Unit 2

Steam Power Plant

2.1 INTRODUCTION

Description

The fuel used in a steam power plant is coal. Coal contains elements which get oxidised during reaction with oxygen, supplied by air in the furnace of the steam generator, with the release of a large amount of energy. The large amount of energy released during the reaction is transferred to water which is converted to high pressure steam. This high pressure steam is made to undergo expansion to low pressure in a turbine, thereby effecting a conversion of low grade heat energy into high grade mechanical work which is manifested as 'Torque' at the turbine shaft.

This torque is transferred directly to the rotor of the electrical generator. Electrical energy is thus produced. The potential of the electrical energy is then raised by transformers.

2.2 FUEL HANDLING SYSTEM

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

1. Coal delivery.
2. Unloading.
3. Preparation.
4. Transfer.
5. Outdoor storage.
6. Covered storage.
7. Inplant handling.
8. Weighing and measuring.
9. Feeding the coal into furnace.

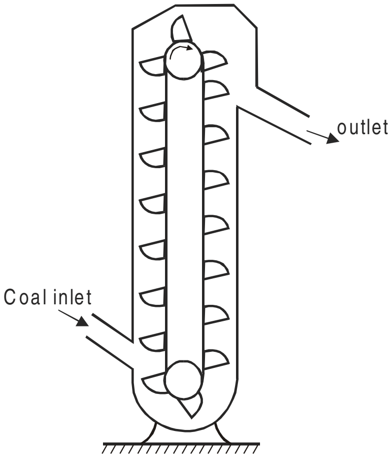


Figure 2.4: Bucket elevator.

4. Grab bucket elevator

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

The grab bucket conveyor can be used with crane or tower as shown in figure 2.5. Although the initial cost of this sytem is high but operating cost is less.

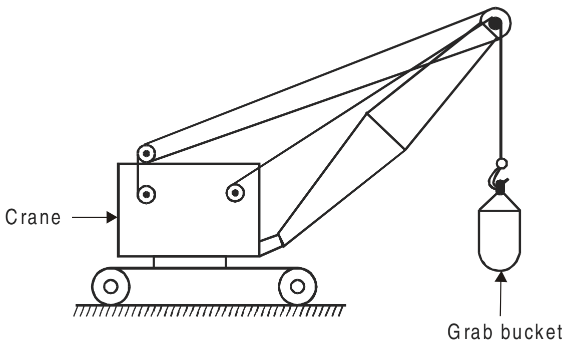


Figure 2.5: Grab bucket elevator.

2.2.1 Storage of Coal

It is desirable that sufficient quantity of coal should be stored. Storage of coal gives protection against the interruption of coal supplies when there is delay in

The coal received by the plant from the mine may vary widely in sizes. It is necessary to make the coal of uniform size before passing the pulveriser for efficient grinding. The coal received from the mine is passed through a preliminary crusher to reduce the size to allowable limit (30 mm). The crushed coal is further passed over magnetic separator which removes pyrites and tramp iron. The further equipment through which coal is passed before passing to pulveriser are already shown in figure 2.7.

2.3 PULVERISING MILLS

2.3.1 Ball Mill

A line diagram of ball mill using two classifiers is shown in figure 2.8. 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. As the drum rotates the coal gets pulverised 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.

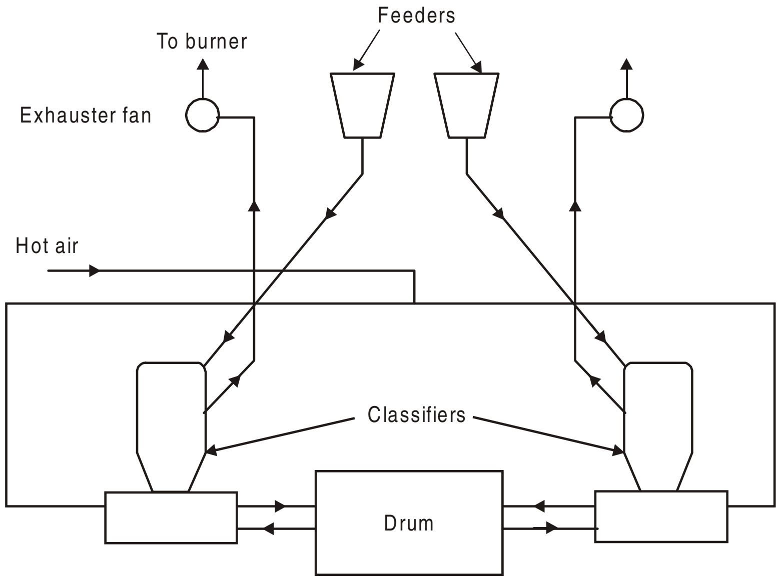


Figure 2.8: Ball mill.

2.3.2 Ball and Race Mills

Figure 2.9 shows a ball and race mill.

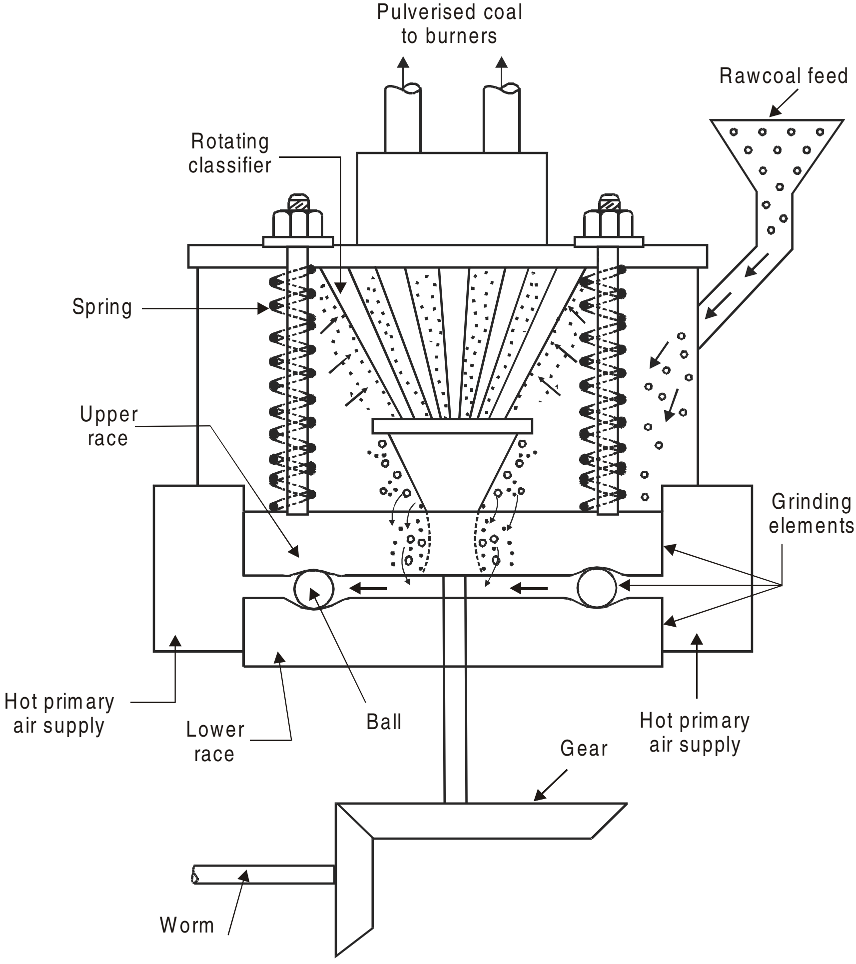


Figure 2.9: Ball and race mill.

In this mill the coal passes between the rotating elements again and again until it has been pulverised 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, whereas the coal particles of required size are discharged from the top of classifier.

Advantages

i) Lower capital cost. ii) Lower power consumption.

iii) Less space required. iv) Less weight.

2.4 PULVERISED COAL FIRING SYSTEM

Pulverised coal firing is done by two systems:

i) Unit system or Direct system. ii) Bin or Central system.

2.4.1 Unit System

In this system (figure 2.10) the raw coal from the coal bunker drops on to the feeder.

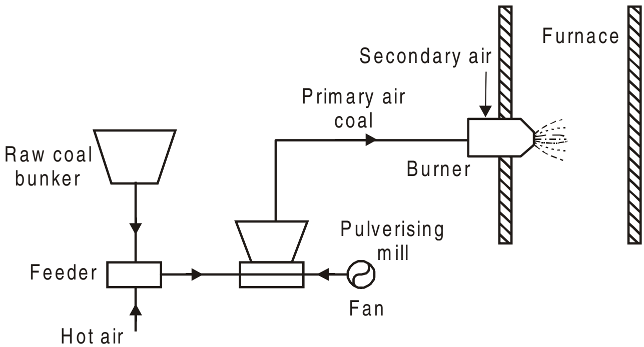


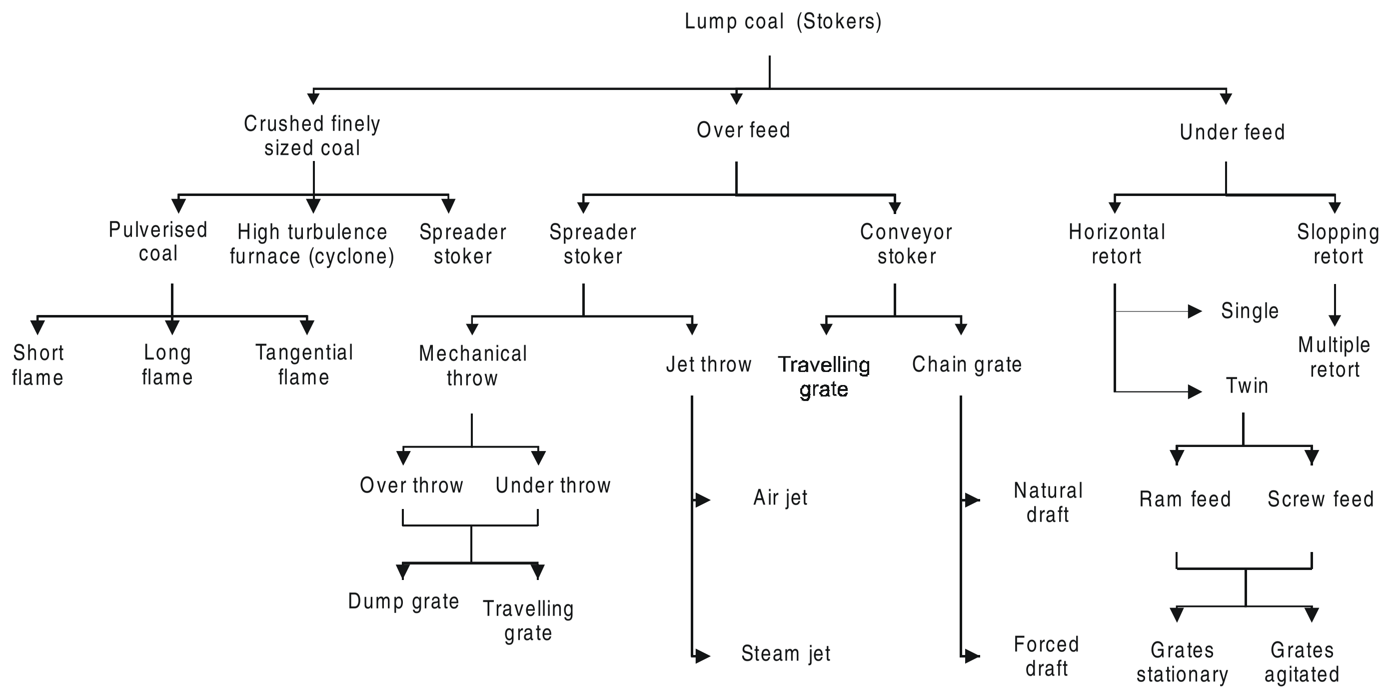
Figure 2.10: Unit system.

Hot air is passed through coal in the feeder to dry the coal. The coal is then transferred to the pulverising mill where it is pulverised. Primary air is supplied to the mill, by the fan. The mixture of pulverised 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.

Advantages

1. The system is simple and cheaper than the central system.
2. There is direct control of combustion from the pulverising mill.
3. Coal transportation system is simple.

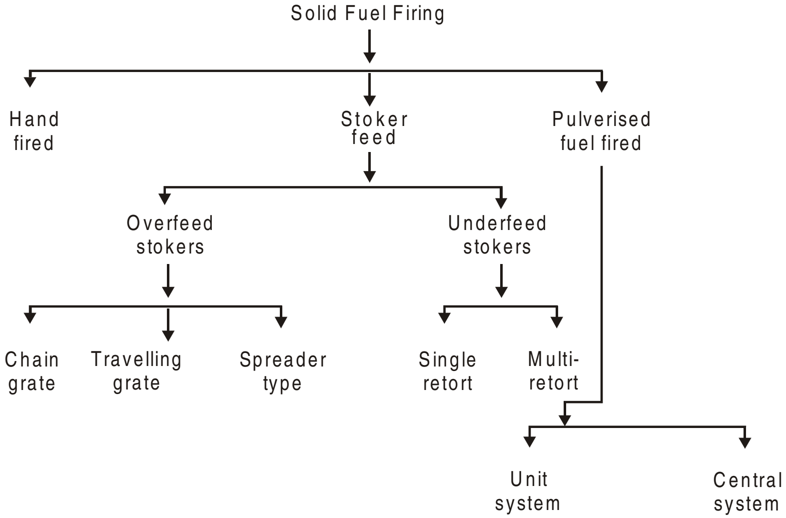
The detailed classification of combustion systems used for coal burning is given below



Classification of combustion system

The hand firing system is the simplest method of fuel firing but it cannot be used in modern power plants as it gives lower combustion efficiency, it does not respond quickly to fluctuation loads and the control of draught is difficult.

2.5.2 Combustion Equipment for Steam Boilers



Common combustion equipment for steam boilers.

2.5.3 Classification of Mechanical Stokers

In small boilers, the grate is stationary and coal is fed manually by shovels. But for more uniform operating condition, higher burning rate and greater efficiency, moving grates or stokers are employed. Stokers may be of the following types:

1. Travelling grate stoker
2. Chain grate stoker
3. Spreader stoker
4. Vibrating grate stoker
5. Underfeed stoker.

2.5.3.1 Travelling grate stokers

The grate surface is made up of a series of cast-iron bars joined together by links to form an endless belt running over two sets of sprocket wheels with a surface as wide as needed (figure 2.12). A coal gate at the rear of the coal hopper regulates the depth of the automatically regulates the speed of the grate to maintain the required steam generation rate. The ash containing a small amount of combustible material is carried over the rear end of the stoker and deposited in the ash pit as shown in figure.

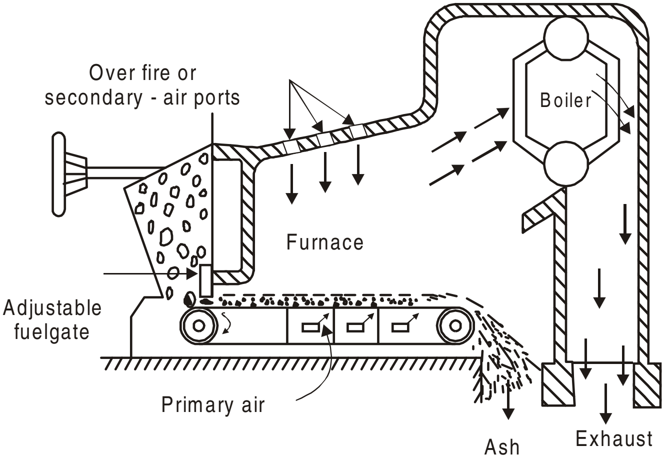


Figure 2.13: Chain grate stoker.

The air required for combustion is supplied through the air inlets situated below the grate. The secondary air is supplied through the openings provided in the furnace wall above the grate as shown in figure. The combination of primary air and over fire air supplied provide turbulence required for rapid combustion. The primary air is brought in from the sides and then it is forced through the upper grate. The air-ducts under the stoker are divided into sections, so that the air supply to different parts of the stoker is regulated to meet the changing demand. The air openings in the grate depend upon the kind of coal burned and vary from 20 to 40% of the total grate area. Air dampers are provided to control the air supply to the various zones. The air dampers enable the operator to control the rate of burning in different zones and thereby reduce to a minimum the coke carry over into the ash pit. If the satisfactory operation cannot be accomplished by adjusting these dampers, then the control is achieved by adjusting the fuel bed depth.

The coal supplied to the grate is regulated by two ways, as by varying the depth of coal on the grate with the help of grate valve and by varying the rate of grate travel. These grates are suitable for low rating of fuel because the fuel must be burnt before it reaches the rear end of the furnace. The rate of burning with this stoker is 200 to 300 kg per m^2 per hour when forced draught is used. Any type of fuel except caking bituminous coal can be used with chain grate stoker. The bituminous coal cannot be used as large percentage of fines results in increased carbon loss.

The advantages and disadvantages of chain grate stoker are listed below.

Advantages

1. It is simple in construction and its initial cost is low.
2. It is more reliable in service therefore maintenance charges are low.
3. It is self-cleaning stoker.
4. The heat release rates can be controlled just by controlling the speed of chain.
5. It gives high heat release rates per unit volume of the furnace.

Disadvantages

1. The amount of coal carried on the grate is small as the increase in grate size creates additional problems. This cannot be used for high capacity boilers (200 tons/hr. or more).
2. The temperature of preheated air is limited to 180ºC.
3. The clinker troubles are very common.
4. Ignition arches are required.

2.5.3.3 Spreader stoker

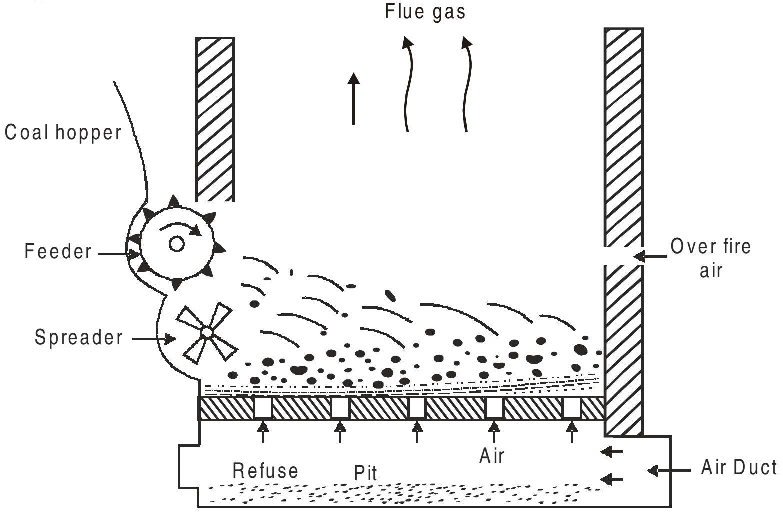


Figure 2.14: Spreader stoker.

A spreader stoker is shown in figure 2.14. 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 the 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.

Advantages

The various advantages of spreader stoker are as follows:

1. Its operation cost is low.
2. A wide variety of coal can be burnt easily by this stoker.
3. A thin fuel bed on the grate is helpful in meeting the fluctuating loads.

2.5.3.4 Vibrating grate stoker

The stoker shakes the fuel bed intermittently, the frequency and amplitude of vibration depending on boiler load. The fuel bed is inclined so that the fuel moves towards the rear of the boiler by gravity with the progress of combustion and then falls into the ash pit. The grate is water-cooled to prevent slagging.

2.5.4 Method of Feeding Coal to Combustion Chamber

2.5.4.1 Overfeed supply of coal

In case of overfeed stoker the coal is fed on to the grate above the point of air admission as shown in figure 2.15.

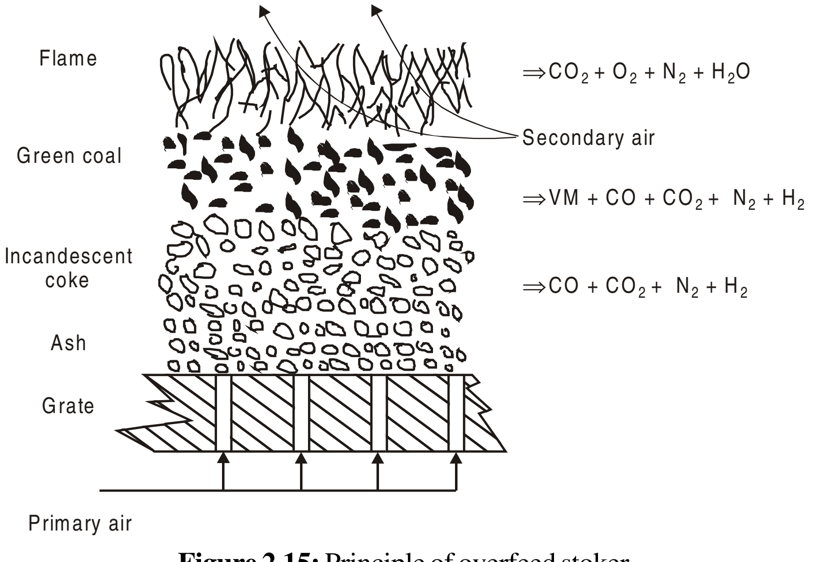


Figure 2.15: Principle of overfeed stoker.

The mechanics of combustion in overfeed stoker is described below.

1. The pressurised air coming from F.D. fan enters under the bottom of the grate. The air passing through the grate is heated by absorbing the heat from the ash and grate itself, whereas the ash and grate are cooled. The hot air then passes through a bed of incandescent coke. As the hot air passes through incandescent coke, the O_2 reacts with C to form CO_2. The rate of carbon-oxidation in this part of fuel bed depends entirely on the rate of air supply. Generally, for a fuel of 8 cm deep, all the O_2 in the air disappears in the incandescent region. The water vapour carried with air also reacts with C in incandescent zone and forms CO, CO_2 and H_2. Part of CO_2 formed reacts with C passing through incandescent zoen and converts into CO. The gases leaving the incandescent region of fuel bed consist of N_2, CO_2, CO, H_2 and H_2O.
2. The raw coal is continuously supplied on the surface of the bed. Here it loses its volatile matter by distillation. The heat required for the distillation of coal is given by incandescent coke below the fresh fuel, hot gases diffusing through the surface of bed and hot gases and flame in the furnace above. The ignition zone lies directly below the raw fuel undergoing distillation.
3. The gases leaving the upper surface of the fuel bed contain combustible volatile matter formed from the raw fuel, N_2, CO_2, CO, H_2 and H_2O. Additional secondary air is supplied at a very high speed to create turbulence which is required for complete combustion of unburned gases. The combustion of the remaining combustible gases is completed in the combustion chamber.
4. The burned gases entering the boiler contain N_2, CO_2, O_2 and H_2O and some CO if the burning is incomplete.
5. During incandescence, the fuel continuously loses its carbon by oxidation until only the ash remains. The primary air supplied from the bottom cools the ash until it rests on a plane immediately adjacent to the grate.

2.5.4.2 Under-feed stoker

In this type of stokers, the fuel and air move in the same direction. The mechanism of combustion in under-feed stoker is described below:

1. Air after passing through the holes in the grate as shown in figure 2.16 meets the raw coal. As it diffuses through the bed of raw coal, it meets with the volatile matter generated by the raw-coal. The heat for distillation comes by conduction from the mass of incandescent fuel bed which exists above the raw coal. The air mixes with the formed volatile matter and passes through the ignition zone and then enters into the region of incandescent coke.

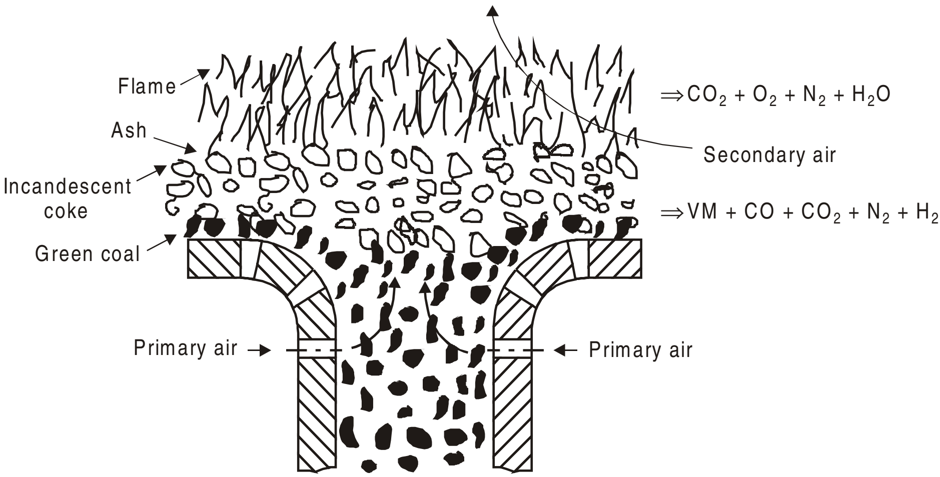


Figure 2.16: Underfeed supply of coal.

2. The reactions which take place in the incandescent zone of under-feed stoker are exactly the same as in the incandescent zone of over-feed stoker except some breaking of the molecular structure of the volatile matter takes place and part of the broken volatile matter reacts with the oxygen of air.

3. The gases coming out of raw fuel bed pass through a region of incandescent ash on the surface of the fuel and finally discharged to the furnace with the constituents like over-feed stoker.

4. The supply of secondary air is required in this case as the gases coming out of fuel bed also contain combustible matter.

5. The ash left at the bottom of the stoker is at a higher temperature than the over-feed stoker.

a) Single retort stoker

The arrangement of single retort stoker is shown in figure 2.17 (a) and 2.17 (b) in form of two views. The fuel is placed in large hopper on the front of the furnace, and then

Bottom and slag may be used as filling material for road construction. Fly ash can partly replace cement for making concrete. Bricks can be made with fly ash. These are durable and strong.

2.7 ASH HANDLING EQUIPMENT

Mechanical means are required for the disposal of ash. The handling equipment should perform the following functions: 1) Capital investment, operating and maintenance charges of the equipment should be low. 2) It should be able to handle large quantities of ash. 3) Clinkers, soot, dust etc. create troubles. The equipment should be able to handle them smoothly. 4) The equipment used should remove the ash from the furnace, load it to the conveying system to deliver the ash to a dumping site or storage and finally it should have means to dispose of the stored ash. 5) The equipment should be corrosion and wear resistant.

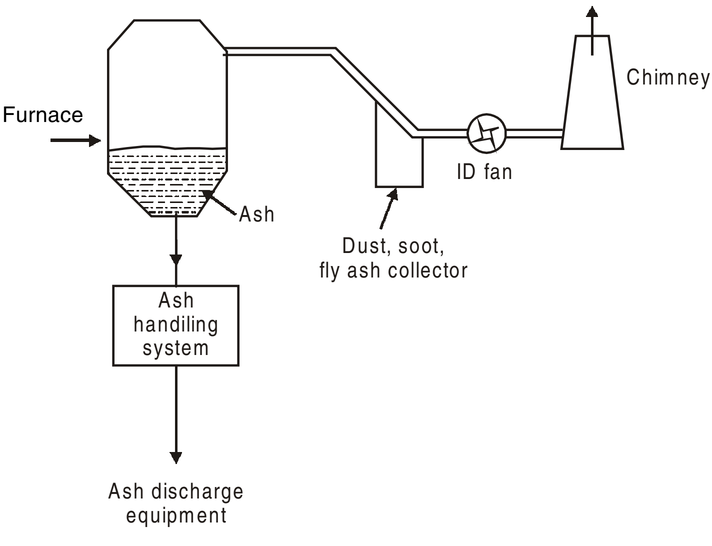


Figure 2.21: Ash handling equipment.

2.8 CLASSIFICATION OF ASH HANDLING SYSTEM

i) Hydraulic system.

ii) Pneumatic system.

iii) Mechanical system.

The commonly used ash discharge equipment is as follows:

i) Rail road cars. ii) Motor truck. iii) Barge.

2.8.1 Hydraulic System

In this system, ash from the furnace grate falls into a system of water possessing high velocity and is carried to the sumps. It is generally used in large power plants. Hydraulic system is of two types, namely, low pressure hydraulic system used for intermittent ash disposal. Figure 2.22 shows hydraulic system.

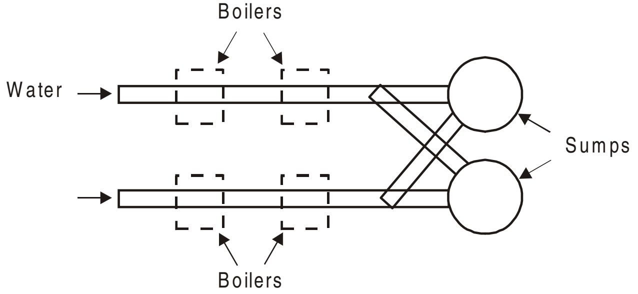


Figure 2.22: Hydraulic system.

In this method water at sufficient pressure is used to take away the ash to sump. Where water and ash are separated. The ash is then transferred to the dump site in wagons, rail cars ro trucks. The loading of ash may be through a belt conveyor, grab buckets. If there is an ash basement with ash hopper the ash can fall, directly in ash car or conveying system.

2.8.2 Water-Jetting System

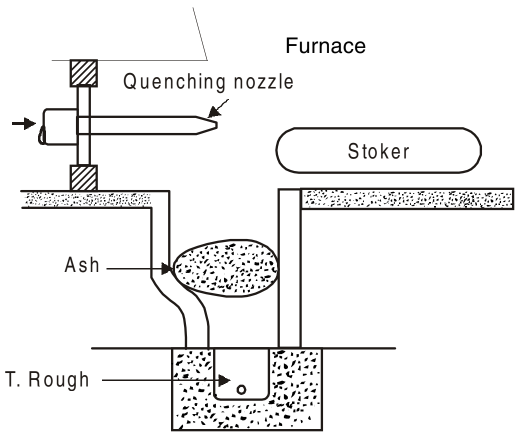


Figure 2.23: Water jetting.

Water jetting of ash is shown in figure 2.23. In this method a low pressure jet of water coming out of the quenching nozzle is used to cool the ash. The ash falls into a trough and is then removed.

2.8.3 Pneumatic System

In this system (figure 2.24) ash from the boiler furnace outlet falls into a crusher where larger ash particles are crushed to small sizes. The ash is then carried by a high velocity air or steam to the point of delivery. Air leaving the ash separator is passed through filter to remove dust etc. so that the exhauster handles clean air which will protect the blades of the exhauster.

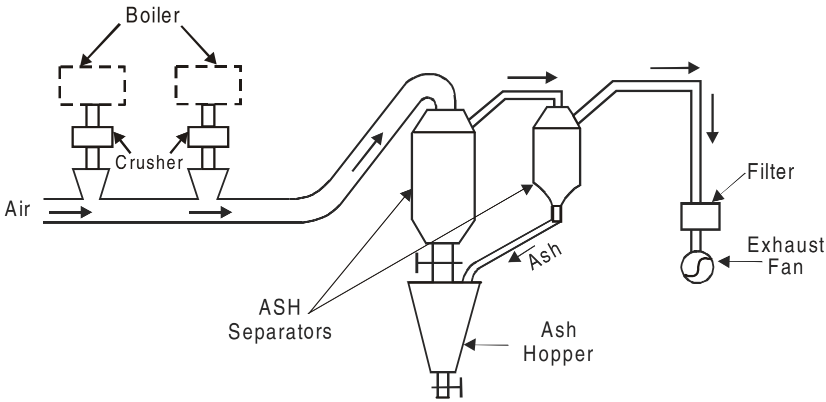


Figure 2.24: Pneumatic system.

2.8.4 Mechanical System

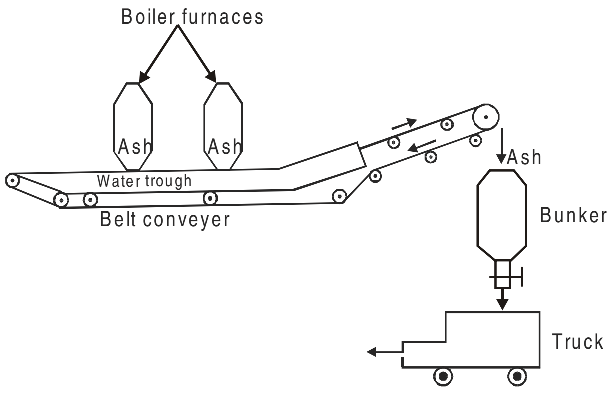


Figure 2.25: Mechanical system.

Figure 2.25 (a) shows a mechanical ash handling system. In this system ash cooled by water seal falls on the belt conveyer and is carried out continuously to the bunker. The ash is then removed to the dumping site from the ash banker with the help of trucks.

2.9 ELECTROSTATIC PRECIPITATOR (ESP)

For power generation steam power plant mainly depend on coal and other fossil fuels to produce electricity. A natural result from the burning of fossil fuels, particularly coal, is the emission of flyash. Ash is mineral matter present in the fuel. For a pulverized coal unit, 60-80% of ash leaves with the flue gas. Historically, flyash emissions have received the greatest attention since they are easily seen leaving smokestacks.

Two emission control devices for flyash are the traditional fabric filters and the more recent electrostatic precipitators. The fabric filters are large baghouse filters having a high maintenance cost (the cloth bags have a life of 18 to 36 months, but can be temporarily cleaned by shaking or back flushing with air). These fabric filters are inherently large structures resulting in a large pressure drop, which reduces the plant efficiency.

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.

2.9.1 The Plate Precipitator

Description

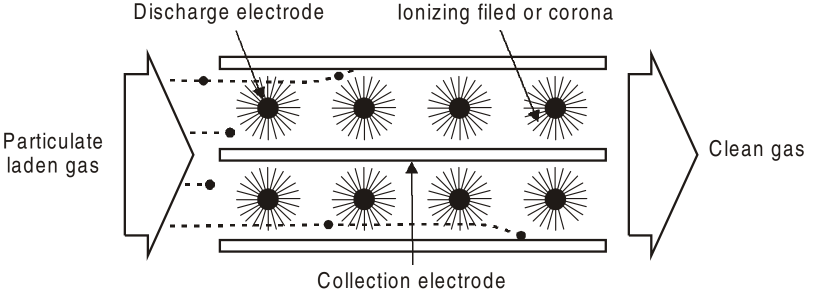


Figure 2.26: Top view of ESP schematic diagram.

The most basic precipitator contains a row of thin wires, and followed by a stack of large flat metal plates, with the plates typically spaced about 1 cm apart. The fluegas laden with flyash is sent through the spaces between the wires, and then passes through the stack of plates.

A negative voltage of several thousand volts is applied between wire and plate. If the applied voltage is high enough an electric discharge ionizes the air around the electrodes. Negative ions flow to the plates and charge the gas-flow particles.

The particles are then routed past positively charged plates, or grounded plates, which attract the now negatively-charged ash particles. The particles stick to the positive plates until they are collected. The air that leaves the plates is then clean from harmful pollutants. Just as the spoon picked the salt and pepper up from the surface they were on, the electrostatic precipitator extracts the pollutants out of the air.

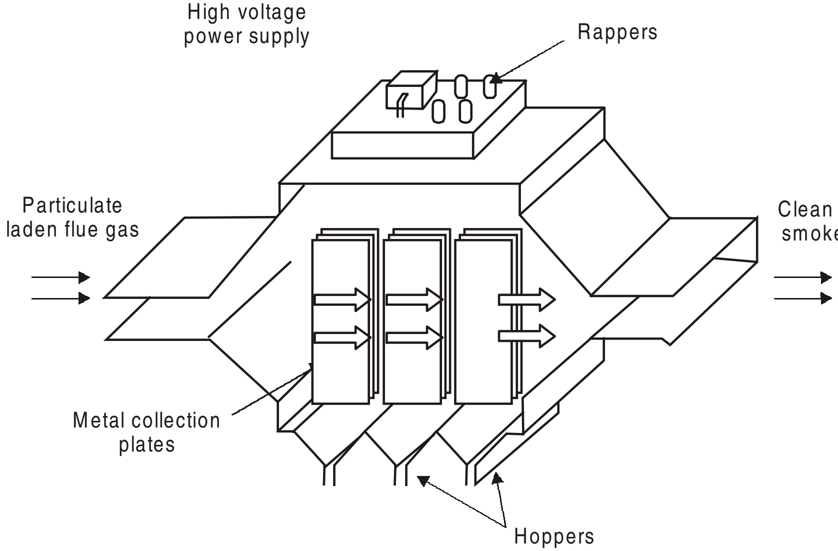


Figure 2.27: Side view of ESP schematic diagram.

Electrostatic precipitators have collection efficiency of 99%, but do not work well for flyash with a high electrical resistivity (as commonly results from combustion of low-sulfur coal). In addition, the designer must avoid allowing unburned gas to enter the electrostatic precipitator since the gas could be ignited.

With electrostatic precipitators, if the collection plates are allowed to accumulate large amounts of particulate matter, the particles often 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.

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.

Electrostatic precipitators are not only used in utility applications but also other industries (for other exhaust gas particles) such as cement (dust), pulp and paper (salt cake and lime dust), petrochemicals (sulfuric acid mist), and steel (dust & fumes).

2.9.2 Wet Electrostatic Precipitator

Electrostatic precipitation is typically a dry process, but spraying moisture to the incoming air flow helps collect the exceptionally fine particulates, and helps reduce the electrical resistance of the incoming dry material to make the process more effective.

A wet electrostatic precipitator (WESP) merges the operational methods of a wet scrubber with an electrostatic precipitator to make a self-washing, self-cleaning yet still high-voltage device.

Advantages

1. This is more effective to remove very small particles like smoke, mist and flyash. Its range of dust removal is sufficiently large (0.01 μ to 1.00 μ). The small dust particles below 10 μ cannot be removed with the help of mechanical separators and wet scrubbers cannot be used if sufficient water is not available. Under these circumstances, this type is very effective.
2. This is also most effective for high dust loaded gas (as high as 100 grams per cu metre). Its efficiency is as high as 99.5%.
3. The draught loss of this separator is the least of all forms (1 cm of water).
4. The maintenance charges are least among all separators.
5. It provides ease of operation.
6. The dust is collected in dry form and can be removed either dry or wet.

Disadvantages

1. The direct current is not available with the modern power plants, therefore, considerable electrical equipment is necessary to convert low voltage (400 V) A.C. to high voltage (60,000) D.C. This increases the capital cost of the equipment as high as 40 to 60 cents per 1000 kg of rated installed steam generating capacity.
2. The running charges are also considerably high as the amount of power required for charging is considerably large.
3. The space required is larger than wet system.

4. The efficiency of the collector is not maintained if the gas velocity exceeds that for which the plant is designed. The dust carried with the gases increases with an increase of gas velocity. The efficiency decreases from 100 to 80% when the gas flow increases from 1000 m^3/min to 60×1000 m^3/min.

5. Because of the closeness of the charged plates and potential used, it is necessary to protect the entire collector from sparking by providing a fine mesh before the ionising chamber. This is necessary because even the smallest piece of paper might cause sparking when it would be carried across adjacent plates or wires.

2.10 DRAUGHT

Draught is defined as the difference between absolute gas pressure at any point in a gas flow passage and the ambient (same elevation) atmospheric pressure. Draught is plus if $P_{atm} < P_{gas}$ and it is minus $P_{atm} > P_{gas}$. Draught is achieved by small pressure difference which causes the flow of air or gas to take place. It is measured in milimetre (mm) of water.

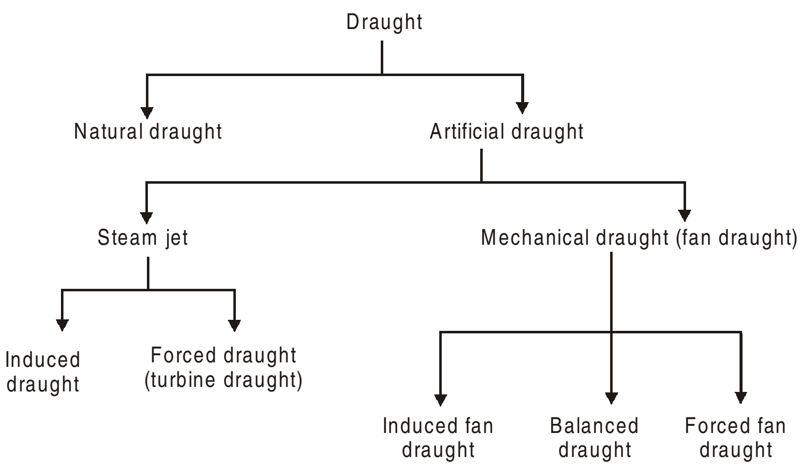
The purpose of draught is as follows:

i) To supply required amount of air to the furnace for the combustion of fuel. The amount of fuel that can be burnt per square foot of grate area depends upon the quantity of air circulated through fuel bed.

ii) To remove the gaseous products of combustion.

2.11 CLASSIFICATION OF DRAUGHT

The following flow chart gives the classification of draughts:



If only chimney is used to produce the draught, it is called natural draught.

Artificial draught

If the draught is produced by steam jet or fan it is known as artificial draught.

Steam jet draught

It employs steam to produce the draught.

Mechanical draught

It employs fan or blowers to produce the draught.

Induced draught

The flue is drawn (sucked) through the system by a fan or steam jet.

Forced draught

The air is forced into the system by a blower or steam jet.

2.12 NATURAL DRAUGHT

Natural draught system employs a tall chimney as shown in figure 2.28. The chimney is a vertical tubular masonry structure or re-inforced concrete. It is constructed for enclosing a column of exhaust gases to produce the draught. It discharges the gases high enough to prevent air pollution. The draught is produced by this tall chimney due to the temperature difference of hot gases in the chimney and cold external air outside the chimney.

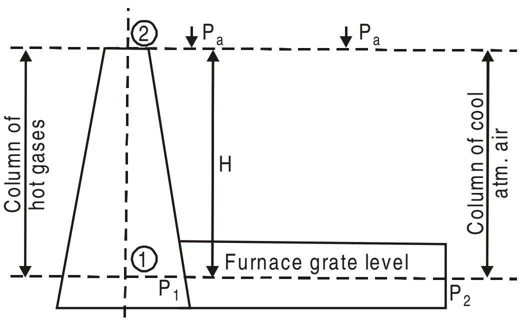


Figure 2.28: Natural draught.

Where H - Height of the chimney (m).

p_a - Atmospheric pressure (N/m^2).

p_1 - Pressure acting on the grate from chimney side (N/m^2).

p_2 - Pressure acting on the grate from atmospheric side (N/m^2).

Due to this pressure difference (p), the atmospheric air flows through the furnace grate and the flue gases flow through the chimney. The pressure difference can be increased by increasing the height of the chimney or reducing the density of hot gases.

2.12.1 Merits of Natural Draught

1. No external power is required for creating the draught.
2. Air pollution is prevented since the flue gases are discharged at a higher level.
3. Maintenance cost is practically nil since there are no mechanical parts.
4. It has longer life.
5. Capital cost is less than that of an artificial draught.

Demerits of natural draught

1. Maximum pressure available for producing draught by the chimney is less.
2. Flue gases have to be discharged at higher temperature since draught increases with the increase in temperature of flue gases.
3. Heat cannot be extracted from the flue gases for economiser, superheater, air pre-heater, etc. since the effective draught will be reduced if the temperature of the flue gases is decreased.
4. Overall efficiency of the plant is decreased since the flue gases are discharged at higher temperatures.
5. Poor combustion and specific fuel consumption is increased since the low velocity of air affects thorough mixing of air and fuel.
6. Not flexible under peak loads since the draught available for a particular height of a chimney is constant.
7. A considerable amount of heat released by the fuel (about 20%) is lost due to flue gases.

2.12.2 Applications

Natural draught system is used only in small capacity boilers and it is not used in high capacity thermal plants.

2.12.3 Calculations of Chimney Height

Let m = Mass of air supplied per kg of fuel.

T_g = Average absolute temperature of chimney gases in K.

T_a = Absolute temperature of the outside the chimney in K.

Therefore the mass of the flue gases formed = $(m + 1)$ kg per kg of fuel burnt.

Since the volume of solid or liquid fuel burnt is small as compared to the volume of air supplied, it may be neglected. The volume of chimney gases produced may be taken as equal to the volume of air supplied.

One kg of air occupies 0.7734 m^3 at N.T.P.

Volume per kg of air at temperatur T_a K

$$= 0.7734 \times \frac{T_a}{273}$$

$\therefore$ Volume of m kg of air at T_a K $= \dfrac{0.7734 \times m \times T_a}{273}$

Density of air at T_a K $= \dfrac{\text{Mass}}{\text{Volume}} = \dfrac{m \times 273}{0.7734 \times m \times T_a}$

$$\boxed{\rho_a = \frac{353}{T_a} \text{ kg/m}^3}$$

Since the volume of gas is proportionate to its absolute temperature (by Charles' law),

Volume of chimney gases at T_g K $= \dfrac{0.7734 \text{ m } T_g}{273}$

Similarly,

Density of chimney gases at T_g K $= \dfrac{\text{Mass of the gas}}{\text{Volume of the gas}}$

$$= \frac{(m+1) \times 273}{0.7734 \text{ m } T_g}$$

$$\boxed{\rho_g = \frac{353}{T_g} \cdot \frac{(m+1)}{m} \text{ kg/m}^3}$$

Let H be the height of the chimney in metres measured from the grate level, h be the draught pressure in mm of water, and A be the area of the furnace grate in m^2.

$\therefore$ Pressure exerted by a column of hot chimney gas of H metre height

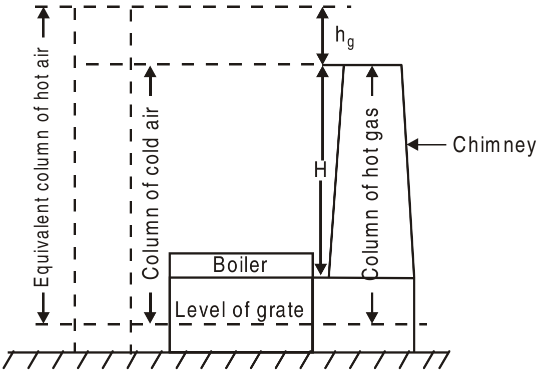


Figure 2.29: Chimney draught.

$$P = \text{density} \times 9.81 \times H \ \text{N/m}^2$$

$$\frac{353}{T_g} \cdot \left(\frac{m+1}{m}\right) \cdot 9.81 \times H \ \text{N/m}^2$$

Similarly, pressure exerted by a column of cold outside air of the same area and H metre height

$$\frac{353}{T_a} \times 9.81 \times H \ \text{N/m}^2$$

Let P = Pressure causing the draught in N/m^2.

As the pressure causing the draught is due to the pressure difference due to column of hot gases inside the chimney and the pressure due to an equal column of outside cold air,

$$P = 9.81H\left(\frac{353}{T_a} - \frac{353}{T_g} \cdot \frac{(m+1)}{m}\right)$$

$$= 353 \times 9.81\ H\left(\frac{1}{T_a} - \frac{1}{T_g} \cdot \frac{(m+1)}{m}\right) \qquad ...(1)$$

We know that $P = \rho gh = 1000 \times 9.81 \times \frac{h}{1000} = 9.81h \ \text{N/m}^2$

Substitute this value in equation (1)

$$9.81\ h = 353 \times 9.81\ H\left(\frac{1}{T_a} - \frac{1}{T_g} \cdot \frac{(m+1)}{m}\right)$$

$$h = 353\ H\left(\frac{1}{T_a} - \frac{1}{T_g}\,\frac{(m+1)}{m}\right) \text{mm of water} \qquad ...(2)$$

Equation (2) can be modified to express the draught in terms of column of hot gases. Let h_g be the height of column of hot gases which will produce the pressure P.

$\therefore$ Pressure exerted by this column of hot gases,

$$P = \text{density} \times 9.81 \times h_g$$

$$P = \frac{353}{T_g} \times \left(\frac{m+1}{m}\right) \times 9.81\ h_g \qquad ...(3)$$

Equating equation (3) and (1)

$$\frac{353}{T_g}\left(\frac{m+1}{m}\right) \times 9.81 \times h_g = 353 \times 9.81\ H\left(\frac{1}{T_a} - \frac{1}{T_g}\,\frac{(m+1)}{m}\right)$$

$$h_g = H\left[\frac{m}{m+1} \cdot \frac{T_g}{T_a} - 1\right] \qquad ...(4)$$

Calculations of chimney diameter

The velocity of the gases passing through the chimney is given by $V = \sqrt{2gh_g}$ assuming there is no loss.

If the pressure loss in the chimney due to friction is equaivalent to h_f.

The velocity of flue gases in the chimney,

$$V = \sqrt{2g\left(h_g - h_f\right)}$$

$$= \sqrt{2 \times 9.81\left(h_g - h_f\right)}$$

$$= 4.43\sqrt{h_g\left(1 - \frac{h_f}{h_g}\right)}$$

$$= K\sqrt{h_g}$$

Where $K = 4.43\sqrt{1 - \frac{h_f}{h_g}}$

$K = 0.825$ for brick chimney

$K = 1.1$ for steel chimney.

The mass of gases flowing through any cross section of the chimney is given by

$$m_g = A \times V \times \rho_g \text{ kg/s}$$

$$\therefore \frac{\pi}{4} D^2 \times V \times \rho_g = m_g$$

$$D = 1.128\sqrt{\frac{m_g}{V.\rho_g}}$$

Where D is the diameter at any cross section of the chimney.

Condition for maximum discharge through the chimney

$$\boxed{T_g = 2.T_a \frac{(m+1)}{m}} \qquad ...(5)$$

Substitute equation (5) in (4)

Equation (4) becomes, $h_g = H\left[\frac{2.T_a\,(m+1)}{T_a} \times \frac{m}{m+1} - 1\right]$

$= H\,(2 - 1)$

$= H$ metres

Therefore, when maximum discharge takes place the height of the coloumn of hot gas which would produce a draught will be equal to the height of the chimney. By substituting the value of T_g in equation (2), we get

$$h = \frac{176.5\ H}{T_a}$$

2.13 ARTIFICIAL DRAUGHT

It has been seen that the draught produced by chimney is affected by the atmospheric conditions. It has no flexibility, poor efficiency and tall chimney is required. In most of the modern power plants, the draught used must be independent of atmospheric condition, and it must have greater flexibility (control) to take the fluctuating loads on the plant.

Today's large steam power plants requireing 20 thousand tons of steam per hour would be impossible to run without the aid of draft fans. A chimney of any reasonable height would be incapable of developing enough draft to move the tremendous volume of air and gases (400×10^3 m^3 to 800×10^3 m^3 per minute). The further advantage of fans is to reduce the height of the chimney needed.

The draught required in actual power plant is sufficiently high (300 mm of water) and to meet high draught requirements, some other system must be used, known as artifical draught. The artificial draught is produced by a fan and it is known a fan (mechanical) draught. Mechanical draught is preferred for central power stations.

2.13.1 Forced Draught

In a forced draught system, a blower is installed near the base of the boiler and air is forced to pass through the furnace, flues, economiser, air-preheater and to the stack. This draught system is known as positive draught system or forced draught system because the pressure and air is forced to flow through the system. The arrangement of the system is shown in figure 2.30. A stack or chimney is also used in this system as shown in figure but its function is to discharge gases high in the atmosphere to prevent the contamination. It is not much significant for producing draught therefore height of the chimney may not be very much.

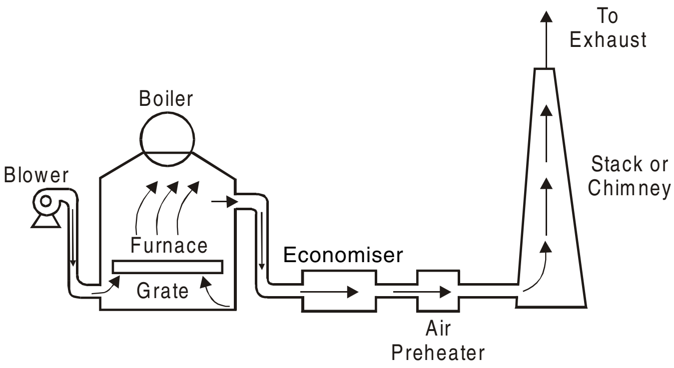


Figure 2.30: Forced draught.

2.13.2 Induced Draught

In this system, the blower is located near the base of the chimney instead of near the grate. The air is sucked in the system by reducing the pressure through the system below atmosphere. The induced draught fan sucks the burned gases from the furnace and the pressure inside the furnace is reduced below atmosphere and induces the atmospheric air to flow through the furnace. The action of the induced draught is similar to the action of the chimney. The draught produced is independent of the temperature of the hot gases therefore the gases may be discharged as cold as possible after recovering as much heat as possible in air-preheater and economiser.

This draught is used generally when economiser and air-preheater are incorporated in the system. The fan should be located at such a place that the temperature of the gas handled by the fan is lowest. The chimney is also used in this system and its function is similar as mentioned in forced draught but total draught produced in induced draught system is the sum of the draughts produced by the fan and chimeny. The arrangement of the system is shown in figure 2.31.

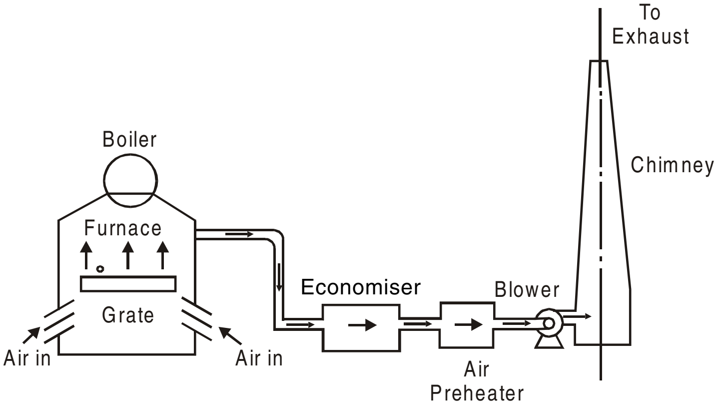


Figure 2.31: Induced draught.

2.13.3 Balanced Draught

It is always preferable to use a combination of forced draught and induced draught instead of forced or induced draught alone.

If the forced draught is used alone, then the furnace cannot be opened either for firing or inspection because the high pressure air inside the furnace will try to blow out suddenly and there is every chance of blowing out the fire completely and furnace stops.

If the induced draught is used alone, then also furnace cannot be opened either for firing or inspection because the cold air will try to rush into the furnace as the pressure inside the furnace is below atmospheric pressure. This reduces the effective draught and dilutes the combustion.

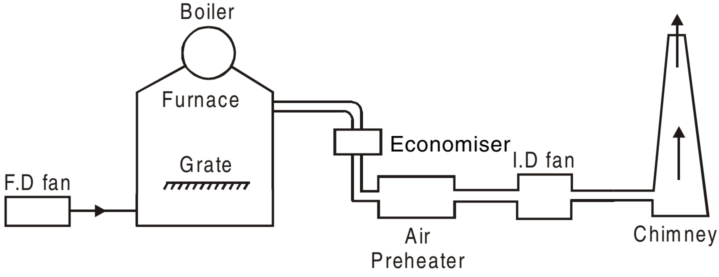


Figure 2.32: Balanced draught.

To overcome both the difficulties mentioned above either using forced draught or induced draught alone, a balanced draught is always preferred. The balanced draught is a combination of forced and induced draught. The forced draught overcomes the resistance of the fuel bed therefore sufficient air is supplied to the fuel bed for proper and complete combustion. The induced draught fan removes the gases from the furnace maintaining the pressure in the furnace just below atmosphere. This helps to prevent the blow-off of flames when the doors are opened as the leakage of air is inwards.

The arrangement of the balanced draught is shown in figure 2.32. Also the pressure inside the furnace is near atmospheric therefore there is no danger of blowout or there is no danger of inrushing the air into the furnace when the doors are opened for inspection.

2.14 COMPARISON OF FORCED AND INDUCED DRAUGHT

S.No	*Forced draught*	*Induced draught*
1.	The size and power required by the F.D. fan is less.	The size and power required by I.D. fan is more.
2.	Volume of gas handled is less.	Volume of gas handled is more.
3.	Water cooled bearings are not required.	Water cooled bearings are required to withstand high temperature flue gas.
4.	There is no chance of air leakage as the pressure inside the furnace is above atmospheric.	Continuous air leakage is possible as the pressure inside the furnace is less than atmosphere.
5.	The flow of air through the grate and furnace is uniform.	Flow of air is not uniform.
6.	The heat transfer efficiency will be increased.	There may a chance of reduction in heat transfer efficiency.

2.15 MERITS AND DEMERITS OF MECHANICAL DRAUGHT OVER NATURAL DRAUGHT

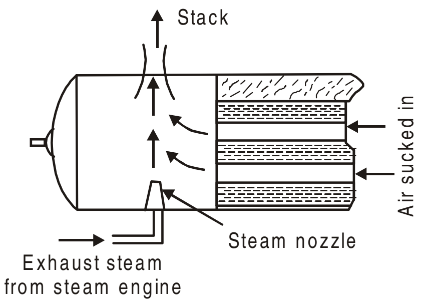
S.No	*Mechanical draught*	*Natural (chimney) draught*
	Merits:	**Demerits:**
1.	Evaporative capacity is increased since draught is more and the rate of combustion in increased.	Evaporative capacity is less since draught is less.
2.	Low grade fuel can be used since the intensity of mechanical draught is more.	High grade fuels are used.
3.	Independent of atmospheric temperature.	Dependent on atmospheric temperature.
4.	Better control of combustion and evaporation since the air flow can be regulated to suit the combustion.	Combustion cannot be controlled since air flow cannot be regulated.
5.	Thermal efficiency of the plant is more since heat in flue gases can be recovered using economiser, air pre-heater etc).	Thermal efficiency of the plant is less since the flue gases have to be discharged at high temperatures.
6.	Chimney height is reduced since the function of the chimney is only to discharge flue gases at a convenient height in the atmosphere.	Chimney height is more to have the required draught.
7.	Fuel consumption for the given power is less.	Fuel consumption for the given power is more.
8.	Used in high capacity power plants.	Used in small capacity boilers.
	Demerits:	**Merits:**
1.	External power is required to drive the fan.	No external power is needed to for the draught.
2.	Capital cost is high.	Capital loss is less.
3.	Running and maintenance costs (of the fan) are high.	Maintenance cost is practically nil since there are no mechanical parts.

2.16 STEAM JET DRAUGHT

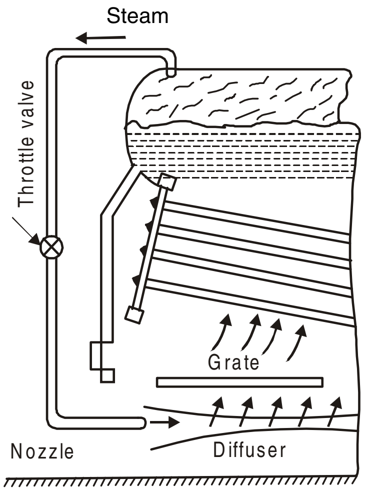
The artificial draught produced by the steam jet is known as steam jet draught. They may be induced or forced depending upon the location of the steam jet.

Induced steam jet draught

In this type, the exhaust steam from the engine is forced into the smoke box through a nozzle (figure 2.33 (a)). When the steam flows through the nozzle, a partial vacuum is created and the air is induced to the furnace through the flues and grate.



(a) Induced steam jet draught.



(b) Forced steam jet draught.

Figure 2.33

Forced steam jet draught

In this system, steam passes through a throttle valve from the boiler. Then the steam passes through a nozzle which is projecting into a diffuser pipe (figure 2.33 (b)). The steam comes out of the nozzle with high velocity and draws air along with it. The kinetic energy of the mixture of steam and air is converted into pressure energy when it passes through the diffuser pipe. Thus air is forced through the fuel bed, furnace and passed through the chimney.

Merits of steam jet draught

1. This system is very simple and low in cost.
2. Low grade fuels can be used.
3. Space required is less.

Demerits of steam jet draught

1. It can be operated only when the steam is raised.
2. The draught produced is very low.

2.17 CONDENSER

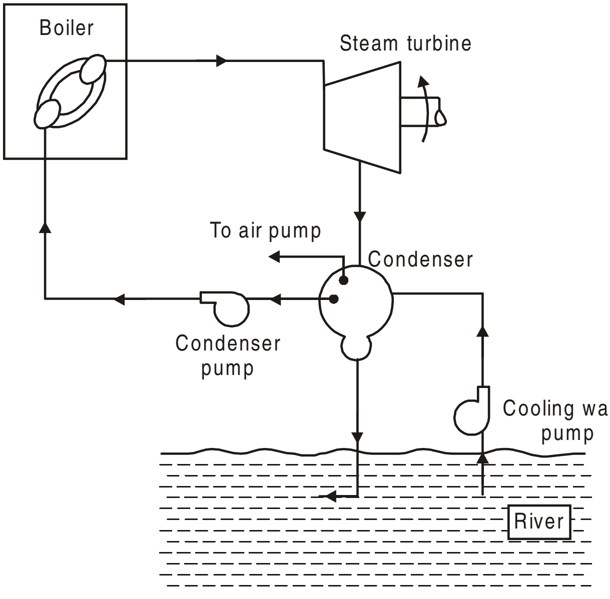
A condenser is a device in which the steam is condensed by cooling it with water. The condensed steam is known as condensate. The following are the advantages of installing a condenser in a steam power plant.

1. More work is done by the given amount of steam than could be obtained without a condenser. Thus, the efficiency of the power plant is increased.
2. Steam consumption is reduced for the given output.
3. The condensate is recovered for the boiler feed water.

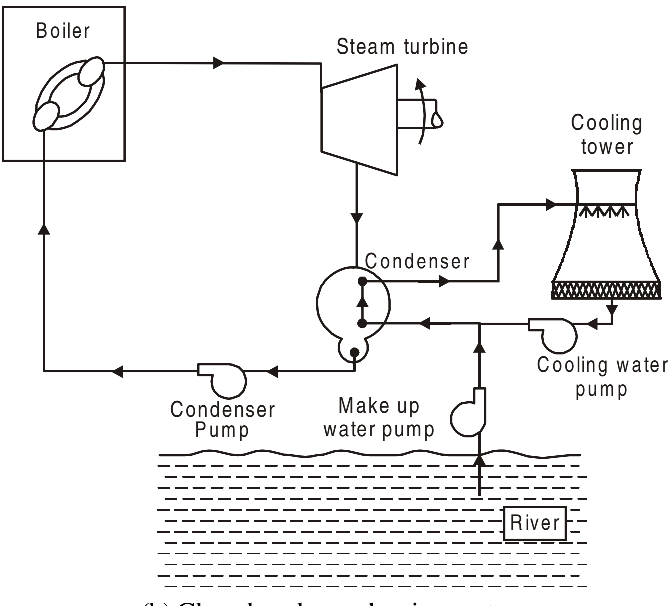
The steam power plants using condenser are shown in figure 2.34 (a) shows that the cooling water used in condenser is not re-circulated again and again but discharged to the downstream side of the river. Whereas figure 2.34 (b) shows that the cooling water is re-circulated again and again by passing through the cooling tower.

The essential elements of a steam condensing plant is given below:

1. A closed vessel in which the steam is condensed.
2. A pump to deliver condensed steam to the hot well from the condenser.
3. A dry air-pump to remove air and other non-condensable gases.
4. A feed pump to deliver water to the boiler from hot well.
5. Another pump for circulating cooling water.
6. An arrangement for re-cooling the circulating water from the condenser such as cooling tower or spray pond.



(a) Open cycle condensing system

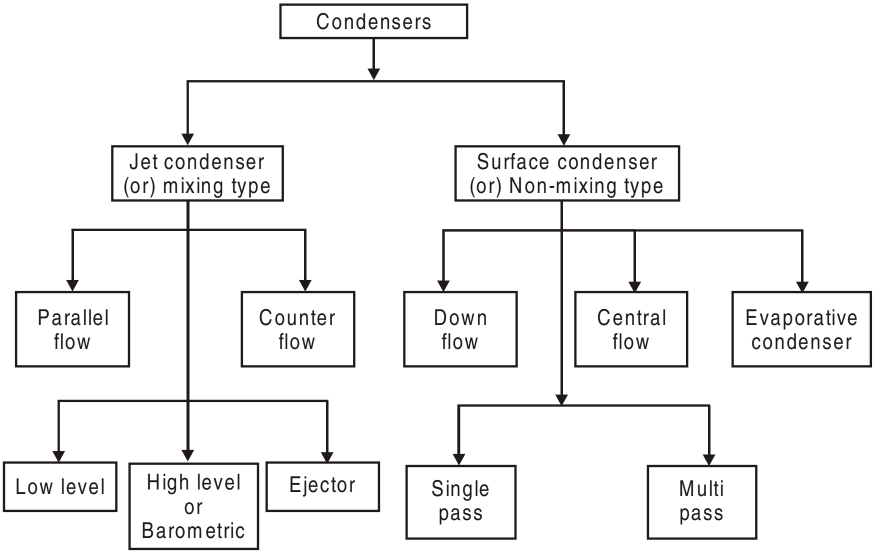


(b) Closed cycle condensing system

Figure 2.34

2.18 CLASSIFICATION OF CONDENSERS

Condensers are classified as follows:



In jet condensers, there is direct contact between the cooling water and the steam which is to be condensed.

In surface condensers, there is no direct contact between the cooling water and the steam which is to be condensed.

In parallel flow jet condensers, the flow of steam and cooling water are in the same direction.

In counter flow jet condensers, the steam and cooling water flow in opposite directions.

In low level jet condensers, the condensate is pumped by means of a condensate pump into the hot well.

In high level jet condensers, the condensate falls to the hot well by the barometric leg provided in the condenser.

In ejector condensers, a number of convergent nozzles are used.

In down flow surface condensers, the condensed steam flows down from the condenser.

In central flow surface condensers, the condensed steam moves towards the centre of condenser tubes.

mixed with water and condensed. In the converging cones, pressure energy is partly converted into kinetic energy. In diverging cones, the kinetic energy is partly converted into pressure energy. The pressure obtained is higher than atmospheric pressure and this forces the condensate to the hot well.

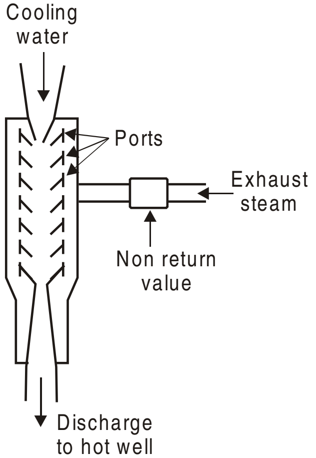


Figure 2.37: Ejector condenser.

2.18.1.4 Merits and Demerits of jet condensers

Merits

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

Demerits

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

The arrangement of the surface condenser is shown in figure 2.39. It consists of cast iron air-tight cylindrical shell closed at each end as shown in figure. A number of water tubes are fixed in the tube plates which are located between each cover head and shell.

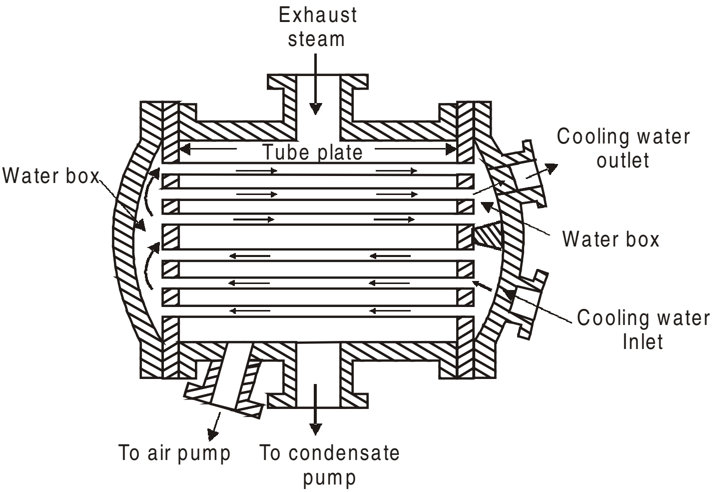


Figure 2.39: Surface condenser.

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

2.18.2.2 Central flow condenser

Figure 2.40 shows a central flow condenser. In this condenser the steam passages are all around the periphery of the shell. Air is pumped away from the centre of the condenser. The condensate moves radially towards the centre of tube next. Some of the exhaust steam while moving towards the centre meets the undercooled condensate and pre-heats it thus reducing undercooling.

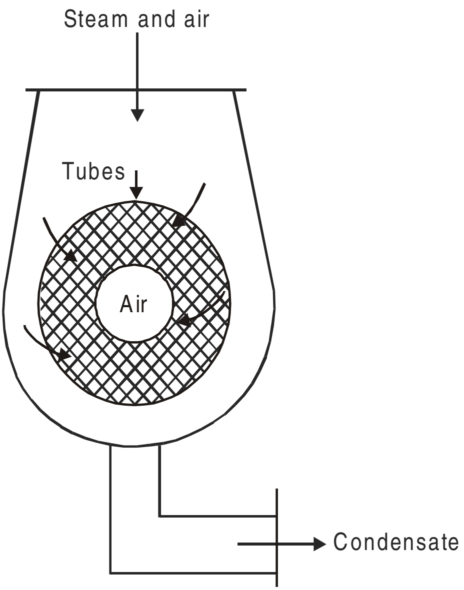


Figure 2.40: Central flow condenser.

2.18.2.3 Evaporative condenser

In this condenser steam to be condensed in passed through a series of tubes and the cooling water falls over these tube in the form of spray. A steam of air flows over the tubes to increase evaporation of cooling water which further increases the condensation of steam.

These condensers are more preferable where acute shortage of cooling water exists. The arrangement of the condenser is shown in figure 2.41. Water is sprayed through the nozzles over the pipe carrying exhaust steam and forms a thin film over it. The air is drawn over the surface of the coil with the help of induced fan as shown in figure. The air passing over the coil carries the water from the surface of condenser coil in the form of vapour. The latent heat required for the evaporation of water vapour is taken from the water film formed on the condenser coil and drops the temperature of the water film and this helps for heat transfer from the steam to the water. This mode of heat transfer reduces the cooling water requirement of the condenser to 10% of the requirement of surface condensers. The water particles carried with air due to high velocity of air are removed with the help of eliminator as shown in the figure. The make-up water (water vapour and water particles carried with air) is supplied from outside source.

The various disadvantages of the surface condenser are as follows:

i) The capital cost is more.

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

iii) It is bulky and requires more space.

2.19 SOURCES OF AIR IN CONDENSERS

The sources of air in a condenser are given below:

1. The exhaust steam from the turbine may contain certain amount of air. This is because, some air is dissolved in the feed water supplied to the boiler and carried by the steam to the turbine.
2. Atmospheric air may leak through various joints and also through the condenser.
3. In jet condensers, water used for cooling may contain some air.
4. Air may also leak through relief valves and other accessories.

2.20 EFFECTS OF AIR LEAKAGE

The effects of air leakage into a condenser are given below:

1. Thermal efficiency of the plant is reduced. The back pressure on the prime mover is increased by the presence of air in the condenser. There is a loss of heat drop and it reduces thermal efficiency of the plant.
2. More cooling water is required. The presence of air reduces saturation temperature of air. This increases latent heat of steam. Hence more cooling water is required to condense this steam.
3. Heat transfer rate is reduced because the air has poor thermal conductivity.

2.21 COOLING TOWERS

2.21.1 Introduction

In the power industry, energy in the form of heat is transformed to energy in the form of electricity. Unfortunately, this transformation is not accomplished on a one-to-one ratio. Although designers continuously seek newer and better ways to improve overall system efficiency, considerably more units of heat must be input than are realized as equivalent units of electric output. System equilibrium requires that this excess heat be dissipated ultimately to the atmosphere.

The traditional vehicle used to transport the lion's share of this waste heat to atmosphere is water, using the principle of evaporation as the primary mechanism of heat transfer. Where available and ecologically acceptable, water from rivers, lakes, or oceans is often used on a once-through basis, schematically shown in figure 2.42. Taken from the river, water absorbs heat from the steam condenser and returns to the river (at an elevated temperature) downstream from its point of extraction.

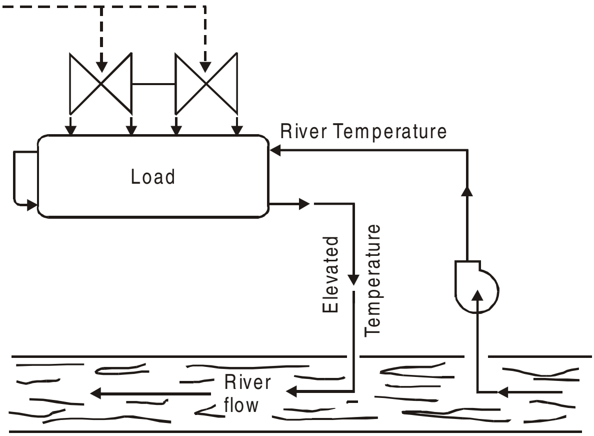


Figure 2.42: One-through system.

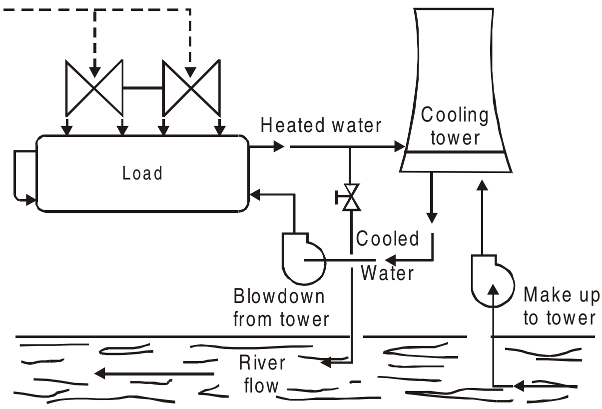


Figure 2.43: Closed-circuit system.

In an increasing number of cases, because of qualitative and quantitative restrictions regarding the use of natural waterways, plants make use of a closed-circuit system typical of that depicted in figure 2.43. As shown, the system's dependence on the river is limited to the requirement for a supply of make up water and, perhaps, as a point of discharge of

Note that the applied heat load establishes only a required temperature differential in the condenser-water circuit and is unconcerned with the actual hot- and cold-water temperatures themselves. Therefore, the more indication of a heat load is meaningless to the application engineer attempting to size a cooling tower properly. Loads must be expressed in terms of a specific flow to be cooled from an established hot-water temperature to a required cold-water temperature. Knowing any two of these parameters, the specifier can determine the third by a simple transposition of terms in equation (7).

Since the cooling-tower designer must also know the heat content of the air at the point of design, as evidenced by equation (7), the specifier must also establish the design wet-bulb temperature.

2.21.3 Types of Cooling Towers

Although cooling towers are designed and manufactured in numerous types, sizes, and configurations, ranging from the relatively small factory-assembled types to the structurally imposing hyperbolic towers that dominate many plant sites, those capable of handling loads of the magnitude developed in the power generation industry are comparatively few. They are characterized by shape, flow relationship of air and water, manner of producing airflow, and heat-transfer methodology generally, as follows.

Induced draft vs. forced draft

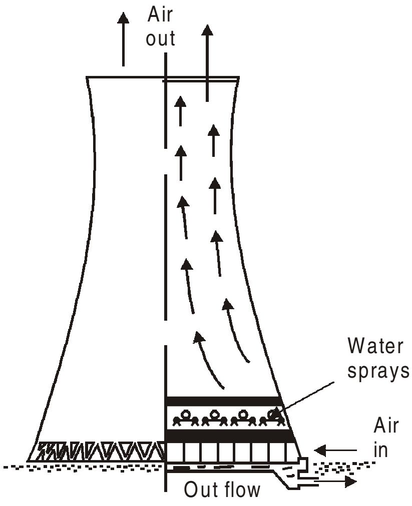


Figure 2.45: Counterflow natural-draft tower.

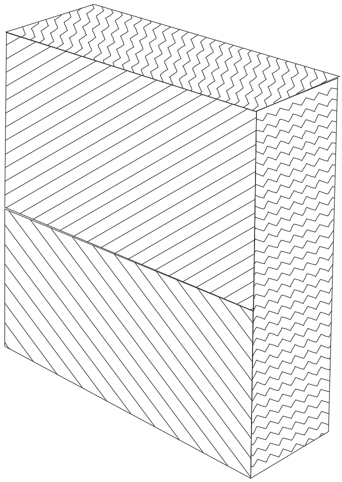


Figure 2.54: Film-type fill.

and retardation of the water. The resultant small vertical dimension, plus relatively wide vertical spacing of the splash bars, therefore provides the least opposition to airflow in the horizontal direction typical of crossflow. Its use in counterflow towers, where airflow is essentially vertical, requires an increase in fan power, which is normally considered unacceptable in today's market.

Film type

Film-type fill has gained prominence in the cooling tower industry because of its ability to expose greater water surface within a given packed volume. As can be seen in figure 2.50, water flows in a thin "film" over vertically oriented sheets of fill which are spaced appropriately for either vertical or horizontal air passage. Therefore, film-type fill is equally effective in either type of cooling tower.

For purposes of clarity, the fill sheets in figure 2.55, are shown to be flat. In practice, these sheets predominantly of polyvinyl chloride (PVC) material are molded into unique patterns to create a certain amount of turbulence within the airstream and to further extend the exposed water surface. The fill pack indicated in figure 2.55, for example, is manufactured in a cross-corrugated configuration, with the contact points of the corrugations providing the proper spacing. Other shapes may include regular protrusions to maintain spacing.

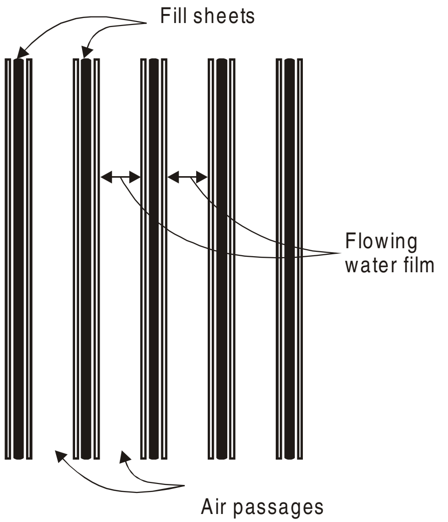


Figure 2.55: Film-fill concept.

Although film-type fill currently predominates the cooling-tower industry, there is no present indication that splash-type fill will become obsolete in the foreseeable future. The narrow passages afforded by close spacing of fill sheets makes film fill very sensitive to water quality. High turbidity, leaves, debris, or the presence of algae, slime, or coagulants can diminish passage size or, in extreme cases, lead to complete plugging. In geothermal applications, therefore, as well as installations tapping turbid water as a source of makeup, splash fill continuous to be the fill of choice.

2.21.5 Factors Affecting Tower Size and Performance

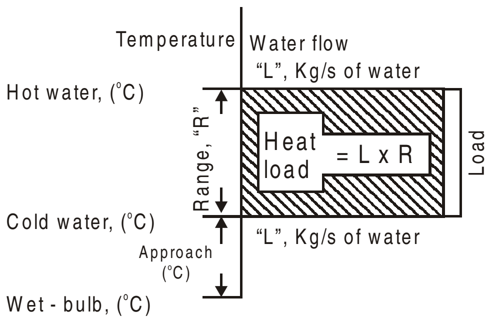


Figure 2.56: Parameters affecting tower size.

As one might gather from a study of figure 2.56, several parameters of choice affect the size of a cooling tower. Among these areas the system-related aspects of heat load, range, and approach; and wet-bulb temperature, which is site-related. In addition to these parameters, site-related interference must be considered, as well as recirculation, which is influenced by tower design and orientation. The effect of all these factors on tower size is discussed here.

Heat load, range, and Approach

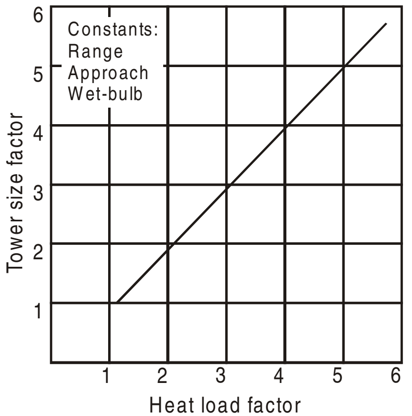


Figure 2.57: Effect of heat load on tower size.

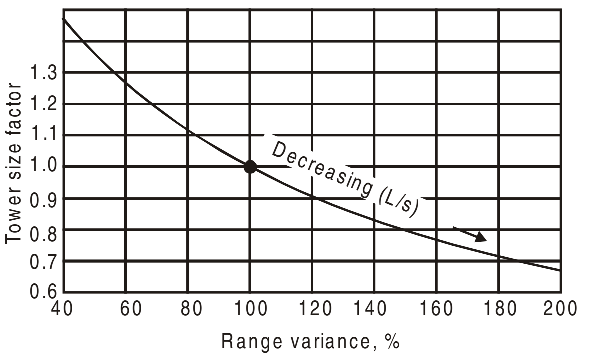


Figure 2.58: Effect of varying range of tower size.

As seen in figure 2.57, at a given range, approach, and wet-bulb temperature, tower size varies directly and linearly with heat load. The larger the heat load, the bigger the required tower will be.

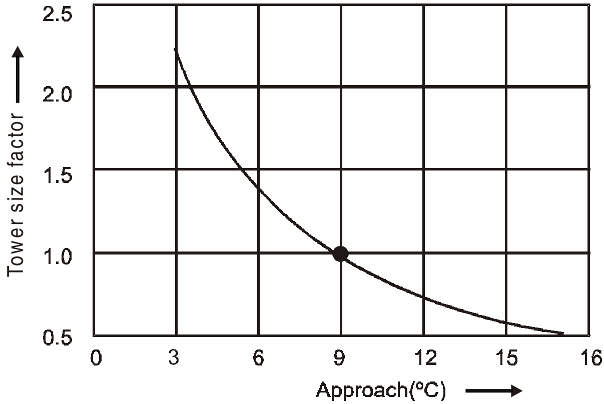


Figure 2.59: Effect of chosen approach on tower size.

Tower size varies inversely with range (figure 2.58). Increasing the range increases the temperature differential between the incoming hot water and the incoming air, thereby increasing the driving force for enthalpy exchange and reducing the size of the tower.

Tower size varies inversely with approach. A longer approach requires a smaller tower (figure 2.59). Conversely, a smaller approach requires an increasingly large tower, and at an approach of 2.8°C, the effect on tower size begins to become asymptotic. For that reason, it is not customary in the cooling tower industry to guarantee approaches of less than 2.8°C.

Wet-bulb temperature

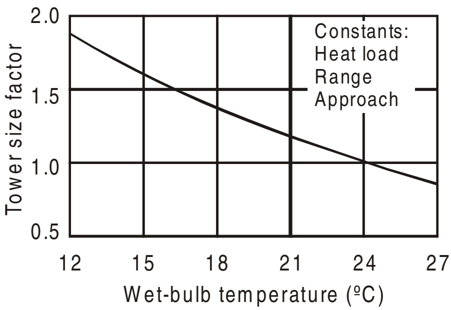


Figure 2.60: Effect of wet-bulb temperature on tower size.

Tower size varies inversely with the design wet-bulb temperature. When heat load, range, and approach values are fixed, increasing the design wet-bulb temperature reduces the size of the tower (figure 2.60). Since the primary exchange of heat in a cooling tower is through evaporation, the fact that ability of air to absorb moisture increases with higher temperatures accounts for this size reduction.

In attempting to understand these effects, readers must not allow themselves to become confused regarding the relative relationship of cold-water temperature, wet-bulb temperature, and approach. The inverse effect of design wet-bulb temperature on tower size applies only when approach values are held constant, that is, when the cold-water temperature is altered in the same direction as the changed wet-bulb temperature and by the same number of degrees.

SOLVED PROBLEMS

Problems on Draught

1. **Estimate the height of a chimney required to produce a static draught of 18 mm of water if the mean temperature of the flue gases in the chimney is 260°C and the temperature of outside air is 25°C. The densities of atmospheric air and the flue gases at N.T.P. are 1.293 and 1.34 kg/m³ respectively.**

Solution:

$$\text{Density of air at } 25^\circ\text{C} = \frac{1.293 \times 273}{(25 + 273)}$$

$$= 1.184 \text{ kg/m}^3$$

$$\text{Density of flue gases at } 260^\circ\text{C} = \frac{1.34 \times 273}{(260 + 273)}$$

$$= 0.686 \text{ kg/m}^3$$

Pressure difference is given as

$$P = 9.81\,H\,(\rho_{air} - \rho_g)\ \text{N/m}^2$$

$$\text{But } P = 9.81\,H = 9.81 \times 18 = 176.58\ \text{N/m}^2$$

$$\therefore 176.58 = 9.81\,H\,(1.184 - 0.686)$$

$$H = \frac{176.58}{9.81\,(1.184 - 0.686)}$$

$$\boxed{H = 36.14\,\text{m}}$$

2. A 50 m high chimney is full of hot gases at a temperature of 350°C. The air supplied for the complete combustion of 1 kg of fuel is 18 kg. If the temperature of the outside air is 27°C. Find the draught: a) In terms of column of hot gases and b) In terms of water column.

Given data:

$$H = 50\,m$$

$$T_g = 350°C = 350 + 273 = 623\,K$$

$$m = 18\,kg$$

$$T_a = 27°C = 27 + 273 = 300\,K$$

Solution:

a) The draught in terms of column of hot gases is given by

$$h_g = H\left[\frac{T_g}{T_a} \times \frac{m}{m+1} - 1\right]$$

$$= 50\left[\frac{623}{300} \times \frac{18}{(18+1)} - 1\right]$$

$$= 50\,(0.967) = 48.35 \text{ metres of hot gas column.}$$

b) The draught in terms of water column is given by,

$$h = 353\,H\left[\frac{1}{T_a} - \frac{1}{T_g} \cdot \frac{(m+1)}{m}\right]$$

$$= 353 \times 50\left[\frac{1}{300} - \frac{1}{623}\left(\frac{18+1}{18}\right)\right]$$

$$= 28.92 \text{ mm of water column.}$$

3. A boiler is equipped with a 30 m hgih chimney. The temperature of the flue gases passing through the chimney is 250°C and the temperature of the outside air is 25°C. The amount of air supplied is 18 kg per kg of fuel. Calculate: a) The theoretical draught in mm of water, b) The velocity of the flue gases passing through the chimney of 60% of the theoretical draught is lost in friction at the grate and passage.

Given data:

$$H = 30\,m$$

$T_g = 250°C + 273 = 523\ K$

$T_a = 25°C + 273 = 298\ K$

$m = 18\ kg$

Solution:

a) The theoretical draught in mm of water is given by

$$h = 353\ H\left[\frac{1}{T_a} - \frac{1}{T_g}\cdot\left(\frac{m+1}{m}\right)\right]$$

$$= 353 \times 30\left[\frac{1}{298} - \frac{1}{523}\left(\frac{18+1}{18}\right)\right]$$

$= 14.163$ mm of H_2O.

b) The draught produced in terms of a colum of hot gas in metre is given by

$$h_g = H\left[\frac{T_g}{T_a} \times \frac{m}{m+1} - 1\right]$$

$$= 30\left[\frac{523}{298} \times \left(\frac{18}{18+1}\right) - 1\right]$$

$= 19.879$ m of hot gas column.

As 60% draught is lost in friction,

The available draught is, $h_a = 19.879 \cdot (1 - 0.60)$

$= 7.951$ m

Let V - Velocity of the flue gases in m/s

$$\therefore V = \sqrt{2g\ h_a} = \sqrt{2 \times 9.81 \times 7.951}$$

$= 12.49$ m/s.

4. A chimney has a height of 40 m. The temperature of the outside air is 20ºC. Calculate the draught in mm of water when the mean temperature of the chimney gases is such as to cause the mass of these flue gases discharged in a given time to be maximum 18 kg of air per kg of coal is required for complete combustion.

Given data:

$H = 40\ m$

$$T_a = 20°C + 273 = 293\ K$$

$$m = 18\ kg$$

Solution:

For maximum discharge $T_g = 2\ T_a \times \dfrac{m+1}{m}$

$$= 2 \times 293 \times \frac{(18+1)}{18}$$

$$\boxed{T_g = 618.55\ K}$$

The draught in mm of water column is given by

$$h = 353\ H\left[\frac{1}{T_a} - \frac{1}{T_g} \cdot \left(\frac{m+1}{m}\right)\right]$$

$$= 353 \times 40\left[\frac{1}{293} - \frac{1}{618.55}\left(\frac{18+1}{18}\right)\right]$$

$$= 24.09 \text{ mm of } H_2O$$

For maximum discharge, the total static draught produced in a column of hot gases is equal to the height of the chimney which is 40 m.

Figure 2.2 shows a belt conveyor. It consists of an endless belt moving over a pair of end drums (rollers). At some distance a supporting roller is provided at the centre. The belt is made up of rubber or canvas. Belt conveyor is suitable for the transfer of coal over long distances. It is used in medium and large power plants. The initial cost of the system is not high and power consumption is also low. The inclination at which coal can be successfully elevated by belt conveyor is about 20º. Average speed preferred than other types.

Advantages of belt conveyor

1. Its operation is smooth and clean.
2. It requires less power as compared to other types of systems.
3. Large quantities of coal can be discharged quickly and continuously.
4. Material can be transported on moderate inclines.

2. Screw conveyor

It consists of an endless helicoid screw fitted to a shaft (figure 2.3). The screw while rotating in a trough transfers the coal from feeding end to the discharge end.

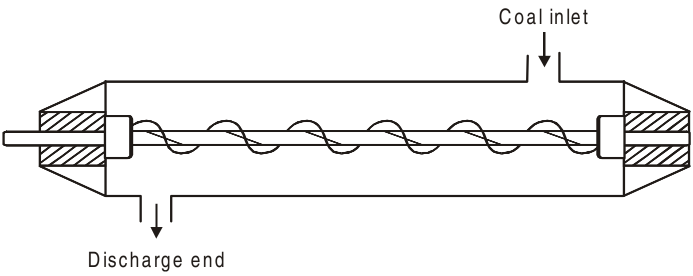


Figure 2.3: Screw conveyor.

This system is suitable, where coal is to be transferred over shorter distance and space limitations exist. The initial cost of the consumption is high and there is considerable wear of screw. Rotation of screw varies between 75-125 r.p.m.

3. Bucket elevator

It consists of buckets fixed to a chain (figure 2.4). The chain moves over two wheels. The coal is carried by the buckets from bottom and discharged at the top.

If only chimney is used to produce the draught, it is called natural draught.

Artificial draught

If the draught is produced by steam jet or fan it is known as artificial draught.

Steam jet draught

It employs steam to produce the draught.

Mechanical draught

It employs fan or blowers to produce the draught.

Induced draught

The flue is drawn (sucked) through the system by a fan or steam jet.

Forced draught

The air is forced into the system by a blower or steam jet.

2.12 NATURAL DRAUGHT

Natural draught system employs a tall chimney as shown in figure 2.28. The chimney is a vertical tubular masonry structure or re-inforced concrete. It is constructed for enclosing a column of exhaust gases to produce the draught. It discharges the gases high enough to prevent air pollution. The draught is produced by this tall chimney due to the temperature difference of hot gases in the chimney and cold external air outside the chimney.

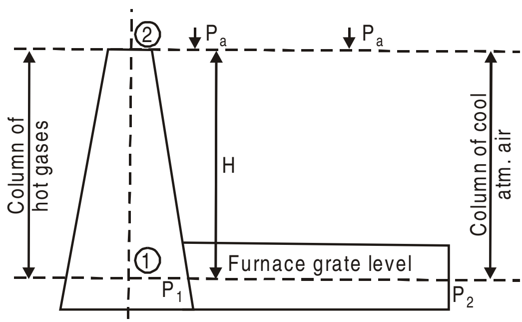


Figure 2.28: Natural draught.

Where H - Height of the chimney (m).

p_a - Atmospheric pressure (N/m^2).

p_1 - Pressure acting on the grate from chimney side (N/m^2).

p_2 - Pressure acting on the grate from atmospheric side (N/m^2).

- ***The essential elements of a steam condensing plant is given below:*** 1) A closed vessel in which the steam is condensed, 2) A pump to deliver condensed steam to the hot well from the condenser, 3) A dry air-pump to remove air and other non-condensable gases, 4) A feed pump to deliver water to the boiler from hot well.
- ***The jet condensers are sub-divided into the following categories:*** 1) Low level counter flow jet condenser, 2) High level (or) Barometric jet condenser, 3) Ejector condenser.
- ***Surface Condenser:*** 1) Down flow condenser, 2) Central flow condenser, 3) Evaporative condenser.
- ***The various advantages of a surface condenser are as follows:*** i) The condensate can be used as boiler feed water, ii) Cooling water of even poor quality can be used because the cooling water does not come in direct contact with steam, iii) High vacuum (about 73.5 cm of Hg) can be obtained in the surface condenser. This increases the thermal efficiency of the plant.
- ***The various disadvantages of the surface condenser are as follows:*** i) The capital cost is more, ii) The maintenance cost and running cost of this condenser is high, iii) It is bulky and requires more space.

REVIEW QUESTIONS

1. Name the steps involved in coal handling system?
2. Name any five conveyors used in steam power plant?
3. What do you mean by pulverised coal?
4. Draw and explain ball mill?
5. Name any two pulverised coal firing systems.
6. State the advantages of pulverised coal firing?
7. State the classification of combustion system.
8. State the classification of mechanical stokers.
9. Draw and explain chain grate stokers.
10. Draw and explain over feed supply of coal.
11. What do you mean by ash handling system?
12. Draw and explain of layout of ash handling system.