ME8792 Power Plant Engineering

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UNIT I COAL BASED THERMAL POWER PLANTS

RANKINE CYCLE :

Steam engine and steam turbines in which steam is used as working medium follow Rankine cycle. This cycle can be carried out in four pieces of equipment joint by pipes for conveying working medium as shown in Fig. 1.1. The cycle is represented on Pressure Volume P-V and S-T diagram as shown in Figs. 1.2 and 1.3 respectively.

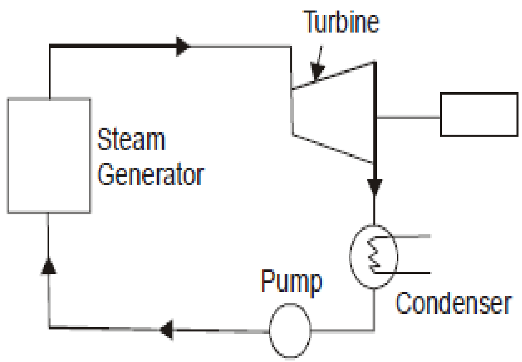


Fig. 1.1

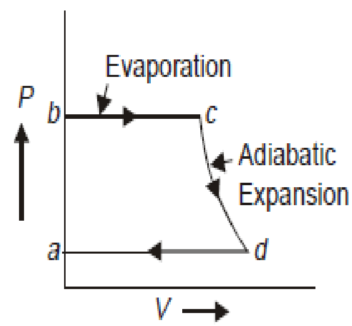


Fig. 1.2

Efficiency of Rankine cycle

$$= (H_1 - H_2)/ (H_1 - H_{w2})$$

where,

H_1 = Total heat of steam at entry pressure

H_2 = Total heat of steam at condenser pressure (exhaust pressure)

H_{w2}= Total heat of water at exhaust pressure

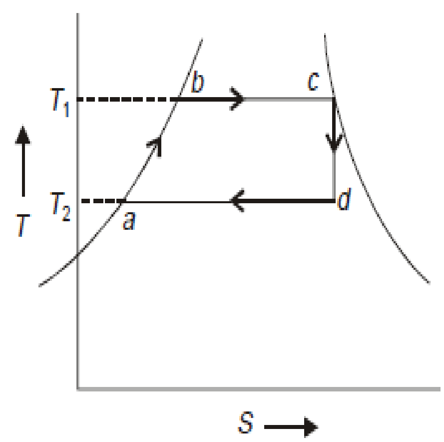


Fig. 1.3

Reheat cycle

In this cycle steam is extracted from a suitable point in the turbine and reheated generally to the original temperature by flue gases. Reheating is generally used when the pressure is high say above 100 kg/cm^2. The various advantages of reheating are as follows:

(*i*) It increases dryness fraction of steam at exhaust so that blade erosion due to impact of water particles is reduced.

(*ii*) It increases thermal efficiency.

(*iii*) It increases the work done per kg of steam and this results in reduced size of boiler.

The disadvantages of reheating are as follows:

(*i*) Cost of plant is increased due to the reheater and its long connections.

(*ii*) It increases condenser capacity due to increased dryness fraction.

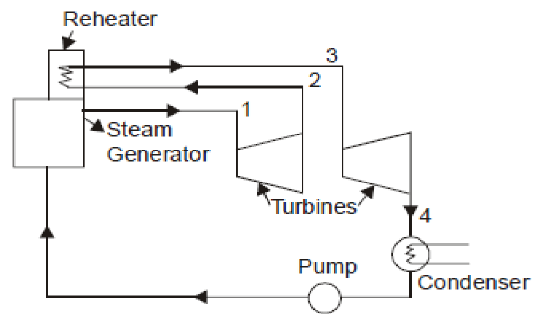


Fig. 1.4

Fig. 1.4 shows flow diagram of reheat cycle. First turbine is high-pressure turbine and second turbine is low pressure (L.P.) turbine. This cycle is shown on T-S (Temperature entropy) diagram (Fig. 1.5).

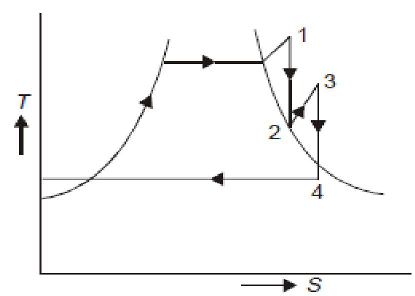


Fig. 1.5

If,

H_1 = Total heat of steam at 1

H_2 = Total heat of steam at 2

H_3 = Total heat of steam at 3

H_4 = Total heat of steam at 4

H_{w4} = Total heat of water at 4

Efficiency = $\{(H_1 - H_2) + (H_3 - H_4)\}/\{H_1 + (H_3 - H_2) - H_{w4}\}$

REGENERATIVE CYCLE (FEED WATER HEATING)

The process of extracting steam from the turbine at certain points during its expansion and using this steam for heating for feed water is known as Regeneration or Bleeding of steam. The arrangement of bleeding the steam at two stages is shown in Fig. 1.6.

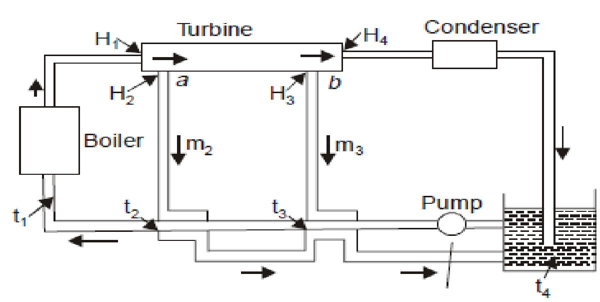


Fig. 1.6

Let,

m_2 = Weight of bled steam at a per kg of feed water heated

m_2 = Weight of bled steam at a per kg of feed water heated

H_1 = Enthalpies of steam and water in boiler

H_{w1} = Enthalpies of steam and water in boiler

H_2, H_3 = Enthalpies of steam at points a and b

t_2, t_3 = Temperatures of steam at points a and b

H_4, H_{w4} = Enthalpy of steam and water exhausted to hot well.

Work done in turbine per kg of feed water between entrance and a

$$= H_1 - H_2$$

Work done between a and $b = (1 - m_2)(H_2 - H_3)$

Work done between b and exhaust $= (1 - m_2 - m_3)(H_3 - H_4)$

Total heat supplied per kg of feed water $= H_1 - H_{w2}$

Efficiency (η) = Total work done/Total heat supplied

$$= \{(H_1 - H_2) + (1 - m_2)(H_2 - H_3) + (1 - m_2 - m_3)(H_3 - H_4)\}/(H_1 - H_{w2})$$

BINARY VAPOUR CYCLE

In this cycle two working fluids are used. Fig. 1.7 shows Elements of Binary vapour power plant. The mercury boiler heats the mercury into mercury vapours in a dry and saturated state.

These mercury vapours expand in the mercury turbine and then flow through heat exchanger where they transfer the heat to the feed water, convert it into steam. The steam is passed through the steam super heater where the steam is super-heated by the hot flue gases. The steam then expands in the steam turbine.

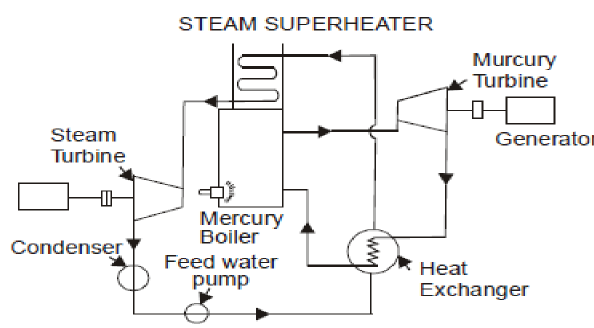


Fig. 1.7

REHEAT-REGENERATIVE CYCLE

In steam power plants using high steam pressure reheat regenerative cycle is used. The thermal efficiency of this cycle is higher than only reheat or regenerative cycle. Fig. 1.8 shows the flow diagram of reheat regenerative cycle. This cycle is commonly used to produce high pressure steam (90 kg/cm^2) to increase the cycle efficiency.

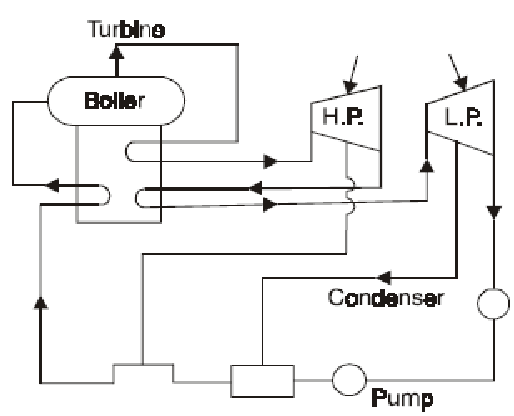


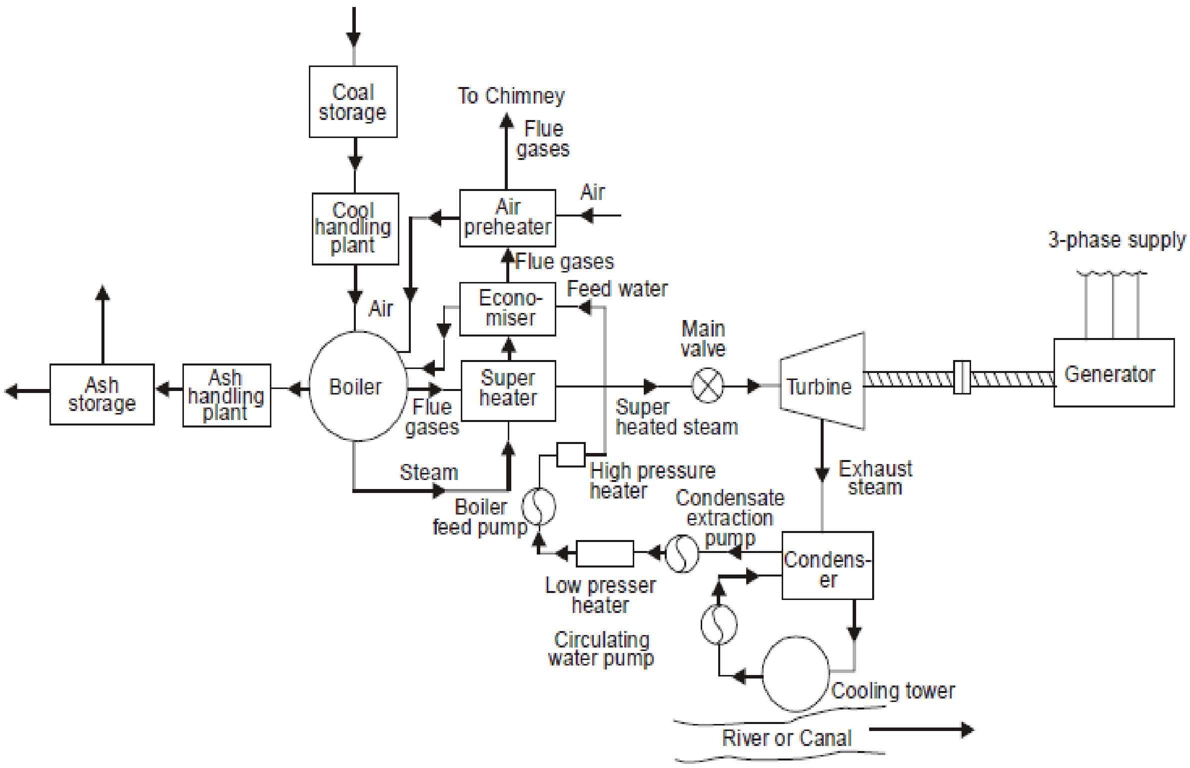
Fig. 1.8

COAL BASED POWER PLANT:

Coal needs to be stored at various stages of the preparation process, and conveyed around the CPP facilities. Coal handling is part of the larger field of bulk material handling, and is a complex and vital part of the CPP

STEAM POWER PLANT:

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



LAYOUT OF COAL BASED POWER PLANT

The four main circuits one would come across in any thermal power plant layout are

- Coal and Ash Circuit
- Air and Gas Circuit
- Feed Water and Steam Circuit

- Cooling Water Circuit

Coal and Ash Circuit

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

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

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

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

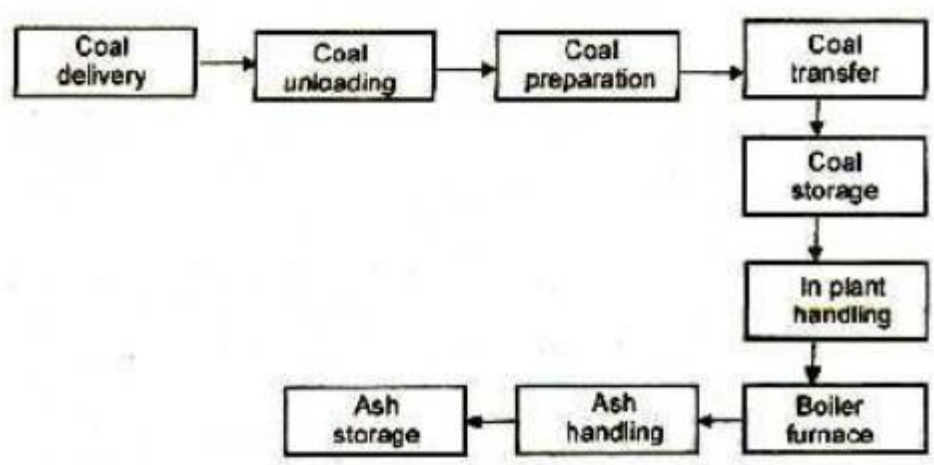
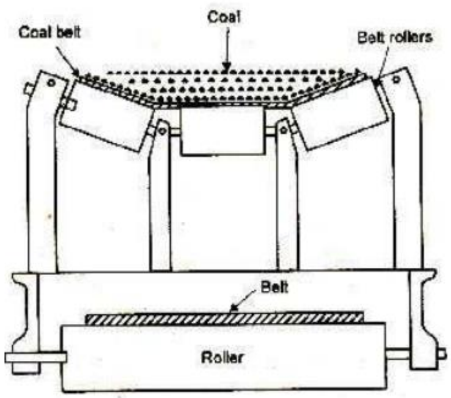


Figure: Fuel (coal) and ash circuit

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

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

Figure: Belt Conveyor



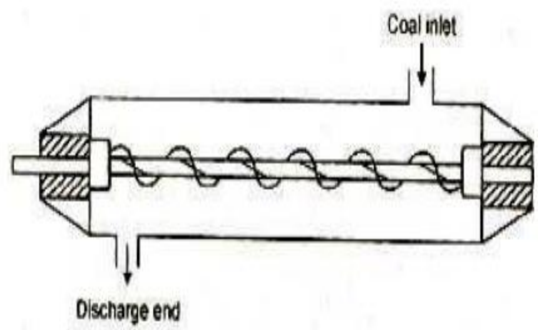
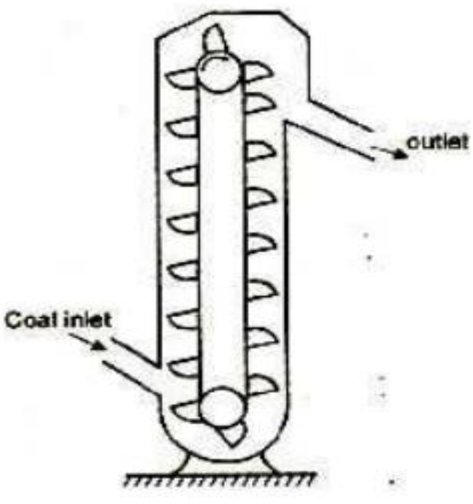


Figure: Screw conveyor



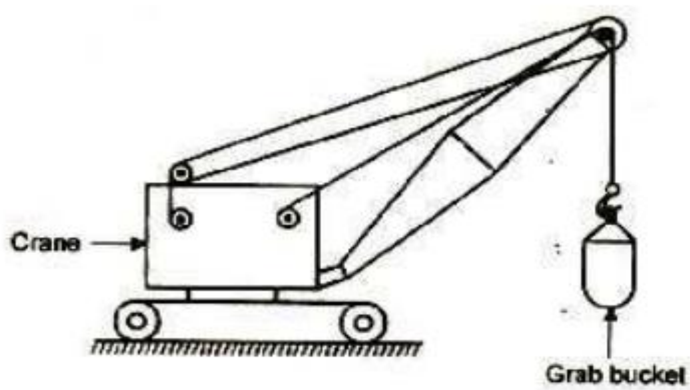


Figure: Bucket elevator

Figure: Grab bucket elevator.

Air and Gas Circuit

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

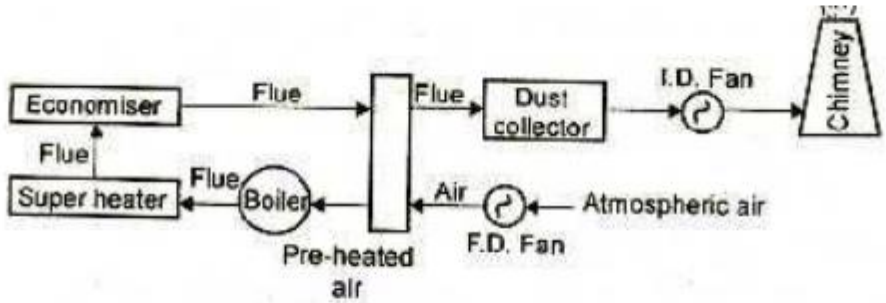


Figure: Air and flue gas circuit

Feed Water and Steam Circuit

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

Cooling Water Circuit

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

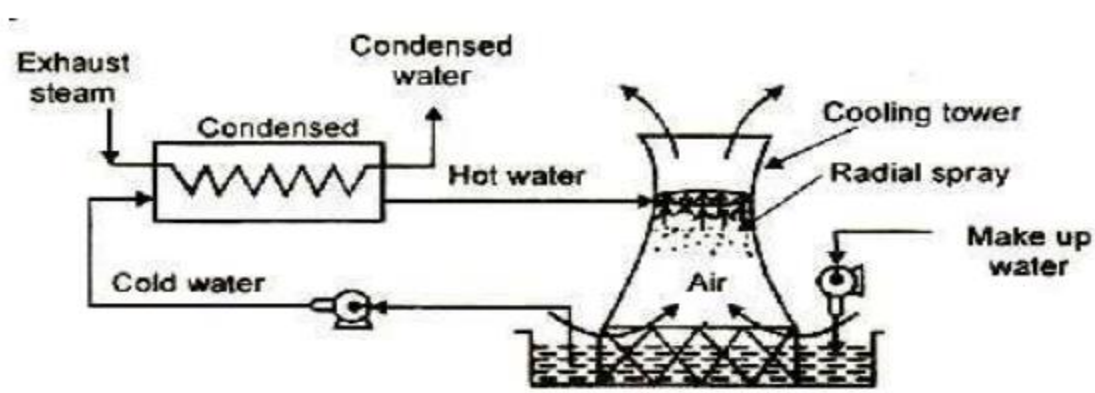


Figure: Cooling water current.

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

shows a schematic arrangement of equipment of a steam power station. Coal received in coal storage yard of power station is transferred in the furnace by coal handling unit. Heat produced due to burning of coal is utilized in converting water contained in boiler drum into steam at suitable pressure and temperature. The steam generated is passed through the superheater. Superheated steam then flows through the turbine. After doing work in the turbine die pressure of steam is reduced. Steam leaving the turbine passes through the condenser which maintain the low pressure of steam at the exhaust of turbine. Steam pressure in the condenser depends upon flow rate and temperature of cooling water and on effectiveness of air removal equipment. Water circulating through the condenser may be taken from the various sources such as river, lake or sea. If sufficient quantity of water is not available the hot water coming out of the condenser may be cooled in cooling towers and circulated again through the condenser. Bled steam taken from the turbine at suitable extraction points is sent to low pressure and high pressure water heaters.

Air taken from the atmosphere is first passed through the air pre-heater, where it is heated by flue gases. The hot air then passes through the furnace. The flue gases after passing over boiler and

superheater tubes, flow through the dust collector and then through economiser, air pre-heater and finally they are exhausted to the atmosphere through the chimney.

Stockpiles

Stockpiles provide surge capacity to various parts of the CPP. ROM coal is delivered with large variations in production rate of tonnes per hour (tph). A ROM stockpile is used to allow the wash plant to be fed coal at lower, constant rate. A simple stockpile is formed by machinery dumping coal into a pile, either from dump trucks, pushed into heaps with bulldozers or from conveyor booms. More controlled stockpiles are formed using stackers to form piles along the length of a conveyor.

Stacking

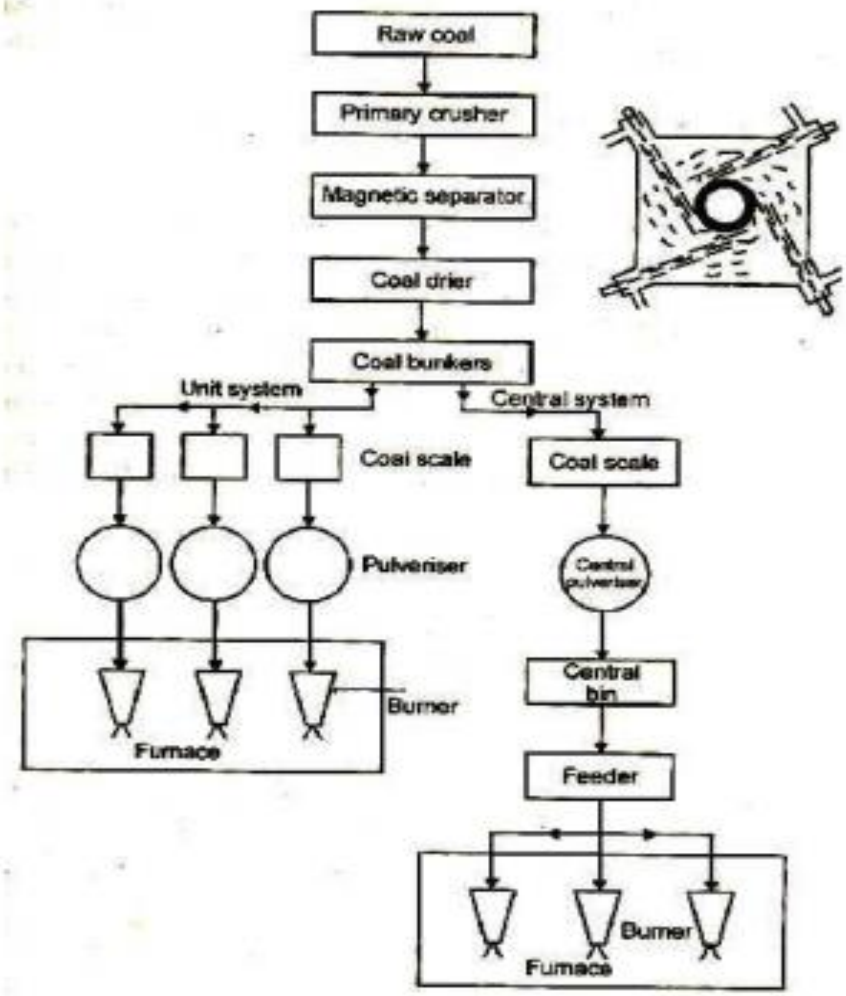
Travelling, lugging boom stackers that straddle a feed conveyor are commonly used to create coal stockpiles.

Reclaiming

Tunnel conveyors can be fed by a continuous slot hopper or bunker beneath the stockpile to reclaim material. Front-end loaders and bulldozers can be used to push the coal into feeders. Sometimes front-end loaders are the only means of reclaiming coal from the stockpile. This has a low up-front capital cost, but much higher operating costs, measured in dollars per tonne handled. High-capacity stockpiles are commonly reclaimed using bucket-wheel reclaimers. These can achieve very high rates

PULVERISER:

A pulverizer or grinder is a mechanical device for the grinding of many different types of materials. For example, they are used to pulverize coal for combustion in the steam-generating furnaces of fossil fuel power plants.



Types of pulverizers

Ball and tube mills

A ball mill is a pulverizer that consists of a horizontal rotating cylinder, up to three diameters in length, containing a charge of tumbling or cascading steel balls, pebbles, or rods.

A tube mill is a revolving cylinder of up to five diameters in length used for fine pulverization of ore, rock, and other such materials; the material, mixed with water, is fed into the chamber from one end, and passes out the other end as slime (slurry).

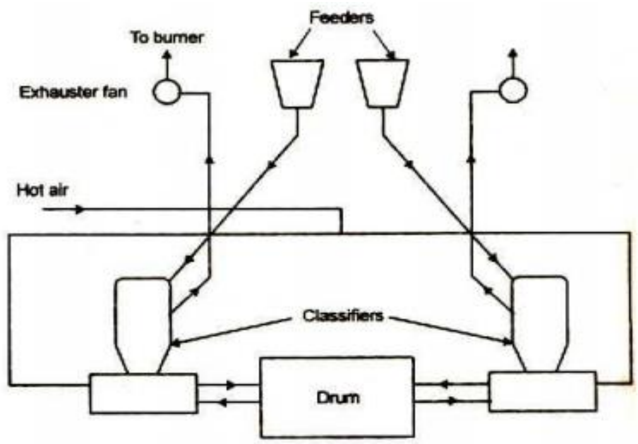


Figure: Ball mill

Ring and ball mill

This type of mill consists of two rings separated by a series of large balls. The lower ring rotates, while the upper ring presses down on the balls via a set of spring and adjuster assemblies. The material to be pulverized is introduced into the center or side of the pulverizer (depending on the design) and is ground as the lower ring rotates causing the balls to orbit between the upper and lower rings. The pulverized material is carried out of the mill by the flow of air moving through it. The size of the pulverized particles released from the grinding section of the mill is determined by a classifer separator.

Vertical roller mill

Similar to the ring and ball mill, this mill uses large "tires" to crush the coal. These are usually found in utility plants Raw coal is gravity-fed through a central feed pipe to the grinding table where it flows outwardly by centrifugal action and is ground between the rollers and table. Hot primary air for drying and coal transport enters the wind box plenum underneath the grinding table and flows upward through a swirl ring having multiple sloped nozzles surrounding the grinding table. The air mixes with and dries coal in the grinding zone and carries pulverized coal particles upward into a classifier.

Fine pulverized coal exits the outlet section through multiple discharge coal pipes leading to the burners, while oversized coal particles are rejected and returned to the grinding zone for further grinding. Pyrites and extraneous dense impurity material fall through the nozzle ring and are plowed, by scraper blades attached to the grinding table, into the pyrites chamber to be removed. Mechanically, the vertical roller mill is categorized as an applied force mill. There are three grinding roller wheel assemblies in the mill grinding section, which are mounted on a loading frame via pivot point. The fixed-axis roller in each roller wheel assembly rotates on a segmental-lined grinding table that is supported and driven by a planetary gear reducer direct-coupled to a motor. The grinding force for coal pulverization is applied by a loading frame. This frame is connected by vertical tension rods to three hydraulic cylinders secured to the mill foundation. All forces used in the pulverizing process are transmitted to the foundation via the gear reducer and loading elements. The pendulum movement of the roller wheels provides a freedom for wheels to move in a radial direction, which results in no radial loading against the mill housing during the pulverizing process.

Depending on the required coal fineness, there are two types of classifier that may be selected for a vertical roller mill. The dynamic classifier, which consists of a stationary angled inlet vane assembly surrounding a rotating vane assembly or cage, is capable of producing micron fine pulverized coal with a narrow particle size distribution. In addition, adjusting the speed of the rotating cage can easily change the intensity of the centrifugal force field in the classification zone to achieve coal fineness control real-time to make immediate accommodation for a change in fuel or boiler load conditions. For the applications where a micron fine pulverized coal is not necessary, the static classifier, which consists of a cone equipped with adjustable vanes, is an option at a lower cost since it contains no moving parts. With adequate mill grinding capacity, a vertical mill equipped with a static classifier is capable of producing a coal fineness up to 99.5% or higher <50 mesh and 80% or higher <200 mesh, while one equipped with a dynamic classifier produces coal fineness levels of 100% <100 mesh and 95% <200 mesh, or better.

Bowl mill

Similar to the vertical roller mill, it also uses tires to crush coal. There are two types, a deep bowl mill, and a shallow bowl mill.

Demolition pulverizer

An attachment fitted to an excavator. Commonly used in demolition work to break up large pieces of concrete.

COMBUSTION EQUIPMENTS:

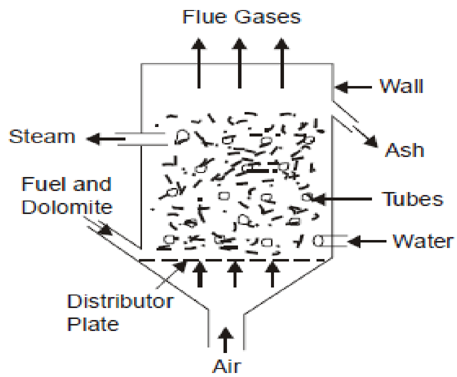
Combustion control options range from electro / mechanical through to full microprocessor control systems to match both application and customer needs. Cochran supply an extensive range of fuel handling equipment to complement and help ensure that the optimum performance from the combustion and control equipment is maintained. Fuel handling equipment includes gas boosters, oil pumping and heating stations, fuel metering and instrumentation packages are available to match individual installation requirements.

STOCKERS:

A mechanical stoker is a device which feeds coal into the firebox of a boiler. It is standard equipment on large stationary boilers and was also fitted to large steam locomotives to ease the burden of the fireman. The locomotive type has a screw conveyor (driven by an auxiliary steam engine) which feeds the coal into the firebox. The coal is then distributed across the grate by steam jets, controlled by the fireman. Power stations usually use pulverized coal-fired boilers.

Burning of pulverised coal has some problems such as particle size of coal used in pulverised firing is limited to 70-100 microns, the pulverised fuel fired furnances designed to burn a particular can not be used other type of coal with same efficiency, the generation of high temp. about (1650 C) in the furnace creates number of problems like slag formation on super heater, evaporation of alkali metals in ash and its deposition on heat transfer surfaces, formation of SO_2 and NO_X in large amount.

Fluidised Bed combustion system can burn any fuel including low grade coals (even containing 70% ash), oil, gas or municipal waste. Improved desulphurisation and low NO_X emission are its main characteristics. :shows basic principle of Fluidised bed combustion (FBC) system. The fuel and inert material dolomite are fed on a distribution plate and air is supplied from the bottom of distribution plate. The air is supplied at high velocity so that solid feed material remains in suspension condition during burning. The heat produced is used to heat water flowing through the tube and convert water into steam: During burning SO_2 formed is absorbed by the dolomite and thus prevents its escape with the exhaust gases. The molten slag is tapped from the top surface of the bed. The bed temperature is nearly 800-900'C which is ideal for sulphur retention addition of limestone or dolomite to the bed brings down SO_2 emission level to about 15% of that in conventional firing methods.



The amount of NO_X is produced is also reduced because of low temperature of bed and low excess air as compared to pulverised fuel firing.

The inert material should be resistant to heat and disintegra-tion and should have similar density as that of coal. Limestone, or dolomite, fused alumina, sintered ash are commonly used as inert materials.

Various advantages of FBC system are as follows:

(*i*) FBC system can use any type of low grade fuel including municipal wastes and therefore is a cheaper method of power generation.

(*ii*) It is easier to control the amount of SO_2 and NO_X, formed during burning. Low emission of SO_2 and NO_X. will help in controlling the undesirable effects of SO_2 and NO_X. during combustion. SO_2 emission is nearly 15% of that in conventional firing methods.

(*iii*) There is a saving of about 10% in operating cost and 15% in the capital cost of the power plant.

(*iv*) The size of coal used has pronounced effect on the operation and performance of FBC system. The particle size preferred is 6 to 13 mm but even 50 mm size coal can also be used in this system.

ASH HANDLING SYSTEMS:

Ash Handling Systems is the none / un combusted portion or residue, after taking combustion of any solid fuel .Solid fuel is usually coal. And any coal contains some non combustible portion which is called ash. Content of that coal.

There are different types of ashes.

- Bottom ash
- fly ash.

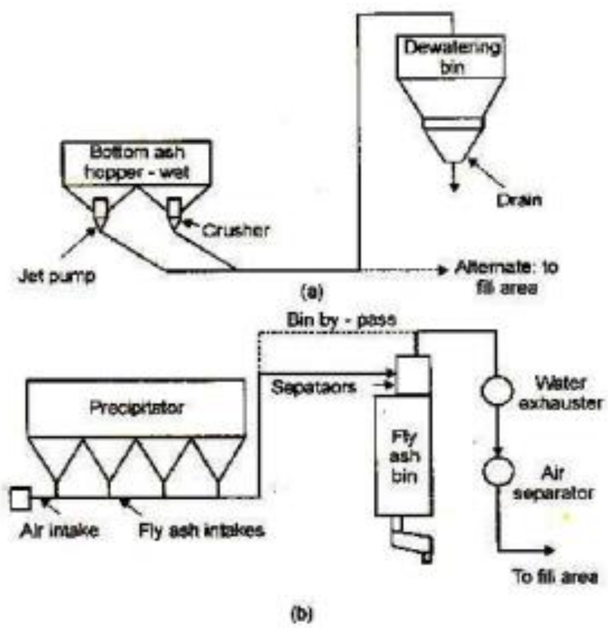


Figure: Layout of ash handling system.

Bottom ash is the residue which remains in the solid form at the bottom and fly ash is the light particle which goes out along with exhaust gases, and usually they are collected in chimneys.

Taking their so formed ash away from the Plant / Boiler is called – "ASH HANDLING SYSTEM" This is done in either

- Mechanical conveying
- Pneumatic conveying

Mechanical system requires conveyors, and Pneumatic system requires – compressed air to carry out the ash.

- Ash Handling Systems
- Bulk Material Handling Systems
- Conveyors And Material Handling Equipments
- Process Equipments And Storage Equipments
- Portable Handling Equipments

- Rotary Equipments
- Pneumatic Conveying Systems
- Magnetic Equipments
- Vibratory Equipments
- Spares
- Overhead Bag Handling Systems

ELECTROSTATIC PRECIPITATOR:

An electrostatic precipitator (ESP), or electrostatic air cleaner is a particulate collection device that removes particles from a flowing gas (such as air) using the force of an induced electrostatic charge. Electrostatic precipitators are highly efficient filtration devices that minimally impede the flow of gases through the device, and can easily remove fine particulate matter such as dust and smoke from the air stream. In contrast to wet scrubbers which apply energy directly to the flowing fluid medium, an ESP applies energy only to the particulate matter being collected and therefore is very efficient in its consumption of energy (in the form of electricity).

Modern industrial electrostatic precipitators

ESPs continue to be excellent devices for control of many industrial particulate emissions, including smoke from electricity-generating utilities (coal and oil fired), salt cake collection from black liquor boilers in pulp mills, and catalyst collection from fluidized bed catalytic cracker units in oil refineries to name a few. These devices treat gas volumes from several hundred thousand ACFM to 2.5 million ACFM (1,180 m^3/s) in the largest coal-fired boiler applications. For a coal-fired boiler the collection is usually performed downstream of the air preheater at about 160 °C (320 deg.F) which provides optimal resistivity of the coal-ash particles. For some difficult applications with low-sulfur fuel hot-end units have been built operating above 371 °C (700 deg.F).

The original parallel plate–weighted wire design (described above) has evolved as more efficient (and robust) discharge electrode designs were developed, today focusing on rigid (pipe-frame) discharge electrodes to which many sharpened spikes are attached (barbed wire), maximizing corona production. Transformer-rectifier systems apply voltages of 50 – 100 kV at relatively high current densities. Modern controls, such as an automatic voltage control, minimize electric sparking and prevent arcing (sparks are quenched within 1/2 cycle of the TR set), avoiding damage to the components. Automatic plate-rapping systems and hopper-evacuation systems remove the collected particulate matter while on line, theoretically allowing ESPs to stay in operation for years at a time.

Wet electrostatic precipitator

A wet electrostatic precipitator (WESP or wet ESP) operates with saturated air streams (100% relative humidity). WESPs are commonly used to remove liquid droplets such as sulfuric acid mist from industrial process gas streams. The WESP is also commonly used where the gases are high in moisture content, contain combustible particulate, have particles that are sticky in nature.

The preferred and most modern type of WESP is a down flow tubular design. This design allows the collected moisture and particulate to form a slurry that helps to keep the collection surfaces clean. Plate style and up flow design WESPs are very unreliable and should not be used in applications where particulate is sticky in nature.

Consumer-oriented electrostatic air cleaners

The two-stage design (charging section ahead of collecting section) has the benefit of minimizing ozone production which would adversely affect health of personnel working in enclosed spaces. For shipboard engine rooms where gearboxes generate an oil fog, two-stage ESP's are used to clean the air improving the operating environment and preventing buildup of flammable oil fog accumulations. Collected oil is returned to the gear lubricating system.

With electrostatic precipitators, if the collection plates are allowed to accumulate large amounts of particulate matter, the particles can sometimes bond so tightly to the metal plates that vigorous washing and scrubbing may be required to completely clean the collection plates. The close spacing of the plates can make thorough cleaning difficult, and the stack of plates often cannot be easily disassembled for cleaning. One solution, suggested by several manufacturers, is to wash the collector plates in a dishwasher. Some consumer precipitation filters are sold with special soak-off cleaners, where the entire plate array is removed from the precipitator and soaked in a large container overnight, to help loosen the tightly bonded particulates.

DRAUGHT:

Most boilers now depend on mechanical draught equipment rather than natural draught. This is because natural draught is subject to outside air conditions and temperature of flue gases leaving the furnace, as well as the chimney height. All these factors make proper draught hard to attain and therefore make mechanical draught equipment much more economical

There are three types of mechanical draught:

Induced draught: This is obtained one of three ways, the first being the "stack effect" of a heated chimney, in which the flue gas is less dense than the ambient air surrounding the boiler. The denser column of ambient air forces combustion air into and through the boiler. The second method is through use of a steam jet. The steam jet oriented in the direction of flue gas flow induces flue gasses into the stack and allows for a greater flue gas velocity increasing the overall draught in the furnace. This method was common on steam driven locomotives which could not have tall chimneys. The third method is by simply using an induced draught fan (ID fan) which removes flue gases from the furnace and forces the exhaust gas up the stack. Almost all induced draught furnaces operate with a slightly negative pressure.

Forced draught: Draught is obtained by forcing air into the furnace by means of a fan (FD fan) and ductwork. Air is often passed through an air heater; which, as the name suggests, heats the air going into the furnace in order to increase the overall efficiency of the boiler. Dampers are used to control the quantity of air admitted to the furnace. Forced draught furnaces usually have a positive pressure.

Balanced draught: Balanced draught is obtained through use of both induced and forced draught. This is more common with larger boilers where the flue gases have to travel a long distance through many boiler passes. The induced draught fan works in conjunction with the forced draught fan allowing the furnace pressure to be maintained slightly below atmospheric.

COGENERATION:

Decentralized combined heat and power production-cogeneration is a very flexible and efficient way of utilizing fuels. Cogeneration based on biomass is environmentally friendly, and all kinds of biomass resources can be used.

The role combined heat and power production plays in Danish energy supply originates from the decision in 1978 to establish a national natural gas grid. At present the natural gas system is one factor blocking the utilization of biomass and natural gas in decentralized cogeneration plants, because a great part of the heat market is lost for decentralized cogeneration due to the individual gas supply.

In June 1986 it was decided that 450 mW decentralized heat and power plants should be established. These are very efficient and environmentally compatible, if they are based on natural gas or biomass. The interest in biomass as basis for combined heat and power production is caused partly by environmental considerations, and partly by the desire in agriculture and forestry to get rid of an increasing surplus of residue products, typically straw and wood chips.

But exceeding the problem with an insufficient heat market, the energy policy has caused that until now there has been no sufficiently purposeful and ambitious aiming at the cogeneration technologies, that first of all shall lead to an increased use of biomass in heat and power supply.

COGENERATION — WHY

There is a large political interest in changing the local heat supply to combined heat and power supply—this means cogeneration of heat and power.

It is a fundamental physical condition that not all-latent energy of a fuel can be converted into tractive power, *e.g.* to run a car. The main part of the energy is necessarily transformed to waste heat, which in the car example disappears by motor cooling and with the exhaust.

Cogeneration plants can be used in all situations where a given heat demands exists. This includes all together an extremely large number of district heating plants, institutions, co-operative building societies, industries, etc.

For the cogeneration technologies, the primary interest is due to, that a very large percentage of the fuel's energy content is utilized, typically 85-95%. This must be compared to the relatively low energy efficiency of centralized thermal power plants, the annual mean efficiency is about 55% in the ELSAM area (Jutland, Funen).

Another important reason for the interest in decentralized cogeneration is the possibility to utilize renewable bio fuels straw, wood, manure, etc. There are furthermore a few circumstances which are not that much noticed in the political debate.

First of all a large number of cogeneration plants increase the security of power supply. It is not usual that the large power units break down, but it happens. It is obvious that the consequences of missing a large unit are much more significant, than if it is one of the much smaller cogeneration plants.

Second there is a considerable energy loss from the power grid. In the ELSAM area it is good 7% in average. But this figure covers very large variations through the day, and furthermore depends very much on the voltage level. Thus the energy loss from the low-voltage grid is much larger than from the high-voltage grid. All in this entire means that *e.g.* on a winter day at 5 pm there is a large energy loss from the low-voltage grid.

Exactly because many of the cogeneration plants are coupled on the low-voltage grid, they also reduce the grid loss, which influence the overall energy efficiency.

COGENERATION TECHNOLOGIES

(*a*) Gas Engines. The most common type of combined heat and power production in Denmark is connected to gas-fired internal combustion engines, which is a well-known technology. They can be found on the market at sizes from 7 kW power to about 4 mW power, and the power efficiency is good 20% for the small engines and over 40% for the largest. As power production is viewed as the main purpose, it is important that the power efficiency is continuously increased.

The lower limit for a profitable cogeneration plant is a heat demand of 15,000 m natural gas per year and a power consumption of 50,000 kWh per year with the current engines at the market.

The gas engine fuel is mainly natural gas and it will remain like this for several years. A few plants are based on biogas, which will gain increased utilization, while various types of biogas plants are developed and established.

It is assumed that gas from thermal gasification of straw and wood will also spread as fuel for stationary cogeneration plants during the coming years.

There are some differences between cogeneration plants according to operation strategy. The larger plants, typically connected to a district heating plant or an industrial company, are mainly in operation during daytime at weekdays. It is because the payment for power is most favourable at that time, which again is due to that the capacity is paid for during the periods with high consumption. In these cases the cogeneration plant produces heat both for covering the actual consumption and for storage in large water storages. The storages are then emptied for heat at night and during the weekend. It is a political request that 90% of the annual heat consumption must be supplied from the engine; a gas boiler supplies the rest.

This operation strategy is only realistic when using natural gas as fuel, as there is enough at a certain time. Contrary to continuously gas production from a biogas or gasification plant. On the other hand, the demand for a variable power production will increase, when cogeneration plants with variable production are established.

The smaller plants are typically base load plants that operate day and night. They supply power to own installations and cover the power consumption. In this case the plant has 2 power meters; one that registers buy from the power utility when the consumption exceeds the production, and another that registers sale when own consumption is less than the actual production.

This type of cogeneration plants has severe environmental and resource advantages.

Natural gas is the least polluting of the fossil fuels. It is partly due to the relatively high hydrogen content that becomes water in the combustion. The CO_2 emission from natural gas is therefore smaller than from oil and coal.

The NO_x pollution from the engines are reduced according to authorities' demand by mounting a 3-way catalyzer or more often by using low-NO_x engines (lean burn). The smallest engines are excepted from these requirements.

According to resources, the advantage is as already mentioned a higher energy efficiency than at centralized thermal power plants.

(*b*) Gas Turbines. Some larger district heating plants have based their heat and power production on gas turbines. They can be regulated less than gas engines, and as they by mean of their size presuppose a large heat demand there will not be space for many new in the future. There are simply not that many cities with a sufficiently large heat demand. Apparently there is neither any product development-taking place to increase the power efficiency, as it is the case for gas engines.

Combined heat and power production based on steam

The Danish effort to increase the use of biomass mainly straw and wood as fuel in combined heat and power production increasingly draws the attention towards steam engines and steam turbines.

The steam engine is a well-known technology, but for different reasons it hasn't been developed for several years. One of the problems has been the contact between lubricating oil and steam. This problem has been solved with a new design of the steam generator, which is manufactured in Denmark and is just ready for the market.

The advantage of this cogeneration technology is that biomass can be combusted directly in the steam boiler and obtain the wanted steam pressure of 20-30 bars.

The disadvantage is that power efficiency will hardly exceed 15%. Therefore it is a question if the steam engine is able to compete with cogeneration based on gasified biomass in the longer term.

There seem to be better possibilities for steam turbines with a combination of direct stoking of biomass in the boiler, and superheating of the steam with natural gas. A Danish district heating plant is preparing a test plant based on this technology. Its advantage is significantly higher power efficiency than the steam engine.

(*c*) The Stirling Engine. The Stirling engine is a hot-air engine, named after the Scottish priest Stirling who invented it in 1817. Since then it has been designed and manufactured in a vast number of designs.

In spite of intensive and expensive research it is nearly without importance, as the research has been aimed at developing a car engine, which it is not suitable for.

On the other hand there are large perspectives in viewing it as a stationary combined heat and power plant. There is a growing understanding of this that has resulted in new research and production aimed at this. About 150 pieces have been made in batch production in India. This is a simple low-pressure design with a power efficiency of about 10%.

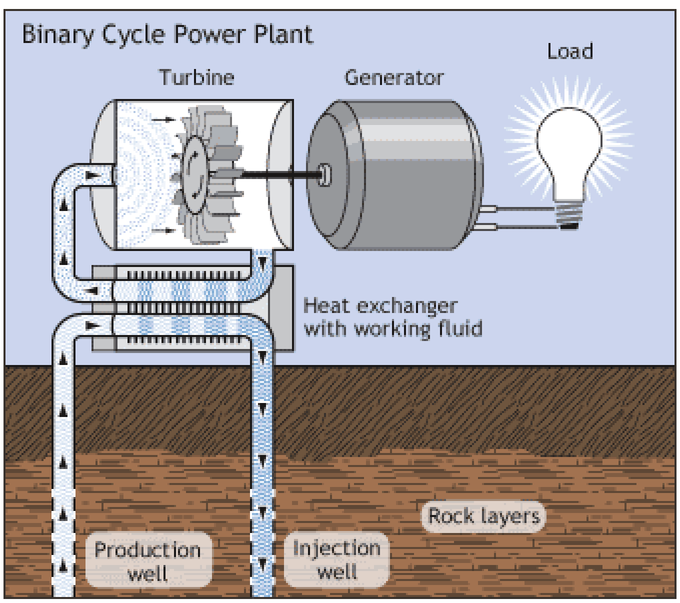
A **supercritical steam generator** is a type of boiler that operates at supercritical pressure, frequently used in the production of electric power.

In contrast to a subcritical boiler, a supercritical steam generator operates at pressures above the critical pressure — 3,200 psi or 22 MPa — in which bubbles can form. Instead, liquid water immediately becomes steam. Water passes below the critical point as it does work in a high pressure turbine and enters the generator's condenser, resulting in slightly less fuel use and therefore less greenhouse gas production.Technically, the term "boiler" should not be used for a supercritical pressure steam generator as no "boiling" actually occurs in the device.

BINARY CYCLE POWER 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. Because resources below 300°F represent the most common geothermal resource, a significant proportion of geothermal electricity in the future could come from binary-cycle plants.



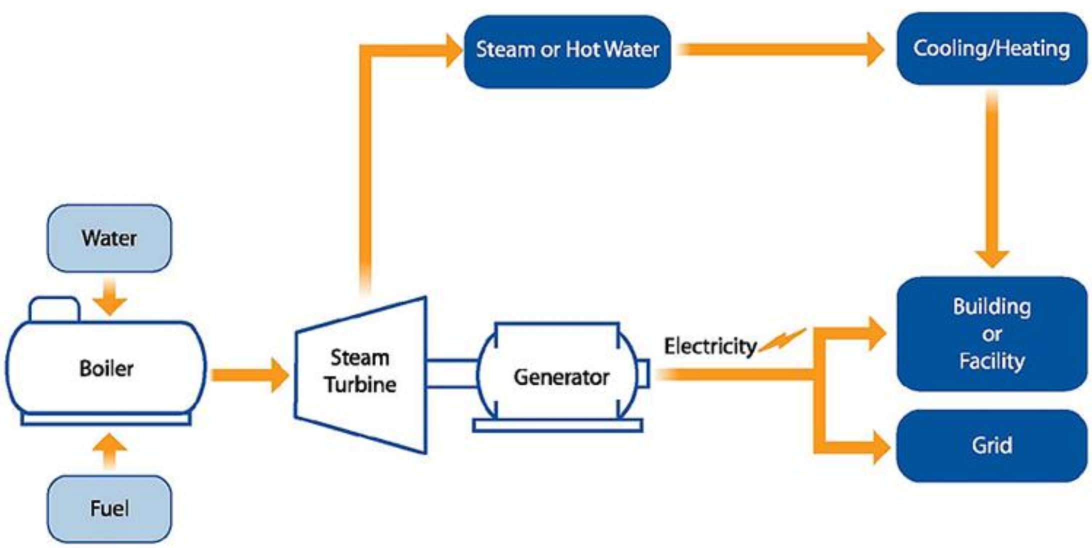
Cogeneration or **combined heat and power** (**CHP**) is the use of a heat engine or power station to generate electricity anduseful heat at the same time. **Trigeneration** or **combined cooling, heat and power** (**CCHP**) refers to the simultaneous generation of electricity and useful heating and cooling from the combustion of a fuel or a solar heat collector.

Cogeneration is a thermodynamically efficient use of fuel. In separate production of electricity, some energy must be discarded as waste heat, but in cogeneration some of this thermal energy is put to use. All thermal power plants emit heat during electricity generation, which can be released into the natural environment through cooling towers, flue gas, or by other means. In contrast, CHP captures some or all of the by-product for heating, The supply of high-temperature heat first drives a gas or steam turbine-powered generator and the resulting low-temperature waste heat is then used for water or space heating as described in cogeneration. At smaller scales (typically below 1 MW) agas engine or diesel engine may be used. Trigeneration differs from cogeneration in that the waste heat is used for both heating and cooling, typically in an absorption refrigerator. CCHP systems can attain higher overall efficiencies than cogeneration or traditional power plants. In the United States, the application of trigeneration in buildings is called **building cooling, heating and power** (**BCHP**). Heating and cooling output may operate concurrently or alternately depending on need and system construction.

Cogeneration was practiced in some of the earliest installations of electrical generation. Before central stations distributed power, industries generating their own power used exhaust steam for process heating. Large office and apartment buildings, hotels and stores commonly generated their own power and used waste steam for building heat. Due to the high cost of early purchased power, these CHP operations continued for many years after utility electricity became available

Steam Turbines

Steam turbines systems can use a variety of fuels, including natural gas, solid waste, coal, wood, wood waste, and agricultural by-products. Steam turbines are highly reliable and can meet multiple heat grade requirements. Steam turbines typically have capacities between 50 kW and 250 MW and work by combusting fuel in a boiler to heat water and create high-pressure steam, which turns a turbine to generate electricity.[12]The low-pressure steam that subsequently exits the steam turbine can then be used to provide useful thermal energy, as shown in Figure 3. Ideal applications of steam turbine-based cogeneration systems include medium- and large-scale industrial or institutional facilities with high thermal loads and where solid or waste fuels are readily available for boiler use.



: Steam Boiler with Steam Turbine

Water Tube Boilers:

Babcock and Wilcox boiler:

It is a water tube boiler used in steam power plants. In this, water is circulated inside the tubes and hot gases flow over the tubes.

Description:

The Babcock and Wilcox boiler consists of

1. Steam and water drum (Boiler shell)
2. Water tubes
3. Uptake – header and down – comer
4. Grate
5. Furnace
6. Baffles
7. Superheater
8. Mud box
9. Inspection doors
10. Damper

1. Steam and Water drum (Boiler Shell)

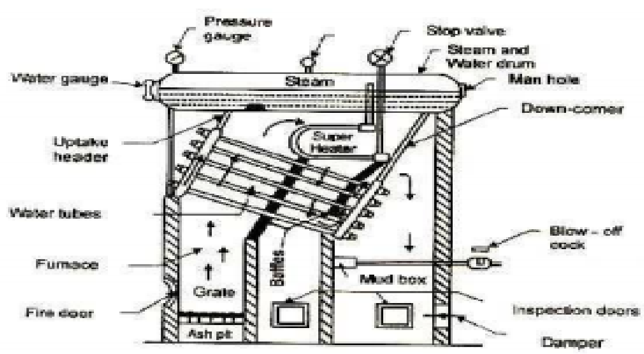
One half of the drum which is horizontal is filled up with water and steam remains on the other half. It is about 8 metres in length and 2 metres in diameter.

2. Water tubes

Water tubes are placed between the drum and the furnace in an inclined position (at an angle of 10º to 15º) to promote water circulation. These tubes are connected to the uptake – header and the down – comer as shown.

3. Uptake – Header and Down – comer (or Down take – Header)

The drum is connected at one end to the uptake – header by short tubes and at the other end to the down – comer by long tubes.



Fluidized Bed Combustion (FBC) Boiler

Fluidized bed combustion (FBC) has emerged as a viable alternative and has significant advantages over conventional firing system and offers multiple benefits – compact boiler design, fuel flexibility, higher combustion efficiency and reduced emission of noxious pollutants such as SOx and NOx. The fuels burnt in these boilers include coal, washery rejects, rice husk, bagasse & other agricultural wastes. The fluidized bed boilers have a wide capacity range- 0.5 T/hr to over 100 T/hr.

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

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

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

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

Atmospheric Fluidized Bed Combustion (AFBC) Boiler

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

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

Pressurized Fluidized Bed Combustion (PFBC) Boiler

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

Atmospheric Circulating Fluidized Bed Combustion Boilers (CFBC)

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

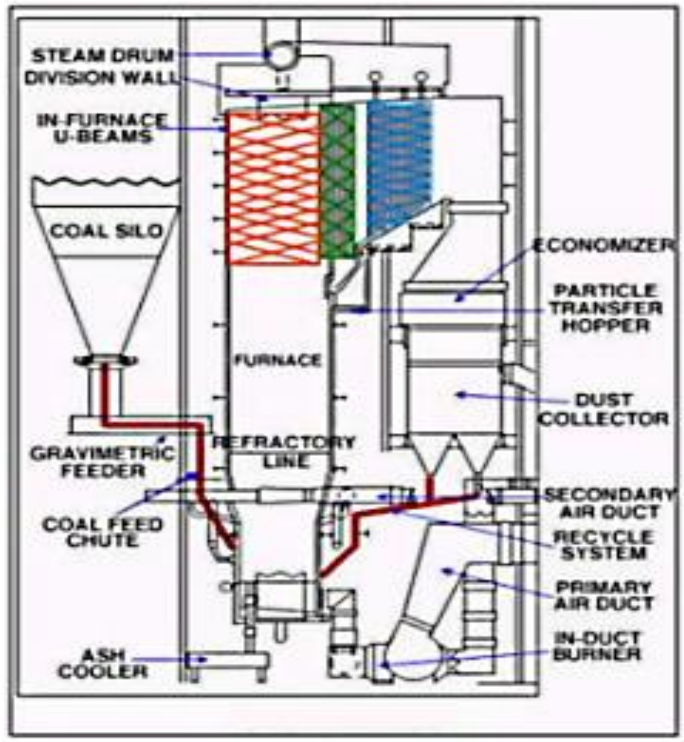


Fig: CFBC Boiler

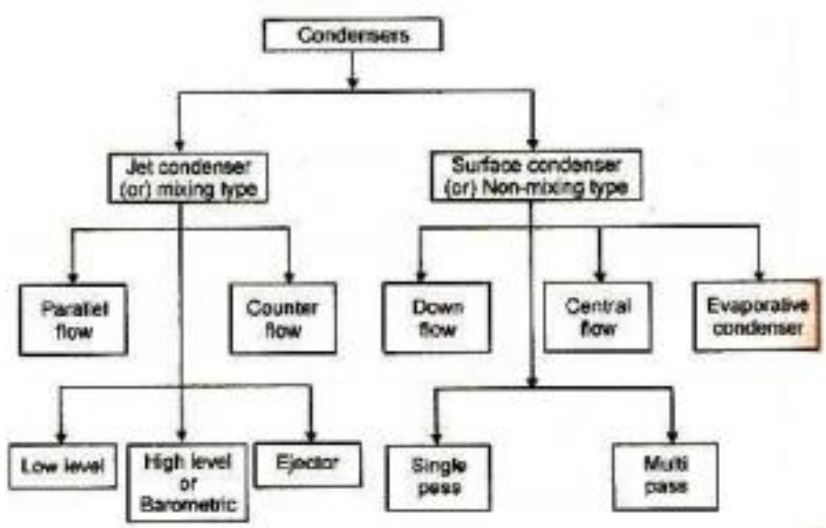
Reference:
http://www.tbwindia.com/boiler/cfbc_system.asp

CFBC boilers are generally more economical than AFBC boilers for industrial application requiring more than 75 – 100 T/hr of steam. For large units, the taller furnace characteristics of CFBC boilers offers better space utilization, greater fuel particle and sorbent residence time for efficient combustion and SO_2 capture, and easier application of staged combustion techniques for NOx control than AFBC steam generators.

Stoker Fired Boilers

Stokers are classified according to the method of feeding fuel to the furnace and by the type of grate. The main classifications are spreader stoker and chain-gate or traveling-gate stoker.

condensers



FEEDWATER TREATMENT

All natural sources of water contain impurities as well as dissolved gasses. The amount of these impurities depends on type of water source and location. **Why it is necessary to treat the raw water?** Raw water coming from different sources contains dissolved salts and un-dissolved or suspended impurities. It is necessary to remove harmful salts dissolved into the water before feeding it to the boiler. Because-

1. The deposition of dissolved salts and suspended impurities will form a scale on the inside wall of different heat-exchangers and thus there will create excessive pressure and thermal stress (due to uneven heat exchange across the wall of heat-exchanger) inside the heat-exchangers, which may lead to the explosion and serious hazards for boilers.
2. The harmful dissolved salts may react with various parts of boiler through which it flows, thereby corrode the surfaces.
3. Corrosion damage may occur to turbine blades.

Hence, **boiler feed water treatment** is very much required to remove such dissolved and suspended impurities from water before feeding it to boiler.

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

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

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

External Treatment

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

If the turbidity of clarified effluent is high, positive filtration is needed. Both gravity filters and pressure-type filters are used, but the latter is preferred. A granular medium like sand is commonly used for filtration. The pressure difference across the filtering medium is an indication of solid accumulation. When it reaches a given limit, the solids are removed from the bed by backwashing. Further filtration by activated carbon can absorb organics and remove residual chlorine from the chlorination process.

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

Demineralizing Plant

The process of removing dissolved solids in water by *ion exchange* is called *demineralization*. Two types of resins, cation and anion, are used. The cation

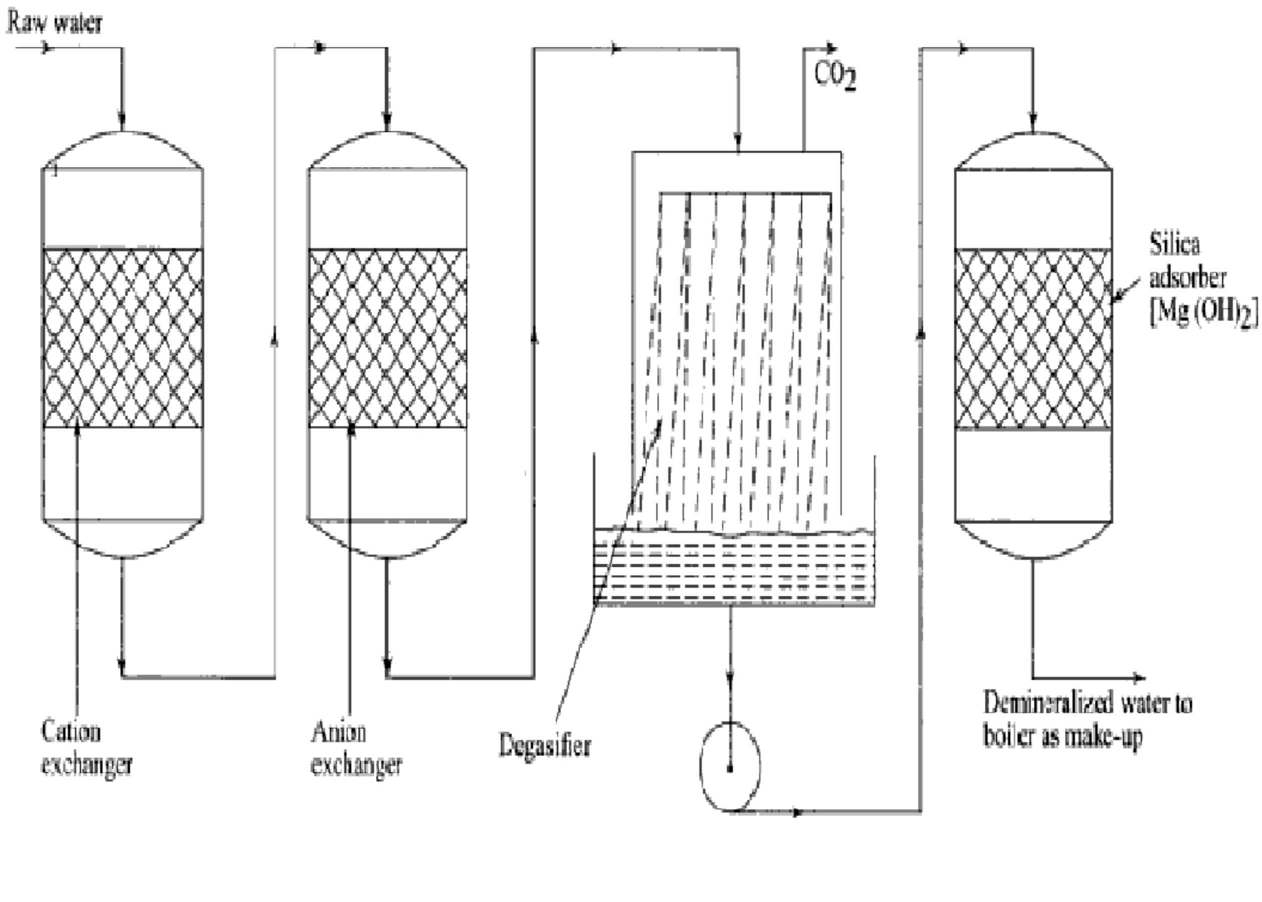
resin is the hydrogen zeolite where the hydrogen ion is exchanged for the cations calcium, magnesium and sodium, and the anion resin adsorbs the anions chlorides, nitrates and sulphates, as discussed above. Both ion-exchange processes are reversible, and the resins are restored to their original form by regeneration,

A typical dimineralizing plant consisting of a cation exchanger, an anion exchanger, a degasifier and a silica adsorber in series is shown in Fig. 6.67. In the degasifier, carbon dioxide gas is removed by aeration. Silica in water is very detrimental at high pressure. It vaporizes at high pressure and flows with steam, condenses on turbine blades in the form of hard glassy scales which are difficult to remove. Magnesium hydroxide is often used to adsorb silica from water.

The membrane treatment for removing the total dissolved solids from make-up water is also an energy efficient process and is gradually gaining more acceptance. It uses the principle of either *reverse osmosis* or *electrodialysis*. The driving force for reverse osmosis is the application of counter pressure to normal osmotic pressure, driving water molecules through the membranes in preference to dissolved salts. The basis of electrodialysis is the reverse of that of reverse osmosis in that it moves dissolved salts away from the water accruing a practical advantage because the quantity of salts is far less than the water volume. The membranes used in either process are expensive, and coagulation, settling and filtration are used first to protect them.

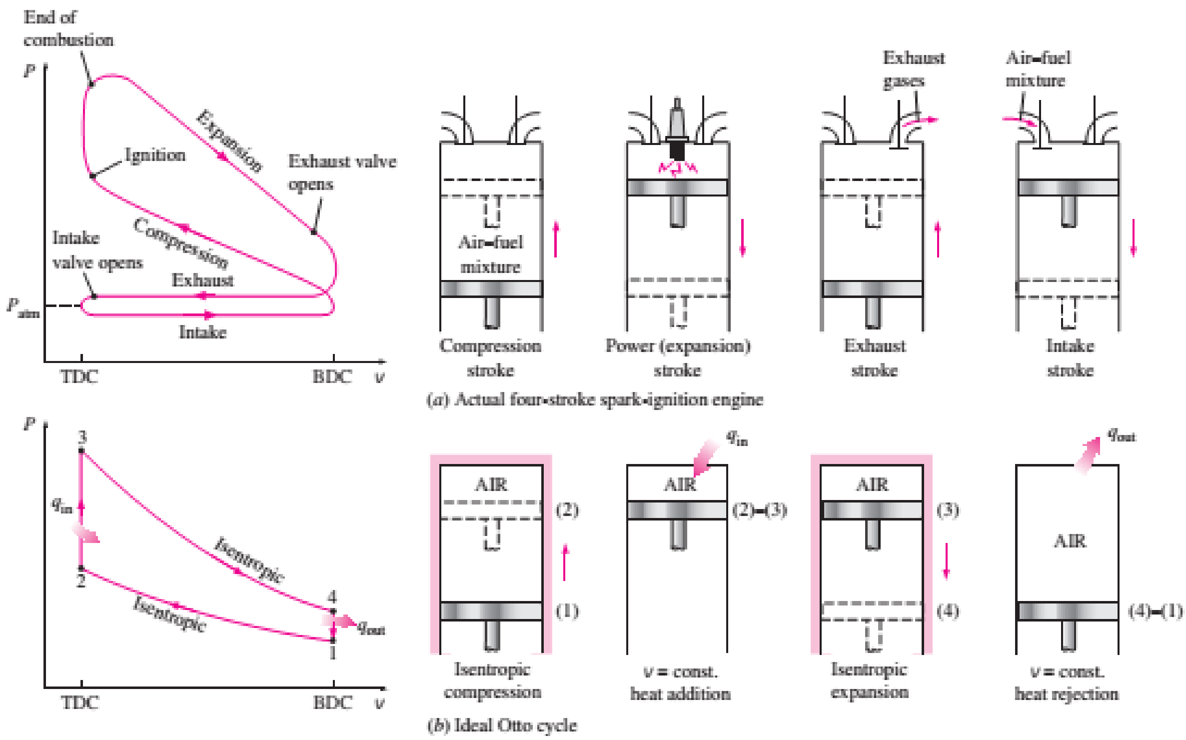
DEAERATION

Deaeration (degasification) is one of the most important steps in boiler water treatment. It depends on the decrease in solubility of dissolved gases, notably O_2 and CO_2 as the water temperature is increased. The deaerator is a direct contact feedwater heater which has been described



UNIT II DIESEL, GAS TURBINE AND COMBINED CYCLE POWER PLANTS

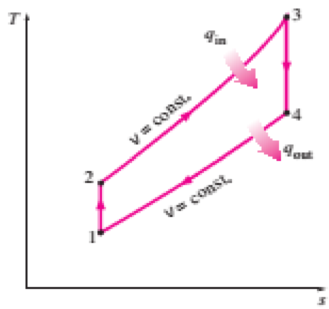
OTTO CYCLE:



Actual and ideal cycles in spark-ignition engines and their *P-v* diagrams.

Initially, both the intake and the exhaust valves are closed, and the piston is at its lowest position (BDC). During the *compression stroke*, the piston moves upward, compressing the air–fuel mixture. Shortly before the piston reaches its highest position (TDC), the spark plug fires and the mixture ignites, increasing the pressure and temperature of the system. The high-pressure gases force the piston down, which in turn forces the crankshaft to rotate, producing a useful work output during the *expansion* or *power stroke*. At the end of this stroke, the piston is at its lowest position (the completion of the first mechanical cycle), and the cylinder is filled with combustion products. Now the piston moves upward one more time, purging the exhaust gases through the exhaust valve (the *exhaust stroke*), and down a second time, drawing in fresh air–fuel mixture through the intake valve (the *intake stroke*). Notice that the pressure in the cylinder is slightly above the atmospheric value during the exhaust stroke and slightly below during the intake stroke.

Otto cycle. It consists of four internally reversible processes:



T-s diagram of the ideal Otto cycle.

1-2 Isentropic compression
2-3 Constant-volume heat addition
3-4 Isentropic expansion
4-1 Constant-volume heat rejection

The execution of the Otto cycle in a piston–cylinder device together with a *P-v* diagram is illustrated The *T-s* diagram of the Otto cycle is given in Fig

The Otto cycle is executed in a closed system, and disregarding the changes in kinetic and potential energies, the energy balance for any of the processes is expressed, on a unit-mass basis, as

$$(q_{in} - q_{out}) + (w_{in} - w_{out}) = \Delta u \qquad \text{(kJ/kg)}$$

No work is involved during the two heat transfer processes since both take place at constant volume. Therefore, heat transfer to and from the working fluid can be expressed as

$$q_{in} = u_3 - u_2 = c_v(T_3 - T_2)$$

and

$$q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$$

Then the thermal efficiency of the ideal Otto cycle under the cold air standard assumptions becomes

$$\eta_{th,Otto} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{T_4 - T_1}{T_3 - T_2} = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)}$$

Processes 1-2 and 3-4 are isentropic, and $v_2 = v_3$ and $v_4 = v_1$. Thus,

$$\frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{k-1} = \left(\frac{v_3}{v_4}\right)^{k-1} = \frac{T_4}{T_3}$$

Substituting these equations into the thermal efficiency relation and simplifying give

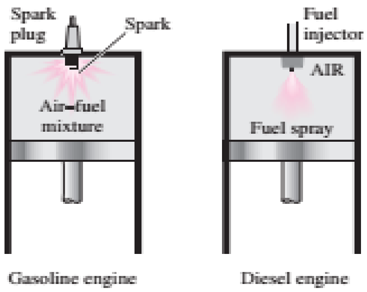
$$\eta_{th,Otto} = 1 - \frac{1}{r^{k-1}}$$

where

$$r = \frac{V_{max}}{V_{min}} = \frac{V_1}{V_2} = \frac{v_1}{v_2}$$

is the **compression ratio** and k is the specific heat ratio c_p/c_v.

Equation shows that under the cold-air-standard assumptions, the thermal efficiency of an ideal Otto cycle depends on the compression ratio of the engine and the specific heat ratio of the working fluid. The thermal efficiency of the ideal Otto cycle increases with both the compression ratio



FIGURE

In diesel engines, the spark plug is replaced by a fuel injector, and only air is compressed during the compression process.

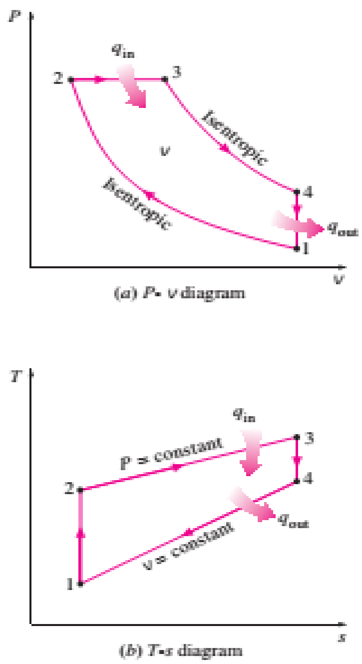


FIGURE 9–21

T-s and *P-v* diagrams for the ideal Diesel cycle.

DIESEL CYCLE: THE IDEAL CYCLE FOR COMPRESSION-IGNITION ENGINES

The Diesel cycle is the ideal cycle for CI reciprocating engines. The CI engine, first proposed by Rudolph Diesel in the 1890s, is very similar to the SI engine discussed in the last section, differing mainly in the method of initiating combustion. In spark-ignition engines (also known as *gasoline engines*), the air–fuel mixture is compressed to a temperature that is below the autoignition temperature of the fuel, and the combustion process is initiated by firing a spark plug. In CI engines (also known as *diesel engines*), the air is compressed to a temperature that is above the autoignition temperature of the fuel, and combustion starts on contact as the fuel is injected into this hot air. Therefore, the spark plug and carburetor are replaced by a fuel injector in diesel engines

In gasoline engines, a mixture of air and fuel is compressed during the compression stroke, and the compression ratios are limited by the onset of autoignition or engine knock. In diesel engines, only air is compressed during the compression stroke, eliminating the possibility of autoignition. Therefore, diesel engines can be designed to operate at much higher compression ratios, typically between 12 and 24. Not having to deal with the problem of autoignition has another benefit: many of the stringent requirements placed on the gasoline can now be removed, and fuels that are less refined (thus less expensive) can be used in diesel engines.

The fuel injection process in diesel engines starts when the piston approaches TDC and continues during the first part of the power stroke. Therefore, the combustion process in these engines takes place over a longer interval. Because of this longer duration, the combustion process in the ideal Diesel cycle is approximated as a constant-pressure heat-addition process. In fact, this is the only process where the Otto and the Diesel cycles differ. The remaining three processes are the same for both ideal cycles. That is, process 1-2 is isentropic compression, 3-4 is isentropic expansion, and 4-1 is constant-volume heat rejection. The similarity between the two cycles is also apparent from the *P-v* and *T-s* diagrams of the Diesel cycle, shown in

Noting that the Diesel cycle is executed in a piston–cylinder device, which forms a closed system, the amount of heat transferred to the working fluid at constant pressure and rejected from it at constant volume can be expressed as

$$q_{in} - w_{b,out} = u_3 - u_2 \rightarrow q_{in} = P_2(v_3 - v_2) + (u_3 - u_2)$$
$$= h_3 - h_2 = c_p(T_3 - T_2)$$

and

$$-q_{out} = u_1 - u_4 \rightarrow q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$$

Then the thermal efficiency of the ideal Diesel cycle under the cold-air-standard assumptions becomes

$$\eta_{th,Diesel} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{T_4 - T_1}{k(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{kT_2(T_3/T_2 - 1)}$$

We now define a new quantity, the **cutoff ratio** r_c, as the ratio of the cylinder volumes after and before the combustion process:

$$r_c = \frac{V_3}{V_2} = \frac{v_3}{v_2}$$

Utilizing this definition and the isentropic ideal-gas relations for processes 1-2 and 3-4, we see that the thermal efficiency relation reduces to

$$\eta_{th,Diesel} = 1 - \frac{1}{r^{k-1}}\left[\frac{r_c^k - 1}{k(r_c - 1)}\right]$$

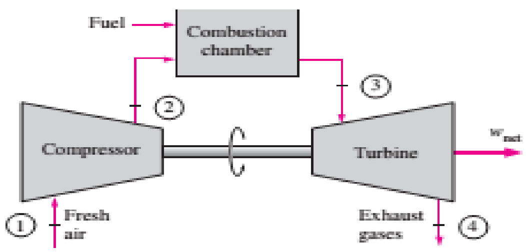
BRAYTON CYCLE: THE IDEAL CYCLE FOR GAS-TURBINE ENGINES

The Brayton cycle was first proposed by George Brayton for use in the reciprocating oil-burning engine that he developed around 1870. Today, it is used for gas turbines only where both the compression and expansion processes take place in rotating machinery. Gas turbines usually operate on an *open cycle*, as shown in Fig. Fresh air at ambient conditions is drawn into the compressor, where its temperature and pressure are raised. The high-pressure air proceeds into the combustion chamber, where the fuel is burned at constant pressure. The resulting high-temperature gases then enter the turbine, where they expand to the atmospheric pressure while producing power. The exhaust gases leaving the turbine are thrown out (not recirculated), causing the cycle to be classified as an open cycle.

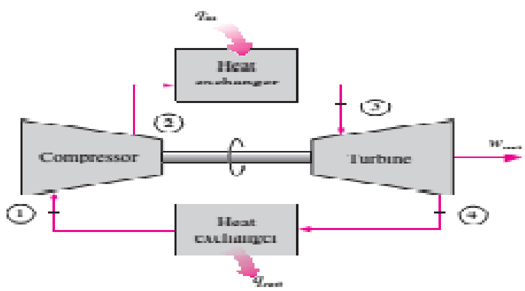
The open gas-turbine cycle described above can be modeled as a *closed cycle*, as shown in Fig. by utilizing the air-standard assumptions. Here the compression and expansion processes remain the same, but the combustion process is replaced by a constant-pressure heat-addition process from an external source, and the exhaust process is replaced by a constant-pressure heat-rejection process to the ambient air. The ideal cycle that the working fluid undergoes in this closed loop is the **Brayton cycle**, which is made up of four internally reversible processes:

1-2 Isentropic compression (in a compressor)

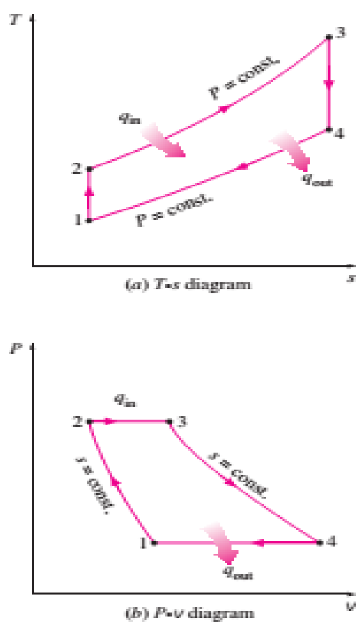
2-3 Constant-pressure heat addition



An open-cycle gas-turbine engine.



A closed cycle gas turbine engine.



IGURE

-s and P-v diagrams for the ideal Brayton cycle.

3-4 Isentropic expansion (in a turbine)

4-1 Constant-pressure heat rejection

The T-s and P-v diagrams of an ideal Brayton cycle are shown in Fig. Notice that all four processes of the Brayton cycle are executed in steady-flow devices; thus, they should be analyzed as steady-flow processes. When the changes in kinetic and potential energies are neglected, the energy balance for a steady-flow process can be expressed, on a unit–mass basis, as

$$(q_{in} - q_{out}) + (w_{in} - w_{out}) = h_{exit} - h_{inlet}$$

Therefore, heat transfers to and from the working fluid are

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

and

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

Then the thermal efficiency of the ideal Brayton cycle under the cold-air-standard assumptions becomes

$$\eta_{th,Brayton} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{c_p(T_4 - T_1)}{c_p(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)}$$

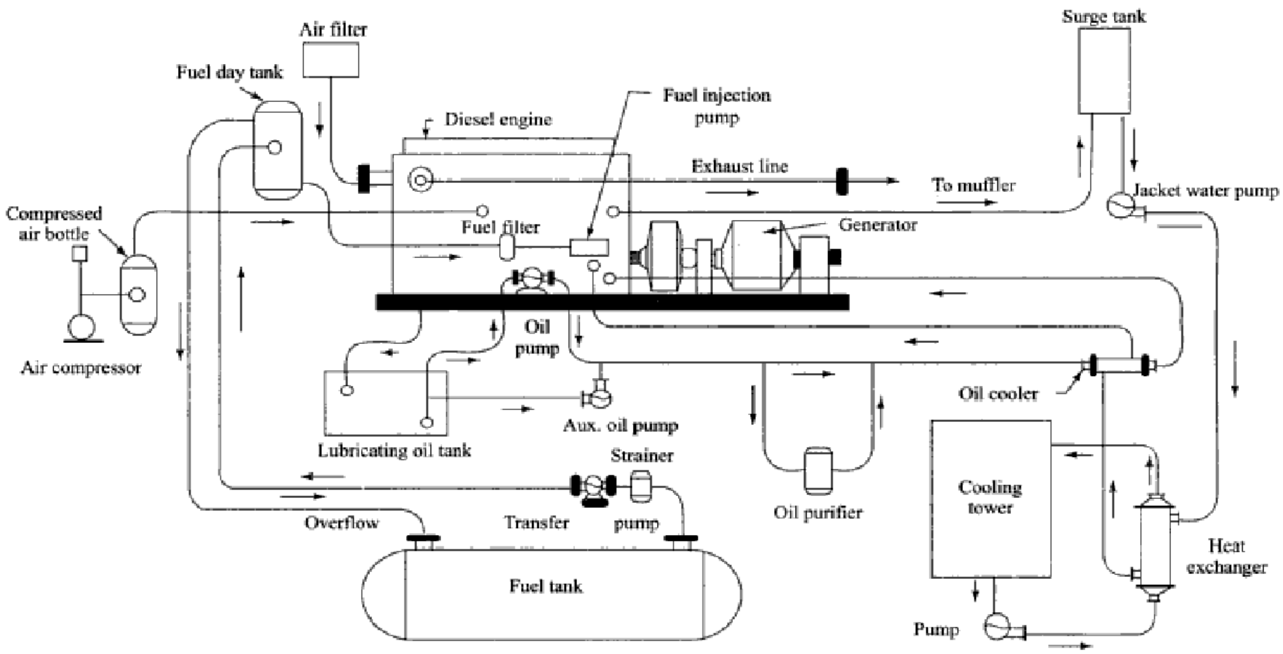
Processes 1-2 and 3-4 are isentropic, and $P_2 = P_3$ and $P_4 = P_1$. Thus,

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

Substituting these equations into the thermal efficiency relation and simplifying give

$$\eta_{th,Brayton} = 1 - \frac{1}{r_p^{(k-1)/k}}$$

Diesel power plant

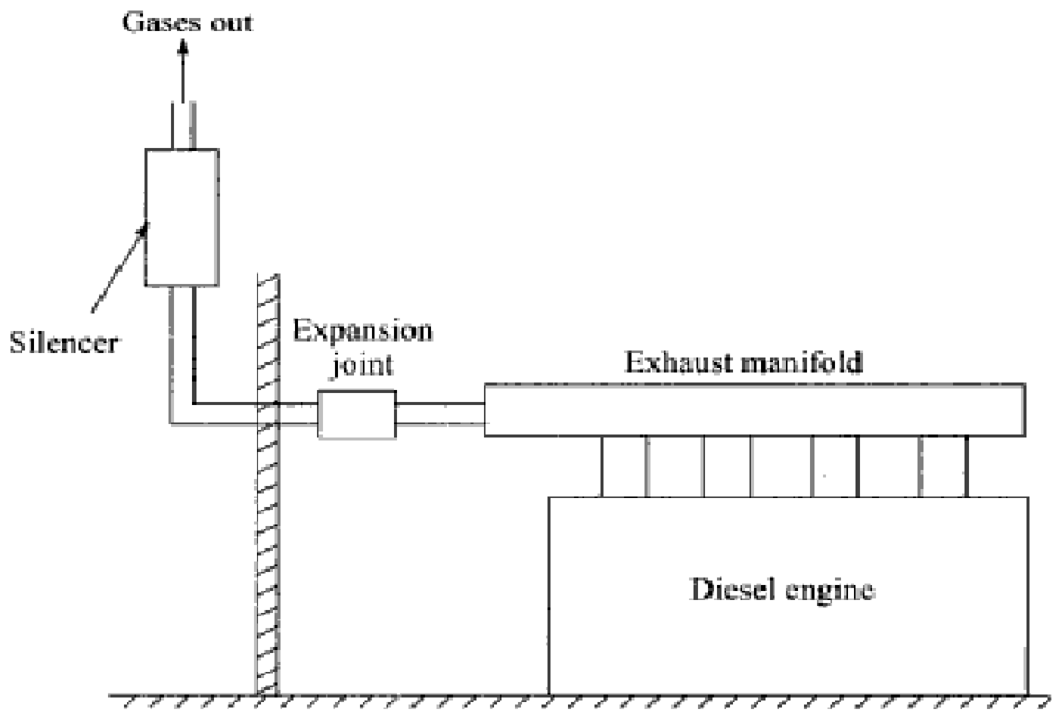


Schematic arrangement of a diesel engine power plant

1. *Engine* It is the main component of the plant and is directly coupled to the generator.

2. *Air intake system* It conveys fresh air through louvres and air filter that removes dirt, etc. causing wear of the engine. Supercharger, if fitted, is generally driven by the engine itself and it augments the power output of the engine.

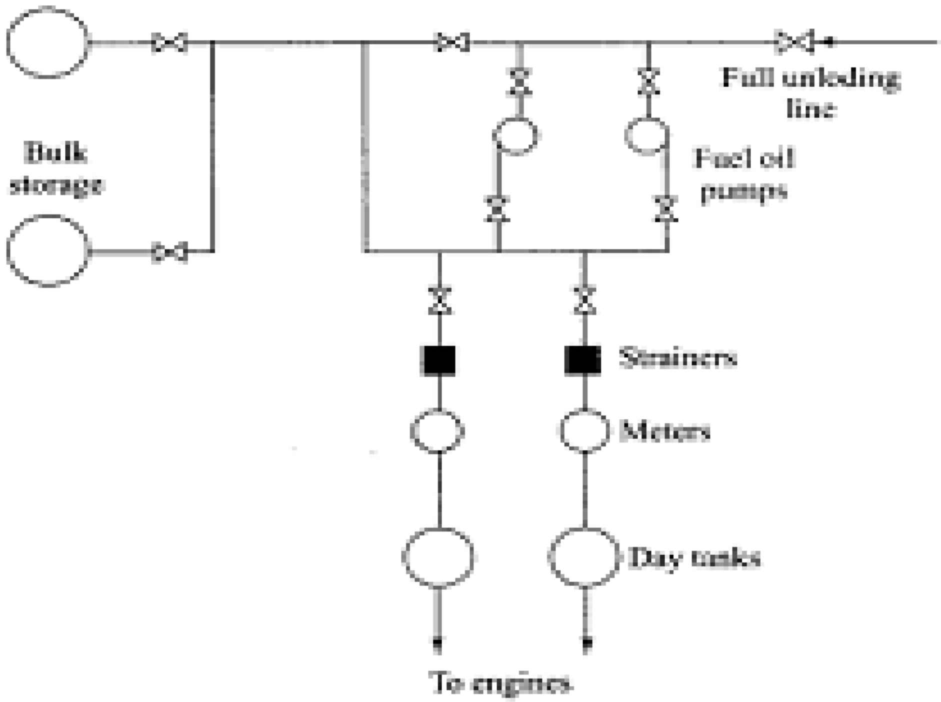
3. *Exhaust system* It discharges the engine exhaust to the atmosphere. The exhaust manifold connects the engine cylinder exhaust outlets to the exhaust pipe which is provided with a muffler or silencer to reduce pressure on the exhaust line and eliminate most of the noise which may result if gases are discharged directly to the atmosphere. The exhaust pipe should have flexible tubing system to take up the effects of expansion due to high temperature and also isolate the exhaust system from the engine vibration



Diesel engine exhaust system

There is scope of waste heat utilization from the diesel engine exhaust by installing a waste heat boiler to raise low pressure steam which can be used for any process, purpose or for generating electricity. The hot exhaust may also be utilized to heat water in a gas-to-water heat exchanger which can be in the form of a water coil installed in the exhaust muffler. It can also be used for air heating where the exhaust pipe is surrounded by the cold air jacket.

4. *Fuel system* Fuel oil may be delivered at the plant site by trucks, railway wagons or barges and oil tankers. An unloading facility delivers oil to the main storage tanks from where oil is pumped to small service storage tanks known as engine day tanks, which store oil for approximately eight hours of operation Coils heated by hot water or steam reduce oil viscosity to reduce pumping power.



Fuel storage in a diesel engine power plant

The fuel injection system is the heart of a diesel engine. Engines driving electric generators have lower speeds and simple combustion chambers that promote good mixing of fuel and air. The fuel injection system performs the following functions.

(a) Filter the fuel
(b) Meter the correct quantity of the fuel to be injected
(c) Time the injection process
(d) Regulate the fuel supply
(e) Secure fine atomization of fuel oil
(f) Distribute the atomized fuel properly in the combustion chamber.

Oil is atomized either by air blast or pressure jet. Early diesel engines used air blast fuel atomization where compressed air at about 70 bar was used to atomize as well as to inject the fuel oil. For this an air compressor and a storage tank are needed, which becomes expensive. In pressure jet atomization the fuel oil is forced to flow through spray nozzles at a pressure above 100 bar. It is known as solid injection, which is more common. Solid injection systems may be classified as follows.

(a) Common rail injection system
(b) Individual pump injection system
(c) Distributor system

(a) *Common rail injection system* A single pump supplies fuel under high pressure to a fuel header or common rail The high pressure in the header forces the fuel to each of the nozzles located in the cylinders. At the proper time a mechanically operated valve (by means of a push rod and a rocker arm) allows the fuel to enter the cylinder through the nozzle. The amount of fuel entering the cylinder is regulated by varying the length of the push rod stroke.

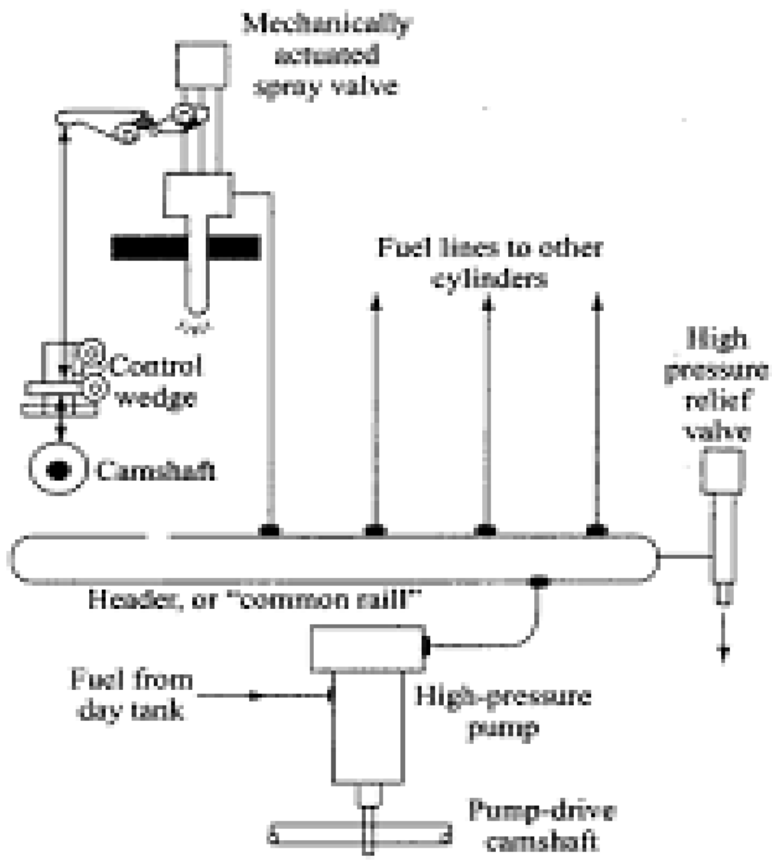
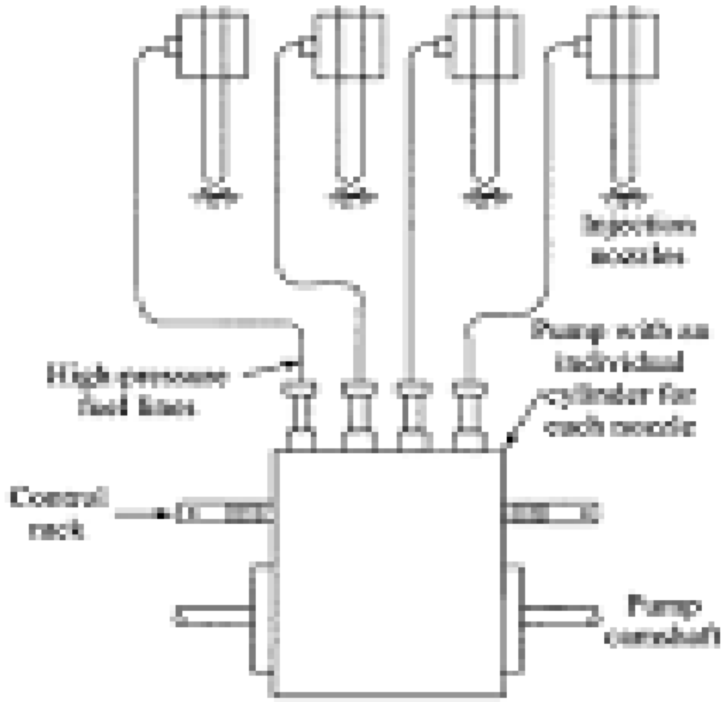


Fig. 11.5 *Common-rail injection system*

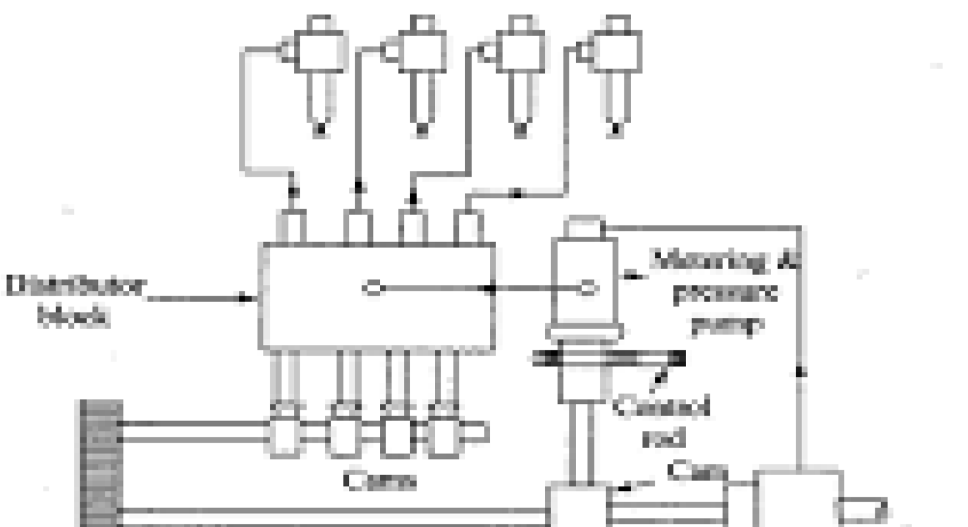
(b) *Individual pump injection system* Each cylinder is provided with one pump and one injector The pump directly feeds oil to the cylinder, meters the oil and controls the injection timing. The nozzle contains a delivery valve actuated by fuel oil pressure.

(c) *Distributor system* In this system the fuel is metered at a central point. A pump pressurises, meters the fuel and times the injection The fuel is then distributed to cylinders in correct firing order by cam-operated poppet valves which open to admit oil to the fuel nozzle.

Fuel pump It consists of a plunger (L) driven by a cam and tappet mechanism, which reciprocates inside a barrel B A vertical groove in the plunger leads to a helical groove. The delivery valve (V) lifts off its seat under oil pressure against the spring force (S). When the plunger is at the bottom, the supply port Y and the spill port (SP) are uncovered and low pressure filtered oil is forced into the barrel. As the plunger moves up, the ports Y and SP are closed and oil gets compressed lifting the delivery valve



Individual pump injection system



Distributor fuel injection system

V to enter the injector nozzle through the passage *P*. When the plunger moves up further, the port *SP* gets connected to the fuel at its top through the vertical groove resulting in a sudden drop in pressure and the delivery valve falls back to its seat against the spring force. The plunger is rotated by the rack *R* operated by a governor. By rotating the plunger the position of the helical groove relative to the supply port *V* can be varied. The length of stroke during

5. *Cooling system* The temperature of the gases inside the cylinder may be as high as 2750°C. If there is no external cooling, the cylinder walls and piston will tend to assume the average temperature of the gases which may be of the order of 1000° to 1500°C. The cooling of the engine is necessary for the following reasons.

(a) The lubricating oil used determines the maximum engine temperature that can be used. This temperature varies from 160°C to 200°C. Above these temperatures the lubricating oil deteriorates very rapidly and may evaporate and burn damaging the piston and cylinder surfaces. Piston seizure due to overheating may also occur.

(b) The strength of the materials used for various engine parts decreases with increase in temperature. Local thermal stresses can develop due to uneven expansion of various parts, often resulting in cracking.

(c) High engine temperatures may result in very hot exhaust valve, giving rise to pre-ignition and detonation or knocking.

(d) Due to high cylinder head temperature, the volumetric efficiency and hence power output of the engine are reduced.

Following are the two methods of cooling the engine.

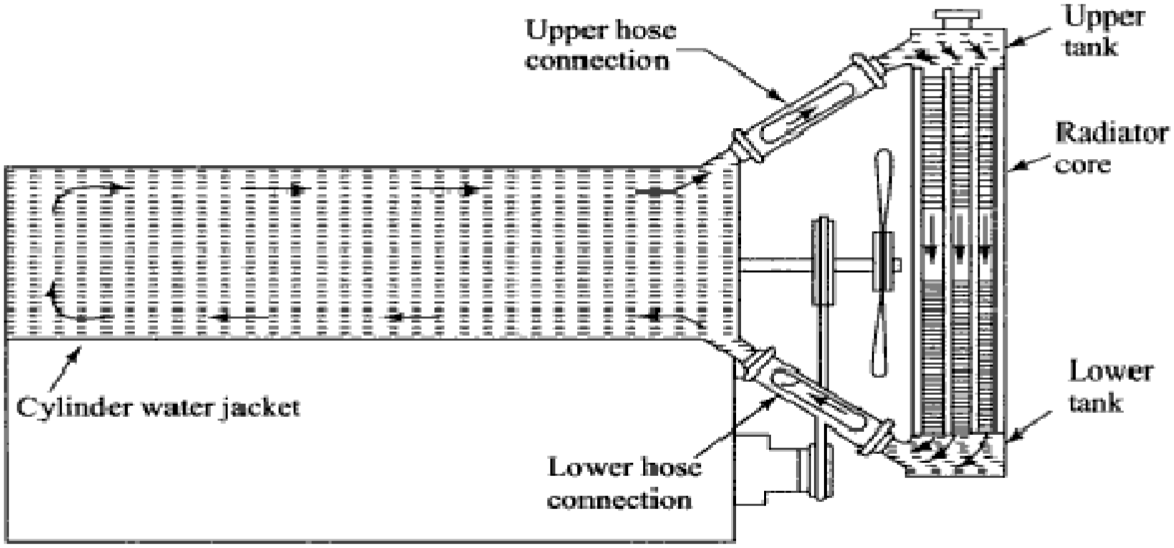
(i) Air cooling
(ii) Water cooling

Air cooling is used in small engines, where fins are provided to increase heat transfer surface area.

Big diesel engines are always water cooled. The cylinder and its head are enclosed in a water jacket which is connected to a radiator. Water flowing in the jacket carries away the heat from the engine and becomes heated. The hot water then flows into the radiator and gets cooled by rejecting heat to air from the radiator walls. Cooled water is again circulated in the water jacket.

Various methods used for circulating the water around the cylinder are the following.

(a) *Thermosiphon cooling* In this method water flow is caused by density difference The rate of circulation is however slow and insufficient.



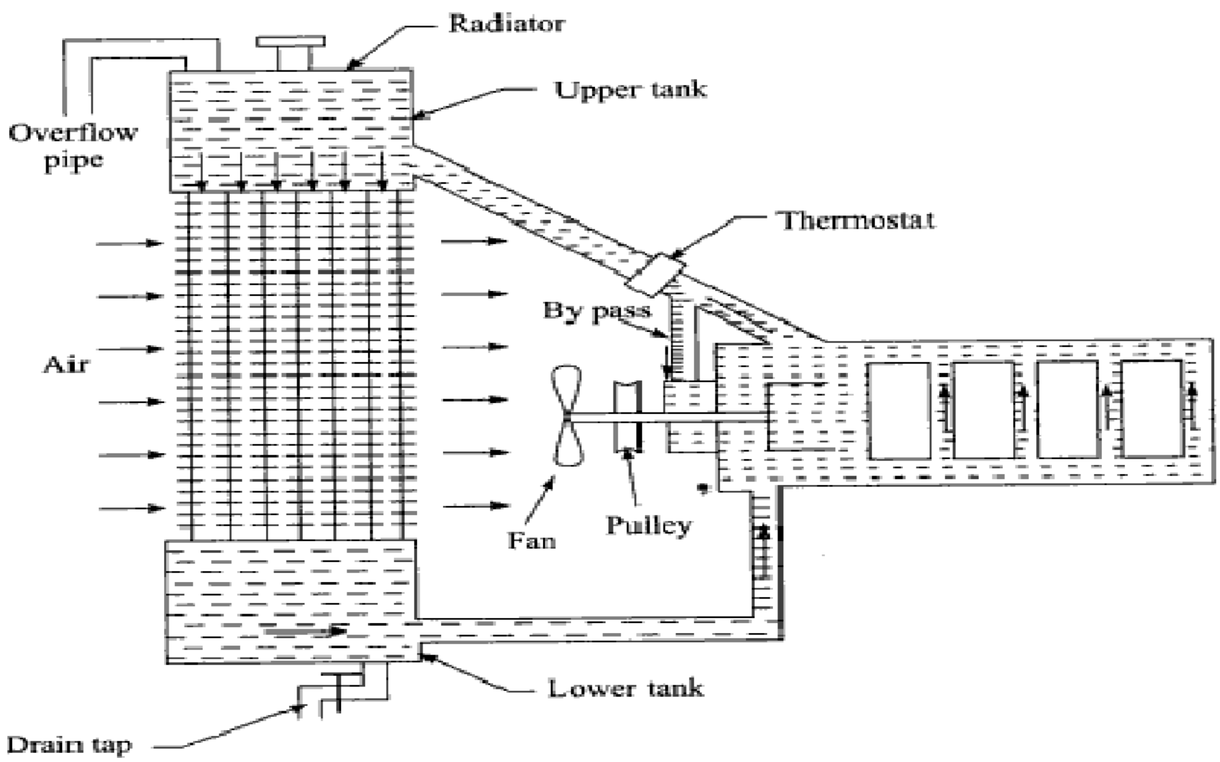
Thermosiphon cooling

(b) *Forced cooling by pump* In this method a pump, taking power from the engine, forces water to circulate, ensuring engine cooling under all operating conditions. There may be overcooling which may cause low temperature corrosion of metal parts due to the presence of acids.

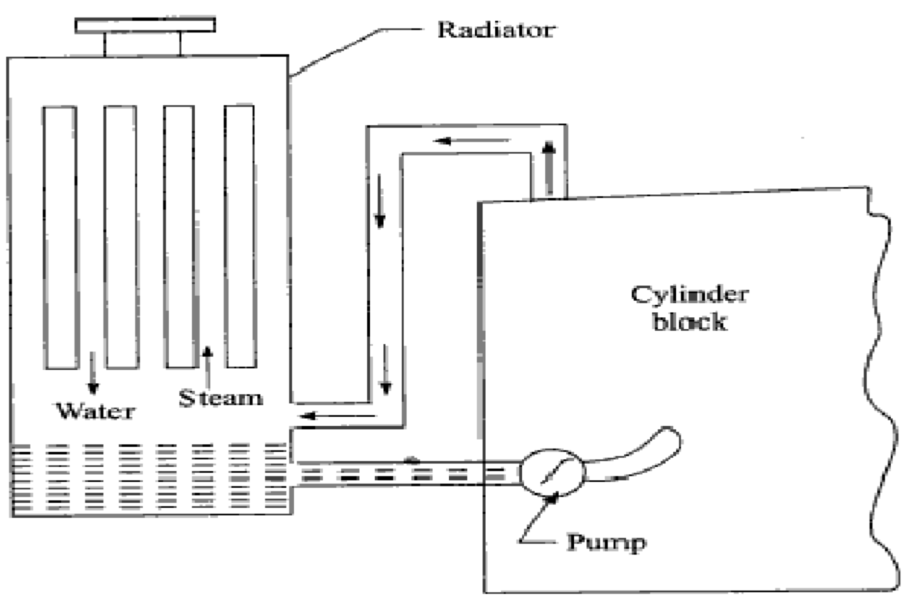
(c) *Thermostat cooling* This is a method in which a thermostat maintains the desired temperature and protects the engine from getting overcooled

(d) *Pressurized water cooling* In this method a higher water pressure, 1.5 to 2 bar, is maintained to increase heat transfer in the radiator. A pressure relief valve is provided against any pressure drop or vacuum.

(e) *Evaporative cooling* In this method water is allowed to evaporate absorbing the latent heat of evaporation from the cylinder walls. The cooling circuit is such that the coolant is always liquid and the steam flashes in a separate vessel



Thermostat cooling



Evaporative cooling

7. *Starting of engine* Following are the three common methods of starting an engine.

(i) By an auxiliary engine, which is mounted close to the main engine and drives the latter through a clutch and gears.

(ii) By using an electric motor, in which a storage battery of 12 to 36 volts is used to supply power to an electric motor that derives the engine.

(iii) By compressed air system, in which compressed air at about 17 bar supplied from an air tank is admitted to a few engine cylinders making them work like reciprocating air motors to run the engine shaft. Fuel is admitted to the remaining cylinders and ignited in the normal way causing the engine to start. The compressed air system is commonly used for starting large diesel engines employed for stationary power plant service.

Gas Turbine Power Plants

Schematic arrangement of a gas turbine power plant:

The schematic arrangement of a gas turbine power plant is shown in Figure below.The main components of the plant are :

(i) Compressor

(ii) Regenerator

(iii) Combustion chamber

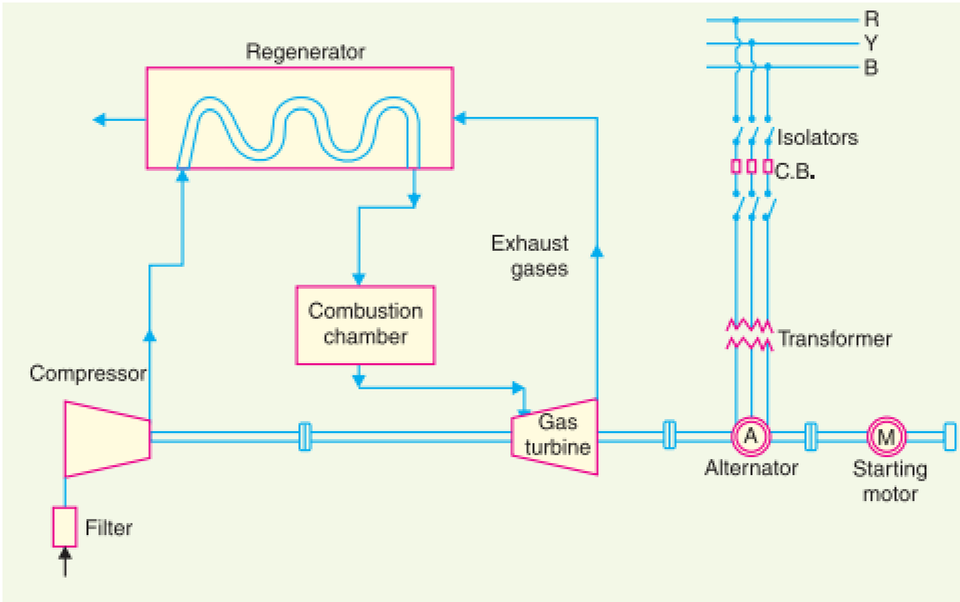
(iv) Gas turbine

(v) Alternator

(vi) Starting motor

(i) **Compressor :** The compressor used in the plant is generally of rotator type. The air at atmospheric pressure is drawn by the compressor via the filter which removes the dust from air. The rotatory blades of the compressor push the air between stationary blades to raise its pressure. Thus air at high pressure is available at the output of the compressor.

(ii) **Regenerator :** A regenerator is a device which recovers heat from the exhaust gases of the turbine. The exhaust is passed through the regenerator before wasting to atmosphere. A regenerator consists of a nest of tubes contained in a shell. The compressed air from the compressor passes through the tubes on its way to the combustion chamber. In this way, compressed air is heated by the hot exhaust gases.



Schematic arrangement of gas turbine power plant.

Gas turbine power plant

(iii) **Combustion chamber :** The air at high pressure from the compressor is led to the combustion chamber via the regenerator.In the combustion chamber, heat is added to the air by burning oil.The oil is injected through the burner into the chamber at high pressure to ensure atomization of oil and its thorough mixing with air.The result is that the chamber attains a very high temperature (about 3000 F).The combustion gases are suitably cooled to 1300
F to 1500F and then delivered to the gas turbine.

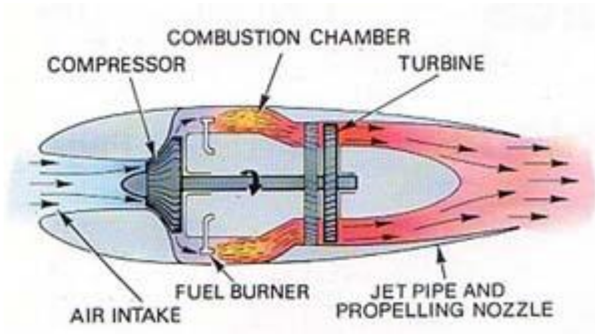
(iv) **Gas turbine :** The products of combustion consisting of a mixture of gases at high temperature and pressure are passed to the gas turbine.These gases in passing over the turbine blades expand and thus do the mechanical work. The temperature of the exhaust gases from the turbine is about 900F.

(v) **Alternator :** The gas turbine is coupled to the alternator.The alternator converts mechanical energy of the turbine into electrical energy.The output from the alternator is given to the bus-bars through transformer, circuit breakers and isolators.

(vi) **Starting motor :** Before starting the turbine, compressor has to be started. For this purpose,an electric motor is mounted on the same shaft as that of the turbine.The motor is energised by the batteries.Once the unit starts, a part of mechanical power of the turbine drives the compressor and there is no need of motor now.

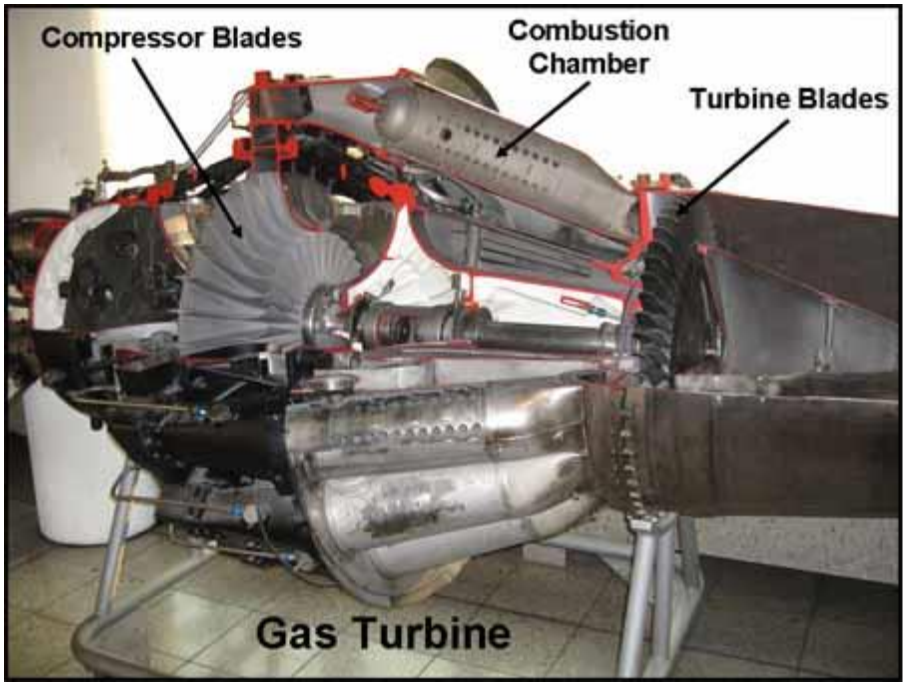
Gas Turbine Working Principle

Gas turbine engines derive their power from burning fuel in a combustion chamber and using the fast flowing combustion gases to drive a turbine in much the same way as the high pressure steam drives a steam turbine.



One major difference however is that the gas turbine has a second turbine acting as an air compressor mounted on the same shaft. The air turbine (compressor) draws in air, compresses it and feeds it at high pressure into the combustion chamber increasing the intensity of the burning flame.
It is a positive feedback mechanism. As the gas turbine speeds up, it also causes the compressor to speed up forcing more air through the combustion chamber which in turn increases the burn rate of the fuel sending more high pressure hot gases into the gas turbine increasing its speed even more. Uncontrolled runaway is prevented by controls on the fuel supply line which limit the amount of fuel fed to the turbine thus limiting its speed.

The thermodynamic process used by the gas turbine is known as the Brayton cycle. Analogous to the Carnot cycle in which the efficiency is maximised by increasing the temperature difference of the working fluid between the input and output of the machine, the Brayton cycle efficiency is maximised by increasing the pressure difference across the machine. The gas turbine is comprised of three main components: a compressor, a combustor, and a turbine. The working fluid, air, is compressed in the compressor (adiabatic compression - no heat gain or loss), then mixed with fuel and burned by the combustor under constant pressure conditions in the combustion chamber (constant pressure heat addition). The resulting hot gas expands through the turbine to perform work (adiabatic expansion). Much of the power produced in the turbine is used to run the compressor and the rest is available to run auxiliary equipment and do useful work. The system is an open system because the air is not reused so that the fourth step in the cycle, cooling the working fluid, is omitted.



Gas Turbine Aero Engine (Deutches Museum)

Gas turbines have a very high power to weight ratio and are lighter and smaller than internal combustion engines of the same power. Though they are mechanically simpler than reciprocating engines, their characteristics of high speed and high temperature operation require high precision components and exotic materials making them more expensive to manufacture.

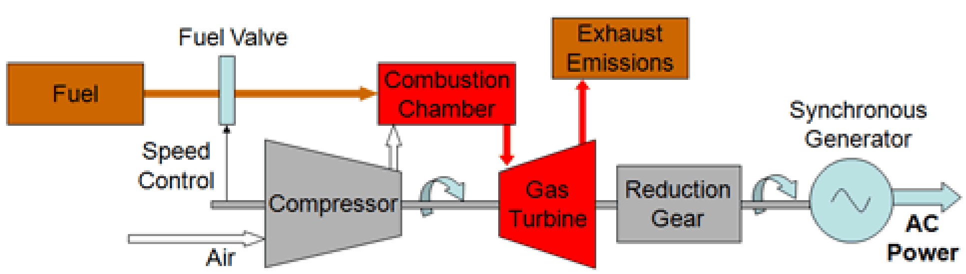
Electrical Power Generation

In electricity generating applications the turbine is used to drive a synchronous generator which provides the electrical power output but because the turbine normally operates at very high rotational speeds of 12,000 r.p.m or more it must be connected to the generator through a high ratio reduction gear since the generators run at speeds of 1,000 or 1,200 r.p.m. depending on the AC frequency of the electricity grid.

Turbine Configurations

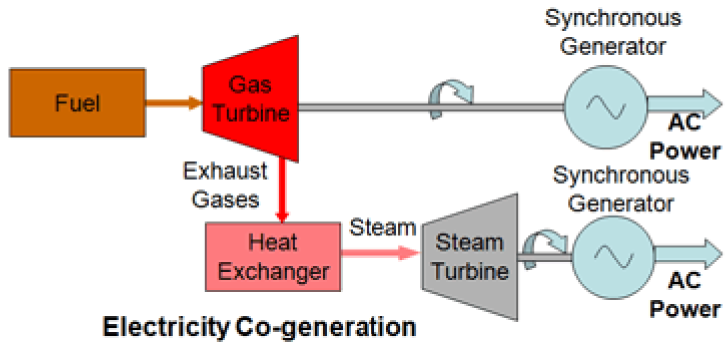
Gas turbine power generators are used in two basic configurations

- **Simple Systems** consisting of the gas turbine driving an electrical power generator.



Gas Turbine Electric Power Generation

- **Combined Cycle Systems** which are designed for maximum efficiency in which the hot exhaust gases from the gas turbine are used to raise steam to power a steam turbine with both turbines being connected to electricity generators.



Turbine Performance

- **Turbine Power Output**
  To minimise the size and weight of the turbine for a given output power, the output per pound of airflow should be maximised. This is obtained by maximising the air flow through the turbine which in turn depends on maximising the pressure ratio between the air inlet and exhaust outlet. The main factor governing this is the pressure ratio across the compressor which can be as high as 40:1 in modern gas turbines. In simple cycle applications, pressure ratio increases translate into efficiency gains at a given firing temperature, but there is a limit since increasing the pressure ratio means that more energy will be consumed by the compressor.

- **System Efficiency**
  Thermal efficiency is important because it directly affects the fuel consumption and operating costs.
  - **Simple Cycle Turbines**
    A gas turbine consumes considerable amounts of power just to drive its compressor. As with all cyclic heat engines, a higher maximum working temperature in the machine means greater efficiency (Carnot's Law), but in a turbine it also means that more energy is lost as waste heat through the hot exhaust gases whose temperatures are typically well over 1,000°C . Consequently simple cycle turbine efficiencies are quite low. For heavy plant, design efficiencies range between 30% and 40%. (The efficiencies of aero engines are in the range 38% and 42% while low power microturbines (<100kW) achieve only 18% to 22%). Although increasing the firing temperature increases the output power at a given pressure ratio, there is also a sacrifice of efficiency due to the increase in losses due to the cooling air required to maintain the turbine components at reasonable working temperatures.

  - **Combined Cycle Turbines**
    It is however possible to recover energy from the waste heat of simple cycle systems by using the exhaust gases in a hybridsystem to raise steam to drive a steam turbine electricity generating set . In such cases the exhaust temperature may be reduced to as low as 140°C enabling efficiencies of up to 60% to be achieved in combined cycle systems.

In combined-cycle applications, pressure ratio increases have a less pronounced effect on the efficiency since most of the improvement comes from increases in the Carnot thermal efficiency resulting from increases in the firing temperature.

Thus simple cycle efficiency is achieved with high pressure ratios. Combined cycle efficiency is obtained with more modest pressure ratios and greater firing temperatures.

Fuels

One further advantage of gas turbines is their fuel flexibility. They can be adapted to use almost any flammable gas or light distillate petroleum products such as gasoline (petrol), diesel and kerosene (paraffin) which happen to be available locally, though natural gas is the most commonly used fuel. Crude and other heavy oils and can also be used to fuel gas turbines if they are first heated to reduce their viscosity to a level suitable for burning in the turbine combustion chambers.

Applications

Gas turbines can be used for large scale power generation. Examples are applications delivering 600 MW or more from a 400 MW gas turbine coupled to a 200 MW steam turbine in a co-generating installation. Such installations are not normally used for base load electricity generation, but for bringing power to remote sites such as oil and gas fields. They do however find use in the major electricity grids in peak shaving applications to provide emergency peak power.

Low power gas turbine generating sets with capacities up to 5 MW can be accommodated in transportation containers to provide mobile emergency electricity supplies which can delivered by truck to the point of need.

Integrated gasification combined cycle

An **integrated gasification combined cycle** (**IGCC**) is a technology that uses a high pressure gasifier to turn coal and other carbon based fuels into pressurized gas—synthesis gas (syngas). It can then remove impurities from the syngas prior to the power generation cycle. Some of these pollutants, such as sulfur, can be turned into re-usable byproducts through the Claus process. This results in lower emissions of sulfur dioxide, particulates, mercury, and in some cases carbon dioxide. With additional process equipment, a water-gas shift reaction can increase gasification efficiency and reduce carbon monoxide emissions by converting it to carbon dioxide. The resulting carbon dioxide from the shift reaction can be separated, compressed, and stored through sequestration. Excess heat from the primary combustion and syngas fired generation is then passed to a steam cycle, similar to a combined cycle gas turbine. This process results in improved thermodynamic efficiency compared to conventional pulverized coal combustion.

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

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

IGCC plants are advantageous in comparison to conventional coal power plants due to their high thermal efficiency, low non-carbon greenhouse gas emissions and capability to process low grade coal. The key disadvantage is the amount of CO2 released without pre-combustion capture.[2]

Benefits and drawbacks

A major drawback of using coal as a fuel source is the emission of carbon dioxide and other pollutants, including sulfur dioxide, nitrogen oxide, mercury, and particulates. Almost all coal-fired power plants use pulverized coal combustion, which grinds the coal to increase the surface area, burns it to make steam, and runs the steam through a turbine to generate electricity. Pulverized coal plants can only capture carbon dioxide after combustion when it is diluted and harder to separate. In comparison, gasification in IGCC allows for separation and capture of the concentrated and pressurized carbon dioxide before combustion. Syngas cleanup includes filters to remove bulk particulates, scrubbing to remove fine particulates, and solid absorbents for mercury removal. Additionally, hydrogen gas is used as fuel, which produces no pollutants under combustion.[4]

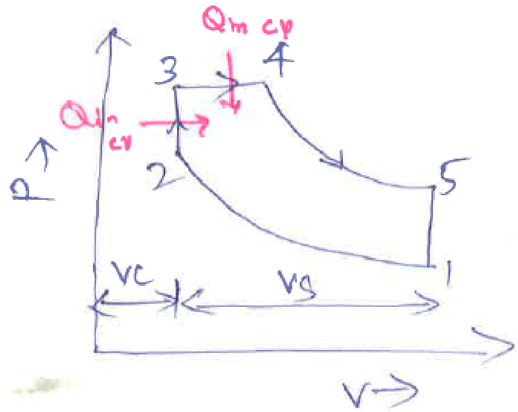
IGCC also consumes less water than traditional pulverized coal plants. In a pulverized coal plant, coal is burned to produce steam, which is then used to create electricity using a steam turbine. Then steam exhaust must then be condensed with cooling water, and water is lost by evaporation. In IGCC, water consumption is reduced by combustion in a gas turbine, which uses the generated heat to expand air and drive the turbine. Steam is only used to capture the heat from the combustion turbine exhaust for use in a secondary steam turbine. Currently, the major drawback is the high capital cost compared to other forms of power production. To become an economically viable source of energy, gasification-based plants must become comparable to pulverized coal and natural gas plants in terms of capital costs.

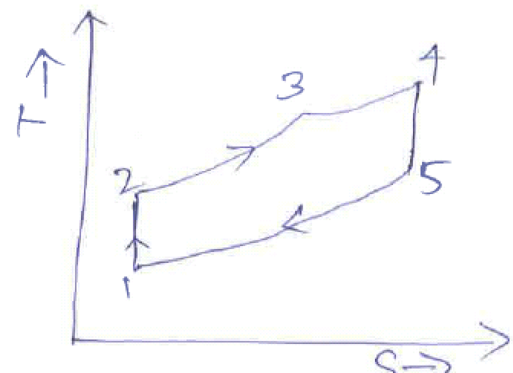
DUAL CYCLE:

Heat addition takes place partially by Constant volume and remaining by Constant Pressure.

It Consists of

* Two reversible adiabatic or Isentropic
* Two Constant volume
* One Constant Pressure





T-s diagram.

Process 1-2: Isentropic Compression Process

Process 2-3: Constant volume heat addition Process.

$$Q_{s1} = m \times C_v (T_3 - T_2)$$

Process 3-4: Constant pressure heat addition process.

$$Q_{s2} = m C_p (T_4 - T_3)$$

Process 4-5: Isentropic expansion process

Process 5-1: Constant volume heat rejection process.

$$Q_R = m \times C_v (T_5 - T_1)$$

Total heat supplied,

$$Q_S = Q_{S1} + Q_{S2}$$
$$= m C_v (T_3 - T_2) + m C_p (T_4 - T_3)$$

$$\eta = \frac{W}{Q_S} = \frac{Q_S - Q_R}{Q_S}$$

$$= \frac{m C_v (T_3 - T_2) + m C_p (T_4 - T_3) - m C_v (T_5 - T_1)}{m C_v (T_3 - T_2) + m C_p (T_4 - T_3)}$$

$$= 1 - \frac{T_5 - T_1}{(T_3 - T_2) + \gamma (T_4 - T_3)}$$

Compression ratio, $r = V_1/V_2$

Pressure ratio $k = P_3/P_2$

cut off ratio, $\rho = V_4/V_3$

Expansion ratio $\frac{V_5}{V_4} = \frac{V_1}{V_4} = \frac{V_1}{V_2} \times \frac{V_2}{V_4}$

$$= \frac{V_1}{V_2} \times \frac{V_3}{V_4} = r/\rho$$

Consider Process 1-2

$$T_2/T_1 = (V_1/V_2)^{\gamma-1} = (r)^{\gamma-1}$$

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

Process 2-3

Constant volume Process, $\frac{P_2}{T_2} = \frac{P_3}{T_3}$

$$T_3 = \frac{P_3}{P_2} T_2 = K \cdot T_1 (r)^{\gamma-1}$$

Process 3-4;

Constant pressure Process $\frac{V_3}{T_3} = \frac{V_4}{T_4}$

$$T_4 = \frac{V_4}{V_3} T_3 = \rho \cdot K \cdot T_1 (r)^{\gamma-1}$$

Consider Process 4-5 : Isentropic Process

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

$$T_5 = \frac{T_4}{(r/\rho)^{\gamma-1}} = \frac{T_4\ \rho^{\gamma-1}}{(r)^{\gamma-1}} = \frac{T_1 (r)^{\gamma-1} k\cdot\rho\cdot\rho^{\gamma-1}}{(r)^{\gamma-1}}$$

$$= T_1 \cdot k \cdot \rho^{\gamma}$$

Sub/. T_2, T_3, T_4 & T_5 in η eqn.

$$\eta = 1 - \frac{T_1 k\rho^{\gamma} - T_1}{[T_1 (r)^{\gamma-1} k - T_1 (r)^{\gamma-1}] + \gamma [T_1 (r)^{\gamma-1} k\rho - T_1 (r)^{\gamma-1} k]}$$

$$= 1 - \frac{T_1 (k\rho^{\gamma} - 1)}{T_1 (r)^{\gamma-1} [(k-1) + \gamma k (\rho - 1)]}$$

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

UNIT III NUCLEAR POWER PLANTS

NUCLEAR POWER PLANT:

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

Nuclear power provides about 6% of the world's energy and 13–14% of the world's electricity, with the U.S., France, and Japan together accounting for about 50% of nuclear generated electricity. Also, more than 150 naval vessels using nuclear propulsion have been built. Just as many conventional thermal power stations generate electricity by harnessing the thermal energy released from burning fossil fuels, nuclear power plants convert the energy released from the nucleus of an atom, typically via nuclear fission.

NUCLEAR REACTOR TECHNOLOGY

When a relatively large atomic nucleus (usually uranium-235 or plutonium-239) absorbs a neutron, a fission of the atom often results. Fission splits the atom into two or more smaller nuclei with kinetic energy (known as fission products) and also releases gamma radiation and free neutrons .[59] A portion of these neutrons may later be absorbed by other fissile atoms and create more fissions, which release more neutrons, and so on

NUCLEAR ENERGY:

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

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Nuclear power is controversial and there is an ongoing debate about the use of nuclear energy. Proponents, such as the World Nuclear Association and IAEA, contend that nuclear power is a sustainable energy source that reduces carbon emissions. Opponents, such as Greenpeace International and NIRS, believe that nuclear power poses many threats to people and the environment.

NUCLEAR FISSION:

In nuclear physics and nuclear chemistry, nuclear fission is a nuclear reaction in which the nucleus of an atom splits into smaller parts (lighter nuclei), often producing free neutrons and photons (in the form of gamma rays). The two nuclei produced are most often of comparable size, typically with a mass ratio around 3:2 for common fissile isotopes. Most fissions are binary fissions, but occasionally (2 to 4 times per 1000 events), three positively-charged fragments are produced in a ternary fission. The smallest of these ranges in size from a proton to an argon nucleus.

Fission is usually an energetic nuclear reaction induced by a neutron, although it is occasionally seen as a form of spontaneous radioactive decay, especially in very high-mass-number isotopes. The unpredictable composition of the products (which vary in a broad probabilistic and somewhat chaotic manner) distinguishes fission from purely quantum-tunnelling processes such as proton emission, alpha decay and cluster decay, which give the same products every time.

Fission of heavy elements is an exothermic reaction which can release large amounts of energy both as electromagnetic radiation and as kinetic energy of the fragments (heating the bulk material where fission takes place). In order for fission to produce energy, the total binding energy of the resulting elements must be less than that of the starting element. Fission is a form of nuclear transmutation because the resulting fragments are not the same element as the original atom.

NUCLEAR FUSION:

In nuclear physics, nuclear chemistry and astrophysics nuclear fusion is the process by which two or more atomic nuclei join together, or "fuse", to form a single heavier nucleus. This is usually accompanied by the release or absorption of large quantities of energy. Large-scale thermonuclear fusion processes, involving many nuclei fusing at once, must occur in matter at very high densities and temperatures.

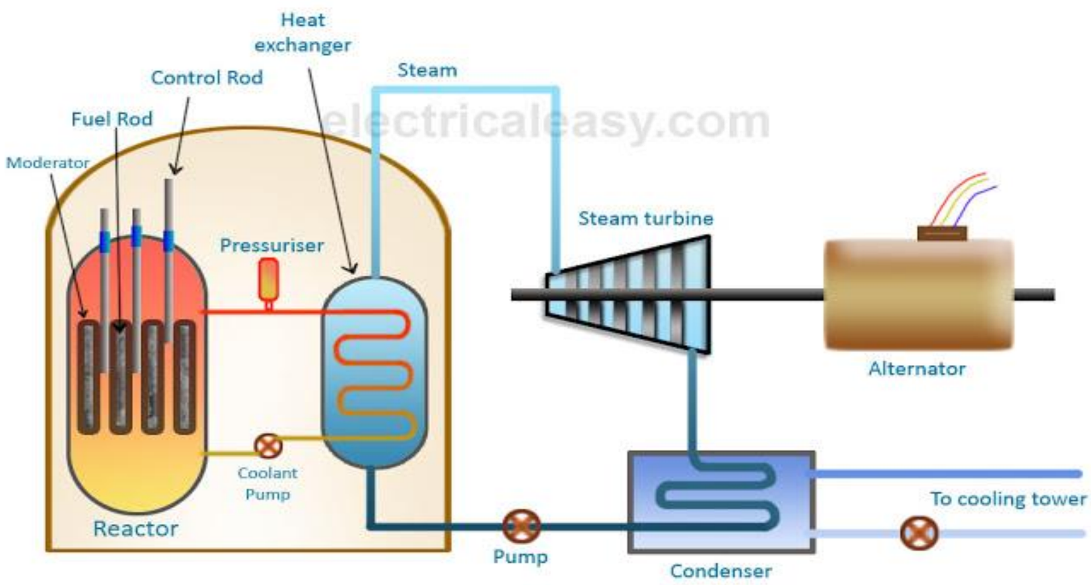
The fusion of two nuclei with lower masses than iron (which, along with nickel, has the largest binding energy per nucleon) generally releases energy while the fusion of nuclei heavier than iron absorbs energy. The opposite is true for the reverse process, nuclear fission.

In the simplest case of hydrogen fusion, two protons must be brought close enough for the weak nuclear force to convert either of the identical protons into a neutron, thus forming the hydrogen isotope deuterium. In more complex cases of heavy ion fusion involving two or more nucleons, the reaction mechanism is different, but the same result occurs— smaller nuclei are combined into larger nuclei.

Nuclear fusion occurs naturally in all active stars. Synthetic fusion as a result of human actions has also been achieved, although this has not yet been completely controlled as a source of nuclear power (see: fusion power). In the laboratory, successful nuclear physics experiments have been carried out that involve the fusion of many different varieties of nuclei, but the energy output has been negligible in these studies. In fact, the amount of energy put into the process has always exceeded the energy output.

CONSTRUCTION OF NUCLEAR POWER PLANT:

Heavy elements such as Uranium (U^{235}) or Thorium (Th^{232}) are subjected to nuclear fission reaction in a nuclear reactor. Due to fission, a large amount of heat energy is produced which is transferred to the reactor coolant. The coolant may be water, gas or a liquid metal. The heated coolant is made to flow through a heat exchanger where water is converted into high-temperature steam. The generated steam is then allowed to drive a steam turbine. The steam, after doing its work, is converted back into the water and recycled to the heat exchanger. The steam turbine is coupled to an alternator which generates electricity.



layout of a nuclear power station.

Basic Components Of A Nuclear Power PlantNuclear ReactorA nuclear reactor is a special apparatus used to perform nuclear fission.Since the nuclear fission is radioactive, the reactor is covered by a protective shield. Splitting up of nuclei of heavy atoms is called as nuclear fission, during which huge amount of energy is released. Nuclear fission is done by bombarding slow moving neutrons on the nuclei of heavy element. As the nuclei break up, it releases energy as well as more neutrons which further cause fission of neighboring atoms. Hence, it is a chain reaction and it must be controlled, otherwise it may result in explosion.

A nuclear reactor consists of fuel rods, control rods and moderator. A fuel rod contains small round fuel pallets (uranium pallets). Control rods are of cadmium which absorb neutrons. They are inserted into reactor and can be moved in or out to control the reaction. The moderator can be graphite rods or the coolant itself.

Two types of nuclear reactors that are widely used -

1. **Pressurised Water Reactor (PWR)** -

   This type of reactor uses regular water as coolant. The coolant (water) is kept at very high pressure so that it does not boil. The heated water is transferred through heat exchanger where water from secondary coolant loop is converted into steam. Thus the secondary loop is completely free from radioactive stuff. In a PWR, the coolant water itself acts as a moderator. Due to these advantages, pressurised water reactors are most commonly used.

2. **Boiling Water Reactor (BWR)** -

   In this type of reactor only one coolant loop is present. The water is allowed to boil in the reactor. The steam is generated as it heads out of the reactor and then flows through the steam turbine. One major disadvantage of a BWR is that, the coolant water comes in direct contact with fuel rods as well as the turbine. So, there is a possibility that radioactive material could be placed on the turbine.

Heat Exchanger

In the heat exchanger, the primary coolant transfers heat to the secondary coolant (water). Thus water from the secondary loop is converted into steam. The primary system and secondary system are closed loop, and they are never allowed to mix up with each other. Thus, heat exchanger helps in keeping secondary system free from radioactive stuff. Heat exchanger is absent in boiling water reactors.

Steam Turbine

Generated steam is passed through a steam turbine, which runs due to pressure of the steam. As the steam is passed through the turbine blades, the pressure of steam gradually decreases and it expands in volume. The steam turbine is coupled to an alternator through a rotating shaft.

Alternator

The steam turbine rotates the shaft of an alternator thus generating electrical energy. Electrical output of the alternator is the delivered to a step up transformer to transfer it over distances.

Condenser

The steam coming out of the turbine, after it has done its work, is then converted back into water in a condenser. The steam is cooled by passing it through a third cold water loop.

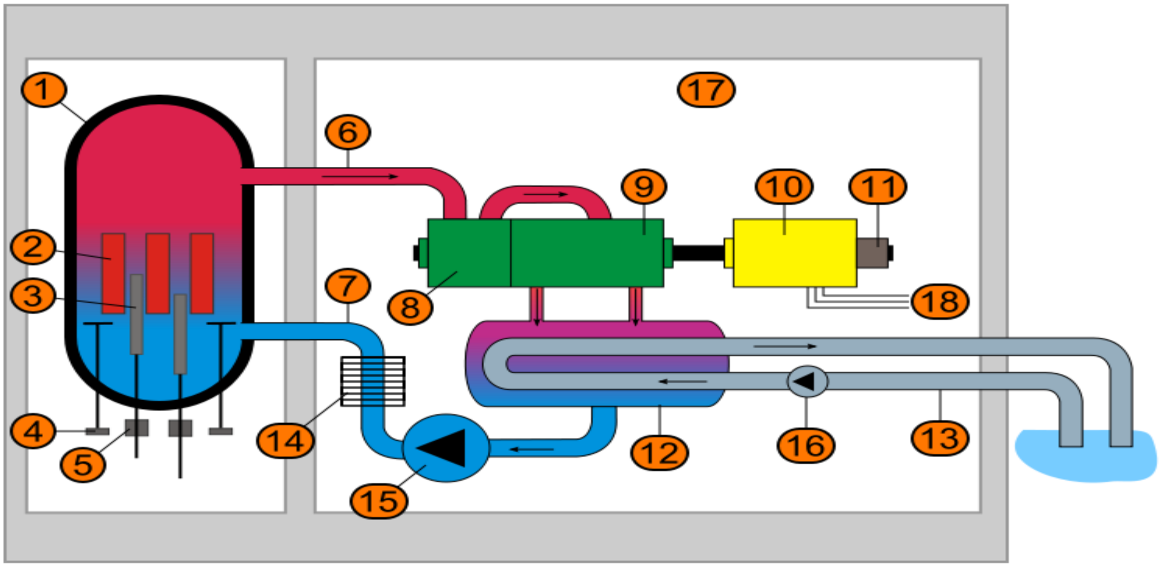
WORKING OF NUCLEAR REACTOR

Nuclear plants, like plants that burn coal, oil and natural gas, produce electricity by boilingwater into steam. This steam then turns turbines to produce electricity. The difference is thatnuclear plants do not burn anything. Instead, they use uranium fuel, consisting of solidceramic pellets, to produce electricity through a process called fission.Nuclear power plants obtain the heat needed to produce steam through a physical process.This process, called fission, entails the splitting of atoms of uranium in a nuclear reactor.The uranium fuel consists of small, hard ceramic pellets that are packaged into long, vertical tubes. Bundles of this fuel are inserted into the reactor

TYPES OF REACTORS:

boiling water reactor (**BWR**):

The **boiling water reactor** (**BWR**) is a type of light water nuclear reactor used for the generation of electrical power. It is the second most common type of electricity-generating nuclear reactor after the pressurized water reactor (PWR), also a type of light water nuclear reactor. The main difference between a BWR and PWR is that in a BWR, thereactor core heats water, which turns to steam and then drives a steam turbine. In a PWR, the reactor core heats water, which does not boil. This hot water then exchanges heat with a lower pressure water system, which turns to steam and drives the turbine. The *boiling water reactor* (BWR) uses demineralized 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 it 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, 1000–1100 psi) so that it boils in the core at about 285 °C (550 °F). In comparison, there is no significant boiling allowed in a pressurized water reactor (PWR) because of the high pressure maintained in its primary loop—approximately 158 atm (16 MPa, 2300 psi). The core damage frequency of the reactor was estimated to be between 10^{-4} and 10^{-7} (i.e., one core damage accident per every 10,000 to 10,000,000 reactor years).



Schematic diagram of a *boiling water reactor* (BWR)
1. Reactor pressure vessel 2. Nuclear fuel element 3. Control rods 4. Recirculation pumps 5. Control rod drives 6. Steam 7. Feedwater 8. High pressure turbine 9. Low pressure turbine 10. Generator 11. Exciter 12. Condenser 13. Coolant 14. Pre-heater 15. Feedwater pump 16. Cold water pump 17. Concrete enclosure 18. Connection to electricity grid

Advantages

- The reactor vessel and associated components operate at a substantially lower pressure of about 70–75 bars (1,020–1,090 psi) compared to about 155 bars (2,250 psi) in a PWR.
- Pressure vessel is subject to significantly less irradiation compared to a PWR, and so does not become as brittle with age.Operates at a lower nuclear fuel temperature.
- Fewer components due to no steam generators and no pressurizer vessel. (Older BWRs have external recirculation loops, but even this piping is eliminated in modern BWRs, such as the ABWR.)
- Measuring the water level in the pressure vessel is the same for both normal and emergency operations, which results in easy and intuitive assessment of emergency conditions.
- Can operate at lower core power density levels using natural circulation without forced flow.

Disadvantages

- BWRs require more complex calculations for managing consumption of nuclear fuel during operation due to "two phase (water and steam) fluid flow" in the upper part of the core. This also requires more instrumentation in the reactor core.
- Larger pressure vessel than for a PWR of similar power, with correspondingly higher cost, in particular for older models that still use a main steam generator and associated piping.
- Contamination of the turbine by short-lived activation products. This means that shielding and access control around the steam turbine are required during normal operations due to the radiation levels arising from the steam entering directly from the reactor core. This is a moderately minor concern, as most of the radiation flux is due to Nitrogen-16 (activation of oxygen in the water), which has a half-life of 7 seconds, allowing the turbine chamber to be entered into within minutes of shutdown.

Pressurized water reactors (**PWRs**

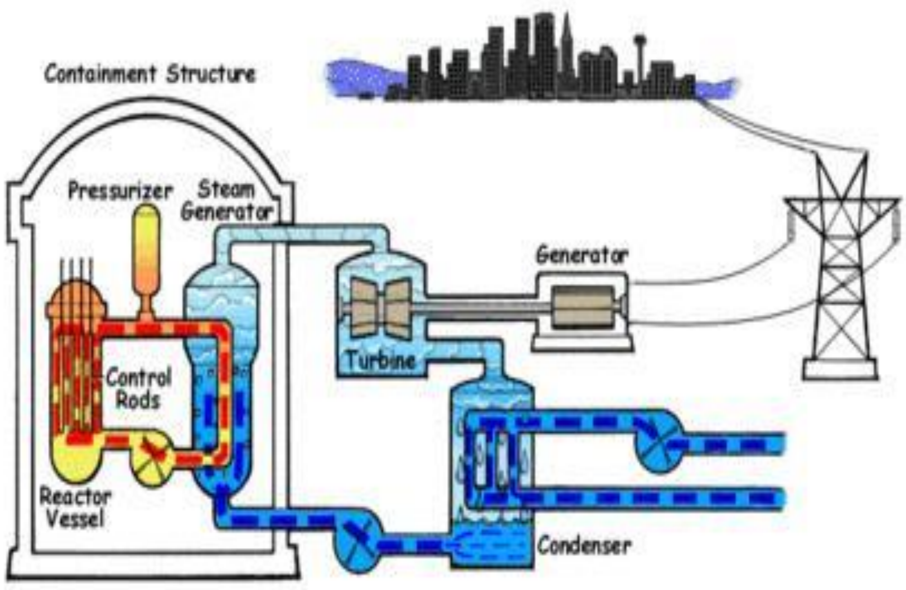
Pressurized water reactors (**PWRs**) are one of three types of light water reactor (LWR), the other types being boiling water reactors (BWRs) andsupercritical water reactors (SCWRs). In a PWR, the primary coolant (water) is pumped under high pressure to the reactor core where it is heated by the energy generated by the fission of atoms. The heated water then flows to a steam generatorwhere it transfers its thermal energy to a secondary system where steam is generated and flows to turbines which, in turn, spin an electric generator. In contrast to a boiling water reactor, pressure in the primary coolant loop prevents the water from boiling within the reactor. All LWRs use ordinary water as both coolant and neutron moderator.

Nuclear fuel in the reactor vessel is engaged in a fission chain reaction, which produces heat, heating the water in the primary coolant loop by thermal conduction through the fuel cladding. The hot primary coolant is pumped into a heat exchanger called the steam generator, where it flows through hundreds or thousands of small tubes. Heat is transferred through the walls of these tubes to the lower pressure secondary coolant located on the sheet side of the exchanger where the coolant evaporates to pressurized steam. The transfer of heat is accomplished without mixing the two fluids to prevent the secondary coolant from becoming radioactive. Some common steam generator arrangements are u-tubes or single pass heat exchangers.

In a nuclear power station, the pressurized steam is fed through a steam turbine which drives an electrical generator connected to the electric grid for transmission. After passing through the turbine the secondary coolant (water-steam mixture) is cooled down and condensed in a condenser. The condenser converts the steam to a liquid so that it can be pumped back into the steam generator, and maintains a vacuum at the turbine outlet so that the pressure drop across the turbine, and hence the energy extracted from the steam, is maximized. Before being fed into the steam generator, the condensed steam (referred to as feedwater) is sometimes preheated in order to minimize thermal shock.

The steam generated has other uses besides power generation. In nuclear ships and submarines, the steam is fed through a steam turbine connected to a set of speed reduction gears to a shaft used for propulsion. Direct mechanical action by expansion of the steam can be used for a steam-powered aircraft catapult or similar applications.District heating by the steam is used in some countries and direct heating is applied to internal plant applications.

Two things are characteristic for the pressurized water reactor (PWR) when compared with other reactor types: coolant loop separation from the steam system and pressure inside the primary coolant loop. In a PWR, there are two separate coolant loops (primary and secondary), which are both filled with demineralized/deionized water. A boiling water reactor, by contrast, has only one coolant loop, while more exotic designs such as breeder reactors use substances other than water for coolant and moderator (e.g. sodium in its liquid state as coolant or graphite as a moderator). The pressure in the primary coolant loop is typically 15–16 megapascals (150–160 bar), which is notably higher than in othernuclear reactors, and nearly twice that of a boiling water reactor (BWR). As an effect of this, only localized boiling occurs and steam will recondense promptly in the bulk fluid. By contrast, in a boiling water reactor the primary coolant is designed to boil.[



LAYOUT OF NUCLEAR POWER PLANT

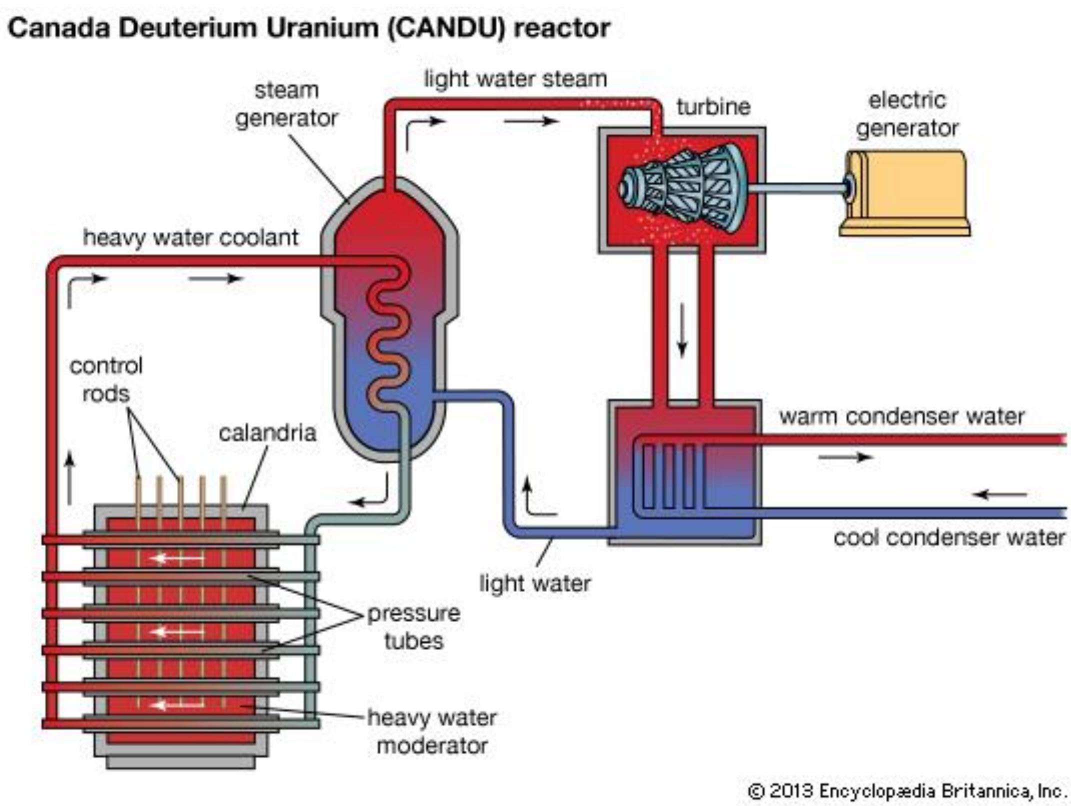
CANADA DEUTERIUM-URANIUM REACTOR (CANDU):

Fission reactions in the reactor core heat pressurized heavy water in a *primary cooling loop*. A heat exchanger, also known as a steam generator, transfers the heat to a light-water *secondary cooling loop*, which powers a steam turbine with an electrical generator attached to it (for a typical Rankine thermodynamic cycle). The exhaust steam from the turbines is then condensed and returned as feedwater to the steam generator, often using cooling water from a nearby source, such as a lake, river, or ocean. Newer CANDU plants, such as the Darlington Nuclear Generating Station near Toronto, Ontario, use a diffuser to spread the warm outlet water over a larger volume and limit the effects on the environment. A cooling tower can be used, but it reduces efficiency and increases costs considerably. Some of the unique features of the CANDU design are listed below:

1. Use of natural uranium: Since CANDU uses heavy water as moderator and also as coolant, it has the luxury of maintaining a very high neutron economy. This means that the subsequent neutrons resulting from fission are used more effectively and there are fewer losses

(compared to light water moderated reactors). This allows the use of natural uranium as fuel and saves the cost of enrichment.

2. Pressure-tube design: pressurized water reactors (PWR) and boiling water reactors (BWR) are mostly pressure-vessel type reactors. CANDU instead uses pressure tubes. Each pressure tube is inside the**calandria** tubes and there are normally 380-480 such tubes assembled in a reactor. This design enables the use of online refuelling and many other unique features of CANDU.
3. Refuelling the reactor while it is in operation: Unlike PWRs and BWRs, CANDU reactors do not undergo batch refuelling. Instead two robotic machines hook up to the reactor faces and open the end caps of a pressure tube. One machine simply pushes in the new fuel, whereby the depleted fuel is pushed out and collected at the other end.



In a light water reactor (LWR), the entire reactor core is a single large pressure vessel containing the light water, which acts as moderator and coolant, and the fuel arranged in a series of long bundles running the length of the core. At the time of CANDU's design, Canada lacked the heavy industry to cast and machine thepressure vessels. In CANDU the pressure (and the fuel bundles) is contained in much smaller (10 cm diameter), easier-to-fabricate tubes. Each bundle is a cylinder assembled from alloy tubes containing ceramic pellets of fuel. In older designs the assembly had 28 or 37 half-meter-long fuel tubes with 12 such assemblies lying end to end in a pressure tube. The newer CANFLEX bundle has 43 tubes, with two pellet sizes (so the power rating can be increased without melting the hottest pellets). It is about 10 centimetres (3.9 in) in diameter, 0.5 metres (20 in) long and weighs about 20 kilograms (44 lb) and replaces the 37-tube bundle. To allow the neutrons to flow freely between the bundles, the tubes and bundles are made of neutron-transparent zircaloy (zirconium + 2.5% wt niobium).

The zircaloy tubes are surrounded by a much larger low-pressure tank known as a calandria, which contains the majority of the moderator. To keep the hot coolant from boiling the moderator, a calandria tube surrounds each pressure tube, with insulating carbon dioxide gas in between. Slowing down neutrons releases energy, so a cooling system dissipates the heat. The moderator is actually a large heat sink that acts as an additional safety feature. The use of individual high pressure fuel channels passing through the CANDU's low-pressure moderator calandria makes it easier to refuel: a pressure-vessel reactor must be shut down, the pressure dropped, the lid removed, and a sizeable fraction of the fuel, e.g. one-third, replaced all at once. In CANDU, individual channels can be refuelled without taking the reactor offline, improving the capacity factor. One fueling machine inserts new fuel into one end of the channel while the other receives discharged fuel from the opposite end. One significant operational advantage of online refuelling is that a failed or leaking fuel bundle can be removed from the core once it has been located, thus reducing the radiation fields in the primary systems.

BREEDER REACTOR:

A **breeder reactor** is a nuclear reactor that generates more fissile material than it consumes. These devices achieve this because their neutron economy is high enough to breed more fissile fuel than they use from fertile material, such as uranium-238 or thorium-232. Breeders were at first found attractive because their fuel economy was better than light water reactors,

TYPES:

- **Fast breeder reactor** or FBR uses fast (unmoderated) neutrons to breed fissile plutonium and possibly higher transuranics from fertile uranium-238. The fast spectrum is flexible enough that it can also breed fissile uranium-233 from thorium, if desired.
- **Thermal breeder reactor** use thermal spectrum (moderated) neutrons to breed fissile uranium-233 from thorium (thorium fuel cycle). Due to the behavior of the various nuclear fuels, a thermal breeder is thought commercially feasible only with thorium fuel, which avoids the buildup of the heavier transuranics.

Breeder reactor concepts

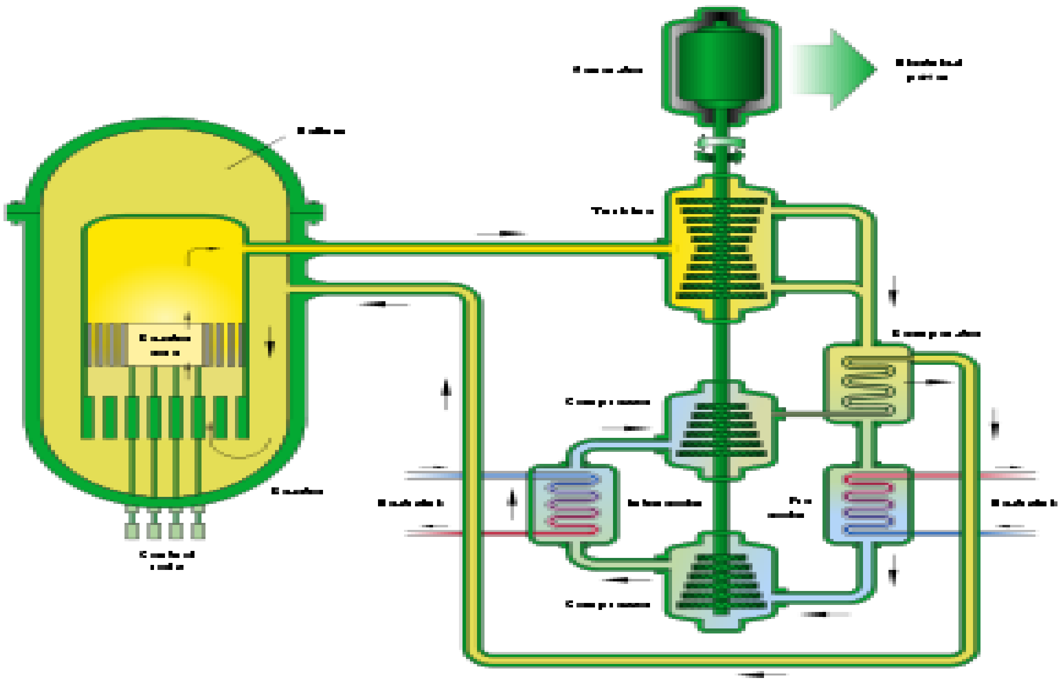
There are several concepts for breeder reactors; the two main ones are:

- Reactors with a fast neutron spectrum are called fast breeder reactors (FBR) – these typically utilize uranium-238 as fuel.
- Reactors with a thermal neutron spectrum are called thermal breeder reactors – these typically utilize thorium-232 as fuel.

GAS-COOLED FAST REACTOR (GFR):

The **gas-cooled fast reactor** (**GFR**) system is a nuclear reactor design which is currently in development. Classed as aGeneration IV reactor, it features a fast-neutron spectrum and closed fuel cycle for efficient conversion of fertile uranium and management of actinides. The reference reactor design is a helium-cooled system operating with an outlet temperature of 850 °C using a direct Brayton closed-cycle gas turbine for high thermal efficiency. Several fuel forms are being considered for their potential to operate at very high temperatures and to ensure an excellent retention of fission products: compositeceramic fuel, advanced fuel particles, or ceramic clad elements of actinide compounds. Core configurations are being considered based on pin- or plate-based fuel assemblies or prismatic blocks, which allows for better coolant circulation than traditional fuel assemblies.

The reactors are intended for use in nuclear power plants to produce electricity, while at the same time producing (breeding) new nuclear fuel.



layout of GAS-COOLED FAST REACTOR (GFR)

Fast reactors were originally designed to be primarily breeder reactors. This was because of a view at the time of their conception that there was an imminent shortage of uranium fuel for existing reactors. The projected increase in uranium price did not materialize, but if uranium demand increases in the future, then there may be renewed interest in fast reactors.

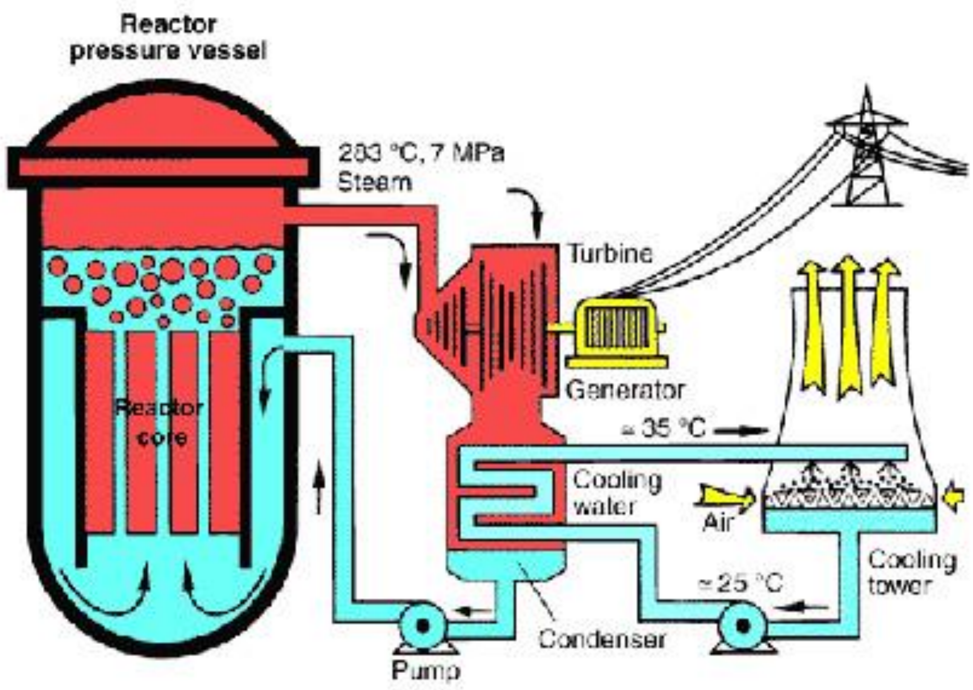
The GFR base design is a fast reactor, but in other ways similar to a high temperature gas-cooled reactor. It differs from the HTGR design in that the core has a higher fissile fuel content as well as a non-fissile, fertile, breeding component, and of course there is no neutron moderator. Due to the higher fissile fuel content, the design has a higher power density than the HTGR.

LIQUID METAL COOLED NUCLEAR REACTOR, LIQUID METAL FAST REACTOR OR **LMFR** :

A **liquid metal cooled nuclear reactor**, **liquid metal fast reactor** or **LMFR** is an advanced type of nuclear reactor where the primary coolant is a liquid metal. Liquid metal cooled reactors were first adapted for nuclear submarine use but have also been extensively studied for power generation applications.

Because the metal coolants have much higher density than the water used in most reactor designs, they remove heat more rapidly and allow much higher power density. This makes them attractive in situations where size and weight are at a premium, like on ships and submarines. To improve cooling with water, most reactor designs are highly pressurized to raise the boiling point, which presents safety and maintenance issues that liquid metal designs lack. Additionally, the high temperature of the liquid metal can be used to produce vapour at higher temperature than in a water cooled reactor, leading to a higher thermodynamic efficiency. This makes them attractive for improving power output in conventional nuclear power plants.

Liquid metals, being electrically highly conductive, can be moved by electromagnetic pumps. Disadvantages include difficulties associated with inspection and repair of a reactor immersed in opaque molten metal, and depending on the choice of metal, fire hazard risk (for alkali metals), corrosion and/or production of radioactive activation products may be an issue.



Layout of liquid metal cooled nuclear reactor, **liquid metal fast reactor**

In practice, all liquid metal cooled reactors are fast neutron reactors, and to date most fast neutron reactors have been liquid metal cooled fast breeder reactors (LMFBRs), or naval propulsion units. The liquid metals used typically need good heat transfer characteristics. Fast neutron reactor cores tend to generate a lot of heat in a small space when compared to reactors of other classes. A low neutron absorption is desirable in any reactor coolant, but especially important for a fast reactor, as the good neutron economy of a fast reactor is one of its main advantages. Since slower neutrons are more easily absorbed, the coolant should ideally have a low moderation of neutrons. It is also important that the coolant does not cause excessive corrosion of the structural materials, and that its melting and boiling points are suitable for the reactor's operating temperature.

Ideally the coolant should never boil as that would make it more likely to leak out of the system, resulting in a loss-of-coolant accident. Conversely, if the coolant can be prevented from boiling this allows the pressure in the cooling system to remain at neutral levels, and this dramatically reduces the probability of an accident. Some designs immerse the entire reactor and heat exchangers into a pool of coolant, virtually eliminating the risk that inner-loop cooling will be lost.

NUCLEAR WASTE AND ITS DISPOSAL:

Radioactive waste is a waste product containing radioactive material. It is usually the product of a nuclear process such as nuclear fission, though industries not directly connected to the nuclear power industry may also produce radioactive waste.

Radioactivity diminishes over time, so in principle the waste needs to be isolated for a period of time until it no longer poses a hazard. This can mean hours to years for some common medical or industrial radioactive wastes, or thousands of years for high-level wastes from nuclear power plants and nuclear weapons reprocessing.

The majority of radioactive waste is " low-level waste", meaning it has low levels of radioactivity per mass or volume.

The main approaches to managing radioactive waste to date have been segregation and storage for short-lived wastes, near-surface disposal for low and some intermediate level wastes, and deep burial or transmutation for the long-lived, high-level wastes.

A summary of the amounts of radioactive wastes and management approaches for most developed countries are presented and reviewed periodically as part of the IAEA Joint Convention on Safety of Spent Fuel Management and the Safety of Radioactive Waste Management.

Types of radioactive waste

Although not significantly radioactive, *uranium mill tailings* are waste. They are byproduct material from the rough processing of uranium-bearing ore. They are sometimes referred to as 11(e)2 wastes, from the section of the U.S. Atomic Energy Act that defines them. Uranium mill tailings typically also contain chemically hazardous heavy metals such as lead and arsenic. Vast mounds of uranium mill tailings are left at many old mining sites, especially in Colorado, New Mexico, and Utah.

Low level waste (LLW) is generated from hospitals and industry, as well as the nuclear fuel cycle. It comprises paper, rags, tools, clothing, filters, etc., which contain small amounts of mostly short-lived radioactivity. Commonly, LLW is designated as such as a precautionary measure if it originated from any region of an 'Active Area', which frequently includes offices with only a remote possibility of being contaminated with radioactive materials. Such LLW typically exhibits no higher radioactivity than one would expect from the same material disposed of in a non-active area, such as a normal office block. Some high activity LLW requires shielding during handling and transport but most LLW is suitable for shallow land burial. To reduce its volume, it is often compacted or incinerated before disposal. Low level waste is divided into four classes, class A, B, C and GTCC, which means "Greater Than Class C".

Intermediate level waste (ILW) contains higher amounts of radioactivity and in some cases requires shielding. ILW includes resins, chemical sludge and metal reactor fuel cladding, as well as contaminated materials from reactor decommissioning. It may be solidified in concrete or bitumen for disposal. As a general rule, short-lived waste (mainly non-fuel materials from reactors) is buried in shallow repositories, while long-lived waste (from fuel and fuel-reprocessing) is deposited in deep underground facilities. U.S. regulations do not define this category of waste; the term is used in Europe and elsewhere.

Spent Fuel Flasks are transported by railway in the United Kingdom. Each flask is constructed of 14 in (360 mm) thick solid steel and weighs in excess of 50 tons

High level waste (HLW) is produced by nuclear reactors. *It* contains fission products and transuranic elements generated in the reactor core. It is highly radioactive and often thermally hot. HLW accounts for over 95% of the total radioactivity produced in the process of nuclear electricity generation. The amount of HLW worldwide is currently increasing by about 12,000 metric tons every year, which is the equivalent to about 100 double-decker buses or a two-story structure

with a footprint the size of a basketball court. A 1000-MWe nuclear power plant produces about 27 tonnes of spent nuclear fuel (unreprocessed) every year.

Transuranic waste (TRUW) as defined by U.S. regulations is, without regard to form or origin, waste that is contaminated with alpha-emitting transuranic radionuclides with half-lives greater than 20 years, and concentrations greater than 100 nCi/g (3.7 MBq/kg), excluding High Level Waste. Elements that have an atomic number greater than uranium are called transuranic ("beyond uranium"). Because of their long half-lives, TRUW is disposed more cautiously than either low level or intermediate level waste. In the US it arises mainly from weapons production, and consists of clothing, tools, rags, residues, debris and other items contaminated with small amounts of radioactive elements (mainly plutonium).

Under US law, transuranic waste is further categorized into "contact-handled" (CH) and "remote-handled" (RH) on the basis of radiation dose measured at the surface of the waste container. CH TRUW has a surface dose rate not greater than 200 mrem per hour (2 mSv/h), whereas RH TRUW has a surface dose rate of 200 mrem per hour (2 mSv/h) or greater. CH TRUW does not have the very high radioactivity of high level waste, nor its high heat generation, but RH TRUW can be highly radioactive, with surface dose rates up to 1000000 mrem per hour (10000 mSv/h). The US currently permanently disposes of defense-related TRUW at the Waste Isolation Pilot Plant.

Preventing of Waste

Due to the many advances in reactor design, it is today possible to reduce the radioactive waste by a factor 100. This can be done by using new reactor types such as Generation_IV_reactor. This reducion of nuclear waste is possible these new reactor types are capable of burning the lower actinides.

Management of Waste

Modern medium to high level transport container for nuclear waste. High-level radioactive waste management, List of nuclear waste treatment technologies, and Environmental effects of nuclear power Of particular concern in nuclear waste management are two long-lived fission products, Tc-99 (half-life 220,000 years) and I-129 (half-life 17 million years), which dominate spent fuel radioactivity after a few thousand years. The most troublesome transuranic elements in spent fuel are Np-237 (half-life two million years) and Pu-239 (half life 24,000 years). Nuclear waste requires sophisticated treatment and management to successfully isolate it from interacting with the biosphere. This usually necessitates treatment, followed by a long-term management strategy involving storage, disposal or transformation of the waste into a non-toxic form. Governments around the world are considering a range of waste management and disposal options, though there has been limited progress toward long-term waste management solutions.

UNIT IV POWER FROM RENEWABLE ENERGY

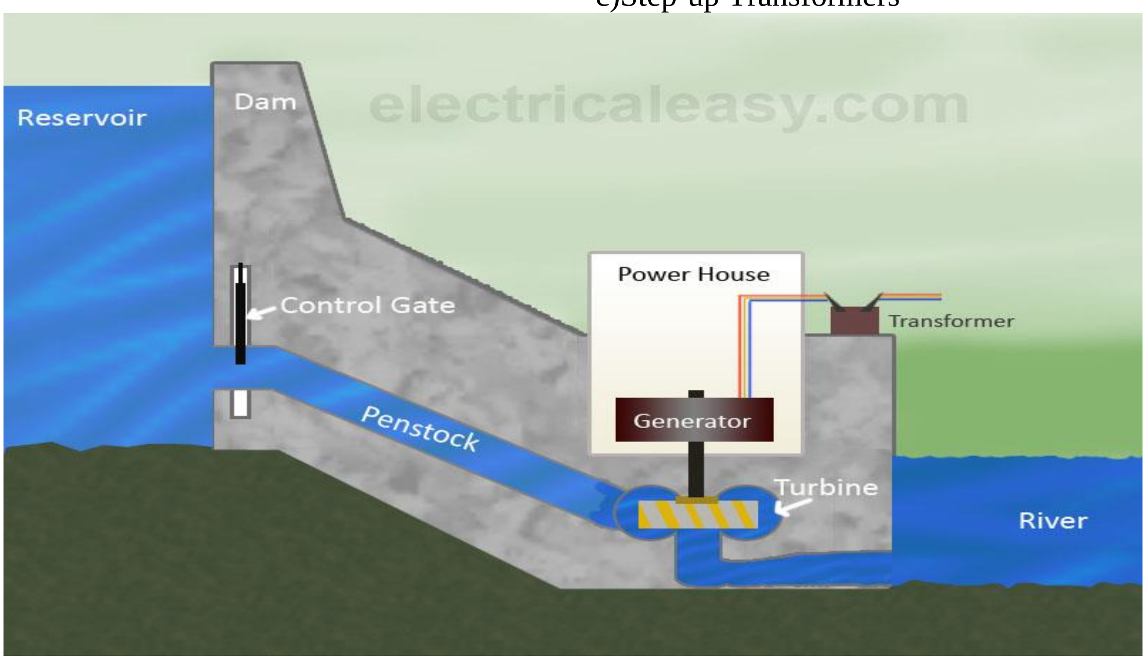
HYDRO ELECTRIC POWER (HYDEL POWER):

Hydro-electric power is generated by the flow of water through turbine, turning the blades of the turbine. A generator shaft connected to this turbine also turns and hence generates electricity

CONSTRUCTION OF HYDRO ELECTRIC POWER PLANT:

The main components of a hydel power plant are:

I. Dam/Reservoir/Large buffer tank
II. Penstock
III. Power House
a)Turbines
b)Generators
c)Step-up Transformers



LAYOUT OF A HYDROELECTRIC POWER PLANT AND ITS BASIC COMPONENTS.

Dam and Reservoir: The dam is constructed on a large river in hilly areas to ensure sufficient water storage at height. The dam forms a large reservoir behind it. The height of water level (called as water head) in the reservoir determines how much of potential energy is stored in it.

Control Gate: Water from the reservoir is allowed to flow through the penstock to the turbine. The amount of water which is to be released in the penstock can be controlled by a control gate. When the control gate is fully opened, maximum amount of water is released through the penstock.

Penstock: A penstock is a huge steel pipe which carries water from the reservoir to the turbine. Potential energy of the water is converted into kinetic energy as it flows down through the penstock due to gravity.

Water Turbine: Water from the penstock is taken into the water turbine. The turbine is mechanically coupled to an electric generator. Kinetic energy of the water drives the turbine and consequently the generator gets driven. There are two main types of water turbine; (i) Impulse turbine and (ii) Reaction turbine. Impulse turbines are used for large heads and reaction turbines are used for low and medium heads.

Generator**:** A generator is mounted in the power house and it is mechanically coupled to the turbine shaft. When the turbine blades are rotated, it drives the generator and electricity is generated which is then stepped up with the help of a transformer for the transmission purpose.

Surge Tank: Surge tanks are usually provided in high or medium head power plants when considerably long penstock is required. A surge tank is a small reservoir or tank which is open at the top. It is fitted between the reservoir and the power house. The water level in the surge tank rises or falls to reduce the pressure swings in the penstock. When there is sudden reduction in load on the turbine, the governor closes the gates of the turbine to reduce the water flow. This causes pressure to increase abnormally in the penstock. This is prevented by using a surge tank, in which the water level rises to reduce the pressure. On the other hand, the surge tank provides excess water needed when the gates are suddenly opened to meet the increased load demand.

WORKING:

A hydel power station makes use of the daily rise and fall of ocean water due to tides; such sources are highly predictable, and if conditions permit construction of reservoirs, can also be dispatchable to generate power during high demand periods. Less common types of hydro schemes use water's kinetic energy or undammed sources such as undershot water wheels. Tidal power is viable in a relatively small number of locations around the world

Types Of Hydro-Power Plants

Conventional Plants:

Conventional plants use potential energy from dammed water. The energy extracted depends on the volume and head of the water. The difference between height of water level in the reservoir and the water outflow level is called as water head.

Pumped Storage Plant:

In pumped storage plant, a second reservoir is constructed near the water outflow from the turbine. When the demand of electricity is low, the water from lower reservoir is pumped into the upper (main) reservoir. This is to ensure sufficient amount of water available in the main reservoir to fulfil the peak loads.

Run-Of-River Plant:

In this type of facility, no dam is constructed and, hence, reservoir is absent. A portion of river is diverted through a penstock or canal to the turbine. Thus, only the water flowing from the river is available for the generation. And due to absence of reservoir, any oversupply of water is passed unused.

Advantages Of A Hydroelectric Power Plant

- No fuel is required as potential energy is stored water is used for electricity generation
- Neat and clean source of energy
- Very small running charges - as water is available free of cost
- Comparatively less maintenance is required and has longer life
- Serves other purposes too, such as irrigation

Disadvantages

- Very high capital cost due to construction of dam
- High cost of transmission – as hydro plants are located in hilly areas which are quite away from the consumers

SIZES, TYPES AND CAPACITIES OF HYDROELECTRIC FACILITIES:

Large facilities

Large-scale hydroelectric power stations are more commonly seen as the largest power producing facilities in the world, with some hydroelectric facilities capable of generating more than double the installed capacities of the current largest nuclear power stations.

Small

Small hydro is the development of hydroelectric power on a scale serving a small community or industrial plant. The definition of a small hydro project varies but a generating capacity of up to 10 megawatts (MW) is generally accepted as the upper limit of what can be termed small hydro.

Micro

Micro hydro is a term used for hydroelectric power installations that typically produce up to 100 kW of power. These installations can provide power to an isolated home or small community, or are sometimes connected to electric power networks. There are many of these installations around the world, particularly in developing nations as they can provide an economical source of energy without purchase of fuel.[20] Micro hydro systems complement photovoltaic solar energy systems because in many areas, water flow, and thus available hydro power, is highest in the winter when solar energy is at a minimum.

Pico

Pico hydro is a term used for hydroelectric power generation of under 5 kW. It is useful in small, remote communities that require only a small amount of electricity. For example, to power one or two fluorescent light bulbs and a TV or radio for a few homes.[21] Even smaller turbines of 200-300W may power a single home in a developing country with a drop of only 1 m (3 ft). A Pico-hydro setup is typically run-of-the-river, meaning that dams are not used, but rather pipes divert some of the flow, drop this down a gradient, and through the turbine before returning it to the stream.

Underground

An underground power station is generally used at large facilities and makes use of a large natural height difference between two waterways, such as a waterfall or mountain lake. An underground tunnel is constructed to take water from the high reservoir to the generating hall built in an underground cavern near the lowest point of the water tunnel and a horizontal tailrace taking water away to the lower outlet waterway.

An **impulse turbine** has fixed nozzles that orient the steam flow into high speed jets. These jets contain significant kinetic energy, which the rotor blades, shaped like buckets, convert into shaft rotation as the steam jet changes direction. A pressure drop occurs across only the stationary blades, with a net increase in steam velocity across the stage. As the steam flows through the nozzle its pressure falls from inlet pressure to the exit pressure (atmospheric pressure, or more usually, the condenser vacuum). Due to this higher ratio of expansion of steam in the nozzle the steam leaves the nozzle with a very high velocity. The steam leaving the moving blades is a large portion of the maximum velocity of the steam when leaving the nozzle. The loss of energy due to this higher exit velocity is commonly called the "carry over velo city" or "leaving loss".

Reaction Turbines

In the **reaction turbine**, the rotor blades themselves are arranged to form convergent nozzles. This type of turbine makes use of the reaction force produced as the steam accelerates through the nozzles formed by the rotor. Steam is directed onto the rotor by the fixed vanes of the stator. It leaves the stator as a jet that fills the entire circumference of the rotor. The steam then changes direction and increases its speed relative to the speed of the blades. A pressure drop occurs across both the stator and the rotor, with steam accelerating through the stator and decelerating through the rotor, with no net change in steam velocity across the stage but with a decrease in both pressure and temperature, reflecting the work performed in the driving of the rotor.

WIND TURBINE POWER PLANT:

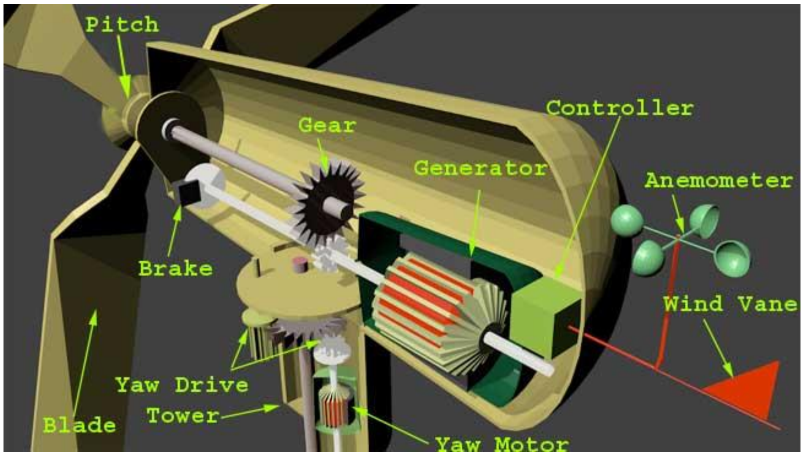
MAJOR PARTS OF WIND TURBINE:

Tower of Wind Turbine

Tower is very crucial part of wind turbine that supports all the other parts. It is not only support the parts but raise the wind turbine so that its blades safely clear the ground and so it can reach the stronger winds at higher elevations. The height of tower depends upon the power capacity of wind turbines. Larger turbines usually mounted on tower ranging from 40 meter to 100 meter.

Nacelle of Wind Turbine:

Nacelle is big box that sits on the tower and house all the components in a wind turbine. It houses Power Converter, Shaft, Gearbox, Generator, Turbine controller, Cables, Yaw drive.



Layout of wind turbine

Rotor Blades of Wind turbine

Blades are the mechanical part of wind turbine that converts wind kinetic energy into mechanical energy. When the wind forces the blades to move, it transfers some of its energy to the shaft. Blades are shaped like airplane wings blades can be as long as 150 feet wind turbine

Shaft of Wind Turbine

The shaft is connected to the rotor. When the rotor spins, the shaft spins as well. In this way, the rotor transfers its mechanical, rotational energy to shaft which enters to an electrical generator on the other end.

Gearbox

The rotor turns the shaft at low speed ex. 20 rpm but for generator to generate electricity we need higher speed. Gearbox increases the speed to much higher value required by most generator to produce electricity. For example, if Gearbox ratio is 1:80 and if rotor speed is 15 rpm then gearbox will increase the speed to $15 \times 80 = 1200$ rpm that is given to generator shaft.

GENERATOR

Generator is electrical device that converts mechanical energy received from shaft into electrical energy. It works on electromagnetic induction to produce electrical voltage or electrical current. A simple generator consists of magnets and a conductor. The conductor is typically a coiled wire. Inside the generator shaft connects to an assembly of permanent magnets that surrounded by magnets and one of those parts is rotating relative to the other, it induce the voltage in the conductor.When the rotor spins to the shaft, the shaft spins the assembly of magnets and generate voltage in the coil of wire.

Power Converter

Because wind is not always constant so electrical potential generated from generator is not constant but we need a very stable voltage to feed the grid. Power converter is an electrical device that stabilizes the output alternating voltage transferred to the grid.

Turbine Controller

Turbine controller is a computer (PLC) that controls the entire turbine. It starts and stops the turbine and runs self diagnostic in case of any error in the turbine.

Anemometer

It measures the wind speed and passes the speed information to PLC to control the turbine power

Wind Vane

It senses the direction of wind and passes the direction to PLC then PLC faces the blades in such a way that it cuts the maximum wind.

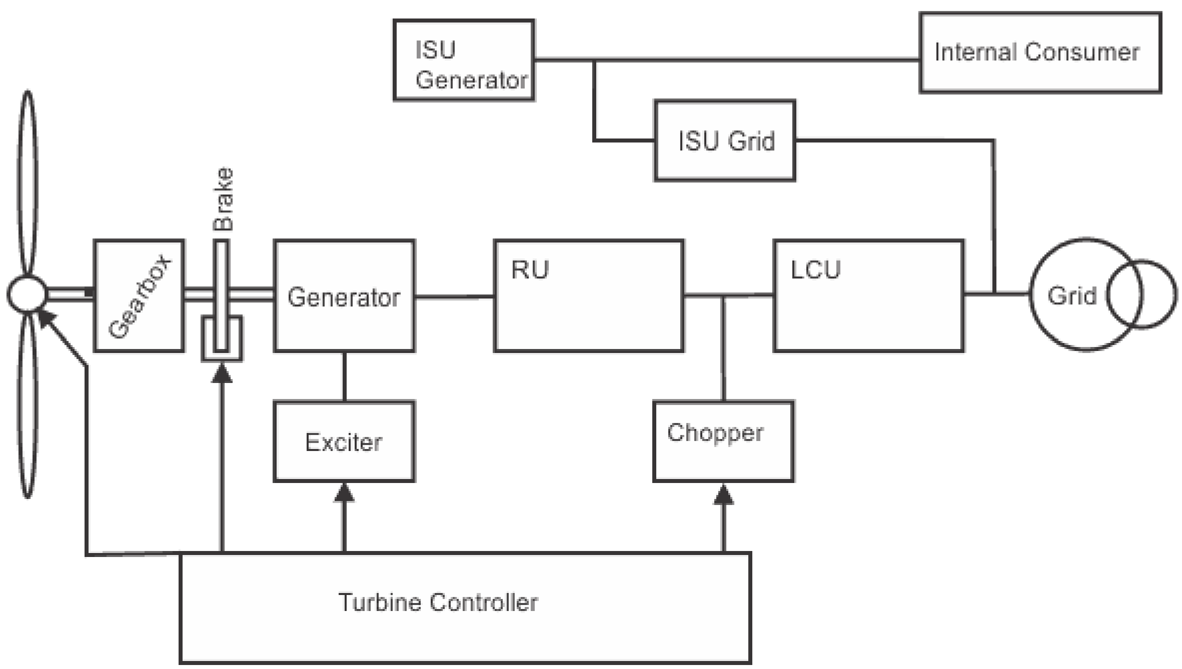
Pitch Drive

Pitch drive motors control the angle of blades whenever wind changes it rotates the angle of blades to cut the maximum wind, which is called pitching of blades.

Yaw Drive

Blades and other components in wind turbine is housed in Nacelle , whenever any change in wind direction is there Nacelle has to move in the direction of wind to extract the maximum energy from wind. For this purpose yaw drive motor are used to rotate the nacelle .It is controlled by PLC that uses the wind vane information to sense the wind direction.

Working of Wind Turbine



Layout of wind turbine power plant

WORKING:

When the wind strikes the rotor blades, blades start to rotating. Rotor is directly connected to high speed gearbox. Gearbox converts the rotor rotation into high speed which rotates the electrical generator. An exciter is needed to give the required excitation to the coil so that it can generate required voltage. The exciter current is controlled by a turbine controller which senses the wind speed based on that it calculate the power what we can achieve at that particular wind speed.

Then output voltage of electrical generator is given to a rectifier and rectifier output is given to line Converter unit to stabilise the output ac that is feed to the grid by a high voltage transformer. An extra units is used to give the power to internal auxiliaries of wind turbine (like motor, battery etc.), this is called Internal Supply unit. ISU can take the power from grid as well as from wind. Chopper is used to dissipate extra energy from the RU for safety purpose.

Internal Block diagram of wind turbine

Types of Wind Turbine

There are generally two kinds of wind turbines. Horizontal axis and vertical axis. Horizontal axis is divided as upwind and downwind whereas vertical axis is divided as a drag based and lift based as shown in below.

I. Horizontal Axis Wind Turbine or HAWT – Up wind
II. Horizontal Axis Wind Turbine or HAWT – Down wind
III. Vertical Axis Wind Turbine or VAWT – Drag based
IV. Vertical Axis Wind Turbine or VAWT – Lift based

horizontal axis wind turbine

In Horizontal Axis Up Wind turbine, the shaft of turbine and alternator both are aligned horizontally and the turbine blades are placed at the front of the turbine that means air strikes the turbine blades before the tower. In the case of Vertical Axis Down Wind turbine the shafts of the rotor and generator are also placed horizontally but turbine blades are placed after the turbine that means the wind strikes the tower before the blades.

Vertical Axis Wind Turbine

If we observe VAWT drag based turbine, the generator shaft is located vertically with the blades positioning up and the turbines are normally mounted on the ground or on a tiny tower. This type is also called the Savonius turbine, after its inventor, S.I. Savonius. In the case of VAWT lift based turbine, the generator shaft is placed vertically with the blade's position is up.

Now days Horizontal axis wind turbines are most popular because of high efficiency. Since the blades always move perpendicularly to the wind, and receive power through the whole rotation.

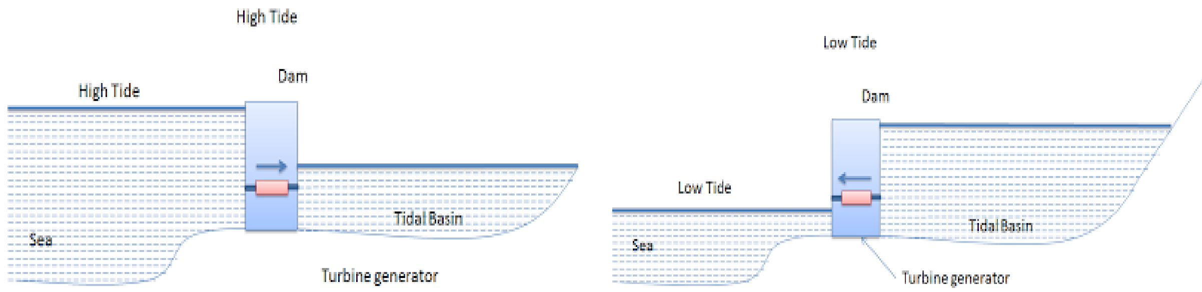
TIDAL POWER GENERATION:

PRINCIPLE OF TIDAL POWER GENERATION:

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

Working of Tidal power generation:

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



Working of Tidal power generation

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

During low tide period, water flows from tidal basin to sea, as the water level in the basin is more than that of the tide in the sea. During this period also, the flowing water rotates the turbine and generates power. The generation of power stops only when sea level and the tidal basin level are equal. For the generation of power economically using this source of energy requires some minimum tide height and suitable site.

Advantages of tidal power plants

1. It is free from pollution as it does not use any fuel.
2. It is superior to hydro-power plant as it is totally independent of rain.
3. It improves the possibility of fish farming in the tidal basins and it can provide recreational facilities to visitors and holiday makers

Disadvantages of tidal power plants:

1. Tidal power plants can be developed only if natural sites are available on the bay.

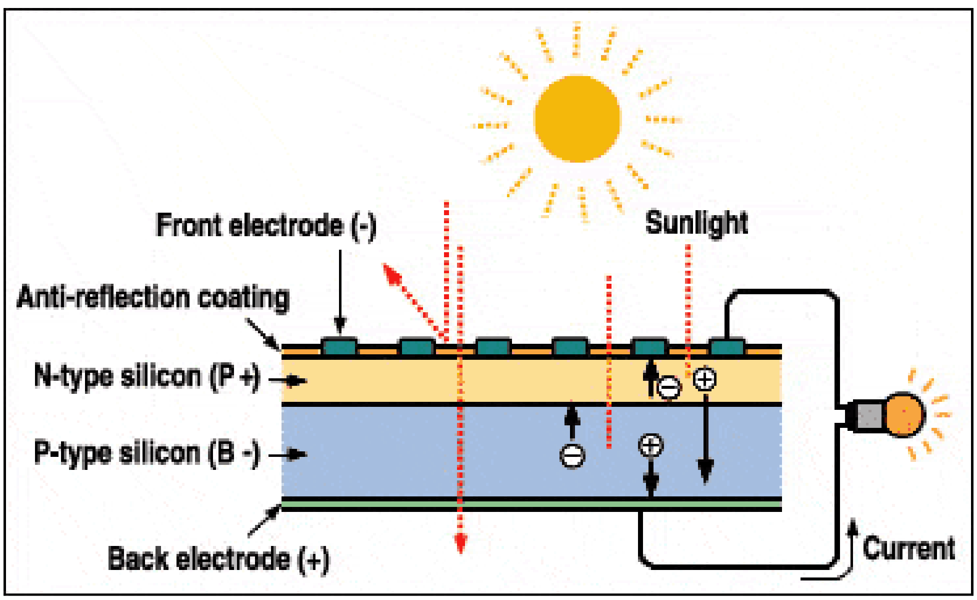
2. As the sites are available on the bays which are always far away from load centers, the power generated has to be transmitted to long distances. This increases the transmission cost and transmission losses.
3. The supply of power is not continuous as it depends upon the timing of tides.
4. The navigation is obstructed.
5. Utilization of tidal energy on small scale is not economical.

Solar Photovoltaic cell (SPV)

Solar cells are semiconductor devices that produce electricity from sunlight by means of photovoltaic effect, without using moving parts, consuming no conventional fossil fuels, creating no pollution.

A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon.

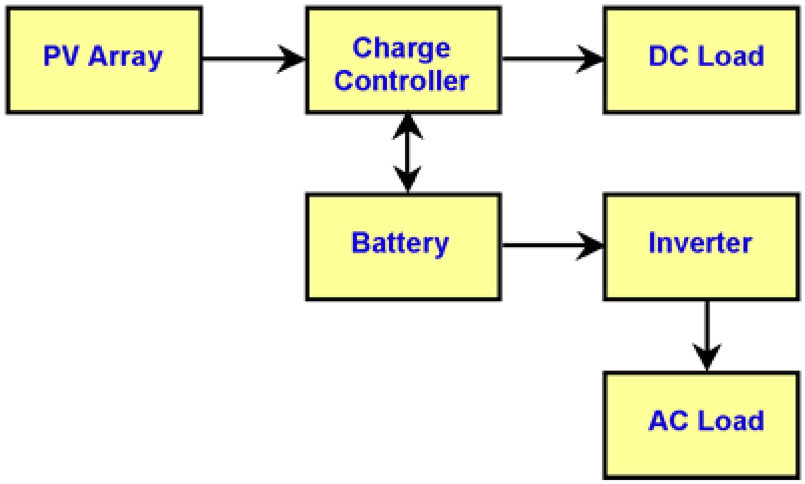
An electrical field is created near the top surface of the cell where these two materials are in contact, called the P-N junction.When sunlight strikes the surface of a PV cell, this electrical field provides momentum and direction to light-stimulated electrons, resulting in a flow of current when the solar cell is connected to an electrical load.



PV systems are classified into

1. Stand alone PV system
2. Grid connected PV system

Stand alone PV system

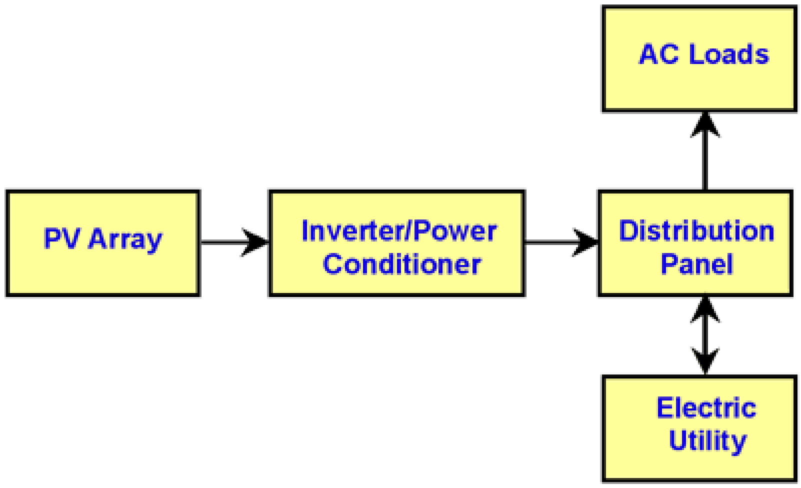


Batteries are often used in PV systems for the purpose of storing energy produced by the PV array during the day, and to supply it to electrical loads as needed (during the night and periods of cloudy weather).

Other reasons batteries are used in PV systems are to operate the PV array near its maximum power point, to power electrical loads at stable voltages, and to supply surge currents to electrical loads and inverters. In most cases, a battery charge controller is used in these systems to protect the battery from overcharge and over discharge.

Grid connected PV system

Photovoltaic systems can be designed to provide DC and/or AC power service, can operate interconnected with or independent of the utility grid, and can be connected with other energy sources and energy storage systems.



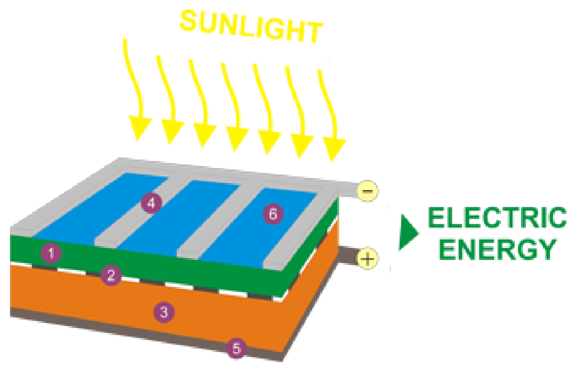
SOLAR THERMAL ENERGY (**STE**):

Solar thermal energy (**STE**) is a form of energy and a technology for harnessing solar energy to generate thermal energy orelectrical energy for use in industry, and in the residential and commercial sectors.

THE PRINCIPLE OF OPERATION OF A PV CELL

In 1839, French physicist Alexander E. Becquerel discovered the photovoltaic effect involving conversion of solar energy into electrical energy in semiconductor element. Photovoltaic cell consists of high-purity silicon. On the silicon, a PN (positive-negative) junction was formed as a potential barrier.

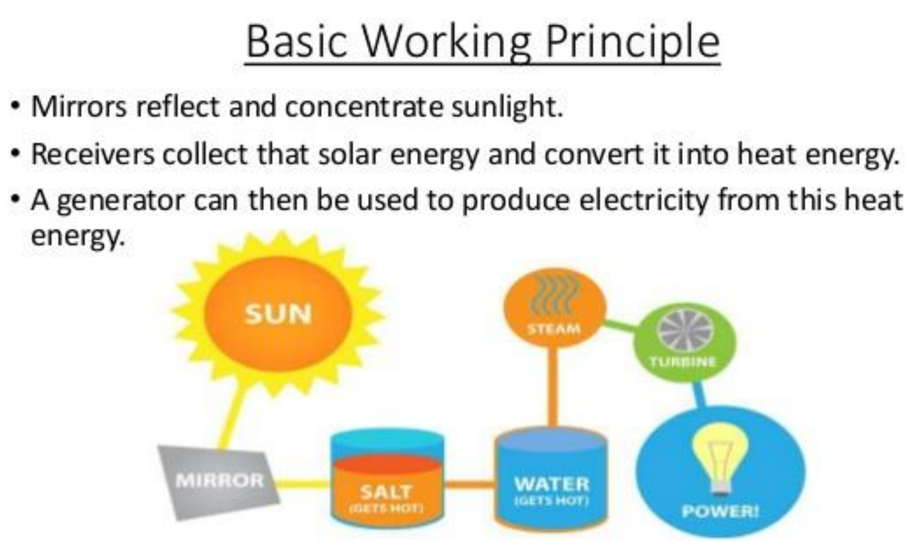
Photons falling on the PN junction cause the rise of pairs of opposite electrical charge carriers (electron – hole), which as a result of the presence of PN junction are separated in two different directions. Electrons go to the semiconductor N and holes go to the semiconductor P. The voltage will arise on the junction. Because the separated electrical charges are redundant carriers, having so called, infinite life and a PN junction voltage is constant, the junction, on which the light falls acts as a stable electric cell.

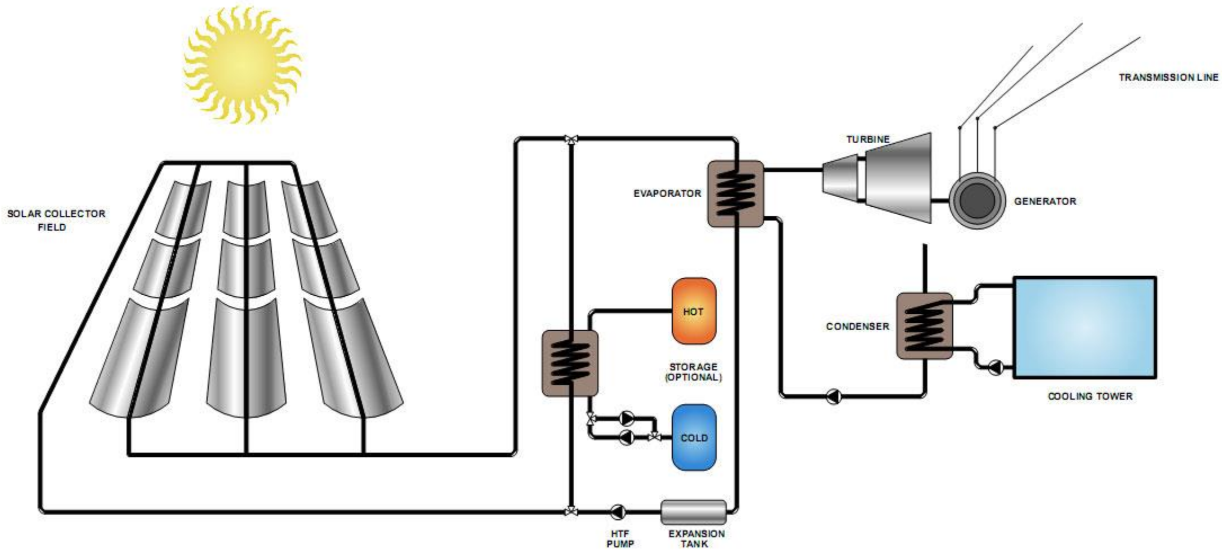


Construction of a photovoltaic cell

1. semiconductor 2. p-n junction 3. semiconductor 4. 5. metallic connection6. anti-glare material

Solar thermal collectors are classified by the United States Energy Information Administration as low-, medium-, or high-temperature collectors. Low-temperature collectors are flat plates generally used to heat swimming pools. Medium-temperature collectors are also usually flat plates but are used for heating water or air for residential and commercial use. High temperature collectors concentrate sunlight using mirrors or lenses and are generally used for fulfilling heat requirements up to 300 deg C / 20 bar pressure in industries, and for electric power production. Two categories include Concentrated Solar Thermal (CST) for fulfilling heat requirements in industries, and Concentrated Solar Power (CSP) when the heat collected is used for power generation.





LAYOUT OF SOLAR THERMAL TOWER POWER PLANTS

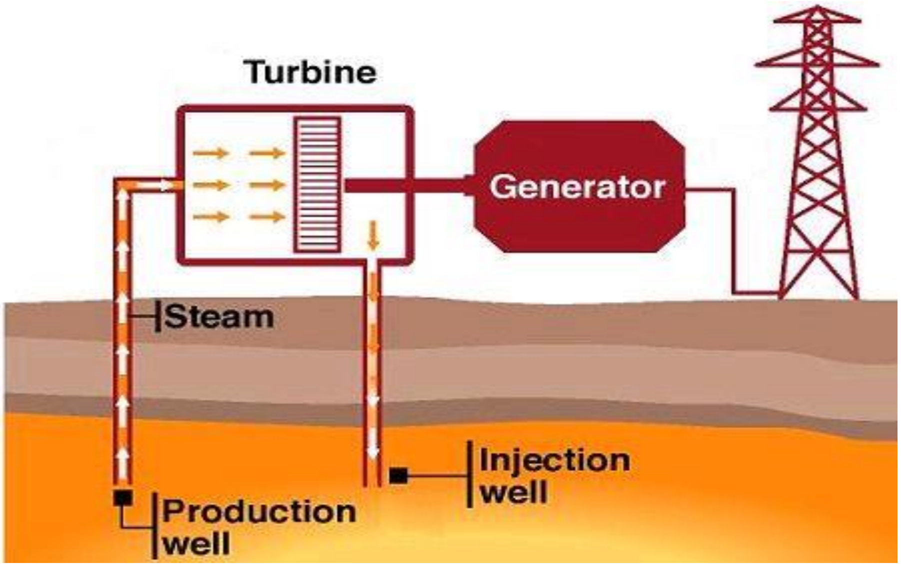
In solar thermal tower power plants, hundreds or even thousands of large two-axis tracked mirrors are installed around a tower. These slightly curved mirrors are also called heliostats; a computer calculates the ideal position for each of these, and a motor drive moves them into the sun. The system must be very precise in order to ensure that sunlight is really focused on the top of the tower. It is here that the absorber is located, and this is heated up to temperatures of 1000°C or more. Hot air or molten salt then transports the heat from the absorber to a steam generator; superheated water steam is produced there, which drives a turbine and electrical generator, as described above for the parabolic trough power plants.

GEOTHERMAL POWER PLANTS:

There are several different main types of geothermal plants:

I. Dry steam
II. Flash steam
III. Binary cycle

What these types of geothermal power plants all have in common is that they use steam turbines to generate electricity. This approach is very similar to other thermal power plants using other sources of energy than geothermal.



LAYOUT OF GEOTHERMAL POWER PLANT

Water or working fluid is heated (or used directly incase of geothermal dry steam power plants), and then sent through a steam turbine where the thermal energy (heat) is converted to electricity with a generator through a phenomenon called electromagnetic induction. The next step in the cycle is cooling the fluid and sending it back to the heat source.

Water that has been seeping into the underground over time has gained heat energy from the geothermal reservoirs. There no need for additional heating, as you would expect with other thermal power plants. Heating boilers are not present in geothermal steam power plants and no heating fuel is used.

Production wells (red on the illustrations) are used to lead hot water/steam from the reservoirs and into the power plant.Rock catchers are in place to make sure that only hot fluids is sent to the turbine. Rocks can cause great damage to steam turbines.Injection wells (blue on the illustrations) ensure that the water that is drawn up from the production wells returns to the geothermal reservoir where it regains the thermal energy (heat) that we have used to generate electricity.

Depending on the state of the water (liquid or vapor) and its temperature, different types of power plants are used for different geothermal reservoirs. Most geothermal power plants extract water, in its vapor or liquid form, from the reservoirs somewhere in the temperature-range 100-320°C (220-600°F).

Geothermal Dry Steam Power Plants:

This type of geothermal power plant was named dry steam since water water that is extracted from the underground reservoirs has to be in its gaseous form (water-vapor).

Geothermal steam of at least 150°C (300°F) is extracted from the reservoirs through the production wells (as we would do with all geothermal power plant types), but is then sent directly to the turbine. Geothermal reservoirs that can be exploited by geothermal dry steam power plants are rare.

Geothermal Flash Steam Power Plants:

Geothermal flash steam power plants uses water at temperatures of at least 182°C (360°F). The term flash steam refers the process where high-pressure hot water is flashed (vaporized) into steam inside a flash tank by lowering the pressure. This steam is then used to drive around turbines.

By using a working fluid (binary fluid) with a much lower boiling temperature than water, thermal energy in the reservoir water flashes the working fluid into steam, which then is used to generate electricity with the turbine. The water coming from the geothermal reservoirs through the production wells is never in direct contact with the working fluid. After the some of its thermal energy is transferred to the working fluid with a heat exchanger, the water is sent back to the reservoir through the injection wells where it regains it's thermal energy.

These power plants have a thermal efficiency rate of only 10-13%. However, geothermal binary cycle power plants enable us, through lowering temperature requirements, to harness geothermal energy from reservoirs that with a dry- or a flash steam power plant wouldn't be possible.

Depending on what type of geothermal power plant, location and various other factors, the thermal efficiency rate is not more than 10-23%. Technically, low efficiency rates do not affect operational costs of a geothermal power plant, as it would with power plants that are reliant on fuels to heat a working fluid.

Electricity generation does suffer from low thermal efficiency rates, but the byproducts, exhaust heat and warm water, have many useful purposes. By not only generating power, but also taking advantage of the thermal energy in the byproducts, overall energy efficiency increases. This is what we call geothermal cogeneration or combined heat and power (CHP). Here are some good examples of this:

i. District heating
ii. Greenhouses
iii. Timber mills
iv. Hot springs and bathing facilities
v. Agriculture

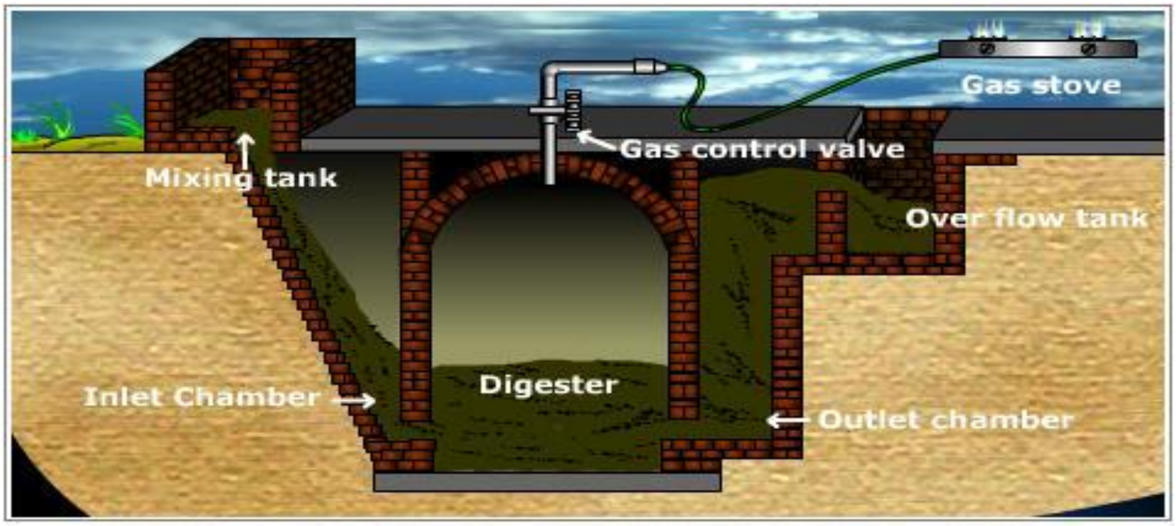
BIOGAS POWER PLANTS:

Biogas is a clean and efficient fuel. It is a mixture of methane (CH_4), carbon dioxide (CO_2), hydrogen (H_2) and hydrogen sulphide (H_2S).

Construction

The biogas plant is a brick and cement structure having the following five sections:

- Mixing tank present above the ground level.
- Inlet chamber: The mixing tank opens underground into a sloping inlet chamber.
- Digester: The inlet chamber opens from below into the digester which is a huge tank with a dome like ceiling. The ceiling of the digester has an outlet with a valve for the supply of biogas.
- Outlet chamber: The digester opens from below into an outlet chamber.
- Overflow tank: The outlet chamber opens from the top into a small over flow tank.



LAYOUT OF BIOGAS POWER PLANT

Working

- The various forms of biomass are mixed with an equal quantity of water in the mixing tank. This forms the slurry.
- The slurry is fed into the digester through the inlet chamber.
- When the digester is partially filled with the slurry, the introduction of slurry is stopped and the plant is left unused for about two months.
- During these two months, anaerobic bacteria present in the slurry decomposes or ferments the biomass in the presence of water.
- As a result of anaerobic fermentation, biogas is formed, which starts collecting in the dome of the digester.
- As more and more biogas starts collecting, the pressure exerted by the biogas forces the spent slurry into the outlet chamber.
- From the outlet chamber, the spent slurry overflows into the overflow tank.

- The spent slurry is manually removed from the overflow tank and used as manure for plants.
- The gas valve connected to a system of pipelines is opened when a supply of biogas is required.
- To obtain a continuous supply of biogas, a functioning plant can be fed continuously with the prepared slurry.

Advantages of fixed dome type of biogas plant

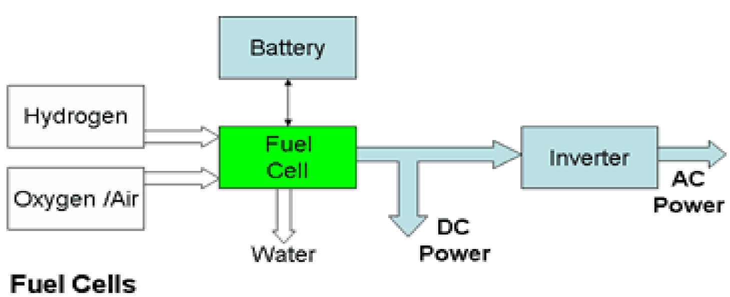
- Requires only locally and easily available materials for construction.
- Inexpensive.
- Easy to construct.

Limitations of biogas plants

- Initial cost of installation of the plant is high.
- Number of cattle owned by an average family of farmers is inadequate to feed a biogas plant.

Fuel Cells

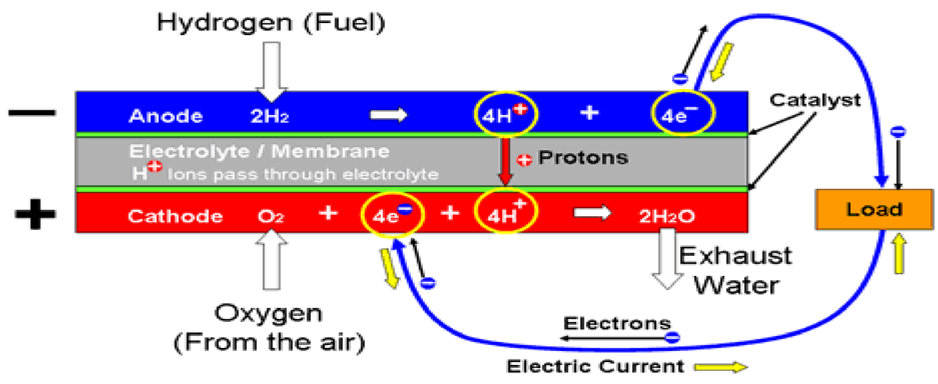
The fuel cell was takes in Hydrogen and Oxygen from the air and puts out electricity, heat, and water. It doesn't use fossil fuels and it doesn't produce greenhouse gases and so it should be the ideal solution to providing distributed or portable electrical power.



LAYOUT OF FUEL CELL POWER PLANT

Proton Exchange Membrane (PEM) Fuel Cell

The most common fuel cells use Hydrogen as the fuel and Oxygen from the air as the oxidant. The basic reaction can be illustrated by the Proton Exchange Membrane (PEM) fuel cell. (Also called the Polymer Electrolyte Membrane fuel cell.)



Fuel Cell Electrochemistry

The overall equation for the reaction is

$$2H_2 + O_2 \Rightarrow 2H_2O$$

- **The Electrodes**

  The electrodes are made from porous carbon which allows the active gases to pass through and the electrode surfaces support platinum catalysts.

- **The Electrolyte**

  The electrolyte is a thin, fragile sheet of acidic, solid organic polymer about 50 microns (2 thousandths of an inch) thick which permits the passage of Hydrogen ions but is impermeable to electrons. Acidic compounds are fluids with free Hydrogen ions and these are the fuel cell's charge carriers.

- **The Active Chemicals**

  The Hydrogen is supplied to the anode where it is oxidized losing electrodes in the process. The positive Hydrogen ions (protons) migrate across the electrolyte through the membrane to the anode while at the same time the electrons travel round the external circuit to the cathode.

The Oxygen is supplied to the cathode where it is reduced, picking up the electrons and the ions from the Hydrogen to form water.

- **The Electrical Energy**

The electron flow between the anode and the cathode caused by the chemical reactions in the cell represents the conventional electrical current flowing in the opposite direction. This electrical current is available to do work in the external circuit.

- **Catalysts**

Catalysts are needed to increase the rate of oxidation at the anode and the rate of reduction at the cathode. In this way they allow the chemical reaction to take place at a lower temperature. Alternatively to avoid the cost of expensive catalysts, some fuel cells are designed to work at elevated temperatures.

The platinum catalyst used in PEM and some other cells is very expensive and extremely sensitive to poisoning by even small amounts of Carbon Monoxide making it necessary to employ an additional filtering processes in the system to eliminate potential contaminants.

Balance of Plant (BOP)

The fuel cell stack alone can not generate electricity. Practical systems need sub-systems to supply the fuel and to provide the necessary control over the processes involved in the energy conversion. The essential ancillary equipment , the so called "balance of plant", can be just as expensive and complex as the fuel cell stack itself. Some of this equipment is outlined in the following list;

Fuel Supply or Storage

The largest item is the reformer which provides local generation of the Hydrogen fuel. The reformer itself must have storage capacity for the reformate fuel used in the process. If Hydrogen generation is not part of the system, there must be some form of storage to carry the Hydrogen fuel to be consumed by the fuel cell. This requires expensive high pressure tanks or cryogenic storage tanks (See also below) Pumps, Compressors and Expanders Pumps are needed to pump the reactant air through the stack and to provide forced cooling. Higher power systems require compressors to handle the higher airflow rates. Expanders are needed to reduce the high pressure of the stored Hydrogen to the required input pressure at the stack.

Filters

Filters are needed to remove any contaminants from the fuel supplies which could poison the catalysts or damage the cells reducing their power production and ultimately causing their shut down. Particular offenders are Carbon Monoxide, resulting from incomplete reactions in the reformer

Thermal Management

High power systems use forced cooling with fluid coolants to remove the heat. This requires fluid pumps and a radiator/heat exchanger to expel the heat. The system also requires heaters to bring the stack temperature up to its operating point on start up.

An overall thermal management system is required to balance the heat flows to keep the temperature of the stack at its optimum operating point.

Water Management

The conductivity of the electrolyte in the cell is proportional to the water content and it must be kept moist to remain conductive. The airflow and the heat generation in the cell tend to work against this. Consequently the air supplied to the cell must be humidified to stop electrolyte drying out and this requires a humidifier.

Cold temperature operation in freezing conditions also brings problems due to the formation of ice crystals which can damage the electrolyte or membrane. The system must incorporate a method of purging the water or alternative anti-freeze controls. Another pump may be required to remove surplus water from the cathode.

Electrical Power Management

Though some fuel cells may be required to provide a steady operating current and voltage, most systems must be responsive to variable demands. This means that the system should provide for a variable output current and as a consequence, all the fuel, air and water flows must be varied accordingly. At the same time the heat dissipation will change and the temperature must be maintained within its designed operating range. The same will apply to the reformer if this is part of the system.

The fuel cell system output voltage is fixed but the application may require a different voltage or, in the case of most distributed power generators, an alternating current output. In these cases DC/DC converters or AC inverters may be an integral part of the system.

Electric Motors

Motors of different sizes are required to drive the pumps and compressors.

Sensors

Sensors are required to monitor temperatures, pressures, fluid and gas flows as well as electrical currents and voltages.

Battery

The fuel cell does not start to deliver electrical energy until it approaches its operating point. During start up, batteries are required to power all the electronic control systems, as well as the pumps, compressors and heaters needed to get the stack up to its operating point. The battery also provides an independent stable voltage to power the system electronics. **Safety Systems**

Safety systems must provide fail safe operation, protecting the system from out of tolerance conditions and abuse and shutting it down if necessary.

Control System

The system could not function without comprehensive electronic control systems to manage all the sub-systems listed above.

UNIT V ENERGY, ECONOMIC AND ENVIRONMENTAL ISSUES OF POWER PLANTS

TARIFFS:

In economic terms, electricity (both power and energy) is a commodity capable of being bought, sold and traded. An electricity market is a system for effecting purchases, through bids to buy; sales, through offers to sell; and short-term trades, generally in the form of financial or obligation swaps. Bids and offers use supply and demand principles to set the price. Long-term trades are contracts similar to power purchase agreements and generally considered private bi-lateral transactions between counterparties.

Wholesale transactions (bids and offers) in electricity are typically cleared and settled by the market operator or a special-purpose independent entity charged exclusively with that function. Market operators do not clear trades but often require knowledge of the trade in order to maintain generation and load balance. The commodities within an electric market generally consist of two types: Power and Energy. Power is the metered net electrical transfer rate at any given moment and is measured in Megawatts (MW). Energy is electricity that flows through a metered point for a given period and is measured in Megawatt Hours (MWh).

Markets for power related commodities are net generation output for a number of intervals usually in increments of 5, 15, and 60 minutes. Markets for energy related commodities required by, managed by (and paid for by) market operators to ensure reliability, are considered Ancillary Services and include such names as spinning reserve, non-spinning reserve, operating reserves, responsive reserve, regulation up, regulation down, and installed capacity.

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In addition, for most major operators, there are markets for transmission congestion and electricity derivatives, such as electricity futures and options, which are actively traded. These markets developed as a result of the restructuring

Determination of cost/Tariff:

The cost of each item mentioned above is simple but the allocation of these items among various classes of consumers is rather difficult. This requires considerable engineering judgment.

The general energy rate or tariff can be given by the following equation

$$E = Ax + By + C$$

Where, E = total amount of bill for the period considered, A = rate per kW of maximum demand,

x = maximum demand in kW, B = energy rate per kW-hr,

y = energy consumed in kW-hr during the period considered

C = Constant amount charged to the consumer during each bill period. This charge is independent of demand or total energy.

Types of Tariffs - The various forms used for changing the consumers as per their energy consumed and maximum demand are discussed below.

1. **Flat demand rate:**

In this type of charging, the charging depends only on the connected load and fixed number of hours of use per month or year. This can be given by the following equation - **$E = Ax$**

The notations are taken as; discussed above. This rate expresses the charge per unit of demand (kW) of the consumer. Here no metering equipments and manpower are required for charging. In this system, the consumer can theoretically use any amount of energy upto that consumed by all connected loads. The unit energy cost decreases progressively with an increased energy usage. The variation in total cost and unit cost are shown in fig. above

2. Straight line meter rate:

This type of charging depends upon the amount of total consumed by the consumer. The bill charge is directly proportional to the energy consumed by the consumer. This can be represented by the following equation. - **$E = By$** The major drawbacks of this system are:

(a) In this type of system, the consumer using no energy ay any amount although he has incurred some expels Power station.

(b) The rate of energy is fixed, therefore this method of does not encourage the consumer to use more power.

The variation in total cost and unit consumed are shown in the figureabove.

3. Block-meter rate:

In previous straight line meter rate the unit charge is same for all magnitudes of energy consumption. The increased consumption spreads the item of fixed charge over a greater number of units of energy. Therefore, the price of energy should decrease with an increase in consumption. The block meter rate is used to overcome this difficulty. This method of charging is represented by the equation.

$$E = B_1y_1 + B_2y_2 + B_3y_3 + \ldots\ldots$$

Where, $B_3 < B_2 < B_1$ and \

(y_1 + y_2 + y_3 +……) = y (total energy consumption)

The level of y_1 , y_2 , y_3 …… is decided by the government to recover the capital cost, In is system, the rate of unit charge decrease with increase in

.

4. **Hopkinson demand rate of Two-part tariff:** this method of charging depends upon the maximum demand and energy consumption. This method is proposed by Dr.' John Hopknson in 1982. This method of charging is represented by the equation – **E = A + By**

In this method two meters are required to record the maximum demand and the energy consumption of the consumer. This method is generally used for the industrial consumers. The variation in total cost with respect to the total energy consumption taking x as parameter is shown in fig above.

5. **Doherty rate or three part tariff:** This method is proposed by Henry L. Doherty. In this method of charging, the consumer has to pay 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 prices and wage charges of the workers etc.

This method of charging is expressed by the equation.- **x = Ax + By + C**

This Doherty method of charging is most commonly used in Tamilnadu and all over India. In this method the customers are discouraged to use more power when the generating capacity is less than the actual demand.

For example, for the first 50kW-hr units the charging rate is fixed as, say, Rs. 2.5/Kw-hr and if it exceeds than this charge is rapidly increased as Rs. 3.5/kW-hr for next 100 kW-hr units (i.e from 51Kw-hr to 150kW-hr) . this method is unfair to the customer, but very common in India and many developing nations.

Load Distribution Parameters

1. **Commercial load: -** it is the combined continuous rating of all the receiving apparatus and devices on consumer's premises. If a consumer has a connections for 3 lamps of 40 watts each and power point of 500 watts for refreigerator and TV consuming 60 watts , then the total connected load of the consumer = [(3*40) + 500 + 60] = 680 watts.

2. **Demand: -** it is the load that is drawn from the source of supply at the receiving terminals averaged over a suitable and specified interval of time.

3. **Maximum demand: -** it is the maximum load that is used by the customer at any time. It is determined by measurement, according to specifications over a prescribed interval of time. It can be less than or equal to connected load. But generally, the actual maximum demand is less than the connected load because all the loads never run in full load at the same time.

4. **Demand factor: -** it is the ratio of of actual maximum demand on the system to the total connected demand of the system,

Demand factor = actual maximum demand / total connected demand

5. **Load factor: -** it is the ratio of average load over a given time interval to the peak load during the same time interval,

Load factor = average load over a time interval / peak load during the same interval

Load factor is always less than unity. It plays an important part on the cost of power generation per unit. The higher the load factor, the lesser will be the cost of power generation per unit for the same maximum demand.

6. **Capacity factor or plant capacity factor: -** it is the ratio of actual energy produced in kilowatt hour(kWh) to the maximum possible energy that could have been produced during the same period.

Capacity factor = average load / rated capacity of the plant

= actual energy produced in kWh / rated capacity of the plant = E /(C*t)

Where, E = energy produced in kWh; C = capacity of the plant in kW;

(t) = total number of hpurs in given period

If the rated capacity of the plant is equal to the peak load, then the load factor and capacity factor will be numerically equal.

7. **Utilization factor: -** it is the ratio of maximum load to the rated capacity of the plant.

Utilization factor = maximum load / rated capacity of the plant

8. **Reserve factor: -** it is the ratio of the load factor to capacity factor

Reserve factor = load factor / capacity factor

9. **Diversity factor: -** it is defined as the ratio of the sum of individual maximum demand to actual peak load of the system

Diversity factor = sum of individual maximum demand / actual peak load of the system

10. **Plant use factor: -** it is the ratio of energy produced in a given time to the maximum possible energy that could have been produced during the same

period of operation

Plant use factor = E / C*t_1 (where, t_1 – actual hours plant in operation)

Acual energy produced in a given time period

Maximum possibleenergy produced by the plant

11. Dump power – this term is used in hydro-electric power plants. It shows the power in excess of the load requirements

12. Firm power – it is the power which should always be available even under emergency condition

13. Prime power - the power which may be mechanical, hydraulic or thermal that are always available for conversion into electric power.

14. Base load and peak load power plants - the **base load** is the load below which the demand never falls and is supplied 100% of the time. The power plant used to supply base loads are called **base load power plants.** These base load plants are loaded heavily. Operating cost of such plants are very important. A high capital cost is permissible, if low operating costs can be maintained. Hydro and nuclear plants are usually classified as base load power plants.

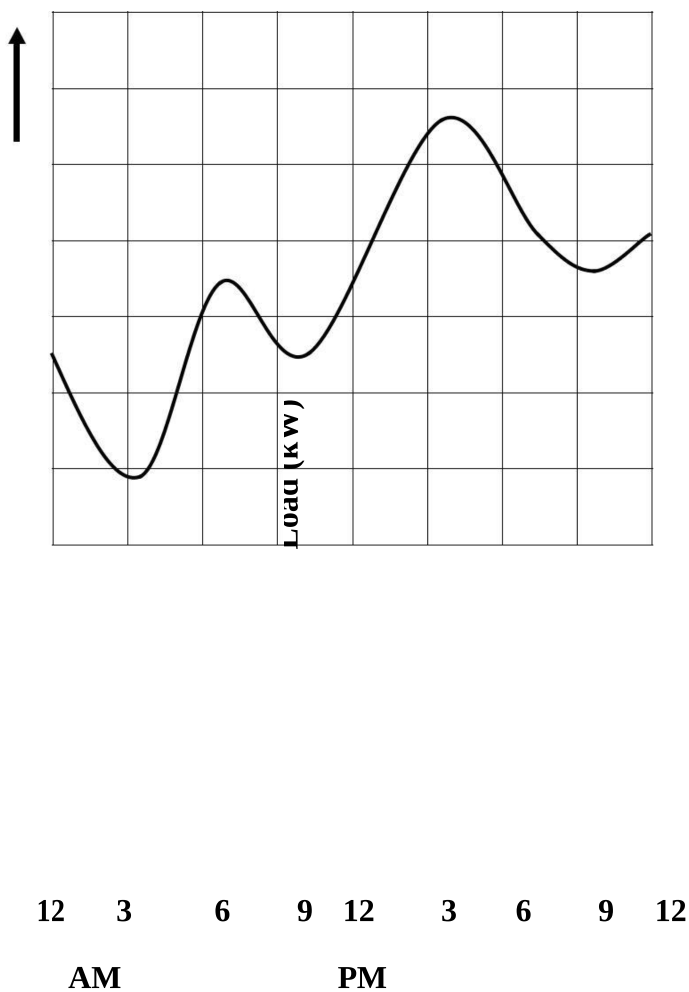
The **peak load** is the load which occurs at the top portion of the load curve. The power plants which are used to supply peak loads are called as **peak load power plants**. The peaking load occurs for about 15% of the time. The peak load power plants are all of smaller capacity, run for a shorter period in the year and work at low load factors. Peak load power plants should be capable of quick starting. Since peaking load plants are used only for a smaller fraction of time, the fuel cost is not of major importance. Minimum capital cost should be the criterion. Diesel power plants are usually classified as peak load power plants.

Load curve: -

it is the graphical representation showing the power demand for every instant during a certain time period. It is drawn between load in kW and time in hours, if it is plotted for one hour, it is called as **hourly load curve** and if the time considered is of 24 hours then it is called **daily load curve,** and if plotted for one year(8760 hours) , then it is **annual load curve.** The area under the load curve represents the energy generated in the period considered. If we divide the area under the curve by the total number of hours, then it will give the average load on the power station.

The peak load indicated by the load curve represents the maximum demand of the power station. This curve gives full information about the incoming load and helps to decide the installed capacity of the power station. It is als useful to decide the economical sizes of various generating units.

A typical daily load curve for a power station is shown above. It may be observed that the maximum load is 40kW from 6 pm to 9 pm . Similarly other loads are plotted in decreasing order and this is called load duration curve. It may be observed that the area under the both curves is equal and represents the total energy delivered by generation station. Load duration curve gives a clear analysis about generating power economically.



Typical daily Load curve

Load duratuion curve: - this curve represents the re-arrangement of all the load elements of load curve in order of decreasing magnitude. This curve is derived from load curve.

Residential load: - this includes domestic lights, power needed for domestic appliances such as radio, television, water heaters, grinders, washing machine, refrigerator, computer, disc washers, room heaters, air conditioner, etc.

Commercial load; - includes lighting for shops, advertisements and electric appliances used in shops, hotels and restaurants.

Industrial load; - consists of load demand of various industries.

Municipal load: - consists of power required for street lights, water supply, and drainage purposes.

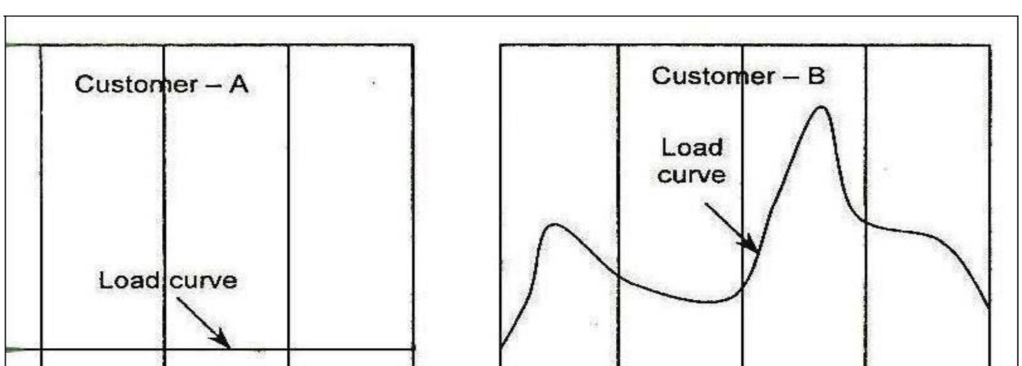
Irrigation load: - includes electric power supply required for pumps to supply water to fields.

Traction load: - consists of power required for tram cars, trolley, buses and railways.

Actual Load Curves

Before studying the types of tariffs, the actual loading and the representing load curves are explained below. - Load curve is a graphical representation which shows the power demands for every instant during certain time period. By drawing these load curves the peak load can be identified and hence the capacity of power plant can be judged.

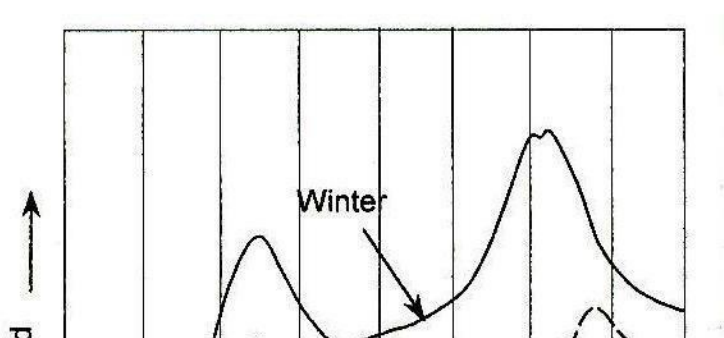
Fig. below shows two load curves in which the energy consumed by the consumer is same but the way adopted to use is different. The design of any power plant is based on the way that the customer adopted to use energy. The customer A and B consume same amount of energy but the nature of consumption is different.



In fig above the peak load is far greater than the first. Therefore, the sting capacity of the plant required to supply the load of B is greater than the capacity required to supply the load of A. The plant designed for customer B is not only bigger in size but it also runs load conditions for the majority of the period. Therefore, the cost of energy supplied to B may be more than the cost of energy supplied to A even the total energy consumed by both customers is same,

As explained earlier, the different types of loads for different types of customers are explained below:

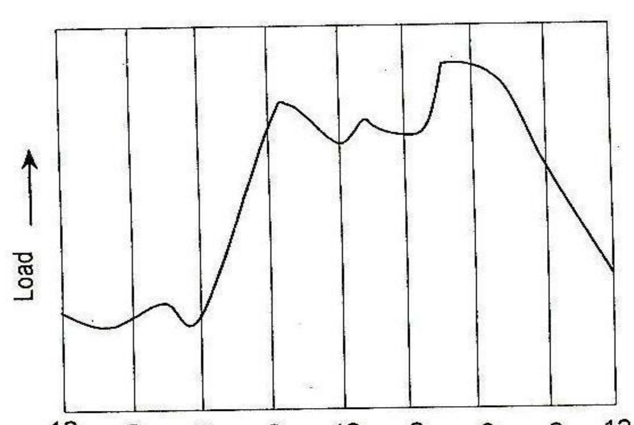
1. Residential load curve: The fig. below shows a typical residential load curve. During the early morning hours (6 A.M to 9 A.M the energy is required for lights, fans, refrigerators, water heaters. After the breakfast (at 9A.M.), the demand decreases and fairly remains constant till about 4 P.M. After 4 P.M, the demand is beginning to increase and attains its peak at 6 P.M. The peak load remains almost constant up to 8P.M, after that it decreases rapidly and attains minimum at 12 P.M, the foresaid statements are applicable for summer season



But during winter season, the load remains constant during day time and will be minimum. After 5P.M the load rapidly approaches its peak. The high demand occurs at about 8P.M.

2. Commercial load curve: - the fig. below shows a typical load curve for commercial usage like shops, office, restaurants etc. The lighting in shops and office starts at 6 A.M for cleaning and sweeping and then it reaches peak at 10 A.M. It remains constant more or less during 10 A.M to 4

P.M.



It increases further during 4 to 7P.M as more lights are required. Then, the load rapidly falls during 7P.M, to 12 P.M as the offices remain closed.

3. Industrial load curve: the fig. below shows a typical load curve for industrial community of one shift basis. In early morning from 5 A.M to 8A.M, the energy demand increases as some of the machinery starts for warming prior to operation. The entire industry starts running and energy demand remains constant from 8 AM to shortly before noon. There is a heavy fall in energy demand during 12 to IP.M, due to lunch hours.

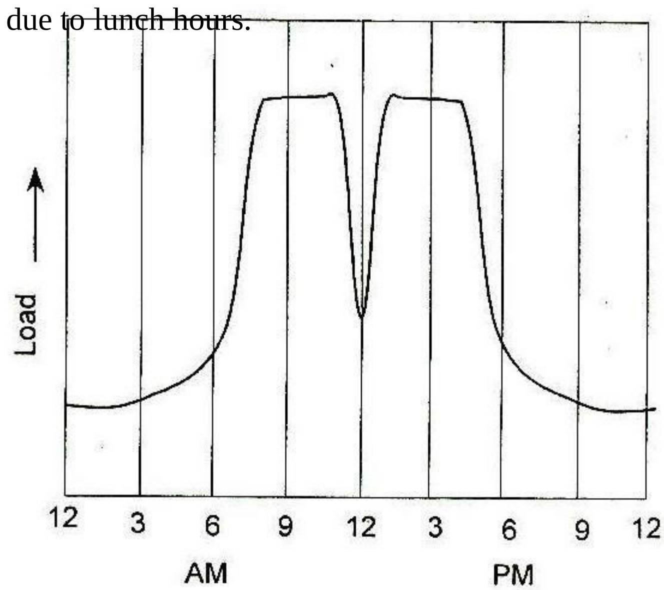


Fig. Industrial load curve for one shift

By 2 P.M again, the load attains the same level as at 8A.M, shortly before 5P.M, the load starts to drop as the shift of work ends. By 6 P.M most of the machines are shut down and load gradually decreases to minimum until 10 A.M. Then the minimum demand continues till the start of next working day.

4. Street lighting curve: -

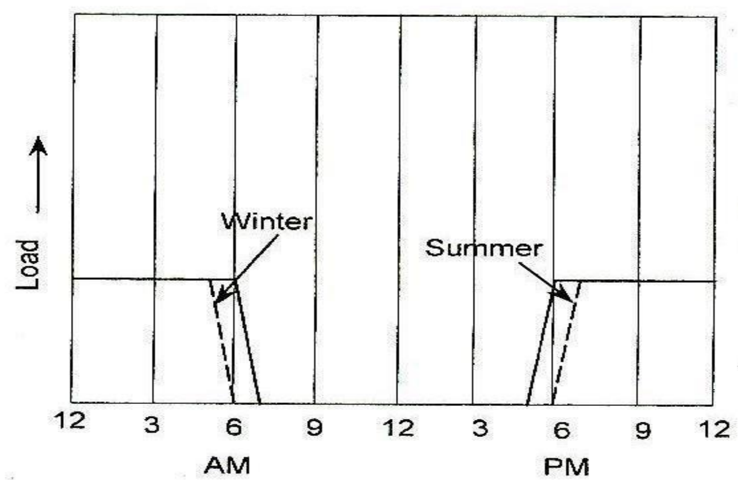


Fig. Street lightning load curve

The figure above shows a typical load curve for street lighting. Street lighting is the only form of load that does not exhibit peak demands. Normally all the street lights are simultaneously swithched 'on' at 6 P.M and are turned 'off' at 6 A.M. The load demand remains more or less constant during these hours.

6. Urban traction load curve: Fig. below shows a typical load curve for urban traction. During midnight hours from 12P.M to 5A.M, the demand tapers off as the service reaches its minimum level. As the early factory workers start for work, the required train services increase rapidly and consequent load continuously rises as the factory workers are followed by office workers, school children, college students and early shoppers.
7.

The peak reaches about at 9.3OA.M. After 10 P.M the load rapidly diminishes as some of the trains return to the yards.The minimum load is reached at noon hours and then rises continuously until the evening rush hours. The load again reaches its peak at 5P.M when most workers go back to their homes. The load after 6P.M falls rapidly.

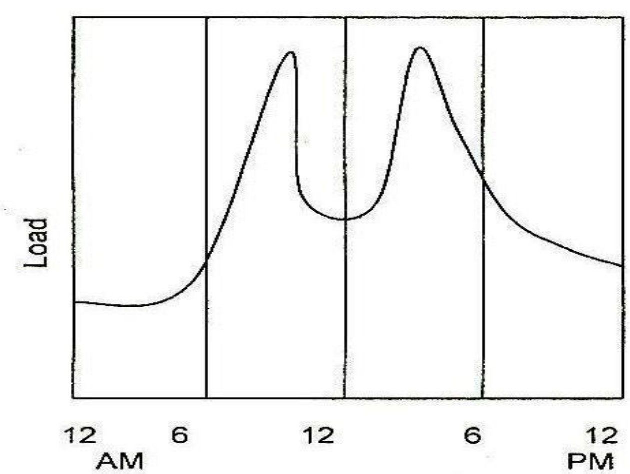


Fig.   ***Urban load curve***

Cost of Electrical Energy: -

Electric power transmission

Electric power transmission or "high voltage electric transmission" is the bulk transfer of electrical energy, from generating power plants to substations located near to population centers. This is distinct from the local wiring between high voltage substations and customers, which is typically referred to as electricity distribution. Transmission lines, when interconnected with each other, become high voltage transmission networks. These are typically referred to as "power grids" or just "the grid", while sometimes, this network is known as the "national grid."

Historically, transmission and distribution lines were owned by the same company, but over the last decade or so many countries have liberalized the electricity market in ways that have led to the separation of the electricity transmission business from the distribution business.

Transmission lines mostly use three-phase alternating current (AC), although single phase AC is sometimes used in railway electrification systems. High-voltage direct-current (HVDC) technology is used only for very long distances (typically greater than 400 miles, or 600 km); submarine power cables (typically longer than 30 miles, or 50 km); or for connecting two AC networks that are not synchronized.

Electricity is transmitted at high voltages (110 kV or above) to reduce the energy lost in long distance transmission. Power is usually transmitted through overhead power lines. Underground power transmission has a significantly higher cost and greater operational limitations but is sometimes used in urban areas or sensitive locations.

A key limitation in the distribution of electricity is that, with minor exceptions, electrical energy cannot be stored, and therefore must be generated as needed. A sophisticated system of control is therefore required to ensure electric generation very closely matches the demand. If supply and demand are not in balance, generation plants and transmission equipment can shut down which, in the worst cases, can lead to a major regional blackout. To reduce the risk of such failures, electric transmission networks are interconnected into regional, national or continental wide networks thereby providing multiple redundant alternate routes for power to flow should (weather or equipment) failures occur. Much analysis is done by transmission companies to determine the maximum reliable capacity of each line which is mostly less than its physical or thermal limit, to ensure spare capacity is available should there be any such failure in another part of the network.

Cost of electricity

A power plant should provide a reliable supply of electricity at minimum cost to the consymers / customers. The cost of electricity may be determined by the following: Fixed cost or capital cost and Operating costs. the total cost of energy produced is the sum total of fixed charges and operating charges.

Total cost = Fixed costs + Operating costs

Fixed cost or capital cost: It is the cost required for the installation of the complete power plant. This cost includes

1. The cost of land, equipments, buildings, transmission and distribution lines cost of planning and designing the plant and many others.
2. Interest,
3. Depreciation cost,
4. Insurance,
5. Management costs, etc

1.The cost of land, equipments, buildings - The cost of land and buildings does not change much with different types of power plants but the equipment cost changes considerably. The cost of buildings can be reduced by eliminating the superstructure on the oiler house and turbine house. To reduce the cost of equipment, unit system may be adopted, reduced by simplifying the piping system and elimination of duplicate system such as steam headers and boiler feed heaters.

The cost of equipment or the plant investment cost is usually expressed on the basis of kW capacity installed. The per kWcapacity may not vary for various thermal power plant where as for hydro-electric power plant, it changes a lot because the cost of hydro-electric power plant depends on the foundation availability, types of dam, available head and spillways used.

2.Interest: - the money needed or an investment may be obtained as loans, through bonds and shares. The interest is the difference between money borrowed and money returned. The rate of interest may be simple rate expressed as % per annum or may be compounded. A suitable rate of interest must be considered on the capital invested.

3. Depreciation cost: - it is the amount to be set aside per year from income to meet the depreciation caused by the ages of service, wear and tear of machinery, and the decrease in the value of equipment due to obsolescence. The power plant and equipment in the plant will have a certain period useful life. After years of use, the equipment loses its efficiency or becomes obsolete and needs replacement. Some times equipment may have to be replaced even when they fairly new, due to more efficient machines are available in the market. Some money is put aside annually to enable for this replacement, when necessary. This is known as **depreciation fund**.

Methods fpr calculating the depreciation cost: -

a) **Straight line method**

b) **Sinking fund method**

c) **Diminishing value method**

a) **Straight line method: -** it is the simplest and commonly used method, based on the assumption that depreciation occurs uniformly for every year

according to a straight line law. The money saved neglects any interest. According to this method, the annual amount to be set aside is calculated by

the following expression:

$$A = \frac{(P - S)}{N}$$

Where, A = Depreciation amount

P = Capital cost of the equipment,

S = Salvage value at the end of the plant life, 'n' = life of plant in years

b) Sinking fund method: - in this method, a sum of money is set aside every years for 'n' yearsand invested to earn compound interest. This method is based on the assumption that the annual uniform deduction from income for depreciation will accumulate to the capital value of the plant at the end of life of the plant.

According to this method, the annual amount to be set aside is calculated by the following expression:

$$A = \frac{r}{(1+r)^n - 1}(P - S)$$

Where, A = amount set aside at the end of first year

P = Capital cost of the equipment,

S = Salvage value at the end of the plant life (n^{th} year)

'n' = life of plant in years

'r' = the interest rate per annum

c) Diminishing value method: - in this method, the amount set aside per year decreases as the life of the plant increases.

Example: -

Given, the equipment cost = Rs.40,000.00

The amount set aside at the beginning of the year is 10% of the initial cost and for every successive year, the amount to be set aside is 10% of the remaining cost

Hence, the amount set aside during first year is

(40,000 x 10/100) = Rs.4000 and remaining amount is Rs. 36,000/= Hence, the amount set aside during second year is

(36,000 x 10/100) = Rs.3600 and remaining amount is Rs. 32,400/= Hence, the amount set aside during third year is

(32,400 x 10/100) = Rs.3240 and remaining amount is Rs. 29,160/= Hence, the amount set aside during fourth year is

(29,160 x 10/100) = Rs.2916 and remaining amount is Rs. 26,244/=

The **main disadvantage** of this method is that it requires heavy investments in the early years when the maintenance charges are minimum and it goes on decreasing as the time passes but the maintenance charges tend to increase.

4. **Insurance: -** nowadays, it becomes necessary to insure the costly equipments especially for the fire or accident risks. A fixed sum is set aside per year as insurance charges. The insurance premium may be 2 to 3% of the equipment cost but annual installment is quite heavy when the capital cost of the equipment is high.

5. **Management cost; -** this cost includes the salary of the management employees working in the plant. This must be paid whether the plant is working or not. Therefore, this cost is included in the fixed cost.

Operatring cost: - the operational cost includes

a) The cost of fuel,

b) The cost of lubricating oil, greases, cooling water,

c) The cost of maintenance and repairs,

d) The cost of operating labour,

e) The supervision cost and

f) Taxes.

These costs vary with the amount of electrical energy produced.

a) Cost of fuel: - the fuel consumption depends on the amount of energy produced. As load increases the fuel consumption will increase so does the cost of fuel. The efficiency of the prime mover is the highest at the rated load.

At lower loads, efficiency decreases and so the fuel consumption will increase. The selection of the fuel and the maximum economy in its use are, therefore, very important consideration in thermal plant design. The cost of the fuel includes not only its price but also its transportation and handling costs also. The cost of fuel depends on the calorific value and its availability.

b) **The cost of lubricating oil, greases, cooling water:** - the cost of these materials also proportional to the amount of energy generated. this cost increases with an increase in life of the power plant as the efficiency of the power plant decreases with age.

c) **The cost of maintenance and repairs: -** in order to avoid breakdowns, maintenance is necessary. it includes periodic cleaning, adjustments and overhauling of equipments. the materials used for maintenance and repairs are also charged under this head. it is necessary to repair when the plant breakdown or steps due to fault in mechanism. the repairs may be major or minor and are charged to the depreciation fund of the equipment. the cost is higher for thermal power plants than hydro power plants.

d) **The cost of operating labour: -** this includes the salary and wages for the operating labour working in the plant. maximum labours are needed in a thermal power plant using coal as a fuel. a hydro power plant or a diesel power plant of same capacity requires a less number of labours. in automated power plant, labour cost is reduced to a greater extent.

e) **The supervision cost: -** it includes the salary of the supervising staff and executives. a good supervision reduces the breakdowns and extends the plant life. the supervising staff includes chief engineer, superintendent, engineers, stores in charges, purchase officers, other supporting staffs and executives, etc.

f) **Taxes: -** the various taxes are included in this head. these are income tax, sales tax, provisional tax, commercial tax, etc.

The Variable Load Operations : - the variable load operation problem affects power plant design and operation as well as the cost of generation. the necessity of supplying variable load influences the characteristics and the method of using the power plant equipment. the generation of power must be regulated according to the demand. for that purpose governing is necessary to achieve it. quick response to varying load is another important requirement of the power plant.

A careful study of the load duration curve helps to decide the capacity of the base load plant and also of the peak load plant. the basic load plant should be run at high load factor. the peak load plant should be of smaller capacity to reduce the cost of generation. it could be a gas turbine unit, pumped storage hydro-system, compressed air energy storage system or a diesel engine depending up on the size and scope of availability.

If the entire load is to be supplied by the same power plant, the generation and the prime mover must be able to take varying load as quick as possible without variation of the voltage or frequency of the system. When the load on the generator increases, it will slow down the rotor and prime mover and therefore, it reduces the frequency. When the speed of the prime mover decreases, the governor must act. It is the function of the governor to control the supply of fuel to the prime mover according to the load. It should be enough to bring back the speed to normal and pick up the load. Frequency stabilizers are used to maintain the frequency constant which may change due to response of the equipment.

In case of thermal power plant, the raw materials used are fuel, air and water to produce variable power. According to the requirements, the raw materials are supplied correspondingly with an increase in the load on the plant, the governor admits more steam and maintain the turbine speed up to certain point, the governor responds rapidly with change in load but beyond this point changes are not rapid. Because of fluctuating steam demand, it becomes very difficult to secure good combustion and steady steam temperature. Therefore, the design of thermal plant for various loads is always more difficult than diesel or hydro-electric power plants and it is always desirable to allow the thermal plant to operate as base load plant.

Economic load sharing between base load plant and peak load plant is desirable. Steam power plant and nuclear power plant are preferred as base load plants whereas diesel power plant and Hydro power plant can be used as peak load plant. Hydro power plant with larger storage can also be used as base load plant.

Economics of Load Sharing Between Generators

During design of power plants, prime importance is given to the economics of load sharing. Engineers are designing the power plant components such as boilers, heat turbines, heat exchangers, condensers, and generators etc for getting the highest thermal efficiency of the plant.

Various methods have been developed for economic operation of the power plant under varying load conditions. Transmission loss is also minimized by introducing the successful design of transmission lines.

The main problem for the electrical power engineers is the economic load sharing of the output of the generators. The proper sharing of load between two generators to give maximum overall efficiency is the major problem in load distribution among generators.

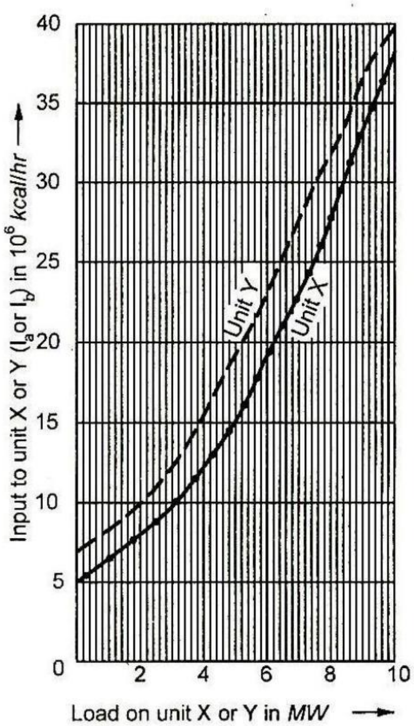


Fig. Input-output curves of unit X and Y

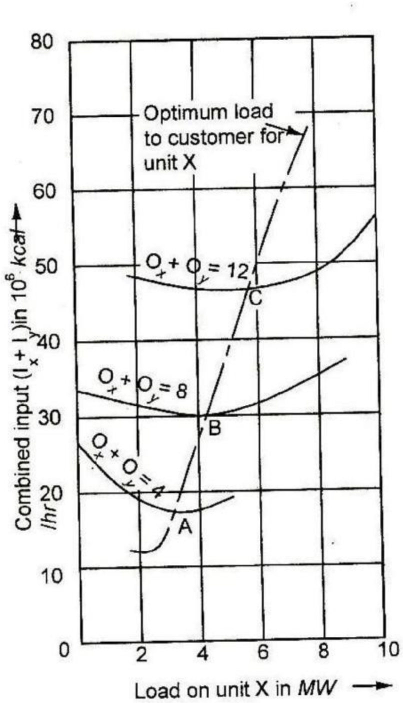


Fig. Variation of combined input with varying load sharing between X and Y

This input-output carries for two generators within a power plant which are operating in parallel and supply a common load is shown in fig below. From this fig, it is evident that the generator X is more efficient than Y throughout its load range as the output of X is more than the output of Y for the same input. Therefore, the engineers may think that they can load generator X first to its full capacity and then for generator Y for the remaining load. But it is not proper distribution as the overall efficiency of the system would not be highest with the distribution of loads as mentioned above. Therefore, it is essential to find out load distribution between generators to give the highest efficiency for the system.

This problem can be resolved by plotting the sum of the inputs of X and Y against the load x for a given constant load on the two limits, as shown in fig above.

Say total load is 4 MW. If the load on X = 0 and Y = 4MW, then the load on X + Y = 4MW. The required input for X and Y can be calculated from the fig above. If the load on X = 1 and Y = 3MW, then again the combined load on X + Y = 4MW and the corresponding required input for X and Y can be calculated from the fig above and different outputs of X as shown in fug above. Such different curves for different constant value of (O_x + O_y) can also be drawn using the same procedure as described above. In the curves drawn, it is clear that one point on the curve the combined input is minimum for a given total load. Corresponding to this point (A) of minimum input to the system for the required output, we can find out the load on the generator X, the load on generator Y is the difference of load sharing, highest efficiency can be achieved.

This method is useful for the system having two generators. If the number of generators supplying the load is more than two, this method becomes cumbersome process.

Economic load sharing between power plants: - different power plants such as hydro, thermal, nuclear, gas turbine, MHD, etc are operated combined to give greater reliability and maximum economic benefits. When the number of power stations works in combination with each other to supply the power to the consumers, the system is known as **interconnected system**.

In an interconnected system, the major problem is division of load among the power plants. The load distribution among the power plants depends upon the operating characteristics of the power plant. The distribution of load among the power plant in an interconnected system is done in such a way that the overall efficiency is achieved.

In the load duration curve, as shown below, the entire area under the load curve is divided into three parts as base load, intermediate load, and peak load. It is not economical to design a power plant to load to the maximum peak load as it works in under-load condition for the most of the time. In order to achieve the maximum possible is the loading of the most efficient power station in the order of merit of low fuel cost. It is made possible by establishing central control room which can control number of power plants simultaneously in the grid system. This also saves the fuel consumption per kW of power generation. In addition to the fuel consumption, there is also savings due to reduced spare capacity required and also due to the employment of large size units.

Base load station takes up the load on the lower region of the load curve. This station is highly efficient and operates on three hift basis throughout the year. The fixed cost of this plant is high. The capacity factor is the index of the return on the capital investment on the plant. Continuous operation of base load of plant at high load factor improves and this makes the operation of the base load plant an economic proposition. Hydro and nuclear power plants are usually classified as base load plants.

The intermediate load stations operate on two or single shift basis. The capital cost of such plant is lower and fuel cost is higher than the base load plants. Thermal stations fall under this category.

Peak loads plant operates only when required for short times under the upper part of the load curve. Plant capacity factor is low as it is operating for short duration. Fuel is very high but total capital cost is less. Diesel engine and gas turbines plants are classified under this category.

Calculation of economic load sharing between peak load and base load plants, operating in parallel: -

For a known load duration curve, Let the operating costs are known and these are given by,

(Operating cost of powerstation 1)

$C_1 = A_1$ (kW) + B_1 (kW.hr) for base load plant (Operating cost of powerstation 2)

$C_2 = A_2$ (kW) + B_2 (kW.hr) for peak load plant

Peak load of the peak load power plant is given by $P_p = P - P_b$ Where, P_p - peak load on peak load plant in kW,

P_b - peak load on the base load plant in kW, And P - peak load of the system in kW

Similarly no. of units generated by the peak load plant is $N_p = N - N_b$ Where, N_p - no. of units generated by peak load plant in Kw.hr,

N_b - no. of units generated by base load plant in Kw.hr, And N - total no. of units generated by the system in Kw.hr Therefore, (Operating cost of powerstation 1)

$C_1 = A_1 (P_b) + B_1 (N_b \text{ kW.hr})$ for base load plant (Operating cost of powerstation 2)

$C_2 = A_2 (P - P_b) + B_2 (N - N_b \text{ kW.hr})$ for peak load plant

The cost of the system $C = (C_1 + C_2) = (A_1 * P_b + B_1 * N_b) + [A_2 (P - P_b) + B_2 (N - N_b)]$

The minimum total cost can be obtained when $(dC / dP_b = 0)$ Therefore, $[(A_1 – A_2) + (B_1 – B_2)](dN_b / dP_b) = 0$

$$(dN_b / dP_b) = [(A_1 – A_2) / (B_1 – B_2)] \text{ hrs.}$$

Thus for economic load sharing, the area under the load curve is so divided by horizontal line that its magnitude is given by

$$H = [(A_1 – A_2) / (B_2 – B_1)] \text{ hrs}$$

This indicates that for economic load sharing, peak load plant should work for H hours per year. The value of H should be always higher.

Therefore, $A_1 > A_2$ and $B_2 > B_1$

That is A_1 is higher and B_1 is lower for base load plant as compared to peak load plant.

Mark the point T on x - axis of load cirvefor the distance of H hours in percentage [(H / 8760)*100]

Draw the vertical line through T which meets the load curve at point P Draw the horizontal line PQ as shown in the figure above.

Now the area A_p above the line PQ gives the energy generated by peak load plant and area below the line PQ gives A_b, the energy generated by the base load plant.

The scale taken for drawing load curve is 1 cm = x % along time axis , and 1 cm = y kW along load axis

Hence,1 cm^2 = (x%)*y; 100% = 8760 hrs; 1 cm^2 = [(x/100)*8760]*y in kWh If areas A_b and A_p in cm^2 are known, then

$N_b = A_b$ *[(x/100)*8760]*y in kWh - for base load plant N_p = A_p*[(x/100)*8760]*y in kWh - for peak load plant

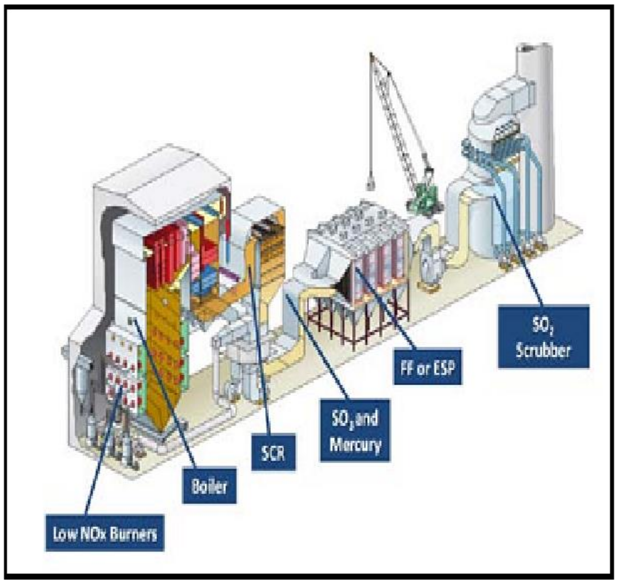
Thus, the load sharing between the two power plants can be attained and this results in overall efficiency of operation.

Pollution control method for coal based thermal power plant:

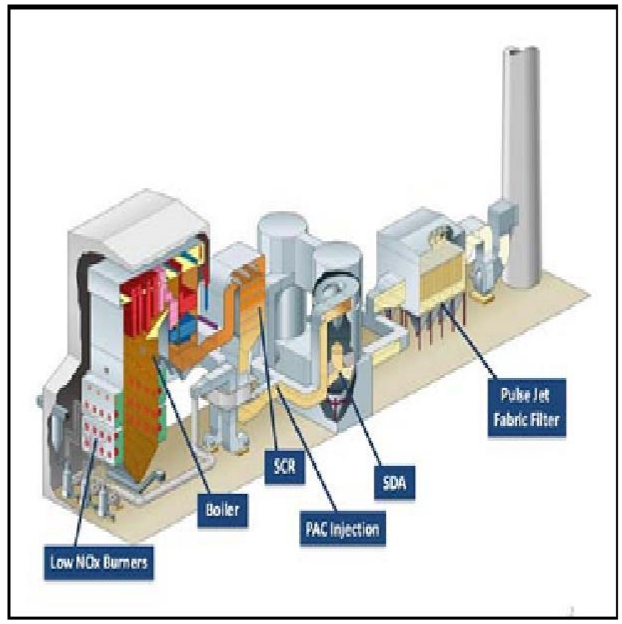
Coal is one of the most abundant energy sources in the world. Advanced emission control technologies are needed to cleanly use coal for electricity generation. Environmental regulations of coal-fired power plants in Asia cover a broad range of requirements. Depending on the area within Asia and the type of coal to be burned, different combinations of technologies are needed to meet local regulations. There are a multitude of advanced emissions control technologies available to address the most common targeted pollutants such as sulfur dioxide (SO2), nitrogen oxides (NOx), and particulate matter (PM), as well as other pollutants which are increasingly becoming targeted worldwide, such as mercury, sulfur trioxide (SO3), condensable PM, and other trace metals. This paper examines state-of-the-art emissions control systems that are available to meet the multi-pollutant requirements for coal-fired power plants. These technologies include selective catalytic reduction (SCR), electrostatic precipitators (ESP), fabric filters, flue gas desulfurization (FGD), wet ESP, dry sorbent injection, and mercury control methods.

Table 1
Formation of Pollutants from Coal Combustion

Raw Coal Constituent	Combustion Result	Required Equipment
Carbon (C)	Heat, Steam, CO_2	Boilers
Nitrogen (N)	NO_x	Burners and SCR Systems
Sulfur (S)	SO_2	Wet and Dry FGD
	SO_3	Sorbent Injection, Wet ESP
Ash	Ash	Ash Handling, Sootblowers, Precipitators, Fabric Filters
Mercury (Hg)	Hg^{++}, Hg^0	Coal Additive, PAC Injection, Wet FGD Enhancement Systems



Typical plant configuration for high sulfur bituminous coal.



Typical plant configuration for low sulfur coal.

Current and pending environmental regulations are becoming increasingly more stringent and intricate, encompassing more air emissions than ever before. Environmental equipment and systems utilized in a flue gas cleaning arrangement have typically been associated with the treatment of one particular pollutant. For example, an SCR system is used to reduce NOx. However, as emissions regulations become more stringent and utilities consider the use of a wide range of fuel types as is currently happening in Asia, the interrelated effects of each component or system in the arrangement on other pollutants must be recognized. Some of these effects are positive and some may be negative. For example, it is known that an SCR oxidizes elemental mercury into ionic (elemental) mercury. Oxidized mercury is much easier to remove in an FGD system. Thus, making the SCR larger will increase mercury removal in the FGD downstream. However, an SCR also oxidizes SO2to SO3, which can become sulfuric acid, H2SO4. Sulfuric acid forms a very fine mist, which is very difficult for a wet FGD to remove. Filterable (solid) particulate is removed in the wet scrubber. The wet scrubber tends to remove 40 to 90% of the flyash entering the scrubber, depending upon the ash inlet loading and the type and configuration of wet scrubber. However, further particulate control is needed to collect this material and to limit its release to the atmosphere. When a plant considers the use of air pollution control technologies, several areas of the boiler island and environmental protection system need to be evaluated to optimize the overall reduction of plant emissions.

Pollution control in nuclear power plant

Types of Radioactive Waste

Radioactive wastes are normally classified into a small number of categories to facilitate regulation of handling, storage and disposal, based on the concentration of radioactive material they contain and the time for which they remain radioactive. The definitions of these categories differ in detail from country to country; however, in general, they can be considered as exempt waste and very low-level waste, low-level waste, intermediate-level waste, and high-level waste.

A. Exempt Waste and Very Low Level Waste

Exempt waste and very low level waste (VLLW) contains radioactive materials at a level which is not considered harmful to people or surrounding environment. It consists mainly of demolished material (such as concrete, plaster, bricks, metal, valves, piping etc.) produced during rehabilitation or dismantling operation on nuclear industrial sites. The waste is therefore disposed of with domestic refuse, although countries such as France are currently developing facilities to store VLLW in specifically designed VLLW disposal facilities.

B. Low-Level Waste

Low level waste (LLW) is generated from hospitals, laboratories and industries, as well as the nuclear fuel cycle. It comprises paper, rags, tools, clothing, filters etc. LLW may include short lived radionuclides at higher levels of activity concentration, and also long lived radionuclides, but only at relatively low levels of activity concentration. It is not dangerous to handle, but must be disposed of more carefully than normal garbage. It doesn't require shielding during handling and transport. LLW can generally be handled using rubber gloves. Much of the waste generated during decommissioning of a nuclear power plant is LLW. To reduce volume, it is often compacted or incinerated before disposal. Worldwide it comprises 90% of the volume but only 1% of the radioactivity of all radwaste.

C. Intermediate-Level Waste

Radioactive waste that requires shielding but needs little or no provision for heat dissipation is classified as intermediate level waste (ILW). Intermediate level waste contains higher amount of radioactivity and may require special shielding. It typically comprises resins, chemical sludge and reactor components as well as contaminated materials from reactor decommissioning. ILW may contain long lived radionuclides, in particular, alpha emitting radionuclides that will not decay to a level of activity concentration acceptable for near surface disposal during the time for which institutional controls can be relied upon. Smaller items and any non-solids may be solidified in concrete or bitumen for disposal. Worldwide it makes up 7% of the volume and has 4% of the radioactivity of all radwaste. It may be solidified in concrete or bitumen for disposal. Generally short-lived waste (mainly from reactors) is buried, but long-lived waste (from reprocessing nuclear fuel) is disposed of deep underground.

D. High-Level Waste

High-level waste (HLW) is defined to be waste that contains such large concentrations of both short and long lived radionuclides that, compared to ILW, a greater degree of containment and isolation from the accessible environment is needed to ensure long term safety. It generates a considerable amount of heat and requires cooling, as well as special shielding during handling and transport. If the used fuel is reprocessed, the separated waste is vitrified by incorporating it into borosilicate (Pyrex) glass which is sealed inside stainless steel canisters for eventual disposal deep underground. If used fuel is not reprocessed, all the highly-radioactive isotopes remain in it, and so the whole fuel assemblies are treated as high-level waste. Both high-level waste and used fuel are very radioactive and people handling them must be shielded from their radiation. Such materials are shipped in special containers which shield the radiation and which will not rapture in an accident. Whether used fuel is reprocessed or not, the volume of high-level waste is modest, about 3 cubic meters per year of vitrified waste, or 25-30 tons of used fuel for a typical large nuclear reactor

Waste Management Principles

On a practical level, the activities necessary for managing radioactive waste properly can be categorized into the following steps:

A. Minimization

Existing facilities can, with foresight and good practice, reduce the amount of waste created. New technologies and plant designs also aim for waste reduction through such means as simplifying maintenance requirements.

B. Conditioning and Packaging

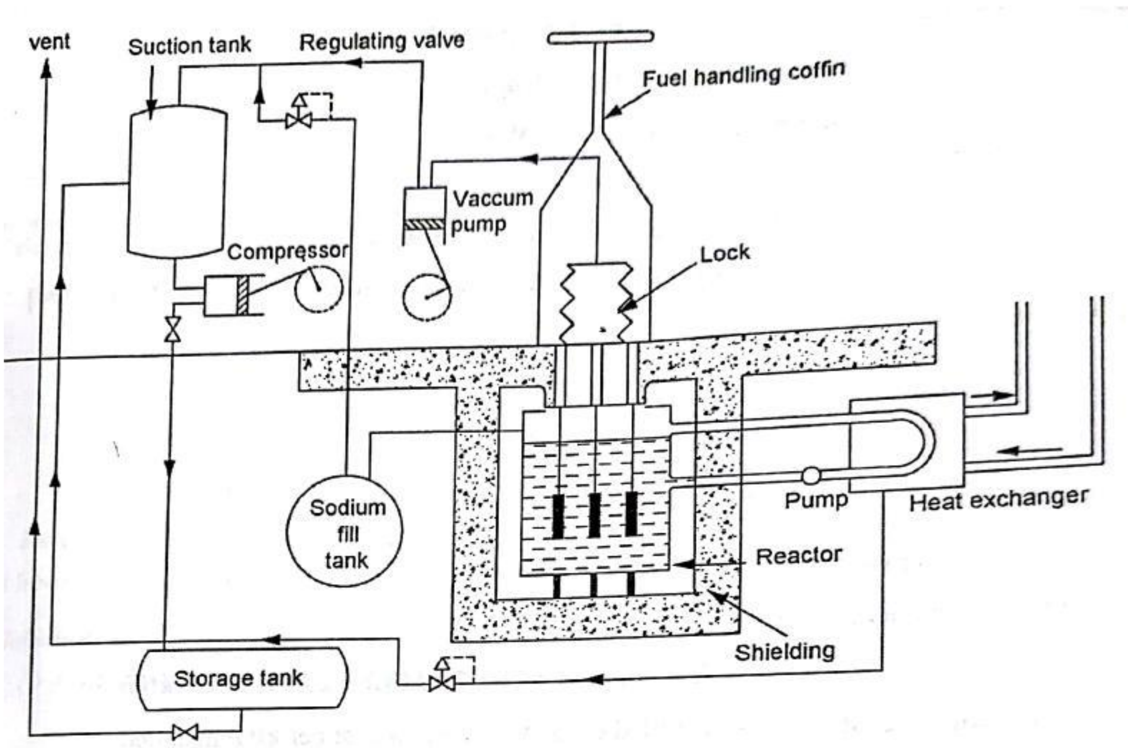
Solid LLW and ILW can often be super-compacted into much smaller volumes. Since liquid wastes cannot be disposed of, they need to be transformed into solids. Radioactive elements can be removed from the liquid by filtration or ion exchange and they dried, absorbed into a fixing medium, or solidified in concrete. After such conditioning, ILW and LLW can be packaged for interim storage or disposal in steel drums or containers. HLW produced during reprocessing emerges as a liquid and needs to be transformed into a solid for long term storage and disposal, normally by a process of vitrification.

C. Interim Storage

Interim storage facilities are generally used for intermediate-level waste (ILW) and high-level waste (HLW). Spent nuclear fuel that has not been reprocessed is initially stored underwater in a storage pool, usually at the reactor site. After some years it can be placed in specialized containers for interim storage or disposal. For HLW, a period of interim storage is always necessary to allow the initially very high level radiation and heat generation to fall.

D. Final Disposal

Disposal is the final step in radioactive waste management. Short lived ILW and LLW are disposed of routinely at numerous sites in many countries; some sites have already been filled and closed. It is expected that for a period of about 100 to 300 years following closure of an ILW/LLW disposal site active or passive controls will be applied, including groundwater monitoring, restrictions on access, periodic maintenance and restrictions on further land use. After this period the radioactive isotopes will have decayed to negligible levels



Management of High-Level Waste

a) Storage and Disposal

B. Reprocessing

D. Vitrification

Management of Low and Intermediate-level Waste

Low-level waste storage technology is well-established. Low-level waste is produced as a result of many commercial processes, and can be generated in solid, liquid and gaseous forms. It includes items that have become contaminated with radioactive material or have become radioactive through exposure to neutron radiation. Low level radioactive waste is generated at facilities such as nuclear power plants, hospitals and research institution. Ion exchange resins and filter materials used to clean water at a nuclear power plant, contaminated hand tools, components, piping, valves and other equipment from nuclear power plants and other industries, research equipment from laboratories where radioactive materials are used, shoe covers, lab coats, cleaning cloths, paper towels and other supplies used in an area where radioactive material is present, containers, cloths, test tubes, bottles used in hospitals to diagnose or treat disease etc are the examples of Low level waste .

Treatment of Liquid Waste

According to the different types of reactors now operating commercially all over the world, different waste streams arises. These streams are different both in activity content and in the amount of liquid waste generated.

A. Ion-Exchange B. Chemical Precipitation C. Evaporation D. Cementation

E. Bituminization

Treatment of Solid Waste

A. Incineration B. Compaction

Treatment of Gaseous Waste

Some airborne radioactive wastes are generated in either particulate or aerosol of gaseous form during normal operation of nuclear power plants. Gaseous radioactive waste is mainly generated from the degassing of the primary system and ventilation systems in the radiation controlled area of nuclear power plants. During reactor operation gaseous radioactive isotopes are created by neutron activation and fission and include tritium, carbon -14, argon-41 and radionuclides of xenon, krypton and iodine. All gaseous effluents at nuclear power plants are treated before discharge to the atmosphere to remove most of the radioactive components from the effluence.Gaseous wastes are filtered, compressed to take up less space, and then allowed to decay for some time period.

Storage of Low and Intermediate-level Waste

Low-level radioactive waste is packaged in containers appropriate to its level of hazard. Some low-level radioactive wastes require shielding with lead, concrete or other materials to protect workers and members of the public. Workers are trained to maintain a safe distanc e from the more highly radioactive materials, to limit the amount of time they spend near the materials, and to monitor the waste to detect any releases. Nuclear power plants may store waste in special buildings that provide an extra degree of shielding. Safe distances must be maintained between the buildings containing radioactive material and the fence restricting public access to licensee property. Low-level waste may be stored to allow short-lived radionuclides to decay to innocuous levels and to provide safe keeping when access to disposal sites is not available. Options for storage of intermediate-level waste (ILW) are similar to those for low-level waste. Additional shielding may be required to limit radiation dose rates near ILW container.International Journal of Renewable Energy Technology Research

Disposal of Low and Intermediate-Level Waste

A. Near Surface Disposal B. Geological Disposal C. Deep Boreholes

D. Disposal in Outer Space E. Rock Melting

Comparison of site selection criteria, relative merits, & demerits

Site Selection of Nuclear Power Station

1. Availability of water: Although very large quantity of water is not regulated as hydro-electric power plant, but still sufficient supply of neutral water is obvious for cooling purposes in nuclear power station. That is why it is always preferable to locate this plant near a river or sea side.

2. Disposal of Water: The byproducts or wastes of nuclear power station are radioactive and may cause severe health hazards. Because of this, special care to be taken during disposal of wastes of nuclear power plant. The wastes must be buried in sufficient deep from earth level or these must be disposed off in sea quite away from the sea share. Hence, during selecting the location of nuclear plant, this factor must be taken into consideration.

3. Distance from Populated Area: As there is always a probability of radioactivity, it is always preferable to locate a nuclear station sufficiently away from populated area.

4. Transportation Facilities: During commissioning period, heavy equipments to be erected, which to be transported from manufacturer site. So good railways and road ways availabilities are required. For availability of skilled manpower good public transport should also be present at the site.

Selection of site for thermal power plant

Transportation network: Easy and enough access to transportation network is required in both power plant construction and operation periods.

Power transmission network: To transfer the generated electricity to the consumers, the plant should be connected to electrical transmission system. Therefore the nearness to the electric network can play a roll.

Geology and soil type: The power plant should be built in an area with soil and rock layers that could stand the weight and vibrations of the power plant.

Earthquake and geological faults: Even weak and small earthquakes can damage many parts of a power plant intensively. Therefore the site should be away enough from the faults and previous earthquake areas.

Topography: It is proved that high elevation has a negative effect on production efficiency of gas turbines. In addition, changing of a sloping area into a flat site for the construction of the power plant needs extra budget. Therefore, the parameters of elevation and slope should be considered.

Rivers and floodways: obviously, the power plant should have a reasonable distance from permanent and seasonal rivers and floodways.

Water resources: For the construction and operating of power plant different volumes of water are required. This could be supplied from either rivers or underground water resources. Therefore having enough water supplies in defined vicinity can be a factor in the selection of the site.

Environmental resources: Operation of a power plant has important impacts on environment. Therefore, priority will be given to the locations that are far enough from national parks, wildlife, protected areas, etc.

Population centers: For the same reasons as above, the site should have an enough distance from population centers.

Need for power: In general, the site should be near the areas that there is more need for generation capacity, to decrease the amount of power loss and transmission expenses.

Land cover: Some land cover types such as forests, orchard, agricultural land, pasture are sensitive to the pollutions caused by a power plant. The effect of the power plant on such land cover types surrounding it should be counted for.

Area size: Before any other consideration, the minimum area size required for the construction of power plant should be defined.

Distance from airports: Usually, a power plant has high towers and chimneys and large volumes of gas. Consequently for security reasons, they should be away from airports.

Archeological and historical sites: Usually historical buildings are fragile and at same time very valuable. Therefore the vibration caused by power plant can damage them, and a defined distance should be considered.

Site Selection for Hydropower Plants

- **Availability of Water:** Run-off data for many years available
- **Water Storage:** for water availability throughout the year
- **Head of Water:** most economic head, possibility of constructing a dam to get required head
- **Geological Investigations:** strong foundation, earthquake frequency is less
- **Water Pollution:** excessive corrosion and damage to metallic structures
- **Sedimentation:** capacity reduces due to gradual deposition of silt
- **Social and Environmental Effects:** submergence of areas, effect on biodiversity (e.g. western ghat), cultural and historic aspects
- **Access to Site:** for transportation of construction material and heavy machinery new railway lines or roads may be needed
- **Multipurpose:** power generation, irrigation, flood control, navigation, recreation; because initial cost of power plant is high because of civil engineering construction work