Air supplied per kg of fuel in each case = *18.5 kg*
Mass of coal burnt per hour = *1820 kg*
Efficiency of the fan = *82 per cent*
Drive formulae, for forced draft and induced draft fans.

Solution. Temperature of gases, $T_g = 240 + 273 = 513$ K
Temperature of air, $T_a = 20 + 273 = 293$ K
Mass of air used, $m_a = 18.5$ kg
Mass of coal used, $M = 1820$ kg
Draught produce by the fan, $h_w = 54$ mm of water
Efficiency of each fan, $\eta_f = 82$ per cent.

(*i*) **Power of motor required to drive induced draught fan, P_{ID} :**

Using the relation :

$$P_{ID} = \frac{0.998 \times 10^{-8} h V_0 m_a M T_g}{\eta_f} \text{ kW}$$

$$= \frac{0.998 \times 10^{-8} \times 54 \times 0.7734 \times 18.5 \times 1820 \times 513}{0.82}$$

(where $V_o = 0.7734$ m^3 at 0°C and 760 mm of Hg)

$$= \mathbf{8.78\ kW.\ (Ans.)}$$

(*ii*) **Power of a motor required to drive forced draught fan, P_{FD} :**

$$P_{FD} = \frac{0.998 \times 10^{-8} h V_0 m_a M T_a}{\eta_f} \text{ kW}$$

$$= \frac{0.998 \times 10^{-8} \times 54 \times 0.7734 \times 18.5 \times 1820 \times 293}{0.82}$$

$$= \mathbf{5.014\ kW.\ \ (Ans.)}$$

Power required to drive fan :

Let, p = Draught, ρ_a,
h_f = Draught produced by the fan, mm
V = Volumetric flow rate of combustion air at fan conditions, m^3/h, and
η_f = Fan efficiency.

Power required
$$= \frac{pV}{\eta_f} = \frac{\rho g h_f V}{\eta_f} = \frac{1000 \times g \times h_f V}{1000 \times \eta_f \times 3600} \text{ W}$$

$$= \frac{g h_f V}{\eta_f \times 1000 \times 3600} \text{ kW} = 2.725 \times 10^{-6} \frac{hV}{\eta_f} \text{ kW} \quad ...(3.18)$$

(*i*) ***Forced draught (F.D.) fan power, P_{FD} :***

Let, M = Quantity of fuel burnt per hour,
m_a = Mass of air supplied, kg/kg of fuel,
T_a = Temperature of atmospheric air, and
T_0 = Temperature at N.T.P.

Volume of air at T_0, $V_o = \frac{m_a M}{\rho}$

The steam generated is employed for the following *purposes* :

(*i*) For generating power in steam engines or steam turbines.

(*ii*) In the textile industries for sizing and bleaching etc. and many other industries like sugar mills ; chemical industries.

(*iii*) For heating the buildings in cold weather and for producing hot water for hot water supply.

The *Primary requirements* of steam generators or boilers are :

(*i*) The water must be contained safely.

(*ii*) The steam must be safely delivered in desired condition (as regards its pressure, temperature, quality and required rate).

3.14.2. Classification of Boilers

The boilers may be classified as follows :

1. Horizontal, vertical or inclined

If the axis of the boiler is horizontal, the boiler is called as horizontal, if the axis is vertical, it is called vertical boiler and if the axis is inclined it is known as inclined boiler. *The parts of a horizontal boiler can be inspected and repaired easily but it occupies more space. The vertical boiler occupies less floor area.*

2. Fire tube and water tube

In the fire tube boilers, the hot gases are inside the tubes and the water surrounds the tubes. Examples : *Cochran, Lancashire* and *Locomotive boilers.*

In the water tube boilers, the water is inside the tubes and hot gases surround them. Examples : *Babcock* and *Wilcox, Stirling, Yarrow boiler etc.*

3. Externally fired and internally fired

The boiler is known as externally fired if the fire is outside the shell. Examples : *Babcock and Wilcox boiler, Stirling boiler etc.*

In case of internally fired boilers, the furnace is located inside the boiler shell. Examples : *Cochran, Lancashire boiler etc.*

4. Forced circulation and natural circulation

In *forced circulation* type of boilers, the circulation of water is done *by a forced pump. Examples* : *Velox, Lamont, Benson boiler etc.*

In *natural circulation* type of boilers, circulation of water in the boiler takes place due to *natural convention* currents produced by the application of heat. Examples : *Lancashire, Babcock* and *Wilcox boiler* etc.

5. High pressure and low pressure boilers

The boilers which produce steam at *pressures of 80 bar and above* are called *high* pressure boilers. *Examples* : *Babcock* and *Wilcox, Velox, Lamont, Benson boilers.*

The boilers which produce steam at pressure *below 80 bar* are called low pressure boilers. *Examples* : *Cochran, Cornish, Lancashire and Locomotive boilers.*

6. Stationary and portable

Primarily, the boilers are classified as either stationary (*land*) or mobile (*marine* and *locomotive*).

- Stationary boilers are used for power plant-steam, for central station utility power plants, for plant process steam etc.
- Mobile boilers or portable boilers include locomotive type, and other small units for temporary use at sites (just as in small coalfield pits).

3.14.5. Essentials of a Good Steam Boiler

A good boiler should possess the following *features* :

1. The boiler should produce the maximum weight of steam of the required quality at minimum expenses.
2. Steam production rate should be as per requirements.
3. It should be absolutely reliable.
4. It should occupy minimum space.
5. It should be light in weight.
6. It should be capable of quick starting.
7. There should be an easy access to the various parts of the boiler for repairs and inspection.
8. The boiler components should be transportable without difficulty.
9. The installation of the boiler should be simple.
10. The tubes of the boiler should not accumulate soot or water deposits and should be sufficiently strong to allow for wear and corrosion.
11. The water and gas circuits should be such as to allow minimum fluid velocity (for low frictional losses).

3.14.6. Boiler Terms

Shell. The shell of a boiler consists of one or more steel plates bent into a cylindrical form and riveted or welded together. The shell ends are closed with the end plates.

Setting. The primary function of setting is to confine heat to the boiler and form a passage for gases. It is made of brickwork and may form the wall of the furnace and the combustion chamber. It also provides support in some types of boilers (*e.g.*, Lancashire boilers).

Grate. It is the platform in the furnace upon which fuel is burnt and it is made of cast iron bars. The bars are so arranged that air may pass on to the fuel for combustion. The area of the grate on which the fire rests in a coal or wood fired boiler is called grate surface.

Furnace. It is a chamber formed by the space above the grate and below the boiler shell, in which combustion takes place. It is also called a fire-box.

Water space and steam space. The volume of the shell that is occupied by the water is termed *water space* while the entire shell volume less the water and tubes (if any) space is called *steam space.*

Mountings. The items such as stop valve, safety valves, water level gauges, fusible plug, blow-off cock, pressure gauges, water level indicator etc. are termed as mountings and a *boiler cannot work safely without them.*

Accessories. The items such as superheaters, economisers, feed pumps etc. are termed as accessories and they form integral part of the boiler. They *increase the efficiency of the boiler.*

Water level. The level at which water stands in the boiler is called *water level*. The space above the water level is called *steam space.*

Foaming. Formation of steam bubbles on the surface of boiler water due to high surface tension of the water.

Scale. A deposit of medium to extreme hardness occurring on water heating surfaces of a boiler because of an undesirable condition in the boiler water.

Blowing off. The removal of the mud and other impurities of water from the lowest part of the boiler (where they usually settle) is termed as *'blowing off'*. This is accomplished with the help of a blow off cock or valve.

Lagging. Blocks of asbestos or magnesia insulation wrapped on the outside of a boiler shell or steam piping.

At the ends of each cross tube are provided hand holes to give access for cleaning these tubes. The combustion gases after heating the water and thus converting it into steam escape to the atmosphere through the chimney. Manhole, is provided to clean the interior of the boiler and exterior of the combustion chamber and chimney. The various mountings shown in Fig. 3.51 are (*i*) Pressure gauge, (*ii*) Water level gauge or indicator, (*iii*) safety valve, (*iv*) steam stop valve, (*v*) feed check valve, and (*vi*) water level gauge.

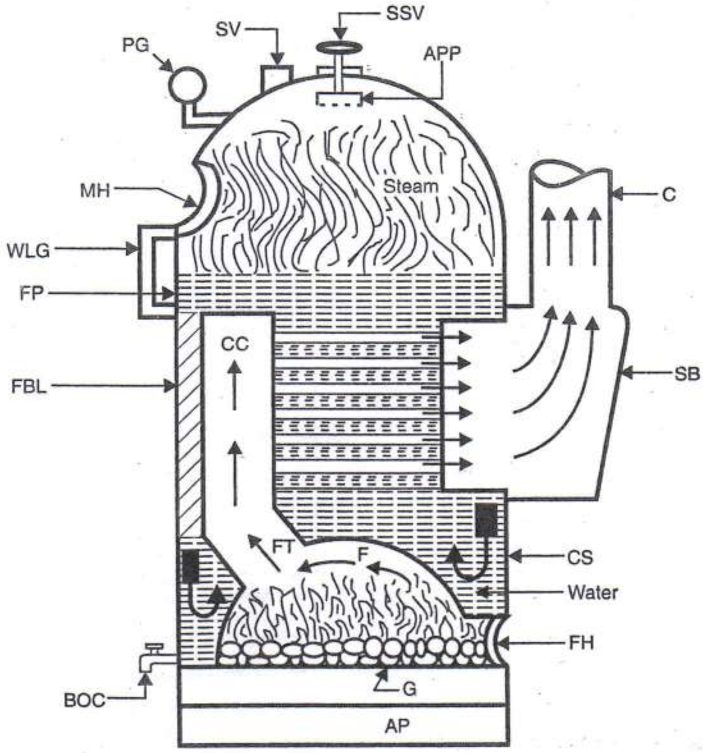
Flow of combustion gases and circulation of water in water jackets are indicated by arrows in Fig. 3.51.

The rate of production in such a boiler normally does not exceed 2500 kg/h and pressure is normally limited to 7.5 to 10 bar.

A simple vertical boiler is self-contained and can be transported easily.

3.14.7.2. Cochran boiler

It is *one of the best* types of vertical multi-tubular boiler, and has a number of horizontal fire tubes.



CS = Cylindrical shell	*FT* = Flue tube
CC = Combustion chamber	*SB* = Smoke box
FBL = Fir brick lining	*C* = Chimney
F = Furnace (dome shaped)	*FH* = Fire hole
G = Grate	*BOC* = Blow-off cock
AP = Ash pit	*SSV* = Steam stop valve
SV = Safety valve	*APP* = Antipriming pipe
MH = Man hole	*PG* = Pressure gauge
WLG = Water level gauge	

Fig. 3.52. Cochran boiler.

The specifications of Cornish Boiler are given below :

No. of flue tubes	......	One
Diameter of the shell	......	1.25 to 1.75 m
Length of the shell	......	4 to 7 m
Pressure of the steam	......	10.5 bar
Steam capacity	......	6500 kg/h.

Refer Fig. 3.53. It consists of a cylindrical shell with flat ends through which passes a smaller flue tube containing the furnace. The products of combustion pass from the fire grate forward over the brickwork bridge to the end of the furnace tube ; they then return by the two side flues to the front end of the boiler, and again pass to the back end of a flue along the bottom of the boiler to the chimney.

The various boiler mountings which are used on this boiler are : (*i*) Steam stop valve (*ii*) Pressure gauge, (*iii*) Water gauge, (*iv*) Fusible plug, (*v*) Blow off cock, (*vi*) High steam Low water safety valve, (*vii*) Feed check valve, and (*viii*) Man hole.

The advantage possessed by this type of boiler is that the sediment contained in the water falls to the bottom, where the plates are not brought into contact with the hottest portion of the furnace gases. The reason for carrying the product of combustion first through the side flues, and lastly through the bottom flue, is because the gases, having parted with much of their heat by the time they reach the bottom flue, are less liable to unduly heat the plates in the bottom of the boiler where the sediment may have collected.

3.14.7.4. Lancashire boiler

This boiler is *reliable,* has *simplicity of design, ease of operation* and *less operating and maintenance costs.* It is commonly used in *sugar-mills* and *textile industries* where alongwith the power steam and steam for the process work is also needed. In addition this boiler is used when larger reserve of water and steam are needed.

The *specifications* of Lancashire boiler are given below :

Diameter of the shell	...... 2 to 3 m
Length ~~Diameter~~ of the shell	...... 7 to 9 m
Maximum working pressure	...... 16 bar
Steam capacity	...... 9000 kg/h
Efficiency	...... 50 to 70%

Refer Fig. 3.54. The Lancashire boiler consists of a cylindrical shell inside which two large tubes are placed. The shell is constructed with several *rings* of cylindrical from and it is placed horizontally over a brickwork which forms several channels for the flow of hot gases. These two tubes are also constructed with several rings of cylindrical form. They pass from one end of the shell to the other and are covered with water. The furnace is placed at the front end of each tube and they are known as furnace tubes. The coal is introduced through the fire hole into the grate. There is low brickwork fire bridge at the back of the gate to prevent the entry of the burning coal and ashes into the interior of the furnace tubes.

The combustion products from the grate pass up to the back end of the furnace tubes and then in downward direction. Thereafter they move through the bottom channel or bottom flue up to the front end of the boiler where they are divided and pass up to the side flues. Now they move along the two side flues and come to the chimney flue from where they lead to the chimney. To

3.14.7.5. Locomotive boilers

It is mainly employed in locomotives though it may also be used as a stationary boiler. It is compact and its capacity for steam production is quite high for its size as it can raise large quantity of steam rapidly.

Dimensions and the specifications of the locomotives boilers (made at Chitranjan works in India) are given below :

Barrel diameter	...... 2.095 m
Length of the barrel	...... 5.206 m
Size of the tubes (superheater)	...... 14 cm
No. of superheater tubes	 38
Size of ordinary tubes	...... 5.72 cm
No. of ordinary tubes	 116
Steam capacity	...... 9000 kg/h
Working pressure	...... 14 bar
Grate Area	...... 4.27 m^2
Coal burnt/h	...... 1600 kg
Heating surface	...... 271 m^2
Efficiency	...... 70%

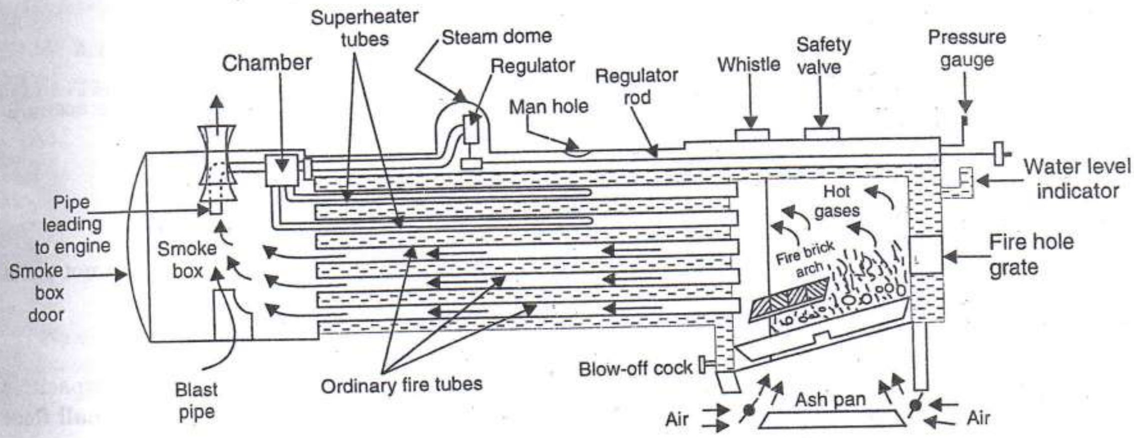
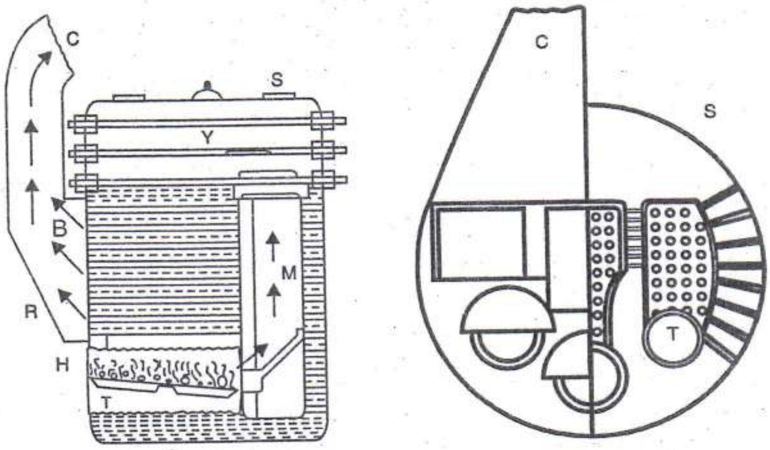


Fig. 3.55. Locomotive boiler.

Refer Fig. 3.55. The locomotive boiler consists of a cylindrical barrel with a rectangular fire box at one end and a smoke box at the other end. The coal is introduced through the fire hole into the grate which is placed at the bottom of the fire box. The hot gases which are generated due to burning of the coal are deflected by an arch of fire bricks, so that walls of the fire box may be heated properly. The fire box is entirely surrounded by water except for the fire hole and the ash pit which is situated below the fire box is fitted with dampers at its front and back ends. The dampers control the flow of air to the grate. The hot gases pass from the fire box to the smoke box through a series of fire tubes and then they are discharged into the atmosphere through the chimney. The fire tubes are placed inside the barrel. Some of these tube are of larger diameter and the others of smaller diameter. The superheater tubes are placed inside the fire tubes of larger diameter. The heat of the hot gases is transmitted into the water through the heating surface of the fire tubes. The steam generated is collected over the water surface.

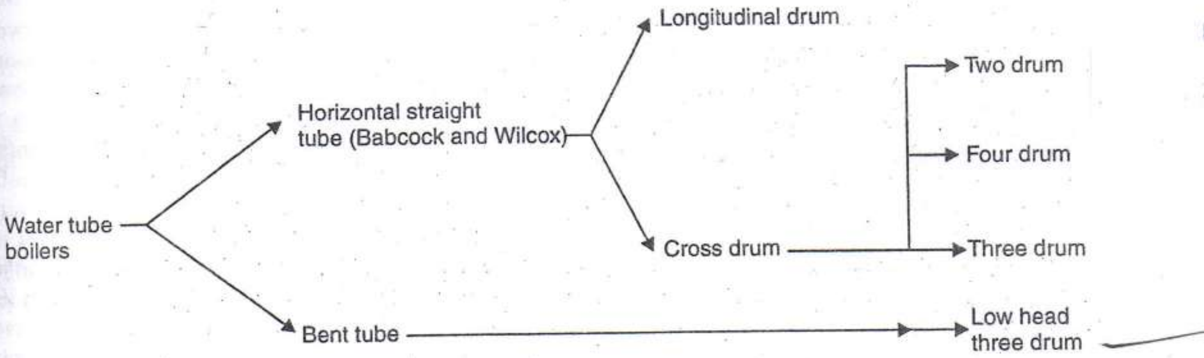


T = Furnace tube	R = Smoke box door
H = Fire hole	C = Chimney
M = Combustion chamber	S = Shell
B = Smoke box	Y = Bar stays.

Fig. 3.56. Scotch boiler.

3.14.8. Water Tube Boilers

The types of water tube boilers are given below :



3.14.8.1. Babcock and wilcox water-tube boiler

The water tube boilers are used exclusively, when pressure above 10 bar and capacity in excess of 7000 kg of steam per hour is required. Babcock and Wilcox water-tube boiler is an example of horizontal straight tube boiler and may be designed for stationary or marine purposes.

The particulars (dimensions, capacity etc.) relating to this boiler are given below :

Diameter of the drum	......	1.22 to 1.83 m
Length	......	6.096 to 9.144 m
Size of the water tubes	......	7.62 to 10.16 cm
Size of superheater tubes	......	3.84 to 5.71 cm
Working pressure	......	40 bar (max.)
Steaming capacity	......	40000 kg/h (max.)
Efficiency	......	60 to 80%

drum. The steam then enters through the antipriming pipe and flows in the superheater tubes where it is further heated and is finally taken out through the main stop valve and supplied to the engine when needed.

At the lowest point of the boiler is provided a mud collector to remove the mud particles through a blow-down-cock.

The entire boiler except the furnace are hung by means of metallic slings or straps or wrought iron girders supported on pillars. This arrangement enables the drum and the tubes to expand or contract freely. The brickwork around the boiler encloses the furnace and the hot gases.

The various mountings used on the boiler are shown in Fig. 3.57.

A Babcock Wilcox water-tube boiler with cross drum differs from longitudinal drum boiler in a way that how drum is placed with reference to the axis of the water tubes of the boiler. The longitudinal drum restricts number of tubes that can be connected to one drum circumferentially and limits the capacity of the boiler. In the cross drum there is no limitation of the number of connecting tubes.

The pressure of steam in case of cross drum boiler may be as high as 100 bar and steaming capacity upto 27,000 kg/h.

3.14.8.2. Striling boiler

Stirling water-tube boiler is an example of *bent tube* boiler. The main elements of a bent type water tube boiler are essentially drum or drums and headers connected by bent tubes. For large central power stations these boilers are very popular. They have steaming capacities as high as 50,000 kg/h and pressure as high as 60 bar.

Fig. 3.58 shows a small-sized stirling water-tube boiler. It consists of two upper drums known as steam drums and a lower drum known as mud or water drum. The steam drums are connected to mud drum by bank of bent tubes. The steam and water space of the steam drums are interconnected with each other, so that balance of water and steam may be obtained. For carrying out cleaning operation manhole at one end of each drum is provided. The feed water from the economiser (not shown) is delivered to the steam drum-1 which is fitted with a baffle. The baffle deflects the water to move downwards into the drum. The water flows from the drum 1 to the mud drum through the rearmost water tubes at the backside. So the mud particles and other impurities will move to the mud drum, where these particles may be deposited. As this drum is not subjected to high temperature, so the impurities may not cause harm to the drum. The blow off cock blows off the impurities. The baffle provided at the mud drum deflects the pure water to move upwards to the drum 1 through the remaining half of the water tubes at the back. The water also flows from it to the drum 2 through the water tubes which are just over the furnace. So they attain a higher temperature than the remaining portion of the boiler and a major portion of evaporation takes place in these tubes. The steam is taken from the drum 1 through a steam pipe and then it passes through the superheater tubes where the steam is superheated. Finally, the steam moves to the stop valve from where it can be supplied for further use.

The combustion products ensuing from the grate move in the upward and downward directions due to the brickwall baffles and are finally discharged through the chimney into the atmosphere. Fire brick arch gets incandescent hot and helps in combustion and preventing the chilling of the furnace when fire door is opened and cold air rushes in.

The steam drums and mud drum are supported on steel beams independent of the brickwork.

It is lighter and more flexible than the straight tube boilers. But it is comparatively more difficult to clean and inspect the bent tubes.

3.14.9.2. Unique features of the high pressure boilers

Following are the *unique features* of high pressure boilers :

1. Method of water circulation
2. Type of tubing
3. Improved method of heating.

1. *Method of water circulation.* The circulation of water through the boiler may be *natural circulation* due to density difference or *forced circulation.* In all modern high pressure boiler plants, the water circulation is maintained with the help of pump which forces the water through the boiler plant. The use of natural circulation is limited to sub-critical boilers due to its limitations.

2. *Type of tubing.* In most of the high pressure boilers, the water circulated through the tubes and their external surfaces are exposed to the flue gases. In water-tube boilers, if the flow takes place through one continuous tube, the large pressure drop takes place due to friction. This is *considerably reduced by arranging the flow to pass through parallel system of tubing.* In most of the cases, several sets of the tubings are used. This type of arrangement helps to *reduce the pressure loss,* and better control over the quality of the steam.

3. *Improved method of heating.* The following improved methods of heating may be used to increase the heat transfer :

(*i*) The saving of heat by *evaporation of water* above critical pressure of the steam.

(*ii*) The heating of water can be made by *mixing the superheated steam.* The mixing phenomenon *gives highest heat transfer co-efficient.*

(*iii*) The overall heat transfer coefficient can be increased by *increasing the water velocity inside the tube and increasing the gas velocity above sonic velocity.*

3.14.9.3. Advantages of high pressure boilers

The following are the *advantages* of high pressure boilers :

1. In high pressure boilers pumps are used to maintain forced circulation of water through the tubes of the boiler. This *ensures positive circulation of water and increases evaporative capacity of the boiler and less number of steam drums will be required.*
2. The *heat of combustion is utilised more efficiently* by the use of small diameter tubes in large number and in multiple circuits.
3. *Pressurised combustion* is used which *increases rate of firing of fuel* thus increasing the rate of heat release.
4. Due to compactness less floor space is required.
5. The tendency of scale formation is eliminated due to high velocity of water through the tubes.
6. All the parts are uniformly heated, therefore, the danger of overheating is reduced and thermal stress problem is simplified.
7. The differential expansion is reduced due to uniform temperature and this reduces the possibility of gas and air leakages.
8. The components can be arranged horizontally as high head required for natural circulation is eliminated using forced circulation. There is a greater flexibility in the components arrangement.
9. The steam can be raised quickly to meet the variable load requirements without the use of complicated control devices.
10. The *efficiency of plant is increased upto 40 to 42 percent* by using high pressure and high temperature steam.

drum. The steam circulating pump draws saturated steam from the evaporating drum and passes it through radiant and convective superheaters where steam is heated to required temperature. *From the superheater about one-third of the superheated steam passes to the prime mover (turbine) the remaining two-thirds passing through the water in the evaporating drum in order to evaporate feed water.*

This boiler can carry higher salt concentrations than any other type and is more compact than indirectly heated boilers having natural circulation. These qualities fit it for land or sea transport power generation.

Loeffler boilers with generating capacity of 100 tonnes/h and operating at 140 bar are already commissioned.

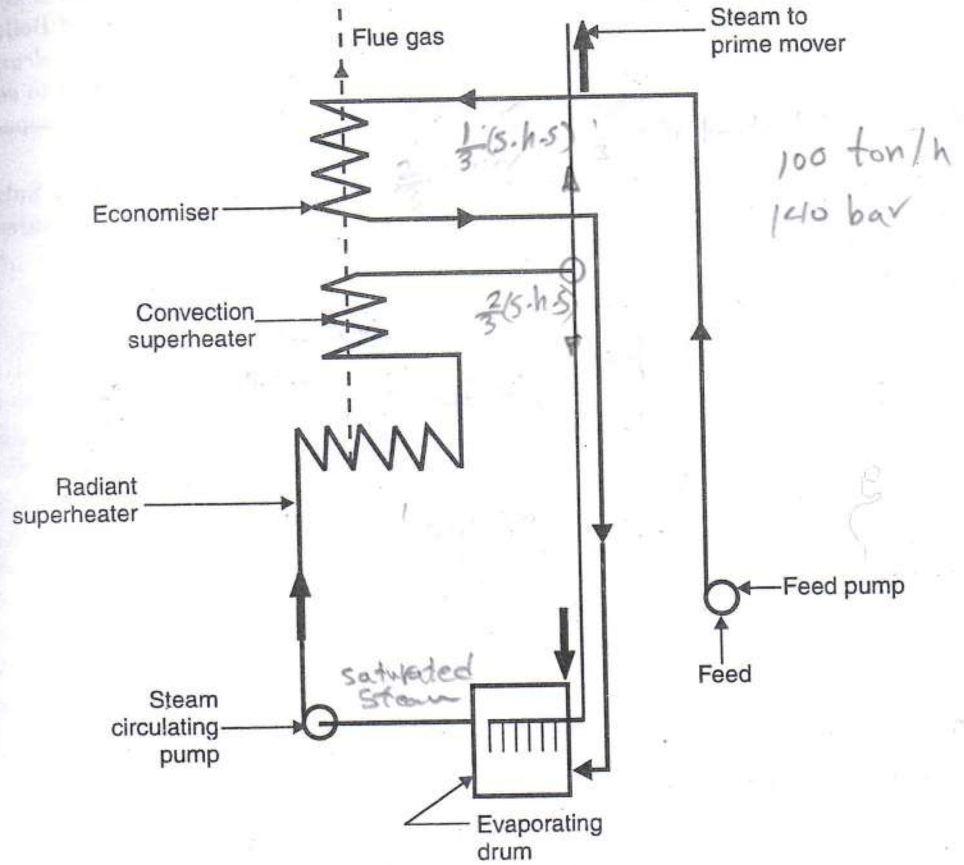


Fig. 3.60. Loeffler boiler.

Once Through Boilers :

Owing to the sharply increasing costs of construction and fuel it becomes essential for the designers to economise on the installation cost and to increase fuel efficiency in the new stations by using modern sophisticated technology. Higher size units with higher steam parameters seem a natural choice for economical installation and operation of thermal power plants. The 800 MW units would be designed on supercritical steam pressure with a drumless boiler on *once through principle*.

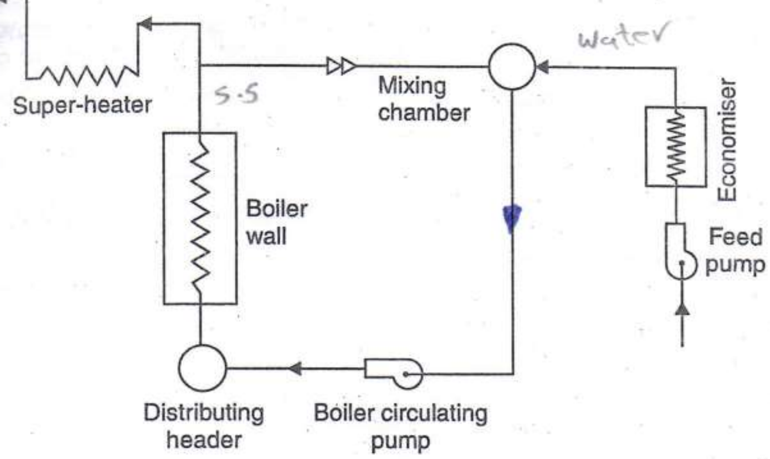


Fig. 3.62. Combined circulatory pump.

Advantages of Once through boilers

The following are the *advantages of once through boilers for large thermal units :*

1. No higher limit for the higher steam pressure.
2. Full steam temperature can be maintained over a wider range of load.
3. Starting and cooling down of the boiler is fast.
4. No circulation disturbance due to rapid pressure fluctuations.
5. A once through boiler is smaller in size and weighs less in comparison to a natural circulation boiler.
6. Easy control of steam temperature during start-up and shut-down (which is very advantageous for start-up of boiler and turbine)
7. Greater freedom in arrangement and location of heating surfaces.
8. Easy to adopt variable pressure operation for better performance at part load operation.
9. Elimination of heavy walled drum decreases the metallurgical sensitivity of boiler against changes in pressure.

Flash Steam Generator :

- A flash steam generator is a special form of boiler having basically *a helix tube fired by down jet combustion of gas or oil.* Water is pumped into the helix and at exit 90 percent of it is in the form of steam, the remaining water fraction being collected in the separator. The *tube helix principle, which eliminates the need for a water space, gives an extremely high heat output in a small area.*
- The *combustion efficiency* is about 80 percent on oil, and 73 percent on gas.
- The *advantages* are *very rapid response* (full steam production within about five minutes) and output ranges upto an evaporation rate of about 1 kg/s with operating steam pressure ranging from 3 to 70 bar.
- This type of boiler is more suitable when the plant is designed to take peak loads.

3.14.9.6. Benson boiler

In the LaMont boiler, the main difficult experienced *is the formation and attachment of bubbles on the inner surfaces of the heating tubes. The attached bubbles to the tube surface*

3. It can be started very quickly because of welded joints.
4. Natural convection boilers require expansion joints but these are not required for Benson boiler as the pipes are welded.
5. The furnace walls of the boiler can be more efficiently protected by using smaller diameter and closed pitched tubes.
6. The transfer of parts of the boiler is easy as no drums are required and majority of the parts are carried to the site without pre-assembly.
7. It can be operated most economically by varying the temperature and pressure at part loads and overloads. The desired temperature can also be maintained constant at any pressure.
8. The blow-down losses of the boiler are hardly 4% of natural circulation boiler of the same capacity.
9. Explosion hazards are not severe as it consists of only tubes of small diameter and has very little storage capacity.
10. The superheater in a Benson boiler is an integral part of forced circulation system, therefore, no special starting arrangement for superheater is required.

3.14.9.7. Velox boiler

It is a well known fact that when the gas velocity exceeds the sound-velocity, the heat is transferred from the gas at a much higher rate than rates achieved with sub-sonic flow. The advantage of this theory is taken to effect the large heat transfer from a smaller surface area in this boiler.

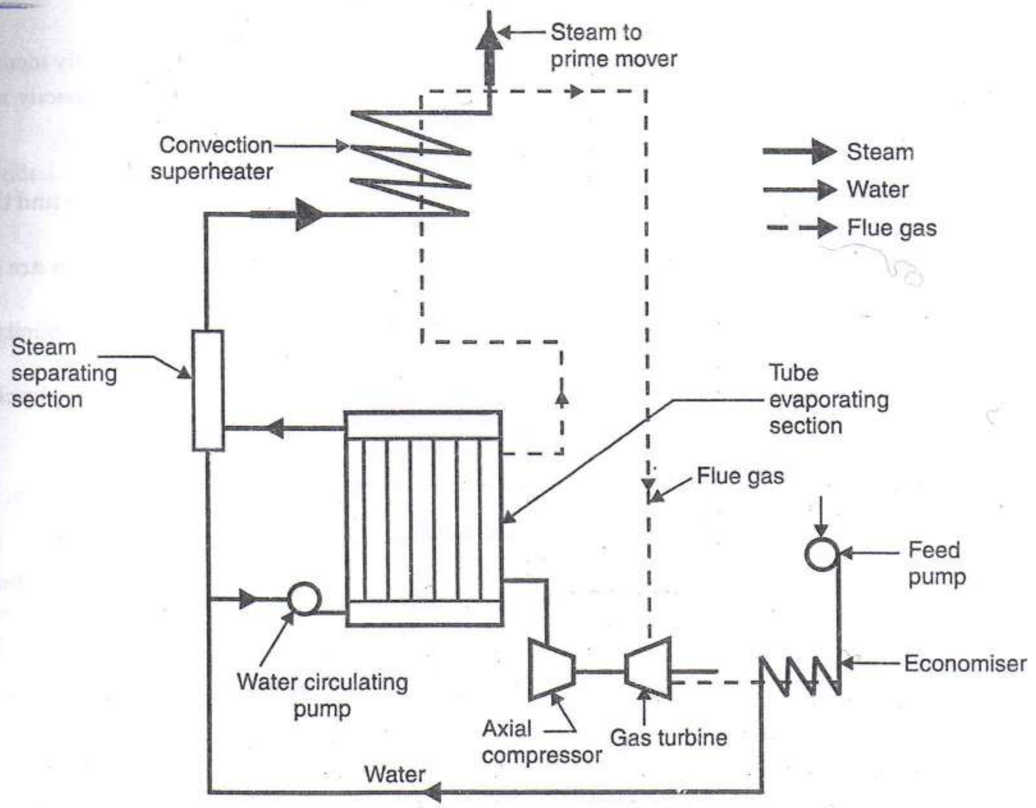


Fig. 3.64. Velox boiler.

The hot ash released from the boiler furnaces is made to fall over the belt conveyor after cooling it through water seal. This cooled ash is transported to an ash bunker through the belt conveyor. From ash bunker the ash is removed to the dumping site through trucks.

2. Hydraulic system

In this system ash is carried with the flow of water with high velocity through a channel and finally dumped in the sump. This system is subdivided as follows :

(*a*) Low pressure system

(*b*) High pressure system.

(*a*) ***Low pressure system.*** Refer Fig. 3.40. In this system a trough or drain is provided below the boilers and the water is made to flow through the trough. The ash directly falls into the troughs and is carried by water to sumps. In the sump the ash and water are made to pass through a screen so that water is separated from ash ; this water is pumped back to the trough for reuse and ash is removed to the dumping yard.

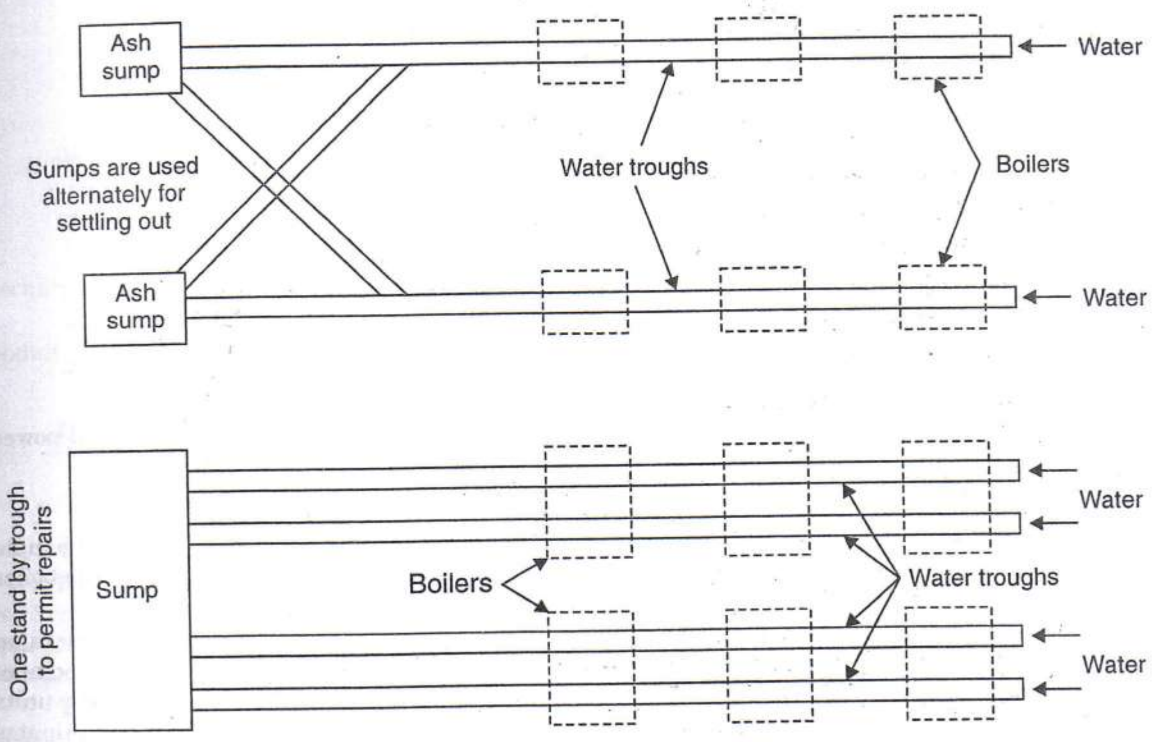


Fig. 3.40. Low pressure system.

The ash carrying capacity of this system is 50 tonnes/hour and distance covered is 500 metres.

(*b*) ***High pressure system.*** Refer Fig. 3.41. The hoppers below the boilers are fitted with water nozzles at the top and on the sides. The top nozzles quench the ash while the side ones provide the driving force for the ash. The cooled ash is carried to the sump through the trough. The water is again separated from ash and recirculated.

The ash carrying capacity of this system is as large as 120 tonnes per hour and the distance covered is as large as 1000 metres.

The power plant load can be reduced by dropping the supply voltage. Thus a 5 percent reduction in supply voltage results in similar reduction in the load. An electric supply undertaking has to maintain the voltage within 10 percent of the declared pressure as per Indian Electricity Act ; So *during peak hours the voltage can be reduced within the allowable limits in order to meet the demand without use of additional units.* By using this technique saving of capital cost is materialised.

When a new unit is to be added to the existing power station, its size is decided on the following considerations :

1. Effect of additional unit on the thermal efficiency of the plant.
2. Expected rate of increase of maximum demand over the next few years.
3. The room available for the additional unit.
4. The suitability of the generator to the existing system regarding temperature, pressure etc.

Rating of Units :

Normally the output of units is classified under the following heads :

(*i*) Economical rating

(*ii*) Maximum continuous rating.

A generator need not operate most economically at full load. For the most economical operation, the present trend is towards economical running at 75-85 percent of full load.

Maximum continuous rating of a generating unit is the maximum load at which it can be run continuously for several hours. It is normally 10-15 percent less than the maximum capacity of the unit.

3.7. CHOICE OF STEAM CONDITIONS

The choice of steam conditions depends upon the following factors :

1. Price of coal.
2. Capital cost of the plant.
3. Time available for erection.
4. Thermal efficiency obtainable.
5. The station 'load factor'.

The present trend is towards adoption of high pressures and high temperatures. The effect of increased pressure and temperature on the efficiency and cost of plant is illustrated with the help of Figs. 3.4 and 3.5. It is evident from the curves that :

(*i*) *With the increase in pressure the efficiency obeys the 'law of diminishing returns'.*

(*ii*) With the increase in temperature the efficiency obeys the '*straight line law*' indicating the desirability of adopting the highest possibe temperature. The strength of material available limits the adoption of high temperatures. Beyond 500°C there is a very rapid change in the physical properties of the material and the problem becomes complicated. *With the increase in pressures the degree of superheat should be decreased in order to keep the total temperature within limits.*

For entirely new stations, present practice favours the use of steam pressures around 60 bar, but there is a profitable field for higher pressures of the order of 100 bar, when the problem is that of *increasing thermal efficiency of existing medium pressure units.*

It may be noted that *consumption of steam per kilo-watt hour decreases with the increased pressure.*

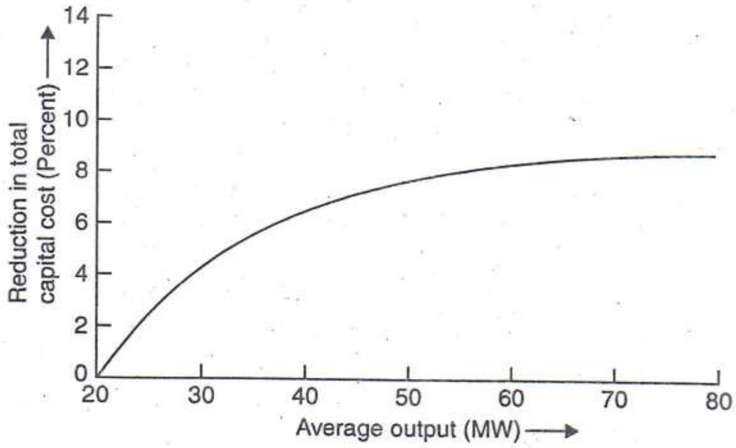


Fig. 3.6

Fig. 3.7 indicates that *steam consumption decreases with increase in the capacity of the unit.*

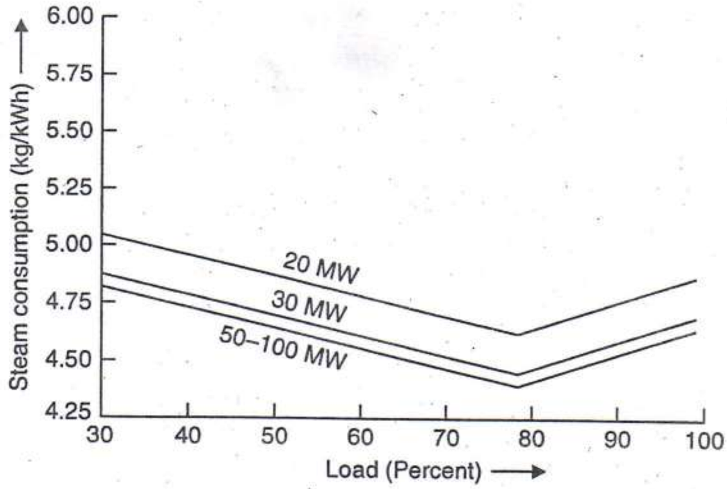


Fig. 3.7

3.8. FUEL HANDLING

3.8.1. Introduction

Three types of fuels can be burnt in any type of steam generating plant : 1. Solid fuel such as *coal* ; 2. Liquid fuel as oil and 3. Gaseous fuel as gas. Supply of these fuels to the power plants from various sources is one of the important considerations for a power plant engineer. The handling of these fuels is an important aspect. The following factors should be considered in selecting the fuel handling system :

1. Plant fuel rate.
2. Plant location in respect of fuel shipping.
3. Storage area available.

3.8.4. Coal Handling

Refer Fig. 3.8.

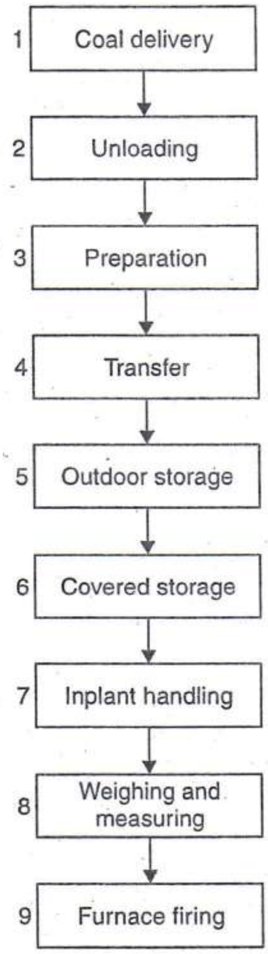


Fig. 3.8. Various stages in coal handling.

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

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

Fig. 3.9 shows the outline of coal handling equipment.

1. Coal delivery. From the supply points the coal may be delivered to power station though rail, road, river or sea.

— Plants situated near the river or sea may make use of navigation facilities.

(iv) Unloading bridges

(v) Self unloading boats.

3. **Preparation.** If the coal when delivered is in the form of lumps (not of proper size), the coal preparation may be carried out by :

(i) Breakers
(ii) Crushers
(iii) Sizers
(iv) Dryers
(v) Magnetic separators.

4. **Transfer.** 'Transfer' means the handling of coal between the unloading point and the final storage point from where it is discharged to the firing equipment. The following equipment may be used for transfer of coal :

1. Belt conveyors
2. Screw conveyors
3. Vee bucket elevator and conveyor
4. Pivoted bucket conveyor
5. Grab bucket conveyor
6. Flight conveyers (or scrapers)
7. Skip hoists
8. Mass flow conveyor
9. Chutes.

(i) **Belt conveyor.** Refer Fig. 3.11. A belt conveyor is very suitable means of transporting large quantities of coal over large distances. It consists of an endless belt (made of rubber, convas or

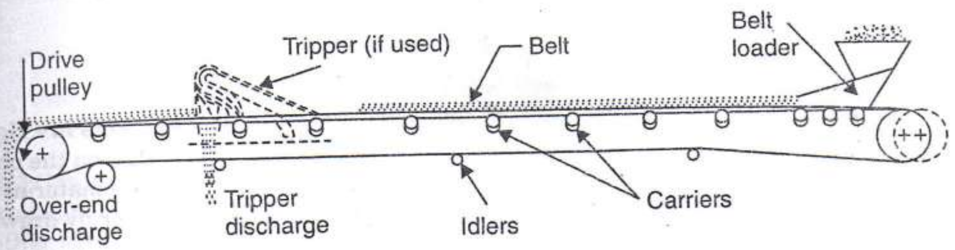


Fig. 3.11. Belt conveyor.

balata) running over a pair of end drums or pulleys and supported by a series of rollers (known as idlers) provided at regular intervals. The return idlers which support the empty belt are plain rollers and are spaced wide apart. The initial cost of the system is not high. The inclination at which coal can be successfully elevated by belt conveyor is about 20°. Average speed of the belt conveyor is 60 to 100 metres per minute. The load carrying capacity of the belt may vary from 50 to 100 tonnes/hour and it can easily be transferred through 400 metres. It is used in *medium and large power plants.*

Advantages :

1. Most economical method of coal transport in medium and large capacity plants.
2. Its operation is smooth and clean.
3. Repair and maintenance costs minimum.
4. Large quantities of coal can be discharged quickly and continuously.
5. Power consumption minimum.
6. The rate of coal transfer can be easily varied by just varying the belt speed.
7. Coal being transferred is protected.

Disadvantages :

1. Not suitable for greater heights and short distances.

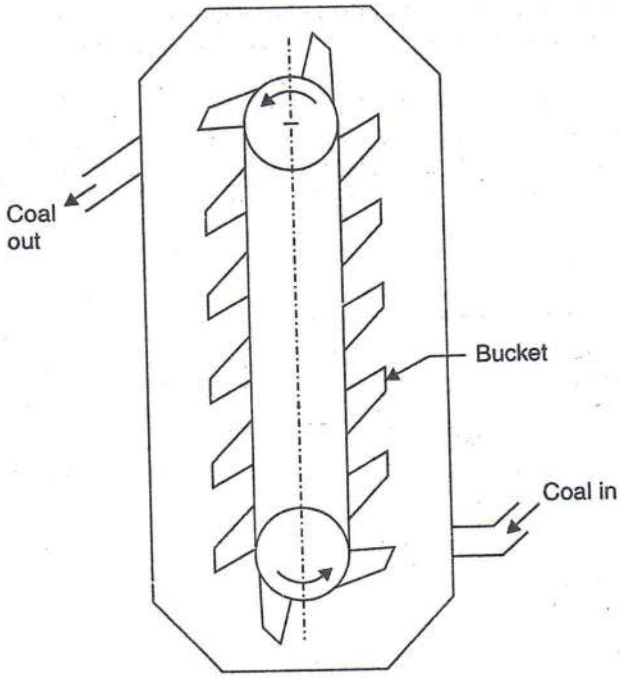


Fig. 3.13. Bucket elevator.

(*v*) **Grab bucket conveyor.** Refer Fig. 3.14. It is a form of hoist which lifts and transfers the load on a single rail or track from one point to another. This is a costly machine and is justified only when other arrangements are not possible. Capacity of a grab bucket may be about 50 tonnes per hour.

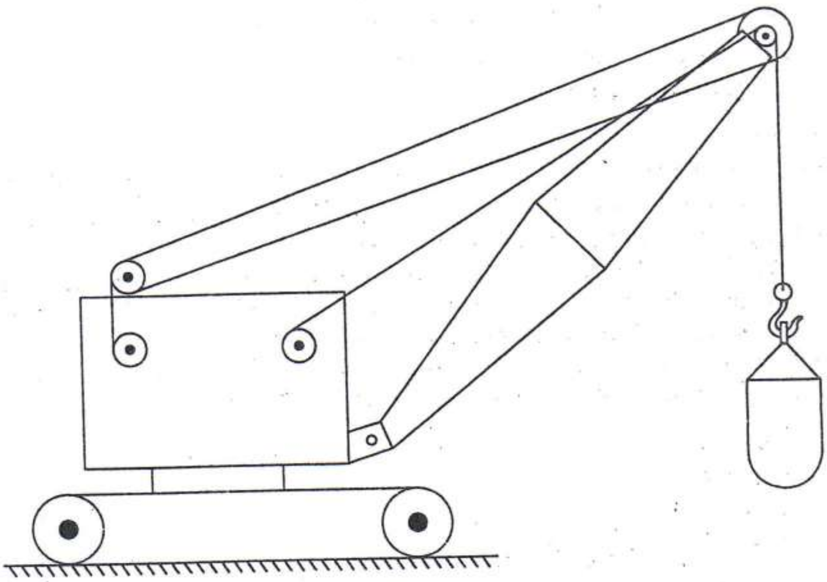


Fig. 3.14. Grab bucket conveyor.

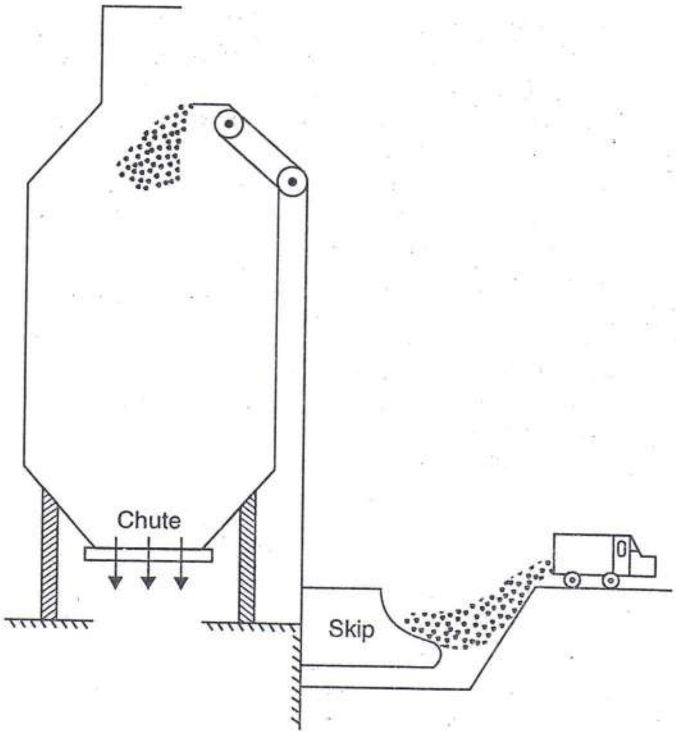


Fig. 3.15. (*a*) Skip hoist.

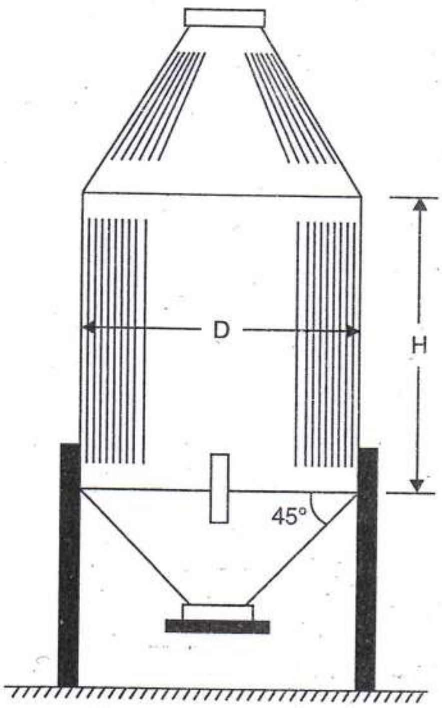


Fig. 3.16. Cylindrical bunker.

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

3.9. COMBUSTION EQUIPMENT FOR STEAM BOILERS

3.9.1. General Aspects

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

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

The basic requirements of combustion equipment :

1. Thorough mixing of fuel and air.

2. Optimum fuel-air ratios leading to most complete combustion possible maintained over full load range.

3. Ready and accurate response of rate of fuel feed to load demand (usually as reflected in boiler steam pressure).

4. Continuous and reliable ignition of fuel.

5. Practical distillation of volatile components of coal.

6. Adequate control over point of formation and accumulation of ash, when coal is the fuel.

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

Transportation costs add less to the delivery price of oil than gas ; also fuel oil may be stored in tanks at a reasonable cost, whereas, gas cannot. Hence although fuel oil is usually more costly

Advantages of stoker firing :

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

Disadvantages :

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

Classification of stoker firing :

Automatic stokers are *classified* as follows :

1. Overfeed stokers
2. Underfeed stokers.

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

1. Overfeed stokers

Principle of operation. Refer Fig. 3.18. The principle of an overfeed stoker is discusse below :

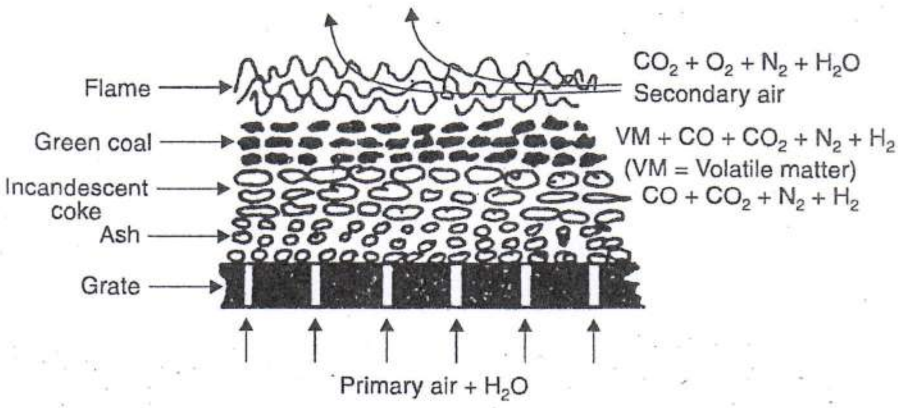


Fig. 3.18. Principle of overfeed stoker.

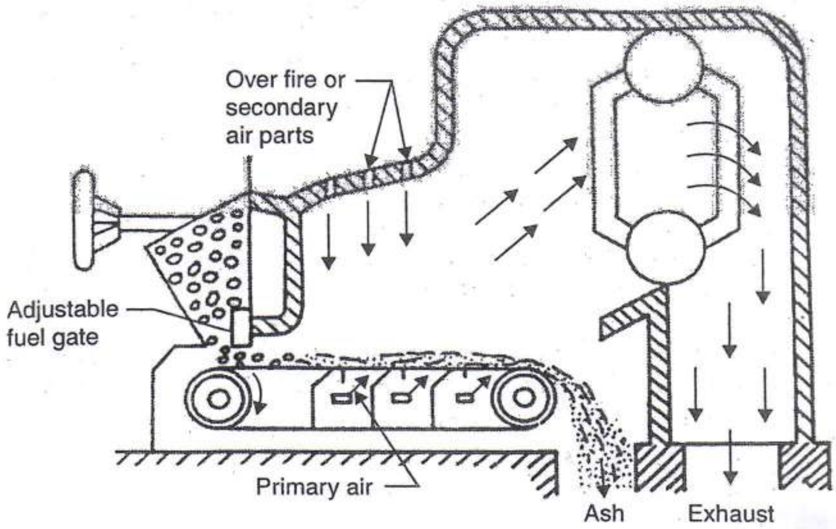


Fig. 3.19. Chain grate stoker.

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

Advantages of chain grate stoker :

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

Disadvantages :

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

2. Spreader stoker. Refer Fig. 3.20.

— In this type of stoker the coal is not fed into furnace by means of grate. The function of the grate is only to support a bed of ash and move it out of the furnace.

— From the coal hopper, coal is fed into the path of a rotor by means of a conveyer, and is thrown into the furnace by the rotor and is *burnt in suspension*. The *air for combustion* is supplied through the holes in the grate.

— The *secondary air* (or overfire *air*) to *create turbulence and supply oxygen for thorough combustion of coal* is supplied through *nozzles* located directly above the ignition arch.

— Unburnt coal and ash are deposited on the grate which can be moved periodically to remove ash out of the furnace.

— Spreader stokers *can burn any type of coal.*

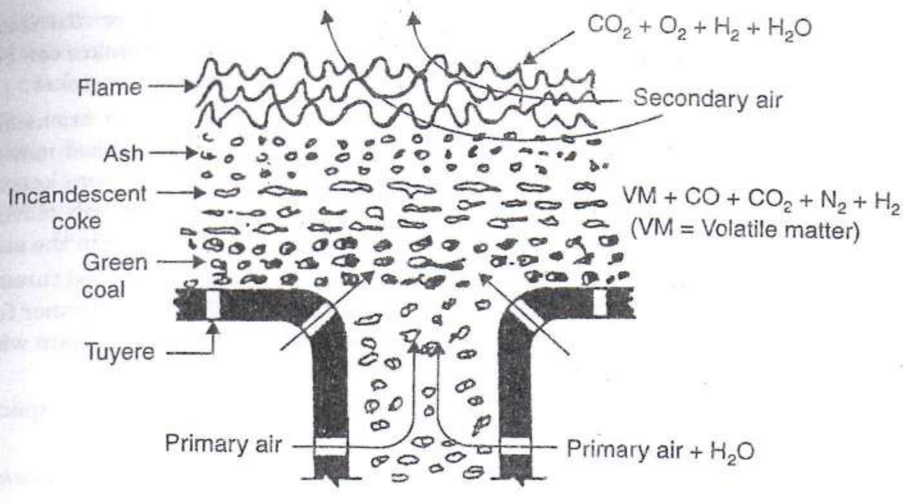


Fig. 3.21. (*a*) Principle of underfeed feeders.

Multi-retort underfeed stokers :
Refer Fig. 3.21 (*b*).

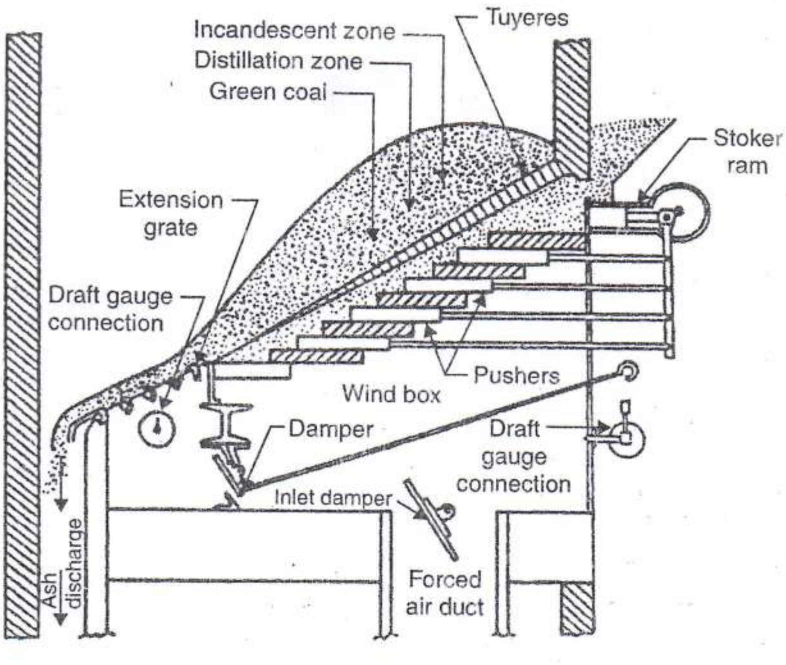


Fig. 3.21. (*b*) Multi-retort underfeed stokers.

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

it before entering into the combustion chamber is known as 'Primary air' and the amount of air which is supplied separately for completing the combustion is known as *'Secondary air'*.

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

Fig. 3.22 shows elements of pulverised coal system.

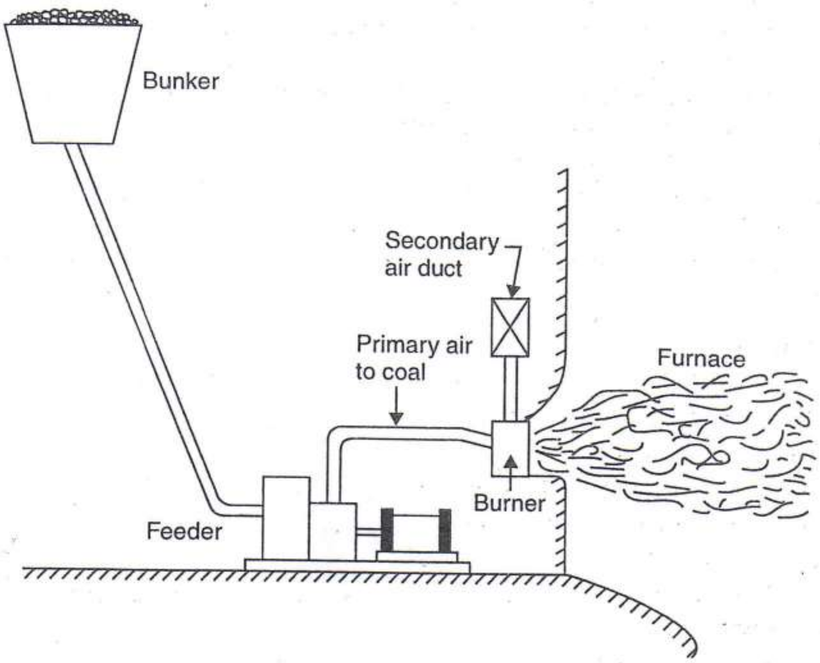


Fig. 3.22. Elements of pulverised coal system.

Advantages :

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

Advantages :

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

Disadvantages :

1. Firing aisle is obstructed with pulverising equipment, unless the latter is relegated to a basement.
2. The mills operate at variable load, a condition not especially conducive to best results.
3. With load factors in common practice, total mill capacity must be higher than for the central system.
4. Flexibility is less than central system.

Central system :

This system is illustrated in Fig. 3.24.

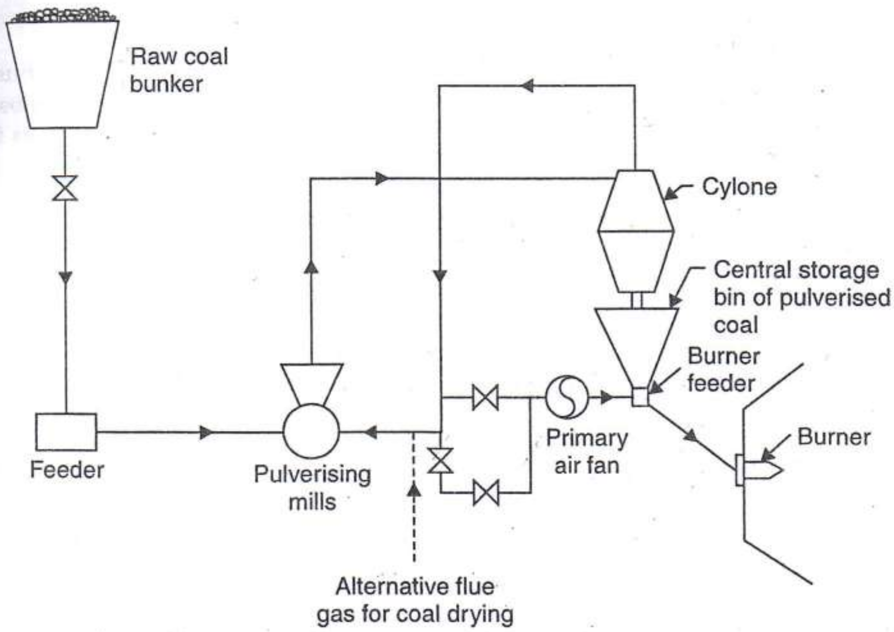


Fig. 3.24. Central system.

A central pulverising system employs a limited number of large capacity pulverisers at a central point to prepare coal for all the burners. Driers, if required, are conveniently installed at this point. From the pulveriser the coal is transported to a central storage bin where it is deposited and its transporting air vented from the bin through a *"cyclone"*. This bin may contain from 12 to 24

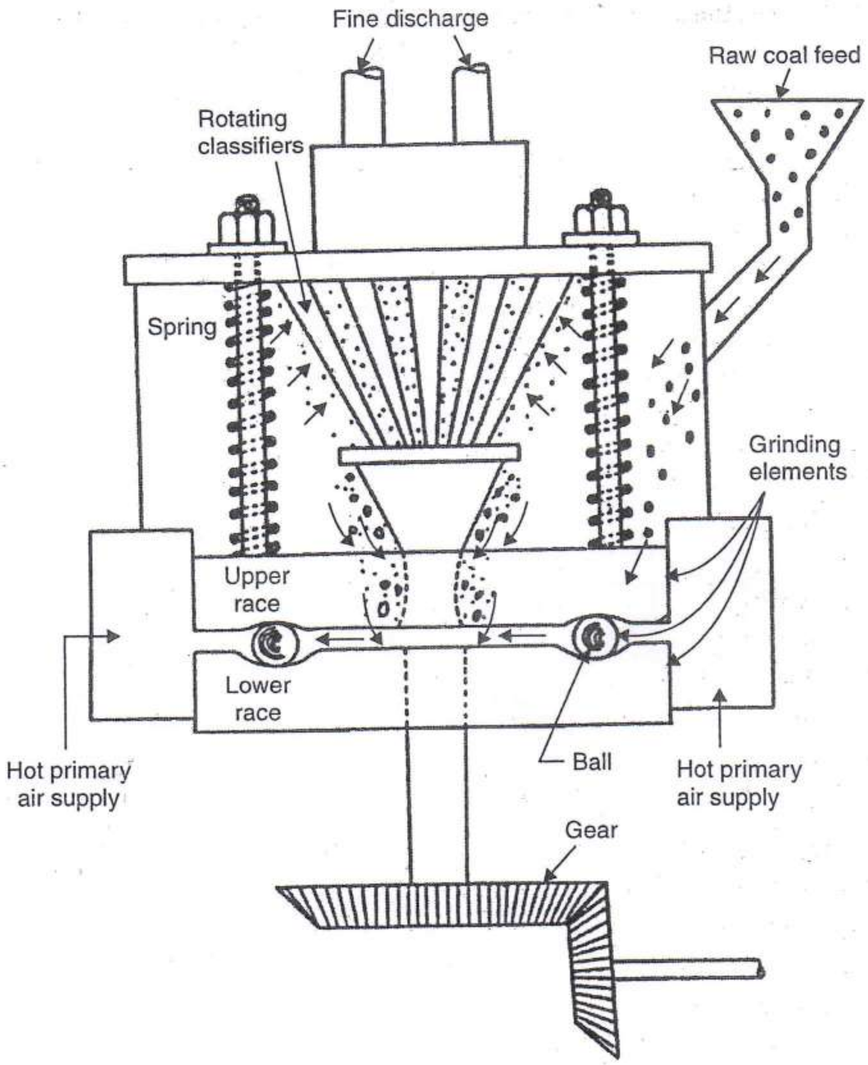


Fig. 3.25. Ball and race mill.

Ball mill. The ball mill operates something like a foundry tumbling barrel. The large rotating drum (100—200 r.p.m.) contains a quantity of iron balls mixed with the coal. As the drum turns balls are carried upward to be dropped on the coal while others, remaining in the agitated mixture, grind the coal at random between them. The coal is fed into one end and reduced in size by this action until it can be swept out of the mill by a current of air. Fig. 3.26 shows the principle of ball mill.

Hammer mills. These mills have swinging hammers or bars, into the path of which is fed the coal to be pulverised. Grinding is done by a combination of impact on the large particles and attrition on the smaller ones. Hot air is given to dry the coal. These mills are excellent dryers. It is *compact, low in cost* and *simple*. Its *maintenance is costly* and the *power consumption is high when fine powder is required. Its capacity is limited.*

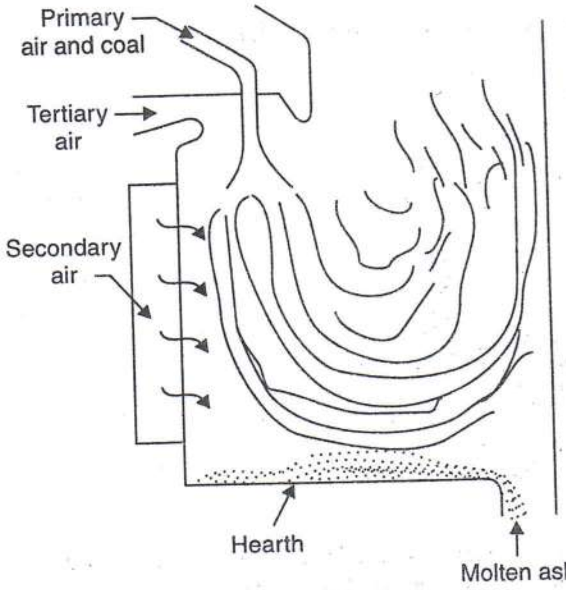


Fig. 3.28. Long flame burner.

2. Turbulent burners. Refer Fig. 3.29. It is also called a *short flame burner*. These burners can fire horizontally or at some inclinations by adjustment. The fuel-air mixture and secondary hot air are arranged to pass through the burner in such a way that there is good mixing and the mixture is projected in highly turbulent form in the furnace. Due to high turbulence created before entering the furnace, the mixture burns intensely and combustion is completed in short distance.

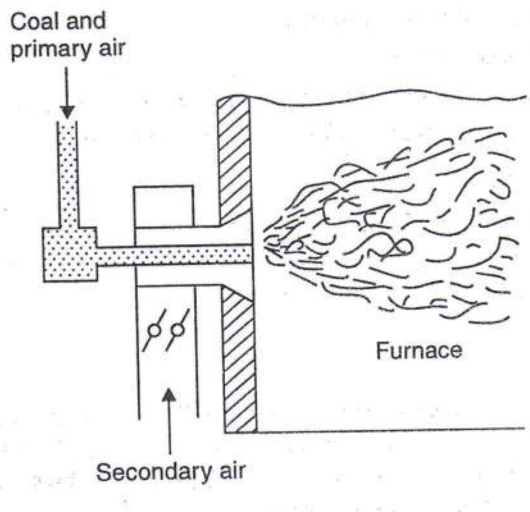


Fig. 3.29. Turbulent burner.

This burner gives *high rate of combustion compared with other types*. This is generally *preferred for high volatile coals*. All modern plants use this type of burner.

3. Tangential burners. These burners are set as shown in Fig. 3.30. In this case four burners are located in the four corners of the furnace and are fired in such a way that the four flames are

It consists of a horizontal cylindrical drum having a diameter varying from 2 to 4 metres depending upon the capacity of the boiler. Depending upon the capacity of the burner the number of cyclone burners used may be one or more. If the number of cyclone burners used is more than one, the diameter of each burner is less. These burners are attached to the side of the furnace wall and have vents for primary air, *crushed coal* (6 mm diameter maximum size) and secondary air. It is *water-cooled*. The horizontal axis of the burner is slightly deflected towards the boiler.

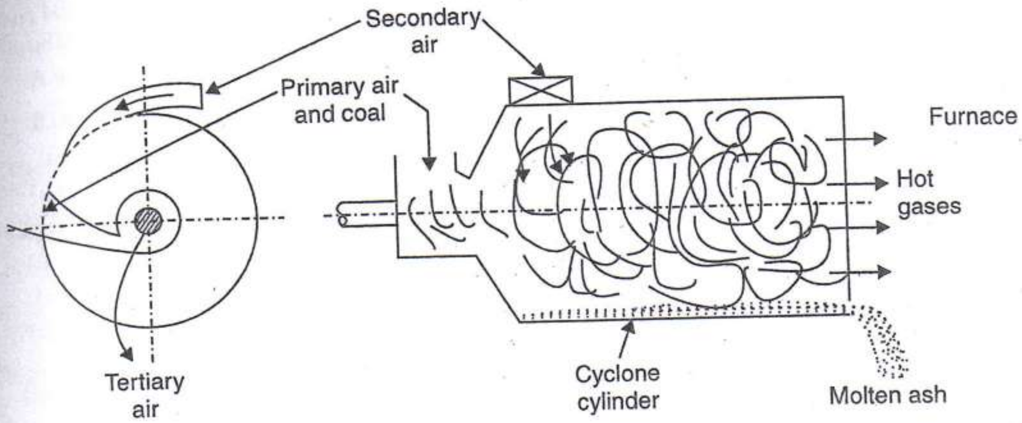


Fig. 3.31. Cyclone burner.

The cyclone burner receives crushed coal carried in primary air (at 80 cm water pressure) at the left end. Tangential entry of the coal throws it to the surface of the cylindrical furnace. Secondary air enters the furnace through tangential ports at the upper edge at high speed and creates a strong and highly turbulent vortex. Extremely high heat liberation rate and use of preheated air cause high temperatures to the tune of 2000°C in the cyclone. The fuel supplied is quickly consumed and liberated ash forms a molten film flowing over the inner wall of the cylinder. Due to horizontal axis of the burner being tilted the molten ash flows to an appropriate disposal system. The cyclone furnace gives best results with low grade fuels.

Advantages :

1. High furnace temperatures are obtained.
2. Simplified coal existing equipments can be used instead of costly pulverised mills.
3. The cyclone burners reduce the percentage of excess air used.
4. It can burn poorer and cheaper grades of coal.
5. As the swirling effect and consequently the mixing of air and crushed coal is better, it provides for a higher furnace capacity and efficiency.
6. Boiler efficiency is increased.
7. The cost of milling in cyclone fire is less as the finer particles are not required in this case.
8. Combustion rates can be controlled by simultaneous manual adjustment of fuel feed and air flow and response in firing rate changes is comparable to that of pulverised coal firing.

3.9.4.2. Oil burners

Principle of oil firing. *The functions of an oil burner are to mix the fuel and air in proper proportion and to prepare the fuel for combustion.* Fig. 3.32 shows the principle of oil firing.

whereas, high ratio may extinguish the flame due to increased proportions of circulated products. An optimum ratio may be determined for different fuels experimentally.

In recirculation burner (utilising the above principle) circulation system is separated from the combustion by a solid wall.

(d) ***Wick burners.*** In this type of a burner a cotton or asbestos wick is used which raises the liquid fuel by capillary action. The fuel from the uppermost part of the wick is evaporated due to radiant heat from the flame and the nearby heated surfaces. Air is admitted through holes in the surrounding walls.

A wick burner is suitable for models or domestic appliances.

2. Atomising fuel burners. Following are the *requirements of an automising fuel burner :*

(*i*) To automise the fuel into fine particles of equal size.

(*ii*) To supply air in required quantity at proper places in the combustion chamber.

(*iii*) To give high combustion intensity.

(*iv*) To give high thermal efficiency.

(*v*) To operate without difficulty at varying loads.

(*vi*) To create necessary turbulence inside the combustion chamber for proper combustion of fuel.

(*vii*) To minimise soot formation and carbon deposit, particularly on the burner nozzle.

(*a*) ***Mechanical atomising burners.*** A mechanical atomising oil burner consists of the following four principal parts :

(*i*) Atomiser (*ii*) Air register (*iii*) Diffuser (*iv*) Burner throat opening.

(*i*) *Atomiser.* It breaks up the oil mechanically into a fine uniform spray that will burn with minimum of excess air when projected into the furnace. The spray is produced by using relatively high pressure to force oil at high velocity through small tangential passages of sprayer plate into a chamber where it is rapidly rotated, centrifugal force in the rotating oil causes it to break up into a thin layered, mist like, hollow conical spray as it is released through the orifice plate.

(*ii*) *Air register.* An air register is an integral part of the oil-burner assembly. It consists of a number of overlapping vanes which deliver the air for combustion to the furnace throat with the correct degree of spin.

(*iii*) *Diffuser.* It is a shield in the form of a perforated hollow metal cone mounted near the furnace end of the atomiser assembly. *It stabilises the flame to prevent it from being blown away from the atomiser tip.*

(*iv*) *Burner throat opening.* It is circular and concentric with burner outlet. It is made of refractory. The atomiser and diffuser assembly should be so positioned that the flame clears the throat opening sufficiently to avoid striking. This burner has an insulated front and thus is designed to operate with preheated air.

(*b*) *Steam atomising burners.* Of various methods of oil atomisation, that which employs steam is usually the most convenient. This method may, however, absorbs some 4 to 5% of the total amount of steam generated. These burners may be divided into two categories :

(*i*) The outside mix

(*ii*) The inside mix.

In case of *outside mixing* [Fig. 3.33 (*a*)] *type burners,* oil is ejected through one side of the holes and is blasted by a high velocity jet of steam issuing from other holes. *Mixing*, however, occurs *outside the burner*.

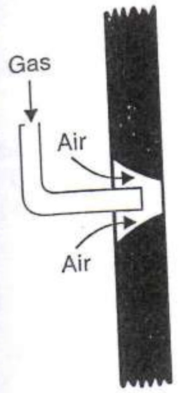


Fig. 3.34

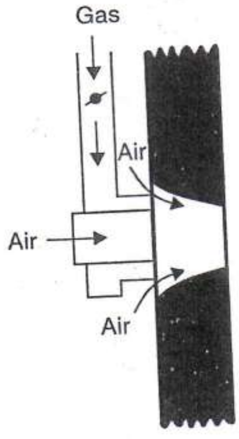


Fig. 3.35

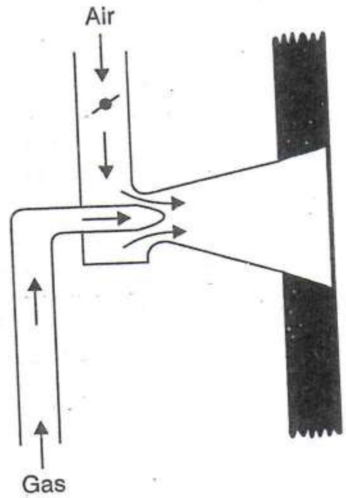


Fig. 3.36

Refer Fig. 3.34. In this burner the mixing is poor and a fairly long flame results.

Refer Fig. 3.35. This is a *ring type burner* in which a short flame is obtained.

Refer Fig. 3.36. This arrangement is used when both gas and air are under pressure.

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

3.10. FLUIDISED BED COMBUSTION (FBC)

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

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

Fig. 3.37 shows the arrangement of the FBC system.

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

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

11. The large quantity of bed material acts as a thermal storage which reduces the effect o any fluctuation in fuel feed ratio.

3.11. ASH HANDLING

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

Handling of ash includes :

(*i*) Its removal from the furnace.

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

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

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

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

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

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

3.11.1. Ash Handling Equipment

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

1. It should have enough capacity to cope with the volume of ash that may be produced in station.

2. It should be able to handle large clinkers, boiler refuse, soot etc. with little personal atte tion of the workmen.

3. It should be able to handle hot and wet ash effectively and with good speed.

4. It should be possible to minimise the corrosive or abrasive action of ashes and dust nı sance should not exist.

5. The plant should not cost much.

6. The operation charges should be minimum possible.

7. The operation of the plant should be noiseless as much as possible.

8. The plant should be able to operate effectively under all variable load conditions.

9. In case of addition of units, it should need minimum changes in original layout of plar

10. The plant should have high rate of handling.

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

(*i*) Bucket elevator

(*ii*) Bucket conveyor

(*iii*) Belt conveyor

(*iv*) Pneumatic conveyor

(*v*) Hydraulic sluicing equipment

(*vi*) Trollies or rail cars etc.

The hot ash released from the boiler furnaces is made to fall over the belt conveyor after cooling it through water seal. This cooled ash is transported to an ash bunker through the belt conveyor. From ash bunker the ash is removed to the dumping site through trucks.

2. Hydraulic system

In this system ash is carried with the flow of water with high velocity through a channel and finally dumped in the sump. This system is subdivided as follows :

(*a*) Low pressure system

(*b*) High pressure system.

(*a*) ***Low pressure system.*** Refer Fig. 3.40. In this system a trough or drain is provided below the boilers and the water is made to flow through the trough. The ash directly falls into the troughs and is carried by water to sumps. In the sump the ash and water are made to pass through a screen so that water is separated from ash ; this water is pumped back to the trough for reuse and ash is removed to the dumping yard.

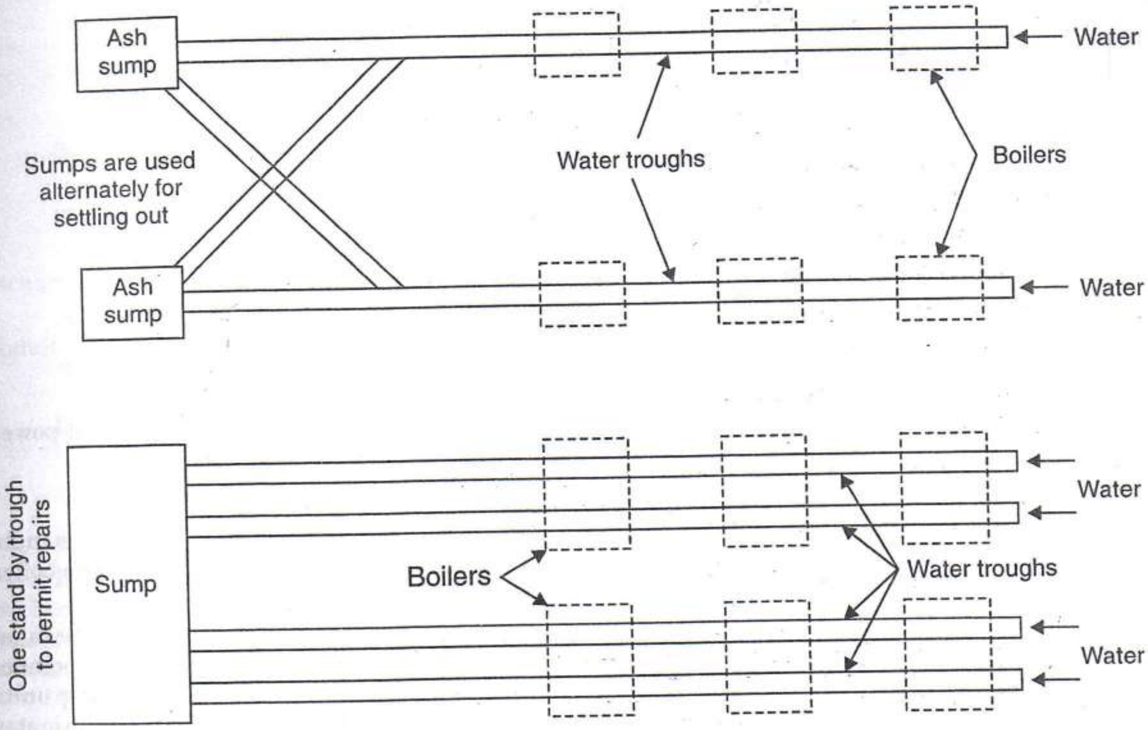


Fig. 3.40. Low pressure system.

The ash carrying capacity of this system is 50 tonnes/hour and distance covered is 500 metres.

(*b*) ***High pressure system.*** Refer Fig. 3.41. The hoppers below the boilers are fitted with water nozzles at the top and on the sides. The top nozzles quench the ash while the side ones provide the driving force for the ash. The cooled ash is carried to the sump through the trough. The water is again separated from ash and recirculated.

The ash carrying capacity of this system is as large as 120 tonnes per hour and the distance covered is as large as 1000 metres.

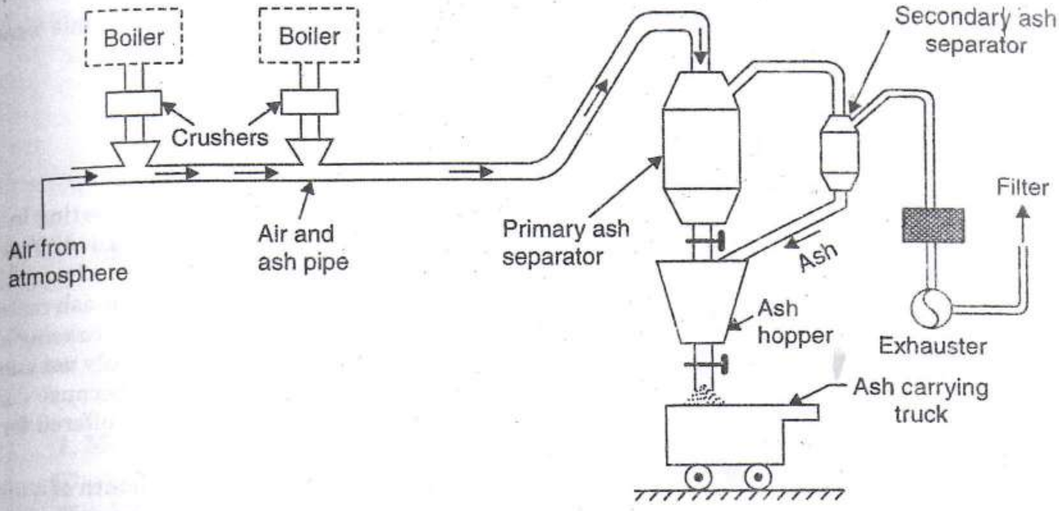


Fig. 3.42. Pneumatic or vacuum extraction ash handling system.

Advantages :

1. No spillage and rehandling.

2. High flexibility.

3. There is no chance of ash freezing or sticking in the storage bin and material can be discharged freely by gravity.

4. The dustless operation is possible as the materials are handled totally in an enclosed conduit.

5. The cost of plant per tonne of ash discharged is less in comparison to other systems.

Disadvantages :

1. There is a large amount of wear in the pipe work necessitating high maintenance charges.

2. More noisy than other systems.

4. Steam jet system

In this case steam at sufficiently high velocity is passed through a pipe and dry solid materials of considerable size are carried along with it. In a high *pressure steam jet system* a jet of high pressure steam is passed in the direction of ash travel through a conveying pipe in which the ash from the boiler ash hopper is fed. The ash is deposited in the ash hopper.

This system can remove economically the ash through a horizontal distance of 200 m and through a vertical distance of 30 m.

Advantages :

1. Less space requirement.

2. Less capital cost in comparison to other systems.

3. Auxiliary drive is not required.

4. It is possible to place the equipment in awkward position too.

Disadvantages :

1. Noisy operation.

2. This system necessitates continuous operation since its capacity is limited to about 7 tonnes per hour.

The dust collectors may be *classified* as follows :

1. Mechanical dust collectors :

(*i*) Wet type (Scrubbers)

(*a*) Spray type

(*b*) Packed type

(*c*) Impingement type

(*ii*) Dry type

(*a*) Gravitational separators

(*b*) Cyclone separators

2. Electrical dust collectors :

(*i*) Rod type

(*ii*) Plate type.

1. Mechanical dust collectors

The basic principles of mechanical dust collectors is shown in Fig. 3.44.

Fig. 3.44 (*a*). Enlarging the duct cross-sectional area to slow down the gas gives the heavier particles a chance to settle out.

Fig. 3.44 (*b*). When a gas makes a sharp change in flow direction, the heavier particles tend to keep going in the original direction and so settle out.

Fig. 3.44 (*c*) Impingement baffles have more effect on the solid particles than the gas, helping them to settle out.

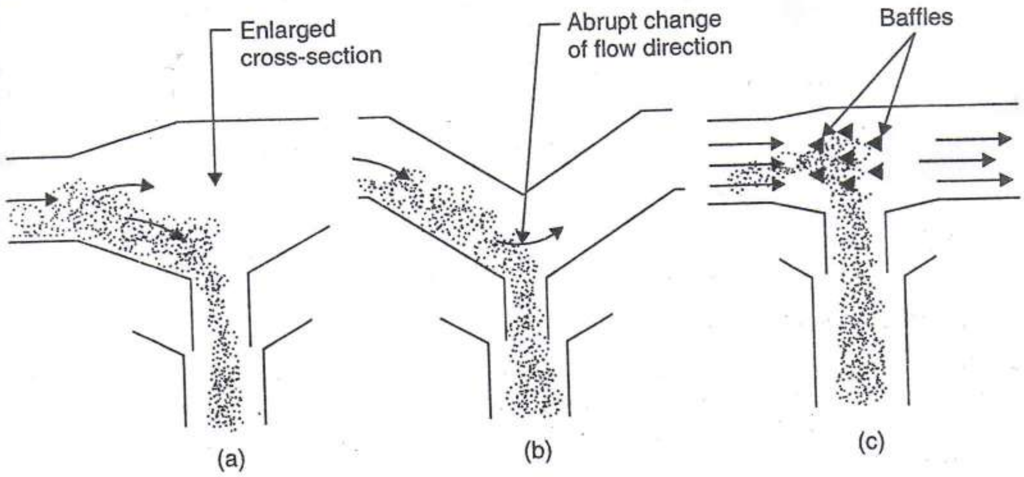


Fig. 3.44. Principles used in dust collection.

(*i*) **Wet type dust collectors.** Wet types, called *scrubbers*, operate with water sprays to wash dust from the air. Such large quantities of wash water are needed for central station gas washing that this system is *seldom* used. It also produces a waste water that may require chemical neutralization before it can be discharged into natural bodies of water.

(*ii*) **Dry type dust collectors.** It is a commonly used dust collector.

(*a*) **Gravitational separators.** These collectors act by slowing down gas flow so that particles remain in a chamber long enough to settle to the bottom. They are not very suitable because of large chamber volume needed.

(*i*) Source of high voltage,
(*ii*) Ionizing and collecting electrodes,
(*iii*) Dust-removal mechanism, and
(*iv*) Shell to house the elements.

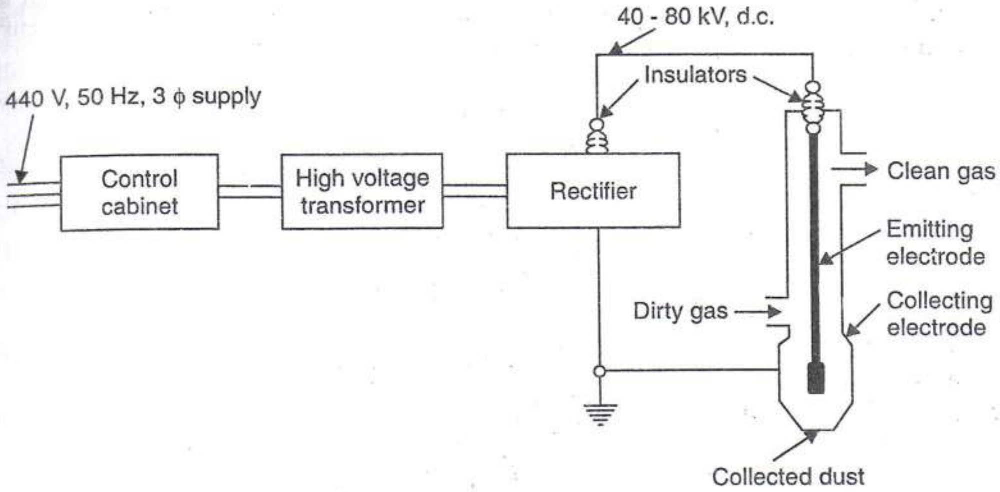


Fig. 3.46. Basic elements of electrostatic precipitators.

The precipitator has two sets of electrodes, insulated from each other, that maintain an electrostatic field between them at high voltage. The field ionizes dust particles that pass through it, attracting them to the electrode of opposite charge. The high voltage system maintains a negative potential of 30,000 to 60,000 volts with the collecting electrodes grounded. The collecting electrodes have a large contact surface. Accumulated dust falls of the electrode when it is rapped mechanically.

A wet type of this unit removes dust by a water film flowing down on the inner side of the collecting electrode. These units have collection efficiency of the order of 90%.

The advantages and disadvantages of an electrostatic precipitator are listed below :

Advantages :

1. Can effectively remove very small particles like smoke, mist and flyash.
2. Easy operation.
3. The draught loss is quite less (1 cm of water).
4. Most effective for high dust loaded gas.
5. As compared to other separators its maintenance charges are minimum.
6. The dust is collected in dry form and can be removed either dry or wet.

Disadvantages :

1. Space requirement is more (than wet system)
2. Necessary to protect the entire collector from sparking.
3. Running charges are considerably high.
4. Capital cost of equipment is high.
5. The collection efficiency is not maintained if the gas velocity exceeds that for which the plant is designed.

3.12.5. Installation of Dust Collectors

Dust collectors are installed *between the boiler and the chimney, usually on the chimney side of the air heater, if there is one.* There would be some advantages from the stand point of heater cleanliness were the collector to be put ahead of it, however, the practice seems to be to follow with the collector, and use blowers to keep the heater surfaces clean. Where there is more than one boiler, the practice is to use an individual collector for each boiler. In some cases a low resistance inertial and an electrostatic precipitator have been installed in series, again with *pros* and *cons* as to which should be ahead of the other. Generally, the mechanical type is placed first in the gas flow. Another characteristic of interest in a combination is the *variation of collection efficiency with the gas flow. As the flow increases, the electrostatic efficiency decreases, the cyclone efficiency increases.*

During the original power plant layout a dust collector should receive careful consideration.

3.12.6. Uses of Ash and Dust

The *uses of ash and dust* are listed below :

1. Ash is widely used in the production of cement.

2. Ash is used in the production of concrete. 20 percent fly-ash and 30 percent bottom ash are presently used constructively in U.S.A.

3. Because of their better alkali values, they are used for treating acidic soils. It has been found that if ash is used in limited quantity in soil, it increases the yield of corn, turnip etc.

4. From the ash, the metals such as Al, Fe, Si and titanium can be recovered.

3.12.7. General Layout of Ash Handling and Dust Collection System

Fig. 3.49 shows the general layout of ash handling and dust collection system which is self explanatory.

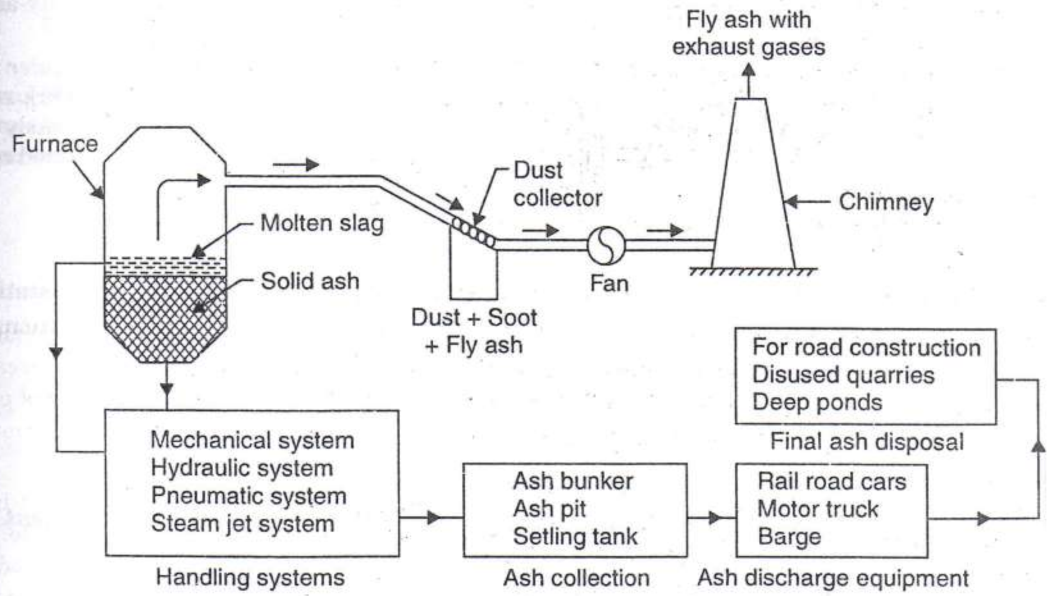


Fig. 3.49. General layout of ash handling and dust collection system.

داسطارق جبار حسن

Chapter 2: Steam boilers

1- Feed water treatment

1.1. introduction

The sources of the earth's water supply its rainfall. This initially pure water which is neutral in reaction (pH=7) passes through the atmosphere and absorbs Co_2 and O_2, the presence of Co_2 and other impurities cause it to become slightly acid. This slightly acidity causes it to dissolved certain rock and mineral deposits on the ground, as a result the water tends to lose its soft character and become hard. Therefore water available for supply to boiler contains many dissolved and dissolved impurities.

2.1. Impurities in water

The impurities present in the feed water are classified as given below:-

1- un dissolved and suspended materials (oil, mud, sand).

2- dissolved salts (calcium, magnesium, sodium).

3- dissolved gases (O_2, CO_2).

3.1. Effects of impurities :

1- Scale formation:- feed water is containing a group of impurities in dissolved and suspended form which flow into the boiler for continuous generation of steam. During the conversion of water into steam in boiler the solubility of dissolved salts (Ca, Mg) decreases with increase in temperature then salts and suspended impurities stay in boiler and form scale. Scale in boiler creates a problem because:

- the low degree of thermal conductivity (reduce rate of heat transfer).
- reduce the flow area and increase the pressure required to maintain the flow.
- cause over heating of tube material.

Note. Sodium salts are highly soluble in water and is non scale forming.

2- Corrosion: - the corrosion is the eating away pieces of piping and boiler metal and requires major repairs or expensive shut-down for replacement. The corrosion is caused due to acid present (low PH) in the water in the presence of CO_2 and O_2. The O_2 is carried with air which generally escapes into the condenser, the CO_2 is formed due to decomposition of bicarbonates in boiler and CO_2 combines with water to form weak acid known as carbonic acid. This slowly reacts with iron and other metals to form their bicarbonates which again decomposing and new CO_2 release and the cycle is repeated. The corrosion causes pitting and grooving on metal surface and reduces the strength of metal.

3- Foaming and priming (carry over) :- foaming is the formation of small stable bubbles in the boiler. The foam is caused in the boiler due to:

- dissolved and suspended impurities
- excess in alkalinity (high PH)
- excess in total dissolved solid (TDS)

Foaming prevents the free escape of steam from boiler and prevents its formation (decrease boiler efficiency). Priming is carry over small water particles with steam as it leaves the boiler and also some solid dissolved, this is undesirable as the contaminated steam is unsuitable for steam turbines. The priming (carry over) is appeared due to, foaming, (TDS), improper boiler design and improper firing method.

4- Caustic embrittlement:- the caustic embrittlement is the weak of boiler metal due to inner crack. This is caused by long exposure of boiler metal to alkaline water under high pressure, the presence of (NaoH) is most responsible for embrittlement.

The object of water treatment is to prevent scale forming on heating surfaces, prevent corrosion, caustic cracking and to enable clean steam to be produced.

1.4. Methods of feed water treatment

There are different methods for feed water treatment and the choice of method depends on many factors, as the composition of the water supply, the quantity of make-up water required, boiler operating conditions and cost. These methods are classified as below:

1- External treatment
- mechanical for suspended impurities.
- chemical for dissolved salts.
- thermal for dissolved gases.

2- Internal treatment: chemical treatment for dissolved salts.
3- Conditioning treatment; chemical addition after external treatment.

1. External treatment:- if impurities remove from the water before supplying it to the boiler, then this method is known as external treatment which is classified as below:

a. Mechanical treatment

The suspended solid impurities are removed by this method which includes:

- sedimentation - coagulation - filtration.

Sedimentation involves allowing water to remain stand in big tanks, the solid matter settles down due to gravity and it is removed periodically. In coagulation system, some coagulant like aluminum soleplate adds to this to form colloidal which settles down quickly. The suspended solids which cannot remove by sedimentation and coagulation are removing by filtration.

b. Chemical treatment

The dissolved solids (salts) are removed by this method which is divided into:-

- lime-soda - ion exchange – demineralization

1- Lime-soda: - The object of this method is to add correct amount of lime and sodium carbonate (soda) to row water so that the calcium and magnesium salts are precipitated out of solution.

$$Ca\,(HCo_3) + Ca\,(oH)_2 \longrightarrow 2\,CaCo_3\downarrow + 2\,H_2o$$

$$Mg(HCO_3)_2 + Ca(oH)_2 \longrightarrow 2\,CaCo_3\downarrow + Mg\downarrow(oH)_2 + 2\,H_2o$$

$$Mg\,So_4 + Ca(oH)_2 \longrightarrow Mg(oH)_2\downarrow + CaSo_4$$

$$CaSo_4 + Na_2\,Co_3 \longrightarrow Na_2So_4 + CaCo_3\downarrow$$

This method is usually considered unsuitable for water with a low initial hardness (up to 100 ppm).

2. Ion exchange (typical Na_2Z):- In this method the removed of hardness salts is achieved by interchanging them for other non-scale forming salts (sodium salts). The raw water passes through a bed of zeolite which has the property of exchanging its sodium ion for calcium and magnesium ions within the water,

$$Na_2Z + Ca(HCo_3)_2 \longrightarrow CaZ + 2\,NaHCo_3$$
$$Na_2Z + Ca\,So_4 \longrightarrow CaZ + 2\,Na_2So_4$$

The zeolite, in taking up the calcium and magnesium salts from the water, becomes saturated and needs to be regenerated and this is accomplished by stopping the flow of raw water and passing a strong solution of brine through the bed,

$$CaZ + 2\,NaCl \longrightarrow Na_2Z + CaCl_2$$

This method is more suitable for a raw water of law hardness, but because calcium and magnesium salts change to sodium salts in this process it is not recommended for treating water having high bicarbonate salts.

3. Demineralization: - This process results water having a high purity required for high pressure boiler. First the raw water is passed through a bed of hydrogen exchange (cat-ion) which has a property of converting all salts present in the water into the corresponding acids.

$$\begin{array}{lcl} RH^{+} + CaSo_4 & \longrightarrow & R\,Ca \;+ HSo_4 \\ \quad\;\; MgCl_2 & & \;\;\; Mg \quad\;\; Cl \\ \quad\;\; Ca(HCo_3) & & \qquad\qquad Co_3 \end{array}$$

The second phase is to pass the acidic water through a bed of acid-absorbing resin (an-ion) where acids are removed resulting in a softened water of negligible hardness,

$$\begin{array}{lcl} ROH^{-} + HSo_4 & \longrightarrow & R\,So_4 \;+ H_2o \\ \qquad\qquad\; Cl & & \quad Cl \end{array}$$

For regenerate cat-ion,

$$\begin{array}{lcl} RNa + HCl & \longrightarrow & RH + CaCl \\ \;\; Ca & & \qquad\;\; Na \\ \;\; Mg & & \qquad\;\; Mg \end{array}$$

And for anion,

$$\begin{array}{lcl} RSo_4 + NaOH & \longrightarrow & ROH + NaSo_4 \\ \; Cl & & \qquad\qquad\;\; Cl \end{array}$$

c. Thermal treatment

The dissolved gases like O_2 and CO_2 in the water are removed by thermal treatment. The heating removes the dissolved gasses from the water as the gas absorption capacity of water decreases with increasing temperature. The device used for thermal treatment is the thermal or heat deaerator in which the temperature raises to saturated (boiling) temperature at a certain pressure.

2. Internal treatment

If the dissolved solids in the water are removed in the boiler itself by a chemical treatment, then this method is known as internal treatment. Internal treatment is generally confined to low pressure boiler operation and it is not recommended for water tube boiler. Internal treatment is accomplished by adding chemicals to the boiler water either to precipitate the impurities so that can be remove in the form of sludge or to convert them into salts which will stay in water and do not harm.

The common internal treatment used is:

a. Sodium carbonate treatment, the main disadvantage of this process it is lead to increase alkalinity very rapidly with an increase in pressure and temperature and also with increasing temperature and pressure the rate of generation of CO_2 increasing. For this reason the use of sodium carbonate is limited to boiler pressure of (10 bar).

b. sodium phosphate, for higher pressure boiler phosphate compounds are used instead of carbonate.

c. colloidal treatment, to remove the sludge formed effectively from the boiler.

d. blow down, the sludge formed from internal chemical treatment increases because there is continued addition of make-up water. Sludge become undesirable so it increases alkalinity and causes foaming and carry over, also (TDS) increase as chemical add which produce undesirable foaming and carry over, therefore some water having a high concentration of salts remove from the boiler by blow down system which is a valve connected to the lowest water space and replace by feed water of much lower solids.

3. Conditioning treatment

These terms imply treatment supplementary to that carried out on the water before feeding it into the boiler. This treatment is necessary since no external treatment regardless of efficiency can remove all harmful salts and gases. The injection of additional chemicals either into the feed water prior to its entering the boiler or into the boiler itself nullifies the effect of any residual hardness and corrosive elements present in the externally feed water. The chemicals are,

- sodium phosphate: to treat salts
- sodium sulfate, caustic soda: to treat corrosive element
- colloidal element: to condition sludge.

The blow down process is needed from time to time when these chemical add.

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Pollution

Pollution is the introduction of contaminants into the natural environment that cause adverse change.[1] Pollution can take the form of chemical substances or energy, such as noise, heat or light. Pollutants, the components of pollution, can be either foreign substances/energies or naturally occurring contaminants. Pollution is often classed as point source or nonpoint source pollution. In 2015, pollution killed 9 million people in the world.[2][3]


Thermal oxidizers purify industrial air flows.

Contents


The litter problem on the coast of Guyana, 2010

History

Air pollution has always accompanied civilizations. Pollution started from prehistoric times when man created the first fires. According to a 1983 article in the journal *Science*, "soot" found on ceilings of prehistoric caves provides ample evidence of the high levels of pollution that was associated with inadequate ventilation of open fires."[4] Metal forging appears to be a key turning point in the creation of significant air pollution levels outside the home. Core samples of glaciers in Greenland indicate increases in pollution associated with Greek, Roman and Chinese metal production,[5] but at that time the pollution was comparatively small and could be handled by nature.

Urban pollution

Air pollution in the US, 1973

The burning of coal and wood, and the presence of many horses in concentrated areas made the cities the primary sources of pollution. The Industrial Revolution brought an infusion of untreated chemicals and wastes into local streams that served as the water supply. King Edward I of England banned the burning of sea-coal by proclamation in London in 1272, after its smoke became a problem.[6][7] But the fuel was so common in England that this earliest of names for it was acquired because it could be carted away from some shores by the wheelbarrow.

It was the industrial revolution that gave birth to environmental pollution as we know it today. London also recorded one of the earlier extreme cases of water quality problems with the Great Stink on the Thames of 1858, which led to construction of the London sewerage system soon afterward. Pollution issues escalated as population growth far exceeded view ability of neighborhoods to handle their waste problem. Reformers began to demand sewer systems, and clean water.[8]

In 1870, the sanitary conditions in Berlin were among the worst in Europe. August Bebel recalled conditions before a modern sewer system was built in the late 1870s:

> "Waste-water from the houses collected in the gutters running alongside the curbs and emitted a truly fearsome smell. There were no public toilets in the streets or squares. Visitors, especially women, often became desperate when nature called. In the public buildings the sanitary facilities were unbelievably primitive....As a metropolis, Berlin did not emerge from a state of barbarism into civilization until after 1870."[9]

The primitive conditions were intolerable for a world national capital, and the Imperial German government brought in its scientists, engineers and urban planners to not only solve the deficiencies but to forge Berlin as the world's model city. A British expert in 1906 concluded that Berlin represented "the most complete application of science, order and method of public life," adding "it is a marvel of civic administration, the most modern and most perfectly organized city that there is."[10]

The emergence of great factories and consumption of immense quantities of coal gave rise to unprecedented air pollution and the large volume of industrial chemical discharges added to the growing load of untreated human waste. Chicago and Cincinnati were the first two American cities to enact laws ensuring cleaner air in 1881. Pollution became a major issue in the United States in the early twentieth century, as progressive reformers took issue with air pollution caused by coal burning, water pollution caused by bad sanitation, and street pollution caused by the 3 million horses who worked in American cities in 1900, generating large quantities of urine and manure. As historian Martin Melosi notes, The generation that first saw automobiles replacing the horses saw cars as "miracles of cleanliness.".[11] By the 1940s, however, automobile-caused smog was a major issue in Los Angeles.[12]

Other cities followed around the country until early in the 20th century, when the short lived Office of Air Pollution was created under the Department of the Interior. Extreme smog events were experienced by the cities of Los Angeles and Donora, Pennsylvania in the late 1940s, serving as another public reminder.[13] Air pollution would continue to be a problem in England, especially later during the industrial revolution, and extending into the recent past with the Great Smog of 1952.

Awareness of atmospheric pollution spread widely after World War II, with fears triggered by reports of radioactive fallout from atomic warfare and testing.[14] Then a non-nuclear event, The Great Smog of 1952 in London, killed at least 4000 people.[15] This prompted some of the first major modern environmental legislation, The Clean Air Act of 1956.

Pollution began to draw major public attention in the United States between the mid-1950s and early 1970s, when Congress passed the Noise Control Act, the Clean Air Act, the Clean Water Act and the National Environmental Policy Act.[16]

Severe incidents of pollution helped increase consciousness. PCB dumping in the Hudson River resulted in a ban by the EPA on consumption of its fish in 1974. Long-term dioxin contamination at Love Canal starting in 1947 became a national news story in 1978 and led to the Superfund legislation of 1980.[17] The pollution of industrial land gave rise to the name brownfield, a term now common in city planning.

Smog Pollution in Taiwan

The development of nuclear science introduced radioactive contamination, which can remain lethally radioactive for hundreds of thousands of years. Lake Karachay, named by the Worldwatch Institute as the "most polluted spot" on earth, served as a disposal site for the Soviet Union throughout the 1950s and 1960s. Chelyabinsk, Russia, is considered the "Most polluted place on the planet".[18]

Nuclear weapons continued to be tested in the Cold War, especially in the earlier stages of their development. The toll on the worst-affected populations and the growth since then in understanding about the critical threat to human health posed by radioactivity has also been a prohibitive complication associated with nuclear power. Though extreme care is practiced in that industry, the potential for disaster suggested by incidents such as those at Three Mile Island and Chernobyl pose a lingering specter of public mistrust. Worldwide publicity has been intense on those disasters.[19] Widespread support for test ban treaties has ended almost all nuclear testing in the atmosphere.[20]

International catastrophes such as the wreck of the Amoco Cadiz oil tanker off the coast of Brittany in 1978 and the Bhopal disaster in 1984 have demonstrated the universality of such events and the scale on which efforts to address them needed to engage. The borderless nature of atmosphere and oceans inevitably resulted in the implication of pollution on a planetary level with the issue of global warming. Most recently the term persistent organic pollutant (POP) has come to describe a group of chemicals such as PBDEs and PFCs among others. Though their effects remain somewhat less well understood owing to a lack of experimental data, they have been detected in various ecological habitats far removed from industrial activity such as the Arctic, demonstrating diffusion and bioaccumulation after only a relatively brief period of widespread use.

A much more recently discovered problem is the Great Pacific Garbage Patch, a huge concentration of plastics, chemical sludge and other debris which has been collected into a large area of the Pacific Ocean by the North Pacific Gyre. This is a less well known pollution problem than the others described above, but nonetheless has multiple and serious consequences such as increasing wildlife mortality, the spread of invasive species and human ingestion of toxic chemicals. Organizations such as 5 Gyres have researched the pollution and, along with artists like Marina DeBris, are working toward publicizing the issue.

Pollution introduced by light at night is becoming a global problem, more severe in urban centres, but nonetheless contaminating also large territories, far away from towns.[21]

Growing evidence of local and global pollution and an increasingly informed public over time have given rise to environmentalism and the environmental movement, which generally seek to limit human impact on the environment.

Forms of pollution

The major forms of pollution are listed below along with the particular contaminant relevant to each of them:

- Air pollution: the release of chemicals and particulates into the atmosphere. Common gaseous pollutants include carbon monoxide, sulfur dioxide, chlorofluorocarbons (CFCs) and nitrogen oxides produced by industry and motor vehicles. Photochemical ozone and smog are created as nitrogen oxides and hydrocarbons react to sunlight. Particulate matter, or fine dust is characterized by their micrometre size PM_{10} to $PM_{2.5}$.
- Light pollution: includes light trespass, over-illumination and astronomical interference.
- Littering: the criminal throwing of inappropriate man-made objects, unremoved, onto public and private properties.
- Noise pollution: which encompasses roadway noise, aircraft noise, industrial noise as well as high-intensity sonar.
- Soil contamination occurs when chemicals are released by spill or underground leakage. Among the most significant soil contaminants are hydrocarbons, heavy metals, MTBE,[22] herbicides, pesticides and chlorinated hydrocarbons.
- Radioactive contamination, resulting from 20th century activities in atomic physics, such as nuclear power generation and nuclear weapons research, manufacture and deployment. (See alpha emitters and actinides in the environment.)
- Thermal pollution, is a temperature change in natural water bodies caused by human influence, such as use of water as coolant in a power plant.
- Visual pollution, which can refer to the presence of overhead power lines, motorway billboards, scarred landforms (as from strip mining), open storage of trash, municipal solid waste or space debris.
- Water pollution, by the discharge of wastewater from commercial and industrial waste (intentionally or through spills) into surface waters; discharges of untreated domestic sewage, and chemical contaminants, such as chlorine, from treated sewage; release of waste and contaminants into surface runoff flowing to surface waters (including urban runoff and agricultural runoff, which may contain chemical fertilizers and pesticides); waste disposal and leaching into groundwater; eutrophication and littering.
- Plastic pollution: involves the accumulation of plastic products in the environment that adversely affects wildlife, wildlife habitat, or humans.

The Lachine Canal in Montreal, Quebec, Canada.

Blue drain and yellow fish symbol used by the UK Environment Agency to raise awareness of the ecological impacts of contaminating surface drainage.

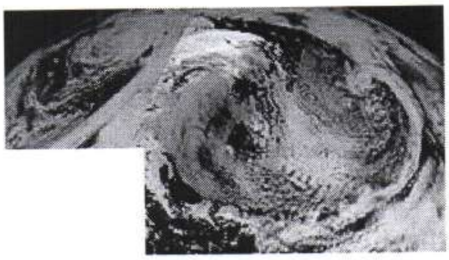
Pollutants

A pollutant is a waste material that pollutes air, water or soil. Three factors determine the severity of a pollutant: its chemical nature, the concentration and the persistence.

Cost of pollution

Pollution has cost.[23][24][25] Manufacturing activities that cause air pollution impose health and clean-up costs on the whole society, whereas the neighbors of an individual who chooses to fire-proof his home may benefit from a reduced risk of a fire spreading to their own houses. If external costs exist, such as pollution, the producer may choose to produce more of the product than would be produced if the producer were required to pay all associated environmental costs. Because responsibility or consequence for self-directed action lies partly outside the self, an element of externalization is involved. If there are external benefits, such as in public safety, less of the good may be produced than would be the case if the producer were to receive payment for the external benefits to others.

Sources and causes



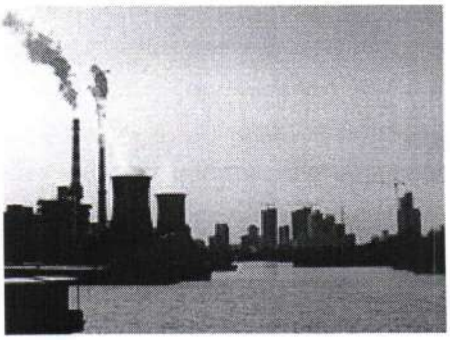
Air pollution produced by ships may alter clouds, affecting global temperatures.

Air pollution comes from both natural and human-made (anthropogenic) sources. However, globally human-made pollutants from combustion, construction, mining, agriculture and warfare are increasingly significant in the air pollution equation.[26]

Motor vehicle emissions are one of the leading causes of air pollution.[27][28][29] China, United States, Russia, India[30] Mexico, and Japan are the world leaders in air pollution emissions. Principal stationary pollution sources include chemical plants, coal-fired power plants, oil refineries,[31] petrochemical plants, nuclear waste disposal activity, incinerators, large livestock farms (dairy cows, pigs, poultry, etc.), PVC factories, metals production factories, plastics factories, and other heavy industry. Agricultural air pollution comes from contemporary practices which include clear felling and burning of natural vegetation as well as spraying of pesticides and herbicides[32]

About 400 million metric tons of hazardous wastes are generated each year.[33] The United States alone produces about 250 million metric tons.[34] Americans constitute less than 5% of the world's population, but produce roughly 25% of the world's CO_2,[35] and generate approximately 30% of world's waste.[36][37] In 2007, China has overtaken the United States as the world's biggest producer of CO_2,[38] while still far behind based on per capita pollution - ranked 78th among the world's nations.[39]

In February 2007, a report by the Intergovernmental Panel on Climate Change (IPCC), representing the work of 2,500 scientists, economists, and policymakers from more than 120 countries, said that humans have been the primary cause of global warming since 1950. Humans have ways to cut greenhouse gas emissions and avoid the consequences of global warming, a major climate report concluded. But to change the climate, the transition from fossil fuels like coal and oil needs to occur within decades, according to the final report this year from the UN's Intergovernmental Panel on Climate Change (IPCC).[40]



An industrial area, with a power plant, south of Yangzhou's downtown, China

Some of the more common soil contaminants are chlorinated hydrocarbons (CFH), heavy metals (such as chromium, cadmium–found in rechargeable batteries, and lead–found in lead paint, aviation fuel and still in some countries, gasoline), MTBE, zinc, arsenic and benzene. In 2001 a series of press reports culminating in a book called *Fateful Harvest* unveiled a widespread practice of recycling industrial byproducts into fertilizer, resulting in the contamination of the soil with various metals. Ordinary municipal landfills are the source of many chemical substances entering the soil environment (and often groundwater), emanating from the wide variety of refuse accepted, especially substances illegally discarded there, or from pre-1970 landfills that may have been subject to little control in the U.S. or EU. There have also been some unusual releases of polychlorinated dibenzodioxins, commonly called *dioxins* for simplicity, such as TCDD.[41]

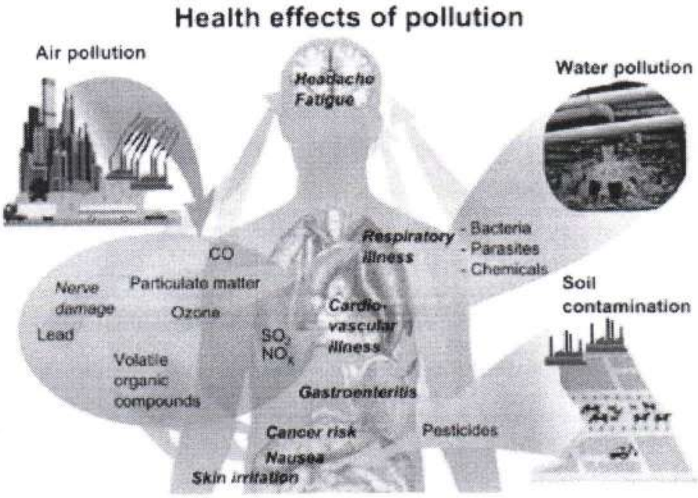
Pollution can also be the consequence of a natural disaster. For example, hurricanes often involve water contamination from sewage, and petrochemical spills from ruptured boats or automobiles. Larger scale and environmental damage is not uncommon when coastal oil rigs or refineries are involved. Some sources of pollution, such as nuclear power plants or oil tankers, can produce widespread and potentially hazardous releases when accidents occur.

In the case of noise pollution the dominant source class is the motor vehicle, producing about ninety percent of all unwanted noise worldwide.

Effects

Human health

Adverse air quality can kill many organisms including humans. Ozone pollution can cause respiratory disease, cardiovascular disease, throat inflammation, chest pain, and congestion. Water pollution causes approximately 14,000 deaths per day, mostly due to contamination of drinking water by untreated sewage in developing countries. An estimated 500 million Indians have no access to a proper toilet,[45][46] Over ten million people in India fell ill with waterborne illnesses in 2013, and 1,535 people died, most of them children.[47] Nearly 500 million Chinese lack access to safe drinking water.[48] A 2010 analysis estimated that 1.2 million people died prematurely each year in China because of air pollution.[49] The WHO estimated in 2007 that air pollution causes half a million deaths per year in India.[50] Studies have estimated that the number of people killed annually in the United States could be over 50,000.[51]



Overview of main health effects on humans from some common types of pollution.[42][43][44]

Oil spills can cause skin irritations and rashes. Noise pollution induces hearing loss, high blood pressure, stress, and sleep disturbance. Mercury has been linked to developmental deficits in children and neurologic symptoms. Older people are majorly exposed to diseases induced by air pollution. Those with heart or lung disorders are at additional risk. Children and infants are also at serious risk. Lead and other heavy metals have been shown to cause neurological problems. Chemical and radioactive substances can cause cancer and as well as birth defects.

An October 2017 study by the Lancet Commission on Pollution and Health found that global pollution, specifically toxic air, water, soils and workplaces, kill nine million people annually, which is triple the number of deaths caused by AIDS, tuberculosis and malaria combined, and 15 times higher than deaths caused by wars and other forms of human violence.[52] The study concluded that "pollution is one of the great existential challenges of the Anthropocene era. Pollution endangers the stability of the Earth's support systems and threatens the continuing survival of human societies."[3]

Environment

Pollution has been found to be present widely in the environment. There are a number of effects of this:

- Biomagnification describes situations where toxins (such as heavy metals) may pass through trophic levels, becoming exponentially more concentrated in the process.
- Carbon dioxide emissions cause ocean acidification, the ongoing decrease in the pH of the Earth's oceans as CO_2 becomes dissolved.
- The emission of greenhouse gases leads to global warming which affects ecosystems in many ways.
- Invasive species can out compete native species and reduce biodiversity. Invasive plants can contribute debris and biomolecules (allelopathy) that can alter soil and chemical compositions of an environment, often reducing native species competitiveness.
- Nitrogen oxides are removed from the air by rain and fertilise land which can change the species composition of ecosystems.
- Smog and haze can reduce the amount of sunlight received by plants to carry out photosynthesis and leads to the production of tropospheric ozone which damages plants.

- Soil can become infertile and unsuitable for plants. This will affect other organisms in the food web.
- Sulfur dioxide and nitrogen oxides can cause acid rain which lowers the pH value of soil.

Environmental health information

The Toxicology and Environmental Health Information Program (TEHIP)[53] at the United States National Library of Medicine (NLM) maintains a comprehensive toxicology and environmental health web site that includes access to resources produced by TEHIP and by other government agencies and organizations. This web site includes links to databases, bibliographies, tutorials, and other scientific and consumer-oriented resources. TEHIP also is responsible for the Toxicology Data Network (TOXNET)[54] an integrated system of toxicology and environmental health databases that are available free of charge on the web.

TOXMAP is a Geographic Information System (GIS) that is part of TOXNET. TOXMAP uses maps of the United States to help users visually explore data from the United States Environmental Protection Agency's (EPA) Toxics Release Inventory and Superfund Basic Research Programs.

Worker productivity

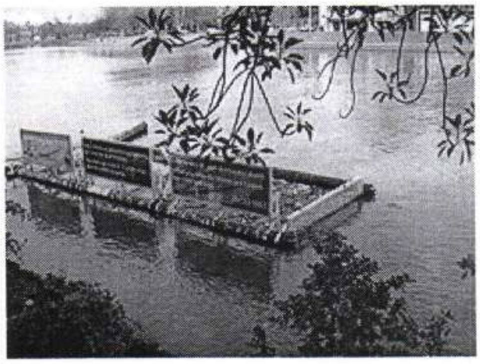
A number of studies show that pollution has an adverse effect on the productivity of both indoor and outdoor workers.[55][56][57]

Regulation and monitoring

To protect the environment from the adverse effects of pollution, many nations worldwide have enacted legislation to regulate various types of pollution as well as to mitigate the adverse effects of pollution.

Pollution control

Pollution control is a term used in environmental management. It means the control of emissions and effluents into air, water or soil. Without pollution control, the waste products from overconsumption, heating, agriculture, mining, manufacturing, transportation and other human activities, whether they accumulate or disperse, will degrade the environment. In the hierarchy of controls, pollution prevention and waste minimization are more desirable than pollution control. In the field of land development, low impact development is a similar technique for the prevention of urban runoff.



A litter trap catches floating waste in the Yarra River, east-central Victoria, Australia

Practices

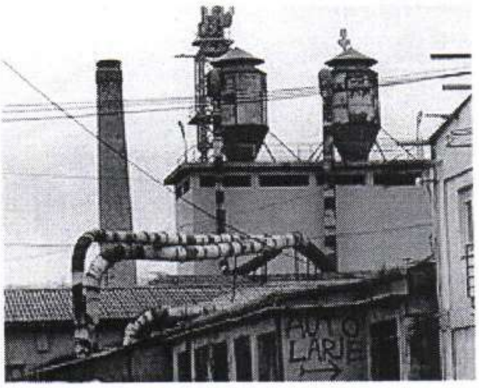
- Recycling
- Reusing
- Waste minimisation
- Mitigating
- Preventing
- Compost

Pollution control devices

- Air pollution control
  - Thermal oxidizer

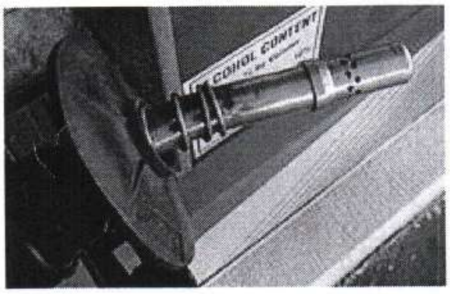
- Dust collection systems
  - Baghouses
  - Cyclones
  - Electrostatic precipitators
- Scrubbers
  - Baffle spray scrubber
  - Cyclonic spray scrubber
  - Ejector venturi scrubber
  - Mechanically aided scrubber
  - Spray tower
  - Wet scrubber
- Sewage treatment
  - Sedimentation (Primary treatment)
  - Activated sludge biotreaters (Secondary treatment; also used for industrial wastewater)
  - Aerated lagoons
  - Constructed wetlands (also used for urban runoff)
- Industrial wastewater treatment
  - API oil-water separators[31][58]
  - Biofilters
  - Dissolved air flotation (DAF)
  - Powdered activated carbon treatment
  - Ultrafiltration
- Vapor recovery systems
- Phytoremediation

Air pollution control system, known as a Thermal oxidizer, decomposes hazard gases from industrial air streams at a factory in the United States of America.

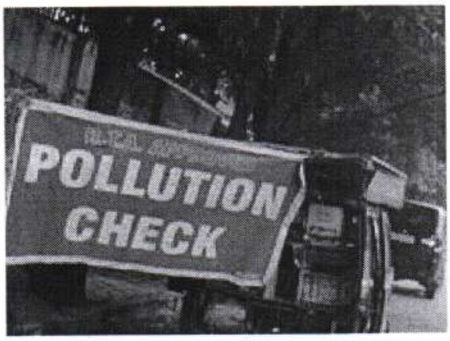


A dust collector in Pristina, Kosovo

Perspectives



Gas nozzle with vapor recovery



A Mobile Pollution Check Vehicle in India.

The earliest precursor of pollution generated by life forms would have been a natural function of their existence. The attendant consequences on viability and population levels fell within the sphere of natural selection. These would have included the demise of a population locally or ultimately, species extinction. Processes that were untenable would have resulted in a new balance brought about by changes and adaptations. At the extremes, for any form of life, consideration of pollution is superseded by that of survival.

For humankind, the factor of technology is a distinguishing and critical consideration, both as an enabler and an additional source of byproducts. Short of survival, human concerns include the range from quality of life to health hazards. Since science holds experimental demonstration to be definitive, modern treatment of toxicity or environmental harm involves defining a level at which an effect is observable. Common examples of fields where practical measurement is crucial include automobile emissions control, industrial exposure (e.g. Occupational Safety and Health Administration (OSHA) PELs), toxicology (e.g. LD_{50}), and medicine (e.g. medication and radiation doses).

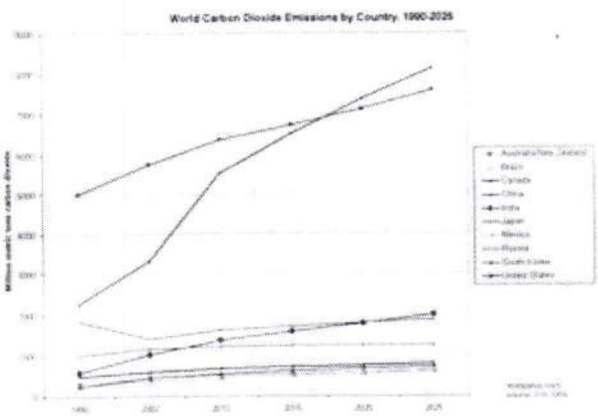
"The solution to pollution is dilution", is a dictum which summarizes a traditional approach to pollution management whereby sufficiently diluted pollution is not harmful.[59][60] It is well-suited to some other modern, locally scoped applications such as laboratory safety procedure and hazardous material release emergency management. But it assumes that the dilutant is in virtually unlimited supply for the application or that resulting dilutions are acceptable in all cases.

Such simple treatment for environmental pollution on a wider scale might have had greater merit in earlier centuries when physical survival was often the highest imperative, human population and densities were lower, technologies were simpler and their byproducts more benign. But these are often no longer the case. Furthermore, advances have enabled measurement of concentrations not possible before. The use of statistical methods in evaluating outcomes has given currency to the principle of probable harm in cases where assessment is warranted but resorting to deterministic models is impractical or infeasible. In addition, consideration of the environment beyond direct impact on human beings has gained prominence.

Yet in the absence of a superseding principle, this older approach predominates practices throughout the world. It is the basis by which to gauge concentrations of effluent for legal release, exceeding which penalties are assessed or restrictions applied. One such superseding principle is contained in modern hazardous waste laws in developed countries, as the process of diluting hazardous waste to make it non-hazardous is usually a regulated treatment process.[61] Migration from pollution dilution to elimination in many cases can be confronted by challenging economical and technological barriers.

Greenhouse gases and global warming

Carbon dioxide, while vital for photosynthesis, is sometimes referred to as pollution, because raised levels of the gas in the atmosphere are affecting the Earth's climate. Disruption of the environment can also highlight the connection between areas of pollution that would normally be classified separately, such as those of water and air. Recent studies have investigated the potential for long-term rising levels of atmospheric carbon dioxide to cause slight but critical increases in the acidity of ocean waters, and the possible effects of this on marine ecosystems.



Historical and projected CO_2 emissions by country (as of 2005).
Source: Energy Information Administration.[62][63]

Most polluting industries

The Pure Earth, an international non-for-profit organization dedicated to eliminating life-threatening pollution in the developing world, issues an annual list of some of the world's most polluting industries.[64]

- Lead-Acid Battery Recycling
- Industrial Mining and Ore Processing
- Lead Smelting
- Tannery Operations
- Artisanal Small-Scale Gold Mining
- Industrial/Municipal Dumpsites
- Industrial Estates
- Chemical Manufacturing
- Product Manufacturing
- Dye Industry
- Globalisation

World's worst polluted places

The Pure Earth issues an annual list of some of the world's worst polluted places.[65]

- Agbogbloshie, Ghana
- Chernobyl*, Ukraine
- Citarum River, Indonesia
- Dzershinsk*, Russia
- Hazaribagh, Bangladesh
- Kabwe*, Zambia
- Kalimantan, Indonesia
- Matanza Riachuelo, Argentina
- Niger River Delta, Nigeria
- Norilsk*, Russia

See also

- Environmental health
- Environmental racism
- Marine pollution
- Pollutants
- Hazardous Substances Data Bank
- Regulation of greenhouse gases under the Clean Air Act
- Biological contamination
- Chemical contamination

Air pollution

- Air dispersion modeling
- Arden Pope
- Atmospheric chemistry observational databases - links to freely available data.
- Climate change
- Emission standard
- Light pollution
- Greenhouse gas

Soil contamination

- Environmental soil science
- List of solid waste treatment technologies
- List of waste management companies
- List of waste management topics

Water pollution

- Cruise ship pollution
- Marine debris
- Marine pollution
- Ship pollution
- Stormwater
- Wastewater
- Wastewater quality indicators

Other

- Contamination control
- Earth Day
- Externality
- Genetic pollution
- Global warming
- Heat pollution
- List of environmental issues
- Noise health effects
- Space debris
- radioactivity

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