SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – I – STEAM POWER PLANT – SMEA1403

THERMAL POWER PLANT - PLANT LAYOUT

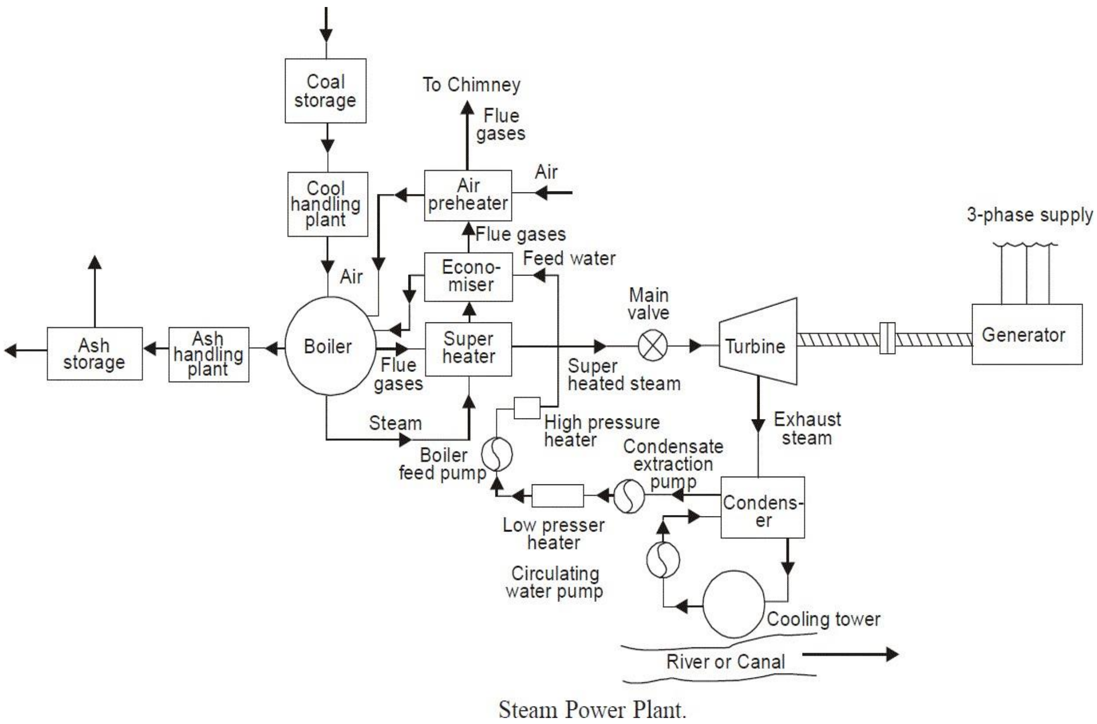


Figure 1.1 Thermal Power Plant Layout

COMPONENTS

- High pressure boiler
- Prime mover
- Condensers and cooling towers
- Coal handling system
- Ash and dust handling system
- Draught system
- Feed water purification plant
- Pumping system
- Air Pre-heater, Economizer, Super Heater, Feed Heaters.

FOUR CIRCUITS OF WORKING

- Coal & Ash Circuit
- Air & Flue Gas Circuit

- Feed Water & Steam Circuit
- Cooling Water Circuit

COAL HANDLING SYSTEM

STEPS INVOLVED IN COAL HANDLING

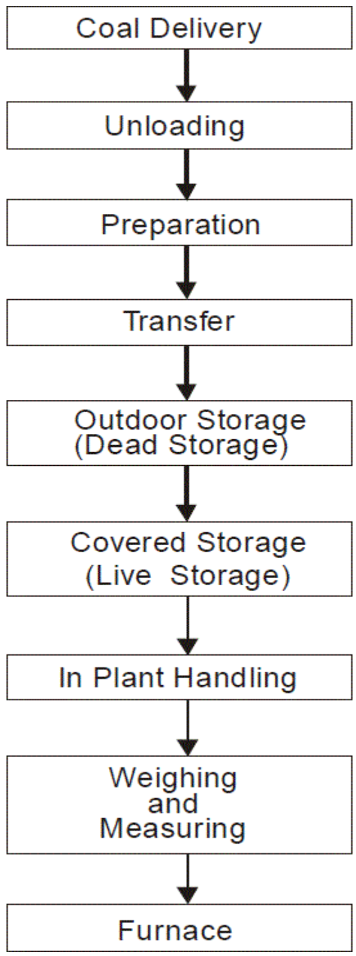


Figure 1.2 Coal Handling

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

(i) Coal delivery (ii) Unloading (iii) Preparation (iv) Transfer

(v) Outdoor storage (vi) Covered storage (vii) In plant handling

(viii) Weighing and measuring (ix) Feeding the coal into furnace.

COAL DELIVERY

The coal from supply points is delivered by ships or boats to power stations situated near to sea or river whereas coal is supplied by rail or trucks to the power stations which are situated away from sea or river. The transportation of coal by trucks is used if the railway facilities are not available.

UNLOADING

The type of equipment to be used for unloading the coal received at the power station depends on how coal is received atthe power station. If coal is delivered by trucks, there is no need of unloading device as the trucks may dump the coal to the outdoor storage. In case the coal is brought by railway wagons, ships or boats, the unloading may be done by car shakes, rotary car dumpers, cranes, grab buckets and coal accelerators.

COAL DELIVERY

The coal from supply points is delivered by ships or boats to power stations situated near to sea or river whereas coal is supplied by rail or trucks to the power stations which are situated away from sea or river. The transportation of coal by trucks is used if the railway facilities are not available.

PREPARATION

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

TRANSFER

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

- Belt conveyors
- Screw conveyors
- Bucket elevators
- Grab bucket elevators
- Skip hoists
- Flight conveyor

BELT CONVEYOR

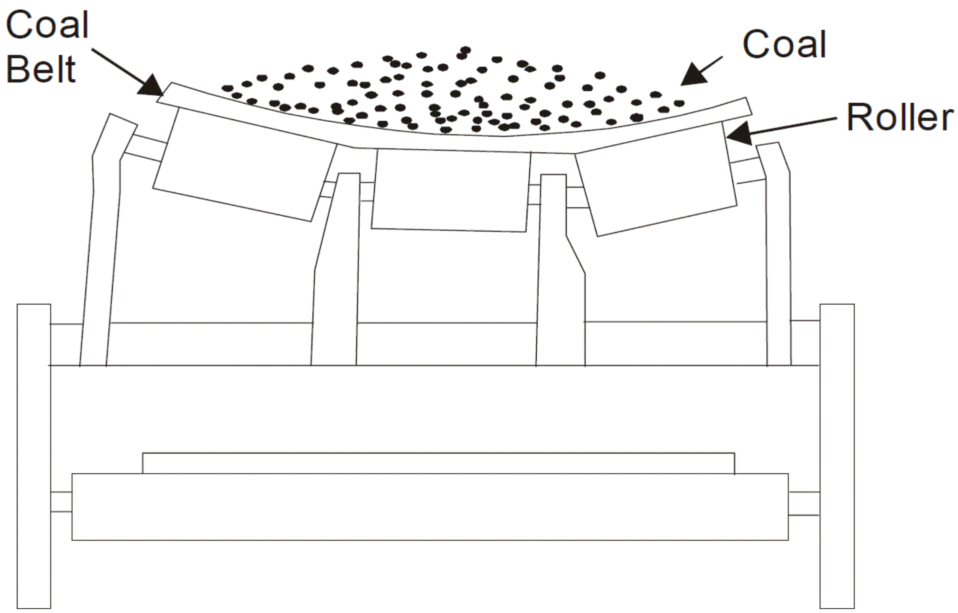


Figure 1.3 Belt Conveyor

It consists of an endless belt. Moving over a pair of end drums (rollers). At some distance a supporting roller is provided at the centre. The belt is made, up of rubber or canvas. Belt conveyor is suitable for the transfer of coal over long distances. It is used in medium and large power plants. The initial cost of the system is not high and power consumption is also low. The inclination at which coal can be successfully elevated by belt conveyor is about 20. Average speed of belt conveyors varies between 200-300 rpm. This conveyor is preferred than other types.

ADVANTAGES

- Its operation is smooth and clean.
- It requires less power as compared toother types of systems.
- Large quantities of coal can be discharged quickly and continuously.
- Material can be transported on moderate inclines.

SCREW CONVEYOR

It consists of an endless helicoid screw fitted to a shaft. The screw while rotating in a trough transfers the coal from feeding end to the discharge end. This system is suitable, where coal is to be transferred over shorter distance and space limitations exist. The initial cost of the system is low. It suffers from the drawbacks that the power consumption is high and there is considerable wear of screw. Rotation of screw varies between 75-125 rpm.

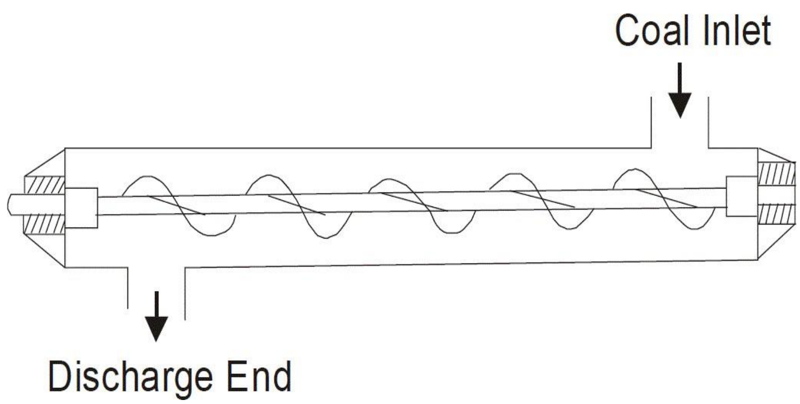


Figure 1.4 Screw Conveyor

BUCKET ELEVATOR

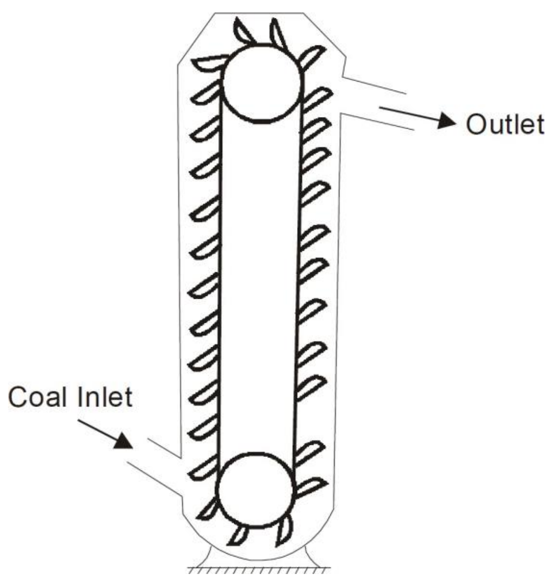


Figure 1.5 Bucket Elevator

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

GRAB BUCKET ELEVATOR

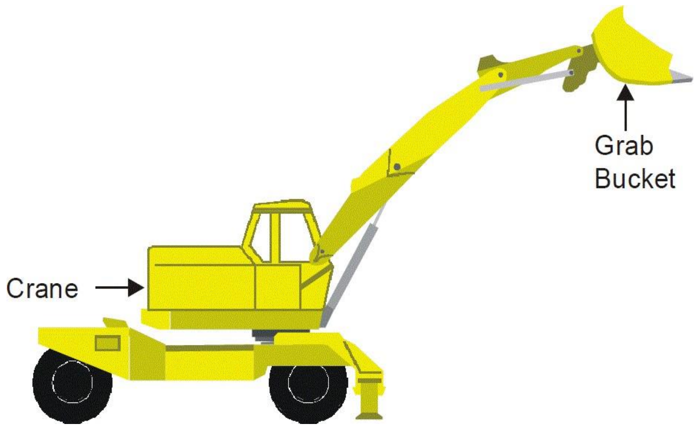


Figure 1.6 Grab Bucket Elevator

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

SKIP HOIST

It consists of a vertical or inclined hoist way a bucket or a car guided by a frame and a cable for hoisting the bucket.

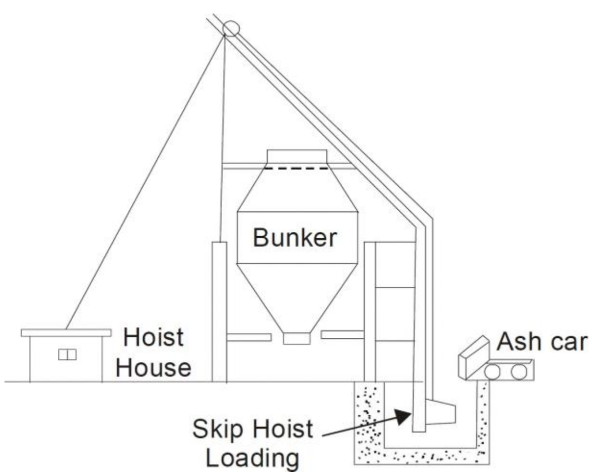


Figure 1.7 Skip Hoist

The bucket is held in upright position. It is simple and compact method of elevating coal or ash.

FLIGHT CONVEYOR

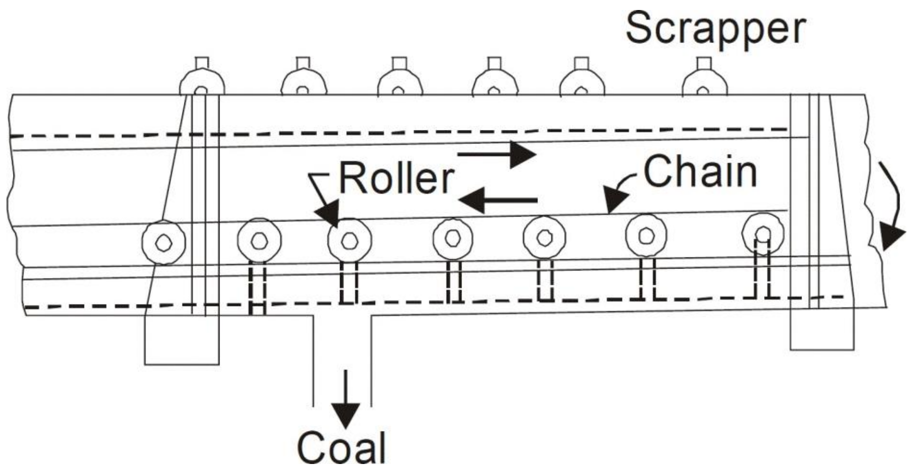


Figure 1.8 Flight Conveyor

It consists of one or two strands of chain to which steel scraper or flights are attached which scrap the coal through a trough having identical shape. This coal is discharged in the bottom of trough. It is low in first cost but has large energy consumption. There is considerable wear. Skip hoist and bucket elevators lift the coal vertically. Belts and flight conveyors move the coal horizontally or on inclines.

STORAGE OF COAL

It is desirable that sufficient quantity of coal should be stored. Storage of coal gives protection against the interruption of coal supplies. Also when the prices are low, the coal can be purchased and stored for future use. The amount of coal to be stored depends on the availability of space for storage, transportation facilities, the amount of coal that willwhether away and nearness to coal mines of the power station.

The coal is stored by the following methods:

STOCKING THE COAL IN HEATS

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

UNDER WATER STORAGE

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

IN PLANT HANDLING

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

CYLINDRICAL BUNKER

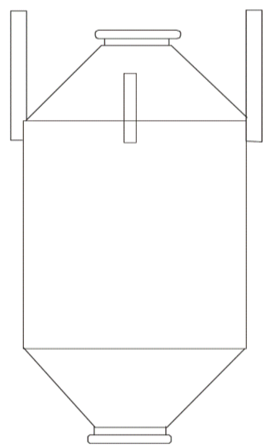


Figure 1.9 Cylindrical Bunker

COAL WEIGHING METHODS

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

Mechanical (ii) Pneumatic (iii) Electronic

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

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

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

ASH HANDLING SYSTEM

A large quantity of ash is, produced in steam power plants using coal. 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 gases.

It is desirable to quench the ash before handling due to following reasons:

- Quenching reduces the temperature of ash.
- It reduces the corrosive action of ash.
- Ash forms clinkers by fusing in large lumps and by quenching clinkers will disintegrate.
- Quenching reduces the dust accompanying the ash.
- Handling of ash includes its removal from the furnace, loading on the conveyors and delivered to the fill from where it can be disposed off.

GENERAL LAYOUT OF ASH HANDLING AND DUST COLLECTION SYSTEM

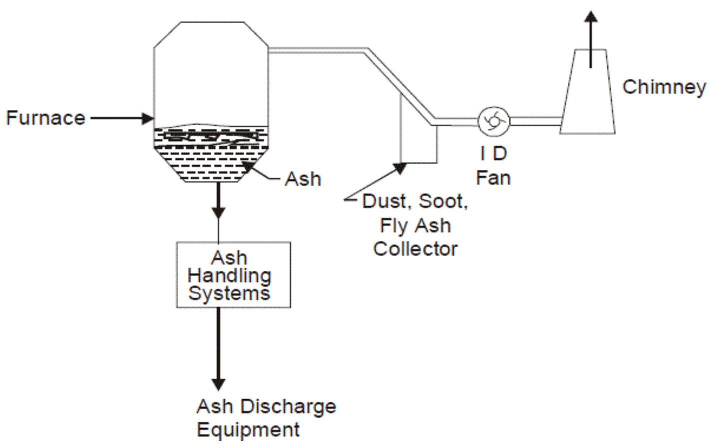


Figure 1.10 Ash Handling & Dust Collection System – General Layout

ASH HANDLING SYSTEMS

The commonly used ash handling systems are as follows:

- Hydraulic system

- Pneumatic system
- Mechanical system

ASH HANDLING - HYDRAULIC SYSTEM

In this system, ash from the furnace grate falls into a system of water possessing high velocity and is carried to the sumps. It is generally used in large power plants.

Hydraulic system is of two types:

- Low pressure hydraulic system used for continuous removal of ash, and
- High pressure system which is used for intermittent ash disposal.

ASH HANDLING – HYDRAULIC SYSTEM

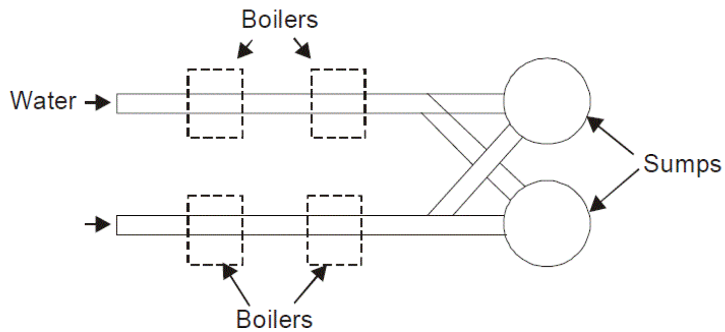


Figure 1.11 Sump System

In this method water at sufficient pressure is used to take away the ash to sump. Where water and ash are separated.

WATER JETTING

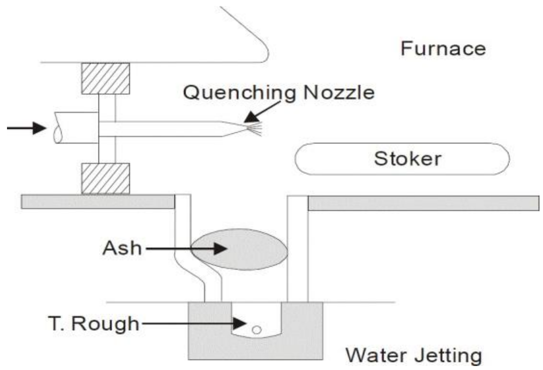


Figure 1.12 Water Jetting System

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

ASH HANDLING – PNEUMATIC SYSTEM

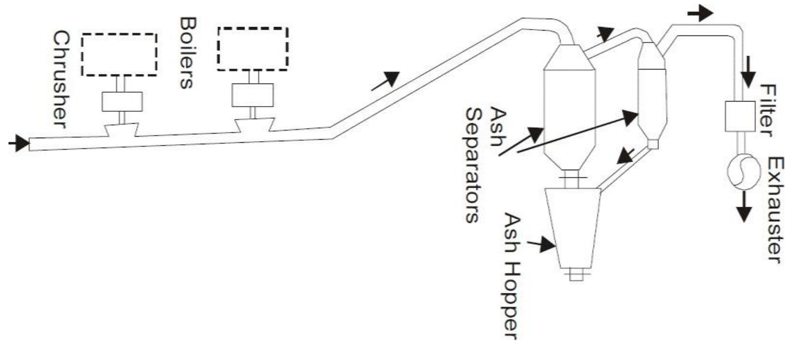


Figure 1.13 Pneumatic System

In this system ash from the boiler furnace outlet falls into a crusher where larger ash particles are crushed to small sizes. The ash is then carried by a high velocity air or steam to the point of delivery. Air leaving the ash separator is passed through filter to remove dust etc. so that the exhauster handles clean air which will protect theblades of the exhauster.

ASH HANDLING – MECHANICAL SYSTEM

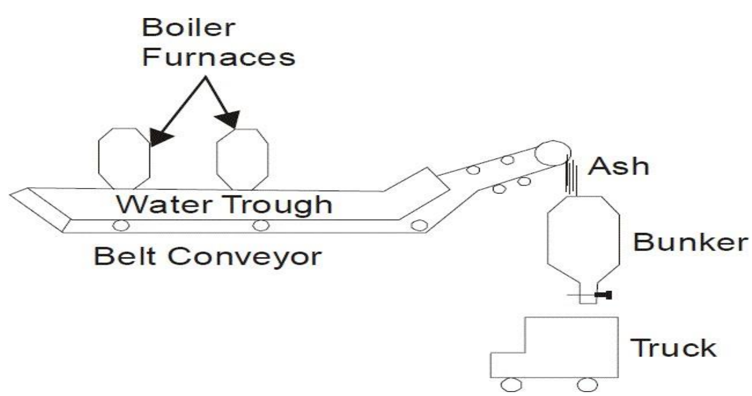


Figure 1.14 Mechanical Ash handling System

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

SMOKE AND DUST REMOVAL

In coal fed furnaces the products of combustion contain particles of solid matter floating in suspension. This may be smoke or dust. The production of smoke indicates that combustion conditions are faulty and amount of smoke produced can be reduced by improving the furnace design. To avoid the atmospheric pollution, the flyash must be removed from the gaseous products of combustion before they leaves the chimney. The removal of dust and cinders from the flue gas is usually effected by commercial dust collectors which are installed between the boiler outlet and chimney usually in the chimney side of air pre-heater.

TYPES OF DUST COLLECTORS

The various types of dust collectors are as follows:

- Mechanical dust collectors.
- Electrical dust collectors.

MECHANICAL DUST COLLECTORS

GRAVITATIONAL SEPARATORS

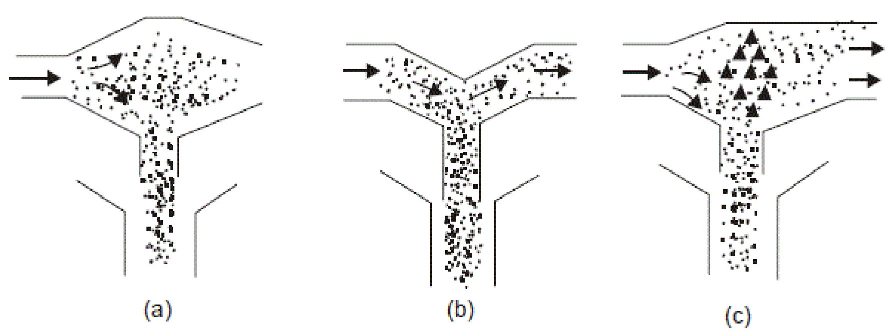


Figure 1.15 Gravitational Separators

Mechanical dust collectors are sub-divided into wet and dry types. In wet type collectors also known as scrubbers, water sprays are used to wash dust from the air. As shown in Fig.1.15 (a) by increasing the cross- sectional area of duct through which dust laden gases are passing, the velocity of gases is reduced and causes heavier dust particles to fall down. Changing the direction of flow Fig. 1.15 (b) of flue gases causes the heavier particles of settle out. Sometime baffles are provided as shown in Fig. 1.15 (c) to separate the heavier particles.

ELECTROSTATIC PRECIPITATORS

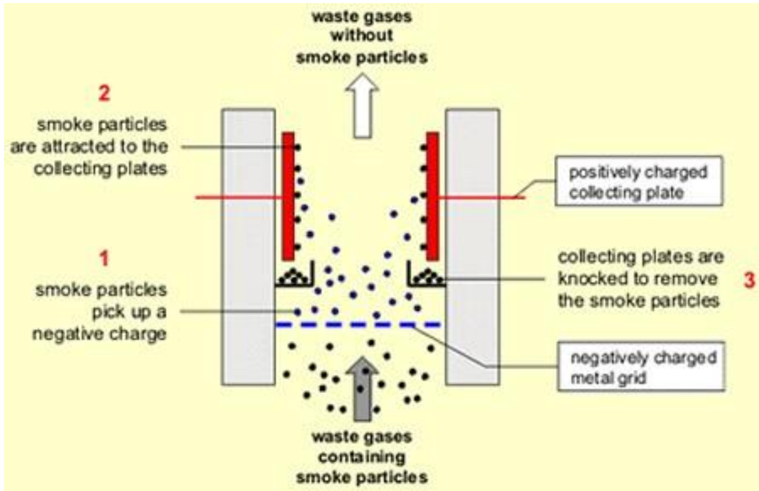


Figure 1.16 Electrostatic Precipitator

It has two sets of electrodes, insulated from each other that maintain an electrostatic field between them at high voltage. The flue gases are made to pass between these two sets of electrodes. The electric field ionises the dust particle; that pass through it attracting them to the electrode of opposite charge. The other electrode is maintained at a negative potential of 30,000 to 60,000 volts. The dust particles are removed from the collecting electrode by rapping the electrode periodically. The electrostatic precipitator is costly but has low maintenance cost.

SUPER HEATER

It is integral part of boiler and is placed in the path of hot flue gases from the furnace. The heat recovered from the flue gases is used in superheating the steam before entering into the turbine (i.e., prime mover).Its main purpose is to increase the temperature of saturated steam without raising its pressure.

Following are the advantages of using Super heater.

- There is an increase in efficiency of the steam power plant.
- Erosion of turbine blade is minimized (or) even eliminated.
- Steam consumption of the prim-mover is reduced.

- Condensation loss in the pipes is reduced.
- It removes entrained water particles from the steam conveyed to the steam turbines and increases the temperature of saturated steam.

Whatever type of boiler is used, steam will leave the water at its surface and pass into the steam space. Steam formed above the water surface in a shell boiler is always saturated and cannot become superheated in the boiler shell, as it is constantly in contact with the watersurface. If superheated steam is required, the saturated steam must pass through a super heater. This is simply a heat exchanger where additional heat is added to the saturated steam. In water-tube boilers, the super heater may be an additional pendant suspended in the furnace area where the hot gases will provide the degree of superheat required. In other cases, it superheats the steam generated by the boiler and increases the temperature steam above saturation temperature at constant pressure. Superheaters are placed in the path of flue gases to recover some of their heat. In bigger installations, the super heaters are placed in an independently fired furnace. Such super heaters are called separately fired or portable super heaters.

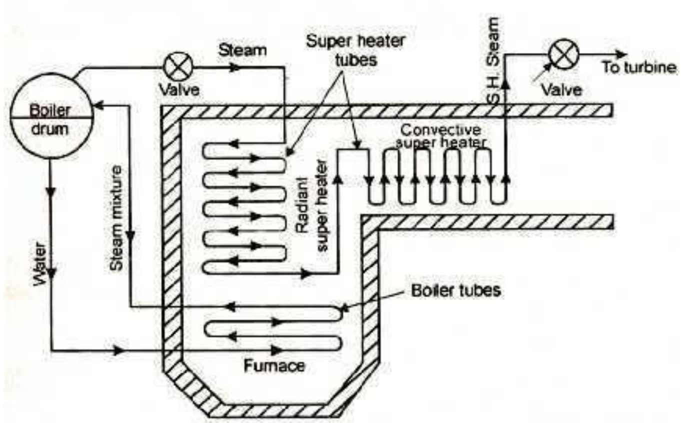


Figure 1.29 Superheater

WORKING

Steam stop valve is opened. The steam (wet or dry) from the evaporator drum is passed through the super heater tubes. First the steam is passed through the radiant super heater and then to the convective super heater. The steam is heated when it passes through these super heaters and converted into superheated steam.This superheated steam is supplied to the turbine through a valve.

Applications

This type of super heaters are used in modern high pressure boilers.

AIR PREHEATERS

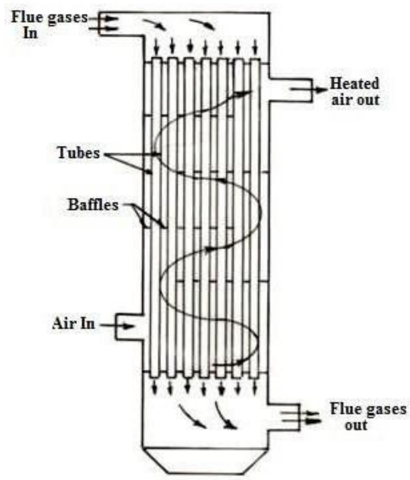


Figure 1.30 Air Preheater

Air pre-heaters are provided in boilers to preheat the combustion air. There are two main types: recuperative and regenerative air heaters. Tubular or recuperative air pre-heaters are provided in boilers of medium and small range of steam generation. This type of air pre-heater becomes very large in size if they have to be used in very high capacity boilers like 600 tons/hr of steam production and above. In these cases regenerative air pre-heaters are used. The arrangement of all these air pre-heaters differs with the design and, in large, the way they are combined for very high capacity boilers. Regenerative air per-heaters are compact and can have a stationary or rotating hood. A combination of tubular and regenerative type of air pre-heaters is usedin very high capacity boilers. The tubular being used for primary air heating and the regenerative used for the secondary air heating. In case the boiler designers do not want to go for a combination of tubular and regenerative air pre-heater, then they have a choice of tri-sector regenerative air heater. Normally the ambient air is heated to about 300 to 350 degree centigrade. This results in a flue gas temperature drop of around 230 to 250 degree centigrade. So for each degree pick up in air temperature, roughly 0.8 degree drop in flue gas temperature is achieved.

ECONOMIZER

The feed water from the high pressure heaters enters the economizer and picks up heat from the flue gases after the low temperature super heater. Many types of economizer are designed for picking up heat from the flue gas. These can be classified as an inline or staggered arrangement based on the type of tube arrangement. The staggered arrangement is compact and occupies less volume for the same amount of heat transfer when compared to the inline arrangement. Economizers are also designed with plain tube and fined tubes. The fins can be longitudinal or spiral. All these types are suitable for clean fuels like gas, oil, and low ash coals. For high ash coals, only the plain tube inline arrangement is used. This is mainly to reduce ash erosion and thus reduce erosion failures.

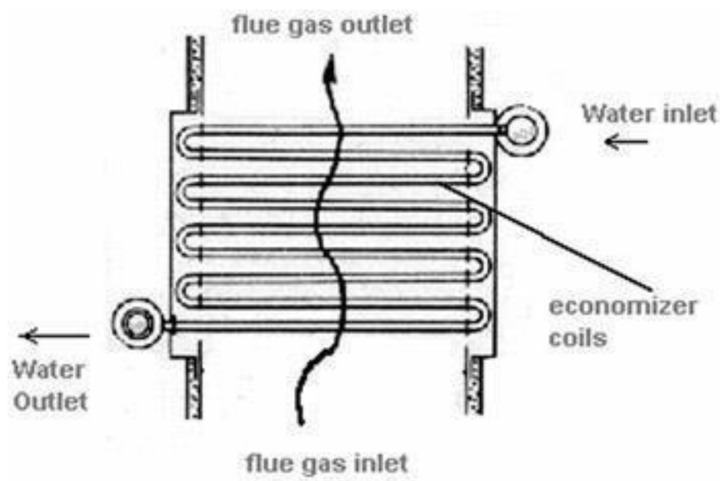


Figure 1.31 Economizer

These economizers pick up about 50 to 55 degrees centigrade in a large capacity boiler, which will reduce the flue gas temperature by about 150 to 170 degree centigrade. The boiler designers always keep the economizer water outlet temperature to about 25 to 35 degrees below the drum saturation temperature. This is done to mainly avoid steaming in the economizer. A steaming economizer generally is less reliable. As a rule of thumb, for every one degree pick up of economizer water temperature, there will be a drop of about 3 to 3.5 degrees.

REHEATER

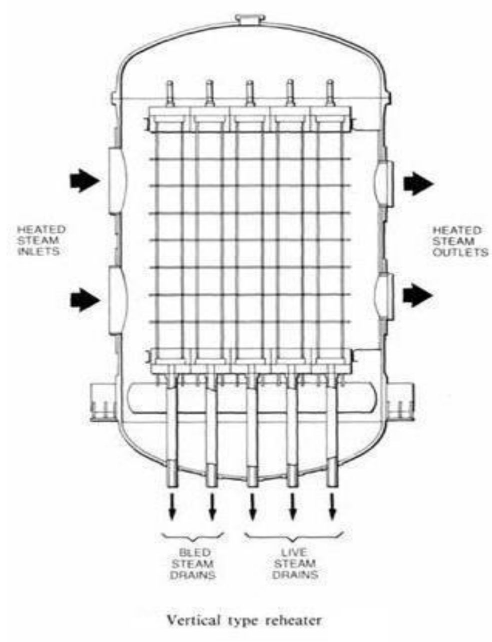


Figure 1.32 Reheater

The purpose of a reheating cycle is to remove the moisture carried by the steam at the final stages of the expansion process. In this variation, two turbines work in series. The first accepts vapour from the boiler at high pressure. After the vapour has passed through the first turbine, it re-enters the boiler and is reheated before passing through a second, lower-pressure, and turbine. The reheat temperatures are very close or equal to the inlet temperatures; whereas the optimums reheat pressure needed is only one fourth of the original boiler pressure. Among other advantages, this prevents the vapour from condensing during its expansion and thereby damaging the turbine blades, and improves the efficiency of the cycle, because more of the heat flow into the cycle occurs at higher temperature. Power plant furnaces may have a reheater section containing tubes heated by hot flue gases outside the tubes. Exhaust steam from the high pressure turbine is passed through these heated tubes to collect more energy before driving the intermediate and then low pressure turbines. The reheater functions similar to the super heater in that it serves to elevate the steam temperature. Primary steam is supplied to the high pressure turbine. After passing through the high pressure turbine, the steam is returned to the steam generator for reheating (in a reheater) after which it is sent to the low pressure turbine. A second reheat cycle may also be provided.

BOILERS

Steam generator is a device or equipment which burns the fuel and facilitates the exchange of heat produced to the water to generate required quantity and quality of steam. Thus, it is a heat exchanger which has the place for burning of fuel and flow of hot flue gases produced and also has space for storing of water and steam. As steam is produced & stored at high pressure than the atmospheric pressure, steam generator is also a pressure vessel. To handle the hot flue gases and to keep high pressure steam, certain other mountings and accessories are also required for its safe and efficient operation. In this way steam generator is not simply a vessel to boil water but it is a complete unit performing the complete task of producing & handling the high-pressure steam by burning of the fuel and exhausting the flue gases efficiently and safely. Most of the boilers are actually a type of shell & tube type heat exchangers.

Supercritical & Subcritical Boiler

Supercritical steam generators (also known as Benson boilers) are frequently used for the production of electric power. They operate at "supercritical pressure". In contrast to a "subcritical boiler", a supercritical steam generator operates at such a high pressure (over 3,200 psi/22.06 MPa or 220.6 bar) that actual boiling ceases to occur, and the boiler has no water - steam separation. There is no generation of steam bubbles within the water, because the pressure is above the "critical pressure" at which steam bubbles can form. It passes below the critical point as it does work in the high pressure turbine and enters the generator's condenser. This is more efficient, resulting in slightly less fuel use. The term "boiler" should not be used for a supercritical pressure steam generator, as no "boiling" actually occurs in this device. Large Subcritical thermal power plants with 170 bar and 540 / 540 ° C (SH / RH) operate at an efficiency of 38 %. Supercritical units operating at 250 bar and 600/615 ° C can have efficiencies in the range of 42 %. Ultra-supercritical units at 300 bar and 615 / 630 °C will still increase the efficiency up to 44 %.Increase in efficiency directly lead to reductions in unit cost of power and CO_2 emissions.

Operational flexibility of Supercritical power plants

Most of the Supercritical units use the once through technology. This is ideal for sliding pressure operation which has much more flexibility in load changes and controlling the power grid. However, this also requires more sensitive and quick responding control systems.

Evaporation end point of these plants

In subcritical units the drum acts as a fixed evaporation end point. The furnace water walls act as the evaporator. Not so in the case of a supercritical unit. The evaporation end point can occur in various levels of the furnace depending on the boiler load the percentage of Superheat in supercritical units is higher than subcritical units. Because of this the furnace tubes act more as super heaters than waterwalls. This necessitates the use of higher grade of materials like alloy steels in the furnace.

Heat transfer area

Higher steam temperatures in supercritical units results in a lesser differential temperature for heat transfer. Because of this heat transfer areas required are higher than subcritical units. Higher Superheat steam temperatures entering the HP turbine also mean higher reheater inlet temperatures which again results in a higher heat transfer areas.

Water Chemistry

In supercritical units the water entering the boiler has to be of extremely high levels of purity. Supercritical boilers do not have a steam drum that separates the steam and the water. If the entering water quality is not good, carry over of impurities can result in turbine blade deposits.

Materials

Super critical power plants use special high grade materials for the boiler tubes. The turbine blades are also of improved design and materials. In fact, the very increase in higher pressure and temperature designs are dependent on the development of newer and newer alloys and tube materials.

Classification of Steam Generators

Depending on the construction and operation, steam generators or commonly named as boilers are classified on the basis of:

(a) ***Alignment of axis of boiler***: Boilers are classified as Horizontal, Vertical and Inclined type boiler. Horizontal boiler occupies more floor area but is easily accessible for inspection and maintenance. Vertical boiler occupies less floor area but difficult to access and clean. In a dairy processing plant, we generally find horizontal type boiler.

(b) Flow of water and hot flue gases through the boiler: Boilers are broadly classified as fire tube and water tube boiler. This is the first major classification of boilers. Most of the boilers are actually shell and tube type heat exchangers in which one fluid i.e. either water or hot gas flows through the shell and other through the tubes. In a boiler, if fire flows through tubes and water remains in the shell, it is called fire tube boiler. Conversely if water flows through tubes and fire or hot flue gases pass through the shell it is called water tube boiler. In a dairy processing plant, fire tube boilers are generally used due to low pressure requirement, comparatively safe, less operational cost and easy to maintain type characteristics.

(c) Location of furnace or burner: Boilers are classified as: Externally fired and internally fired. If fuel is burnt outside the boiler and after burning only, hot flue gases are forced to flow through boiler, it is called externally fired. e.g. Babcock & Wilcox boiler, Sterling boiler etc. If the furnace is located inside the boiler itself, it is called internally fired boiler e.g. Cochran boiler, Lancashire boiler etc.

(d) Mode of water circulation: Boilers are classified as forced circulation and natural circulation boilers. If the water flows through boiler by the force of pump, it is called forced circulation boiler. If water flows due to natural current produced, it is called natural circulation boiler.

(e) Pressure of steam produced: Boilers are classified as high pressure and low pressure boilers. Above 80 bar pressure, boilers are called high pressure boilers and below this limit, Boilers are called low pressure Boilers. In a dairy processing plant where steam is used only for heating purpose and not to produce any mechanical work, low pressure boilers are used. High pressure boilers are used in applications where steam is used as a working agent like in thermal power plants etc. High pressure boilers are Benson, Babcock & Wilcox, and Lamont etc. Low pressure boilers are Cochran, Cornish, Lancashire & Locomotive boilers.

Comparison between fire tube and water tube boilers

Table 1.1 Comparison between fire tube and water tube boilers

S.No	***Fire Tube Boilers***	***Water Tube Boilers***
1.	Hot gases flow through tubes or flues passing through water stored in the shell	Water flows through tubes passing through the passage of the flue gases.

2.	Steam production rate is less i.e. up to 9 tons / hour	Steam production rate is high. It can be up to 450 tones/hour.
3.	Steam pressure is limited to 25 bar approx.	Steam pressure is generally in the range of 125 bar or even more in high pressure or super critical boilers.
4.	Due to low pressure and less production rate of steam, their use is generally limited to processing plant or small size power plants used in private industries.	Due to high pressure and high production rate of steam, these are commonly used in large capacity power plants like thermal plants for power generation.
5.	Chances of bursting are less but in case of bursting, a great damage to the life & property occur. It is because the main shell is under pressure and whole shell bursts.	Chances of bursting are more due to high pressure, but the damage is not as severe as in case of fire tube boilers.
6.	Feed water treatment is necessary but not so critically required because small deposit in the boiler shell does not deteriorate much the performance of boiler.	Feed water treatment is critical and highly essential as even a small deposit in boiler tube may cause overheating and bursting.
7.	Construction is more complicated. It occupies more floor area. Transportation is difficult. Because it comes in assembled position. Hence overall cost is high for a unit steam production rate.	Construction is simpler. It occupies less floor area. Transportation is not difficult because it can be easily dismantled & assembled. Overall cost is less for a unit steam production rate.
8.	Overall efficiency is upto 75%.	Overall efficiency with economizer is 90%

9.	It can cope up with fluctuating load.	It can also bear fluctuating load but only for a shorter period.
10.	It takes time to produce steam and increase the steam pressure at a slower rate.	It produces steam fast and so increases the steam pressure at a faster rate.

Cochran Boiler

It is a best example of vertical fire tube boiler and has a very simple construction. It is internally fired multi tubular and natural circulation boiler. Its working can be well understood with the help of a diagram

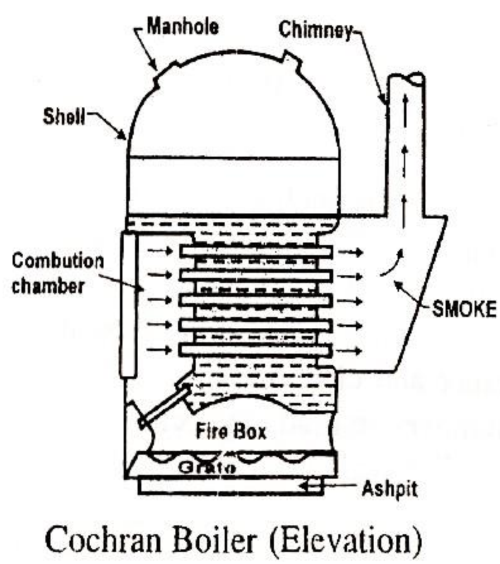


Figure 1.33 Cochran Boiler

Description: Cochran boiler has a vertical cylindrical shell with dome shaped top used as steam space. Furnace is a single piece construction situated at the bottom of the shell. The fuel (coal) is burnt on the grate by supplying air naturally through fire hole. Hot flue gases produced are directed through fire brick lining to the horizontal fire tubes surrounded by water filled in the shell. After exchanging their heat with water flue gases are directed to atmosphere through smoke box and chimney. Ash collects below the grate in the ash pit from where it is periodically removed. The various boiler mountings are also installed over the boiler shell.

Babcock & Wilcox Boiler

It is a simple water-tube boiler and used where higher steam pressure and higher steam production rate is required. It can be used for stationary and marine purposes. It consists of a horizontal shell supported on the masonry structure. The shell is connected to two headers on both ends, which are at different level and connected by a number of inclined tubes. When shell remains filled with water, up to the desired level, the headers and tubes also remain filled with water. The tubes are inclined at an angle of 15˚ and remain suspended/ supported inside the closed furnace/flue gases space. The flue gases produced from burning of the fuel are directed over the tubes in between the baffles forming the zig-zag flame passage. Steam is produced inside the inclined tubes and lifts through the top header and collects in the steam space of the boiler shell. Water from the bottom header comes in place of steam. Water level is checked by level indicator and maintained by feed pump.

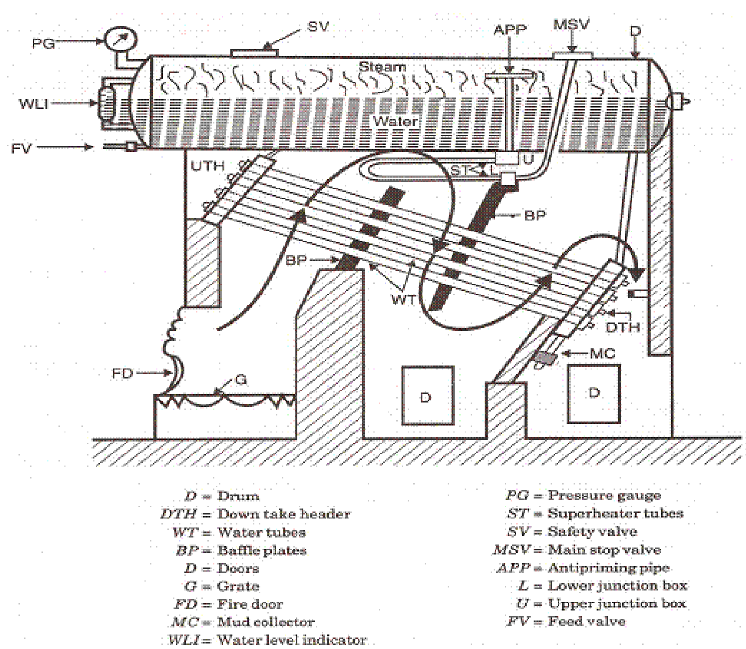


Figure 1.34 Babcock & Wilcox Boiler

The boiler shell & tubes are hung by means of wrought iron girders supported on pillars. This arrangement allows the drum and tubes to expand or contract freely.

Boiler Terms

(i) ***Boiler Shell:*** It is a cylindrical shaped structure fabricated with steel plates rolled & riveted or welded together.

(ii) ***Grate****:* It is a Cast Iron platform in the furnace of boiler on which fuel is burnt. Fuel is coal or wood or any other solid fuel which rests on the perforated surface of grate made of C.I. bars. Air can easily pass through perforated surface from the bottom and also after burning, ash can fall down itself easily.

(iii) ***Furnace/Fire box*****:** It is an enclosed space where fuel is burnt and hot flue gases accumulate. From the furnace, flue gases are directed to flow through the boiler.

(iv) ***Water Space*****:** Volume occupied by water in the boiler is termed as water space which is maintained at a constant level with the help of water level indicator fitted on boiler shell.

(v) ***Steam Space*****:** It is volume occupied by steam over the water surface in boiler. As steam is light, it lifts up and remains in the steam space at the top end of the boiler.

(vi) ***Boiler Mountings***: Various fittings on the boiler like pressure gauge, safety valves etc. which are necessary for its safe and efficient operation are called Boiler Mountings.

(vii) ***Boiler Accessories***: The integral parts of boiler which are required to enhance its efficiency or for overall performance are called accessories e.g. super heater, economizer, feed pump etc.

(viii) ***Foaming****:* The formation of bubbles on the surface of boiling water is called foaming.

(ix) ***Scale****:* The deposits of water salts and foreign particles on the heating surface in the form of a hard layer or film is called scale.

(x) ***Blowing off:*** The suspended impurities in the boiler water usually settle down and are thrown out through a cock due to pressure difference inside and outside the boiler. This process is called blowing off and the cock used is called blow-off-cock.

(xi) ***Lagging***: The insulation block mode or rope made of asbestos or magnesia wrapped or fixed outside the boiler shell and steam pipe are called lagging.

(xii) ***Refractory***: The fire bricks or clay having low thermal diffusivity are used in the furnace walls and other passages of flue gases where flue gases should retain their heat i.e. where heat loss of flue gases is to be prevented.

High Pressure Boilers

A boiler is a closed vessel in which water or other fluid is heated. The heated or vaporized fluid exits the boiler for use in various processes or heating applications. Most boilers produce steam to be used at saturation temperature; that is, saturated steam. Superheated steam boilers vaporize the water and then further heat the steam in a super heater. This provides steam at much higher temperature, but can decrease the overall thermal efficiency of the steam generating plant because the higher steam temperature requires a higher flue gas exhaust temperature. There are several ways to circumvent this problem, typically by providing an economizer that heats the feed water, a combustion air heater in the hot flue gas exhaust path, or both. There are advantages to superheated steam that may, and often will, increase overall efficiency of both steam generation and its utilization: gains in input temperature to a turbine should outweigh any cost in additional boiler complication and expense. There may also be practical limitations in using wet steam, as entrained condensation droplets will damage turbine blades. Superheated steam presents unique safety concerns because, if any system component fails and allows steam to escape, the high pressure and temperature can cause serious, instantaneous harm to anyone in its path. Since the escaping steam will initially be completely superheated vapor, detection can be difficult, although the intense heat and sound from such a leak clearly indicates its presence.

Super heater operation is similar to that of the coils on an air conditioning unit, although for a different purpose. The steam piping is directed through the flue gas path in the boiler furnace. The temperature in this area is typically between 1,300–1,600 degrees Celsius. Some super heaters are radiant type; that is, they absorb heat by radiation. Others are convection type, absorbing heat from a fluid. Some are a combination of the two types. Through either method, the extreme heat in the flue gas path will also heat the super heater steam piping and the steam within. While the temperature of the steam in the super heater rises, the pressure of the steam does not: the turbine or moving pistons offer a continuously expanding space and the pressure remains the same as that of the boiler.

Almost all steam super heater system designs remove droplets entrained in the steam to prevent damage to the turbine blading and associated piping. In all modern power plants, high pressure boilers (> 100 bar) are universally used as they offer the following advantages. In order to obtain efficient operation and high capacity, forced circulation of water through boiler tubes is found helpful.

1. The efficiency and the capacity of the plant can be increased as reduced quantity of steam is required for the same power generation if high pressure steam is used.

2. The forced circulation of water through boiler tubes provides freedom in the arrangement of furnace and water walls, in addition to the reduction in the heat exchange area.

3. The tendency of scale formation is reduced due to high velocity of water.

4. The danger of overheating is reduced as all the parts are uniformly heated.

5. The differential expansion is reduced due to uniform temperature and this reduces the possibility of gas and air leakages.

Lamont Boiler

A forced circulation boiler was first introduced in 1925 by La Mont. The arrangement of water circulation and different components are shown in Figure. The feed water from hot well is supplied to a storage and separating drum (boiler) through the economizer. Most of the sensible heat is supplied to the feed water passing through the economizer. A pump circulates the water at a rate 8 to 10 times the mass of steam evaporated. This water is circulated through the evaporator tubes and the part of the vapour is separated in the separator drum. The large quantity of water circulated (10 times that of evaporation) prevents the tubes from being overheated.

The centrifugal pump delivers the water to the headers at a pressure of 2.5 bar above the drum pressure. The distribution headers distribute the water through the nozzle into the evaporator. The steam separated in the boiler is further passed through the super-heater. Secure a uniform flow of feed water through each of the parallel boiler circuits a choke is fitted entrance to each circuit. These boilers have been built to generate 45 to 50 tons of superheated steam at a pressure of 120 bar and temperature of 500°C. Recently forced circulation has been introduced in large capacity power.

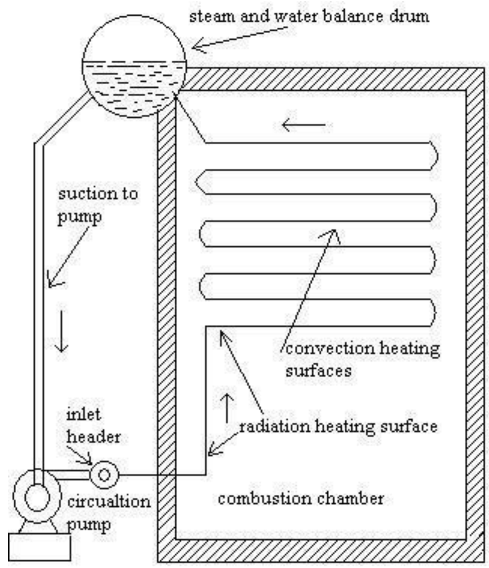


Figure 1.35 La Mont Boiler

Benson Boiler

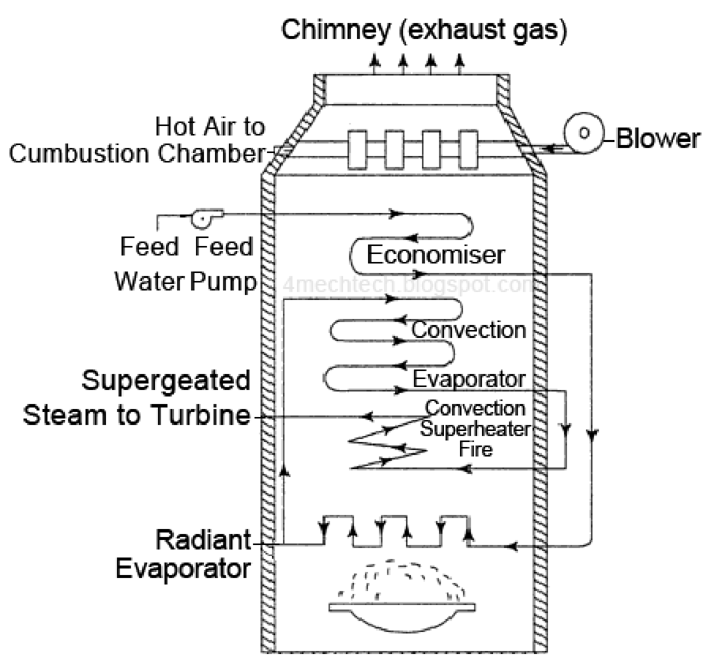


Figure 1.36 Benson Boiler

It is a water tube boiler capable of producing steam at super critical pressure (> 225 bar). At super critical pressure, water flashes into steam without any latent heat requirement. Therefore steam generation is faster. Above critical point, water transforms into steam without boiling and without change in volume. i.e., same density. Super critical steam generation does not have bubble formation and consequent pulsations. Materials of construction should be strong to withstand high pressure and temperature. 130 – 135 tons of steam per hour is generated at > 225 bar and ~90% thermal efficiency.

Velox Boiler

Principle

When the velocity of the gas is greater than the speed of sound, its heat transfer rate is also increases. So more heat is transfer from gas to water as compare when the heat transfer at the subsonic speed. This is the basic principle of it. This boiler can increase the heat transfer rate or can say steam generation rate without increasing boiler size. This is why? Velox boiler is most successful boiler in the gas turbine industries

Construction

Velox boiler is a water tube forced circulation boiler. It has a gas turbine driven air compressor, which compresses the air. This compressed air enters into the vertical combustion chamber, as result, high rate of heat release from the fuel, which increases the flue gases velocity up to the sound velocity. This is a force circulation boiler, so pump is used to circulate water inside the boiler. This boiler also consist water and fire tube to maintain the flow of gas and water inside the boiler. This boiler also consists other necessary mounting and accessories like economizer, super heater, blow off valve, safety valve etc.

Working

The Velox boiler works as a basic heat exchanger. The air is compressed by air compressor driven by gas a turbine driven. This compressed air passes from the combustion chamber, where more heat release by the fuel which increase the velocity of the flue gases up to sound velocity. From the bottom of combustion chamber, this flue gases pass from the fire tubes. These fire tubes surrounded by the evaporator water tubes.

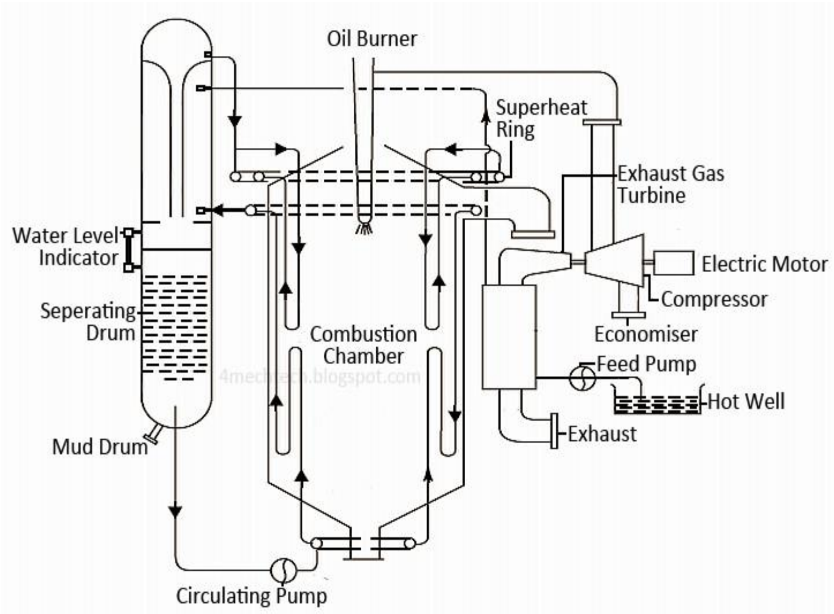


Figure 1.37 Velox Boiler

The water from the economizer passes from the evaporator tube force by a circulating pump. This water passes 15 - 20 time from the evaporator tube at very high speed. Due to this high speed circulation, heat is transfer from the gases to the water at very high rate. The mixture of water and steam is formed which further passes from the water and steam separator.

Loffler boiler

The feed water from the feed tank is supplied to the economizer by feed pump. In the economizer the feed water is made to flow through a number of tubes surrounding which the hot gases leaving the furnace pass over. There is a heat exchange from the hot gases to the feed water, which is preheated in the economizer.

Evaporated Drum

It is housed away from the furnace. It contains a mixture of steam and water. The feed water from the economizer tubes enters the evaporator drum into which is also passed two-thirds of the superheated steam generated by the boiler. The superheated steam gives its superheat to the water in the drum and evaporates it to saturated steam.

Mixing Nozzles

The nozzles distribute and mix the superheated steam throughout the water in the evaporator drum.

Steam circulating pump

A steam circulating pump forces this saturated steam from the evaporator drum to the radiant super heater through the tube of the furnace wall.

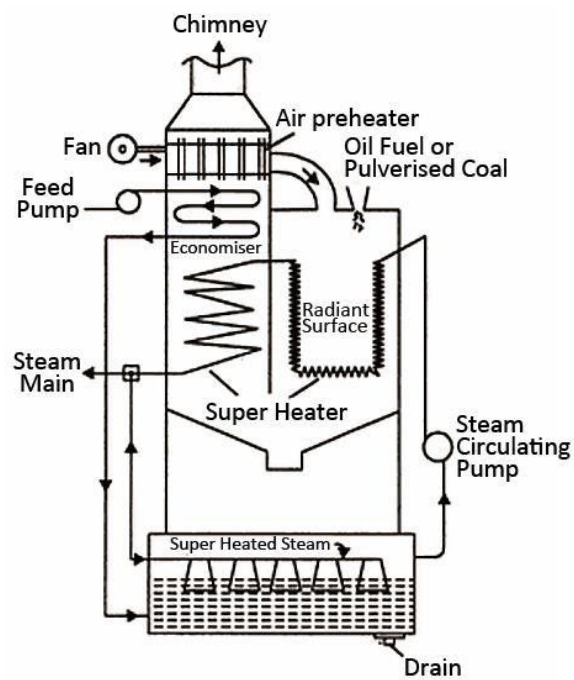


Figure 1.38 Loffler Boiler

The image shows the outline diagram of Loffler Boiler.

Radiant super heater

The radiant super heater is placed in the furnace. The hot gases in the furnace are used for superheating the saturated steam from the drum. The radiant super heater receives heat from the burning fuel through radiation process.

Convection super heater

Steam from the radiant super heater enters the convection super heater where it is finally heated to the desired temperature of 500’C. The convection super heater receives heat from the flue gases entirely by convective heat transfer. Both radiant and convection super heater are arranged in series in the path of the flue gases.

Steam outlet

About one-third of the superheated steam from the convection super heater passes to the steam turbine while the remaining two-thirds is passed on to evaporator drum to evaporate the feed water to saturated steam.

Capacity

Capacity of the Loffler boiler is about 100 Tonnes/Hr. of superheated steam generated at a pressure of 140 kgf/sq.cm and at a temperature of 500'C.

CONDENSER

Condensers are classified as follows

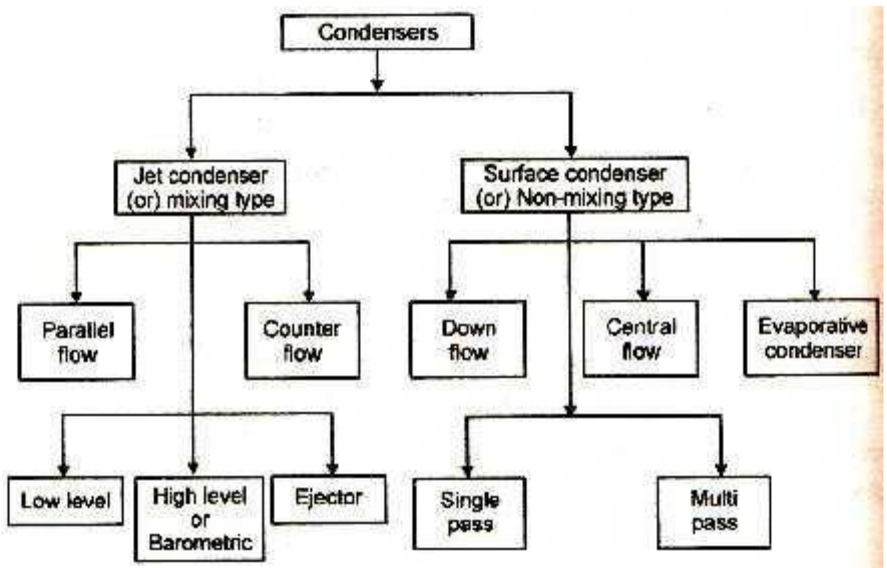


Figure 1.39 Classification of Condensers

- In jet condensers, there is direct contact between the cooling water and the steam which is to be condensed.
- In surface condensers, there is no direct contact between the cooling water and the steam which is to be condensed.
- In parallel flow jet condensers, the flow of steam and cooling water are in the same direction.
- In counter flow jet condensers, the steam and cooling water flow in opposite directions.
- In low level jet condensers, the condensate is pumped by means of a condensate pump into the hot well.
- In high level jet condensers, the condensate falls to the hot well by the barometric leg provided in the condenser.
- In ejector condensers, a number of convergent nozzles are used.
- In down flow surface condensers, the condensed steam flows down from the condenser.
- In central flow surface condensers, the condensed steam moves towards the center of condenser tubes.

➢ In single pass surface condensers, the cooling water flows in the condenser tubes only once.

➢ In multi pass surface condensers, the cooling water flows in the condenser tubes number of times.

Working of Jet condensers

In a jet condenser, the steam to be condensed and the cooling water come in direct contact and the temperature of the condensate is the same as that of the cooling water leaving the condenser? For jet condensers the recovery of the condensate for reuse as boiler feed water is not possible.

Depending upon the arrangement of the removal of condensate, the jet condensers are subdivided in to the following categories

1. Low level counter flow jet condenser.
2. High level (or) barometric jet condenser.
3. Ejector condenser

1. Low level jet condenser

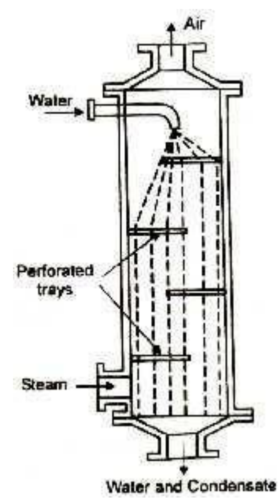


Figure 1.40 Low Level Jet Condenser

A low-level counter flow jet condenser is shown in figure 1.40. In this condenser, the cooling water enters at the top and sprayed through jets. The steam enters at the bottom and mixes with the fine spray of cooling water. The condensate is removed by a separate pump. The air is removed by an air pump separately from the top. In a parallel flow type of this condenser, the cooling water and steam to be condensed move in the same direction. [i.e., from top to bottom].

2. High level jet condenser

A high-level jet condenser is shown in figure. This is similar to a low-level condenser, except that the condenser shell is placed at a height of 10.36 m [barometric height] above the hot well. The column of water in the tail pipe forces the condensate into the hot well by gravity. Hence condensate extraction pump is not required.

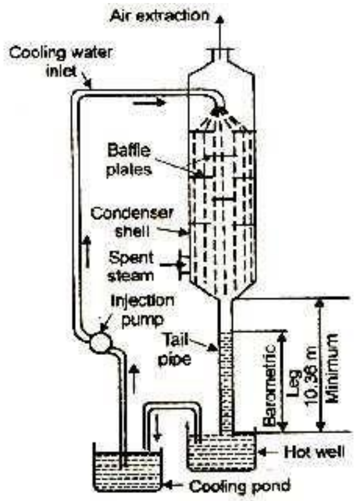


Figure 1.41 2. High level jet condenser

3. Ejector condenser

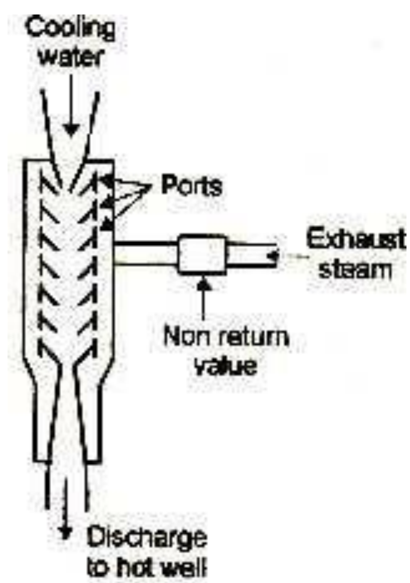


Figure 1.42 Ejector Condenser

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

Merits and Demerits of jet condensers Merits

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

Demerits

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

Working of Surface condensers Surface Condenser

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

1. Down flow condenser
2. Central flow condenser

3. Evaporative condenser

1. Down flow condenser:

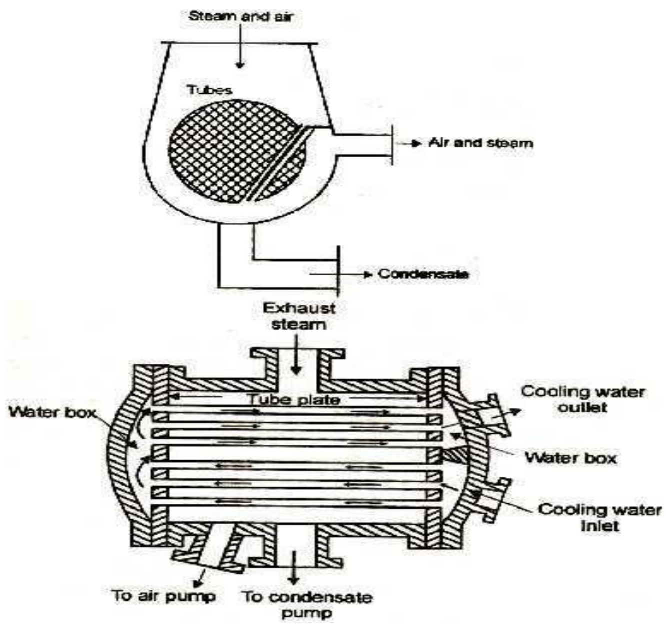


Figure 1.43 Down Flow Condenser

Figure 1.43 shows a sectional view of down flow condenser. Steam enters at the top and flows downward. The water flowing through the tubes in one direction lower half comes out in the opposite direction in the upper half. In this type of condenser, the cooling water and exhaust steam do not come in direct contact with each other as in case of jet condensers. This is generally used where large quantities of inferior water are available and better quantity of feed water to the boiler must be used most economically. The arrangement of the surface condenser is shown in figure. It consists of cast iron airtight cylindrical shell closed at each end as shown in figure. A number of water tubes are fixed in the tube plates which are located between each cover head and shell.

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

2. Central flow condenser

Figure 1.44 shows a central flow condenser. In this condenser the steam passages are all around the periphery of the shell. Air is pumped away from the center of the condenser. The condensate moves radially towards the center of the tube next. Some of the exhaust steam which moving towards the center meets the under cooled condensate and pre-heats it thus reducing under cooling.

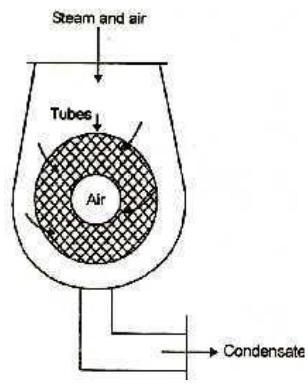


Figure 1.44 Central Flow Condenser

3. Evaporative condenser

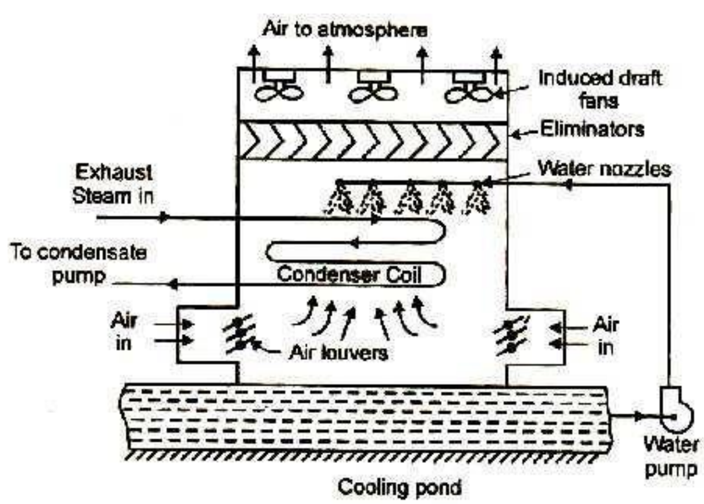


Figure 1.45 Evaporative Condenser

In this condenser steam to be condensed in passed through a series of tubes and the cooling water falls over these tubes in the form of spray. A steam of air flows over the tubes to increase evaporation of cooling water which further increases the condensation of steam. These condensers are more preferable where acute shortage of cooling water exists. The arrangement of the condenser is shown in figure 1.45. Water is sprayed through the nozzles over the pipe carrying exhaust steam and forms a thin film over it. The air is drawn over the surface of the coil with the help of induced fan as shown in figure. The air passing over the coil carries the water from the surface of condenser coil in the form of vapour. The latent heat required for the evaporation of water vapour is taken from the water film formed on the condenser coil and drops the temperature of the water film and this helps for heat transfer from the steam to the water. This mode of heat transfer reduces the cooling water requirement of the condenser to 10% of the requirement of surface condensers. The water particles carried with air due to high velocity of air are removed with the help of eliminator as shown in the figure. The make-up water (water vapour and water particles carried with air) is supplied from outside source. The quantity of water sprayed over the condenser coil should be just sufficient to keep the condenser coil thoroughly wetted. The water flow rate higher than this will only increase the power requirement of water pump without materially increasing the condenser capacity. This type of condenser works better in dry weather (low WBT) compared with wet weather as the water vapour carrying capacity of dry air is higher than wet air at the same temperature. The arrangement of this type of condenser is simple and cheap in first cost. It does not require large quantity of water therefore needs a small capacity cooling water pump. The vacuum maintained in this condenser is not as high as in surface condensers therefore the work done per kg of steam is less with this condenser compared with surface condenser. These condensers are generally preferred for small power plants and where there is acute shortage of cooling water.

Advantages and disadvantages of a surface condenser.

The various advantages of a surface condenser are as follows:

(i) The condensate can be used as boiler feed water.

(ii) Cooling water of even poor quality can be used because the cooling water does not come in direct contact with steam.

(iii) High vacuum (about 73.5 cm of Hg) can be obtained in the surface condenser. This increases the thermal efficiency of the plant.

The various disadvantages of the surface condenser are as follows:

i) The capital cost is more.

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

iii) It is bulky and required more space.

COOLING TOWERS

A cooling tower is a semi-enclosed device for evaporative cooling of water by contact with air. It is a wooden, steel, concrete structure and corrugated surfaces or troughs or baffles or perforated trays are provided inside the tower for uniform distribution and better atomization of water in the tower. The hot water coming out from the condenser are fed to the tower on the top and allowed to tickle in the form of thin sheets or drops. The air flows from the bottom of the atmosphere after effective cooling. An evaporative cooling tower is a machine of relatively simple conception and operation. The water to be cooled for a chiller, industrial process or refrigeration installation is pumped and distributed through spray nozzles over a fill pack or heat exchange surface through which passes an air current commonly generated buy a fan. A small fraction of this water evaporates and the remainder is cooled thanks to the absorption of latent heat of evaporation by the passing air, and fall under gravity into a basin from there it is pumped back to the heat load source.

Cooling Water Systems

Site conditions determine the method to be used for supplying the cooling water to the condensers, and may be one of three systems namely:

1. River sea or canal/lake water system.
2. Combined river and cooling water system.
3. Cooling water or spray pond system.

1. Plants directly using water from river or sea: The water is drawn directly from the river, pumped through the condensers the discharged to the river at a higher temperature, probably 5 to 12^0C in excess of the inlet temperature.

2. Combined river and cooling water system: This type of cooling system uses river water as well as cooling ponds or cooling towers, which overcome the difficulty of re-circulation and meet the requirements of a fishery board on a fairly small river.

3. Cooling tower system :(or closed system): Modern trend is to locate the stem power stations as near as possible to the centre of gravity of the electrical load instead of near a source of natural water to avoid huge transmission costs. Also, there may be constraints imposed by the limitations on thermal discharge to natural waters.

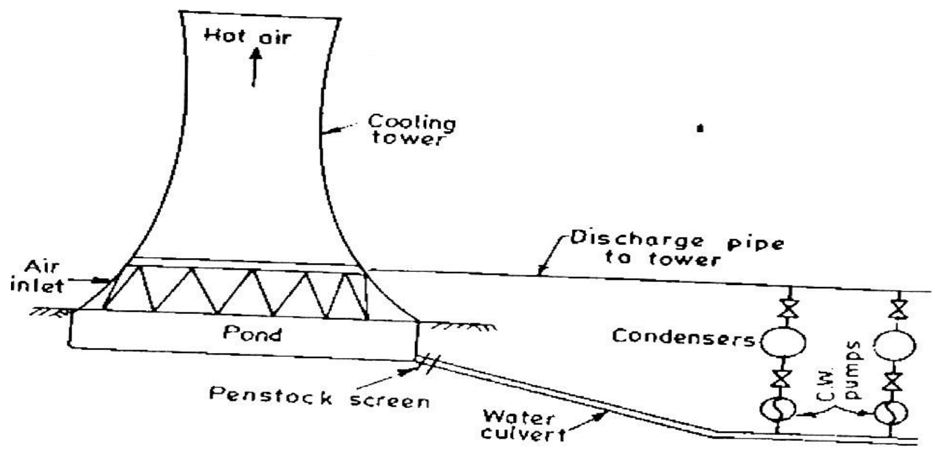


Figure 1.46 Cooling Tower System

Therefore, for large power plants situated away from the source of natural water, enormous quantities of pure water may not be available for once through condenser cooling and the same supply of water may have to be used again the again. Moreover, enough quality of water may not be available for cooling requirement from river. Therefore, there must be some arrangement to recool the circulating water and for this Purpose cooling ponds or cooling towers are needed. This type of cooling water system is known as closed circuit or circulating cooling water system, or closed cooling system. Due to losses caused by the evaporation leakage etc., it is still necessary to have water available to compensate for this loss. Assuming the heat loss to be 1 percent, then the make-up water required per hour in a 300 MW station would be between 650,000 to 750,000 liters per hour. This make up water may be taken from a river, sewage outfall or in times of emergency, from a town main supply, the latter being rather expensive.

COOLING TOWER SYSTEM

The system is similar in many respects to the river circulating system, the main difference being that the cooling water is alternatively warmed and cooled and circulated continuously. The final; inlet temperature to the condensers depends to a large extent on atmospheric conditions, and the temperatures of the cooling water tower is much above that of a river. In this case the hot water coming out of a condenser is passed on to a cooling tower where it is cooled down. The water in the cooling tower is made to trickle down drop by drop and is broken into small particles while passing over the baffling devices. These water particles come in contact with stream of a moving in the opposite direction. As a result of this, some portion of the water gets evaporated and is carried away along with air. The air vaporizes a small percentage of water, thereby cooling the remaining of water. The air gets heated and leaves the tower at the top. The cooled water falls down into a tank at the bottom of the tower from where it can be again circulated to the condenser, through water culver. The heat exchange between air and water through direct contact is from (i) by the evaporative cooling of water or by (ii) the convective heating of air. Cooling by evaporation is the greatest.

Factors affecting the cooling of water in a cooling tower are:

(i) Temperature of air

(ii) Humidity of air

(iii) Temperature of hot water

(iv) Size and height of tower

(v) Velocity of air entering the tower.

(vi) Accessibility of air to all parts of the cooling water

(vii) Degree of uniformity in descending water.

CLASSIFICATION OF COOLING TOWERS

The cooling towers can be classified in two ways:

1. On the basis of material used

(a) Timber

(b) Concrete:

- (i) Ferro – concrete
- (ii) Multi-deck concrete
- (iii) Hyperbolic

(c) Metallic or steel duct type

2. On the basis of draft:

(a) Atmospheric

(b) Natural draft

(c) Mechanical draft:

(i) Induced draft cooling towers

(ii) Forced draft cooling towers

(iii) Combined induced and forced draft cooling towers.

Timber is used for small towers, and are rarely used in modern power Plants due to the following disadvantages:

(1) It deteriorates due to exposure to sun, wind and water

(2) It has short life

(3) Limited cooling capacity

(4) High maintenance charges

(5) The design, construction and layout, speaking generally does not facilitate air circulation. Ferro concrete towers are used on all large capacity stations, but they have high Initial cost. Concrete type cooling towers are becoming more popular due to:

(1) Its large capacity, of the order of 5 x 10^6 liters per hour.

(2) Its improved draft and air circulation.

(3) Low maintenance charges. Its good stability under air pressure and

(4) A wide base lead to stability under wind pressure, double curvature resists buckling and shearing stresses in the structure due to its own weight are suppressed. Multi deck towers are also used in large steam power plants.

Hyperbolic Cooling Towers

The hyperbolic natural draft towers are widely used in Europe. These types are not feasible in locations wherein summer time dry bulb temperature is much higher like in U.S.A. The arrangement of hyperbolic cooling tower is shown in fig.1.47 below.

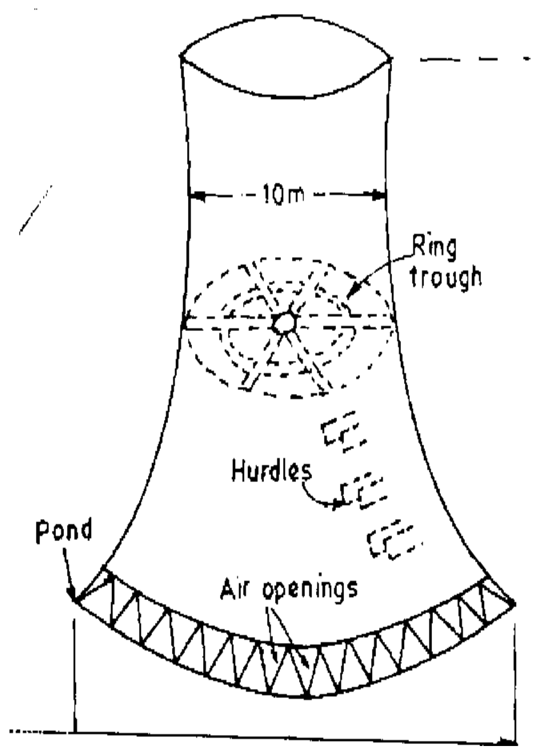


Figure 1.47 Hyperbolic Cooling Towers

Schematic of a Ferro-Concrete Hyperbolic Cooling Tower

The hyperbolic Ferro-concrete tower offers little or no impendence to air flow, and when arranged in groups there is no trouble due to eddies or local depressions. The construction is good from a structural point of view and also provides and regulates adequate air draught as the air streams are directed towards the vertical axis of the tower. The tower consists of a smooth reinforced concrete shell which depending on the capacity, may extend some 80m.The shape of the stack is circular in plan and hyperbolic in profile. This construction offers greater resistance to wind pressure, eliminates shearing stresses and internal bracing, thus avoiding the formation of eddies. Further, the lightness of the steel saves foundation work, and ground loading of 10 tons per sq.m. And under as possible. The tower pond, outlet stair-cases and gangways are constructed as one unit. The shell is supported on specially arranged reinforced concrete columns designed to offer a minimum resistance to air flow through the chimney. These columns take the shear. The operation of this tower is much like that of other natural draft spray cooling towers with hot-water cascading over timber splash type filling through which cooling air is circulating. With the hyperbolic cooling tower, the widening of the top of the chimney permits of condensation taking place within the tower of a certain amount of the water evaporated at lower levels. The velocity of the rising air within the chimney is diminished before exit thereby avoiding eddies around the top.

Some additional advantages of this type of towers are:

1. Power cost and auxiliary equipment’s are eliminated as fans are not needed. Resulting operating and maintenance costs are consequently reduced.
2. Chimney shape creates its own draft, assuring efficient operation even when there is no wind.
3. Cooling capacity of this type of tower is quite comparable with that of multi cell installation of induced draft type towers.
4. Local fogging and warm air circulation, which are there in mechanical draft installations, are also avoided.

Atmospheric cooling Towers

Atmospheric towers have no stacks and have sides fitted with louvers. The air enters through the louvers sides and flows across the unit in a transverse direction. The air circulation takes place horizontally. They are best suited for places where wind velocity is constant, about 3 to 5 kmph. The capacity of this tower varies from 50 to 100 liters per minute per m^2 of base area depending upon the air velocity.

(1) Its initial cost is high

(2) Its performance varies with the seasonal changes in dry bulb temperature and relative humidity of air.

(3) Nuisance is caused due to condensation of moisture from nearby cooling towers to householders.

(4) During winter months trouble may be experienced from ice building up around the tower

and ice deposits on nearby roads may necessitate salting and ashing. It is sometimes necessary to remove some of the stack timber to facilitate the passage of air and so reduce the precipitation outside the top of tower.

Types of Cooling Towers

The cooling towers are mainly divided into two groups.

1. Natural draught cooling towers
2. Mechanical draught cooling towers
    - Forced draught cooling towers
    - Induced draught cooling towers

1. Natural draught cooling towers:

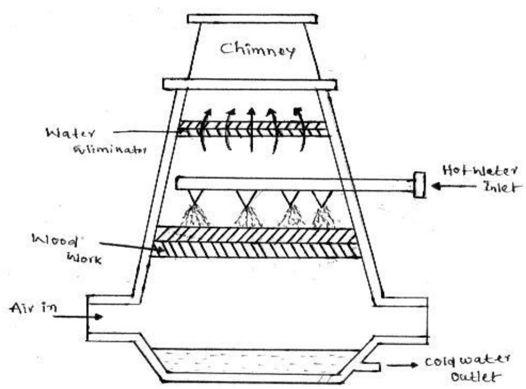


Figure 1.48 Natural draught cooling tower

In this type of tower, hot water from the condenser is pumped to the troughs and nozzles situated near the bottom. Troughs spray the water falls in the form of droplets into a pond situated at the bottom of the tower. The air enters into the cooling tower from air openings provided near the base, rises upward and takes heat of the falling water.

Natural draught towers

Advantages:

1. Low operative and maintenance cost
2. It is easy in operation
3. Less space is required to setup this tower
4. The towers may be as high as 125m and 100m minimum diameter at the base
5. Enlarged top of the tower water to fall out of suspension

Disadvantages:

1. High initial cost
2. Its performance varies with seasonal changes in DBT and RH of air.

Mechanical draught cooling towers

In these towers the draught of air for cooling the tower is produced mechanically by means of propeller fans. These towers are built in cells or units, capacity depending upon the number of cells used.

Forced draught cooling towers

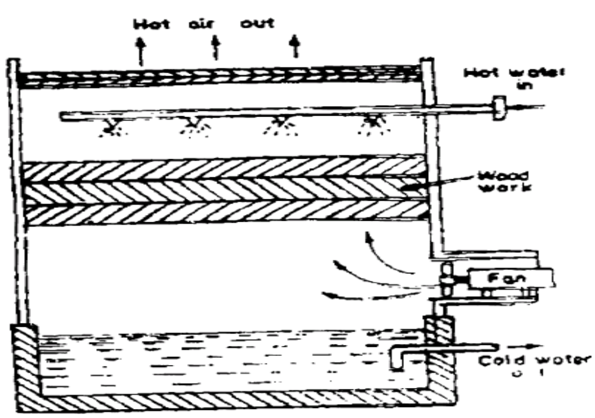


Figure 1.49 Forced draught cooling tower

It is similar to natural draught towers as far as interior construction is concerned but the sites of the tower are closed and form an air water tight structure, except for the fan openings at the base for the inlet of fresh air, and outlet at the top for except of air and vapors. There are hoods at the base projecting from the main portion of the tower where the fans are placed for forcing the air, into the tower.

Forced draught cooling towers

Advantages:

1. It is more efficient
2. No problem of fan blade erosion
3. It is more safe
4. The vibration and noise are minimum

Disadvantages:

1. The fan size is limited to 4m
2. The power requirement is high
3. In the cold weather, ice is formed on nearby equipment and buildings or in the fan housing itself. The frost in the fan outlet can break the fan blades.

Induced draught cooling towers

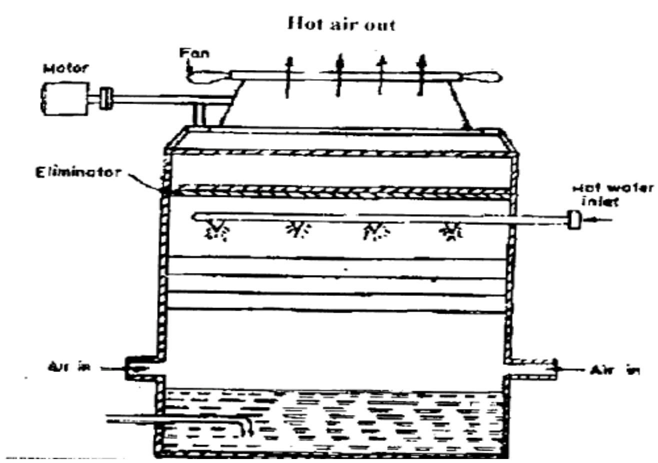


Figure 1.50 Induced draught cooling tower

In these towers, the fans are placed at the top of the tower and drawn the air in through louvers extending all around the tower.

Induced draught cooling towers

Advantages:

1. The coldest water comes in contact with the driest air and warmest water comes in contact with the most humid air.
2. In this tower, the re-circulation is seldom a problem.
3. Initial cost is low because the reduced pump capacity and smaller length of water pipes.
4. Less space required.
5. This tower is capable of cooling of cooling through a wide range.

Disadvantages:

1. The air velocities through the packing are unevenly distributed and it has very little movement near the walls and center of the tower.
2. Higher H.P. motor is required to drive the fan comparatively. This is due to the fact that the static pressure loss is higher as restricted area at base tends to choke off the flow of higher velocity air.

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – 2 – DIESEL, GAS, HYDRO ELECTRIC POWER PLANT – SMEA1403

DIESEL ENGINE POWER PLANT

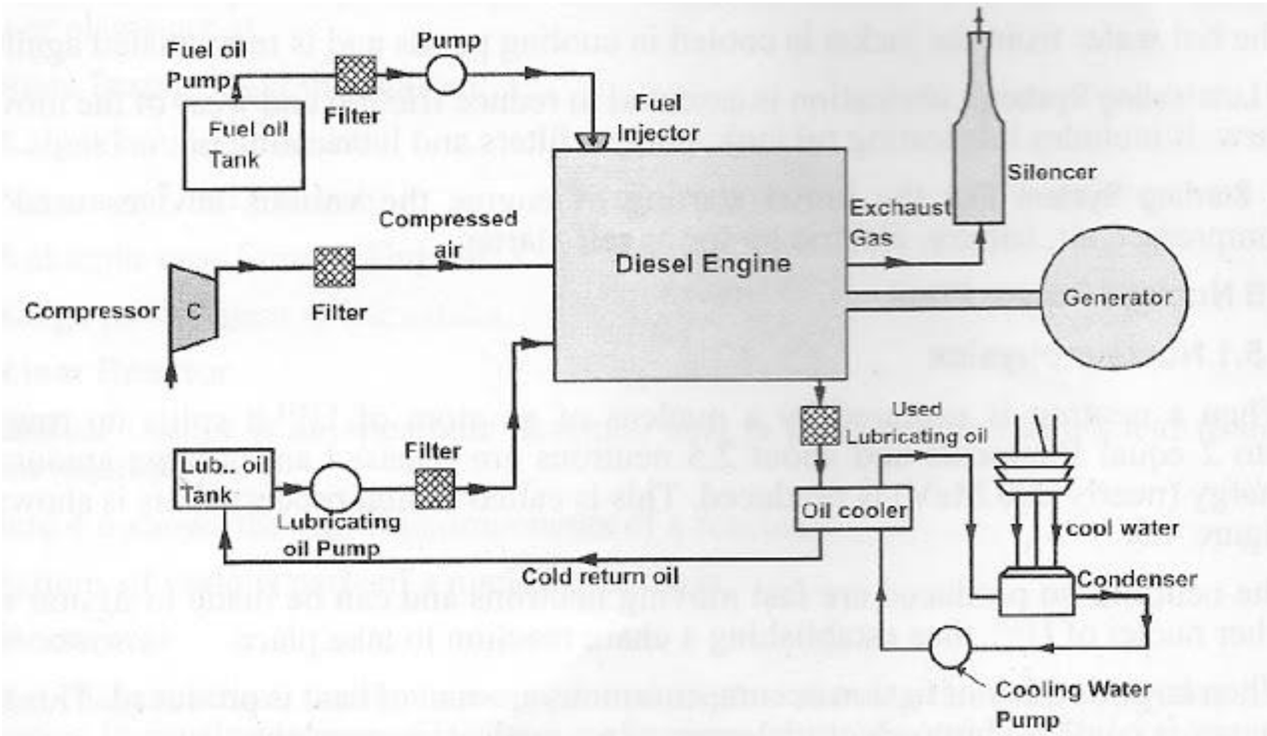


Fig 2.1 Diesel Engine Power Plant Layout

A generating station in which diesel engine is used as the prime mover for the generation of electrical energy is known as diesel power station. In a diesel power station, diesel engine is used as the prime mover. The diesel burns inside the engine and the products of this combustion act as the working fluid to produce mechanical energy. The diesel engine drives alternator which converts mechanical energy into electrical energy. As the generation cost is considerable due to high price of diesel, therefore, such power stations are only used to produce small power. Although steam power stations and hydro-electric plants are invariably used to generate bulk power at cheaper costs, yet diesel power stations are finding favour at places where demand of power is less, sufficient quantity of coal and water is not available and the transportation facilities are inadequate. This plants are also standby sets for continuity of supply to important points such as hospitals, radio stations, cinema houses and telephone exchanges.

Advantages

(a) The design and layout of the plant are quite simple.

(b) It occupies less space as the number and size of the auxiliaries is small.

(c) It can be located at any place.

(d) It can be started quickly and it can pickup load in a short time.

(e) There are no standby losses.

(f) It requires less quantity of water for cooling.

(g) The overall cost is much less than that of steam power station of same capacity.

(h) The thermal efficiency of the plant is higher than that of a steam power station.

(i) It requires less operating staff

Disadvantages

(a) The plant has high running charges as the fuel (diesel) used is costly.

(b) The plant doesn't work satisfactorily under overload conditions for a longer period.

(c) The plant can only generate small power.

(d) The cost of lubrication is generally high.

(e) The maintenances charges are generally high

ESSENTIAL ELEMENTS OF DIESEL POWER PLANT

Fuel Supply System

It consists of storage tank, strainers, fuel transfer pump and all day fuel tank. The fuel oil is supplied at the plant site by rail or road. The oil is stored in the storage tank. From the storage tank, oil is pumped to smaller all day tank at daily or short intervals. From this tank, fuel oil is passed through strainers to remove suspended impurities. The clean oil is injected into the engine by fuel injection pump.

Air Intake System

This system supplies necessary air to the engine for fuel combustion. It consists of pipes for the supply of fresh air to the engine manifold. Filters are provided to remove dust particles from air which may act as abrasive in the engine cylinder. Because a diesel engine requires close tolerances to achieve its compression ratio, and because most diesel engines are either turbocharged or supercharged, the air entering the engine must be clean, free of debris, and as cool as possible. Also, to improve a turbocharged or supercharged engine’s efficiency, the compressed air must be cooled after being compressed. The air intake system is designed to perform these tasks. Air intake systems are usually one of two types, wet or dry. In a wet filter intake system, as shown in the Figure 2.2, the air is sucked or bubbled through a housing that holds a bath of oil such that the dirt in the air is removed by the oil in the filter. The air then flows through a screen-type material to ensure any entrained oil is removed from the air. In a dry filter system, paper, cloth, or a metal screen material is used to catch and trap dirt before it enters the engine. In addition to cleaning the air, the intake system is usually designed to intake fresh air from as far away from the engine as practicable, usually just outside of the engine’s building or enclosure. This provides the engine with a supply of air that has not been heated by the engine’s own waste heat. The reason for ensuring that an engine's air supply is as cool as possible is that cool air is denser than hot air. This means that, per unit volume, cool air has more oxygen than hot air. Thus, cool air provides more oxygen per cylinder charge than less dense, hot air. More oxygen means a more efficient fuel burn and more power

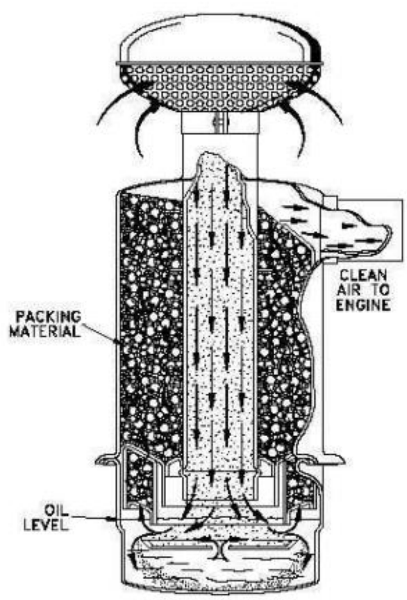


Fig 2.2 Air Intake System

After being filtered, the air is routed by the intake system into the engine's intake manifold or air box. The manifold or air box is the component that directs the fresh air to each of the engine’s intake valves or ports. If the engine is turbocharged or supercharged, the fresh air will be compressed with a blower and possibly cooled before entering the intake manifold or air box. The intake system also serves to reduce the air flow noise.

Exhaust System

This system leads the engine exhaust gas outside the building and discharges it into atmosphere. A silencer is usually incorporated in the system to reduce the noise level. The exhaust system of a diesel engine performs three functions. First, the exhaust system routes the spent combustion gasses away from the engine, where they are diluted by the atmosphere. This keeps the area around the engine habitable. Second, the exhaust system confines and routes the gases to the turbocharger, if used. Third, the exhaust system allows mufflers to be used to reduce the engine noise.

Cooling System

The heat released by the burning of fuel in the engine cylinder is partially converted into work. The remainder part of the heat passes through the cylinder wall, piston, rings etc. and may cause damage to system. In order to keep the temperature of the engine parts within the safe operating limits, cooling is provided. The cooling system consists of a water source, pump and cooling towers. The pump circulates water through cylinder and head jacket. The water takes away heat form the engine and it becomes hot. The hot water is cooled by cooling towers and re circulated for cooling.

Lubricating System

The system minimizes the wear of rubbing surfaces of the engine. It comprises of lubricating oil tank, pump, filter and oil cooler. The lubrication oil is drawn from the lubricating oil tank by the pump and is passed through filter to remove impurities. The clean lubrication oil is delivered to the points which require lubrication. The oil coolers incorporated in the system keep the temperature of the oil low.

Engine Starting System

This is an arrangement to rotate the engine initially, while starting, until firing starts and the unit runs with its own power. Small sets are started manually by handles but for larger units, compressed air is used for starting. In the latter case, air at high pressure is admitted to a few of the cylinders, making them to act as reciprocating air motors to turn over the engine shaft. The fuel is admitted to the remaining cylinders which makes the engine to start under its own power.

Working of Diesel Engine Power Plants

- Diesel engines or compression ignition engines as they are called are generally classified as two stroke engine and four stroke engines.
- In diesel engine, air admitted into the cylinder is compressed, the compression ratio being 12 to 20.
- At the end of compression stroke, fuel is injected.
- It burns and the burning gases expand and do work on the position.
- The engine is directly coupled to the generator.
- The gases are then exhausted from the cylinder to atmosphere.

Applications of Diesel Engine Power Plant

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

GAS TURBINE POWER PLANT

- Air is compressed (squeezed) to high pressure by a fan-like device called the compressor.
- Then fuel and compressed air are mixed in a combustion chamber and ignited.
- Hot gases are given off, which spin the turbine wheels.
- Most of the turbine's power runs the compressor. Part of it drives the generator/machinery.
- Gas turbines burn fuels such as oil, nature gas and pulverized (powdered) coal.
- Instead of using the heat to produce steam, as in steam turbines, gas turbines use the hot gases directly to turn the turbine blades.
- Gas turbines have three main parts:
    - i) Air compressor
    - ii) Combustion chamber
    - ii) Turbine

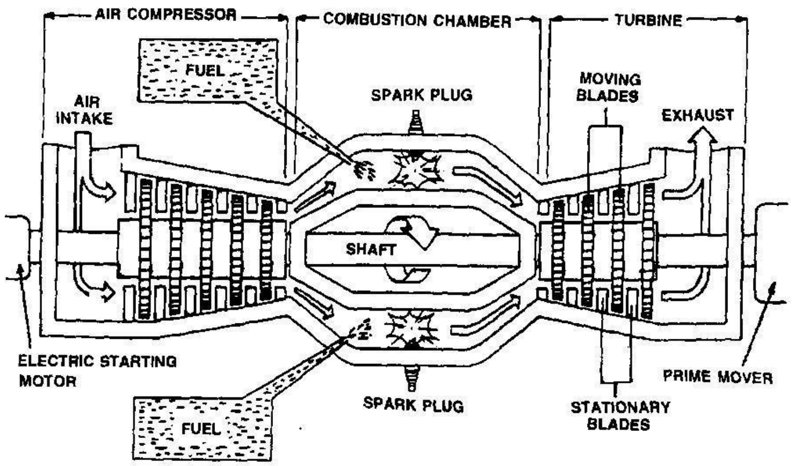


Figure 2.3 Gas Turbine Setup

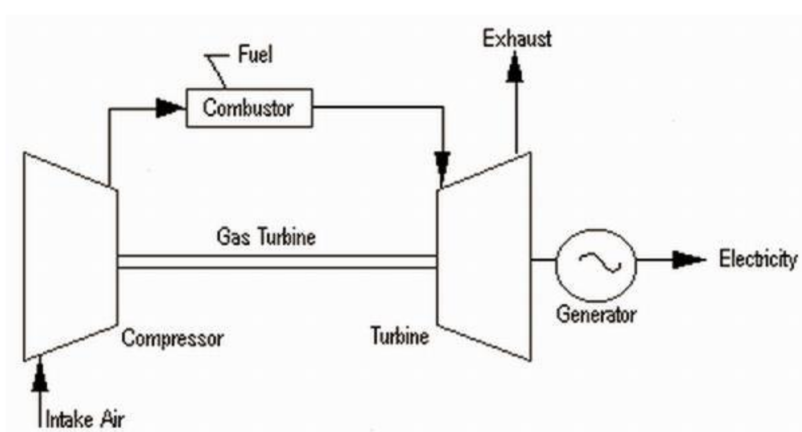


Figure 2.4 General Layout of Gas Turbine Power Plant

Air Compressor

- The air compressor and turbine are mounted at either end on a common horizontal axle (shaft), with the combustion chamber between them.
- Gas turbines are not self-starting. A starting motor initially drives the compressor till the first combustion of fuel takes place, later, part of the turbine's power runs the compressor.
- The air compressor sucks in air and compresses it, thereby increasing its pressure.

Combustion chamber:

- In the combustion chamber, the compressed air combines with fuel and the resulting mixture is burnt.
- The greater the pressure of air, the better the fuel air mixture burns.
- Modern gas turbines usually use liquid fuel, but they may also use gaseous fuel, natural gas or gas produced artificially by gasification of a solid fuel.

Note:

- ✓ The combination of air compressor and combustion chamber is called as gas generator.

Turbine:

- The burning gases expand rapidly and rush into the turbine, where they cause the turbine wheels to rotate.
- Hot gases move through a multistage gas turbine.
- Like in steam turbine, the gas turbine also has fixed (stationary) and moving (rotor) blades.
- The stationary blades guide the moving gases to the rotor blades and adjust its velocity.
- The shaft of the turbine is coupled to a generator or machinery to drive it.

Applications of gas turbine:

- Gas turbines are used to drive pumps, compressors and high speed cars.
- Used in aircraft and ships for their propulsion. They are not suitable for automobiles because of their very high speeds.
- Power generation (used for peak load and as stand-by unit).

Note: Gas turbines run at even higher temperatures than steam turbines, the temperature may be as high as 1100 – 1260^{0}C.

- The thermal efficiency of gas turbine made of metal components do not exceed 36%.
- Research is underway to use ceramic components at turbine inlet temperature of 1350^{0}C or more, and reach thermal efficiencies over 40% in a 300 kW unit.

Classification of gas turbine

Gas turbines are divided in to two types:

- Open cycle gas turbine
- Closed cycle gas turbine

Open Cycle Gas Turbine

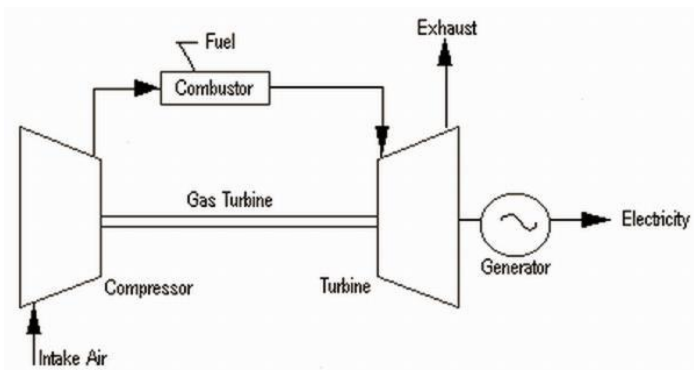


Figure 2.5 Open Cycle Gas Turbine

In the open cycle gas turbine air is drawn in to the compressor from the atmosphere. The compressed air is heated by using the burner; the air must be burned directly. In the combustion chamber the fuel in the air inside maintains at constant pressure. From the combustion chamber the high pressure hot gases drive the turbine. The power must be developed when the turbine shaft rotates. There is no self-starting in the Gas turbines. The starting motor drives the compressor till the fuel is injected in the combustion chamber. If the turbine frights gain speed then the starting motor is disconnected. The power established by the gas turbine is used to initiative the compressor and the remaining is used to initiative other machinery or generator. In the open cycle gas turbine the system and the working fluid are replaced continuously and gases are drained into the atmosphere. Then the total flow derives from the atmosphere and again returns to the surrounding.

Closed Cycle Gas Turbine

According to the closed cycle gas turbine, the compressed air from the surroundings is heated by using the heat exchanger (air heater). At constant pressure from the external source the heat is additionally given to the heat exchanger. High pressure working fluid increases over the turbine and then the power is developed. The exhaust working fluid must be cooled in a pre-cooler.

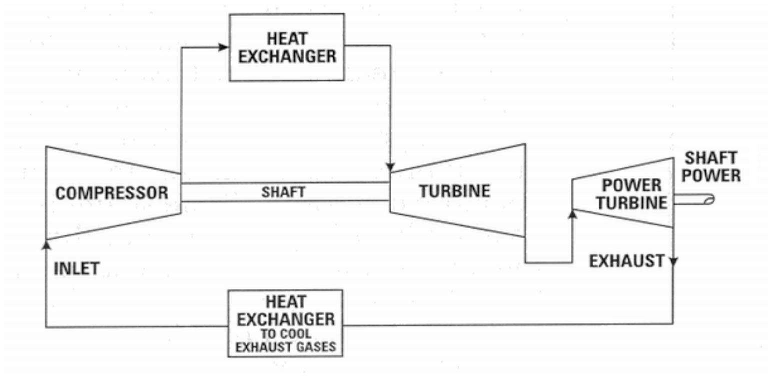


Figure 2.6 Closed Cycle Gas Turbine

Same fluid is sent into the compressor before the process is done. In the turbine same working fluid is always distributed. From an external source the fuel is required for adding heat so the fuel ranges from kerosene and then to the heavy oil. Straightly the fertilizer and coal slurry enter the turbine without reducing the efficiency.

HYDEL POWER PLANT

The schematic representation of a hydro-electric power plant is shown in figure 2.7.

Water reservoir

Continuous availability of water is the basic necessity for a hydro-electric plant. Water collected from catchment area during rainy season is stored in the reservoir. Water surfaces in the storage reservoir us known as head race.

Dam

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

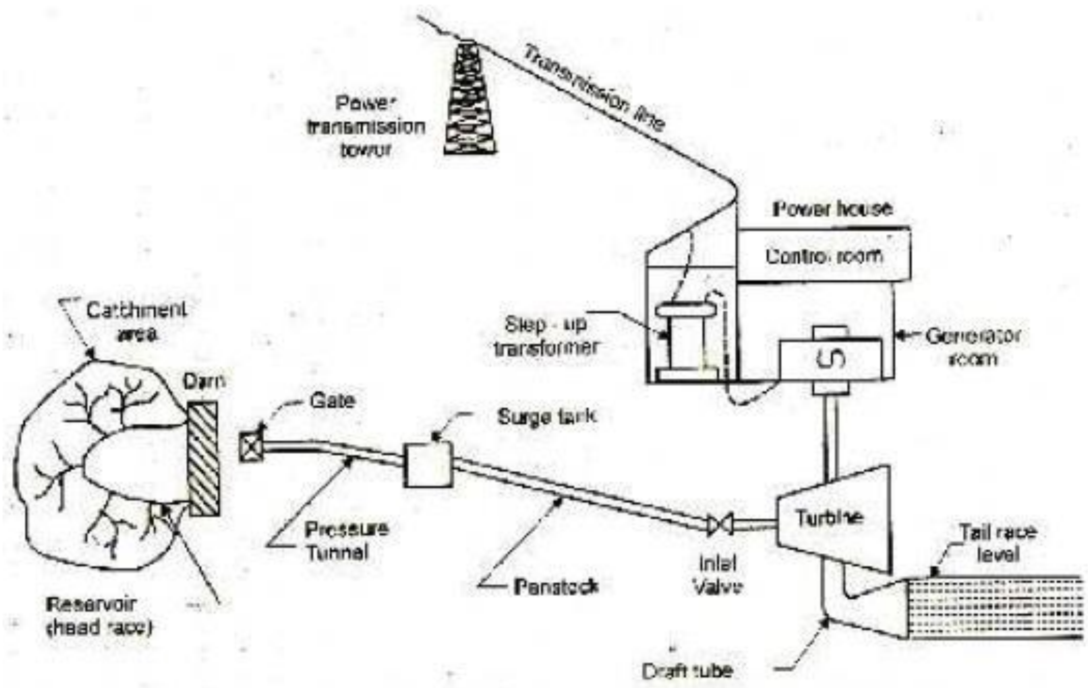


Figure 2.7 Hydel Power Plant Layout

Spillway

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

Pressure tunnel

It carries water from the reservoir to surge tank.

Penstock

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

Surge tank

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

Water turbine

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

Draft tube

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

Tail race

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

Step-up transformer

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

Power house

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

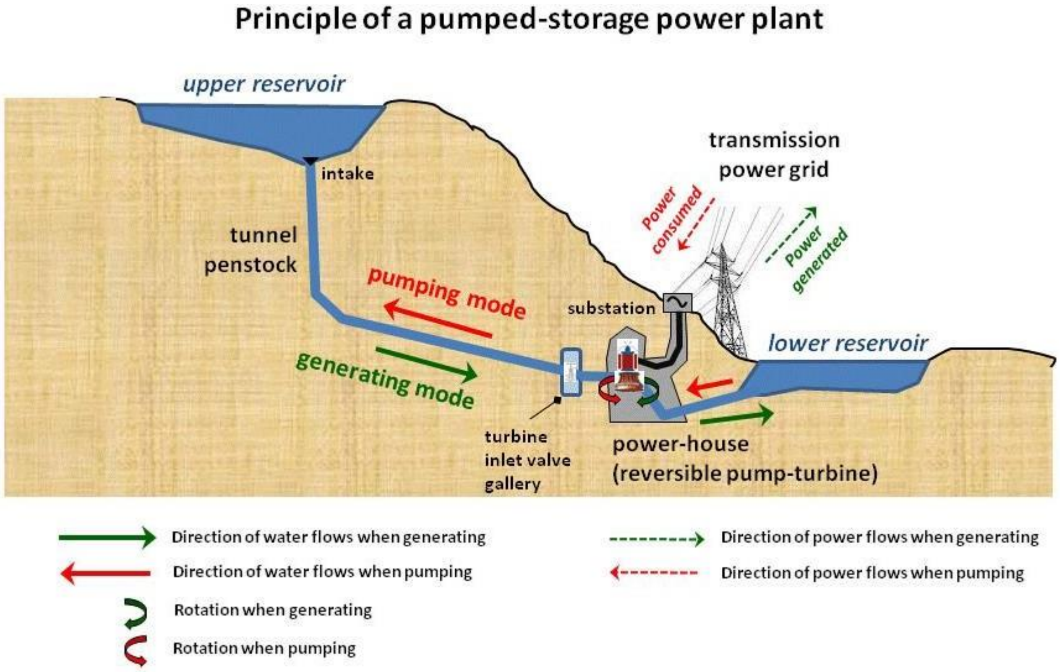


Figure 2.7 Layout of Pumped Storage Power Plant

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF MECHANICAL ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – 3 – NUCLEAR & COMBINED POWER PLANT – SMEA1403

NUCLEAR POWER PLANTS

Basics

Atoms consist of nucleus and electrons. The nucleus is composed of protons and neutrons. Protons are positively charged whereas neutrons are electrically neutral. Atoms with nuclei having same number of protons but difference in their masses are called isotopes. They are identical in terms of their chemical properties but differ with respect to nuclear properties.

Natural Uranium consists of $92U^{238}$ (99.282%), $92U^{235}$ (0.712%) and $92U^{234}$ $92U^{235}$ is used as fuel in nuclear power plants.

Energy from Nuclear Reactions

The sum of masses of protons and neutrons exceeds the mass of the atomic nucleus and this difference is called mass defect Δm. In a nuclear reaction the mass defect is converted into energy known as binding energy according to Einstein's equation ($E=\Delta m\ c^2$). Fissioning one amu of mass results in release of 931 MeV of energy. It has been found that element having higher and lower mass numbers are unstable. Thus the lower mass numbers can be fused or the higher mass numbers can be fissioned to produce more stable elements. This results in two types of nuclear reactions known as fusion and fission. The total energy per fission reaction of U235 is about 200 MeV. Fuel burn-up rate is the amount of energy in MW/days produced by each metric ton of fuel.

Nuclear Fission

When unstable heavy nuclei are bombarded with high energy neutrons, it splits into several smaller fragments. These fragments, or fission products, are about equal to half the original mass. This process is called Nuclear Fission. Two or three neutrons are also emitted. The sum of the masses of these fragments is less than the original mass. This missing mass (about 0.1 percent of the original mass) has been converted into energy. Fission can occur when a nucleus of a heavy atom captures a neutron, or it can happen spontaneously.

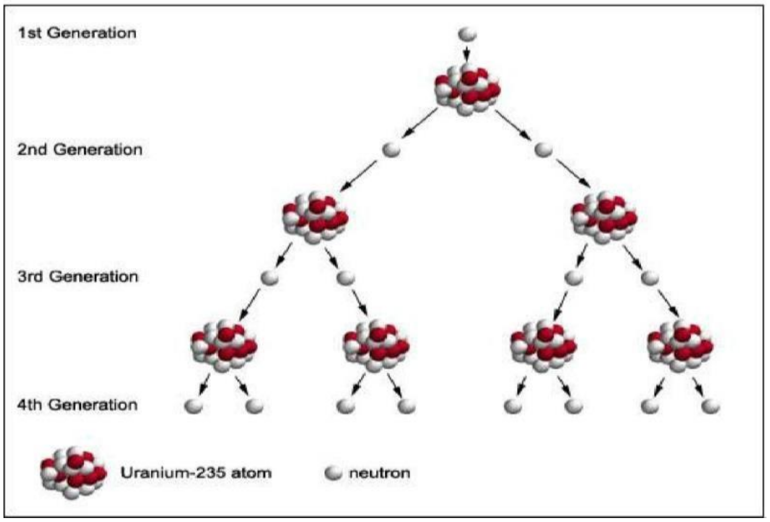


Figure 3.1 Nuclear Fission

Nuclear Fusion

Fusion is the opposite of fission, it is the joining together of two light nuclei to form a heavier one (plus a small fragment). For example if two 2H nuclei (two deuterons) can be made to come together they can form He and a neutron.

$$^{2}H + ^{2}H \rightarrow ^{3}He + n$$

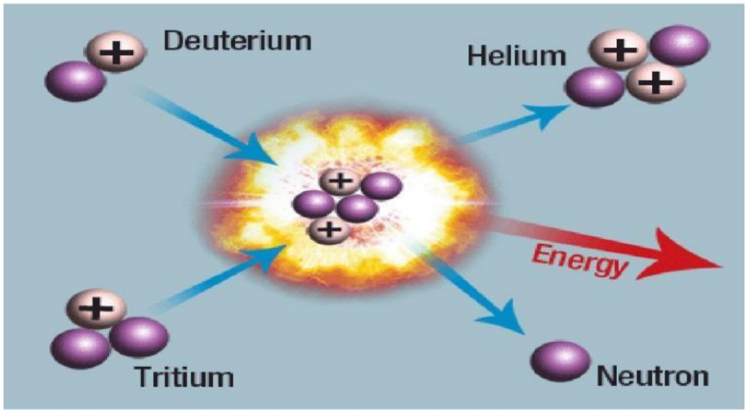


Figure 3.2 Nuclear Fusion

NUCLEAR POWER REACTORS

A nuclear reactor produces and controls the release of energy from splitting the atoms of elements such as uranium and plutonium. In a nuclear power reactor, the energy released from continuous fission of the atoms in the fuel as heat is used to make steam. The steam is used to drive the turbines which produce electricity (as in most fossil fuel plants).

There are several components common to most types of reactors:

Fuel

Usually pellets of uranium oxide (UO_2) arranged in tubes to form fuel rods. The rods are arranged into fuel assemblies in the reactor core.

Moderator

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

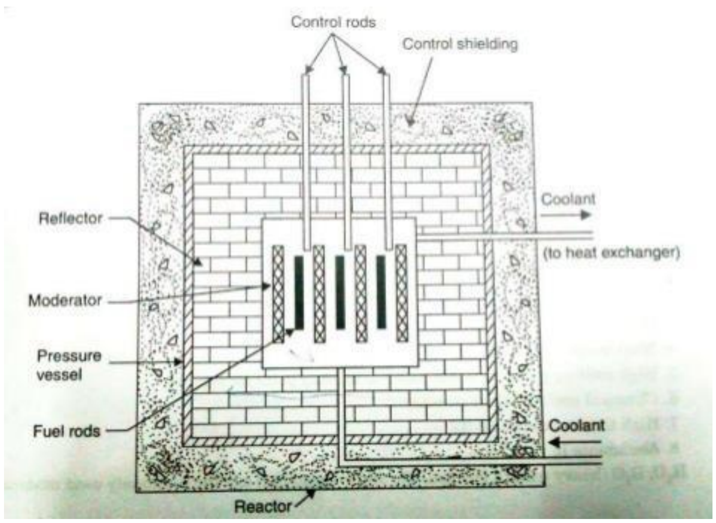


Figure 3.3 Reactor Core

Control Rods

These are made with neutron-absorbing material such as cadmium, hafnium or boron, and are inserted or withdrawn from the core to control the rate of reaction, or to halt it. (Secondary shutdown systems involve adding other neutron absorbers, usually in the primary cooling system.)

Coolant

A liquid or gas circulating through the core so as to transfer the heat from it. In light water reactors the moderator functions also as coolant.

Pressure Vessel or Pressure Tubes

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

Steam Generator

Part of the cooling system where the heat from the reactor is used to make steam for the turbine.

Reflectors

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

Shielding

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

Cladding

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

Coolant

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

Some of the desirable properties of good coolant are listed below

1. It must not absorb the neutrons.
2. It must have high chemical and radiation stability

3. It must be non-corrosive.

4. It must have high boiling point (if liquid) and low melting point (if solid)

5. It must be non-oxidizing and non-toxic.

Classification on the basis of different criteria:

On the Basis of Neutron Energy

(a) Fast Reactor: In these reactors, fission is effected by fast neutrons without any use of moderators.

(b) Thermal Reactors: In these reactors, fission is effected by fast neutrons are slowed down with the use of moderators. The slow neutrons are absorbed by the fissionable fuel and chain reaction is maintained.

On the Basis of Fuel Used

(a) Natural Fuel: In this reactor, natural Uranium is used as fuel and generally heavy water or graphite is used as moderator.

(b) Enriched Uranium: In this reactor, the Uranium used contains 5 to 10% U^{235} and ordinary water can be used as moderator.

On the Basis of Moderator Used

(a) Water moderated

(b) Heavy water moderated

(c) Graphite moderated

(d) Beryllium moderated.

On the Basis of Coolant Used

(a) Water cooled reactors

(b) Gas cooled reactors

(c) Liquid metal cooled reactors

(d) Organic liquid cooled reactors.

Classification by Use

(a) Electricity

Nuclear power plant.

(b) Propulsion

(i) Nuclear marine propulsion.

(ii) Various proposed forms of rocket propulsion.

(c) Other Uses of Heat

(i) Desalination

(ii) Heat for domestic and industrial heating

(iii) Hydrogen production for use in a hydrogen economy

(d) Production Reactors for Transmutation of Elements

(i) **Breeder Reactors:** Fast breeder reactors are capable of producing more fissile materials than they consume during the fission chain reaction (by converting fertile U-238 to Pu-239) which allows an operational fast reactor to generate more fissile material than it consumes. Thus, a breeder reactor, once running, can be re-fueled with natural or even depleted uranium.

(ii) Creating various radioactive isotopes, such as americium for use in smoke detectors, and cobalt-60, molybdenum-99 and others, used for imaging and medical treatment.

(iii) Production of materials for nuclear weapons such as weapons-grade plutonium.

(e) Providing a source of neutron radiation (for example with the pulsed Godiva device) and position radiation (e.g. neutron activation analysis and potassium-argon dating).

(f) **Research Reactor:** Typically reactors used for research and training, materials testing, or the production of radioisotopes for medicine and industry. These are much smaller than power reactors or those propelling ships, and many are on university campuses. There are about 280 such reactors operating, in 56 countries. Some operate with high-enriched uranium fuel, and international efforts are underway to substitute low-enriched fuel.

Boiling Water Reactor (BWR)

The BWR uses demineralized water (light water) as a coolant and neutron moderator. Heat is produced by nuclear fission in the reactor core, and this causes the cooling water to boil, producing steam. The steam is directly used to drive a turbine, after which is cooled in a condenser and converted back to liquid water. This water is then returned to the reactor core, completing the loop. The cooling water is maintained at about 75 atm (7.6 MPa) so that it boils in the core at about 285°C. In comparison, there is no significant boiling allowed in a PWR because of the high pressure maintained in its primary loop - approximately 158 atm (16 MPa, 2300 psi).

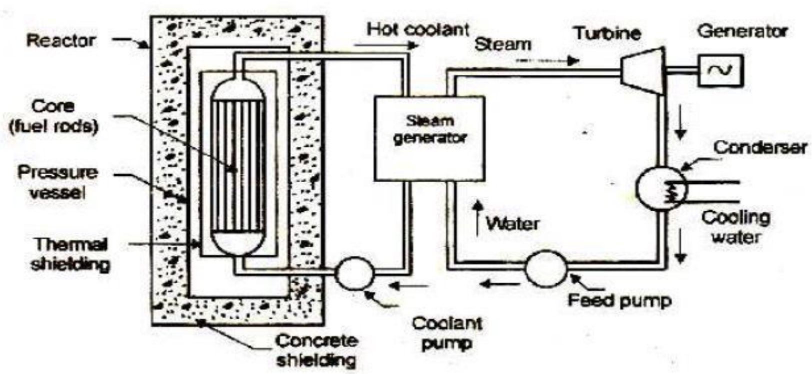


Figure 3.4 Boiling Water Reactor

Pressurized Water Reactor (PWR)

The most widely used reactor type in the world is the Pressurized Water Reactor (PWR) which uses enriched (about 3.2% U235) uranium dioxide as a fuel in zirconium alloy cans. The fuel, which is arranged in arrays of fuel "pins" and interspersed with the movable control rods, is held in a steel vessel through which water at high pressure (to suppress boiling) is pumped to act as both a coolant and a moderator. The high-pressure water is then passed through a steam generator, which raises steam in the usual way.

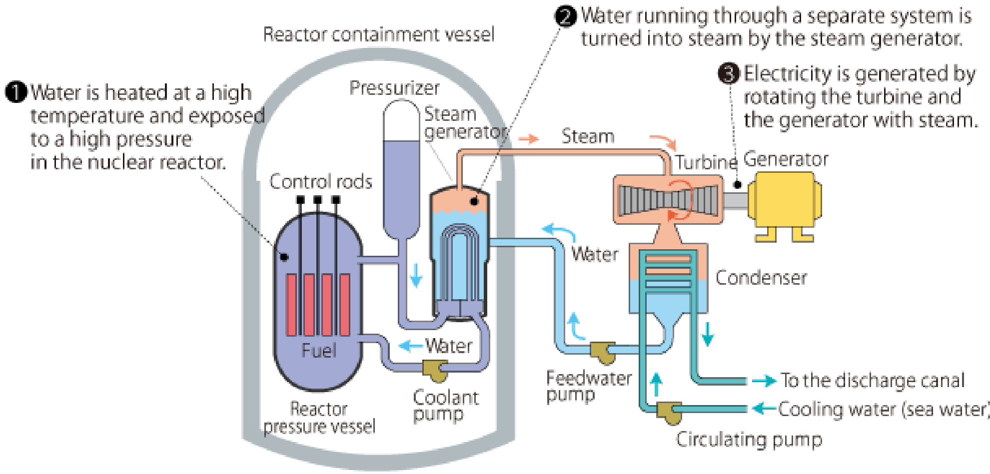


Figure 3.5 Pressurized Water Reactor

Fast Breeder Reactors (FBR)

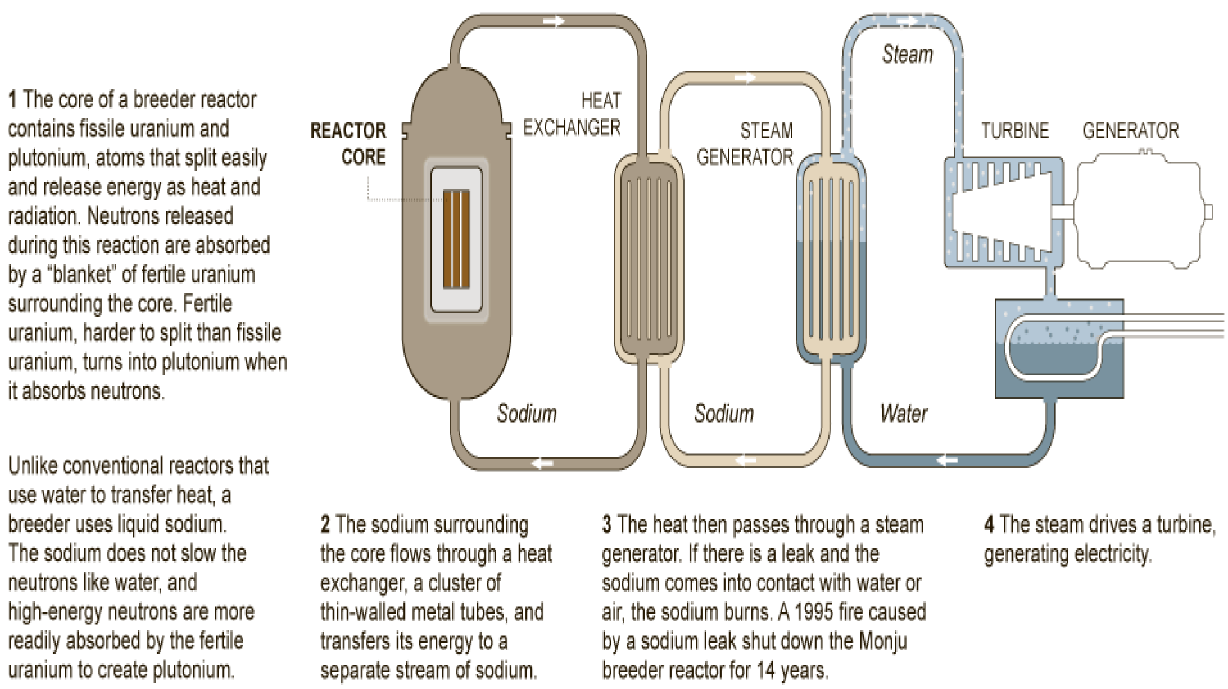


Figure 3.6 Fast Breeder Reactor

- All of today's commercially successful reactor systems are "thermal" reactors, using slow or thermal neutrons to maintain the fission chain reaction in the U 235 fuel. Even with the enrichment levels used in the fuel for such reactors, however, by far the largest numbers of atoms present are U 238, which are not fissile.

- Consequently, when these atoms absorb an extra neutron, their nuclei do not split but are converted into another element, Plutonium.
- Plutonium is fissile and some of it is consumed in situ, while some remains in the spent fuel together with unused U 235. These fissile components can be separated from the fission product wastes and recycled to reduce the consumption of uranium in thermal reactors by up to 40%, although clearly thermal reactors still require a substantial net feed of natural uranium.
- It is possible, however, to design a reactor which overall produces more fissile material in the form of Plutonium than it consumes. This is the fast reactor in which the neutrons are un-moderated, hence the term "fast".
- The physics of this type of reactor dictates a core with a high fissile concentration, typically around 20%, and made of Plutonium. In order to make it breed, the active core is surrounded by material (largely U238) left over from the thermal reactor enrichment process. This material is referred to as fertile, because it converts to fissile material when irradiated during operation of the reactor.
- The successful development of fast reactors has considerable appeal in principle. This is because they have the potential to increase the energy available from a given quantity of uranium by a factor of fifty or more, and can utilise the existing stocks of depleted uranium, which would otherwise have no value.

Factors for Site Selection of NPPs

1. Availability of Water: working fluid
2. Distance from Populated Area: danger of radioactivity
3. Nearness to the load center: reduction in transmission cost
4. Disposal of Waste: radioactive waste
5. Accessibility by Rail and Road: transport of heavy equipment

Advantages of NPPs

1. Reduces demand for fossil fuels
2. Quantity of nuclear fuel is much less: thus reducing transport and resulting costs
3. Area of land required is less: compared to a conventional plant of similar capacity

4. Production of fissile material
5. Location independent of geographical factors: except water requirement

Disadvantages of NPPs

1. Not available for variable loads (load factor-0.8): as the reactors cannot be controlled to respond quickly
2. Economical reason should be substantial
3. Risk of leakage of radioactive material
4. Further investigation on life cycle assessment and reliability needs to be done
5. Perception problems

SAFETY PRECAUTIONS IN NPP

Treatment and Conditioning of Nuclear Wastes

Treatment and conditioning processes are used to convert radioactive waste materials into a form that is suitable for its subsequent management, such as transportation, storage and final disposal. The principal aims are to:

(a) Minimize the volume of waste requiring management via treatment processes.

(b) Reduce the potential hazard of the waste by conditioning it into a stable solid form that immobilizes it and provides containment to ensure that the waste can be safely handled during transportation, storage and final disposal. It is important to note that, while treatment processes such as compaction and incineration reduce the volume of waste, the amount of radioactivity remains the same. As such, the radioactivity of the waste will become more concentrated as the volume is reduced.

Conditioning processes such as cementation and vitrification are used to convert waste into a stable solid form that is insoluble and will prevent dispersion to the surrounding environment. A systematic approach incorporates:

(a) Identifying a suitable matrix material – such as cement, bitumen, polymers or borosilicate glass - that will ensure stability of the radioactive materials for the period necessary. The type of waste being conditioned determines the choice of matrix material and packaging.

(b) Immobilizing the waste through mixing with the matrix material.

(c) Packaging the immobilized waste in, for example, metallic drums, metallic or concrete boxes or containers, copper canisters.

The choice of process used is dependent on the level of activity and the type (classification) of waste. Each country's nuclear waste management policy and its national regulations also influence the approach taken.

Incineration

Incineration of combustible wastes can be applied to both radioactive and other wastes. In the case of radioactive waste, it has been used for the treatment of low-level waste from nuclear power plants, fuel production facilities, research centers (such as biomedical research), medical sector and waste treatment facilities.

Following the segregation of combustible waste from non-combustible constituents, the waste is incinerated in a specially engineered kiln up to around $1000^{o}C$. Any gases produced during incineration are treated and filtered prior to emission into the atmosphere and must conform to international standards and national emissions regulations.

Following incineration, the resulting ash, which contains the radionuclide’s, may require further conditioning prior to disposal such as cementation or bituminization. Compaction technology may also be used to further reduce the volume, if this is cost-effective. Volume reduction factors of up to around 100 are achieved, depending on the density of the waste.

Incineration technology is subject to public concern in many countries as local residents worry about what is being emitted into the atmosphere.

However, modern incineration systems have well engineered high technology processes designed to completely and efficiently burn the waste whilst producing minimum emissions.

The incineration of hazardous waste (e.g. waste oils, solvents) and non-hazardous waste (municipal waste, biomass, tyres and sewage sludge) is also practiced in many countries.

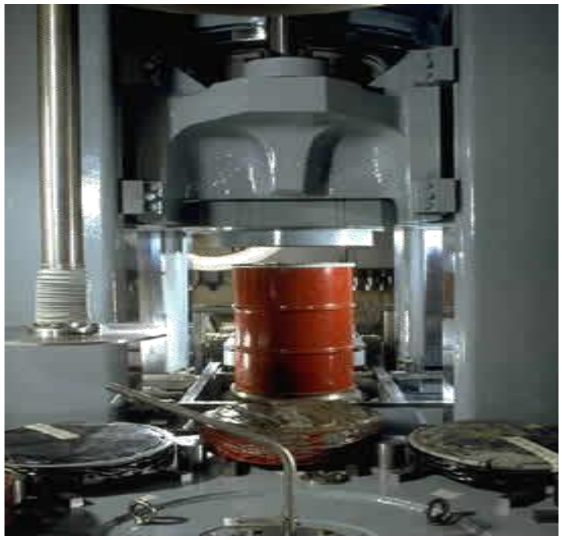


Figure 3.7 Incineration Unit

Compaction

Compaction is a mature, well-developed and reliable volume reduction technology that is used for processing mainly solid man-made low-level waste (LLW). Some countries (Germany, UK and USA) also use the technology for the volume reduction of man-made intermediate-level/transuranic waste. Compactors can range from low-force compaction systems (~ 5 tons or more) through to presses with a compaction force over 1000 tones, referred to as super compactors. Volume reduction factors are typically between 3 and 10, depending on the waste material being treated.

Low-force compaction is typically applied to the compression of bags of rubbish, in order to facilitate packaging for transport either to a waste treatment facility, where further compaction might be carried out, or to a storage/disposal facility. In the case of super compactors, in some applications, waste is sorted into combustible and non-combustible materials. Combustible waste is then incinerated whilst non-combustible waste is super compacted. In certain cases, incinerator ashes are also super compacted in order to achieve the maximum volume reduction.

Figure 3.8 Compaction Unit

Low-force compaction utilizes a hydraulic or pneumatic press to compress waste into a suitable container, such as a 200-litre drum. In the case of a super compactor, a large hydraulic press crushes the drum itself or other receptacle containing various forms of solid low- or intermediate-level waste. The drum or container is held in a mold during the compaction stroke of the super compactor, which minimizes the drum or container outer dimensions. The compressed drum is then stripped from the mold and the process is repeated. Two or more crushed drums, also referred to as pellets, are then sealed inside an over pack container for interim storage and/or final disposal.

A super compaction system may be mobile or stationary in concept, supplied as a basic system manually controlled, with a minimum of auxiliary equipment, to an elaborated computer controlled system which selects drums to be processed, measures weight and radiation levels, compresses the drums, places the crushed drums in over pack containers, seals the over packs, records the drums and over packs content via a computerized storage system. Every year worldwide tens of thousands of drums are volume-reduced and stored, with waste generally being reduced in volume by up to a factor of 5.

Cementation

Cementation through the use of specially formulated grouts provides the means to immobilize radioactive material that is on solids and in various forms of sludge’s and precipitates/gels (flocks) or activated materials. In general the solid wastes are placed into containers. The grout is then added into this container and allowed to set. The container with the monolithic block of concrete/waste is then suitable for storage and disposal. Similarly in the case of sludge’s and flocks, the waste is placed in a container and the grouting mix, in powder form, is added. The two are mixed inside the container and left to set leaving a similar type of product as in the case of solids, which can be disposed of in a similar way.

This process has been used for example in small oil drums and 500-litre containers for intermediate-level wastes and has been extended to ISO shipping containers for low-level waste materials. The technology is being used in the immobilization of many toxic and hazardous wastes that arise outside the nuclear industry and has the potential to be used in many more cases.

Vitrification

The immobilization of high-level waste (HLW) requires the formation of an insoluble, solid waste form that will remain stable for many thousands of years. In general borosilicate glass has been chosen as the medium for dealing with HLW. The stability of ancient glass for thousands of years highlights the suitability of borosilicate glass as a matrix material. This type of process, referred to as vitrification, has also been extended for lower level wastes where the type of waste or the economics have been appropriate. Most high-level wastes other than spent fuel itself arise in a liquid form from the reprocessing of spent fuel. To allow incorporation into the glass matrix this waste is initially calcined (dried) which turns it into a solid form. This product is then incorporated into molten glass in a stainless container and allowed to cool, giving a solid matrix. The containers are then welded closed and are ready for storage and final disposal. Several other alternative ceramic processes have also been developed which also achieve the desired quality of product. In-situ vitrification has also been investigated as a means of 'fixing' activity in contaminated ground as well as creating a barrier to prevent further spread of contamination.

Figure 3.9 Vitrification

Nuclear Power in India

Table 1 List of Nuclear Power Plants in India

Plant	Units	Capacity	Established
Tarapur, Maharashtra	**BWR**	**160x2, 540x2**	**1969, 2005, 2006**
Rawatbhata, Rajasthan	**PHWR**	**110x1, 200x1, 220x4**	**1973, 1981, 2000, 2010**
Kalpakkam, Tamil Nadu	**PHWR**	**220x2**	**1984, 1986**
Narora, UP	**PHWR**	**220x2**	**1991, 1992**
Kakrapar, Gujarat	**PHWR**	**220x2**	**1993, 1995**
Kaiga, Karnataka	**PHWR**	**220x4**	**2000, 2007, 2011**
Kundankulam, Tamil Nadu	**VVER-1000**	**1000x1**	**2013**

COMBINED CYCLE PLANT FOR POWER GENERATION

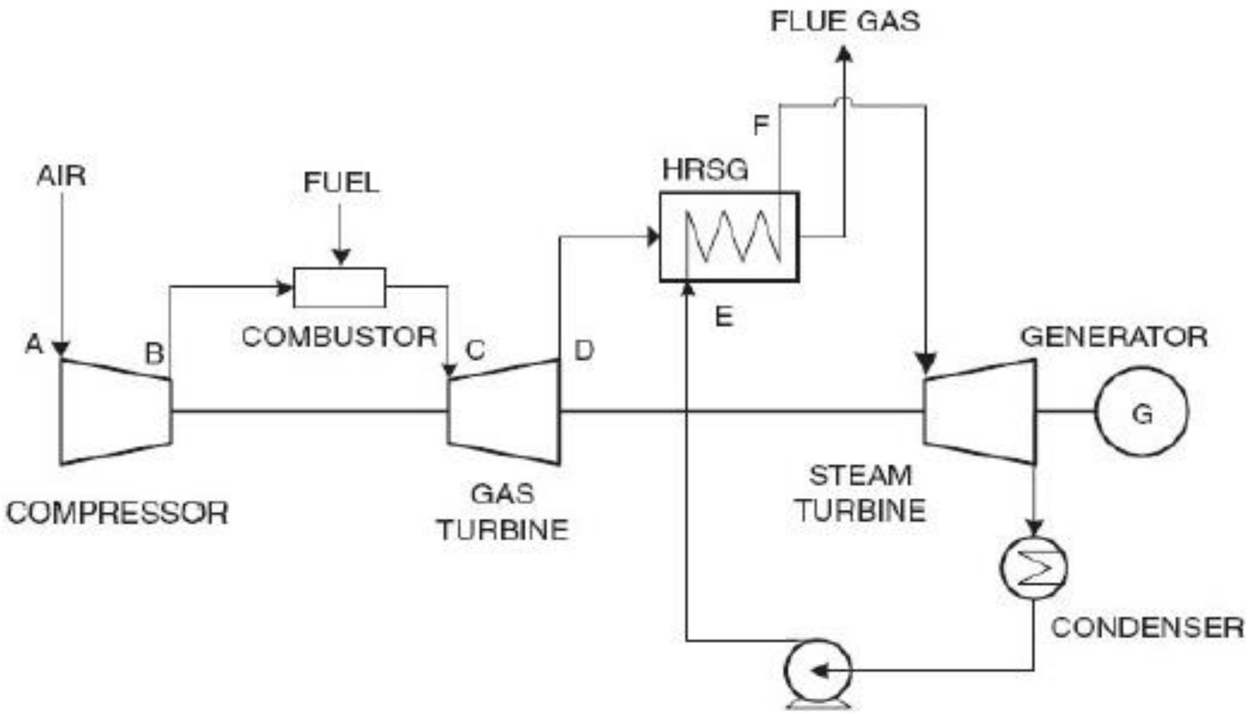


Figure 3.10 Combined Cycle Plant

- Gas turbines have low efficiency in simple cycle operation, the output produced by the steam turbine accounts for about half of the CCGT plant output.
- HRSG is basically a heat exchanger, or rather a series of heat exchangers.
- creates steam for the steam turbine by passing the hot exhaust gas flow from a gas turbine or combustion engine through banks of heat exchanger tubes.
- HRSG can rely on natural circulation or utilize forced circulation using pumps.
- hot exhaust gases flow past the heat exchanger tubes in which hot water circulates, heat is absorbed causing the creation of steam in the tubes.
- tubes are arranged in sections, or modules, each serving a different function in the production of dry superheated steam.
- These modules are referred to as economizers, evaporators, superheaters/reheaters and preheaters.
- The economizer is a heat exchanger that preheats the water to approach the saturation temperature (boiling point), which is supplied to a thick-walled steam drum.
- The drum is located adjacent to finned evaporator tubes that circulate heated water.
- As the hot exhaust gases flow past the evaporator tubes, heat is absorbed causing the creation of steam

in the tubes. The steam-water mixture in the tubes enters the steam drum where steam is separated from the hot water using moisture separators and cyclones.

- The separated water is recirculated to the evaporator tubes. Steam drums also serve storage and water treatment functions.
- An alternative design to steam drums is a once-through HRSG, which replaces the steam drum with thin-walled components that are better suited to handle changes in exhaust gas temperatures and steam pressures during frequent starts and stops.

BINARY CYCLE PLANT FOR POWER GENERATION

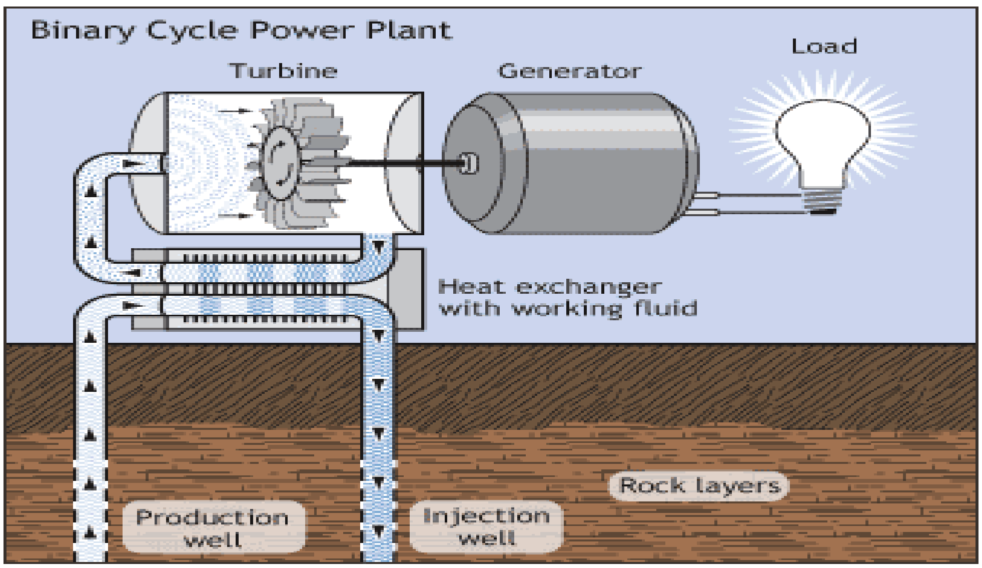


Figure 3.11 Binary Cycle Plant

Binary cycle geothermal power generation plants differ from Dry Steam and Flash Steam systems in that the water or steam from the geothermal reservoir never comes in contact with the turbine/generator units. Low to moderately heated (below 400°F) geothermal fluid and a secondary (hence, "binary") fluid with a much lower boiling point that water pass through a heat exchanger. Heat from the geothermal fluid causes the secondary fluid to flash to vapor, which then drives the turbines and subsequently, the generators.

Binary cycle power plants are closed-loop systems and virtually nothing (except water vapor) is emitted to the atmosphere. Resources below 400°F are the most common geothermal resource, suggesting binary-cycle power plants in the future will be binary-cycle plants.

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – 4 – ECONOMIC AND ENVIRONMENTAL ISSUES – SMEA1403

ECONOMIC ASPECTS OF POWER PLANT

Terms and factors

The main terms and factors are as follows:

1. Load Factor

It is defined as the ratio of the average load to the peak load during a certain prescribed period of time. The load factor of a power plant should be high so that the total capacity of the plant is utilized for the maximum period that will result in lower cost of the electricity being generated. It is always less than unity. High load factor is a desirable quality. Higher load factor means greater average load, resulting in greater number of power units generated for a given maximum demand. Thus, the fixed cost, which is proportional to the maximum demand, can be distributed over a greater number of units (kWh) supplied. This will lower the overall cost of the supply of electric energy.

2. Utility Factor

It is the ratio of the units of electricity generated per year to the capacity of the plant installed in the station. It can also be defined as the ratio of maximum demand of a plant to the rated capacity of the plant. Supposing the rated capacity of a plant is 200 mW. The maximum load on the plant is 100 mW atload factor of 80 per cent, then the utility will be

$= (100 \times 0.8)/(200) = 40\%$

3. Plant Operating Factor

It is the ratio of the duration during which the plant is in actual service, to the total duration of the period of time considered.

4. Plant Capacity Factor

It is the ratio of the average loads on a machine or equipment to the rating of the machine or equipment, for a certain period of time considered. Since the load and diversity factors are not involved with 'reserve capacity' of the power plant, a factor is needed which will measure the reserve, likewise the degree of utilization of the installed equipment. For this, the factor "Plant factor, Capacity factor or Plant Capacity factor" is defined as,

Plant Capacity Factor = (Actual kWh Produced)/(Maximum Possible Energy that might have produced during the same period).

Thus the annual plant capacity factor will be,

= (Annual kWh produced)/[Plant capacity (kW) × hours of the year]

The difference between load and capacity factors is an indication of reserve capacity.

5. Demand Factor

The actual maximum demand of a consumer is always less than his connected load since all the appliances in his residence will not be in operation at the same time or to their fullest extent. This ratio of' the maximum demand of a system to its connected load is termed as demand factor. It is always less than unity.

6. Diversity Factor

Supposing there is a group of consumers. It is known from experience that the maximum demands of the individual consumers will not occur at one time. The ratio of the sum of the individual maximum demands to the maximum demand of the total group is known as diversity factor. It is always greater than unity.

High diversity factor (which is always greater than unity) is also a desirable quality. With a given number of consumers, higher the value of diversity factor, lower will be the maximum demand on the plant, since,

Diversity factor = Sum of the individual maximum Demands/Maximum demand of the total group So, the capacity of the plant will be smaller, resulting in fixed charges.

7. Load Curve

It is a curve showing the variation of power with time. It shows the value of a specific load for each unit of the period covered. The unit of time considered may be hour, days, weeks, months or years.

8. Load Duration Curve

It is the curve for a plant showing the total time within a specified period, during which the load equalled or exceeded the values shown.

9. Dump Power

This term is used in hydro plants and it shows the power in excess of the load requirements and it is made available by surplus water.

10. Firm Power

It is the power, which should always be available even under emergency conditions.

11. Prime Power

It is power, may be mechanical, hydraulic or thermal that is always available for conversion into electric power.

12. Cold Reserve

It is that reserve generating capacity which is not in operation but can be made available for service.

13. Hot Reserve

It is that reserve generating capacity which is in operation but not in service.

14. Spinning Reserve

It is that reserve generating capacity which is connected to the bus and is ready to take the load.

15. Plant Use Factor

This is a modification of Plant Capacity factor in that only the actual number of hours that the plant was in operation is used. Thus Annual Plant Use factor is,

= (Annual kWh produced) / [Plant capacity (kW) × number of hours of plant operation]

FACTOR EFFECTING POWER PLANT DESIGN

Following are the factor effecting while designing a power plant.

(1) Location of power plant

(2) Availability of water in power plant

(3) Availability of labour nearer to power plant

(4) Land cost of power plant

(5) Low operating cost

(6) Low maintenance cost

(7) Low cost of energy generation

(8) Low capital cost

EFFECT OF POWER PLANT TYPE ON COSTS

The cost of a power plant depends upon, when a new power plant is to set up or an existing plant is to be replaced or plant to be extended. The cost analysis includes taxes.

1. Fixed Cost

It includes Initial cost of the plant, Rate of interest, Depreciation cost, Taxes, and Insurance.

2. Operational Cost

It includes Fuel cost, Operating labour cost, Maintenance cost, Supplies, Supervision, Operating taxes.

EFFECT OF PLANT TYPE ON RATES (TARIFFS OR ENERGY ELEMENT)

Rates are the different methods of charging the consumers for the consumption of electricity. It is desirable to charge the consumer according to his maximum demand (kW) and the energy consumed (kWh). The tariff chosen should recover the fixed cost, operating cost and profit etc. incurred in generating the electrical energy.

REQUIREMENTS OF A TARIFF

Tariff should satisfy the following requirements:

(1) It should be easier to understand.

(2) It should provide low rates for high consumption.

(3) It should encourage the consumers having high load factors.

(4) It should take into account maximum demand charges and energy charges.

(5) It should provide less charges for power connections than for lighting.

(6) It should avoid the complication of separate wiring and metering connections.

TYPES OF TARIFFS

The various types of tariffs are as follows,

(1) Flat demand rate

(2) Straight line meter rate

(3) Step meter rate

(4) Block rate tariff

(5) Two part tariff

(6) Three part tariff.

The various types of tariffs can be derived from the following general equation:

$$Y = DX + EZ + C$$

where

Y = Total amount of bill for the period considered.

D = Rate per kW of maximum demand.

X = Maximum demand in kW. E

= Energy rate per kW.

Z = Energy consumed in kWh during the given period.

C = Constant amount to be charged from the consumer during each billing period.

Various type of tariffs are as follows:

(1) Flat Demand Rate. It is based on the number of lamps installed and a fixed number of hours of use per month or per year. The rate is expressed as a certain price per lamp or per unit of demand (kW) of the consumer. This energy rate eliminates the use of metering equipment. It is expressed by the expression.

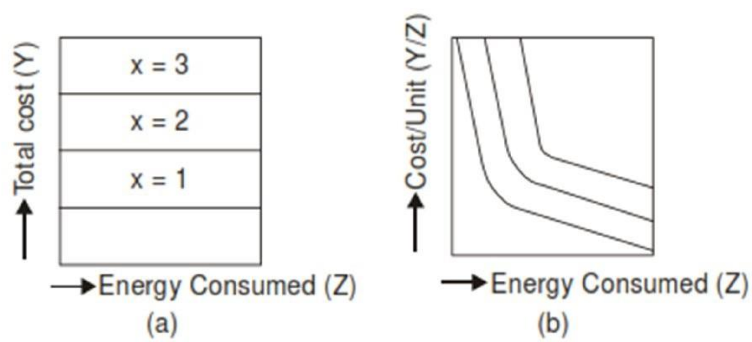


Fig. 4.1 Tariff Calculation

2) Straight Line Meter Rate. According to this energy rate the amount to be charged from the consumer depends upon the energy consumed in kWh which is recorded by a means of a kilowatt hour meter. It is expressed in the form

$$Y = EZ$$

This rate suffers from a drawback that a consumer using no energy will not pay any amount although he has incurred some expense to the power station due to its readiness to serve him. Secondly since the rate per kWh is fixed, this tariff does not encourage the consumer to use more power.

(3) Step Meter Rate. According to this tariff the charge for energy consumption goes down as the energy consumption becomes more. This tariff is expressed as follows.

$Y = EZ$ If $0 \leq Z \leq A$

$Y = E_1Z_1$ If $A \leq Z_1 \leq B$ $Y =$

E_2Z_2 If $B \leq Z_2 \leq C$

And so on. Where E, E_1, E_2 are the energy rate per kWh and A, B and C, are the limits of energy consumption.

4) Block Rate Tariff. According to this tariff a certain price per units (kWh) is charged for all or any part of block of each unit and for succeeding blocks of energy the corresponding unit charges decrease.

It is expressed by the expression

$$Y = E_1Z_1 + E_2Z_2 + E_3Z_3 + E_4Z_4 + ...$$

where E_1, E_2, E_3.... are unit energy charges for energy blocks of magnitude Z_1, Z_z, Z_g,.... respectively.

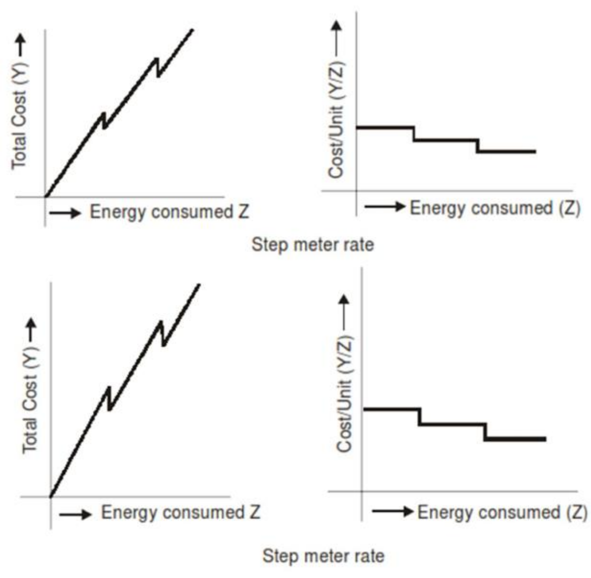


Fig. 4.2 Block Rate Tariff

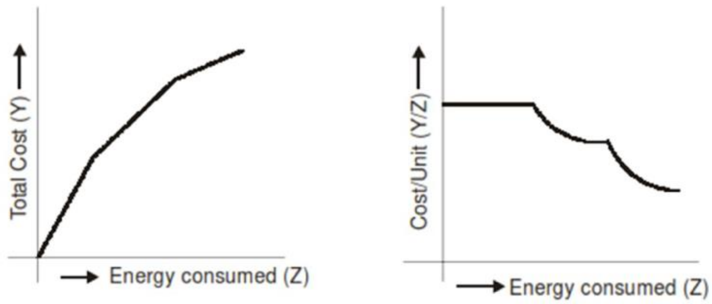


Fig. 4.3 Block Rate Tariff

5) Two Part Tariff (Hopkinson Demand Rate). In this tariff the total charges are based on the maximum demand and energy consumed. It is expressed as

$$Y = D \cdot X + EZ$$

A separate meter is required to record the maximum demand. This tariff is used for industrial loads.

(6) Three-Part Tariff (Doherty Rate). According to this tariff the customer pays some fixed amount in addition to the charges for maximum demand and energy consumed. The fixed amount to be charged depends upon the occasional increase in fuel price, rise in wages of labour etc. It is expressed by the expression

$$Y = DX + EZ + C$$

EFFECT OF PLANT TYPE ON FIXED ELEMENTS

Various types of fixed element are :

(1) Land

(2) Building

(3) Equipment

(4) Installation of Machine

(5) Design and planning

The fixed element means which are not movable, and for any types of power plant, the fixed elements play a major role. Since each cost is added to the final cost of our product (electricity in case of Power plant). So when a power plant is established, the first selection is fixed element.

Effect of plant on land is as cost of land.

EFFECT OF PLANT TYPE ON CUSTOMER ELEMENTS

The costs included in these charges depend upon the number of customers. The various costs to be considered are as follows:

(1) Capital cost of secondary distribution system and depreciation cost, taxes and interest on this capital cost.

(2) Cost of inspection and maintenance of distribution lines and the transformers.

(3) Cost of labour required for meter reading and office work.

(4) Cost of publicity.

ECONOMICS IN PLANT SELECTION

A power plant should be reliable. The capacity of a power plant depends upon the power demand. The capacity of a power plant should be more than predicted maximum demand. It is desirable that the number of generating units should be two or more than two. The number of generating units should be so chosen that the plant capacity is used efficiently. Generating cost for large size units running at high load factor is substantially low.

However, the unit has to be operated near its point of maximum economy for most of the time through a proper load sharing programme. Too many stand bys increase the capital investment and raise the overall cost of generation. The thermal efficiency and operating cost of a steam power plant depend upon the steam conditions such as throttle pressure and temperature. The efficiency of a boiler is maximum at rated capacity. Boiler fitted with heat recovering devices like air preheater, economiser etc. gives efficiency of the order of 90%. But the cost of additional equipment (air preheater economiser) has to be balanced against gain in operating cost. Power can be produced at low cost from a hydropower plant provided water is available in large quantities. The capital cost per unit installed is higher if the quantity of water available is small. While installing a hydropower plant cost of land, cost of water rights, and civil engineering works cost should be properly considered as they involve large capital expenditure. The other factor, which influences the choice of hydropower plant, is the cost of power transmission lines and the loss of energy in transmission. The planning, design and construction of a hydro plant is difficult and takes sufficient time.

The nuclear power plant should be installed in an area having limited conventional power resources. Further a nuclear power plant should be located in a remote or unpopulated are to avoid damage due to radioactive leakage during an accident and also the disposal of radioactive waste should be easy and a large quantity of water should be available at the site selected. Nuclear power becomes competitive with conventional coal fired steam power plant above the unit size of 500 mW. The capital cost of a nuclear power plant is more than a steam power plant of comparable size. Nuclear power plants require less space as compared to any other plant of equivalent size. The cost of maintenance of the plant is high.

The diesel power plant can be easily located at the load centre. The choice of the diesel power plant depends upon thermodynamic considerations. The engine efficiency improves with compression ratio but higher pressure necessitates heavier construction of equipment with increased cost. Diesel power plants are quite suitable for smaller outputs. The gas turbine power plant is also suitable for smaller outputs. The cost of a gas turbine plant is relatively low. The cost of gas turbine increases as the sample plant is modified by the inclusion of equipment like regenerator, reheater, and intercooler although there is an improvement in efficiency of the plant by the above equipment. This plant is quite useful for regions where gaseous fuel is available in large quantities.

In order to meet the variable load the prime movers and generators have to act fairly quickly to take up or shed load without variation of the voltage or frequency of the system. This requires that supply of fuel to the prime mover should be carried out by the action of a governor. Diesel and hydropower plants are quick to respond to load variation as the control supply is only for the prime mover. In a steam power plant control is required for the boilers as well as turbine. Boiler control may be manual or automatic for feeding air, feed water fuel etc. Boiler control takes time to act and therefore, steam powers plants cannot take up the variable load quickly. Further to cope with variable load operation it is necessary for the power station to keep reserve plant ready to maintain reliability and continuity of power supply at all times. To supply variable load combined working of power stations is also economical. For example to supply a load the base load may be supplied by a steam power plant and peak load may be supplied by a hydropower plant or diesel power plant.

The size and number of generating units should be so chosen that each will operate on about full load or the load at which it gives maximum efficiency. The reserve required would only be one unit of the largest size. In a power station neither there should be only one generating unit nor there a large number of small sets of different sizes. In steam power plant generating sets of 80 to 500 MW are quite commonly used whereas the maximum size of diesel power plant generating sets is about 4000 kW. Hydro-electric generating sets up to a capacity of 200 MW are in use in U.S.A.

ECONOMICS OF POWER GENERATION

Economy is the main principle of design of a power plant. Power plant economics is important in controlling the total power costs to the consumer. Power should be supplied to the consumer at the lowest possible cost per kWh. The total cost of power generation is made up of fixed cost and operating cost. Fixed cost consists of interest on capital, taxes, insurance and management cost. Operating cost consists of cost of fuel labour, repairs, stores and supervision. The cost of power generation can be reduced by,

(i) Selecting equipment of longer life and proper capacities.

(ii) Running the power station at high load factor.

(iii) Increasing the efficiency of the power plant.

(iv) Carrying out proper maintenance of power plant equipment to avoid plant breakdowns.

(v) Keeping proper supervision as a good supervision is reflected in lesser breakdowns and extended plant life.

(vi) Using a plant of simple design that does not need highly skilled personnel.

Power plant selection depends upon the fixed cost and operating cost. The fuel costs are relatively low and fixed cost and operation and maintenance charges are quite high in a case of a nuclear power plant. The fuel cost in quite high in a diesel power plant and for hydro power plant the fixed charges are high of the order of 70 to 80% of the cost of generation. Fuel is the heaviest items of operating cost in a steam power station. A typical proportion of generating cost for a steam power station is as follows:

Fuel cost = 30 to 40%

Fixed charges for the plant = 50 to 60%

Operation and maintenance cost = 5 to 10%

The power generating units should be run at about full load or the load at which they can give maximum efficiency. The way of deciding the size and number of generating units in the power station is to choose the number of sets to fit the load curve as closely as possible. It is necessary for a power station to maintain reliability and continuity of power supply at all times. In an electric power plant, the capital cost of the generating equipment's increases with an increase in efficiency. The benefit of such increase in the capital investment will be realized in lower fuel costs as the consumption of fuel decreases with an increase in cycle efficiency. Fig. 4.4 shows the variation of fixed cost and operation cost with investment.

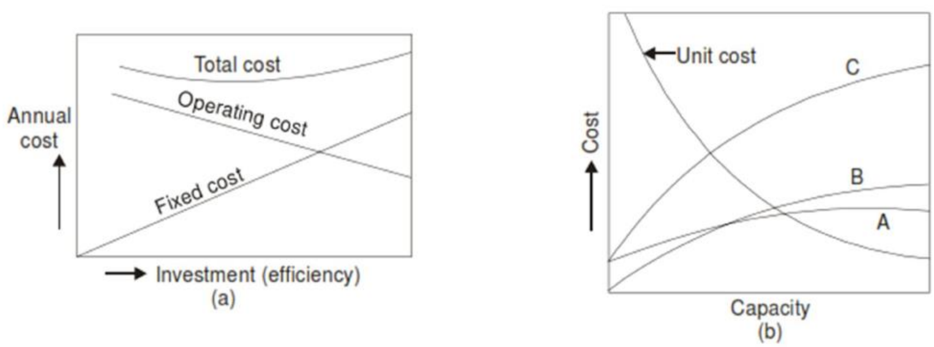


Fig. 4.4 Variation of Fixed Cost

LOAD CURVES

The load demand on a power system is governed by the consumers and for a system supplying industrial and domestic consumers, it varies within wide limits. This variation of load can be considered as daily, weekly, monthly or yearly. Typical load curves for a large power system are shown in Fig. 4.5.

These curves are for a day and for a year and these show the load demanded by the consumers at any particular time. Such load curves are termed as “Chronological load Curves”. If the ordinates of the chronological load curves are arranged in the descending order of magnitude with the highest ordinates on left, a new type of load curve known as “load duration curve” is obtained. Fig. 3.6 shows such a curve. If any point is taken on this curve then the abscissa of this point will show the number of hours per year during which the load exceeds the value denoted by its ordinate. Another type of curve is known as “energy load curve” or the “integrated duration curve”. This curve is plotted between the load in kW or MW and the total energy generated in kWh. If any point is taken on this curve, abscissa of this point show the total energy in kWh generated at or below the load given by the ordinate of this point. Such a curve is shown in Fig. 5.5. In Fig. 6(*b*), the lower part of the curve consisting of the loads which are to be supplied for almost the whole number of hours in a year, represents the “Base Load”, while the upper part, comprising loads which are required for relatively few hours per year, represents the “Peak Load”.

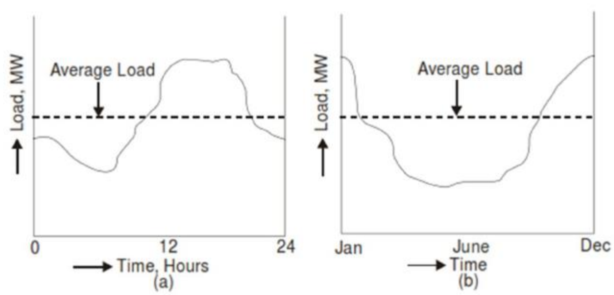


Fig. 4.5 Chronological Load Curves (a) Daily Load Curve (b) Yearly Load Curve.

IDEAL AND REALIZED LOAD CURVES

From the standpoint of equipment needed and operating routine, the ideal load on a power plant would be one of constant magnitude and steady duration. However, the shape of the actual load curve (more frequently realized) departs far from this ideal, (Fig. 4.6). The cost to produce one unit of electric power in the former case would be from 1/2 to 3/4 of that for the latter case, when the load does not remain constant or steady but varies with time. This is because of the lower first cost of the equipment due to simplified control and the elimination of various auxiliaries and regulating devices. Also, the ideal load curve will result in the - improved operating conditions with the various plant machines (for example turbine and generators etc.) operating at their best efficiency. The reason behind the shape of the actual realized load curve is that the various users of electric power (industrial, domestic etc.) impose highly variable demands upon the capacity of the plant.

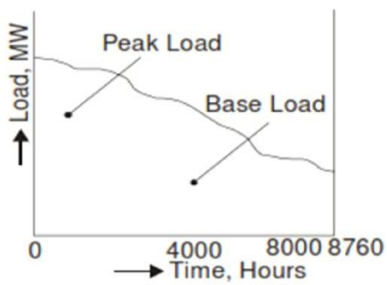


Fig. 4.6. Load Duration Curve.

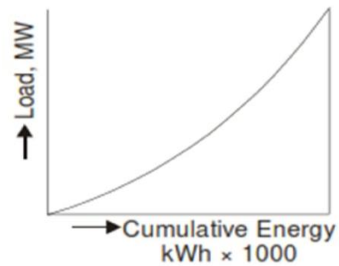


Fig. 4.7. Energy Load Curve.

EFFECT OF VARIABLE LOAD ON POWER PLANT DESIGN

The characteristics and method of use of power plant equipment is largely influenced by the extent of variable load on the plant. Supposing the load on the plant increases. This will reduce the rotational speed of the turbo-generator. The governor will come into action operating a steam valve and admitting more steam and increasing the turbine speed to its normal value. This increased amount of steam will have to be supplied by the seam generation. The governor response from load to turbine is quite prompt, but after this point, the governing response will be quite slower. The reason is explained as given below:

In most automatic combustion control systems, steam pressure variation is the primary signal used. The steam generator must operate with unbalance between heat transfer and steam demand long enough to suffer a slight but definite decrease in steam pressure. The automatic combustion controller must then increase fuel, air and water flow in the proper amount. This will affect the operation of practically every component of auxiliary equipment in the plant. Thus, there is a certain time lag element present in combustion control. Due to this, the combustion control components should be of most efficient design so that they are quick to cope with the variable load demand.

Variable load results in fluctuating steam demand. Due to this it become, very difficult to secure good combustion since efficient combustion requires the co-ordination of so many various services. Efficient combustion is readily attained under steady steaming conditions. In diesel and hydro power plants, the total governing response is prompt since control is needed only for the prime mover. The variable load requirements also modify the operating characteristics built into equipment.

Due to non-steady load on the plant, the equipment cannot operate at the designed load points. Hence for the equipment, a flat-topped load efficiency curve is more desirable than a peaked one. Regarding the plant units, if their number and sizes have been selected to fit a known or a correctly predicted load curve, then, it may be possible to operate them at or near the point of maximum efficiency. However, to follow the variable load curve very closely, the total plant capacity has usually to be sub-divided into several power units of different sizes. Sometimes, the total plant capacity would more nearly coincide with the variable load curve, if more units of smaller unit size are employed than a few units of bigger unit size.

Also, it will be possible to load the smaller units somewhere near their most efficient operating points. However, it must be kept in mind that as the unit size decreases, the initial cost per kW of capacity increases. Again, duplicate units may not fit the load curve as closely as units of unequal capacities. However, if identical units are installed, there is a saving in the first cost because of the duplication of sizes, dimensions of pipes, foundations, wires insulations etc. and also because spare parts required are less.

EFFECT OF VARIABLE LOAD ON POWER PLANT OPERATION

In addition to the effect of variable load on power plant design, the variable load conditions impose operation problems also, when the power plant is commissioned. Even though the availability for service of the modern central power plants is very high, usually more than 95%, the public utility plants commonly remain on the “readiness-to-service” bases. Due to this, they must keep certain of their reserve capacity in “readiness-to-service”. This capacity is called “spinning reserve” and represents the equipment standby at normal operating conditions of pressure, speed etc.

Normally, the spinning reserve should be at least equal to the least unit actively carrying load. This will increase the cost of electric generation per unit (kWh). In a steam power plant, the variable load on electric generation ultimately gets reflected on the variable steam demand on the steam generator and on various other equipment. The operation characteristics of such equipment are not linear with load, so, their operation becomes quite complicated. As the load on electrical supply systems grow, a number of power plants are interconnected to meet the load. The load is divided among various power plants to achieve the utmost economy in the whole system. When the system consists of one base load plant and one or more peak load plants, the load in excess of base load plant capacity is dispatched to the best peak system, all of which are nearly equally efficient, the best load distribution needs thorough study and full knowledge of the system.

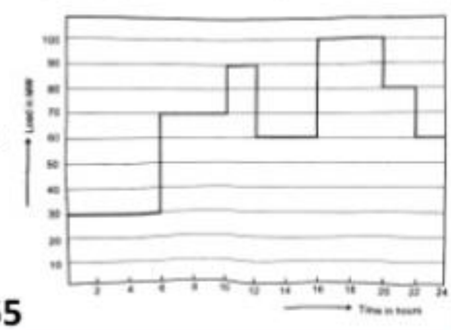
NUMERICAL PROBLEMS RELATED TO ECONOMICS OF POWER PLANT

A power station supplies the following loads are necessary to the customers

Time hours	0 – 6	6 – 10	10 – 12	12 – 16	16 – 20	20 – 22	22 – 24
Load (MW)	**30**	**70**	**90**	**60**	**100**	**80**	**60**

Find 1) Draw the load curve & Estimate the load factor of the plant
2) What is the load factor of a standby equipment of 30 MW capacity if it takes up all loads above 70 MW   3) What is its Use factor ?

Solution



Energy Generated = **Area under the curve**

$= 30 \times 6 + 70 \times 4 + 90 \times 2 + 60 \times 4 + 100 \times 4 + 80 \times 2 + 60 \times 2$

$= 1560$ MWh

Load factor $= \frac{AVERAGE\ LOAD}{PEAK\ LOAD}$, Average Load $= \frac{1560}{24}$ **= 65 MW**

Maximum Demand = 100 MW, Load factor $= \frac{65}{100} = \mathbf{0.65}$

Load Factor of a Standby Equipment

The standby equipment's supplies the power at three situations (more than 70 MW)

90 – 70 = 20 MW for 2 hours, 100 – 70 = 30 MW for 4 hours, 80-70 = 10 MW for 2 hours

Energy Generated = **Area under the curve** $= 20 \times 2 + 30 \times 4 + 10 \times 2 = 180$ MWh

Total Operation hours for standby equipment = 2 + 4 + 2 = 8 hours

Average Load $= \frac{180}{8}$ **= 22.5 MW, Load factor** $= \frac{22.5}{30} = \mathbf{0.75}$

Use Factor $= \frac{Energy\ produced\ in\ a\ given\ period}{Capacity\ of\ the\ plant \times Actual\ number\ of\ hours\ the\ plant\ in\ operation} = \frac{180}{30 \times 8} = \mathbf{0.75}$

The maximum demand of a power station is 96000 kW & daily load curve is described as follows

Time hours	0 – 6	6 – 8	8 – 12	12 – 14	14 – 18	18 – 22	22 – 24
Load (MW)	48	60	72	60	84	96	48

(i) Determine the load factor of power station

(ii) What is the load factor of standby equipment rated at 30 MW that takes up all load in excess of 72 MW? Also calculate its Use factor.

Solution

Energy Generated = **Area under the curve** = $48 \times 6 + 60 \times 2 + 72 \times 4 + 60 \times 2 + 84 \times 4 + 96 \times 4 + 48 \times 2$
= 1632 MWh

Load factor = $\frac{AVERAGE\ LOAD}{PEAK\ LOAD}$, Average Load = $\frac{1632}{24}$ = **68 MW**

Maximum Demand = 96000 kW = 96 MW, **Load factor** = $\frac{68}{96}$ = **0.71**

Load Factor of a Standby Equipment

The standby equipment's supplies the power at two situations (more than 72 MW)

84 – 72 = 12 MW for 4 hours, 96 – 72 = 24 MW for 4 hours

Energy Generated = **Area under the curve** = $12 \times 4 + 24 \times 4$ = 144 MWh

Total Operation hours for standby equipment = 4 + 4 = 8 hours

Average Load = $\frac{144}{8}$ = **18 MW, Load factor** = $\frac{18}{24}$ = **0.75**

Use Factor = $\frac{Energy\ produced\ in\ a\ given\ period}{Capacity\ of\ the\ plant \times Actual\ number\ of\ hours\ the\ plant\ in\ operation} = \frac{144}{30 \times 8}$ = **0.6**

A peak load on the thermal power plant is 75MW. The loads having maximum demands of 35MW, 20MW, 15MW & 18MW are connected to the power plant. The capacity of the plant is 90MW and annual load factor is 0.53. Calculate the average load on power plant, energy supplied per year, demand factor and Diversity factor.

Given

Max. demand or Peak load = 75 MW, Capacity of the plant = 90 MW, Annual Load factor = 0.53

Solution

Load factor = $\frac{AVERAGE\ LOAD}{PEAK\ LOAD}$, **0.53** = $\frac{AVERAGE\ LOAD}{75}$, **Average Load = 39.75 MW**

Energy Supplied per Year = Average load × Number of hours in one year
= 39.75 × 365 × 24 = 348210 MWh

Demand Factor = $\frac{MAXIMUM\ LOAD}{CONNECTED\ LOAD} = \frac{75}{35+20+15+18}$ = **0.85**

Diversity Factor = $\frac{SUM\ OF\ INDIVIDUAL\ MAXIMUM\ DEMANDS}{MAXIMUM\ DEMAND\ OF\ THE\ WHOLE} = \frac{35+20+15+18}{75}$ = **1.17**

The following data for a 2200 kW diesel power station is given. The peak load on the plant is 1600kW and its load factor is 45%. Capacity cost / kW installed = Rs.15000, Annual costs = 15% of capital, Annual Maintenance cost = Fixed Rs. 1,00,000 and Variable cost Rs.2,00,000, annual operating cost = Rs.6,00,000. , Cost of Fuel = Rs.0.8 per kg, Cost of lubricating oil = Rs. 40 per kg, C.V of Fuel = 40,000 kJ/kg, Consumption of fuel = 0.5 kg/kwh, Consumption of Lubricating oil = 1/400 kg/kwh. Determine (a) the annual energy produced (b)cost of generation per kwh (c) Efficiency

Solution

Capital Cost = Rs. 15,000 / kW

Capital cost of 2200 kW plant = 15,000 × 2200 = **Rs. 33 × 10^6^**

Annual cost = 15 % of Capital = $\frac{15}{100} \times 33 \times 10^6$ = **Rs. 4.95 × 10^6^**

Load Factor = $\frac{AVERAGE\ LOAD}{PEAK\ LOAD}$, $0.45 = \frac{AVERAGE\ LOAD}{1600}$, **Average Load = 720 kW**

Average Load = $\frac{TOTAL\ ENERGY}{TIME\ PERIOD}$, **Total energy produced** = 720 × 365 × 24 = **6.31×10^6 kWh**

Consumption of fuel = 0.5 kg/kwh
Fuel cost = Rs.0.8 per kg
For 6.31×10^6 kWh,
Mass of Fuel = $0.5 \times 6.31 \times 10^6$ = **3.154×10^6 kg**
Fuel cost = $0.8 \times 3.154 \times 10^6$ = **Rs. 2.523×10^6**

Consumption of Lubricating oil = 1/400 kg/kwh
Cost of lubricating oil = Rs. 40 per kg
For 6.31×10^6 kWh,
Mass of Lubricating oil = $(1/400) \times 6.31 \times 10^6$
= **15775 kg**
Lubri. oil cost = 0.40 × 15775 = **Rs. 0.631×10^6**

The following data for a 2200 kW diesel power station is given. The peak load on the plant is 1600kW and its load factor is 45%. Capacity cost / kW installed = Rs.15000, Annual costs = 15% of capital, Annual Maintenance cost = Fixed Rs. 1,00,000 and Variable cost Rs.2,00,000, annual operating cost = Rs.6,00,000. , Cost of Fuel = Rs.0.8 per kg, Cost of lubricating oil = Rs. 40 per kg, C.V of Fuel = 40,000 kJ/kg, Consumption of fuel = 0.5 kg/kwh, Consumption of Lubricating oil = 1/400 kg/kwh. Determine (a) the annual energy produced (b)cost of generation per kwh (c) Efficiency.

Solution

Continued from previous slide

Fixed cost = Annual cost + Annual maintenan. fixed cost = $4.95 \times 10^6 + 1,00,000$ = **Rs. 5.05×10^6**

Variable cost = $6,00,000 + 2,00,000 + 2.523 \times 10^6 + 0.631 \times 10^6$ = **Rs. 3.954×10^6**

Total Cost = Fixed cost + Variable cost = $5.05 \times 10^6 + 3.954 \times 10^6$ = **Rs. 9.004×10^6**

Cost of Power = $\frac{Total\ Cost}{Energy\ Produced} = \frac{9.004 \times 10^6}{6.31 \times 10^6}$ = **Rs. 1.43**

Efficiency = $\frac{Output}{Input}$

kW.sec = k($\frac{J}{S}$).S = kJ

Output power = E = 6.31×10^6 **kWh** = $6.31 \times 10^6 \times 3600$ = **2.2716×10^{10} kW-sec = kJ**

Input Power = m' × CV = $3.154 \times 10^6 \times 40,000$ = **1.2626×10^{11} kJ**

$$\eta = \frac{2.2716 \times 10^{10}}{1.2626 \times 10^{11}} = 0.18 = 18\%$$

Example 2.1. *A power station has a maximum demand of 80×10^3 kW and daily load curve is defined as follows :*

Time (hours)	*0-6*	*6-8*	*8-12*	*12-14*	*14-18*	*18-26*	*22-24*
Load (MW)	*40*	*50*	*60*	*50*	*70*	*80*	*40*

(*a*) *Determine the load factors of power station.*

(*b*) *What is the load factor of standby equipment rated at 25 MW that takes up all load in excess of 60 MW ? Also calculate its use factor.*

Solution. (*a*) Load curve is shown in Fig. 2.19. Energy generated (area under the load curve)

$$= 40 \times 6 + 50 \times 2 + 60 \times 4 + 50 \times 2 + 70 \times 4 + 8 \times 4 + 40 \times 2$$

$$= 1360 \text{ MWh} = 1360 \times 10^3 \text{ kWh.}$$

$$\therefore \text{ Average load} = \frac{1360 \times 10^3}{24} = 56{,}666 \text{ kW.}$$

Maximum demand $= 80 \times 10^3$ kW.

$$\text{Load Factor} = \frac{\text{Average load}}{\text{Max. demand}} = \frac{56{,}666}{80{,}000} = 0.71. \text{ Ans.}$$

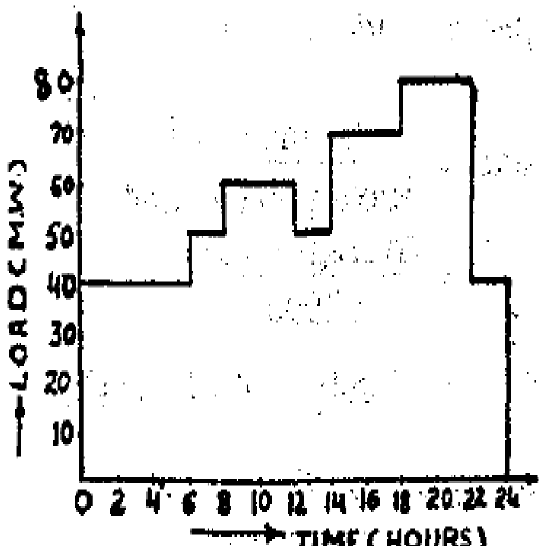


Fig. 2.19

(*b*) Now the standby equipment supplies

10 MW (70 – 60 = 10) for 4 hours

and 20 MW (80 – 60 = 20) for 4 hours.

∴ Energy generated by standby equipment

$$= (10 \times 4 + 20 \times 4) \times 10^3 = 120 \times 10^3 \text{ kWh}$$

Time for which standby equipment remains in operation (from the load curve) = 8 hours

$$\text{Average load} = \frac{120 \times 10^3}{8} = 15 \times 10^3 \text{ kW.}$$

$$\text{Load factor} = \frac{15 \times 10^3}{20 \times 10^3} = \mathbf{0.75.} \quad \textbf{Ans.}$$

$$\text{Use factor} = \frac{E}{C \times t_1}$$

where E = Energy generated

C = Capacity of the standby equipment.

t_1 = Number of hours the plant has been in operation.

$$\therefore \text{ Use factor} = \frac{120 \times 10^3}{25 \times 10^3 \times 8} = \mathbf{0.6.} \quad \textbf{Ans.}$$

Example 2.4. *The annual peak load on a 30 MW power station is 25 MW. The power station supplies loads having maximum demands of 10 MW, 8.5 MW, 5 MW and 4.5 MW. The annual load factor is 45%.*

Find :

(*a*) *Average load,*
(*b*) *Energy supplied per year,*
(*c*) *Diversity factor,*
(*d*) *Demand factor.*

Solution. Capacity of power station = 30 MW

Maximum demand on power station = 25 MW

(*a*) $\text{Load factor} = \dfrac{\text{Average load}}{\text{Maximum demand}}$

$\therefore$ Average load = 0.45 × 25 = 11.25 MW.

(*b*) Energy supplied per year

$= \text{Average load} \times \text{Number of hours in one year}$

$= (11.25 \times 1000) \times 8760 = 98.55 \times 10^6$ kWh.

(*c*) Diversity factor

$$= \frac{\text{Sum of individuals maximum demands}}{\text{Simultaneous maximum demand}}$$

$$= \frac{10 + 8.5 + 5 + 4.5}{25} = \frac{28}{25} = 1.12$$

(*d*) Demand factor of power station

$$= \frac{\text{Maximum demand}}{\text{Connected load}} = \frac{25}{10 + 8.5 + 5 + 4.5} = \frac{25}{28} = 0.89.$$

Example 2.5. *For a power station the yearly load duration curve is a straight line from 30,000 to 4,000 kW. To meet the load three turbo-generator are installed. The capacity of two generators is 15,000 kW each and the third is rated at 5,000 kW. Determine the following :*

(*a*) *Load factor,*
(*b*) *Capacity factor or plant factor,*
(*c*) *Maximum demand.*

Solution. As shown in Fig. 2.20 the load curve is a straight line from 30,000 to 4,000 kW

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

From the given load duration curve.

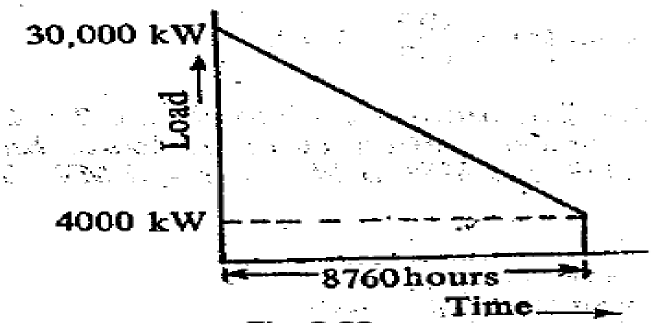


Fig. 2.20

Energy generated per year

$$= \text{Area under the curve}$$

$$= 4000 \times 8760 + \frac{1}{2} \times 8760 \times 2600$$

$$= 8760\,(4000 + 13{,}000) = 8760 \times 17{,}000 \text{ kWh}$$

$$= \frac{\text{Energy generated per year}}{8760}$$

$$\text{Average load} = \frac{8760 \times 17000}{8760} = 17{,}000 \text{ kW}$$

Maximum demand = 30,000 kW.

$$\text{Load factor} = \frac{17{,}000}{30{,}000} = 0.57 = 57\%$$

$$\text{Capacity factor} = \frac{\text{Energy produced}}{\text{Capacity of plant} \times \text{Time}}$$

Capacity of plant = 15,000 + 15,000 + 5,000 = 35,000 kW

$$\text{Capacity factor} = \frac{8760 \times 17{,}000}{35{,}000 \times 8760} = \frac{17{,}000}{35{,}000} = 0.49 = 49\%.$$

Example 2.6. *A power station has two 60 MW units each running for 7000 hours a year and one 30 MW unit running for 1500 hours a year. The energy produced per year is 700×10^6 kWh. Calculate the following :*

(*a*) *Plant load factor*

(*b*) *Plant use factor or utilisation factor.*

Solution. (*a*) Total capacity of power plant,

$$C = 60 + 60 + 30 = 150 \text{ MW} = (150 \times 1000) \text{ kW}.$$

$$\text{Average load} = \frac{700 \times 10^6}{8760} \text{ kW}.$$

(8760 being the number of hours in one year)

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

(Assuming power stations capacity equal to maximum demand)

$$= \frac{700 \times 10^6}{8760 \times 150 \times 1000} = 0.53 = 53\%. \quad \textbf{Ans.}$$

(*b*) Actual energy generated = 700×10^6 kWh.

Energy that could be generated by two 60 MW units and one 30 MW units ,

$$= 2 \times 60 \times 7000 + 30 \times 1500 = 84 \times 10^4 + 45 \times 10^3$$

$$= 88.5 \times 10^4 \text{ MWh} = 88.5 \times 10^4 \times 10^3 \text{ kWh}$$

$$= 885 \times 10^6 \text{ kWh}$$

$$\therefore \text{ Plant use factor} = \frac{700 \times 10^6}{885 \times 10^6} = 0.79 = 79\%. \quad \textbf{Ans.}$$

Example 2.8. *A power station is to supply three region of load whose peak loads are 20 MW, 15 MW and 25 MW. The annual load factor is 50% and the diversity factor of the load at the station is 1.5. Determine the following :*

(*a*) *Maximum demand on the station,*

(*b*) *Installed capacity suggesting number of unit,*

(*c*) *Annual energy supplied.*

Solution. (*a*) Diversity factor

$$= \frac{\text{Sum of individual maximum demand}}{\text{Simultaneous maximum demand}}$$

∴ Simultaneous maximum demand

$$= \frac{\text{Sum of individual maximum demand}}{\text{Diversity factor}}$$

$$= \frac{20 + 15 + 25}{15} = 40 \text{ MW.}$$

Hence maximum demand on station = 40 MW.

(*b*) Installed capacity of the plant can be taken equal to sum of individual maximum demand.

∴ Installed capacity = 20 + 15 + 25 = 60 **MW.**

Two units each of capacity 30 **MW** can be installed.

(*c*) Load factor $= \frac{\text{Average load}}{\text{Maximum demand}}$

Average load = Load factor × Maximum demand

$$= 0.5 \times 40 \times 1000 = 20 \times 1000 \text{ kW.}$$

∴ Energy produced per year

$$= 20 \times 1000 \times 8760 = 175.2 \times 10^6 \text{ kWh.}$$

Example 2.9. *A power station is said to have a use factor of 47% and capacity factor of 40%. How many hours did it operate during the year.*

Solution. Let E = Energy produced

C = Capacity of plant

t_1 = Number of hours the plant has been in operation

t = 8760 hours (number of hours in an year)

$$0.47 = \frac{E}{C \times t_1} \qquad ...(i)$$

$$0.40 = \frac{E}{C \times 8760} \qquad ...(ii)$$

Dividing (*ii*) by (*i*), we get

$$\frac{0.40}{0.47} = \frac{E}{C \times 8760} \times \frac{C \times t_1}{E} = \frac{t_1}{8760}$$

$$t_1 = \frac{0.40 \times 8760}{0.47} = 7455 \text{ hours.}$$

ENVIRONMENTAL HAZARDS OR ISSUES CAUSED BY POWER PLANTS

STEAM POWER PLANT POLLUTANTS

The thermal power plants burning conventional fuels (coal, oil, gas) contribute to air pollution in a large measure. The influence of thermal power plants on the surroundings is determined by their ejection of flue gases, heat and contaminated waste waters. Though thermal power plants are not among the worst contaminants of water basins in terms of scope and composition of their liquid wastes, their discharge into water basins can cause great harm if proper means are not taken for water protection. power plants are follows:

1) CO
2) CO_2
3) SO_2
4) Nitrogen oxides such as Nitric oxide (NO), Nitric dioxide (NO_2)
5) Dust
6) Fly ash

With incomplete combustion of fuel in furnaces, carbon monoxide (CO), hydro carbons CH4, C2H4 etc. are produced. The CO is injurious to human health as it combines with hemoglobin in the red blood corpuscles and thus interfere with their normal function of supplying oxygen to the blood tissues. The thermal power plants contribute substantially to CO2 emissions. CO2 has very harmful effect on atmospheric climate which could turn fertile land into deserts. Therefore the imply cations and control of CO2 need priority study. Sulphur dioxide (SO2) is the main pollutant from steam power plant. The primary source of SO2 in the atmosphere is the combustion of bituminous coal and residual oil fuel. Vegetables are most sensitive to the content of SO2 gas is associated with deterioration of the surfaces of leaves or needles due to destruction of their chlorophyll.

Nitrogen dioxide (NO2) and nitric oxide (NO) are often referred collectively as nitrogen oxides. Nitrogen oxides are toxic and produce a sharp irritating effect. People living in NO2 contaminated areas suffer from reduced respiratory function and have a higher incidence of respiratory diseases. Acid rains are another menace caused by the thermal power plants. Three main constituents of flue gases which mainly effect acidity of rains are SO2 and nitrogen oxides. In the atmosphere SO2 is fairly readily converted into sulphuric acid (H2SO4) whereas the nitrogen oxides get converted into nitric acid (HNO3). During rainy season the acid formed in the atmosphere falls on the ground in the form of rain called acid rain. The effect of this rain is to increase the acidity of lake, well water and water of flowing rivers.

In general SO2 contributes about 60% of the acidity whereas nitrogen oxides contribute 35% carbon dioxide (CO2) also cause the rain to be acidic but to a very small extent.

Maximum permissible limit of nitrogen oxide is 0.05 to 0.1 ppm. The further detrimental effect of acid rains is the reduction of ground fertility and crops yield smoke, dust and fly ash carried by flue gases also produce injurious effects on human health. The quantity of ash. (Q) carried off by flue gases per kg of fuel burnt and taking into account unburnt carbon is found by the following formula

$$Q = K. \frac{W}{100}\left[1 + \frac{P}{100 - P}\right]$$

where K = Fraction of solid particles carried off from furnace with flue gases.

W = Ash content of working mass of fuel in %

P = Content of combustible in fly ash in %

The ash is also a problem as it also emits heat to the atmosphere as well as small particles of ash are carried by the air. Large quantity of heat discharged to the atmosphere also is a cause of pollution. Toxic substances contained in flue gases discharged from stacks of thermal power plants can produce harmful effects on the whole complex of living nature or the biosphere. The biosphere comprises the atmosphere layer near the earth's surface and upper layers of soil and water basins.

Depending on the type of fuel and capacity of boiler the ash collection from thermal power plants can be effected by the following devices:

(i) Ash collectors (ii) Fly ash scrubbers

(iii) Electro-static precipitators.

Fly ash. cinders, various gases and smoke discharged from the stack become atmospheric contaminants. Gases diffuse in all directions. The path followed by the fuel gases depends upon the thermal and dynamic properties of gases and wind flow past the stack.

The various variables affecting the area over which flue gases constituents will settle out are as follows:

(i) Stack height (ii) Stack exit gas velocity

(iii) Wind velocity (iv) Gas temperature

(v) Particle size (vi) Surrounding topography.

The combustible content of stack dust is important in pollution. Coarser particles settle closer to the plant. Flue gases dust quantity and quality depend on the type of fuel and burning equipment. The toxic substances like CO, CO2, SO2, SO3, NO2, ash, hydro carbons etc., contained in the waste gases may be harmful for vegetation, animals, water basins and people even in very low concentrations above the specified safe limits. It is therefore desirable to remove these toxic substances from flue gases as far as possible.

The control of the atmosphere at steam power plant is mainly aimed at minimising the discharge of toxic substances into the atmosphere. Environmental issues in power sector are of major importance in nor country due to the significance of electric power on the economic development process. Seventy percent of power generation in our country is coal based. The environmental impact of power production in general and coal based power production in particular are serious in terms of human health. Coal based power generation affects air, land and water resources. Emission of particulate matter, sulphur dioxide and oxides of nitrogen causes air pollution. Accumulation of ash at power stations pre-empts land and endangers both ground and surface water. The associated increase in coal production to meet the additional demand can degrade more land, deplete water resources and cause water pollution.

Control of Pollutants

The control of the atmosphere at thermal power plants is mainly aimed at minimising the discharge of toxic substances into the atmosphere. The task of preserving the purity of atmosphere and water basins is of national significance. Thermal power plants consume about more than 113 of all the fuel produced and thus can significantly affect the local environment and the whole biosphere. Large condensation plants are among the greatest sources of heavy ejections of contaminants into the atmosphere. The effects of particulate matter in the atmosphere surrounding steam power plant are many and varies. Adverse effects on health, climate and water basin are quite serious. Adverse health effects are associated with SO2 concentrations. Acid fall out in the form of acid rain is one of the more serious environmental hazards of increased concentrations of sulphur and nitrogen oxides in the atmosphere.

As regards thermal power plants the state of environment around them depends on the following:

(i) kind of fuel used,

(ii) organization of fuel combustions,

(iii) operation of dust collecting and gas cleaning plants,

(iv) devices used for ejection of flue gases into the atmosphere,

(v) the influence of thermal power on the surroundings is also determined by their ejection of flue gases, heat and contaminated waste waters.

During high temperature combustion of gaseous or liquid fuel the pollution of the atmosphere by solid particles, CO and SO2 can be kept minimum by suitable organization of the following:

(i) combustion process

(ii) burning gas with excess air

(iii) choice of proper length and diameter of furnace chamber

(iv) correct stabilization of flame.

It is necessary to minimize the emission of SO2 into the atmosphere from thermal power plants as its contribution to pollution is maximum.

Large amounts of air pollutants are produced with coal combustion than any other fuel.

Therefore research is continued on converting coal to cleaner and more convenient gaseous and liquid fuel.

The permissible maximum concentrations of SO2 at ground level are 0.05 to 0.08 ppm for 24 hours, 0.12-0.2 ppm for 1 hour and 0.1 - 0.5 ppm for five minutes. The maximum permissible limit of nitrogen oxide is 0.05 to 0.1 ppm.

Control of particulate matter

Particulate matter which is composed of smoke, dust and other solids made of wide variety of organics and metals contributes to undesirable climatic conditions, especially when combined with smoke (smog). Of the human causes, dust and ash that emanate from industrial processes, fossil power plants, and other combustion processes are the largest contributor, of which power plants contribute about one-third. Sulfur compounds are the largest contributors to particulate matter.

The effects of particulate matter in the atmosphere are many and varied. The major effects of particulate matter are: decreasing visibility, increasing soiling, corrosion, and health hazard that is a complex function of concentration and particle size. These effects the lungs and obstructs the respiratory passages, and thus results in respiratory illness and causes a large increase in the number of bronchitic patients.

Steam power plants generally use the following mechanical arrestors for the removal of solid particles:

(a) Fabric filters (1) Electro-static precipitators

It is economically feasible to obtain a high degree of pollution control over particles which are larger than 2 to 3 microns. About 95% of fly ash under 2 microns in diameter are difficult and costly to be removed. The particulate removal is the major problem (so far as cost is concerned) in power plants using pulverised fuel. Irrespective of all steps taken to remove the particulates from gases before going to stack, about 1% is always discharged to the atmosphere.

The particulates effects can be reduced by using the following:

(a) coal cleaning

(b) using improved electrostatic precipitator design

(c) to control the dust within allowable limit. It can be done by increasing the height of chimney so that the dispersion will be on the larger area thus reducing concentration.

Electrostatic precipitators are used to remove the dust particles from the flue gases. Details of electrostatic precipitator are given in the relevant Chapter. A combination of mechanical and electrostatic precipitators can remove more than 99.5% of the particulate matter from the effluent gases. Fly ash used to remove fly ash. A fly scrubber is explained in the relevant Chapter. Cinder catcher and cyclone dust collector are also explained in the Chapter. Furnaces burning coal in suspension (pulverised coal burners and spreader stokers) throw dust in the form of fly ash and collectors should be installed in the breeching to remove ash particles.

Smoky atmosphere is less healthful than smoke free atmosphere. Smoke has deadly effect on the vegetation principally because of sulphur products it carries. Smoke Corrodes metals and darkens paints. Fuels should be burnt completely to reduce quantity of dust particles in the flue gases.

CONTROL OF SO_2

Since conversion of a relatively small amount of SO_2 to SO_3 can lead to the formation of enough sulfuric acid to cause serious corrosion in boilers. This has been the cause of concern to combustion engineers. In the atmosphere, SO_2 is fairly rapidly converted into sulfuric acid and sulfates, it associates readily with particulate matter in the air, including rain drops. It reduces the productivity of forests and agricultural products. Acidity of certain rivers and lakes threatens to be hazardous to fish and animal life. Acid fall out in the form of acid rain is one of the more serious environmental hazards of increased concentrations of sulfur and nitrogen oxides in the atmosphere.

Solid fuels contain sulphur in the following three forms.

(i) as inclusions of pyrite (FeS_2)

(ii) sulphur in molecules of organic mass of fuel

(iii) sulphate sulphur (in sulphur salts of calcium and alkali metals)

SO_2 is one of the principal toxic component which may pollute the atmosphere substantially.

Following methods are used to reduce the quantity of sulphur dioxide (802) produced during combustion of fuel.

a) Desulphurisation of fuels

b) Decreasing the sulphur content in fuel is called desulphurisation process. This process can remove a substantial amount of sulphur from fuel.

Following three methods are used to remove sulphur from coal:

(i) Chemical treatment (ii) Froth flotation

(iii) Magnetic separation.

These processes leave the coal unchanged in form. In chemical treatment coal is leached with an aqueous solution of ferric sulphate at a temperature in the range of 90—130°C. In froth flotation process the coal is suspended in water through which air is bubbled. The air bubbles tend to attach themselves to the coal particles rather than to the mineral matter. The mineral waste falls to the bottom and is discharged.

In magnetic separation the finely crushed coal is passed through a strong magnetic field which removes pyrite (FeS_2) from coal. Coal itself is non-magnetic.

The sulphur from liquid petroleum fuels is generally removed by reaction with hydrogen gas in the presence of a catalyst at a moderately high temperature and pressure. Sulphur is converted into hydrogen sulphide which is then removed.

c) To use low sulphur fuels. To use low sulphur content fuels is the commercially proved means to control SO_2 emission into atmosphere.

d) Use of tall stakes. To prevent air pollution with SO_2 tall chimneys are used to disperse flue gases over larger area.

e) Cleaning of flue gases. Commonly the three methods used to remove SO, from the flue gases are as follows:

1. Wet scrubbing 2. Solid absorbent

3. Catalytic oxidation.

It is observed that to remove SO_2 from flue gases is more economical as compared to removing sulphur from coal. Methods used to prevent air pollution with SO_2 are different for gaseous, liquid and solid fuels. It is advisable to remove H_2S from natural gas before burning it.

The sulphur content of liquid fuels can be reduced by following ways subjecting the fuel to a high temperature either with the use of oxidants (gasification) or without them (pyrolysis).

The process of gasification is effected at a high temperature (900-1300°C) with a limited admission of oxygen.

Pyrolysis of fuel is carried out at 700-1000°C without an oxidant. Pyrolysis is effected by contacting atomised oil directly with a heat carrier which may be in either a stationary or moving state. The combustible gas thus produced is purified from sulphur compounds and other harmful impurities and used as pure power fuel. Pyrolysis of fuel oil, crude petroleum and heavy petroleum residues can also be made by using liquid heat carriers as fused salts, slags etc.

Wet Scrubber

Wet scrubber also called wet flue gas desulphurisation system uses lime stone in the form of an aqueous slurry. This slurry when brought in contact with the flue gas absorbs 802 in it. Fig. 9 shows schematically the wet lime stone scrubbing process. In this scrubber 502 of exhaust gases is absorbed and reacts chemically with water and lime stone to form products that are transferred from scrubber to tank. In reaction tank chemical reactions take place resulting in disposable precipitates. Make up slurry is added to the tank and scrubbing liquid is sent back to the scrubbing. The thickener receives a mixture of 5 to 15% suspended solids in water which are concentrated by sedimentation and removed to pond or land fill.

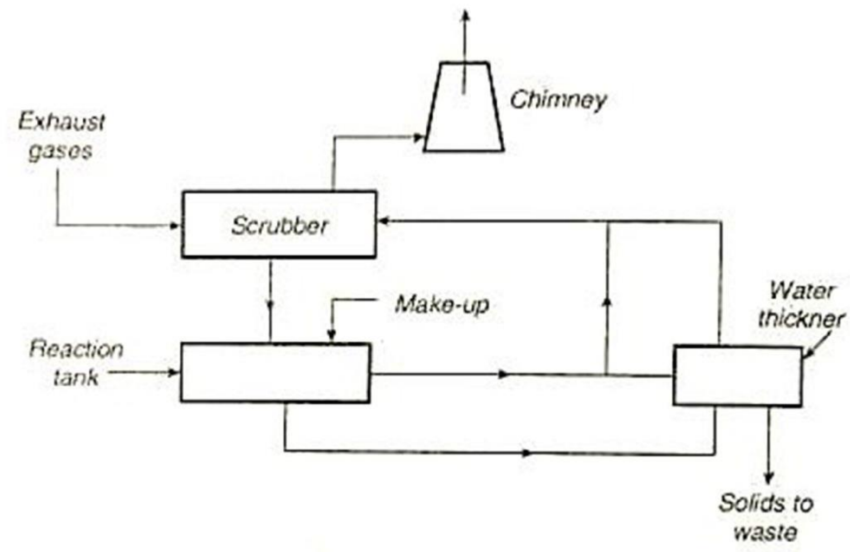


Fig 4.8 Wet Scrubber

In the scrubber following reactions take place.

Fig. 4.8 Wet lime stone scrubbing

$Ca(OH)_2 + SO_2 = CaS0_3 + H_2O$ Ca

$CO_3 + SO_2 = CaSO_3 + CO_2$

The calcium sulphite ($CaS0_3$) SO produced gets partially oxidised to calcium sulphate. In most of the cases products of neutralisation are not utilised but go to waste. Lime stone scrubbers are capable of removing up to 90% of SO_2 from the gases entering the scrubber which may have 0.2 to 0.3% SO_2.

Various advantages of wet scrubber are as follows:

(i) High efficiency

(ii) Low flue gas energy requirement

(iii) Good reliability.

The disadvantages are as follows:

(i) High capital and operating cost

(ii) Costly disposal problem for the waste material which is a water logged sludge.

Catalytic oxidation

It is used to produce sulphuric acid from dilute SO_2 in the flue gas. The sulphuric add is separated from flue gases.

Magnesium oxide scrubbing

In this process magnesium sulphate and sulphite salts are regenerated, producing a concentrated stream of SO2 and magnesium oxide (Mg0) for reuse in the scrubbing loop.

$$Mg0 + SO_2 = MgS0_3$$

The magnesium sulphite formed reacts further with SO2 and water to from magnesium bi-sulphite.

$$MgS0_3 + SO_2 + H_2O = Mg\ (HS0_3)_2$$

The latter is neutralised on addition of MgO.

$$Mg(HS0_3)_2 + Mg0 = 2Mg\ S0_3 + H_2O$$

Magnesium sulphite is calcined at 800-900°C and thus decomposed thermally into the original products as follows:

$$Mg\ SO_3 = Mg0 + SO_2$$

Mg0 is returned into the process whereas SO2 can be reprocessed into sulphuric acid. The principal disadvantage of this process is that it involves numerous procedures with solid substances. It causes abrasion wear of equipment and formation of much dust. Further much heat is needed for the drying of crystals and removal of hydrate moisture.

CONTROL OF NITROGEN OXIDES

Nitrogen dioxide (NO_2) and nitric oxide (NO) are often referred to collectively as nitrogen oxides. Plants using fossil fuels emit nitric oxide which gets oxidised into nitrogen dioxide. Nitrogen oxides possess high biological activity. Nitrogen oxides are poorly soluble in liquids and for that reason can penetrate deep into lungs and can cause harmful diseases.

People living in NO_2 contaminated areas may suffer from following:

(i) reduced respiratory function

(ii) higher incidence of respiratory diseases

(iii) exhibit certain changes in the peripheric blood.

Lower concentration of NO2 though being apparently harmless for plants can inhibit their growth. The combustion of fossil fuels in air is accompanied by the formation of nitric oxide (NO) which is partly oxidised to nitrogen dioxide (NO_2). The resulting mixture of variable composition is represented by the symbol NO_x where x has a value between 1 and 2. Nitrogen oxides (NO and NO_2) are present in flue gases produced by burning coal, oil and gas, in exhaust gases from internal combustion engines and turbines. NOx is formed in high temperature zones of combustion chamber from N_2 and O_2 of air. It is observed that usually up to about 1000°C the formation of NO from air is negligible but above 1000°C the amount increases with increasing temperature. The various methods commonly used to reduce to reduce the emission of NOx from steam Power plants and gas turbine power plant are as follows:

1. Reduction in temperature in combustion zone. By adjusting the combustion conditions to minimise the formation of nitric oxide. The obvious requirements are low combustion temperatures and use of low nitrogen fuels if possible. Although higher temperature during combustion of fuels produce less amount of CO but higher temperatures also lead to the formation of nitric oxide (NO). Therefore, the combustion temperature should be so adjusted that minimum amount of NO and CO are formed.
2. Reduction of residence time in combustion zone. This is the most promising method because reducing the time of residence of combustion products in high temperature zone not only reduces the formation of NO but also produces minimum amount of CO_2, SO_2 and hydrocarbons.
3. Increase in the equivalence ratio in the combustion zone. By carrying out combustion using equivalence ratio of 1.6 to 1.8 the amount of NOx produced can be reduced.

Pollution of biosphere by gaseous contaminants can be avoided by the following:

(i) By using fuel of proper quality

(ii) By cleaning fuel

(iii) By cleaning flue gases

(iv) By using stack of sufficient height for proper dispersion of effluents.

The global concern for the environment protection and pollution control has made it mandatory for most combustion plants to continuously monitor flue gases for pollutants like CO, NO, $S0_2$, and also measure 0_2, temperature, smoke density or dust concentration.
Analyser used for CO, NO and SO_2 and for the reference variable 0_2 may be microprocessor-controlled which feature automatic status monitoring.

CONTROL OF WASTE WATERS

The waste waters discharged from steam power plant pollute the water basin if the waste waters are not properly handled, The waste water discharge into the basins may be in the following forms.

(i) Single

(ii) Periodic

(iii) Continuous with constant flow rate

(iv) Continuous with variable flow rate

(v) Occasional

The most favourable mode of waste water discharged is that at which the maximum permissible (safe) concentration (WC) of impurities in the basin is not exceeded.

Steam Power Plants are the sources of following types of waste waters:

i. Cooling waters which mainly cause thermal contamination.
ii. Waste water of water treatment plants.
iii. Waters from hydraulic ash disposal systems.
iv. Used water after hydraulic cleaning of fuel conveying system.

v. Rain water collected on the territory of power plant.

Cooling waters of steam power plant carry an enormous amount of heat into water basins, waste waters of water treatment plants contain various neutral salts acids and alkalis which may affect water basin by changing pH value of water and by varying the salt concentration in water. The waste waters of hydraulic ash disposal systems should be discharged into water basin only when they contain no coarse particle substances.

Since waste waters usually contain a number of pollutants therefore waste waters should be purified before being discharged into water basins. Use of contaminated waste waters may harm agriculture, fishing industry etc.

Purification of waste waters is carried by number of methods. Some of the methods are as follows:

(a) Methods for direct separation of impurities

(i) Filtering (ii) Centrifuging

(iii) Floatation (iv) Settling and clarifying

(v) Micro straining through fine nets (iv) Coagulation

(b) Bio-chemical methods.

(c) Methods of impurity separation with a change in the phase state of water or impurity.

(d) Methods based on transformation of impurities.

All the waste water drains which individually though small finally add upto a fairly large quantity. The drains from coal handling area are likely to contain high level of suspended Particulate matter for which if required we may have to provide filters. The drains from fuel oil area should be ensured free from oil and grease, for which oil traps should be provided before they join other drains.

It is essential to take weekly samples from these channels for testing and any abnormalities are immediately controlled from source which can be identified. Further regular observations are necessary for any visible abnormalities to take immediate corrective action. In order to assess the impact of the total plant effluents to the surrounding water bodies sampling of surface water from the water body as well as ground water samples in the plant and ash pond surroundings are also necessary. This helps in identifying any adverse impacts of plant water effluents.

Ash Pond

Fly ash is a major solid discharge from the thermal power station Inch is the source of a major worry. The magnitude of the problem is a very huge considering the high ash content of Indian coal. Generally the ash is converted to slurry form and pumped to a large pond. Here the ash is allowed to settle and water should filter out. While the ash settles in the pond it is important to design the system in such a way that a large water sheet is maintained on the surface of the pond, without which the dry areas of pond will create a dust nuisance to the atmosphere. For preventing the ash particles flying, it is better to develop a thick green belt all around the ash dye well in advance. Further, the ash should be used in bricks, cement, road construction etc.

ACID RAIN

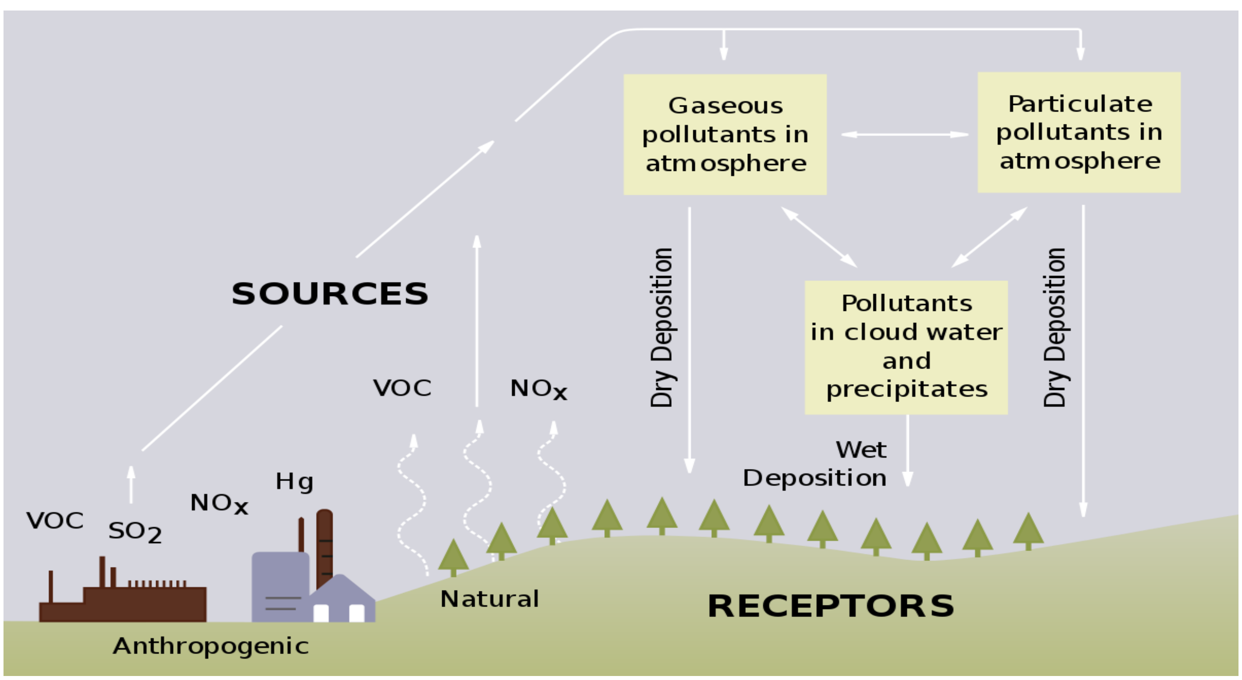


Fig 4.9 Sources of Acid Rain

Acid rain, or acid deposition, is a broad term that includes any form of precipitation with acidic components, such as sulfuric or nitric acid that fall to the ground from the atmosphere in wet or dry forms. This can include rain, snow, fog, hail or even dust that is acidic.

What Causes Acid Rain?

- Acid rain results when sulfur dioxide (SO2) and nitrogen oxides (NOX) are emitted into the atmosphere and transported by wind and air currents. The SO2 and NOX react with water, oxygen and other chemicals to form sulfuric and nitric acids. These then mix with water and other materials before falling to the ground.
- While a small portion of the SO2 and NOX that cause acid rain is from natural sources such as volcanoes, most of it comes from the burning of fossil fuels. The major sources of SO2 and NOX in the atmosphere are:
- Burning of fossil fuels to generate electricity. Two thirds of SO2 and one fourth of NOX in the atmosphere come from electric power generators.
- Vehicles and heavy equipment.
- Manufacturing, oil refineries and other industries.
- Winds can blow SO2 and NOX over long distances and across borders making acid rain a problem for everyone and not just those who live close to these sources.

ENVIRONMENTAL HAZARDS OF NUCLEAR POWER PLANTS

- Nuclear power has ZERO GHG emissions and ZERO air pollution during use.
- But, nuclear energy is responsible for some GHG emissions during manufacturing, transport, installation, and decommissioning – about 0.06 pounds of carbon dioxide equivalent gases per kWh of energy produced compared to 2 pounds per kWh for burning coal.

Water Usage

- Nuclear power can use large amounts of water, but some of this water is returned to its point of origin rather than evaporating, leaving about 400 gallons/MWh consumed in the production of electricity.

Other Impacts

- Land Usage: Like natural gas and coal burning plants, nuclear power plants consume very small amounts of land per electricity produced.
- While nuclear power plants release very small amounts of radiation into water and air surrounding the plants, the most serious environmental (and public health) threat imposed by nuclear energy is that of nuclear waste.
- In theory, nuclear waste can be stored safely in geological repositories (in the earth), but the extreme ecosystem and human health consequences of a leak or release of such waste makes it difficult to find a community willing to store it.

The Bottom Line

- When operating "normally", nuclear energy is safe, clean, and cost effective.
- However, environmental and health impacts can skyrocket during accidents – whether
- Those accidents occur at the nuclear power plants themselves or at waste facilities.

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – 5 – NON-CONVENTIONAL POWER GENERATION – SMEA1403

NON - CONVENTIONAL POWER GENERATION

Introduction

Power is the most important infrastructure input for the development and growth of economy of the country. The energy consumption in the world has been growing at an alarming rate. Fossil fuels, which today meet major part of the energy demand, are being depleted quickly. The stock of coal may not last longer than a few decades. The world has started running out of oil and it is estimated that 80% of the world's supply will be consumed in our lifetimes. The prices of fossil fuels will shortly become higher than any other source of energy option. Fossil fuels are not only depleting rapidly but the use of these fuels also leads to atmospheric carbon emission resulting in global warming. The renewable energy sources are expected to play an important role in solving the energy problems in decentralized locations, rural and remote areas in the years to come. Renewable energy not only augments energy generation but also helps in maintaining a pollution free environment. The harnessing of renewable sources of energy in India constitutes a small but rapidly growing industry. Since fossil fuel, which are main fuels for thermal power are getting exhausted eventually in the next few decades; other systems based on non-conventional and renewable sources are being encouraged. These are solar, wind, sea, geothermal and biomass. As discussed earlier, energy sources are W primary sources and (ii) secondary sources Primary sources are those which are available in nature in raw from, like coal, petroleum-oil, natural gas, wind, water at high level, uranium ore, solar radiation, geothermal fluid, ocean waves, ocean thermal fluid, ocean tides, biomass fuels etc. Thus primary sources include conventional and non- conventional (alternate), renewables and non-renewables. Secondary energy sources are usable energy and are supplied to the user for consumption. Electrical energy, steam, hot water, LPG in cylinders or pipe-lines etc., are the examples of secondary energy sources.

Renewable energy sources are those which are renewed by the nature again and again and their supply is not affected by rate of consumption. Wind energy, solar energy, geothermal energy, ocean wave, hydro energy etc., are the renewable energies. Alternative energy sources are those which are non-traditional. They are alternatives to the conventional energy sources. Today fossil fuel, nuclear and hydro-power sources are considered as conventional sources of energy, while others are non-conventional. The non-conventional sources including hydro power are the renewable sources of energy. Non-renewable energy resources are those which do not get replenished after their consumption e.g., coal once burnt is consumed without replacement of the same. Therefore, the resources which are formed very slowly in nature and which are likely to be exhausted in a few more decades or centuries are called non-renewable. Renewable energy sources like solar, wind, sea waves etc. cannot be stored in original natural form. It is converted continuously to electrical form, transmitted, distributed and utilized without long term storage. The renewables are available free of cost, hence, consumption of renewables should be maximized. This may help in conserving non- renewables for some more decades/centuries. In this book till now we have discussed conventional sources of energy, now;

The advantage of non-conventional energy sources are listed below:

i. Non-depletable

ii. No transmission and distribution losses.

iii. Environment friendly

iv. Low operation and maintenance cost

v. Low gestation

vi. Government provides lot of facilities and promotional measures, such as:

- 100 per cent accelerated depreciation.
- Five-year tax holiday
- Excise duty exemption
- Custom duty reliefs.
- Soft loans
- Power purchase policy by states
- State support

TYPES OF NON-CONVENTIONAL POWER PLANTS

The various non-conventional sources of energy are as follows:

1. Solar energy

2. Wind energy
3. Biomass and Bio-gas
4. Geo-thermal
5. Ocean thermal
6. Ocean wave
7. Tidal
8. Waste
9. Fuel cells
10. MilD (Magneto Hydro Dynamic) generator
11. Mini/Micro Hydro
12. Thermo-electric generation
13. Thermionic Converter

SOLAR ENERGY

Solar energy is a clean, cheap and abundantly available renewable energy. The heat and light radiated by the Sun are received by the earth which supports the environment through the following well known natural effects:

1. Temperature balance on the earth.
2. Photosynthesis by biological plants, production of oxygen and organic materials.
3. Wind due to unequal heating of water and land surfaces.
4. Water cycle i.e., Evaporation > Clouds - > rains ---> water - > evaporation.
5. Heating of ocean water. This gives Ocean Thermal Energy Conversion (OTEC).
6. Waves in Ocean. It gives ocean wave energy
7. Tides in ocean. These give ocean tidal energy.

The Sun produces enormous amount of heat and light through sustained nuclear fusion reactions. The solar energy received on earth in the form of radiation is used for heating and producing electrical energy. Since the Sun is expected to radiate at an essentially constant rate for a few billion years, it may be regarded as an inexhaustible source of useful energy.

India is endowed with a very vast solar energy resource. Most of the parts of the country have about 250-300 sunny days. There is an immense scope and potential for the use of solar energy viz., solar thermal and solar photovoltaic in India. A large number of solar energy applications for rural, remote areas and other applications have contributed in a significant way to the process of commercialization of solar energy products in India.

APPLICATIONS OF SOLAR ENERGY

Direct solar energy applications are discussed below:

1. Solar water heating.
2. Space heating.
3. Space cooling.
4. Solar distillation.
5. Solar pumping.
6. Agriculture and industrial process heat.
7. Solar furnace.
8. Solar cooking.
9. Solar production of hydrogen.
10. Solar green houses.
11. Solar electric power generation by —

(a) Thermal electric conversion using steam generators heated by reflectors.

(b) Photovoltaic electric conversion by using solar photovoltaic cells, which can be used for conversion of solar energy directly into electricity.

The heat from solar collectors is directly used for warming the living spaces of a building in conventional ways e.g., through radiators and hot air registers. When the building does not require heat, the warmed air or liquid from the collector can be moved to a heat storage container. In the case of air, the storage is often a pile of rocks or some other heat- holding material, in the case of liquid; it is usually a large well insulated tank of water which has considerable heat capacity.

Heat is also stored in containers of chemicals called eutectic or phase changing salts. These salts, which store large quantities of heat in a relatively small volume, melt when they are heated and release heat later as they cool and crystallize. When the building needs heat, the air or water from its heating system passes through the storage is warmed, and is then free through the conventional heaters to warm the space. For sunless days or cloudy days, an auxiliary system as a backup, is always required. This is true for solar cooling systems.

Solar thermal collector system gathers heat from the solar radiation and gives it to the heat transport fluid. The heat transport fluid receives the heat from the collector and delivers it to the thermal storage tank, boiler steam generator, heat exchanger etc. Thermal storage system stores heat for a few hours and the heat is released during cloudy hours and at night.

The solar thermal electric power plants are considered to be economically viable only in locations having favorable sunlight throughout the year and the fossil fuels /hydro resources etc., are not available in the vicinity.

The major drawbacks to the extensive application of solar energy are:

The intermittent and variable manner in which it arrives at the earth's surface, and the large area required to collect the energy at a useful rate. Experiments are under-way to use this energy economically for power production, house heating, air conditioning, cooking etc.

SOLAR RADIATION

The solar radiation that penetrates the earth's atmosphere and reaches the surface differs in bath amount and character from the radiation at the top of the atmosphere. In the first place, part of the radiation is reflected back into the space, especially by clouds. The radiation entering the atmosphere is partly absorbed by molecules in the air. Oxygen and ozone (O_3), formed from oxygen, absorb nearly all the ultraviolet radiation and water vapour and carbon dioxide absorb some of the energy in the infrared range. In addition, part of the solar radiation is scattered by droplets in clouds by atmospheric molecules, and by dust particles. Solar radiation that has not been absorbed or scattered and reaches the ground directly from the Sun is called "direct radiation" or "beam radiation" Diffuse radiation is that solar radiation received from the Sun after its direction has been changed by reflection and scattering by the atmosphere. Because of the solar radiation is scattered in all directions in the atmosphere, diffuse radiation comes to the earth from all parts of the sky. The total solar radiation received at any point on the earth's surface is the sum of the direct and diffused radiation. This is referred to in a general sense as the "insolation" at that point. Therefore, the insolation is defined as the total solar radiation energy received on a horizontal surface of unit area (e.g., 1 sq. m) on the ground in unit time (e.g., 1 day). Solar radiations can be converted directly or indirectly in the form of energy such as heat and electricity. Solar power would eliminate most of the serious environmental problems associated with fossil fuel and nuclear power. Energy is released by the Sun as electromagnetic waves of which 99% have wavelengths between 0.2 to 0.4 μ, where μ is micrometer. Solar energy reaching the top of earth's atmosphere consists of about 8% ultra violet radiation (short wave-length less than 0.39 μ), 46% visible light (0.39 to 0.78 μ) and 46% infrared radiation (long wave-length more than 0.78 μ).

Solar Radiation Measurement

Following two type of instruments are used for solar radiation measurement: (i) Pyrheliometer. It collimates the radiation to determine the beam intensity as a function of incident angle.

(ii) Pyronometer. It measures the total hemi-spherical solar radiation. The Pyronometer is quite popular.

Solar Constant

It is the rate at which solar energy arrives at the top of atmosphere. This is the amount of energy received in unit time on a unit area perpendicular to the sun's direction at the mean distance of the earth from the Sun. The rate of arrival of solar radiations vary throughout the year. According to National Aeronautics and Space Administration (NASA) the solar constant is expressed in following three ways.

(i) 1.353 kilowatts per square meter or 1353 watts per square meter.

(ii) (ii) 429.2 Btu per square foot per hour.

(iii) (iii) 1164 kcal per sq. m. per hour.

SOLAR THERMAL COLLECTORS (CONCENTRATORS)

Sunlight has low pressure density (0.1 kW/m2 to 1 kW/m^2), hence, very large surface area of the collectors is required for producing rated power of 1 MW. Efficiency of thermal collectors is very important. This depends on collector layout tracking, atmospheric clarity etc. Other important features of a solar collector system is concentration ratio and temperature range. Main types of solar thermal collectors are:

— Flat plate collectors.

— Concentrating collectors

(a) Line focusing collectors

(b) Point focusing collectors

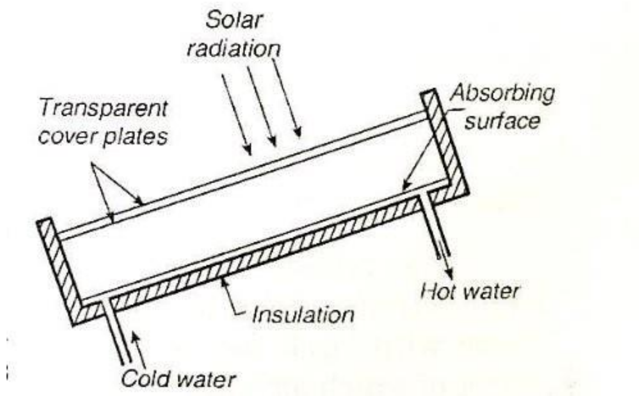


Fig. 5.1 Flat plate collectors

Flat Plate Collectors. A flat plate collector is shown in Fig. 5.1. Flat plate collectors are made in rectangular panels from about 1.7 to 2.9 sq. m in area and are relatively simple to construct and erect. Flat plates can collect and absorb both direct and scattered solar radiation they are thus partially effective even on cloudy days where there is no direct radiation.

The solar rays pass through transparent covers and fall on absorbing surface. The absorbing surface which is usually made of copper, aluminium, or steel coated with a heat resistant black (carbon) point intercepts and absorbs the solar radiation energy. Radiation energy is converted into heat and water flowing through the tubes gets heated. It is not possible to generate steam with plate collectors so this system cannot be used directly to run the prime mover. So some other organic fluid such as Freon- 14, 150 butane etc., which evaporate at low temperature and high pressure by absorbing heat from heated water. The vapours formed can be used to run the prime mover (turbine or engine) to generate power. Insulation is used to prevent loss of heat from the absorber and heat transporting fluid. The insulating materials commonly used are fiber glass or Styrofoam. Flat plate collectors are also called non-concentrating type. These collectors are classified as low temperature collectors because they can generate temperature less than 90 °C and have a collection efficiency of about 30 to 50%.

1. Concentrating Collectors.

Concentrating or focusing collectors are of two types:

(1) Line focusing collectors

(ii) Point focusing collectors.

Focusing collectors collect solar energy with high intensity of solar radiations on the energy absorbing surface. Such collectors generally use optical system in the form of reflectors or refractors and can heat the fluids up to about 500 °C. An important difference between collectors of non-focusing and focusing types is that the latter concentrate only direct radiation coming from a specific direction.

(i) Line Focusing Collectors.

Fig. 2 shows a parabolic trough collector. In this col-lector the solar radiations coming from a particular direction are collected over the area of the reflecting surface and is concentrated at the focus (F) of parabola. Mostly cylindrical parabolic concentrators are used in which absorber is placed along focus axis. Fig. 3 shows a typical cylindrical parabolic collector. It consists of parabolic cylinder reflector to concentrate sunlight on to a collecting pipe. The reflector is steered during day time to keep sunlight focused on the collector. This type of concentrator produces much higher temperature than flat plate collectors. The dimensions of parabolic trough collector or parabolic cylindrical collector can vary over a wide range, the length of a reflector unit may be above 3 to 5 m and width about 1.5 to 2.4 in. Ten or more such units may be connected end to end in a row, several rows being connected in parallel. Parabolic trough reflectors may be made from polished aluminium, silvered glass or a thin film of highly aluminised plastic on a firm base.

(b) Point Focusing Collector. Fig.4 shows a paraboloidal dish collector which bring solar radiation to a focus at a point. In this collector a dish 6.6 meter in diameter made from about 200 curved mirror segments forming a paraboloidal surface is used. The absorber located at the focus is a cavity made of a zirconium-copper alloy with a black chrome selective coating. The heat transport fluid flows into and out of absorber cavity through pipes bonded to the interior. The dish can be turned left and right and up and down so that Sun rays can be focused properly.

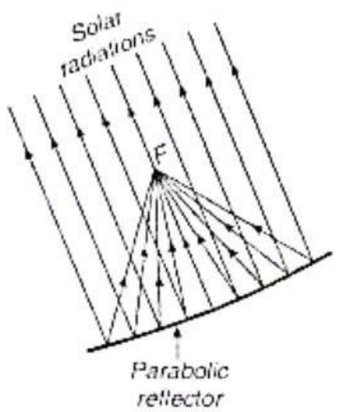


Fig. 5.2 Parabolic trough collector

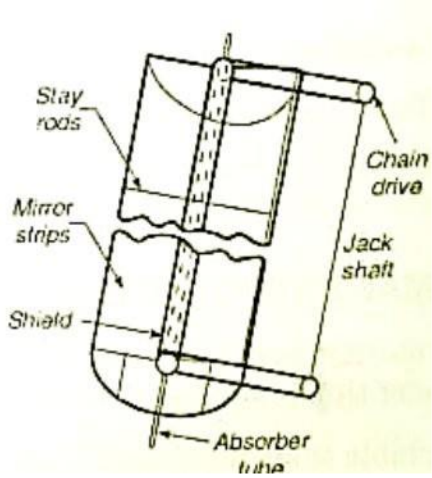


Fig. 5.3 Cylindrical parabolic collector

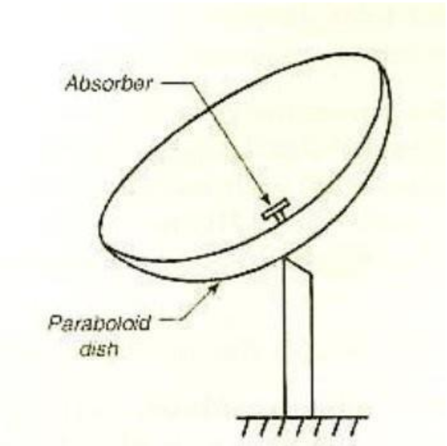


Fig. 5.4 Parabolic dish collector

Advantages and Disadvantages of Concentrating Collectors.

Concentrating collectors have the following advantages over flat collectors:

(i) Reflecting surfaces are structurally simpler and need less material.

(ii) Cost of collecting system per unit area is low.

(iii) The absorber arc of concentration is small and therefore, solar energy concentrated can produce more heat and therefore, working fluid can attain temperature for the same solar energy falling on the concentrator.

(iv) Since the temperature that can be attained with concentrating collector system is higher, the amount of heat which can be stored per unit volume is larger and consequently the heat storage costs are less for concentrator systems than for flat plate collectors.

(v) They have more efficiency.

Disadvantages

i. Diffused solar radiations cannot be focused and is lost.

ii. Initial cost is high.

iii. Costly orienting system for reflector to track the Sun is required.

THERMAL ENERGY STORAGE

Energy storage is essential with solar thermal energy systems and solar electrical power plant because of the following:

(i) Variable solar insolation.

(ii) Cloudy hours and night hours without solar insolation. (iii)Difference between solar energy supply curve and the load curve.

In electrical power systems, following methods of energy storage are being used/considered:

a) Battery storage for PV system.

b) Compressed air energy storage (CAES) is not economical for solar system.

c) Pumped hydro storage not economical for solar systems.

d) Superconducting Magnetic Energy Storage is not suitable for solar systems.

e) Thermal storage for solar thermal power plants.

f) Hydrogen-Fuel cell combination (Futuristic.)

The thermal energy collected during the sun shine is stored in the thermal storage system. The stored thermal energy is released during night and during cloudy hours. Solar thermal system should therefore be supplemented with additional energy supply system. Such systems are called 'Hybrid system' e.g., solar-Diesel Hybrid. In this, solar energy plants are operated in conjunction with a diesel generating set. Such plants are economical for remote, stand- alone plants rated up to 350 KW.

The solar thermal system may be operated in following three modes:

1) Energy Supply Mode (Collection Mode). During the energy supply mode thermal energy collected by the solar collector is supplied to the central receiver or the thermal reservoir. From there, it is supplied to the load.

2) Energy Storage Mode. During the energy storage mode, the thermal energy collected by the solar collectors is given to the storage tank. The material in the storage tank gets heated and stores the sensible heat. Excess energy collected by the system is stored.

3) Energy Release Mode. During the stored energy release mode, the stored thermal energy from the storage tank is released to the load.

Thus during cloudy days or at night, energy previously stored during high insolation times could be used to provide a continuous electrical output or thermal output. Thus the addition of storage can increase the reliability of being able to deliver power at an arbitrary needed time.

Thus storage of solar energy in a solar system may:

1. Permit solar energy to be captured when insolation is highest and then later used when the need is greatest.

2. Make it possible to deliver electrical load power demand during times when insulation is below, normal or non-existent. Storage also make possible to deliver short peaks of power for exceeding the rated power capacity of the plant.

3. Be located near the load, thereby minimizing the need for costly transmission and distribution facilities.

4. Improve the reliability.

5. Permit a better match between the solar energy input and the load demand output than would be the case without storage.

Solar energy storage systems may be broad y classified as shown in Fig 5

The heat transfer fluid, also known as primary coolant, is pumped through the collector piping. The thermal energy collected by the solar collectors is given to the heat transfer fluid. The heat transfer fluid flows from the collectors to the central receiver or storage tanks. Then heat transfer fluid may be same as the working fluid of the thermodynamic cycle or it may be different.

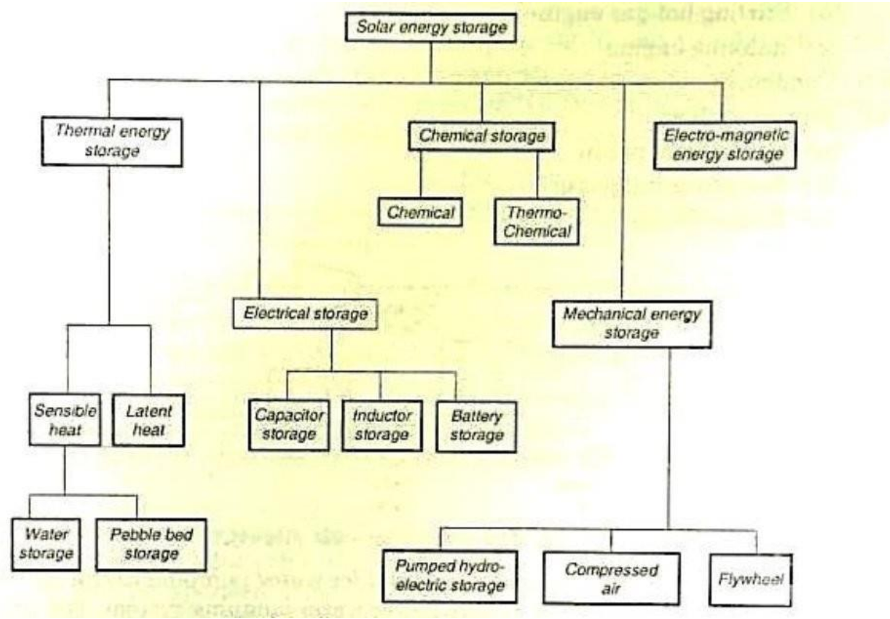


Fig. 5.5. Solar Energy Storage Systems Heat Transfer Fluid (Primary Coolant)

The following heat transfer fluids are common for practical solar thermal systems.

1. Water-steam

2. Liquid metals e.g., Sodium (Na). It has boiling point at 883° C and operating temperature at 540° C.

3. Molten Salts e.g., Nitrate salt mixtures.

4. Gases, such as air, nitrogen, helium.

5. Heat transfer oils

SOLAR PUMPING

The various parts of solar pumping system are as follows:

1. Solar collectors, such as (a) Flat plate collectors (b) Stationary concentrators.

2. Heat exchanger or Boiler

3. Heat engine such as (a)Brayton cycle as turbine (b)Stirling hot gas engine

(c) Rankine engine

4. Condenser

5. Pumps such as (a)Centrifugal pump (b)Reciprocating pump
(c) Rotary pump.

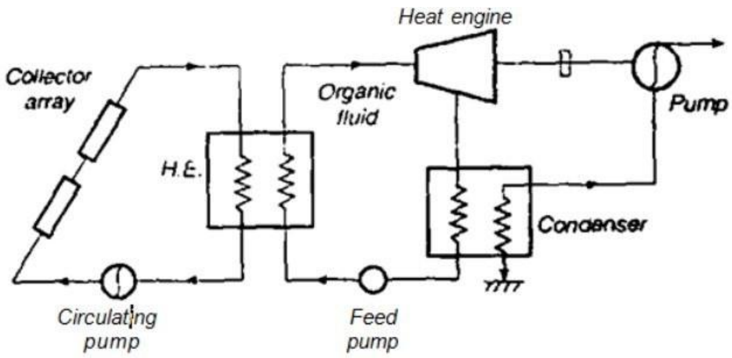


Fig. 5.6. Solar power water pumping

The power generated by solar energy is used for water pumping useful for irrigation purpose. Fig. 5.6 shows a typical solar energy power water pumping system. The primary components of the system are an array of flat plate collectors and Rankine engine with an organic fluid as the working substance. In this system a heat transfer fluid flows through the collector arrays. The fluid gets heated due to solar energy. The fluid (water) is then made to flow through a heat exchanger (boiler) where it transfers its heat to other fluid in the boiler. This other fluid then gets evaporated and expands in the engine before reaching the condenser. Some of the working fluid used in cycle are toluene (CP-25), Monochloro benzene (MCB), and trifluoro ethanol. The major obstacle to the increased use of solar irrigation system is its relatively high capital cost. H.E. in figure indicates heat exchanger.

SOLAR POWER GENERATION

Solar radiation can be converted into two principal forms of energy. One is the heat and the other is electricity. Heat is obtained when solar radiation is absorbed by a black surface.
The heat may be used in various Ways, which may be broadly divided into two categories.

(i) Direct thermal applications like water heating, cooking etc., known as solar thermal power generation.
(ii) (ii) Solar energy can be converted into electrical by solar thermal power generation route or solar radiation can be directly converted into electrical power.
In direct conversion of solar energy into electricity, we may employ photovoltaic, thermoelectric, thermionic and photo chemicals.

SOLAR THERMAL POWER GENERATION

Solar thermal power generation uses power cycles which are broadly classified as:

(i) Low temperature cycle.

(ii) Medium temperature cycle. (iii)High temperature cycle.

Low temperature cycles usually can be used up to 100°C and use flat plate collectors whereas medium temperature cycles are used for temperatures between 150 to 300°C and high temperature cycles are used for temperatures above 300°C. Two principal forms of energy into which solar radiations can be converted for practical applications are as follows:

(i) Heat

(ii) Electricity.

Heat is obtained when solar radiation is absorbed by a black surface. The heat then may use in two ways:

a) Direct thermal applications such as water heating, drying, cooking, distillation etc.

b) In direct conversion so solar energy into electricity using photo voltaic cells, thermo electric thermionic and photo chemicals. Photo voltaic effect is quite popular.

The mechanical power production is called *solar thermal power production system.* So far as conversion of solar energy into electrical energy is concerned it may be done either by solar thermal power production route or solar radiations can be directly converted into electrical power.

Low Temperature Systems. Fig 5.7 shows a low temperature thermal electric power generation scheme using solar pond. Hot water from pond enters an evaporator where the organic working fluid is vaporized. Then the vaporised organic fluid at high pressure enters a turbine and thereby expanding the turbine wheel to produce power.

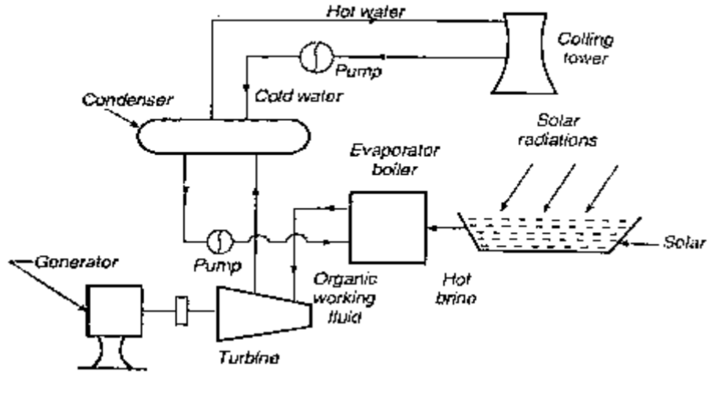


Fig. 5.7 Low Temperature System

The vapour now passes through a condenser where it is condensed to a liquid is pumped back to the evaporator where cycle is repeated.

Another type of low temperature solar power plant is shown is Fig. 5.8. This system uses an array of flat plate collectors to heat water to about 70°C and then in heat exchanger the heat of water is used to boil butane. The butane at high pressure is made to pass through a turbine. This scheme is quite commonly used for lift irrigation purposes.

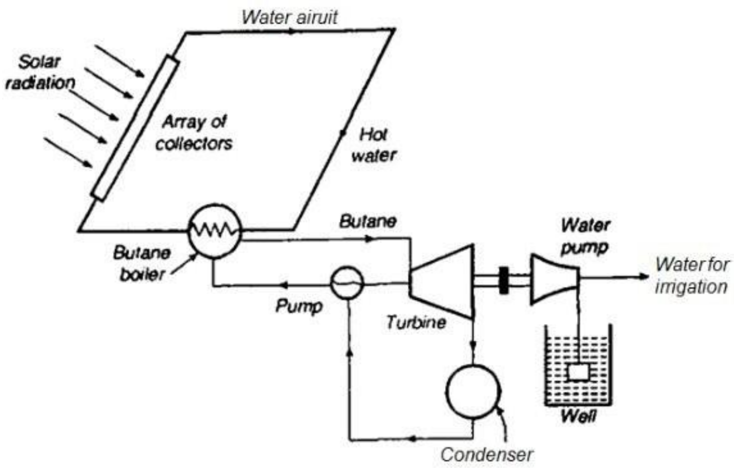


Fig. 5.8 Low temperature solar power plant High Temperature Systems

For efficient conversion of heat energy into mechanical energy and then into electrical energy, the working fluid should be supplied to the turbine at high temperature. To obtain such temperatures (above 175° C) from solar energy requires the use of focusing concentrating collectors. Since these collectors concentrate direct solar radiation, they would be most effective in locations where there is ample sunshine.

Two basic arrangements are used for converting solar radiation into electrical energy:

(a) The central receiver system, commonly known as "power tower".

(b) Distributed collector system.

(a) Tower Solar Power Plant. This type of power plant uses an array of plane mirrors or heliostats which are individually controlled to reflect radiation from the Sun into a boiler mounted on a tall (about 500 m high) tower. The steam is generated in the boiler. The steam may attain a temperature up to 2000°K. The steam so produced is used to drive a turbine coupled to a generator. Fig. 5.9 shows a tower concept type solar power plant.

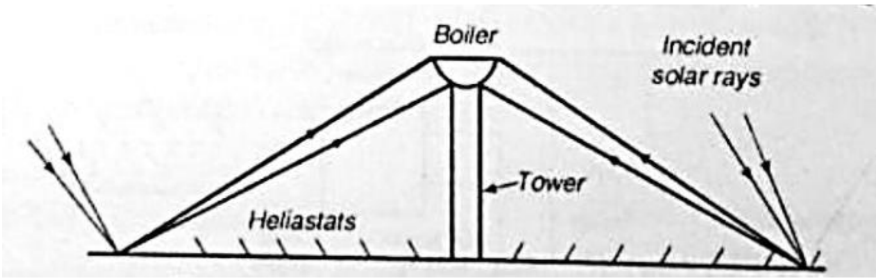


Fig. 5.9 Tower type solar power plant

Another type of solar power plant based on similar principle is shown in Fig 5.10. It uses an array of heliostats guided mirrors to focus sunlight into a cavity type boiler near the ground to produce high temperature high pressure steam which is used to drive a steam turbine. The solar rays striking the mirrored faces of heliostats modules are reflected and concentrated in the cavity of boiler.

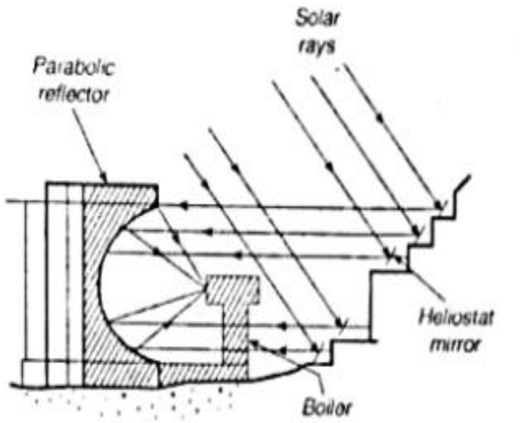


Fig. 5.10 Distributed Collector System

The distributed collector system or solar farms may consist of a number of parabolic trough type (line focusing) collectors or of parboiled dish type (point focusing) collectors. The absorber pipes (or receiver) of the individual collectors are connected so that all the heated fluid is carried to a single location where the electricity is generated. The basic difference between the central receiver and distributed collector system is that in the former the solar energy falling on a large area is transmitted to a central point as radiation, but in the latter, the energy is carried as heat in fluid. In the distributed collector system, heat collected by a fluid flowing through the pipes could be stored at a temperature over 500°C in a molten eutectic salt and used as required to produce steam for electric power generation.

PHOTOVOLTAIC (PV) CELLS OR SOLAR CELL

These cells directly convert solar energy to D.C. power. These cells are made of semiconductors that generate electricity when they absorb light. Solar cells made of single crystal silicon are commonly used as its theoretical efficiency of about 24%. But commercially available cells have an efficiency of about 10 to 12%. Gallium arsenide is another solar cell material. Cells of this material may achieve an efficiency of 20 to 25%. Solar cells made of gallium arsenide can retain efficiency at much higher temperature than cells made of silicon. The silicon cell consists of a single crystal of silicon into which a doping material is diffused to form a semi-conductor. The best known application of photovoltaic cells for electrical power generation has been spacecraft for which silicon solar cell is the most highly developed type.

Various advantages of solar cell are as follows:

(i)They need little maintenance (ii) they have longer life

(iii)They do not create pollution problem (iv) their energy source is unlimited (v) these are easy to fabricate

(vi) They can be made from raw materials which are easily available in larger quantities.

The disadvantages of solar cells are as follows:

(i) Compared with other sources of energy solar cells produce electric power at very high cost.

(ii) Solar cell output is not constant and it varies with the time of day and weather

(iii) They can be used to generate small amount of electric power.

Solar cells have also been used to operate irrigation pumps, navigational signal, highway emergency cell Systems, rail road crossing signals etc.

The most common configuration of a typical solar cell to form a p-n junction semiconductor is shown in Fig. 5.11.

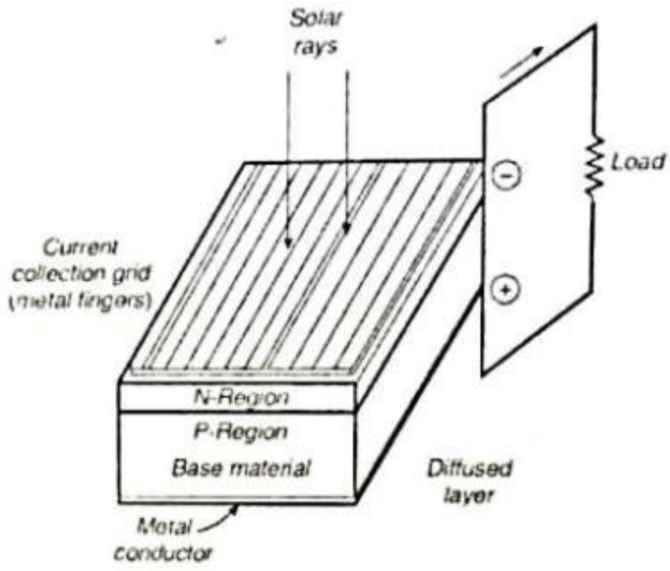


Fig.5.11 typical solar cell

WIND MILLS

Wind energy is used to run wind will which in turn drives a generator to produce electricity. A wind mill converts the kinetic energy of moving air into mechanical motion that can be either used directly to run the machine or to turn the generator to produce electricity. Various types of wind mills are as follows:

(i) Horizontal axis wind mills

(a) Multi blade type wind mill (b) Sail type wind mill

(c) Propeller type wind mill. (ii)Vertical axis wind mills

(a) Savionius type wind mill (b) Darrieus type wind mill.

Vertical axis wind mills are of simple design as compared to the horizontal axis.

Horizontal axis wind mills may be single bladed, double bladed or multi bladed.

Wind energy conversion devices are commonly known as wind turbines because they convert the energy of the wind stream into energy of rotation: the component which rotates is called rotor. The terms turbine and rotor are however often regarded as being synonymous. An electric generator is coupled to the turbine to produce electric power. The combination of the wind turbine and generator is sometimes called as an Aero Generator.

The fraction of free flow wind power than can be extracted by a rotor is called the power coefficient.

K = Power coefficient

$= P_1 / P_2$

Where P_1 = Power of wind rotor

P_2 = Power available in the wind.

The maximum theoretical power coefficient is 0.593. The mass of air is calculated as follow:

Q = Amount of air passing in unit time

= A x V

Where A = Area through which air passes V= Velocity of air

M = Mass of air traversing through area A swept by the rotating blades of wind mill type generator.

$$M=\rho.A.V$$

Where ρ = Density of air

K.E. = Kinetic energy of moving air=$1/2.M.V^2$

$$M=1/2.\ \rho.A.V.\ V^2 =1/2.\ \rho.A.V^3$$

P_2=Available Wind Energy

$$= \text{Kinetic Energy}=1/2.\ \rho.A.V^3$$

The physical conditions in a wind turbine are such that only a fraction of available wind power can be converted into useful work. The power available in the wind increases rapidly with the speed and hence Wind Energy Conversion (WEC) machines should be located preferably in areas where winds are strong and persistent. Wind turbine generators have been built having capacity ranging from a kilowatt or so to a few thousand kilowatts. Wind power has been successfully used for cooling of homes, space heating, for operating irrigation; navigational signals and for offshore drilling operations.

Figure 12 shows the various parts of a wind-electric generating power plant. They are

(i) Wind turbine or rotor

(ii) Wind mill head (iii)Generator

(iv) Supporting structure.

The wind mill head supports the rotor housing the rotor bearings. The moving air makes the blades to rotate and the electricity is produced at the generator. Part A indicated transmission; Speed increases. Drive shaft and bearing brake clutch and coupling.

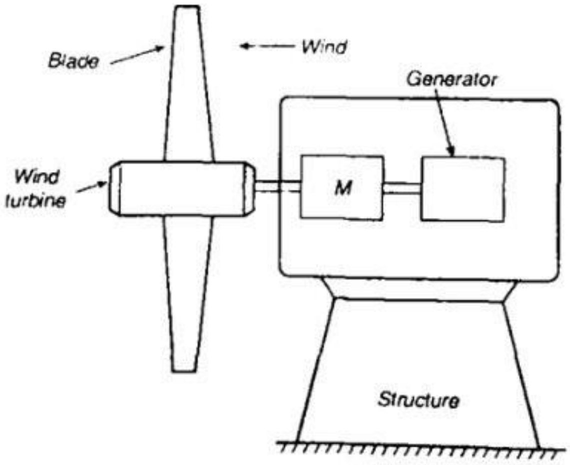


Fig. 5.12. Parts of a wind mill

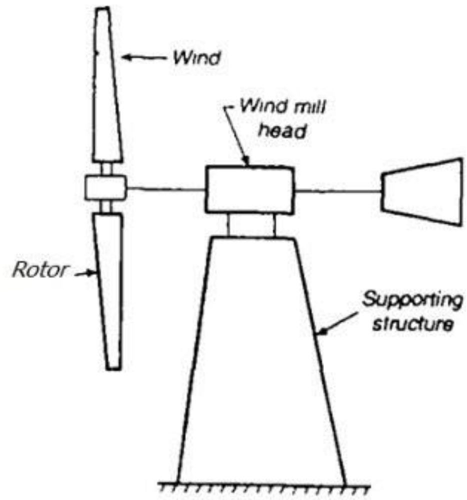


Fig. 5.13. Horizontal axis type wind mill.

Fig. 5.13 shows schematic arrangement of a horizontal axis type wind mill and Fig. 5.14 shows vertical axis type wind mill

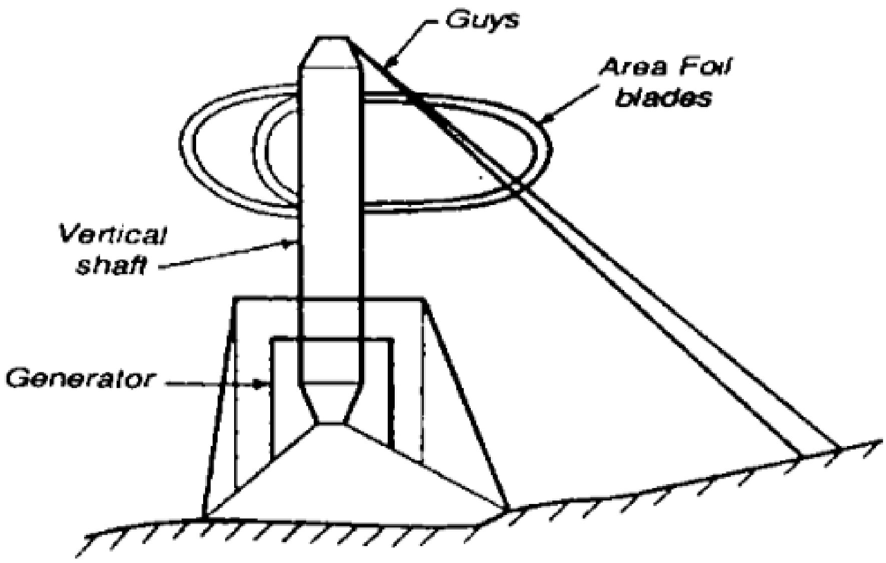


Fig. 5.14. Vertical axis type wind mill.

Basic Components of a Wind Energy Conversion System (WECS)

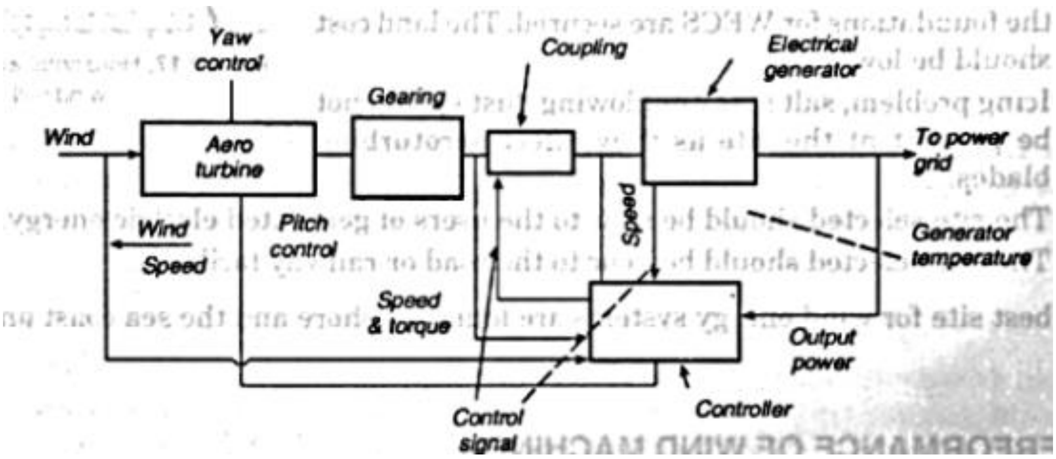


Fig 5.15 wind energy conversion system

Figure 5.15 shows the basic components of a wind energy conversion system. Figure 5.16 shows a horizontal axis multi blade type wind mill.

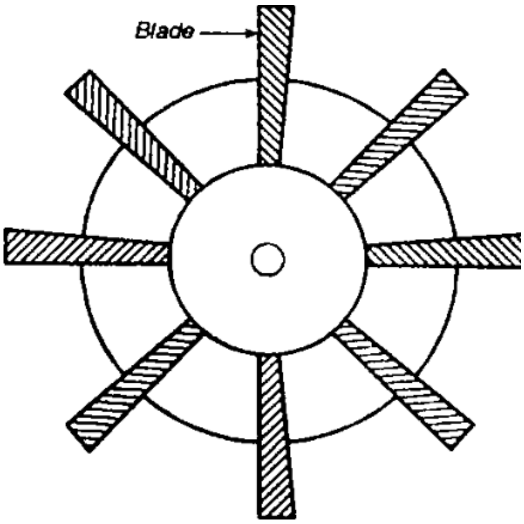


Fig. 5.16. Multi blade wind mill

The blades are made of metallic sheets. They have high starting torque and are economical. Aero turbines convert the wind energy to rotary mechanical energy. A mechanical interface consisting of a step up gear and a coupling transmits the rotary mechanical energy to an electrical generator. The output of generator is connected either to load or power grid. The purpose of controller is to sense wind speed, wind direction, shafts speeds and torques, output power and generator temperature. Figure 5.17 shows a horizontal axis wind mill Dutch type. The blades are made of wood.

Site Selection for Wind Mill Units

Following factors should be considered while locating Wind Energy Conversion Systems (WECS).

(i) Wind energy conversion machines should be installed at sites where winds are strong and persistent. The most suitable sites for wind turbines would be found where the annual average wind speeds are known to be moderately high. It is desirable to have average wind speed of about 3.5-4.5 m/sec which is the lower limit at which WECS generators start turning. An ideal site will be one where a smooth steady wind flows all the time.

(ii) It is desirable to install WECS at higher altitudes because the winds tend to have higher velocities at higher altitudes.

(iii) The ground conditions at the site should be such that the foundations for WECS are secured. The land cost should be low.

(iv) Icing problem, salt spray or blowing dust should not be present at the site as they affect aeroturbing blades.

(v) The site selected should be near to the users of generated electric energy.

(vi) The site selected should be near to the road or railway facilities.

The best site for wind energy systems are found off shore and the sea coast and at mountains.

TIDAL POWER

Ocean tidal power refers to the hydro energy in ocean tides. The ocean tides occur due to gravitational attractive forces from Sun and moon. The level of the ocean water rises periodically during high tides and drops during low tides. The difference in head of water during high tide and low tide is used for rotating hydro turbine-generator units installed within barrages (dams). The time span between high tide and next low tide is 6 hours and 25 minutes and the water head of high tide is 2 to 5 m or even more. In about 24 hours there are two high tides and two low tides. These are called as semiduirnal tides.

Ocean waves and tides contain large amount of energy. Such tides rise and fall and water can be stored during rise period and it can be discharged during fall. Due to low head of water available low head hydroelectric plants can work successfully Fig. 24 shows the schematic layout of a power plant using tidal power. These plants can utilise a head of just a few meters. During high tide the height of tide is above that of tidal basin and the turbine unit operates and generates power. During low tide the height of tide is lower than that of the tidal basin. At this time water is allowed to flow out to drive the turbine unit. The turbine unit does not operate if the tide sea level and basin level are equal.

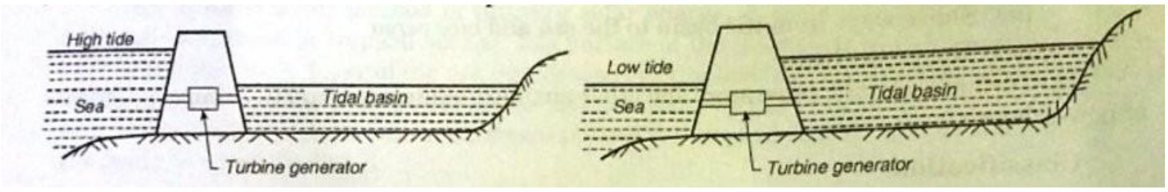


Fig. 5.17 layout of a power plant using tidal power

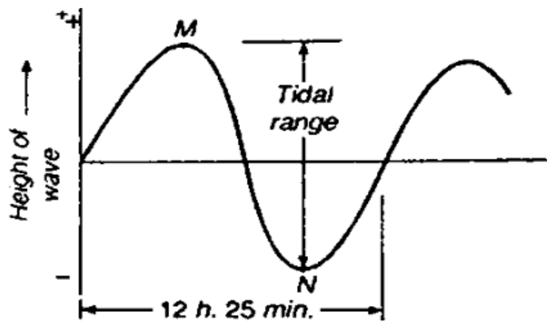


Fig. 5.18 Sinusoidal curve

In India the possible sites, identified for tidal power plants are as follows:

(i) Gulf of Cambay

(ii) Gulf of Kutch

(iii) Sunderban area in West Bengal.

The tidal range in the Gulf of Cambay is about 10.8 meter. Whereas the maximum range of Gulf of Kutch is 7.5 meter. The tidal range in Sunderban area is 4.3 meter. The rise and fall of water level follows a sinusoidal curve as shown in Fig. 5.18 with point M indicating the high tide point and point N indicating the low tide point. The difference between high and low water levels is called the range of the tide.

Advantages

The various advantages of tidal power plants are as follows:

(i) The power generated does not depend on rain. Therefore there is certainty of power supply as the tidal cycle is very definite.

(ii) The tidal power plants are free from pollution. (iii)Unhealthy wastes like ash, gases etc., are not produced. (iv)These plants require lesser space.

(v) Such plants have a unique capacity to meet the peak power demand effectively when they work in combination with hydro power plants and steam power plants.

Disadvantages

The various disadvantages of tidal power plants are as follows:

(i) The capital cost of a tidal power plant is considerably large as compared to steam power plant and hydro power plant.

(ii) The supply of water is not continuous as it depends upon the timing of tides.

(iii) Tidal power plants are located away from load centers. This increases power transportation cost.

Following are the important points for the selection of location of tidal power plant:

(i) The tidal range at the desired location should be adequate throughout the year. (ii)The site selected for tidal power plant should be free from the wave attack of sea. (iii)There should be no appreciable change in tidal pattern at the proposed site.

(iv)The site at which tidal power plant is to be located should not have excessive sediment load.

The three main components of a tidal power plant are as follows:

(i) The dyke to form basic or basin

(ii) Sluice ways from the basin to the sea and vice versa (iii) the power house.

The turbines, electric generators and other auxiliary equipment's are the main equipment's of power house.

Classification

Tidal power plants are classified on the basis of number of basin used for the power generation. They are further subdivided as one way or two way system as per the cycle of operation for power generation.

Various types of tidal power plants are as follows:

(i) 'Single basin system (a)One way system (b)Two way system

(c)Two way with pump storage.

(ii) Double basin system (a) Simple double basin system (b) Double basin with pumping.

Figure 5.19 shows a single basin one way tidal power plant. In this plant a basin is allowed to get filled during the flood tide and during the ebb tide, the water flowing. Single basin one way tidal power from the basin to the sea through the turbine and generates power. The power is available for a short duration during ebb tides.

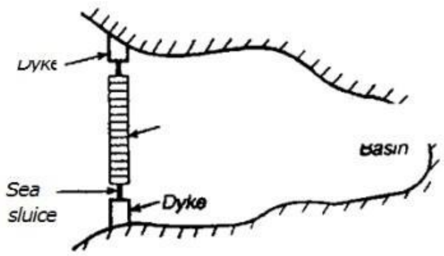


Fig. 5.19 Single basin one-way tidal power plant

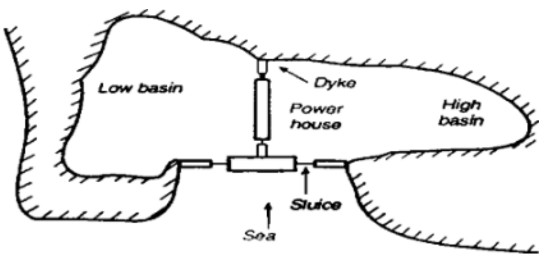


Fig. 5.20 Double basin one-way tidal power plant

In single basin two way tidal power plant the power is generated both during flood tide as well as ebb tide. The direction of flow through the turbines during the ebb and flood tides alternates but machine acts as a turbine for either direction of flow. Figure 5.20 shows a double one way tidal power plant. In this plant one basin in intermittently filled by flood tide and other is intermittently drained by ebb tide.

Regulation of Tidal Power Supply

The tidal power plant generates unregulation power from tides. Some of the methods which help to generate regular power from tidal power plants are as follows:

(i) Combining two or more tidal schemes with different tidal phases.

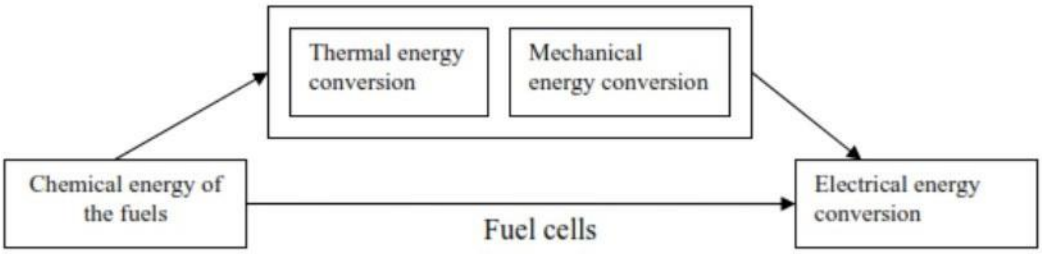
(ii) Providing two basins (one high and one low) having inter-connection with each other and with the sea.

(iii) To inter-connect tidal power plant with (a) steam power plant (b) pumped storage hydro power plant (c) hydro power plant.

Fuel cell

A fuel cell is an electrochemical cell, which can continuously and directly convert the chemical energy of a fuel and an oxidant to electrical energy by a process involving essentially electrode-electrolyte system. The basic principles of a fuel cell are those of the electrochemical batteries. The big difference is that, in the case of batteries, the chemical energy is stored in the substances located inside them. When this energy has been converted to electrical energy, the battery must be thrown away or recharged appropriately. In a fuel cell, the chemical energy is provided by a fuel and an oxidant stored outside the cell in which the chemical reactions take place. As long as the cell is supplied with the fuel and oxidant, electrical power can be obtained.

In direct fuel cell, hydrogen is fed directly as fuel at the cathode and it is further classified as low (25°C-100°C), intermediate (100°C-500°C), high (500°C-1000°C) and very high temperature (above 1000°C) fuel cells depending up on the temperature of operation. In the case of indirect fuel cell, the active fuel is obtained from a source and oxidized, example hydrogen obtained by hydrocarbon cracking. When fuel is reformed by using reformer internally or externally it is known as reformer fuel cells and when this conversion is carried out by bacteria, enzymes and algae it is known as biochemical fuel cell. In biochemical fuel cells, Sulphur containing compounds are biodegraded to form H_2S and O_2 containing wastes are biodegraded to form O_2, which is then used in this fuel cells. In regenerative fuel cells, fuel is used again and again through regeneration, which is done by an external agency. Energy is consumed in the regeneration. Fuel is regenerated from the products by thermal, electrical, photochemical or radiochemical methods. For practical reasons fuel cell systems are simply distinguished by the type of electrolyte used and following names and abbreviations are used: Proton Exchange Membrane Fuel Cells (PEMFC), Alkaline Fuel Cells (AFC), Direct Methanol Fuel Cells (DMFC), Phosphoric Acid Fuel Cells (PAFC), Molten Carbonate Fuel Cells (MCFC), and Solid Oxide Fuel Cell (SOFC). Subsequent classifications are discussed with the system. The fuel cells offer advantages and efficiency reliability and economy cleanliness unique operating characteristics planning flexibility and future development potentials.



Direct Energy conversion in Fuel cells compared to conventional indirect technology

CLASSIFICATION OF FUEL CELLS

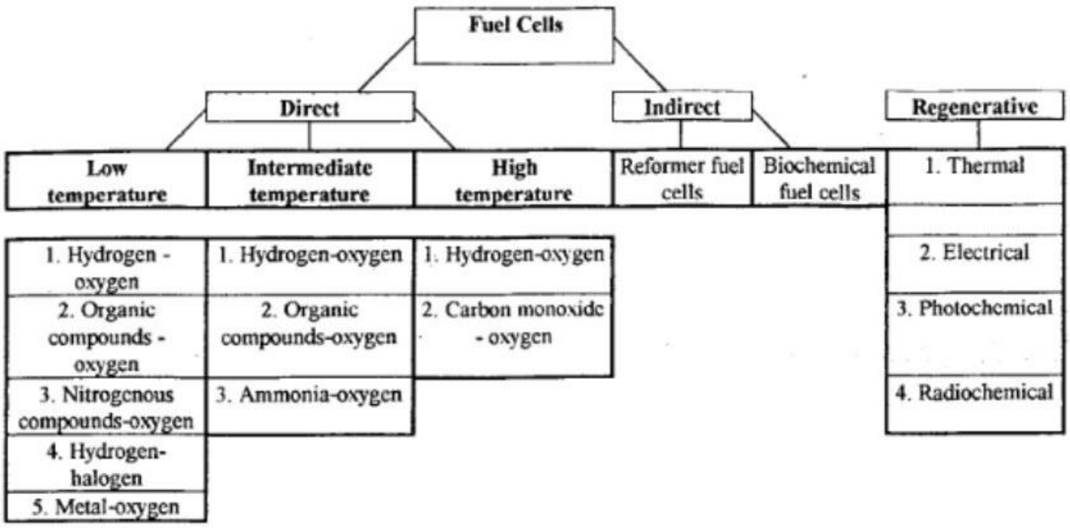


Fig. 5.21 Classification of fuel cells

Efficiency

Fuel cells can convert unto 90% of energy contained in its fuel into useable electric power and heat. Current PAFC designed offer 42% conversion efficiency. It is predicted that MCFC may achieve electrical efficiencies > 60%. As the fuel cells contain fewer moving parts they have higher reliability than ICE. They cannot experience a catastrophic breakdown as can occur with ICE when the rotating parts fail. The quiet electrochemical nature of fuel cell eliminates many of the noise associated with conventional energy systems. No ash or large volume wastes are produced from fuel cell operations. They are among the least hazardous methods of energy conversion due to their comparatively small size, the absence of a combustion engine. The electrochemical reaction of a fuel cell produces water as by product, the quantity being comparatively lower than conventional fossil fuel powered energy systems.

Proton Exchange Membrane Fuel Cell (PEMFC)

Proton exchange membrane fuel cells (PEMFCs) have reached the stage of being in the forefront among the different types of fuel cells. In 1950's Grubb suggested the use of ion-exchange polymeric membrane as the electrolyte for fuel cells. The membrane is nonpermeable to the reactant gases, hydrogen and oxygen but permeable to hydrogen ions, which are the current carriers in the electrolyte.

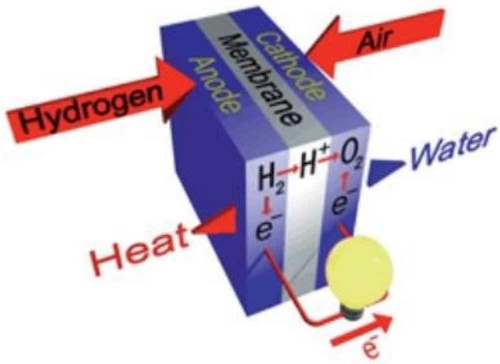


Fig. 5.22 Proton Exchange Membrane Fuel Cell

Electrochemical reaction occurring at the electrodes is as follows:

Anode: $H_{2(g)} \rightarrow 2H^{+}_{(aq)} + 2e^{-}$

Cathode: $\frac{1}{2}O_{2(g)} + 2H^{+}_{(aq)} + 2e^{-} \rightarrow H_2O_{(l)}$

Over all cell reaction: $H_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow H_2O_{(l)}$

Hydrogen from the fuel gas stream is consumed at the anode, yielding electrons and hydrogen ions, which enter the electrolyte. At the cathode, oxygen combines with electrons from the cathode and hydrogen ions from the electrolyte to produce water. Water does not dissolve in the electrolyte and instead it is carried out of the fuel cell by excess oxidant flow.

Alkaline Fuel Cell (AFC)

Alkaline Fuel Cells (AFC) were developed for space use in the 1960's because of their ability to operate over a wide temperature range. It consists of two porous electrodes with liquid KOH electrolyte between them. The hydrogen fuel is supplied to the anode electrode, while oxygen from air is supplied to the cathode. The working temperature ranges from 293 to 363K. The electrical voltage between the anode and the cathode of a single fuel cell is between 0.9 V and 0.5 V depending on the load and the electrochemical reactions taking place at these electrodes. The hydrogen is usually compressed and the oxygen is obtained from the air. It uses a circulating liquid alkaline electrolyte, potassium hydroxide (30-45% KOH). This is an effective heat transfer and water management medium. The fuel cell can produce power at ambient temperatures but is designed to deliver full power at about 343 K, which, with electrical heating, it will normally reach within 10 min of a cold start.

The cell reactions are as follows:

Anode: $H_{2(g)} + 2(OH)^{-}_{(aq)} \rightarrow 2H_2O_{(l)} + 2e^{-}$

Cathode: $\frac{1}{2}O_{2(g)} + H_2O_{(l)} + 2e^{-} \rightarrow 2(OH)^{-}_{(aq)}$

Over all cell reaction: $H_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow H_2O_{(l)}$

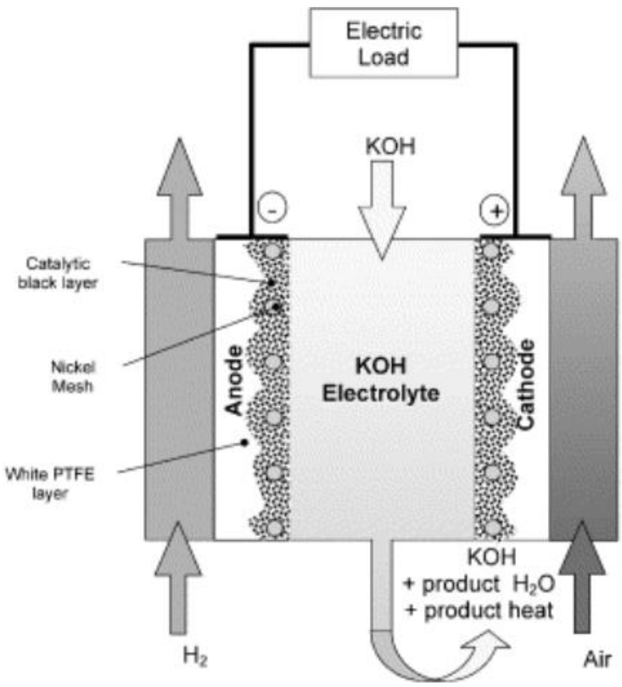


Fig. 5.23 Alkaline Fuel Cell

Direct Methanol Fuel Cells (DMFC)

DMFC is essentially the same as a PEMFC, but in DMFC, methanol is fed directly at the anode which does not require external reforming of the fuel, which leads to highly efficient, low cost and reduced size fuel cell. The operating voltages of systems using methanol directly is 100-200 mV lower than indirect hydrocarbon systems. Methanol permeates from the anode chamber across the membrane, adsorbs onto the cathode catalyst, and reacts with air (O2) resulting in parasitic loss of methanol fuel and reduced cell voltage at higher current densities. Methanol and water react electrochemically at the anode to produce carbon dioxide, protons and electrons. The protons produced migrate through the polymer electrolyte to the cathode where they react with oxygen to produce water. These reactions are promoted by the incorporation of platinum- based electro catalyst materials in the electrodes. Methanol oxidation, which is irreversible, is a six-electron process and the product of oxidation CO is rejected by the electrolyte. The maximum theoretical voltage is 1.186 at 25°C. The potential developed is a mixed potential involving reaction of HCHO and HCOOH species.

Anode : $2CH_3OH_{(aq)} + 2H_2O_{(l)} \rightarrow 2CO_{2(g)} + 6H^+_{(aq)} + 6e^-$

Cathode: $6H^+_{(aq)} + 6e^- + 3O_{2(g)} \rightarrow 3H_2O_{(l)}$

Overall reaction: $2CH_3OH_{(aq)} + 3O_{2(g)} \rightarrow 2CO_{2(g)} + H_2O_{(l)}$

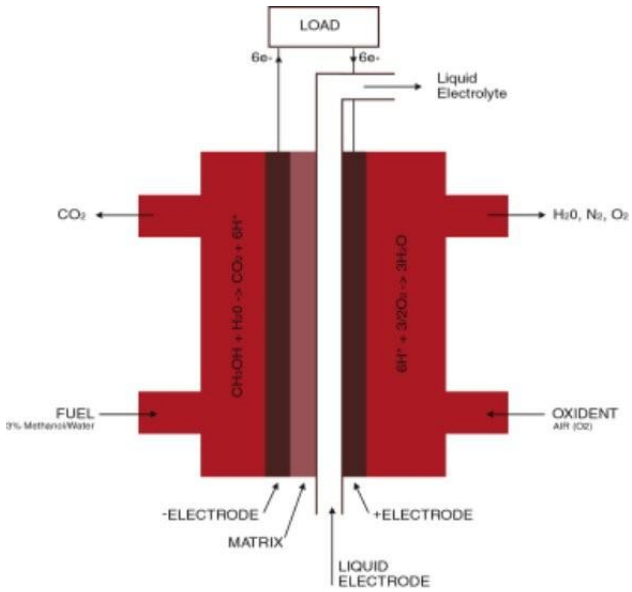


Fig. 5.24 Direct Methanol Fuel Cells

Phosphoric Acid Fuel Cell (PAFC)

The Phosphoric Acid fuel cell (PAFC) is in a mature state in terms of technological advancement. Acid fuel cells with phosphoric acid as electrolyte use relatively clean, reformed fuels (Natural gas, LPG, light distillates). Phosphoric acid has the advantages of good thermal, chemical and electrochemical stability, good capillary properties and low vapour pressures though it is a poor ionic conductor. Among the common acids, it has the lowest volatility and this property allows PAFCs to operate at 463K to 473K for several thousand hours. Other inorganic acids such as HCl, HF, H2SO4 and HClO have lower thermochemical stability and higher vapour pressures and therefore not suitable for operations at high temperatures (>473K). H_3PO_4 is the only inorganic acid that is suggested for its utility in fuel cell applications for these reasons.

Anode: $H_{2(g)} \rightarrow 2H^+_{(aq)} + 2e^-$

Cathode: $\frac{1}{2}O_{2(g)} + 2H^+_{(aq)} + 2e^- \rightarrow H_2O_{(l)}$

Over all cell reaction: $H_{2(g)} + \frac{1}{2}O_{2(g)} + CO_2 \rightarrow H_2O_{(l)} + CO_2$

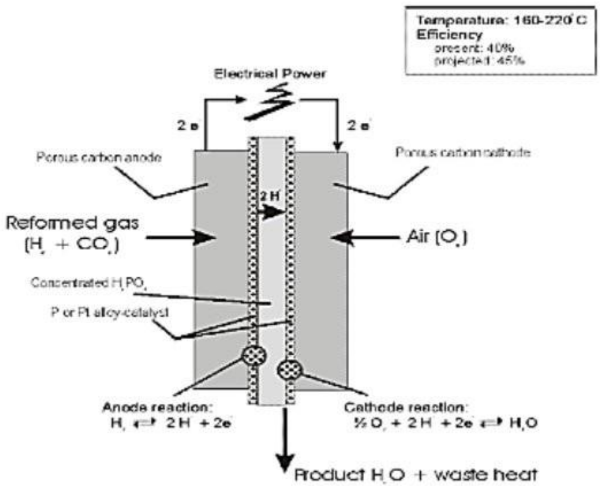


Fig. 5.25 Phosphoric acid fuel cells

The concept of employing "super acids" was discussed many times in the past, but did not progress beyond research age. The water vapor-pressure-concentration characteristics are almost ideal. It permits wide change of vapour pressure across the face of the cell and as a function of current density, without showing a tendency to dry out or become too dilute, this is in marked 4 contrast to KOH solutions, which tend to dry out; electrolyte circulation is essential in alkaline cells. It exhibits high tolerance for reformed hydrocarbons, removal of CO is possible by a shift reaction, and CO_2 is rejected naturally. The major limitation of this acid is that oxygen reduction is very slow even at high temperatures and pressures. Phosphoric acid with the function of the electrolyte is fixed in a porous layer between the electrodes. The advantage of this type of fuel cells is their relatively simple construction, mainly based on the use of carbon, PTFE and SiC which all can be processed by methods which are well-known from the origin of the fuel cell technology and could be easily adjusted to the demands of the fabrication of PAFC fuel cell components.

Molten Carbonate Fuel Cell (MCFC)

Molten carbonate fuel cells are approaching the early stages of commercialization, having been under study and development for more than 40 years. The high operating temperatures of MCFCs offer the prospect of being able to internally reform fuels such as natural gas. Long start-up times are implied, expensive materials are needed, and a number of design challenges are encountered due to leakage, corrosion, and loss through vaporization of the electrolyte. One of the most promising aspects of molten carbonates is the possibility of using, apart hydrogen, low cost fuels, as methanol, gaseous carbon. $CO+H_2$ (syngas) resulting from methane conversion by thermal cracking or reforming reaction. The oxidant is constituted by a mixture of air and carbon dioxide in the proportions of 70% and 30% respectively.

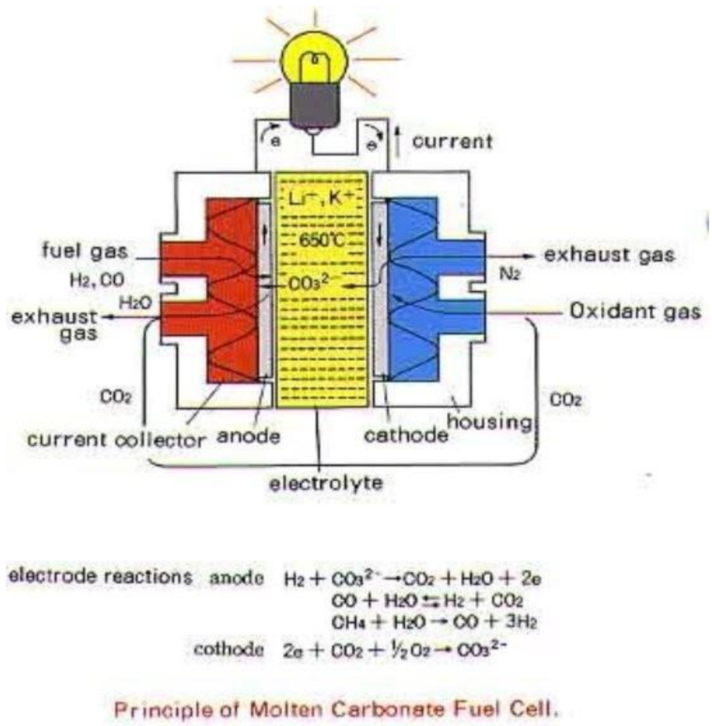


Fig. 5.26 Molten carbonate fuel cells

In operating MCFC, electrons are transferred from the anode through an external circuit to a cathode, where they participate in reduction reactions. Negative charges are conducted by carbonate anions (CO) from the cathode through the molten electrolyte to an anode. At the anode, electrons are produced by oxidation. MCFCs differ in many respects from PAFCs because of their higher operating temperature and the nature of the electrolyte. The higher operating temperature of MCFCs provides the opportunity for achieving higher overall system efficiencies and greater flexibility in the use of available fuels. On the other hand, the higher operating temperature places severe demands on the corrosion stability and life of cell components, particularly in the aggressive environment of the molten carbonate electrolyte. Another difference between PAFCs and MCFCs lies in the method used for electrolyte management in the respective cells. In a PAFC, PTFE serves as a binder and wet-proofing agent to maintain the integrity of the electrode structure and to establish a stable electrolyte/gas interface in the porous electrode. The phosphoric acid is retained in a matrix of PTFE and SiC between the anode and cathode. There are no materials available for use in MCFCs that are comparable to PTFE. Therefore, a different approach is required to establish a stable electrolyte/gas interface in MCFC porous electrodes. The MCFC relies on a balance in capillary pressures to establish the electrolyte interfacial boundaries in the porous electrodes.

Solid Oxide Fuel Cell (SOFC)

In the operation of SOFC, negative charges are conducted by electrons from the anode through an external circuit to the cathode; it is conducted by negative ions (O2-) from the cathode through the electrolyte to the anode.

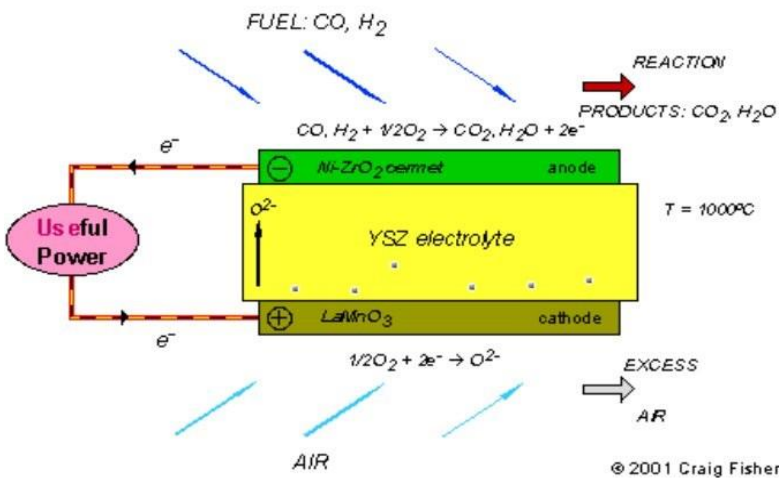


Fig. 5.27 Solid Oxide Fuel Cell

Its typical operating temperature is 1273 K; at this temperature, the electrolyte is an oxygen-ion conductor, and the free energies (as a consequence, the associated Nernst potential) of the overall reactions are substantially lower than at lower temperatures (e.g. 43.3 Kcal/mol at 1200 K vs 54.6 Kcal/mol at 300 K for H). The heat of reaction is almost independent of temperature; therefore the potential (ideal efficiency) is reduced by the high temperature operation. Different SOFC designs have been developed to implement the fuel cell and reformers into the stack and, ultimately, the complete system. Three main designs are encountering rapid development in SOFC technology: tubular, planar and monolithic configurations. Tubular SOFC designs are closer to commercialization and are being produced by several companies around the world. Demonstrations of tubular SOFC technology have produced as much as 220 kW. Since SOFC requires high operating temperatures, their most common application is in large, stationary power plants. The high temperatures open the opportunity for “cogeneration”-using waste heat to generate steam for space hearing, industrial processing, or in a steam turbine to make more electricity. Although they require inverters to change their direct current to alternating current, they can be manufactured in relatively small modular units. The compact size and cleanliness of SOFCs make them especially attractive for urban settings.