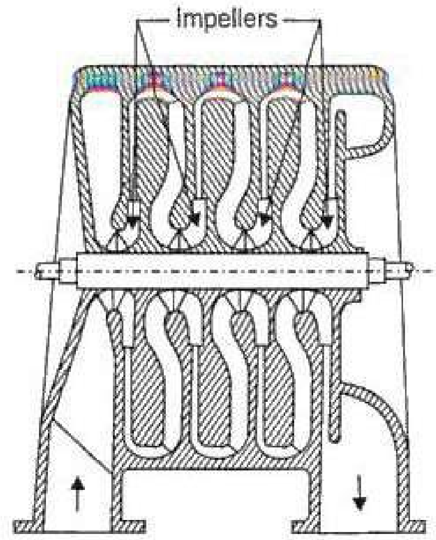


Fig. 4.13. Multi-stage single flow axial compressor.

An axial compressor is capable of *delivering constant volumes of air over varying discharge pressures*. These machines are well suited for large capacities at moderate pressures. If the impeller of a centrifugal compressor is designed to give an axial component of velocity at the exit, the design becomes a *mixed flow type*.

3. Combustor :

The primary function of the *combustor is to provide for the chemical reaction of the fuel and air being supplied by the compressor*. It must fulfil the following *conditions* :

(*i*) Combustion must take place at high efficiency because of the effect of the combustion efficiency on the thermal efficiency of the gas turbine cycle.

(*ii*) The pressure losses must be low.

(*iii*) Ignition must be reliable and accomplished with ease over a wide range of atmospheric condition especially in aircraft installation.

(*iv*) Thorough mixing of fuel and air.

(*v*) Carbon deposits must not be formed under any conditions.

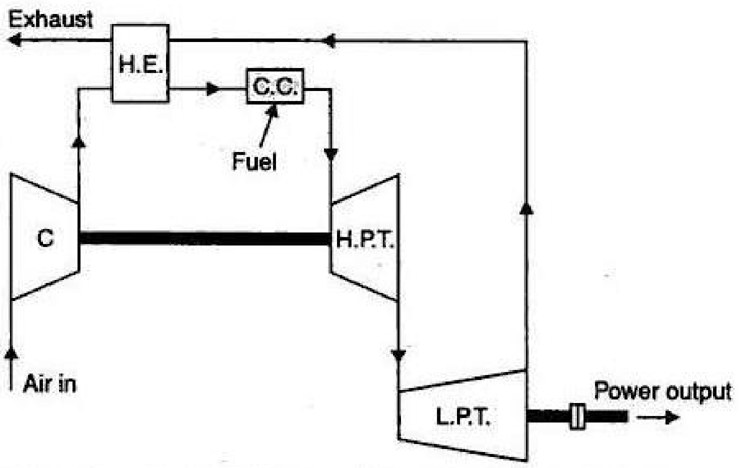
The physical process of combustion may be divided into four important steps :

1. Formation of reactive mixture
2. Ignition
3. Flame propagation
4. Cooling of combustion products with air. Atomisation should be done for perfect burning.

Fig. 4.14 shows an arrangement of a typical combustor design which employs an *outer cylindrical shell* with a *conical inner sleeve* which is provided with ports or slots along the length. At the cone apex is fitted a *nozzle* through which fuel is sprayed in a conical pattern into the sleeve and near this is an *igniting device* or spark plug. A fuel line conveys the fuel to the nozzle. A few air ports provided close to the situation of the nozzle supply the combustion air directly to the fuel and are fitted with vanes to produce a whirling motion of oil and thereby create turbulence. The rest of the air admitted ahead of combustion zone serves to cool the combustor and outlet gases. The combustor is best located between the compressor outlet and turbine inlet and takes the shape of a cylinder. Alternatively, the 'can' arrangement may be used in which the flow is divided to pass through a number of smaller cylindrical chambers. In this latter design the adjacent chambers may be

4.14. VARIOUS ARRANGEMENTS OF GAS TURBINE POWER PLANTS

The various arrangements of gas turbine plants are shown in Figs. 4.17 to 4.22.



H.P.T. = High pressure turbine
L.P.T. = Low pressure turbine
H.E. = Heat exchanger
C.C. = Combustion chamber
C = Compressor

Fig. 4.17. Open cycle gas turbine with separate power turbine.

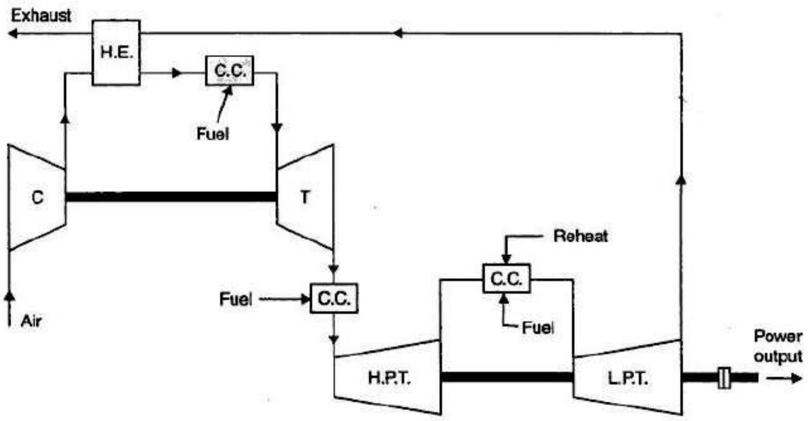
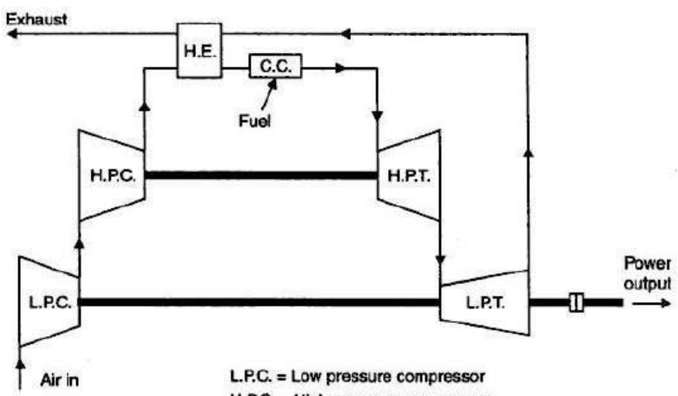


Fig. 4.18. Series flow gas turbine plant.



L.P.C. = Low pressure compressor
H.P.C. = High pressure compressor

Fig. 4.19. Parallel flow gas turbine plant.

UNIT-IV

Hydro-Electric Power Plant

INTRODUCTION

- In hydro-electric plants energy of water is utilised to move the turbines which in turn run the electric generators. The energy of water utilised for power generation may be kinetic or potential. The *kinetic energy* of water is its energy in motion and is a function of mass and velocity, while the *potential energy* is a function of the difference in level/head of water between two points. In either case continuous availability of a water is a basic necessity ; to ensure this, water collected in natural lakes and reservoirs at high altitudes may be utilised or water may be artificially stored by constructing dams across flowing streams. The ideal site is one in which a good system of natural lakes with substantial catchment area, exists at a high altitude. *Rainfall is the primary source of water* and depends upon such factors as temperature, humidity, cloudiness, wind etc. The usefulness of rainfall for power purposes further depends upon several complex factors which include its intensity, time distribution, topography of land etc. However it has been observed that only a small part of the rainfall can actually be utilised for power generation. A significant part is accounted for by *direct evaporation,* while another similar quantity *seeps* into the soil and forms the underground storage. Some water is also absorbed by

CLASSIFICATION OF HYDRO-ELECTRIC POWER PLANTS

Hydro-electric power stations may be *classified* as follows :

A. According to availability of head :

1. High head power plants
2. Medium head power plants
3. Low head power plants.

B. According to the nature of load :

1. Base load plants
2. Peak load plants.

C. According to the quantity of water available :

1. Run-of-river plant without pondage
2. Run-of-river plant with pondage
3. Storage type plants
4. Pump storage plants
5. Mini and micro-hydel plants

A. *According to availability of head :*

The following figures give a rough idea of the heads under which the various types of plants work :

(*i*) High head power plants	100 m and above
(*ii*) Medium head power plants	30 to 100 m
(*iii*) Low head power plants	25 to 80 m.

Note. It may be noted that figures given above overlap each other. Therefore it is difficult to classify the plants directly on the basis of head alone. The basis, therefore, technically adopted is the *specific speed* of the turbine used for a particular plant.

5.6.1. High Head Power Plants

These types of plants work under heads ranging from 100 to 2000 metres. Water is usually stored up in lakes on high mountains during the rainy season or during the season when the snow melts. The rate of flow should be such that water can last throughout the year.

Fig. 5.2 shows high head power plant layout. Surplus water discharged by the spillway cannot endanger the stability of the main dam by erosion because they are separated. The tunnel through the mountain has a surge chamber excavated near the exit. Flow is controlled by head gates at the tunnel intake, butterfly valves at the top of the penstocks, and gate valves at the turbines. This type of site might also be suitable for an underground station.

The *Pelton wheel* is the common primemover used in high *head power plants*.

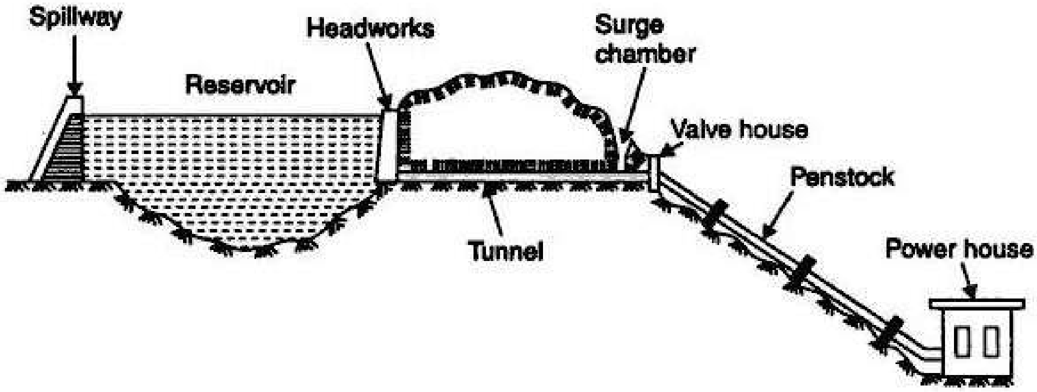


Fig. 5.2. High head power plant layout. The main dam, spillway, and powerhouse stand at widely separated locations. Water flows from the reservoir through a tunnel and penstocks to the turbines.

5.6.2. Medium Head Power Plants

Refer Fig. 5.3. When the operating head of water lies between 30 to 100 metres, the power plant is known as medium head power plant. This type of plant commonly uses *Francis turbines*. The forebay provided at the beginning of the penstock serves as water reservoir. In such plants, the water is generally carried in open canals from main reservoir to the forebay and then to the power-house through the penstock. The forebay itself works as a surge tank in this plant.

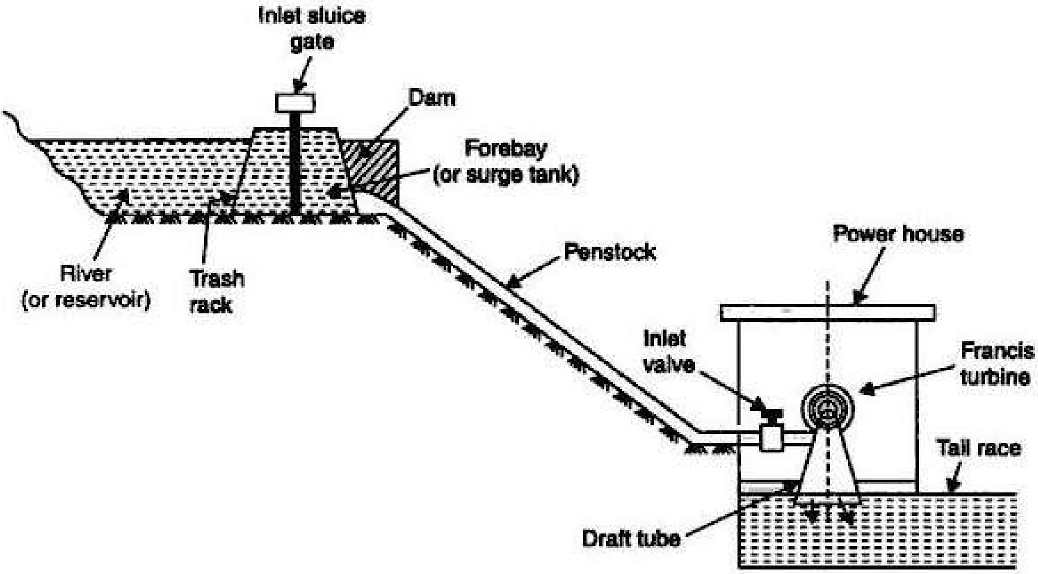


Fig. 5.3. Medium head power plant layout.

5.6.3. Low Head Power Plants

Refer Fig. 5.4. These plants usually consist of a dam across a river. A sideway stream diverges from the river at the dam. Over this stream the power house is constructed. Later this channel joins the river further downstream. This type of plant uses vertical shaft Francis turbine or Kaplan turbine.

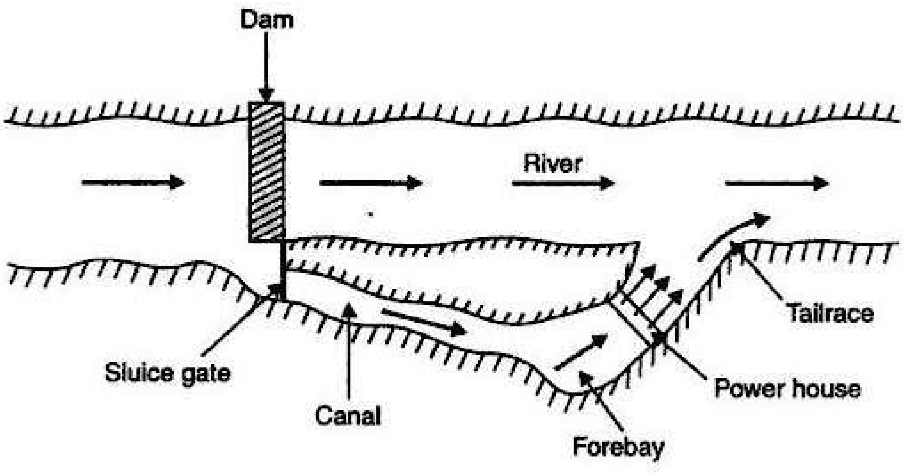


Fig. 5.4. Low head power plant layout.

B. *According to the nature of load :*

5.6.4. Base Load Plants

The plants which cater to the base load of the system are called **base load plants.** These plants are required to *supply a constant power when connected to the grid*. Thus they *run without stop* and are often remote-controlled with which *least staff* is *required for such plants*. Run-of-river plants without pondage may sometimes work as baseload plant, but the firm capacity in such cases, will be much less.

5.6.5. Peak Load Plants

The plants which can supply the power during peak loads are known as **peak load plants.** Some of such plants supply the power during average load but also supply peak load as and when it is there ; whereas other peak load plants are required to work during peak load hours only. The run-of-river plants may be made for the peak load by providing pondage.

C. *According to the quantity of water available :*

5.6.6. Run-of-river Plants without Pondage

A run-of-river plant without pondage, as the name indicates, does not store water and uses the water as it comes. There is *no control on flow of water* so that during high floods or low loads water is wasted while during low run-off the plant capacity is considerably reduced. *Due to non-uniformity of supply and lack of assistance from a firm capacity the utility of these plants is much less* than those of other types. The head on which these plants work *varies considerably*. Such a plant can be made a great deal more useful by providing sufficient storage at the plant to take care of the hourly fluctuations in load. This lends some *firm capacity* to the plant. During good flow conditions these plants may cater to base load of the system, when flow reduces they may supply the peak demands. *Head water elevation for plant fluctuates with the flow conditions*. These plants without storage may sometimes be made to supply the base load, but the firm capacity depends on the minimum flow of river. The run-of-river plant may be made for load service with pondage, though storage is usually seasonal.

5.6.7. Run-of-river Plants with Pondage

Pondage usually refers to the collection of water behind a dam at the plant and increases the stream capacity for a short period, say a week. *Storage* means collection of water in up stream reservoirs and this increases the capacity of the stream over an extended period of several months. Storage plants may work satisfactorily as base load and peak load plants.

This type of plant, as compared to that without pondage, is *more reliable* and its generating capacity *is less dependent on the flow rates of water available*.

5.6.8. Storage Type Plants

A storage type plant is one with a reservoir of sufficiently large size to permit carry-over storage from the wet reason to the dry reason, and thus to supply firm flow substantially more than the minimum natural flow. This plant can be used as base load plant as well as peak load plant as water is available with control as required. The majority of hydro-electric plants are of this type.

5.6.9. Pumped Storage Plants

Refer to Fig. 5.5.

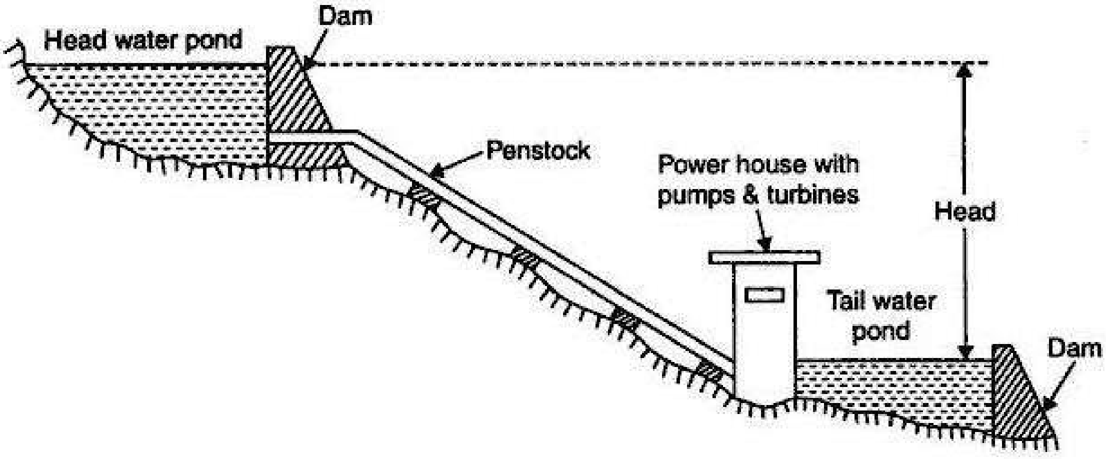


Fig. 5.5. Pumped storage plant.

Pumped storage plants are employed at the places where the quantity of water available for power generation is *inadequate*. Here the water passing through the turbines is stored in *'tail race pond'*. During low load periods this water is pumped back to the head reservoir using the extra energy available. This water can be again used for generating power during peak load periods. Pumping of water may be done seasonally or daily depending upon the conditions of the site and the nature of the load on the plant.

Such plants are *usually interconnected* with steam or diesel engine plants so that off peak capacity of interconnecting stations is used in pumping water and the same is used during peak load periods. Of course, the energy available from the quantity of water pumped by the plant is *less* than the energy input during pumped operation. Again while using pumped water the *power available is reduced* on account of losses occuring in primemovers.

Advantages. The pump storage plants entail the following *advantages* :

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

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

5.7. HYDRAULIC TURBINES

A hydraulic turbine converts the potential energy of water into mechanical energy which in turn is utilised to run an electric generator to get electric energy.

5.7.1. Classification of Hydraulic Turbines

The hydraulic turbines are *classified* as follows :

(*i*) According to the head and quantity of water available.

(*ii*) According to the name of the originator.

(*iii*) According to the action of water on the moving blades.

(*iv*) According to the direction of flow of water in the runner.

(*v*) According to the disposition of the turbine shaft.

(*vi*) According to the specific speed N_s.

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

(*i*) *Impulse turbine*—requires *high head* and *small quantity of flow*.

(*ii*) *Reaction turbine*—requires *low head* and *high rate of flow*.

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

2. According to the name of the originator :

(*i*) *Pelton turbine*—named after Lester Allen Pelton of California (USA). It is an impulse type of turbine and is used for *high head* and *low discharge*.

B. Propeller and Kaplan turbines

- The need to utilize low heads where large volumes of water are available makes it essential to provide a large flow area and to run the machine at very low speeds. The propeller turbine is a reaction turbine used for heads between 4 m and 80 m, and has a specific speed ranging from 300 to 1000. It is purely *axial-flow* device providing the largest possible flow area that will utilize a large volume of water and still obtain flow velocities which are not too large.
- The propeller turbine (Fig. 5.9) consists of an axial-flow runner with four to six or at most ten blades of air-foil shape. The spiral casing and guide blades are similar to those in Francis turbines. In the **propeller turbine** as in Francis turbine the runner blades are *fixed* and *non-adjustable*. However in a *Kaplan turbine* (Fig. 5.10), which is modification of propeller turbine the runner blades are *adjustable and can be rotated about pivots fixed to the boss of the runner. The blades are adjusted automatically by servo-mechanism so that at all loads the flow enters them without shock.*

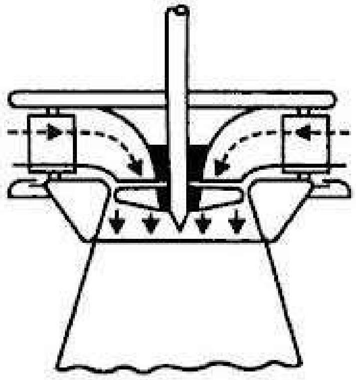
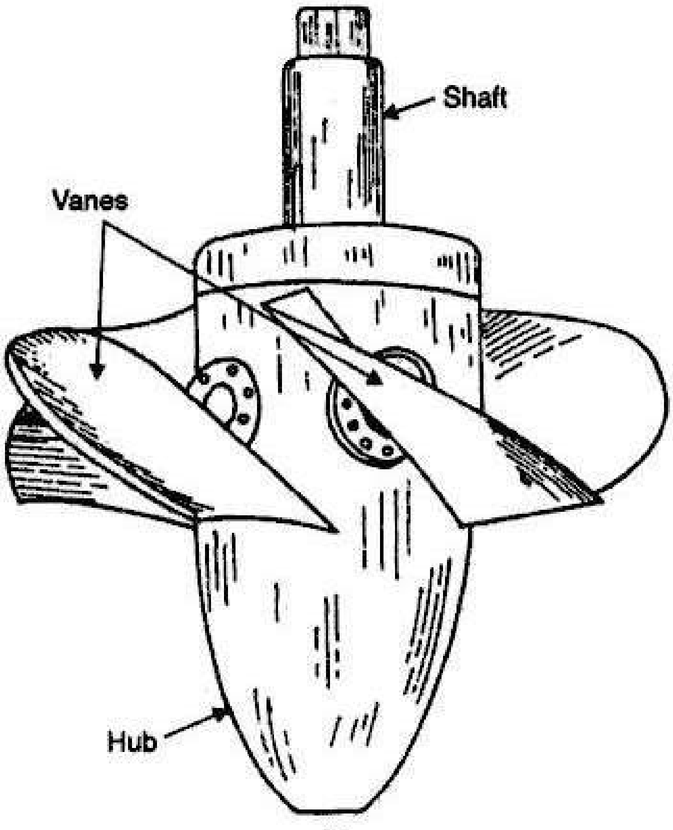


Fig. 5.9. Propeller turbine.

- Kaplan turbines have taken the place of Francis turbines for certain medium head installations. Kaplan turbines with sloping guide vanes to reduce the overall dimensions are being used.



(a)

Comparison of hydraulic turbines :

I. *Francis turbine versus Pelton wheel :*

The Francis turbine claims the following *advantages* over Pelton wheel :

1. In Francis turbine the variation in the operating head can be more easily controlled.
2. In Francis turbine the ratio of maximum and minimum operating heads can be even two.
3. The operating head can be utilized even when the variation in the tail water level is relatively large when compared to the total head.
4. The mechanical efficiency of Pelton decreases faster with wear than Francis.
5. The size of the runner, generator and powerhouse required is small and economical if the Francis turbine is used instead of Pelton wheel for same power generation.

Drawbacks of Francis turbine :

As compared with Pelton wheel, the Francis turbine has the following *drawbacks* :

1. Water which is not clean can cause very rapid wear in high head Francis turbine.
2. The overhaul and inspection is much more difficult comparatively.
3. Cavitation is an ever-present danger.
4. The water hammer effect is more troublesome with Francis turbine.
5. If Francis turbine is run below 50% head for a long period it will not only lose its efficiency but also the cavitation danger will become more serious.

II. *Kaplan verses Francis turbine :*

Kaplan turbine claims the following *advantages* over Francis turbine :

1. For the same power developed Kaplan turbine is more compact in construction and smaller in size.
2. Part-load efficiency is considerably high.
3. Low frictional losses (because of small number of blades used).

5.7.3. Specific Speed of a Turbine

The ***specific speed*** of a turbine is defined *as the speed of a turbine which is identical in shape, geometrical dimensions, blade angles, gate opening etc., with the actual turbine but of such a size that it will develop unit horse power when working under unit head.*

$$\text{Specific speed } N_s = \frac{N\sqrt{P}}{H^{5/4}}$$

(where P is in kW and H in metres)

[N_s (S.I. Units) = 0.86 N_s (metric)]

Specific speed plays an important role for *selecting the type of the turbine.* Also the *performance of a turbine can be predicted* by knowing the specific speed of the turbine.

To compare the characteristics of machines of different types, it is necessary to know a characteristic of an imaginary machine identical in shape. The imaginary turbine is called a *specific turbine.* The specific speed provides a means of comparing the speed of all types of hydraulic turbines on the basis of head and horse power capacity.

If a runner of ***high specific speed*** is used for a given head horse power output, the *overall cost* of installation is *lower*. The selection of *too* high specific speed reaction runner would reduce the size of the runner to such an extent that the discharge velocity of water into the throat of draft tube would be excessive. This is objectionable because a *vacuum* may be created in the extreme case.

The runner of *too high* specific speed with available head *increases the cost of turbine* on account of high mechanical strength required. The runner of *too low* specific speed with low available head *increases the cost of generator* due to the low turbine speed.

An increase in specific speed of turbine is accompanied by lower maximum efficiency and greater depth of excavation of the draft tube. In choosing a high specific speed turbine, an increase in cost of excavation of foundation and draft tube should be considered in addition to the efficiency. The weighted efficiency over the operating range of turbine is more important in the selection of a turbine instead of maximum efficiency.

Table 5.1 gives the specific speeds for various turbines.

Example 5.1. *The following data relate to a proposed hydro-electric station :*

Available head = 28 m ; Catchment area = 420 sq. km ; rainfall = 140 cm/year ; percentage of total rainfall utilized = 68% ; Penstock efficiency = 94% ; turbine efficiency = 80% ; generator efficiency = 84% and load factor = 44%.

(i) Calculate the power developed.

(ii) Suggest suitable machines and specify the same.

Solution. Head available, $H = 28$ m

Catchment area, $A = 420$ sq. km $(= 420 \times 10^6 \text{ m}^2)$

Rainfall $= 140$ cm/year $(= 1.4 \text{ m})$

Rainfall utilized, $h = 68\%$ of the total rainfall

$= (0.68 \times 1.4)$ m per year

Penstock efficiency, $\eta_p = 94\%$

Turbine efficiency, $\eta_t = 80\%$

Generator efficiency, $\eta_g = 84\%$

Load factor $= 44\%$.

(*i*) **Power developed, P :**

Quantity of water available *per year*

$$= A \times h = (420 \times 10^6) \times (0.68 \times 1.4)$$
$$= 399.84 \times 10^6 \text{ m}^3$$

Hence the quantity of water available *per second,*

$$Q = \frac{399.84 \times 10^6}{(365 \times 24) \times 3600} = 12.6 \text{ m}^3$$

$\therefore$ $P = \eta_0 \times wQH$ (where, η_0 = Overall efficiency $= \eta_p \times \eta_t \times \eta_g$)

or $P = \eta_p \times \eta_t \times \eta_g \times wQH$

$$= 0.94 \times 0.8 \times 0.84 \times 9.81 \times 12.6 \times 28 = 2186 \text{ kW}$$

Hence *average output of generating units* = **2186 kW. (Ans.)**

(*ii*) **Machines to be used :**

Total ratings of generators $= \frac{2186}{0.44} = 4968$ kW

Providing *two machines* of equal rating,

Capacity of each unit $= \frac{4968}{2 \times 0.84} = 2957$ each.

As the available head is low, **Kaplan turbines** (propeller type) are suggested, each having a *generating capacity of* **2957 kW. (Ans.)**

Example 5.2. *The following data is available for a hydro-power plant :*

Available head = 140 m ; catchment area = 2000 sq. km ; annual average rainfall = 145 cm ; turbine efficiency = 85% ; generator efficiency = 90% ; percolation and evaporation losses = 16%.

Determine the following :

(i) Power developed.

(ii) Suggest type of turbine to be used if runner speed is to be kept below 240 r.p.m.

Solution. Head available, $H = 140$ m

Catchment area, $A = 200$ sq. km ($= 200 \times 10^6$ m^2)

Annual average rainfall, $h = 145$ cm ($= 1.45$ m)

Turbine efficiency, $\eta_t = 85\%$

Generator efficiency, $\eta_g = 90\%$

Percolation and evaporation losses, $z = 16\% = 0.16$

(*i*) **Power developed, P :**

Quantity of water available for power generation *per year*

$$= A \times h \times (1 - z)$$
$$= 200 \times 10^6 \times 1.45 \times (1 - 0.16) = 2.436 \times 10^8 \text{ m}^3/\text{year}$$

Hence, quantity of water available per second,

$$Q = \frac{2.436 \times 10^8}{(365 \times 24) \times 3600} = 7.72 \text{ m}^3/\text{s}$$

$\therefore$ $P = \eta_0 \times wQH$

$$= \eta_t \times \eta_g \times wQH$$

$$= 0.85 \times 0.9 \times 9.81 \times 7.72 \times 140$$

$$= \mathbf{8111 \text{ kW or } 8.111 \text{ MW.}} \quad \textbf{(Ans.)}$$

(*ii*) **Type of turbine to be used :**

Specific speed, $N_s = \frac{N\sqrt{P}}{H^{5/4}} = \frac{240\sqrt{8111}}{(140)^{5/4}} = 44.28$ r.p.m.

Single Pelton turbine with 4 jets can be used. Further, since head available is large and discharge is low, Pelton turbine will work satisfactorily.

UNIT-V

A plenty of energy is needed to sustain industrial growth and agricultural production. The existing sources of energy such as coal, oil, uranium etc. may not be adequate to meet the ever increasing energy demands. These conventional sources of energy are also depleting and may be exhausted at the end of the century or beginning of the next century. Consequently sincere and untiring efforts shall have to be made by the scientists and engineers in exploring the possibilities of harnessing energy from several non-conventional energy sources. The various non-conventional energy sources are as follows :

(*i*) Solar energy
(*ii*) Wind energy
(*iii*) Energy from biomass and biogas
(*iv*) Ocean thermal energy conversion
(*v*) Tidal energy
(*vi*) Geothermal energy
(*vii*) Hydrogen energy
(*viii*) Fuel cells
(*ix*) Magneto-hydrodynamics generator
(*x*) Thermionic converter
(*xi*) Thermo-electric power.

Advantages of non-conventional energy sources :

The *leading advantages* of non-conventional energy sources are :

1. They do not pollute the atmosphere.
2. They are available in large quantities.
3. They are well suited for decentralised use.

According to energy experts the non-conventional energy sources can be used with advantage for *power generation* as well as other applications in a large number of locations and situations in our country.

7.2. WIND POWER PLANTS

7.2.1. Introduction

The electrical energy can be generated by wind energy. The wind energy, which is an indirect source of energy, can be used to run a wind will which in turn drives a generator to produce electricity. Although wind mills have been used for more than a dozen centuries for grinding grain and pumping water, interest in large scale power generation has developed over the past 50 years. A largest wind generator built in the past was 800 kW unit operated in France from 1958-60. The flexible 3 blades propeller was about 35 m in diameter and produced the rated power in a 60 km/hour wind with a rotation speed of 47 r.p.m. The maximum power developed was 12 MW. In India the interest in the wind mills was shown in the last fifties and early sixties. Apart from importing a few from outside, new designs were also developed, but they did not sustain. It is only in last 10—15 years that development work is going on in many institutions. An important reason for this lack of interest in wind energy must be that wind, in India is relatively low and vary appreciable with seasons. These low and seasonal winds imply a high cost of exploitation of wind energy. In our country high wind speeds are however available in coastal areas of Sourashtra, Western Rajsthan and some parts of central India. In these areas there could be a possibility of using medium and large sized wind mills for generation of electricity.

Characteristics of wind energy :

1. Wind-power systems do not pollute the atmosphere.
2. Fuel provision and transport are not required in wind-power systems.
3. Wind energy is a renewable source of energy.
4. Wind energy when produced on small scale is cheaper, but competitive with conventional power generating systems when produced on a large scale.

Wind energy entails following *shortcomings/problems* :

1. It is fluctuating in nature.
2. Due to its irregularity it needs storage devices.
3. Wind power generating systems produce ample *noise*.

7.2.2. Wind Availability and Measurement

Wind energy can only be economical in areas of good wind availability. Wind energy differs with region and season and also, possibly to an even greater degree with local terrain and vegetation. Although wind speeds generally increase with height, varying speeds are found over different kinds of terrain. Observations of wind speed are carried out at meteorological stations, airports and lighthouses and are recorded regularly with ten minute mean values being taken every three hours at a height of 10 m. But airports, sometimes are in valleys and many wind speed meters are situated low and combinations of various, other factors mean that reading can be misleading. It is difficult, therefore, to determine the real wind speed of a certain place without actual in-situ measurements.

The World Meteorological Organization (WMO) has accepted four methods of wind recording :

(*i*) Human observation and log book.

(*ii*) Mechanical cup-counter anemometers.

(*iii*) Data logger.

(*iv*) Continuous record of velocity and direction.

1. **Human observation and log book.** This involves using the Beaufort Scale of wind strengths which defines visible "symptoms" attributable to different wind speeds. The method is *cheap* and *easily implemented* but is *often unreliable*. The best that can be said of such records is that they are better than nothing.

2. **Mechanical cup-counter anemometers.** The majority of meteorological stations use mechanical cup-counter anemometers. By taking the readings twice or three times a day, it is possible to estimate the mean wind speed. This is a *low cost method*, but is *only relatively reliable*. The instrument has to be in good working order, it has to be correctly sited and should be reliably read at least daily.

3. **Data logger.** The equipment summarizes velocity frequency and direction. It is *more expensive and prone to technical failures but gives accurate data*. The method is tailored to the production of readily interpretable data of relevance to wind energy assessment. It does not keep a time series record but *presents the data in processed form*.

4. **Continuous record of velocity and direction.** This is how data is recorded at major airports of permanently manned meteorological stations. The *equipment is expensive and technically complex*, but it retains a detailed times-series record (second-by-second) of wind direction and wind speed. Results are given in copious quantities of data which require lengthy and expensive analysis.

7.2.3. Types of Wind Mills

The various types of wind mills which are practically useful are shown in Fig. 7.1.

1. **Multiple blade type.** It is the most widely used wind mill. It has 15 to 20 blades made from metal sheets. The *sail type* has three blades made by stitching out triangular pieces of convass cloth. Both these types run at low speeds of 60 to 80 r.p.m.

2. **Savonius type.** This type of windmill has hollow circular cylinder sliced in half and the halves are mounted on vertical shaft with a gap in between. Torque is produced by the pressure difference between the two sides of the half facing the wind. This is quite efficient but needs a large surface area.

3. **Darrieus type.** This wind mill needs much less surface area. It is shaped like an egg beater and has two or three blades shaped like aerofoils.

It may be noted that :

— Both the Savonius and Darrieus types are mounted on a *vertical axis* and hence they *can run independently of the direction of wind.*

— The horizontal axis mills *have to face the direction of the wind* in order to generate power.

Performance of wind mills :

The performance of a wind mill is defined as *'Co-efficient of performance' (K_p)*.

$$K_p = \frac{\text{Power delivered by the rotor}}{\text{Maximum power available in the wind}}$$

or,

$$K_p = \frac{P}{P_{max}} = \frac{P}{\frac{1}{2}\rho A U_w^3}$$

where, ρ = Density of air,

A = Swept area, and

U_w = Velocity of wind.

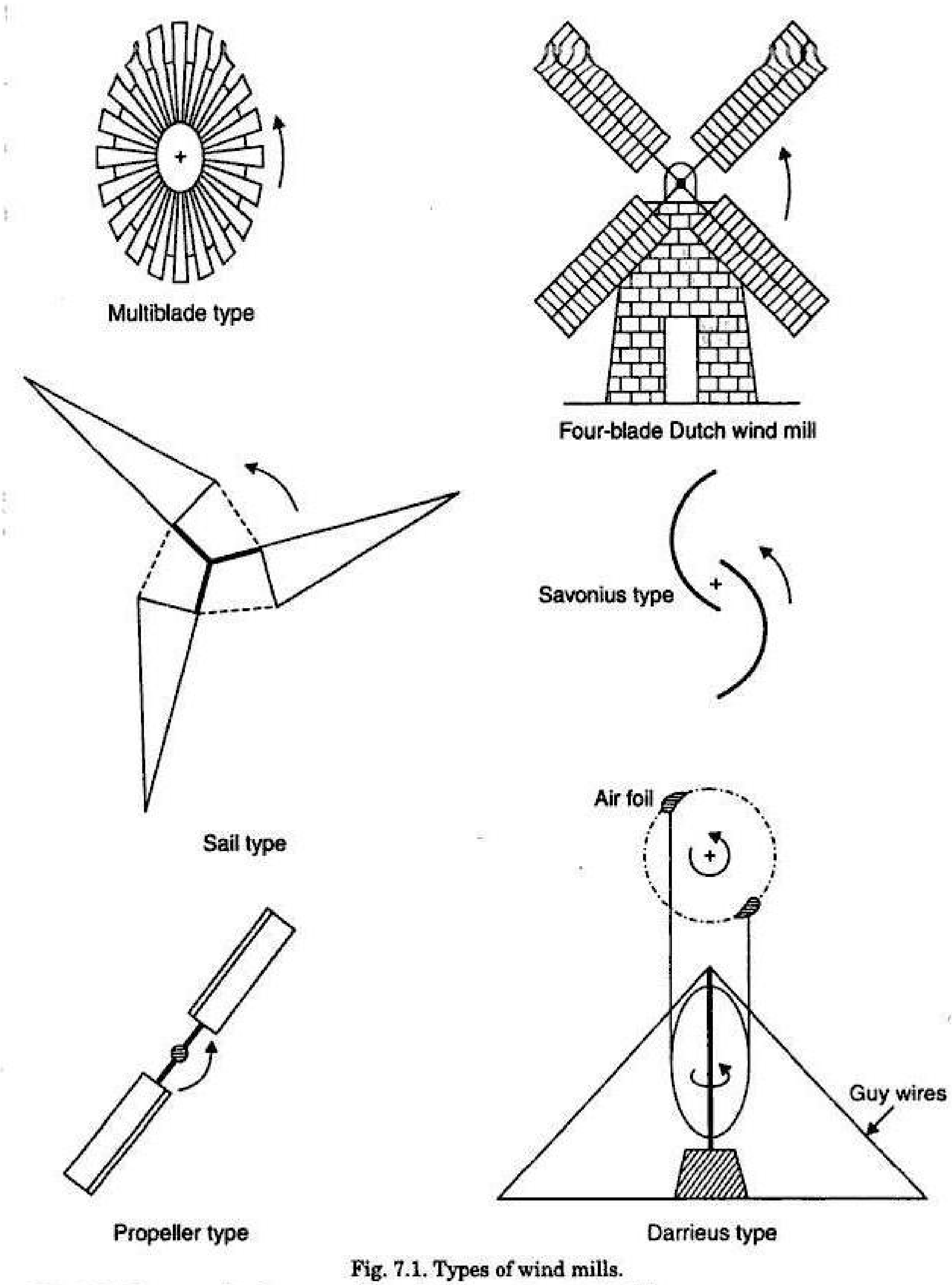


Fig. 7.1. Types of wind mills.

Fig. 7.2 shows a plot between K_p and tip speed ratio U_{bt}/U_w
where U_{bt} = Speed of blade tip.

It can be seen that K_p is the *lowest of Savonius* and *Dutch types* whereas the *propeller types have the highest value*.

In the designing of wind mills, it is upper most to keep the power to weight ratio at the lowest possible level.

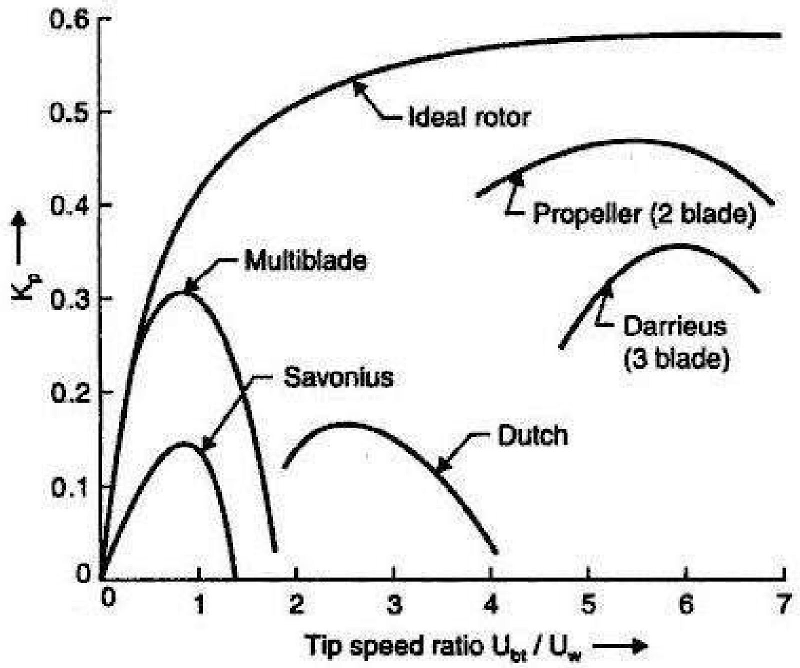


Fig. 7.2. K_p of wind mills.

7.2.4. Wind-Electric Generating Power Plant

Fig. 7.3 shows the various parts of a wind-electric generating power plant. These are :

1. Wind turbine or rotor.
2. Wind mill head—it houses speed increaser, drive shaft, clutch, coupling etc.

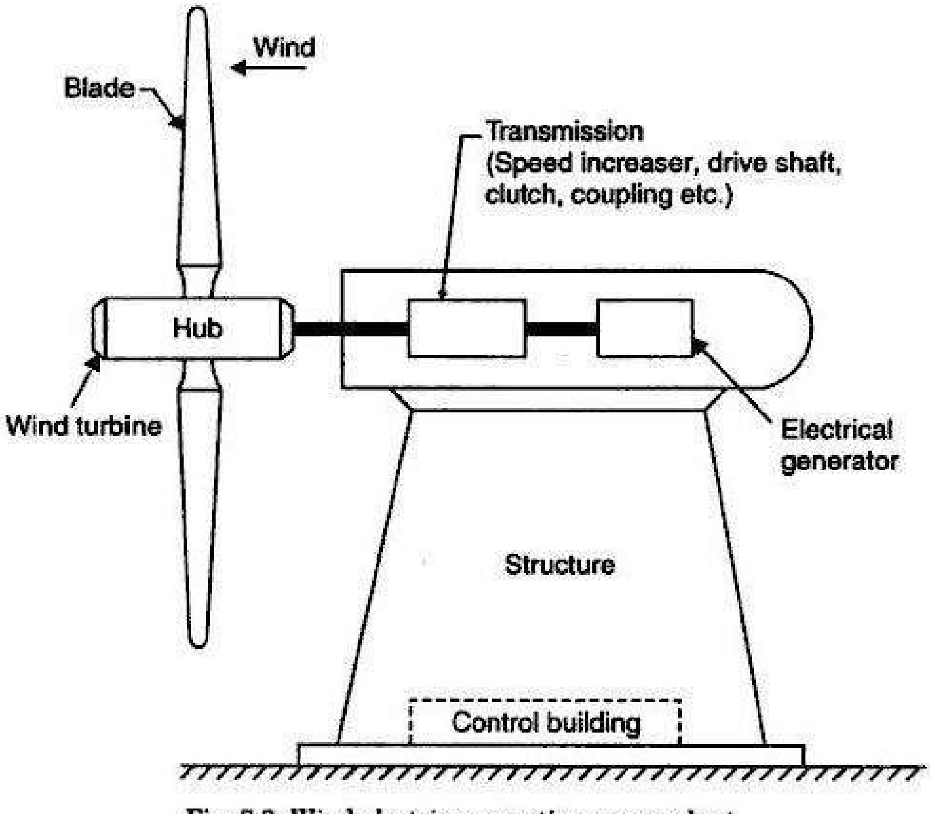


Fig. 7.3. Wind-electric generating power plant.

3. Electrical generator.

4. Supporting structure.

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

— The wind mill head performs the following *functions* :

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

(*ii*) It also houses any control mechanism incorporated like changing the pitch of the blades for safety devices and tail vane to orient the rotor to face the wind, the latter is facilitated by mounting it on the top of the supporting structure on suitable bearings.

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

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

7.2.5. Types of Wind Machines

Wind machines (aerogenerators) are generally *classified* as follows :

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

Horizontal axis wind machines. Fig 7.4 shows a schematic arrangement of a horizontal axis machine. Although the common wind turbine with a horizontal axis is simple in principle,

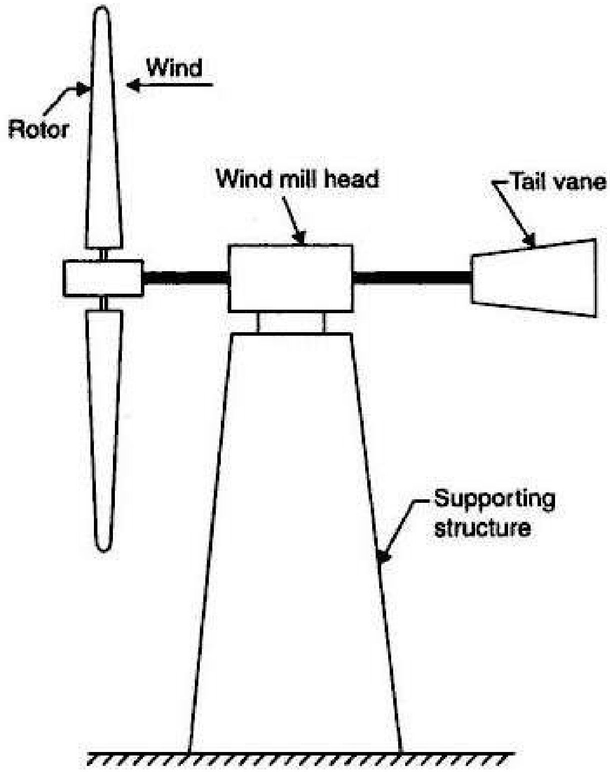


Fig. 7.4. Horizontal axis wind machine.

yet the design of a complete system, especially a large one that would produce electric power economically, is complex. It is of paramount importance that the components like rotor, transmission, generator and tower should not only be as efficient as possible but they must also function effectively in combination.

Vertical axis wind machines. Fig. 7.5 shows vertical axis type wind machine. One of the main advantages of vertical axis rotors is that they do not have to be turned into the windstream as the wind direction changes. Because their operation is independent of wind direction, vertical axis machines are called *panemones.*

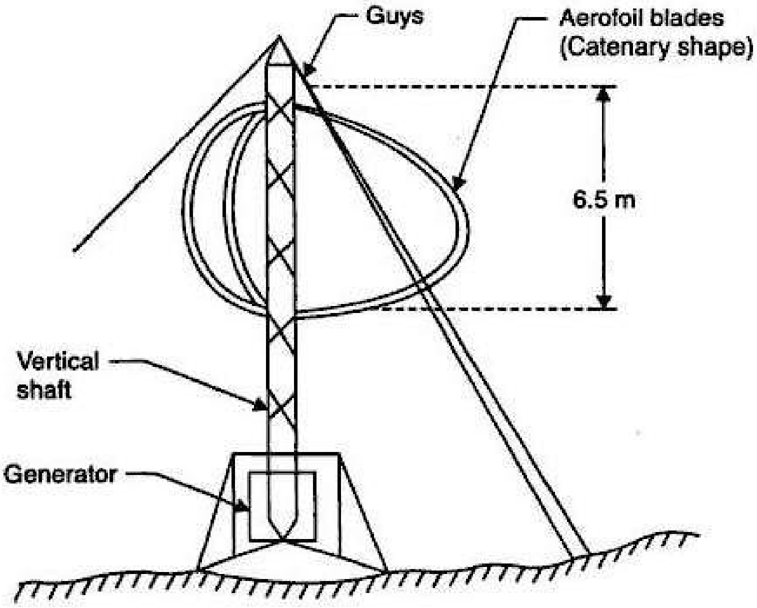


Fig. 7.5. Vertical axis wind machine.

7.2.6. Wind-Powered Battery Chargers

One application of wind energy systems which is of considerable potential importance (to developing countries) is the use of small wind generators to charge batteries for powering lighting, radio communication and hospital equipment. Wind generators have been in use in Europe and North America since the 1920s, although their use declined considerably.

A battery charging system has to include the following :

(*i*) A wind powered generator.

(*ii*) A converter.

(*iii*) A container for the batteries.

Fig. 7.6 shows a set-up of wind powered battery charging system. It is worthnoting that 12 volt batteries, which are rechargeable using wind generators, can be used to power fluorescent tube lighting which is six times more efficient than tungsten filament lamps. Such lighting opens up a number of important development opportunities in areas which normally have no lighting.

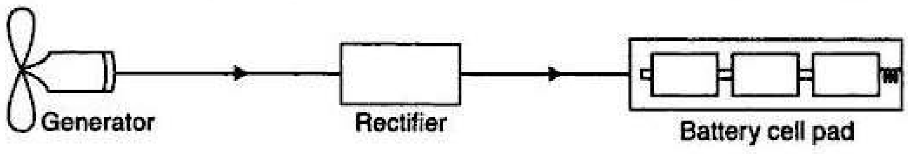


Fig. 7.6

For small wind generators the total system efficiency is made up as follows :

Wind regime matching efficiency	60% (approx.)
Rotor efficiency	35% (approx.)
Generator and wiring efficiency	70% (approx.)
Battery charge/discharge efficiency	70% (approx.)

Cumulatively, a total energy capture efficiency of about 10% is generally obtained from small wind generators utilized for battery charging.

Battery charging wind generators are produced in several countries, notably Australia, France, Sweden, Switzerland, the U.K., the U.S.A. and West Germany. In developing countries production is underway in China and has started in India.

7.2.7. Wind Electricity in Small Independent Grids

Refer to Fig. 7.7. In such systems electricity consumption fluctuates constantly as does the availability of wind energy. The degree of coincidence of supply and demand can be calculated by statistical means and it has been found that electricity supply with an acceptable degrees of reliability cannot be based solely on wind energy. If an extensive grid does not exist, electricity storage (batteries) or a back-up system (diesel) is required. Loads for remote systems of upto 6 kWh/day equivalent to an average power consumption of 250 W with a duty cycle of 24 hours, can be provided with battery storage.

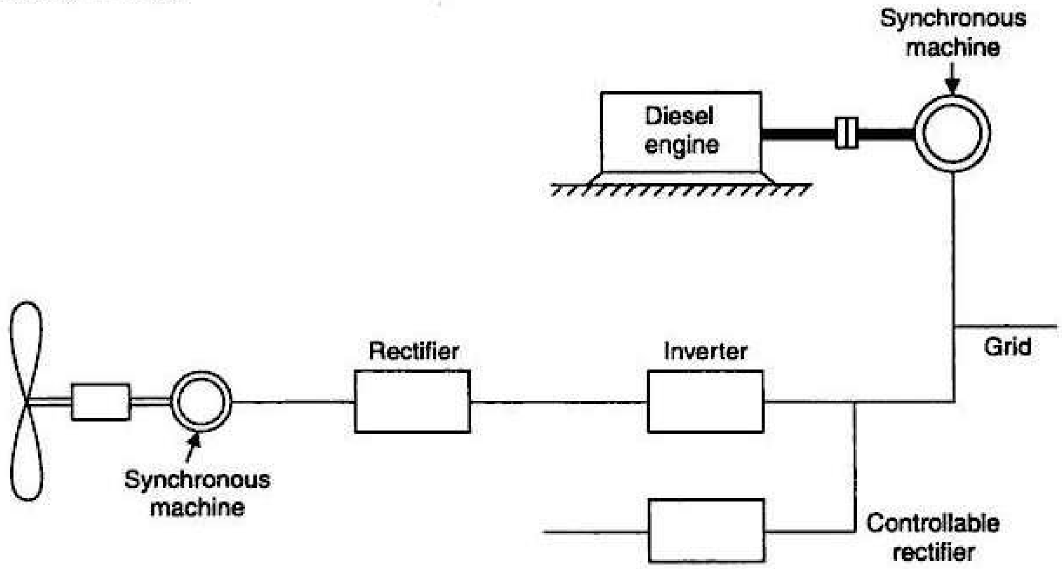


Fig. 7.7. Principle of combined wind/diesel power generation.

If a diesel and wind generator are used in conjunction with a grid, the *diesel generator should only be used when wind energy is absent*. Problems can occur, however, when the diesel generator is called on to change its output frequently as wind energy availability fluctuates. Besides decreasing the oil saving, diesel generation on this basis leads to more frequent overhauls of the generator. Both factors will increase costs. Several methods of overcoming these problems have been tried but there is not yet an established solution. Some development work has still to be done before wind generators can be run in parallel with diesel on a routine basis.

7.2.8. Wind Electricity Economics

Wind generator power costs are heavily linked to the characteristics of a wind resource in a specific location. The cost of supplied power declines as wind speeds increase, and the power supplied increases in proportion to the *cube of the wind speed.*

Matching available energy and load requirements is also important in wind energy economics. The correct size of wind generator must be chosen together with some kind of storage or co-generation with an engine or a grid to obtain the best economy. The ideal application is a task that can utilize a variable power supply, *e.g.*, ice making or water purification.

Regarding the *economics*, the choice of interest rate obviously has a major effect on the overall energy cost. With low interest rates, capital intensive power sources such as solar and wind are favoured. Other factors bearing a strong influence on the economics of wind electricity are the standard of maintenance and service facilities and the cost of alternative energy supplies in the particular area.

7.2.9. Problems in Operating Large Wind Power Generators

The operation of large wind power generators entails the following *problems* :

1. **Location of site.** The most important factor is locating a site big enough which has a reasonable average high wind velocity.

Sourastra and Coastal Regions in India are promising areas.

2. **Constant angular velocity.** A constant angular velocity is a must for generating A.C. (alternating current) power and this means very sensitive governing.

3. **Variation in wind velocity.** The wind velocity varies with time and varies in direction and also varies from the bottom to top of a large rotor (some rotors are as long as 50 meters). This causes fatigue in blades.

4. **Need of a storage system.** At zero velocity conditions, the power generated will be zero and this means some storage system will have to be incorporated along with the wind mill.

5. **Strong supporting structure.** Since the wind mill generator will have to be located at a height, the supporting structure will have to be designed to withstand high wind velocity and impacts. This will add to the initial costs of the wind mill.

6. **Occupation of large areas of land.** Large areas of land will become unavailable due to wind mill gardens (places where many wind mills are located). The whole area will have to be protected to avoid accidents.

Inspite of all these difficulties, interest to develop wind mills is there since this is a clean source of energy.

7.3. TIDAL POWER PLANTS

7.3.1. Introduction

The periodic rise and fall of the water level of sea which are carried by the action of the sun and moon on water of the earth is called the '**tide**'. Tidal energy can furnish a significant portion of all such energies which are renewable in nature. The large scale up and down movement of sea water represents an unlimited source of energy. If some part of this vast energy can be converted into electrical energy, it would be an important source of hydropower.

The *main feature of the tidal cycle is the difference in water surface elevations at the high tide and at the low tide.* If this differential head could be utilized in operating a hydraulic turbine, the tidal energy could be converted into electrical energy by means of an attached generator.

7.3.2. Components of Tidal Power Plants

The following are the *components* of a tidal power plant :

1. The dam or dyke (low wall) to form the pool or basin.
2. Sluice ways from the basins to the sea and *vice versa*.
3. The power house.

Dam or dyke. The function of dam or dyke is to form a barrier between the sea and the basin or between one basin and the other in case of multiple basins.

Sluice ways. These are used to fill the basin during the high tide or empty the basin during the low tide, as per operational requirement. These devices are controlled through gates.

Power house. A power house houses turbines, electric generators and other auxiliary equipment. As far as possible the power house and sluice ways should be in *alignment* with the dam or dyke.

7.3.3. Classification and Operation of Tidal Power Plants

Tidal power plants are *classified* as follows :

1. **Single basin arrangement**

(*i*) Single ebb-cycle system (*ii*) Single tide-cycle system

(*iii*) Double cycle system.

2. **Double basin arrangement**

In a *single basin arrangement* power can be generated only *intermittently*. In this arrangement only one basin interacts with the sea. The two are separated by a dam or dyke and the flow between them is through sluice ways located conveniently along the dam. The rise and fall of tidal water levels provide the potential head.

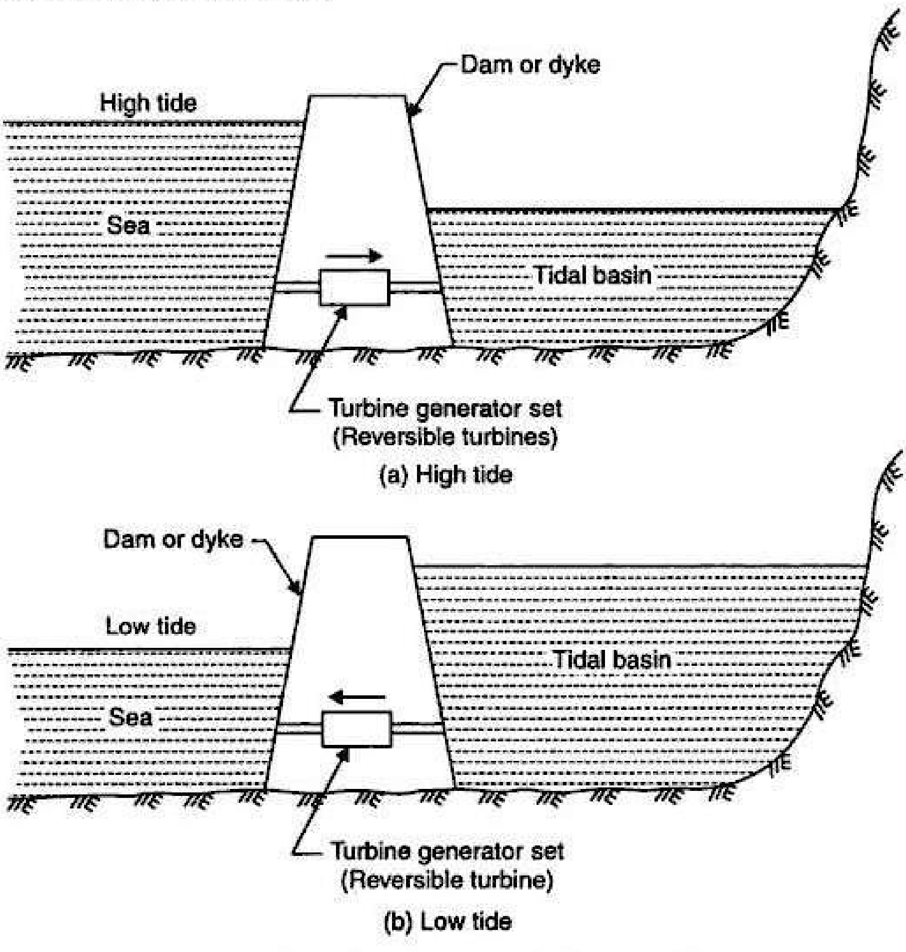


Fig. 7.8. General arrangement of tidal power plant.

GENERAL ASPECTS OF NUCLEAR ENGINEERING

6.1.1. Atomic Structure

- An element is defined as a substance *which cannot be decomposed into other substances.* The *smallest particle* of an element which takes part in chemical reaction is known as an '*atom*'. The word atom is derived from Greek word 'Atom' which means indivisible and for a long time the atom was considered as such. *Dalton's atomic theory* states that (*i*) all the atoms of one element are precisely alike, have the same mass but differs from the atoms of other elements (*ii*) the chemical combination consists of the union of a small fixed number of atoms of one element with a small fixed number of other elements.
- Various atomic models proposed by scientists over the last few decades are : 1. Thompson's plum puddling model, 2. Rutherford's nuclear model, 3. Bohr's model, 4. Sommerfeld's model, 5. Vector model, 6. Wave-mechanical model.
- The complex structure of atom can be classified into *electrons* and *nucleus*. The nucleus consists of *protons* and *neutrons* both being referred as *nucleons*. *Protons* are *positively* charged and *neutrons* are *neutral*, thus making complete nucleus as positively charged.
- The *electrons* carry *negative* charge and circulate about the nucleus. As the positive charge on proton particle is equal to the negative charge on electron particle, and the *number of electrons is equal to the number of protons,* atom is a neutral element. Any addition of the number of electrons to the neutral atom will make it negatively charged. Similarly any subtraction of the electrons will make it positively charged. Such an atom is known as *ion* and the process of charging the atom is termed an *ionisation*.
- The nuclear power engineering is specially connected with *variation of nucleons in nucleus.* Protons and neutrons are the particles having the mass of about 1837 times and 1839 times the mass of an electron.

- The modern atomic theory tells that the atom has a diameter of about 10^{-7} mm. In a neutral atom the electrons are bound to the nucleus by the electrostatic forces, which follows the Coloumb's law of forces, *i.e.*, like charges repel and unlike charges attract each other. The function of electrostatic force is similar to the gravitational force.
- The atomic spectrum study has revealed that every electron in an atom is in one group of specific states of motion which is corresponding to its total energy. In an atom the electrons are spinning around the nucleus in orbits. These orbits are called *shells*, which represent the energy levels for the electrons. *All the electrons having very nearly the same total energy are said to be in the same shell.* The shells have been named as K, L, M, N etc. Each shell consists of the specific maximum number of electrons. The K shell (inner shell) contains **2** electrons, L shell has **8** electrons, M shell is limited to **18** and the N shell possesses **32** electrons. In fact, the number of electrons in any orbit is equal to $2n^2$ where n is the serial number of the orbit taking first orbit nearest to the nucleus, *with the exception that the outermost orbit cannot have more than eight electrons* . In a given atom all orbits may not be complete. It is obvious from the study that *amplitude difference in energy between two shells is much more than the difference in between energy levels in one shell.* In a *shell less than the specified number of electrons may exist but not a large number.* The inner shell is filled up first and then the other successive shells are completed.
- The *chemical properties of the atom varies with composition of number of electrons in various shells and the state of energies within the shells determine the electrical characteristics of the atom.* For example, *Hydrogen* (H_2) consists of one electron in the *first shell*, *Helium* (He) has two electrons in the first shell, *Lithium* (Li) has two electrons in first shell and one is second shell, *Carbon* (C) consists of two electrons in first and four in second shell.

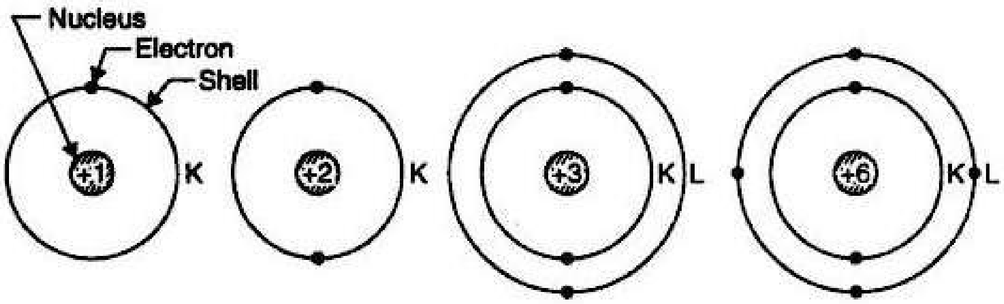


Fig. 6.1 (*a*). Atomic structure of H_2, He, Li and C.

- The electrons lying in the outermost shell are termed *valence electrons.* If the outermost shell is completely filled, the atom is stable and will not take any electron to fill up the gap. However, the incomplete outer shell will try to *snatch* the required number of electrons from the adjacent atom in a matter. The binding force between the electron and nucleus is the electrostatic force of attraction. *To emit one electron energy required is more than the electrostatic force of attraction. When the energy is supplied, the electron jumps from one discrete energy level to another permissible level. The process starts from outer shell.* The electron possesses the energy in two forms, *i.e.*, kinetic energy due to its motion and potential energy due to its position with respect to the nucleus. It is obvious that *electrons cannot exist in between the permissible orbits.*
- The charge of nucleus is represented by the *number of protons* present. This number is known as *atomic number* and designated by the letter Z. It also shows the position of atom in the periodic table. Hydrogen has only one number but natural uranium has ninety two. The atoms having *higher atomic number* have been developed artificially ranging from

93 to 102. These are einsteinium (Z = 99), Ferinium (Z = 100), and mendelevium (Z = 101). Platonium (Z = 94) is an important element to the nuclear power field.

The *mass number* (*A*) is the sum of total number of protons and neutrons in a nucleus. The number of electrons is represented by the letter *N*, *i.e.*, $N = (A - Z)$.

6.1.2. Atomic Mass Unit

The *mass of the atom is expressed in terms of the mass of the electron.* The unit of mass has been considered as $\frac{1}{16}$ th of the mass of neutral oxygen atom which contains 8 protons and 8 neutrons. The atomic mass unit (a.m.u.) is equal to $\frac{1}{16}$ th the mass of oxygen neutral atom.

One a.m.u. = 1.66×10^{-24} g

$$\text{Mass of proton} = 1837 \text{ me} = \frac{1837 \times 9.1 \times 10^{-28}}{1.66 \times 10^{-24}} = 1.00758 \text{ a.m.u.}$$

$$\text{Mass of neutron} = 1839 \text{ me} = \frac{1839 \times 9.1 \times 10^{-28}}{1.66 \times 10^{-24}} = 1.00893 \text{ a.m.u.}$$

It has been concluded that the density of matter in a nucleus is enormous. It has been investigated that the *radius of nucleus is equal* to $1.57 \times 10^{-3} \times 3\sqrt{A}$, where *A* is the number of nucleons in nucleus.

The density of uranium by calculations comes to 1.65×10^{14} g/cm^3. It has been found by calculations that *natural substance has density millions of times lower than that of nuclear matter.*

Electron volt. The energy is expressed in electron volt unit. An electron volt is equal to *work done in moving an electron by a potential difference of one volt.* Or *it is the amount of energy acquired by any particle with one electronic charge, when it falls through a potential of one volt.*

One electron volt = 1.602×10^{-19} joule.

6.1.3. Isotopes

In any atom, the *number of electrons is equal to number of protons.* This is independent of neutrons in the nucleus. *Atoms having different number of neutrons than the number of protons are known as 'Isotopes.'*

Example. Isotopes of hydrogen are shown below [Fig. 6.1 (*b*)].

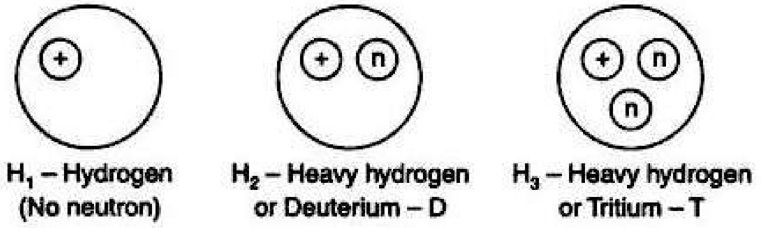


Fig. 6.1 (*b*).

These isotopes have the *same chemical properties* and *have the same atomic number* and *occupy the same place in the periodic table.* But the *nuclear properties* of each of the isotopes are different *because of the different number of neutrons in the nucleus.*

The isotopes of oxygen vary from O_{14} to O_{19}. The change of number of neutrons in nucleus affect the mass of atom.

Example. Weight of heavy hydrogen is twice the weight of simple hydrogen. This means a volume of H_2O weighs less than the same volume of D_2O.

6.1.8. Nuclear Reactions

During a nuclear reaction, the *change in the mass of the particle represents the release or an absorption of energy*. If the total mass of the particle after the reaction is reduced, the process releases the energy, consequently, the increase in the mass of the resultant particle, will cause the absorption of energy.

The equations of nuclear reactions are connected with the resettlement of protons and neutrons within the atom. The equations are much similar to chemical reactions. The energy variation is also of the order of MeV. In simple term the equation shows the *balance of neutron and proton.*

A nuclear reaction is written as follows :

(*i*) The bombarded nuclei or the target nuclei is written first from left hand side.

(*ii*) In the middle within brackets, first is the incident particle and second one the ejected.

(*iii*) On the right hand side, the resultant nucleus is placed.

A *neutron* is written as : ${}_0n^1$ because it has unit mass and it does not have any charge.

An *electron* is written as : ${}_{-1}e^0$ because its mass is negligible as compared to proton or neutron and its charge is equal but opposite to the charge of proton.

Some of the *examples of reactions* are given below :

(*i*) When ${}_{11}Na^{23}$ is bombarded with protons possessing high energy, it is converted to ${}_{12}Mg^{23}$

$${}_{11}Na^{23} + {}_1H^1 \longrightarrow {}_{12}Mg^{23} + {}_0n^1 + q \qquad ...(6.10)$$

(where q = release or absorption of energy in the reaction)

(*ii*) When ${}_{13}Al^{27}$ is bombarded with high energy protons it is transformed to ${}_{14}Si^{27}$.

$${}_{13}Al^{27} + {}_1H^1 \longrightarrow {}_{14}Si^{27} + {}_0n^1 + q \qquad ...(6.11)$$

(*iii*) When ${}_{13}Al^{27}$ is bombarded with deutrons, Al^{28} and proton may be produced.

$${}_{13}Al^{27} + {}_1H^2 \longrightarrow {}_{13}Al^{28} + {}_1H^1 \qquad ...(6.12)$$

The eqns. (6.10), (6.11) and (6.12) may be written in the equation form as given below :

$$Na^{23}(p, n)Mg^{23} \qquad ...(6.13)$$

$${}_{13}Al^{27}(p, n)Si^{27} \qquad ...(6.14)$$

$$Al^{27}(d, p)Al^{28} \qquad ...(6.15)$$

It is evident from the above mentioned reactions that the *nuclear reaction is followed by capturing a particle, resulting in a compound excited nucleus, which undergoes further transformation in a short period of time.*

The *transformation may adopt the following five main different paths :*

1. Elastic scattering. The neutron interacts with the nucleus and after transformation the compound nucleus emits a particle which is identical to the captured one. There is also no change in the resultant nucleus. The *total internal energy* of the bombarded nucleus and the restriking particle *will not change* at all. The process is known as *elastic scattering*. Elastic scattering is also termed as *elastic collision*. When the neutron strikes the nucleus, it imparts the part of initial kinetic energy and momentum to the nucleus which causes the displacement of the nucleus in the crystal lattice by a significant distance and can *change the structural properties of the material.*

In elastic scattering process the *kinetic energy of neutron is reduced and is beneficial to slow down the neutron in reactor*. In this transformation, *there is neither release nor absorption of energy but as a result of collision, redistribution of kinetic energy takes place.*

Example of elastic scattering. When a neutron strikes a light nucleus (*e.g.*, hydrogen nucleus), the velocity of the neutron is very much reduced and the energy is transferred to the proton. Here most of the energy is transferred because both the particles are having nearly the *same masses*. It has been observed that in such a single collision, the loss of energy of the proton is nearly 70 to 75 percent. In case the neutron impacts with the heavy nucleus, the energy loss in single collision is *less*. With carbon nucleus this loss amounts to nearly 12 to 17 percent of the initial value. The reaction is written as $C^{12}(n, n)C^{12}$.

2. Inelastic scattering. The composition of the incident particle and ejected particle remains unchanged. When the particle interacts with the nuclei it loses its kinetic energy and the target nucleus is excited. The energy is released in the form of gamma emission. This transformation is known as *inelastic scattering* or collision. The process is limited to the condition that the neutron should have minimum energy sufficient to excite the target nucleus. The reaction is completed with the absorption or release of energy. The neutron energy loss is of the order of 10 to 20 percent of the initial value.

When a fast moving neutron hits the U^{238} nucleus, the nucleus is excited and there is an emission of gamma quantum [U^{238} $(n, \eta\gamma)$ U^{238}].

3. Capture. In this process the incident particle may be captured or absorbed by the nucleus and may raise the mass number by unity. The nucleus is excited and the energy is emitted in the form of gamma quantum. The *artificial radioactive materials are produced by this process*. In a reactor, Co-60 isotope is produced by bombarding the natural Co-59 with neutrons. The reaction has both the possibilities of producing the stable and unstable nucleus and may result in (n, γ) or (p, γ) reactions. This transformation may take place with elastic scattering. When a neutron interacts with light hydrogen, it forms heavy hydrogen, deuterium. The mass of deuterium is less than its components. This mass defect is corresponding to the release of gamma quantum.

4. In this reaction, the *impinging particle is trapped in the nucleus but the ejected particle is a different one. The composition of the resultant nucleus is also different from the parent nucleus.*

5. 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 U^{233}, U^{235}, Pu^{239} etc. The transformation is known as *fission*. The produced two nuclei are lighter nuclei ; they have *more binding energies per nucleon and hence this reaction always releases the energy* (Fig. 6.2).

6.1.9. Nuclear Cross-sections

Cross-sections (or attenuation coefficients) *are measures of the probability that a given reaction will take place between a nucleus or nuclei and incident radiation.*

Cross-sections are called either *microscopic* or *macroscopic*, depending on whether the reference is to a single nucleus or to the nuclei contained in a unit volume of material.

Microscopic cross-section :

It is a measure of the probability that a given reaction will take place between a single nucleus and an incident particle. Microscopic cross-section is usually denoted by the symbol σ and is expressed in terms of the *effective area that a single nucleus presents for the specified reaction*. Since these cross sections are usually quite small, in the range of 10^{-22} to 10^{-26} cm^2/nucleus it is general practice to express them in terms of a unit called the *barn*, which is 10^{-24} cm^2/nucleus.

Macroscopic cross-sections :

These are the products of microscopic cross-sections and the atomic density in nuclei per cubic centimeter and are equivalent to the total cross-section, for a specific reaction of all the nuclei in 1 cm^3 of material. Macroscopic cross-sections are denoted by the symbol Σ for *neutrons* and μ for *gamma rays* and have the units cm^{-1}.

Gamma ray cross-sections :

Although there are a large number of interaction processes that take place between gamma rays and matter, the most commonly used are the energy-absorption cross-section (used to determine gamma heating and dose rates) and the total attenuation cross-section (used to determine material gamma-ray attenuation and for shielding design).

Neutron cross-sections :

Neutrons undergo a large number of different interaction processes with matter, and, unlike gamma rays, many of these individual interactions must be evaluated. Neutron cross-sections of general use are :

(*i*) Fission
(*ii*) Gamma-ray production
(*iii*) Activation
(*iv*) Elastic scattering
(*v*) Inelastic scattering
(*vi*) Reaction particle production
(*vii*) Total absorption
(*viii*) Total attenuation.

Both neutron and gamma-ray cross-sections are *energy-dependent properties*. Plots of gamma-ray cross-section *vs* photon energy for all materials are, over the energy range of interest, *smooth curves*, whereas for neutron cross sections the curves of many materials *show gross variations from a smooth curve*. The variations in neutron cross-sections show up as peaks and valleys on the cross-section plot ; these peaks are called *resonances*. When a material has a large number of resonance peaks over a portion of the energy range, this portion of the cross-section plot is called a *resonance region*. The *resonance region can have a significant effect on reactor design*, since the material U^{238} which is present in most fuels has a relatively wide resonance region which can cause extensive neutron absorption during the slowing down of neutrons to thermal energy.

The known cross-sections for materials potentially useful in reactor systems are used as primary criteria in materials selection. For example, high-neutron-absorption cross-section materials would not normally be used as materials of construction in the vicinity of a reactor core to prevent competition for the neutrons required to sustain the fission process ; and high activation cross-section materials would not be chosen, if they can be avoided, in a region exposed to a high neutron flux during operation, if that region is to be accessible after reactor shut-down.

6.1.10. Fertile Materials

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 materials*.

Pu^{239} and U^{233} are not found in nature but U^{238} and Th^{232} can produce them by nuclear reactions. When U^{238} is bombarded with slow neutrons it produces ${}_{92}U^{239}$ with half-life of 23.5 days which is unstable and undergoes two beta disintegratio . The resultant Pu^{239} has half-life of 2.44×10^4 yrs and is a good alpha emitter.

$$ {}_{92}U^{238} + {}_0n^1 \longrightarrow {}_{92}U^{239} + \gamma \quad \text{...(6.16)} $$

$$ {}_{92}U^{239} \xrightarrow{\text{23.5 min.}} - {}_{-1}e^0 + {}_{91}Np^{231} \quad \text{...(6.17)} $$

$$ {}_{93}Np^{239} \xrightarrow{\text{2.3 days}} {}_{-1}e^0 + {}_{94}Pu^{239} \quad \text{...(6.18)} $$

During conversion the above noted reactions will take place. The other isotopes of neptunium such as 2.1 day Np^{238} and plutonium can also be produced by the bombardment of heavy particles accelerated by the cyclotron.

The nuclear transformations to convert ${}_{90}Th^{232}$ to U^{233} are given below :

$$ {}_{90}Th^{232} + {}_0n^1 \longrightarrow {}_{90}Th^{233} + \gamma \quad \text{...(6.19)} $$

$$ {}_{90}Th^{233} \xrightarrow{\text{23.3 min.}} {}_{91}Pa^{233} + {}_{-1}e^0 \quad \text{...(6.20)} $$

$$ {}_{91}Pu^{233} \xrightarrow{\text{27.4 days}} {}_{92}U^{233} + {}_{-1}e^0 \quad \text{...(6.21)} $$

U^{235} is the source of neutrons required to derive Pu^{239} and U^{233} from Th^{232} and U^{238} respectively. This process of conversion is performed in the *breeder reactors*.

Other fissionable materials. Th^{227}, Pa^{232}, U^{231}, Np^{238} and Pu^{241} are the other nuclides which are having high cross-sections for neutron thermal fission. Pu^{241} is the important nuclide which is used in plutonium fueled power reactors.

6.1.11. Fission of Nuclear Fuel

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

Fig. 6.3 is a representation of the fission of uranium 235. The *energy released as a result of fission is the basis for nuclear-power generation*. The release of about *2.5 neutrons / fission* makes it possible to produce *sustained fissioning*.

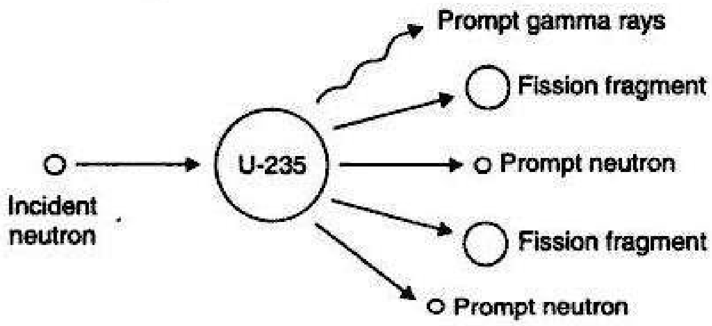


Fig. 6.3. Fission of uranium 235. Incident neutron, upon colliding with U^{235} nucleus, causes fission to take place, resulting in the production of fission fragments, prompt neutrons and prompt gamma rays.

The *fission fragments* that result from the fission process are *radioactive* and decay by emission of beta particles, gamma rays and to a lesser extent alpha particles and neutrons. The neutrons that are emitted after fission, by decay of some of the fission fragments, are called *delayed neutrons*. These are of the utmost importance, since *they permit the fission chain reaction to be easily controlled*.

The total detectable *energy released* owing to the fission of a single nucleus of uranium 235 is 193 MeV, distributed as shown below :

Distribution of fission energy

	MeV
Instantaneous energy release :	
Kinetic energy of fission fragments	168
Prompt-gamma-ray energy	7
Kinetic energy of prompt neutrons	5
Instantaneous total	180
Delayed energy release :	
Beta particle decay of fission products	7
Gamma-ray decay of fission products	6
Delayed total	13

As is shown above, the neutron emitted as a result of fission of a uranium 235 nucleus carry off 5 MeV of kinetic energy. Since on average there are about 2.5 neutrons emitted/U^{235} fission, the average neutron energy is 2 MeV. Actually fission neutrons are emitted with an energy speed of from nearly zero energy to approximately 16 MeV, the bulk of the them being in the 1- to 2-MeV energy region.

Note. Although not strictly a result of the fission process, there is an additional 5 to 8 MeV emitted per fission as a result of the capture of neutrons not used in the fission chain reaction. About 1 MeV of this total is emitted over a period of time owing to decay of activation products, and the remainder is emitted immediately upon neutron capture.

Most of the reactors in existence today or planned for the near future are called *thermal reactors*, since they depend on neutrons which are in or near thermal equilibrium with their surroundings to cause the bulk of fissions. *These reactors make use of the fact that the probability for fission is highest at low energy by slowing down the neutrons emitted as a result of fissioning to enhance fission captures in the fuel.* Loss of neutrons to non-fission-capture processes is lessened by minimising the quantity of non-fissile material in or near the reactor core. *The materials used to decelerate fast neutrons to thermal energy levels* are called **moderators.** Effective and efficient moderators must slow the fission neutrons, in the 1- to 2-MeV range to thermal energy at about 0.025 eV to less than 0.1 eV. This effect must be produced in a small volume and with very little absorption.

The Chain reaction :

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

$$K = \frac{\text{No. of neutrons in any particular generation}}{\text{No. of neutrons in the preceding generation}}$$

If $K > 1$, chain reaction will continue and if $K < 1$, chain reaction cannot be maintained.

Fig. 6.4 shows schematically a chain reaction which when set off ultimately leads to a rapidly growing avalanche having the characteristic of an explosion. The rate of growth of the chain process is shown in Fig. 6.5.

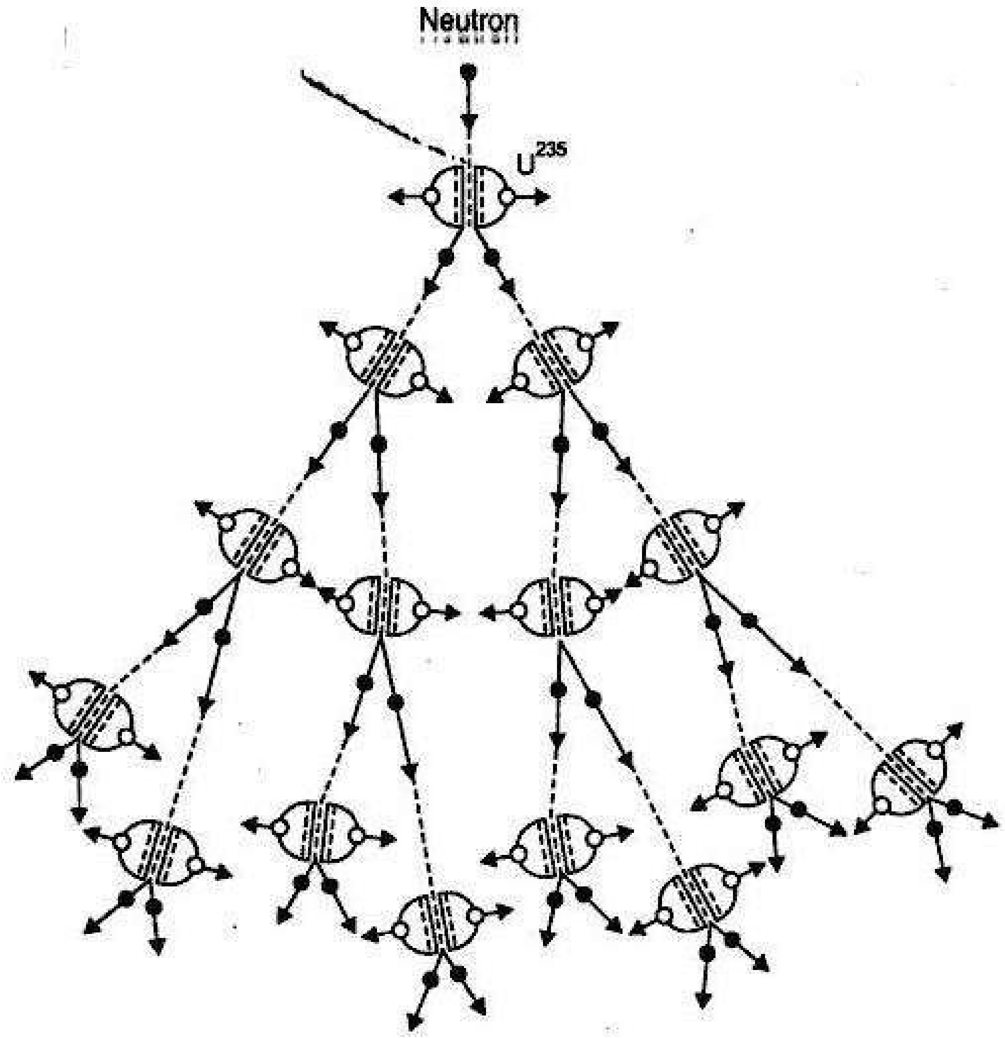


Fig. 6.4. Chain reaction.

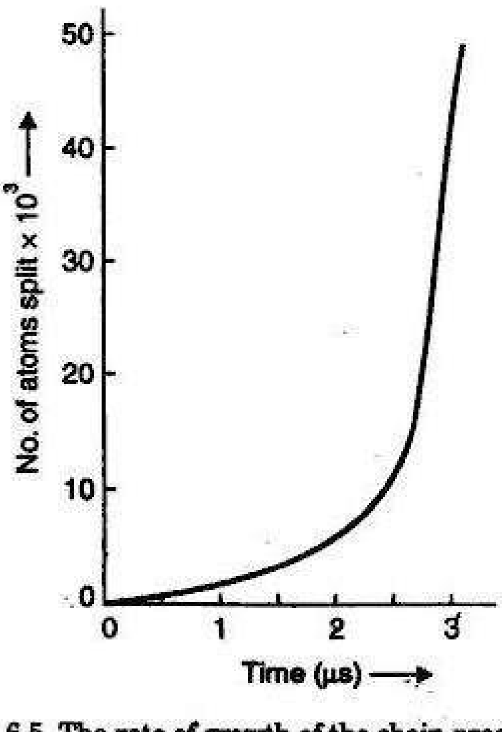


Fig. 6.5. The rate of growth of the chain process.

6.3.4. Power of a Nuclear Reactor

The fission rate of a reactor *i.e.*, total number of nuclei undergoing fission per second in a reactor is

$$= nC\sigma NV = \phi_{nu}\, \sigma NV$$

where, n = Average neutron density *i.e.*, number per m^3,

C = Average speed in m/s,

$\phi_{nu} = nC$ = Average neutron flux,

N = Number of fissile nuclei /m^3,

σ = Fission cross-section in m^2, and

V = Volume of the nuclear fuel.

Since 3.1×10^{10} fission per second generate a power of one watt, the power P of a nuclear reactor is given by,

$$P = \frac{nC\sigma NV}{3.1 \times 10^{10}} \text{ watt}$$

$$= 3.2 \times 10^{-11}\, nC\sigma\, NV \text{ watt}$$

$$= 3.2 \times 10^{-11}\, \phi_{nu}\, \sigma\, NV \text{ watt}$$

Now, NV = Total number of fissile nuclei in the reactor fuel

$$= m \times 6.02 \times 10^{26}/235$$

where, m is the mass of the U^{235} fuel. It is known that fission cross-section σ of U^{235} for thermal neutrons is 582 barns = 582×10^{-28} m^2.

$$\therefore \quad P = \frac{3.2 \times 10^{-11} \times \phi_{nu} \times 582 \times 10^{-28} \times m \times 6.02 \times 10^{26}}{235}$$

$$= 4.77 \times 10^{-12}\, m\, \phi_{nu} \text{ watt}$$

$$\simeq 4.8 \times 10^{-12}\, mnC \text{ watt.}$$

6.4. MAIN COMPONENTS OF A NUCLEAR POWER PLANT

Fig. 6.11 shows schematically a nuclear power plant.

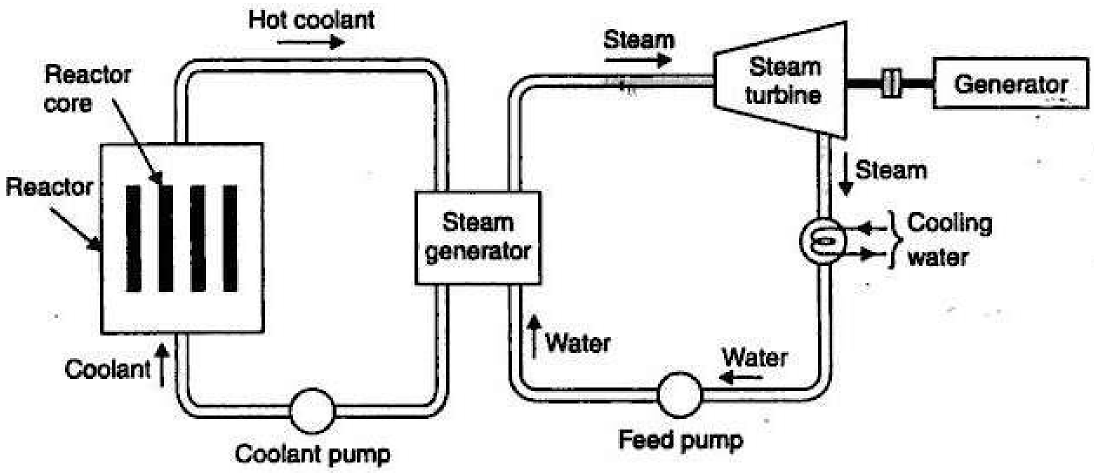


Fig. 6.11. Nuclear power plant.

The *main components of a nuclear power plant* are :

1. Nucl·ar reactor
2. Heat exchanger (steam generator)
3. Steam turbine
4. Condenser
5. Electric generator.

In a nuclear power plant the reactor performs the same function as that of the furnace of steam power plant (*i.e.*, produces heat). The heat liberated in the reactor as a result of the nuclear fission of the fuel is taken up by the coolant circulating through the reactor core. Hot coolant leaves the reactor at the top and then flows through the tubes of steam generator and passes on its heat to the feed water. The steam so produced expands in the steam turbine, producing work and thereafter is condensed in the condenser. The steam turbine in turn runs an electric generator thereby producing electrical energy. In order to maintain the flow of coolant, condensate and feed water pumps are provided as shown in Fig. 6.11.

6.5. DESCRIPTION OF REACTORS

6.5.1. Pressurised Water Reactor (PWR)

A pressurised water reactor, in its simplest form, is a light water-cooled and moderated thermal reactor having an unusual core design, using both natural and highly enriched fuel. The principal parts of the reactor are :

1. Pressure vessel
2. Reactor thermal shield
3. Fuel elements
4. Control rods
5. Reactor containment
6. Reactor pressuriser.

The components of the secondary system of pressurised water plant are similar to those in a normal steam station.

Refer to Fig. 6.12. 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. As such the steam in the turbine is *not radioactive* and need not be shielded. The *pressure* in the primary circuit should be *high* so that the boiling of water takes place at high pressure. A *pressuring tank* keeps the water at about 100 kgf/cm^2 *so that it will not boil*. Electric heating coils in the pressuriser boil some of the water to form steam that collects in the dome. As more steam is forced into the dome by boiling, its pressure rises and pressurises the entire circuit. The pressure may be reduced by providing cooling coils or spraying water on the steam.

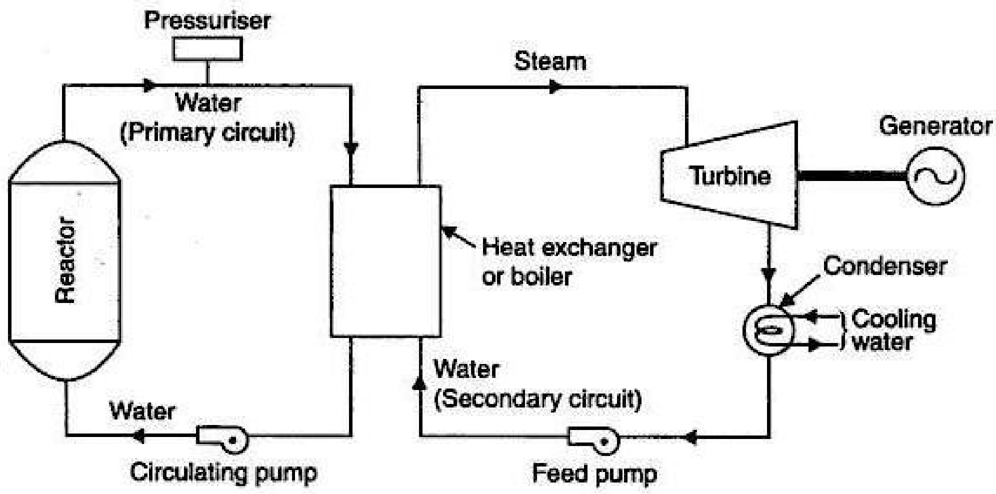


Fig. 6.12. Pressurised water reactor.

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 furnace, the steam formed from the reactor could be superheated.

Advantages of PWR :

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

Disadvantages :

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

6.5.2. Boiling Water Reactor (BWR)

In a boiling water reactor *enriched fuel* is used. As compared to PWR, the arrangement of BWR plant is simple. The plant can be safely operated using natural convection within the core or forced circulation as shown in the Fig. 6.13. For the safe operation of the reactor the pressure in the forced circulation must be maintained constant irrespective of the load. In case of *part load operation of the turbine some steam is by-passed.*

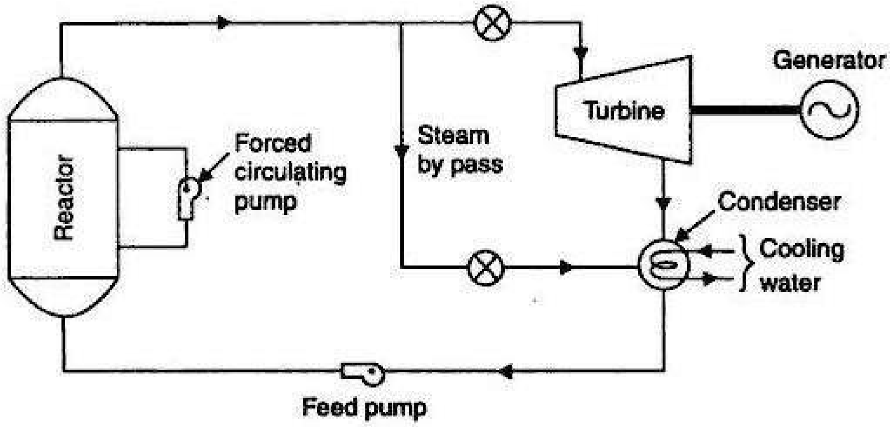


Fig. 6.13. Boiling water reactor.

Advantages of BWR :

1. Heat exchanger circuit is eliminated and consequently there is gain in thermal efficiency and gain in cost.
2. There is use of a lower pressure vessel for the reactor which further reduces cost and simplifies containment problems.
3. The metal temperature remains low for given output conditions.
4. The cycle for BWR is more efficient than PWR for given containment pressure, the outlet temperature of steam is appreciably higher in BWR.
5. The pressure inside the pressure vessel is not high so a thicker vessel is not required.

Disadvantages :

1. Possibility of radioactive contamination in the turbine mechanism, should there be any failure of fuel elements.
2. More elaborate safety precautions needed which are costly.
3. Wastage of steam resulting in lowering of thermal efficiency on part load operation.
4. Boiling limits power density ; only 3 to 5% by mass can be converted to steam per pass through the boiler.
5. The possibility of "burn out" of fuel is more in this reactor than PWR as boiling of water on the surface of the fuel is allowed.

6.5.3. CANDU (Canadian-Deuterium-Uranium) Reactor

CANDU is a thermal nuclear power reactor in which *heavy water* (99.8% deuterium oxide D_2O) *is the moderator and coolant, as well as the neutron reflector.* This reactor was developed in Canada and is being extensively used in this company. A few CANDU reactors are operating or under construction in some other countries as well.