UNIT-11

COMBUSTION PROCESS:

PROPERTIES OF COAL: The properties of coal are broadly classified as

1. Physical properties
2. Chemical properties

Proximate Analysis

Proximate analysis indicates the percentage by weight of the Fixed Carbon, Volatiles, Ash, and Moisture Content in coal. The amounts of fixed carbon and volatile combustible matter directly contribute to the heating value of coal. Fixed carbon acts as a main heat generator during burning. High volatile matter content indicates easy ignition of fuel. The ash content is important in the design of the furnace grate, combustion volume, pollution control equipment and ash handling systems of a furnace.

Significance of Various Parameters in Proximate Analysis

Fixed carbon: Fixed carbon is the solid fuel left in the furnace after volatile matter is distilled off. It consists mostly of carbon but also contains some hydrogen, oxygen, sulphur and nitrogen not driven off with the gases. Fixed carbon gives a rough estimate of heating value of coal

Volatile Matter: Volatile matters are the methane, hydrocarbons, hydrogen and carbon monoxide, and incombustible gases like carbon dioxide and nitrogen found in coal.

Ash Content: Ash is an impurity that will not burn. Typical range is 5 to 40% Ash Reduces handling and burning capacity. Increases handling costs.

Moisture Content: Moisture in coal must be transported, handled and stored. Since it replaces combustible matter, it decreases the heat content per kg of coal. Typical range is 0.5 to 10% Moisture Increases heat loss, due to evaporation and superheating of vapour Helps, to a limit, in binding fines.

Sulphur Content:

Typical range is 0.5 to 0.8% normally. Sulphur Affects clinkering and slagging tendencies Corrodes chimney and other equipment such as air heaters and economisers Limits exit flue gas temperature.

Chemical Properties

Ultimate Analysis:

The ultimate analysis indicates the various elemental chemical constituents such as Carbon, Hydrogen, Oxygen, Sulphur, etc. It is useful in determining the quantity of air required for combustion and the volume and composition of the combustion gases. This information is required for the calculation of flame temperature and the flue duct design etc.

OVERFEED AND UNDERFEED FUEL BEDS:

1. Overfeed Principle. According to this principle (Fig) the primary air enters the grate from the bottom. The air while moving through the grate openings gets heated up and air while moving through the grate openings gets heated up and the grate is cooled.

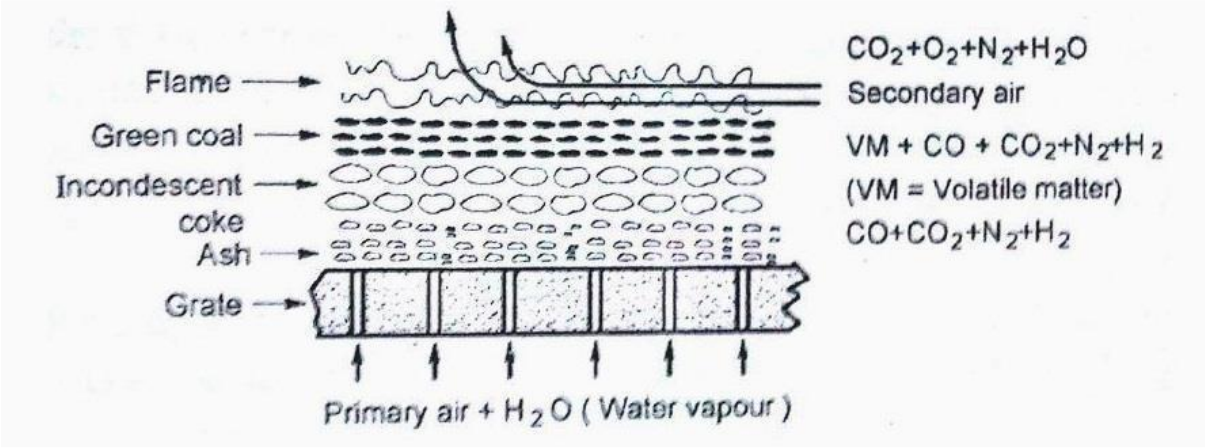
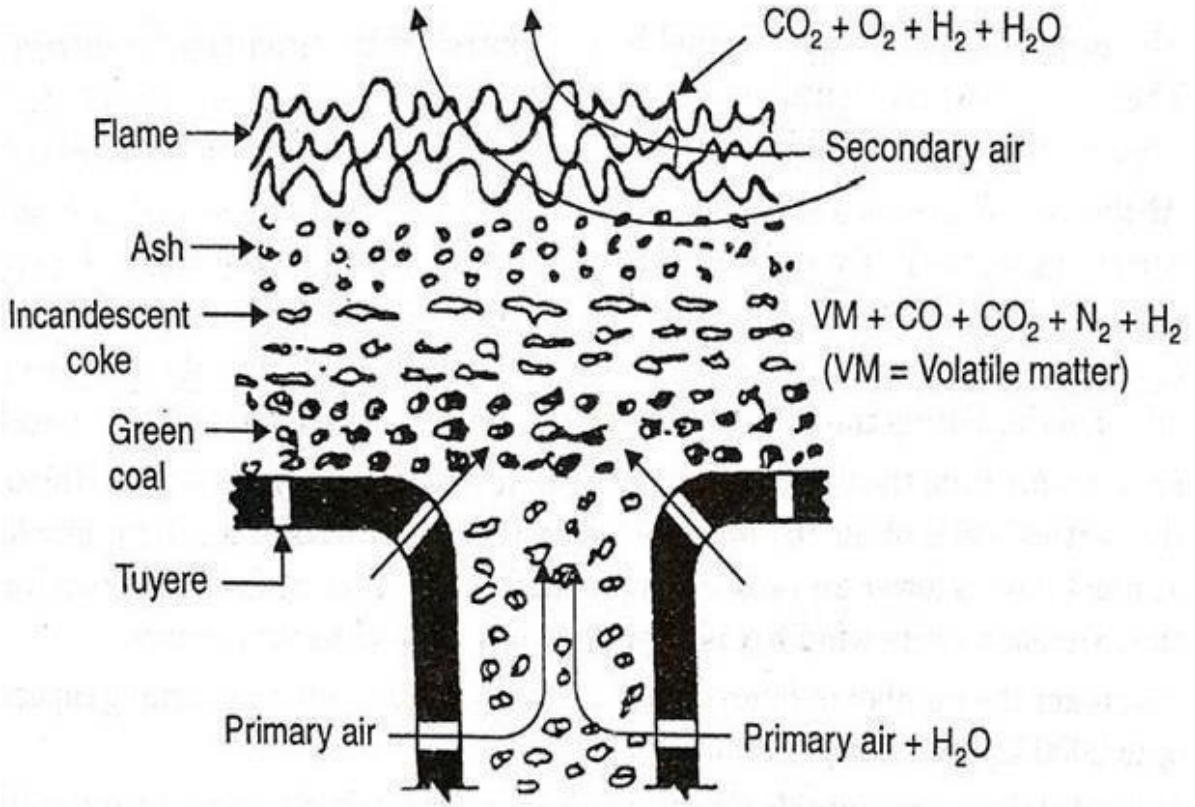


Fig--Overfeed Mechanism

The hot air that moves through a layer of ash and picks up additional energy. The air then passes through a layer of incandescent coke where oxygen reacts with coke to form-C02 and water vapors accompanying the air react with incandescent coke to form CO2, CO and free H2. The gases leaving the surface of fuel bed contain volatile matter of raw fuel and gases like CO2, CO, H2, N2 and H2O. Then additional air known as secondary air is supplied to burn the combustible gases. The combustion gases entering the boiler consist of N2, CO2, O2 and H2O and also CO if the combustion is not complete.

Underfeed Principle. The fig shows underfeed principle. In underfeed principle air entering through the holes in the grate comes in contact with the raw coal (green coal).



Mechanical stokers are commonly used to feed solid fuels into the furnace in medium and large size power plants. The various advantages of stoker firing are as follows :

(i) Large quantities of fuel can be fed into the furnace. Thus greater combustion capacity is achieved.

(ii) Poorer grades of fuel can be burnt easily.

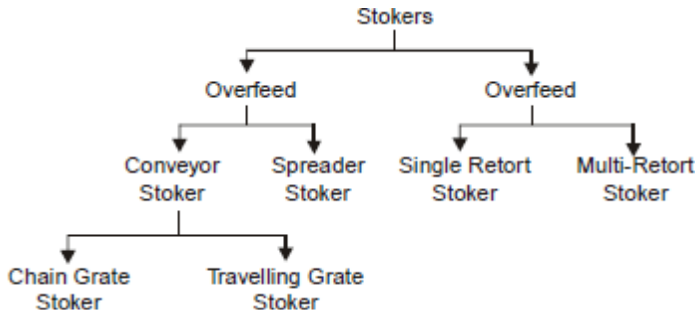
(iii) Stoker save labour of handling ash and are self-cleaning.

(iv) By using stokers better furnace conditions can be maintained by feeding coal at a uniform rate.

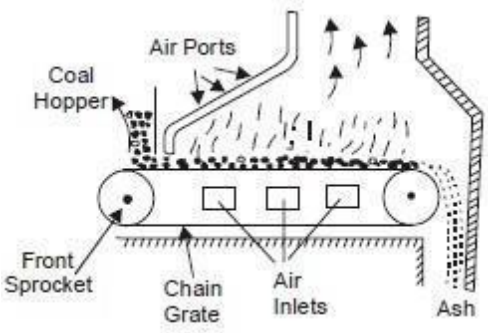
(v) Stokers save coal and increase the efficiency of coal firing. The main disadvantages of stokers are their more costs of operation and repairing resulting from high furnace temperatures.

TYPES OF STOKERS: Charging of fuel into the furnace is mechanized by means of stokers of various types. They are installed above the fire doors underneath the bunkers which supply the fuel. The bunkers receive the fuel from a conveyor.

- Types of Stokers



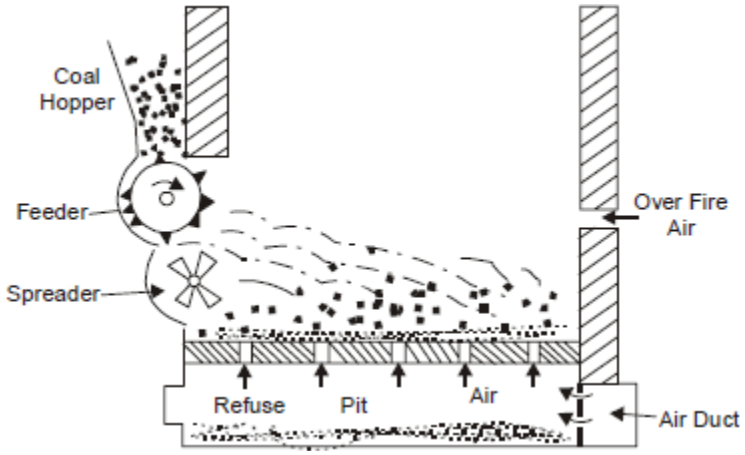
Chain Grate Stoker. Chain grate stoker and travelling grate stoker differ only in grate construction. A chain grate stoker. It consists of an endless chain which forms a support for the fuel bed.



-Chain grate Stoker

The chain travels over two sprocket wheels, one at the front and one at the rear of furnace. The traveling chain receives coal at its front end through a hopper and carries it into the furnace. The ash is tipped from the rear end of chain.

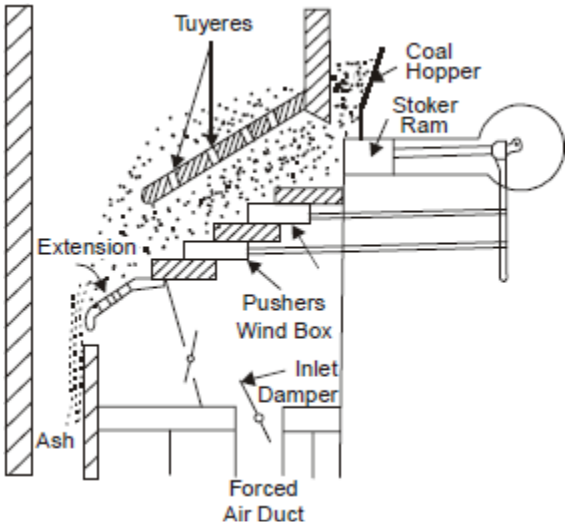
The travelling grate stoker also uses an endless chain but differs in that it carries small grate bars which actually support the fuel fed. It is used to burn lignite, very small sizes of anthracites coke breeze etc.



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Spreaded Stoker

. In this stoker the coal from the hopper is fed on to a feeder which measures the coal in accordance to the requirements. Feeder is a rotating drum fitted with blades. Feeders can be reciprocating rams, endless belts, spiral worms etc. From the feeder the coal drops on to spreader distributor which spread the coal over the furnace. The spreader system should distribute the coal evenly over the entire grate area. The spreader speed depends on the size of coal.

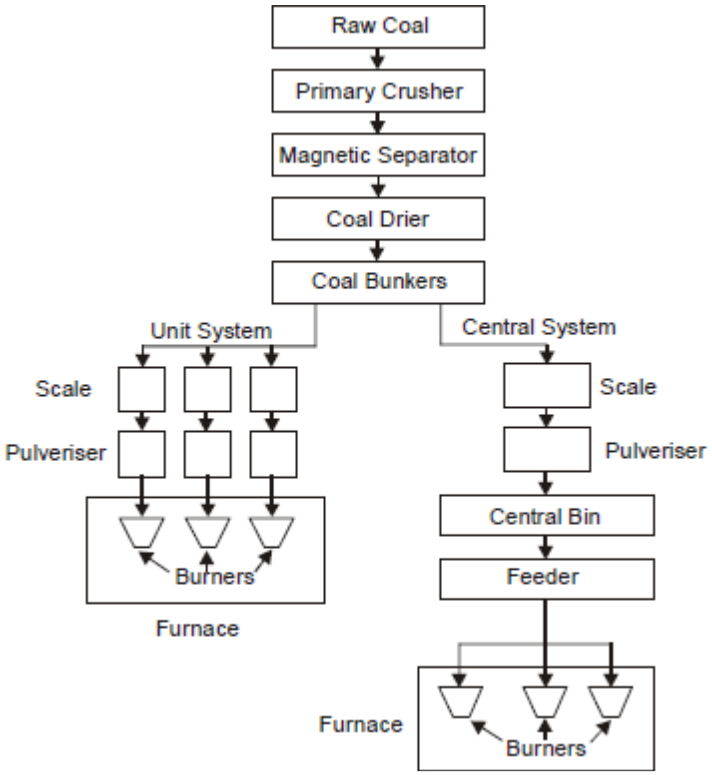


Multi retort stoker

Pulverized Fuel Burning System and its Components:

Coal is pulverized (powdered) to increase its surface exposure thus permitting rapid combustion. Efficient use of coal depends greatly on the combustion process employed. For large scale generation of energy the efficient method of burning coal is confined still to

pulverized coal combustion. The pulverized coal is obtained by grinding the raw coal in pulverizing mills.



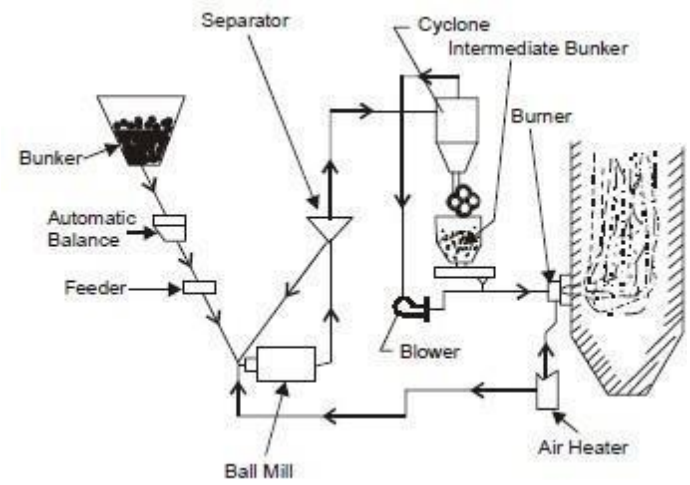
- Components of pulverised fuel burning The various pulverizing mills used are as follows:
(i) Ball mill
(ii) Hammer mill
(iii) Ball and race mill
(iv) Bowl mill.

The essential functions of pulverizing mills are as follows:
(i) Drying of the coal
(ii) Grinding
(iii) Separation of particles of the desired size.

Proper drying of raw coal which may contain moisture is necessary for effective grinding. The coal pulverizing mills reduce coal to powder form by three actions as follows: 29 (i) Impact (ii) Attrition (abrasion) (iii) Crushing. Most of the mills use all the above mentioned all the three actions in varying degrees. In impact type mills hammers break the coal into smaller pieces whereas in attrition type the coal pieces which rub against each other or metal surfaces to disintegrate. In crushing type mills coal caught between metal rolling surfaces gets broken into pieces. The crushing mills use steel balls in a container. These balls act as crushing elements.

BALL MILL:

A line diagram of ball mill using two classifiers is shown in Fig. It consists of a slowly rotating drum which is partly filled with steel balls. Raw coal from feeders is supplied to the classifiers from where it moves to the drum by means of a screw conveyor.

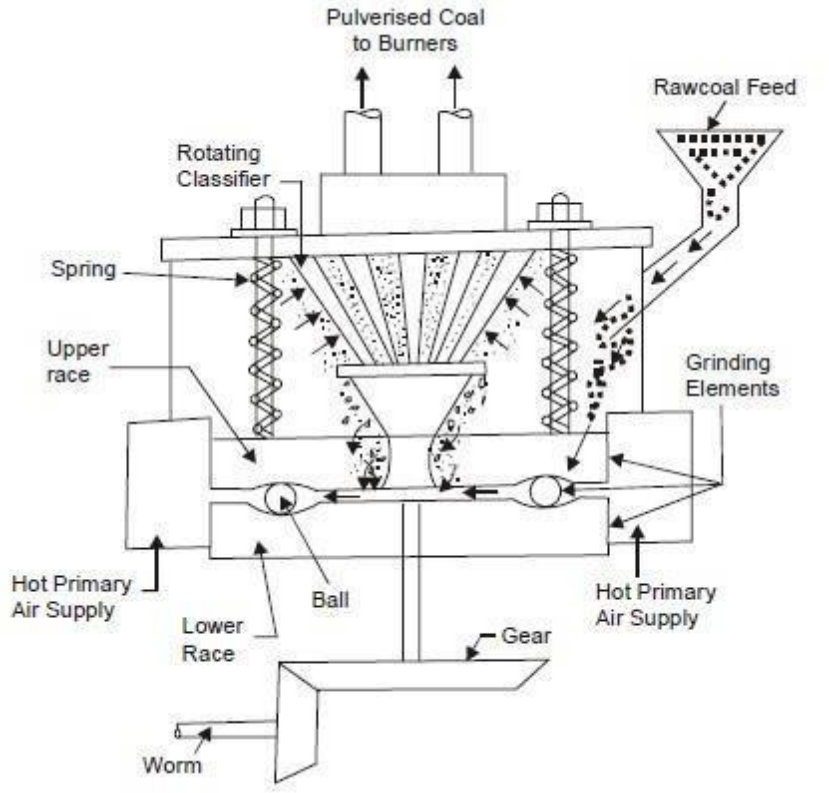


Ball Mill

As the drum rotates the coal gets pulverized due to the combined impact between coal and steel balls. Hot air is introduced into the drum. The powdered coal is picked up by the air and the coal air mixture enters the classifiers, where sharp changes in the direction of the mixture throw out the oversized coal particles. The over-sized particles are returned to the drum. The coal air mixture from the classifier moves to the exhauster fan and then it is supplied to the burners.

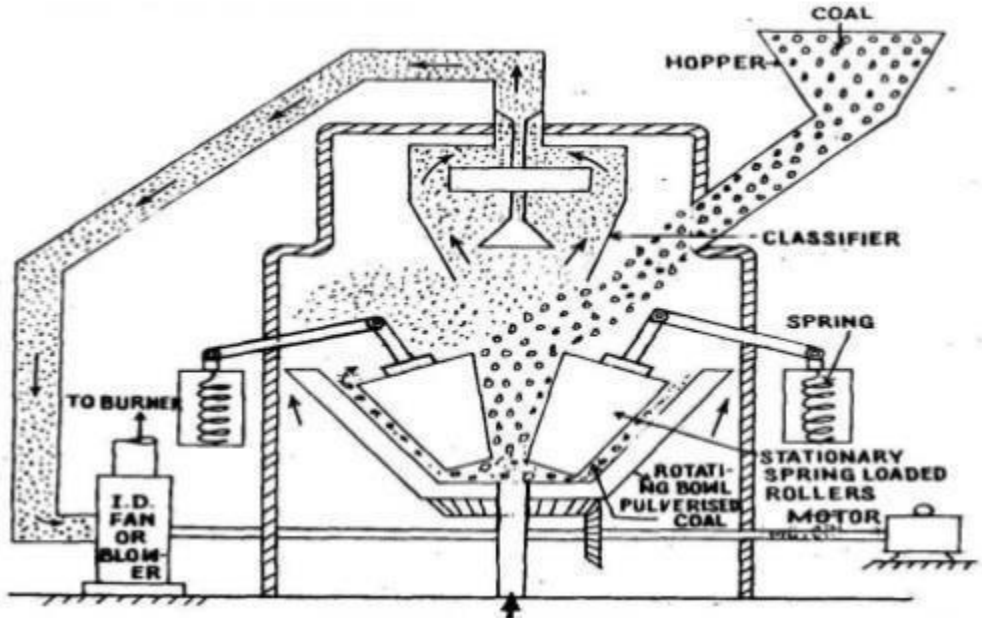
BALL AND RACE MILL

The below fig shows a ball and race mill. In this mill the coal passes between the rotating elements again and again until it has been pulverized to desired degree of fineness. The coal is crushed between two moving surfaces namely balls and races. The upper stationary race and lower rotating race driven by a worm and gear hold the balls between them. The raw coal supplied falls on the inner side of the races. The moving balls and races catch coal between them to crush it to a powder. The necessary force needed for crushing is applied with the help of springs. The hot air supplied picks up the coal dust as it flows between the balls and races, and then enters the classifier. Where oversized coal particles are returned for further grinding, where as the coal particles of required size are discharged from the top of classifier



BOWL MILL:

This pulverizer consists of stationary rollers and a power driven bowl in which pulverization takes place as the coal passes between the sides of the bowl and the rollers.



-Bowl mill

Advantages:

The advantages of using pulverized coal are as follows:

1. It becomes easy to burn wide variety of coal. Low grade coal can be burnt easily.

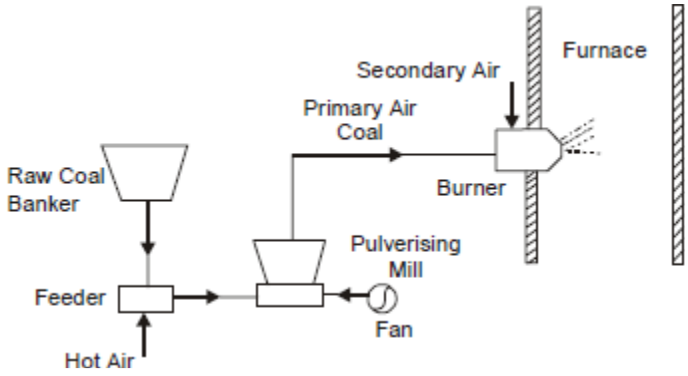
2. 2. Powdered coal has more heating surface area. They permits rapids and high rates of combustion.
3. Pulverized coal firing requires low percentage of excess air.
4. By using pulverized coal, rate of combustion can be adjusted easily to meet the varying load.
5. The system is free from clinker troubles.
6. It can utilize highly preheated air (of the order of 700°F) successfully which promotes rapid flame propagation.
7. As the fuel pulverising equipment is located outside the furnace, therefore it can be repaired without cooling the unit down.

8. High temperature can be produced in furnace.

Disadvantages
1. It requires additional equipment to pulverize the coal. The initial and maintenance cost of the equipment is high.
2. Pulverized coal firing produces fly ash (fine dust) which requires a separate fly ash removal equipment.
3. The furnace for this type of firing has to be carefully designed to withstand for burning the pulverized fuel because combustion takes place while the fuel is in suspension.
4. The flame temperatures are high and conventional types of refractory lined furnaces are inadequate. It is desirable to provide water cooled walls for the safety of the furnaces.
5. There are more chances of explosion as coal burns like a gas.
6. Pulverized fuel fired furnaces designed to burn a particular type of coal cannot be used to any other type of coal with same efficiency.
7. The size of coal is limited. The particle size of coal used in pulverized coal furnace is limited to 70 to 100 microns.

Pulverized coal firing is done by two systems:
(i) Unit System or Direct System.
(ii) Bin or Central System.

Unit System. In this system, the raw coal from the coal bunker drops on to the feeder. Hot air is passed through coal in the feeder to dry the coal. The coal is then transferred to the pulverizing mill where it is pulverized. Primary air is supplied to the mill, by the fan. The mixture of pulverized coal and primary air then flows to burner where secondary air is added. The unit system is so called from the fact that each burner or a burner group and pulveriser constitute a unit.-



UNIT SYSTEM

Advantages:

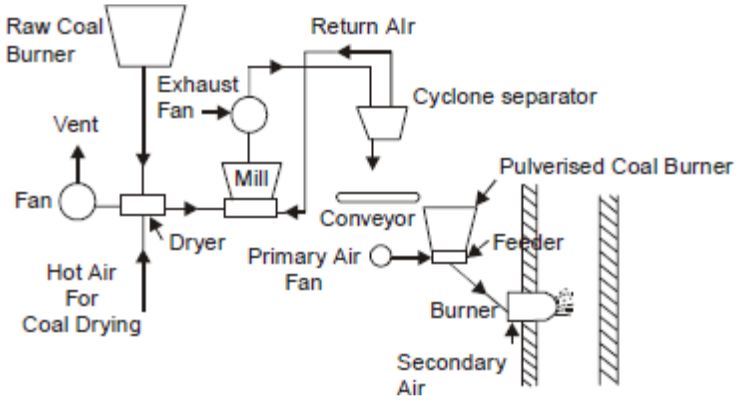
(i) The system is simple and cheaper than the central system.

(ii) There is direct control of combustion from the pulverising mill.

(iii) Coal transportation system is simple.

Bin or Central System.

It is shown in Fig. 1.27. Crushed coal from the raw coal bunker is fed by gravity to a dryer where hot air is passed through the coal to dry it. The dryer may use waste flue gases, preheated air or bleeder steam as drying agent. The dry coal is then transferred to the pulverizing mill. The pulverized coal obtained is transferred to the pulverized coal bunker (bin). The transporting air is separated from the coal in the cyclone separator. The primary air is mixed with the coal at the feeder and the mixture is supplied to the burner.



Advantages:

1. The pulverising mill grinds the coal at a steady rate irrespective of boiler feed.
2. There is always some coal in reserve. Thus any occasional breakdown in the coal supply will not effect the coal feed to the burner.
3. For a given boiler capacity pulverising mill of small capacity will be required as compared to unit system.

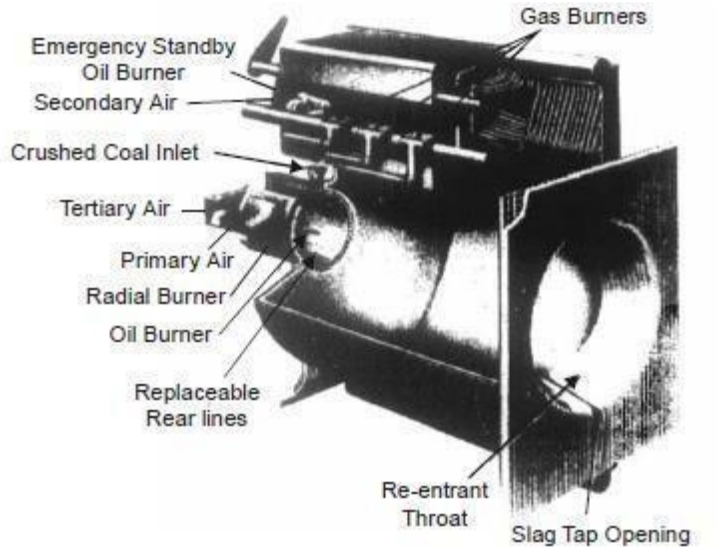
Disadvantages

1. The initial cost of the system is high.
2. Coal transportation system is quite complicated.
3. The system requires more space.

CYCLONE FURNACE:

. It is now widely used to burn poorer grades of coal that contain a high ash content with a minimum of 6 percent to as high as 25 percent, and a high volatile matter, more than 15 percent, to obtain the necessary high rates of combustion. The main advantage is the removal of much of the ash, about 60 percent, coal firing. this materially reduces erosion and fouling of steam-generator surfaces as well as the size of dust-removal precipitators or bag houses at steam-generator exit. Other advantages are that only crushed coal is used and no pulverization equipment is needed and that the boiler size is reduced.Cyclone-furnace firing uses a range of coal sizes averaging 95 percent passing a 4-mesh screen.

The crushed coal is fed into the cyclone burner at left along with primary air, which is about 20 percent of combustion or secondary air. The primary air enters the burner tangentially, thus imparting a centrifugal motion to the coal. The secondary air is also admitted tangentially at the top of the cyclone at high speed, imparting further centrifugal motion. A small quantity of air, called tertiary air, is admitted at the center.



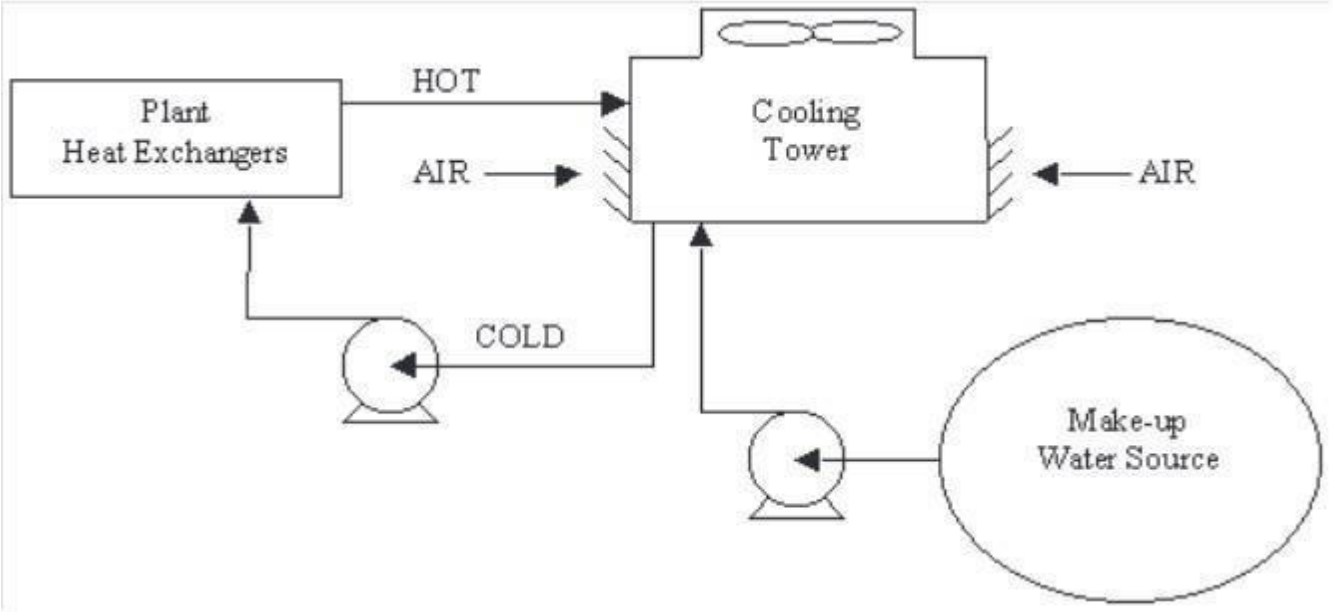
COOLING TOWERS AND HEAT REJECTION:

Cooling towers are a very important part of many chemical plants. The primary task of a cooling tower is to reject heat into the atmosphere.

They represent a relatively inexpensive and dependable means of removing low-grade heat from cooling water.

The make-up water source is used to replenish water lost to evaporation.

Hot water from heat exchangers is sent to the cooling tower. The water exits the cooling tower and is sent back to the exchangers or to other units for further cooling. Typical closed loop cooling tower system is shown in fig



Cooling towers can be split into two distinct categories: open circuit (direct contact) and closed circuit (indirect) systems.

In open circuit systems the recirculating water returns to the tower after gathering heat and is distributed across the tower where the water is in direct contact with the atmosphere as it recirculates across the tower structure.

Closed circuit systems differ in that the return fluid (often water, or sometimes water mixed with glycol) circulates through the tower structure in a coil, while cooling tower water recirculates only in the tower structure itself.

In this case, the return fluid is not exposed directly to the air.
The cooling towers types: -
1. Natural Draft cooling tower
2. Mechanical Draught

Natural Draft Towers
Natural draft towers are designed to move air up through the structure naturally without the use of fans.
They use the natural law of differing densities between the ambient air and warm air in the tower. The warm air will rise within the chimney structure because of its lower density drawing cool ambient air in the bottom portion.

Often times these towers are very tall to induce adequate air flow, and have a unique shape giving them the name ―hyperbolic‖ towers

Mechanical draught Towers — Uses power-driven fan motors to force or draw air through the tower. **Induced draught** — A mechanical draft tower with a fan at the discharge (at the top) which pulls air up through the tower.

The fan induces hot moist air out the discharge. This produces low entering and high exiting air velocities, reducing the possibility of recirculation in which discharged air flows back into the air intake.

Forced draught — A mechanical draft tower with a blower type fan at the intake. The fan forces air into the tower, creating high entering and low exiting air velocities.

The low exiting velocity is much more susceptible to recirculation. With the fan on the air intake, the fan is more susceptible to complications due to freezing conditions.

Another disadvantage is that a forced draft design typically requires more motor horsepower than an equivalent induced draft design.

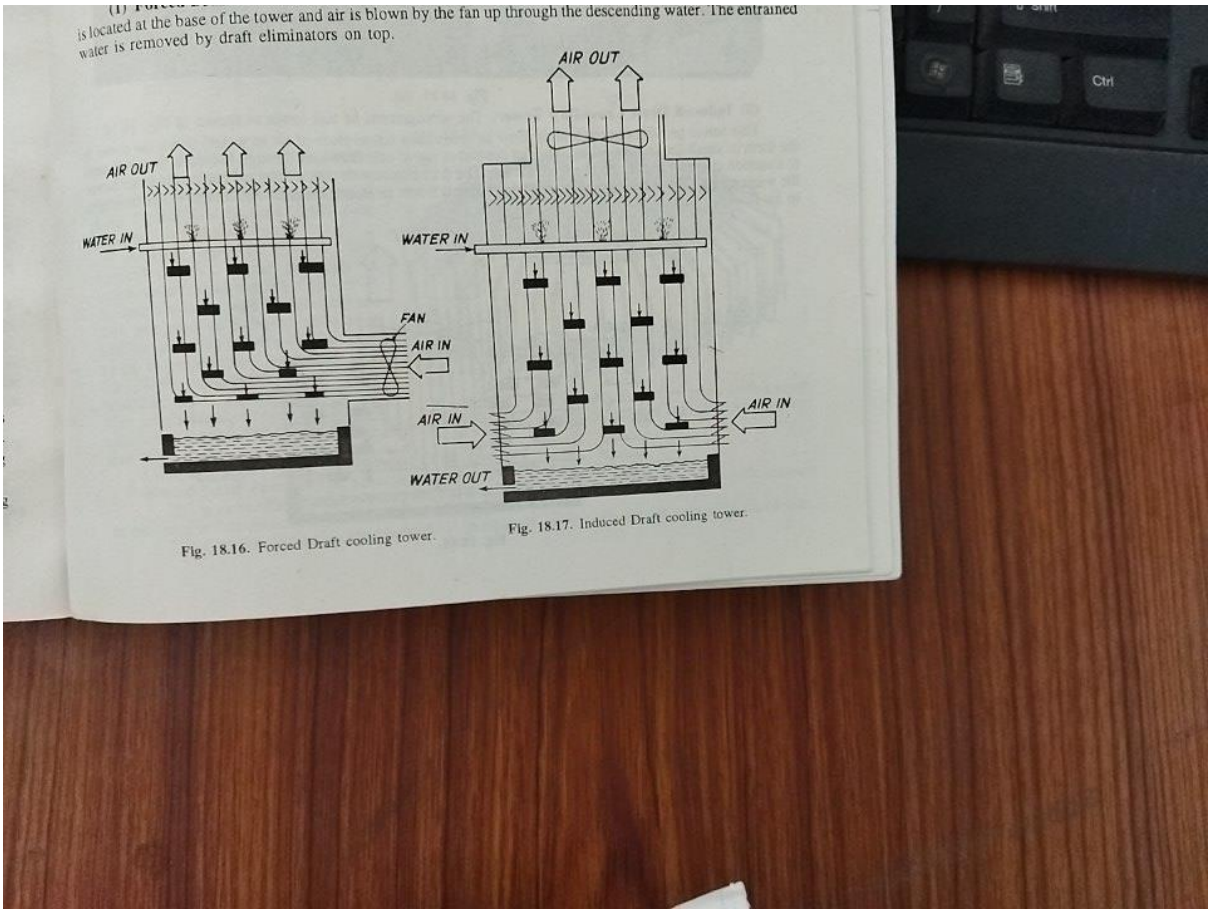


Fig. 18.16. Forced Draft cooling tower.

Fig. 18.17. Induced Draft cooling tower.

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CORROSION AND FEED WATER TREATMENT:

Necessity of Feed Water treatment Raw water (from any water body) contains a variety of impurities.

1. Suspended solids and turbidity (the quality of being cloudy, opaque, or thick with suspended matter.

"the measurement of turbidity is a key test of water quality")

2 Hardness (**water hardness** is the amount of dissolved calcium and magnesium in the **water)**

3 Alkalinity (**Definition** of **alkalinity**: "The buffering capacity of a water body; a measure of the ability of the water body to neutralize acids and bases and thus maintain a fairly stable pH level"

4 Silica

5 . Dissolved gasses (The main **gases dissolved** in purified **water** are **oxygen** and nitrogen, carbon dioxide)

6 Micro-organisms (An organism that can be seen only through a microscope. **Microorganisms** include bacteria, protozoa, algae, and fungi. Although viruses are not considered living organisms, they are sometimes classified as **microorganisms**.)

Water Softening Plant Location:

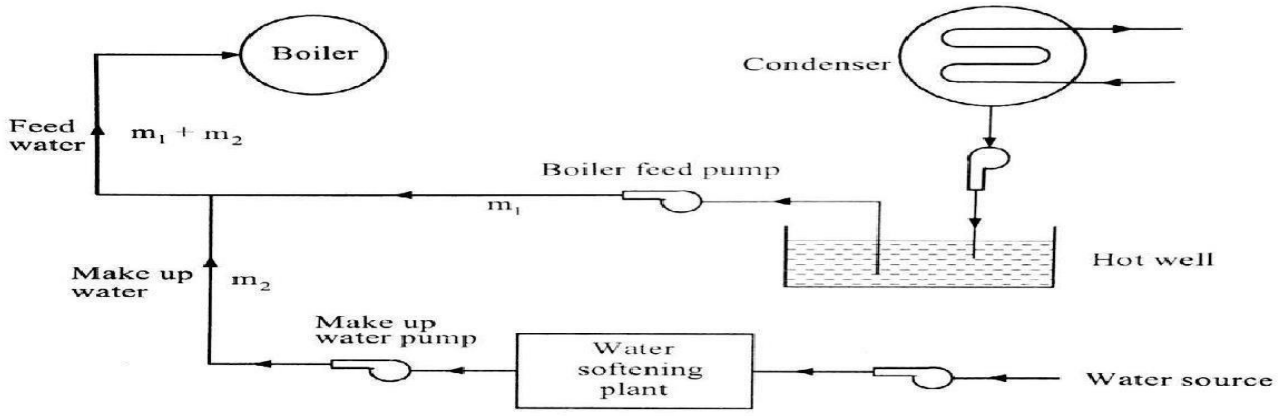


Fig-Water softening plant

Different Impurities in Feed Water:

1. Un dissolved and Suspended Materials

2. Dissolved Salts and Minerals

Calcium and Magnesium Salts: The presence of these salts is recognised by the hardness of the water. These salts are present in the water in the **form of carbonated, bicarbonates, sulphates and chlorides** and cannot be removed just by boiling because they **form a hard scale on heating surfaces**.

3 **Dissolved Gases** Oxygen is corrosive to iron, zinc, brass and other metals. It is present in surface water in dissolved form.

It causes corrosion and pitting of all metal parts with which it comes in contact **esp.** at high temperatures.

Carbon Dioxide produces corrosion and scale forming compounds by combining with other materials. Majority of water contains 2-50 ppm of CO2

4. Other Materials

Free Mineral Acid Usually they are present in water as sulphuric or hydrochloric acid.

Their presence is always undesirable as they result in corrosion. Can be reduced by neutralization with alkalies. Oil: Generally, lubricating oil is carried with steam into the condenser and through the feed water system to the boiler.

It causes sludge, scale and foaming in the boilers. It is generally removed by strainers or baffle separators.

EFFECTS OF IMPURITIES:

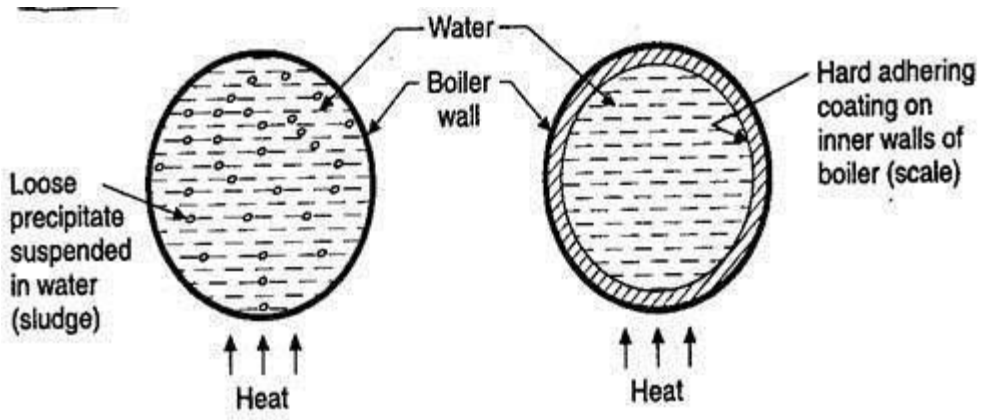
Scale formation,
corrosion
Priming and Foaming
Caustic Embrittlement

Scaling is mainly caused due to salts of **Calcium, Magnesium, Iron, Aluminium and silicates.**

Scales chokes the flow in the piping system and thus require increase in the pressure to maintain water delivery.

Leads to heat transfer drop from flue gases to the water.

Fig : scale formation



CORROSION:

The eating away process of the boiler metal is known as Corrosion. It produces **Pits, Grooves and Cracks** on the surface of the boiler, corrosion in the boiler generally occurs when the boiler water alkalinity is low or when the metal is exposed to oxygen bearing water either during operation or idle periods.

Remedies:-
The use of membrane contractors are the best and most diffused ways to avoid corrosion removing the dissolved gasses (mainly O2 and CO2).

PRIMING AND FOAMING:
Priming is the carryover of varying amounts of droplets of water in the steam (foam and mist), which lowers the energy efficiency of the steam and leads to the deposit of salt crystals on the super heaters and in the turbines.

Priming may be caused by improper construction of boiler, excessive ratings, or

sudden fluctuations in steam demand.
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To prevent foaming and priming we should maintain the concentration of solids at reasonably low levels, Avoiding high water levels, excessive boiler loads, and sudden load changes.

CAUSTIC EMBRITTLEMENT:
The caustic Embrittlement is caused by using highly alkaline water (caustic in water).

It causes the brittleness of metal, which result in cracks formation in boiler shell below the water level. This is caused due to long exposure of boiler steel to combination of stress and highly alkaline water.
The following three conditions contribute to caustic Embrittlement:-
Slow leakage of boiler water through a joint or steam.
Metal is highly stressed at the point of leakage. This may be caused by faulty riveting, misalignment and expansion.

Measures to control :-
Eliminating free sodium hydroxide from boiler water.

Maintaining a definite ratio of sodium nitrate to sodium hydroxide.

METHODS OF WATER TREATMENT:
Internal Treatment
External treatment
Mechanical
Chemical

Zeolite treatment
Demineralization Process
Thermal
De-aeration
Evaporation

The internal feed water treatment is accomplished by adding chemicals to boilers water. The dissolved solids in the water are removed in the boiler itself by a chemical treatment then the method is known as internal treatment.

It is carried out to prevent scale formation and to nullify the effects of external treatment. Some important methods are listed below.

Sodium carbonate (Na2CO3).

Sodium Phosphate treatment.

Sodium aluminate (NaAlO2) treatment.

EXTERNALWATER TREATMENT:

When the makeup water quantity is large and contains considerable suspended and dissolved solid material.

The suspended solid material is generally removed by mechanical means. The dissolved solids are removed with the use of chemical treatment and dissolved gases are generally removed by thermal treatment.

ZEOLITE TREATMENT:

Zeolite is used as catalyst in many industrial purposes such as water purification & air purification. Zeolites are two types : 1. natural 2. artificial

Natural zeolite that is used for water softening is greensand.& artificial is used in water softening & its chemical formula is na2o, AL2O3,nsio2,xh2o. These are used as ion exchanger in water softener.

Advantages:

1. It is very effective in removing hardness

2. It is easy & inexpensive in operation

3. No problem of filtration of softened water & sludge removal

4. It is compact & occupies less space.

Disadvantages:-

1. Filtration of turbid water is required before it is passed through the process

2. Water of high or low PH value has deterious effect on zeolite

3. Treated water contains more sodium salts.

Demineralization or ion exchange process:

Any process which results in the reversible exchange of ions contained in a fluid with those contained on a solid without a permanent change in the solid structure.

Water is treated with an ion exchange resin.

The mineral content of water may be removed by **evaporation** or by **series of cat ion and anion exchangers** to produce essentially distilled water .

Demineralization is often the most economical method of producing make – up water for high pressure boiler.

The functional groups are molecules with exchangeable ions such as H+ or OH-, that can be safely released into the system.

Purpose

Demineralization is the removal of essentially all inorganic salts. In ion exchange demineralization hydrogen cat ion exchange converts dissolved salts to their corresponding acids, and basic anion exchange removes these acids.

Advantages:

It reduce boiler blow down and helps for the production of higher quality steam.

It supplies the purest quality feed water.

It can supply high quality feed water for the period needed to bring about an orderly shutdown to repair the condenser.

Disadvantages:

Its equipment cost is high.

Its operating cost is high.

DE-AERATION:

The dissolved gases in water like O2, CO2, H2S, air, and other gases are responsible for corrosion since these react with impurities and form acids. Therefore, these gases are removed from water before supplied to the boiler by the method of **thermal treatment.**

De-aeration is the process of removing dissolved corrosive gases from water. This process is called **degasification.** These corrosive gases make the water corrosive as they react with metal to form iron oxide.

The removal of gases is accomplished by heating the water to 105-110 with subsequent agitation during heating.

Gas Turbine

A gas turbine is also known as combustion turbine. It is an internal type of combustion engine. In the downstream turbine upstream rotating compressor is coupled in-between combustion chamber also.

It is defined as the principal prime mover which is of the turbine type and the medium of working is permanent gas".

The gas turbine obtains its power by utilizing the energy of burnt gases and air, which is at high temperature and pressure by expanding through the several ring of fixed and moving blades.

a simple gas turbine cycle consists of
(1) A compressor,
(2) A combustion chamber and
(3) A turbine.

Inter-cooler:
The main aim of the intercooler is to reduce the compressor work and it is to be placed between the low pressure and high pressure compressors.

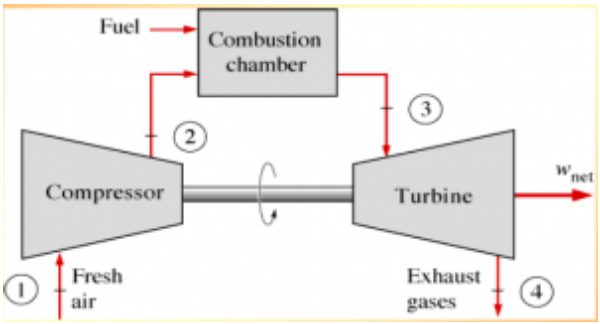
Re-generator:
When the air is entering to the re-generator then preheating is done to reduce the fuel consumption in the combustion chamber, where the efficiency needs to be increased.

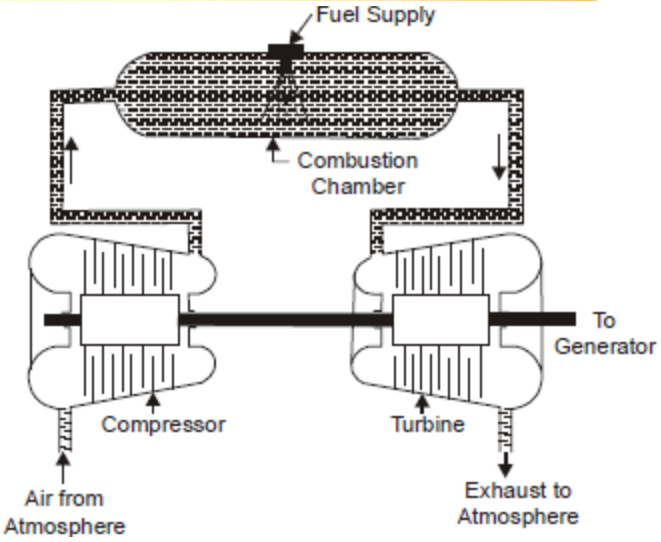
This is done by heat of hot exhaust gases coming out of the turbine.

Combustion chamber:
From the re-generator hot air must be allowed to flow into the combustion chamber. The fuel like natural gas, coal and kerosene are inserted into the combustion chamber.

Gas turbines have been constructed to work on the following: oil, natural gas, coal gas, producer gas, blast furnace and pulverized coal.

(a) Open cycle gas turbine.





The compressor takes in ambient air and raises its pressure. Heat is added to the air in combustion chamber by burning the fuel and raises its temperature.

Open Cycle Gas Turbine The heated gases coming out of combustion chamber are then passed to the turbine where it expands doing mechanical work.

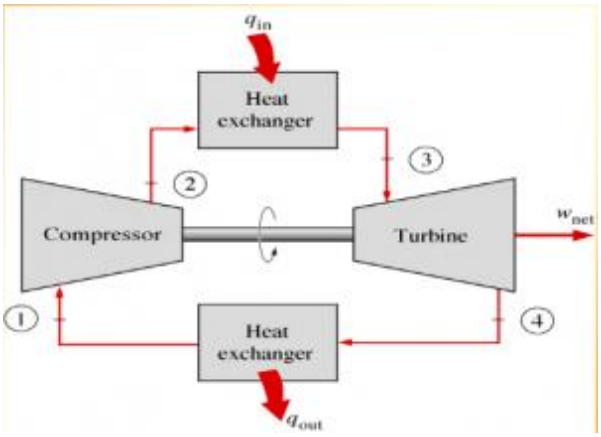
(A) Advantages

1. **Warm-up time.** Once the turbine is brought up to the rated speed by the starting motor and the fuel is ignited, the gas turbine will be accelerated from cold start to full load without warm-up time.
2. **Low weight and size.** The weight in kg per kW developed is less.
3. **Fuels.** Almost any hydrocarbon fuel from high-octane gasoline to heavy diesel oils can be used in the combustion chamber.
4. Open cycle plants occupy comparatively little space.
5 Open-cycle gas turbine power plant, except those having an intercooler, does not require cooling water. Therefore, the plant is independent of cooling medium and becomes self-contained.

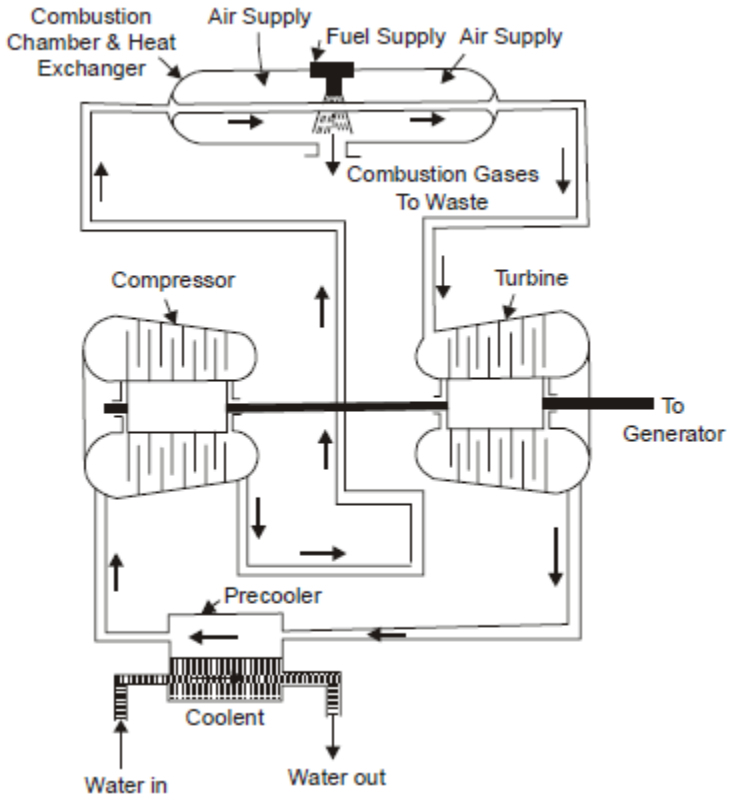
(B) Disadvantages:

1. The part load efficiency of the open cycle plant decreases rapidly as the considerable percentage of power developed by the turbine is used to drive the compressor.
2. The open-cycle gas turbine plant has high air rate compared to the other cycles, therefore, it results in increased loss of heat in the exhaust gases and large diameter ductwork is necessary.

CLOSED CYCLE GAS TURBINE POWER PLANT



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

(A) Advantages

1. The closed cycle avoids erosion of the turbine blades due to the contaminated gases and fouling of compressor blades due to dust.

Therefore, it is practically free from deterioration of efficiency in service..

2. The need for filtration of the incoming air which is a severe problem in open cycle plant is completely eliminated.

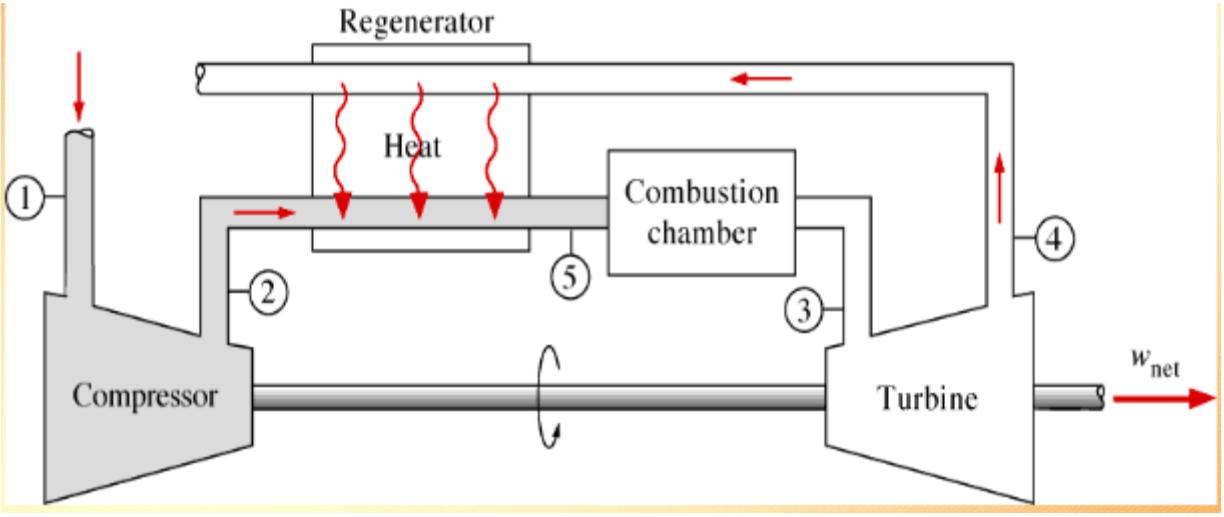
3 . Load variation is usually obtained by varying the absolute pressure and mass flow of the circulating medium, while the pressure ratio, the temperatures and the air velocities remain almost constant.

4 . The density of the working medium can be maintained high by increasing internal pressure range, therefore, the compressor and turbine are smaller for their rated output. The high density of the working fluid further increases the heat transfer properties in the heat exchanger.

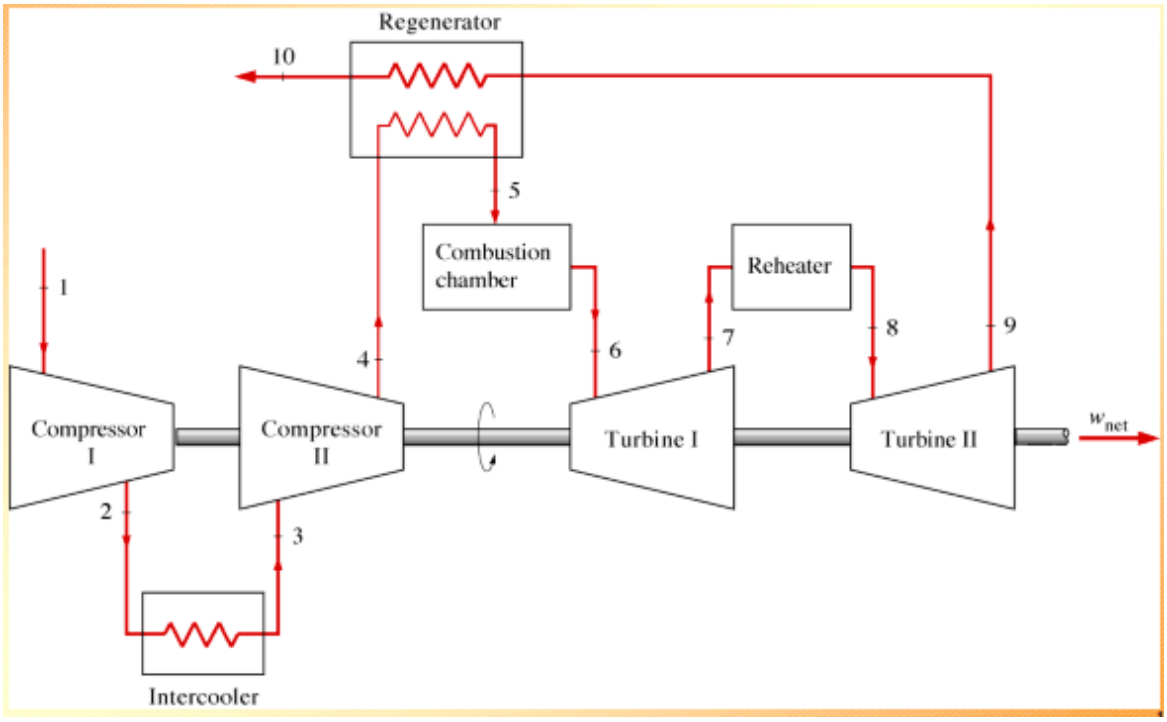
Application of gas turbine power plant:

- To drive generators and supply loads in steam, diesel or hydro plants
- To work with conventional steam boilers as combination plants
- Thermal process industries
- Petro-chemical industries
- Power generation in aircraft and ships for their propulsion.
- They are not suitable for cars because of their high speeds

Regenerator :



Intercooler


Regenerator
10
5
Combustion chamber
Reheater
1
4
6
7
8
9
Compressor I
Compressor II
Turbine I
Turbine II
w_{net}
2
3
Intercooler