3

Steam Power Plant

3.1. **Introduction.** 3.2. **Classification of steam power plants.** 3.3. **Layout of a modern steam power plant.** 3.4. **Essential requirements of steam power station design.** 3.5. **Selection of site for steam power station.** 3.6. **Capacity of steam power plant.** 3.7. **Choice of steam conditions.** 3.8. **Fuel handling** : Introduction, requirements of good coal handling plant, coal handling systems, coal handling, layout of a fuel handling equipment. 3.9. **Combustion equipment for steam boilers** : General aspects, combustion equipment for solid fuels-selection considerations, burning of coal, stoker firing, burners. 3.10. **Fluidised bed combustion (FBC).** 3.11. **Ash handling** : Ash handling equipment, ash handling systems. 3.12. **Dust collection** : Introduction, removal of smoke, removal of dust and dust collectors, efficiency of dust collectors, installation of dust collectors, uses of ash and dust, general layout of ash handling and dust collection system. **3.13.** Chimney draught : Definition and classification of draught, natural draught, chimney height and diameter, condition for maximum discharge through a chimney, efficiency of a chimney, draught losses, artificial draught, forced draught, induced draught, balanced draught, advantages of mechanical draught, steam jet draught. 3.14. **Boilers** : Introduction, classification of boilers, comparison between 'fire tube and water tube' 'boilers, selection of a boiler, essentials of a good steam boiler, boiler terms, fire tube boilers, water tube boilers, high pressure boilers. 3.15. **Accessories** : Feed pumps, injector, economiser, air preheater, superheater, steam separator. 3.16. **Feed water heaters and evaporators** : Feed water heaters, miscellaneous heaters, evaporators, typical utility cycle layout. 3.17. **Performance of boilers** : Evaporative capacity, equivalent evaporation, factor of evaporation, boiler efficiency, heat looses in a boiler plant. 3.18. **Steam nozzles** : Introduction, steam flow through nozzles, discharge through the nozzle and conditions for its maximum value, nozzle efficiency, supersaturated or metastable expansion of steam in a nozzle. 3.19. **Steam turbines** : Introduction, classification of steam turbines, advantages of steam turbine over the steam engines, description of common types of turbines, methods of reducing wheel or rotor speed, difference between impulse and reaction turbines, impulse turbines, reaction turbines, turbine efficiencies, types of power in steam turbine practice, energy losses in steam turbines, steam turbine governing and control, special forms of turbines. 3.20. **Steam condensers** : Introduction, vacuum, organs of a steam condensing plant, classification of condensers, jet condensers, surface condensers, reasons for inefficiency in surface condensers, comparison between jet and surface condensers, selection of condenser, sources of air in condensers, effects of air leakage in condenser, method for obtaining maximum vacuum in condensers, vacuum measurement, vacuum efficiency, condenser efficiency, determination of mass of cooling water, heat transmission through walls of tubes of a surface condenser, methods of cleaning condenser tubes. 3.21. **Cooling ponds and cooling towers** : Introduction, river or sea, cooling ponds, spray ponds, cooling towers, dry cooling towers, maintenance of cooling towers. 3.22. **Feed water treatment** : Classification of impurities in water, troubles caused by the impurities in water, methods of feed water treatment, p-H value of water. 3.23. **Piping system** : Requirements of steam piping system, materials used for pipes, insulation of steam piping, steam pipe fittings, pipe expansion bends. 3.24. **Advantages and disadvantages of steam power plants.** 3.25. **Miscellaneous** : Plant arrangement, useful life of steam power plant components, steam power plant pumps, cost of steam power plant, comparison of various types of power plants, thermal power stations in India, Indian Boilers Act.

3.1. INTRODUCTION

A ***steam power plant*** *converts the chemical energy of the fossil fuels (coal, oil, gas) into mechanical / electrical energy*. This is achieved by raising the steam in the boilers, expanding it through the turbines and coupling the turbines to the generators which convert mechanical energy to electrical energy as shown in Fig. 3.1.

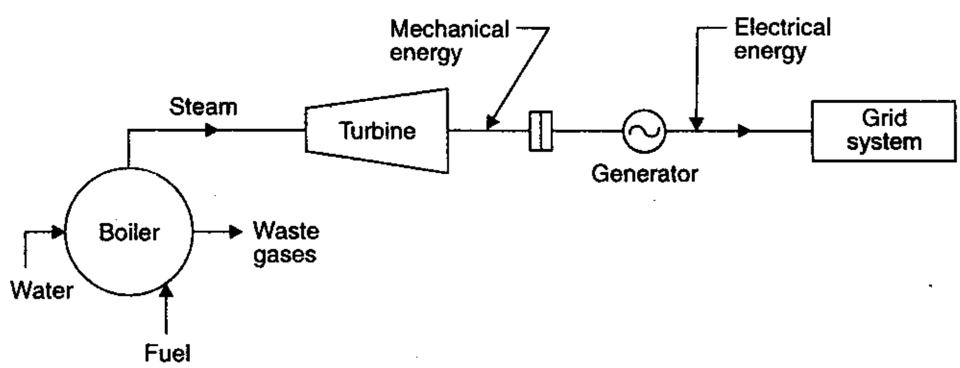


Fig. 3.1. Production of electric energy by steam power plant.

The following two purposes can be served by a steam power plant :

1. To produce electric power.

2. To produce steam for industrial purposes besides producing electric power. The steam may be used for varying purposes in the industries such as *textiles, food manufacture, paper mills, sugar mills* and *refineries* etc.

3.2. CLASSIFICATION OF STEAM POWER PLANTS

The steam power plants may be classified as follows :

1. Central stations.

2. Industrial power stations or captive power stations.

1. **Central stations.** The electrical energy available from these stations is meant for general sale to the customers who wish to purchase it. Generally, these stations are *condensing type* where the exhaust steam is discharged into a condenser instead of into the atmosphere. In the condenser the pressure is maintained below the atmospheric pressure and the exhaust steam is condensed.

2. **Industrial power stations or captive power stations.** This type of power station is run by a manufacturing company for its own use and its output is not available for general sale. Normally these plants are *non-condensing* because a large quantity of steam (low pressure) is required for different manufacturing operations.

In the *condensing steam power plants* the following *advantages* accrue :

(*i*) The amount of energy extracted per kg of steam is *increased* (a given size of the engine or turbine develops more power).

(*ii*) The steam which has been condensed into water in the condenser, can be recirculated to the boilers with the help of pumps.

In non-condensing steam power plants a continuous supply of fresh feed water is required which becomes a problem at places where there is a shortage of pure water.

3.3. LAYOUT OF A MODERN STEAM POWER PLANT

Refer Fig. 3.2. The layout of a modern steam power plant comprises of the following *four circuits* :

1. Coal and ash circuit.
2. Air and gas circuit.
3. Feed water and steam flow circuit.
4. Cooling water circuit.

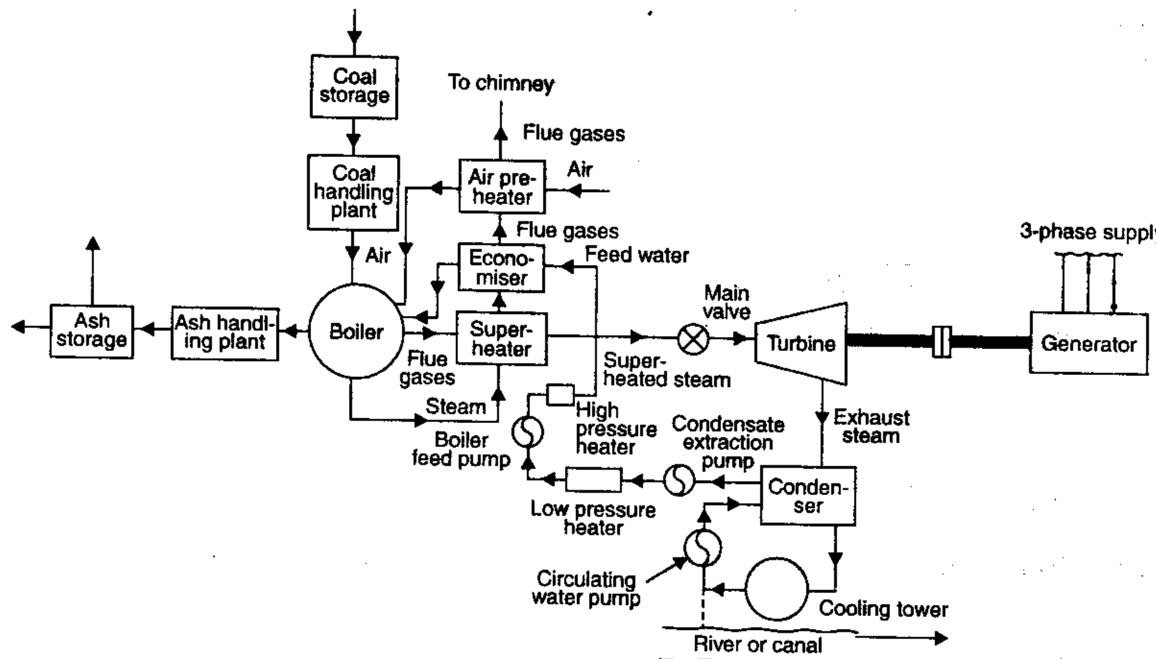


Fig. 3.2. Layout of a steam power plant.

Coal and ash circuit. Coal arrives at the storage yard and after necessary handling, passes on to the furnaces through the *fuel feeding device.* Ash resulting from combustion of coal collects at the back of the boiler and is removed to the ash storage yard through *ash handling equipment.*

Air and gas circuit. Air is taken in from atmosphere through the action of a forced or induced draught fan and passes on to the furnace through the *air preheater*, where it has been heated by the heat of flue gases which pass to the chimney *via* the preheater. The flue gases after passing around boiler tubes and superheater tubes in the furnace pass through a *dust* catching device or precipitator, then through the economiser, and finally through the air preheater before being exhausted to the atmosphere.

Feed water and steam flow circuit. In the water and steam circuit condensate leaving the condenser is first heated in a closed feed water heater through extracted steam from the lowest pressure extraction point of the turbine. It then passes through the *deaerator* and a few more water heaters before going into the boiler through *economiser.*

In the boiler drum and tubes, water circulates due to the difference between the density of water in the lower temperature and the higher temperature sections of the boiler. Wet steam from the drum is further heated up in the superheater before being supplied to the primemover. After expanding in high pressure turbine steam is taken to the reheat boiler and brought to its original dryness or superheat before being passed on to the low pressure turbine. From there it is exhausted through the condenser into the hot well. The condensate is heated in the feed heaters using the steam trapped (bled steam) from different points of turbine.

A part of steam and water is lost while passing through different components and this is compensated by supplying additional feed water. This feed water should be purified before hand, to avoid the scaling of the tubes of the boiler.

Cooling water circuit. The cooling water supply to the condenser helps in maintaining a low pressure in it. The water may be taken from a natural source such as river, lake or sea or the same water may be cooled and circulated over again. In the later case the cooling arrangement is made through spray pond or cooling tower.

Components of a Modern Steam Power Plant. A modern steam power plant comprises of the following *components* :

1. Boiler
   - (*i*) Superheater
   - (*ii*) Reheater
   - (*iii*) Economiser
   - (*iv*) Air-heater
2. Steam turbine
3. Generator
4. Condenser
5. Cooling towers
6. Circulating water pump
7. Boiler feed pump
8. Wagon tippler
9. Crusher house
10. Coal mill
11. Induced draught fans
12. Ash precipitators
13. Boiler chimney
14. Forced draught fans
15. Water treatment plant
16. Control room
17. Switch yard.

3.4. ESSENTIAL REQUIREMENTS OF STEAM POWER STATION DESIGN

The *essential requirements of steam power station design are* :

1. Reliability
2. Minimum capital cost
3. Minimum operating and maintenance cost
4. Capacity to meet peak load effectively
5. Minimum losses of energy in transmission
6. Low cost of energy supplied to the consumers
7. Reserve capacity to meet future demands.

The above essential requirements depend to a large extent on the following :

(*i*) Simplicity of design
(*ii*) Subdivision of plant and apparatus
(*iii*) Use of automatic equipment
(*iv*) Extensibility.

3.5. SELECTION OF SITE FOR STEAM POWER STATION

The following points should be taken into consideration while *selecting the site* for a steam power station :

1. Availability of raw material
2. Nature of land
3. Cost of land
4. Availability of water

5. Transport facilities
6. Ash disposal facilities
7. Availability of labour
8. Size of the plant
9. Load centre
10. Public problems
11. Future extensions.

1. **Availability of raw material.** Modern steam power stations using coal or oil as fuel require huge quantity of it per annum. A thermal power plant of 400 MW capacity requires 5000 to 6000 tonnes of coal per day. Therefore, it is necessary to locate the plant as far as possible near the coalfields in order to save the transportation charges. Besides transportation charges, a plant located away from the coalfields, cannot always depend on the coal deliveries in time (*i*) as there may be failure of transportation system, (*ii*) there may be strike etc. at the mines. For these reasons a considerable amount of coal must be stored at the power stations, this results in :

(*i*) increased investment ;

(*ii*) increased space required at the site of the plant for the storage ;

(*iii*) losses in storage ; and

(*iv*) additional staff requirement.

If it is not possible to locate the plant near the coalfields then the plant should be located as near the railway station as possible. Even if this is not possible then at least arrangement should be made for railway siding to the power plant so that the coal wagons can be shunted from the station to the site of power plant. This applies to plants using oil as fuel, as well.

2. **Nature of land.** The type of the land to be selected should have *good bearing capacity* as it has to withstand the *dead load* of the plant and the *forces transmitted to the foundation* due to the machine operations. The minimum bearing capacity of the land should be 1 MN/m^2.

3. **Cost of land.** Considerable area is required for the power stations. The cost of the land for that purpose should be reasonable. The large plants in the heart of big cities and near the load centre are not economical as the cost of land is very high.

4. **Availability of water.** Steam power stations use water as the working fluid which is repeatedly evaporated and condensed. Theoretically there should be no loss of water, but in fact some make up water is required. Besides this, considerable amount of water is required for condensers. A large quantity of water is also required for disposing the ash if hydraulic system is used. It is, therefore, necessary to locate the power plant near the water source which will be able to supply the required quantity of water throughout the year.

5. **Transport facilities.** Availability of proper transport facilities is another important consideration in locating the thermal power station. It is always necessary to have a railway line available near the power station for bringing in heavy machinery for installation and for bringing the fuel.

6. **Ash disposal facilities.** The ash handling problem is more serious than coal handling because it comes out in hot condition and it is highly corrosive. Its effect on atmospheric pollution are more serious as the human health is concerned. Therefore, there must be sufficient space to dispose of large quantity of ash.

In a power station of 400 MW capacity 10 hectares area is required per year if the ash is dumped to a height of 6.5 metres.

7. **Availability of labour.** During construction of plant enough labour is required. The labour should be available at the proposed site at cheap rate.

8. **Size of the plant.** The expenses involved in electric transmission from a *small plant* are *relatively severe*, owing to the impracticability of using high voltages, so that the electric transmission feature alone becomes dominant in the location of the plant. It case of *large plants*, the costs of transporting enormous quantities of coal and water are considerably high ; therefore, the plant

must be located near the pit head provided the required water quantity must be available as near as possible. The large plants should be located close to the railroad offering adequate services. The economic significance of the large plant with small one is much greater than the mere ratio of size.

9. **Load centre.** A power station must be located *near the loads* to which it is supplying power. However, a plant cannot be located near all loads. As such C.G. of the loads is determined with reference to two arbitrarily chosen axes, this C. G. is known as the load centre (see Fig. 3.3).

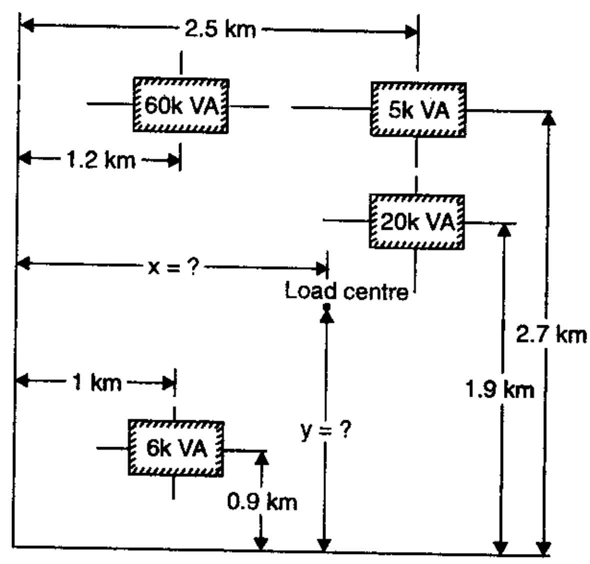


Fig. 3.3. Load centre.

The power plant should be located, as far as possible near the load centre in order to *minimize the cost of transmission lines and also the losses occuring in them.*

10. **Public problems.** In order to avoid the nuisance from smoke, fly ash and heat discharged from the power plant, it should be located far away from the towns.

11. **Future extensions.** The choice of the site should allow for economical extensions consistent with the estimated growth of load.

12. Consent of Town Planning Department must be sought in case urban area is selected for the purpose.

3.6. CAPACITY OF STEAM POWER PLANT

The power plant capacity can be determined by studying *the load duration curve and the anticipated future demands. The minimum capacity of the plant must be equal to at least the peak load.*

(*i*) In case of "*Small loads*", it may be economical to install two units of equipment, each being capable of supplying the maximum demand independently. In the event of failure of one unit or during maintenance etc. at least one unit can be used to maintain uninterrupted supply of energy.

(*ii*) In case of "*medium power plants*", usually the number of units is more than two with the total installed capacity equal to the *maximum demand plus the capacity of two large units.*

(*iii*) "*Large power plants*" are generally *conservately rated.* In the case of steam turbines, there is an overload capacity of 10 to 15% of the rated capacity. With a number of units, peak load can be easily adjusted by overloading some units temporarily.

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.*

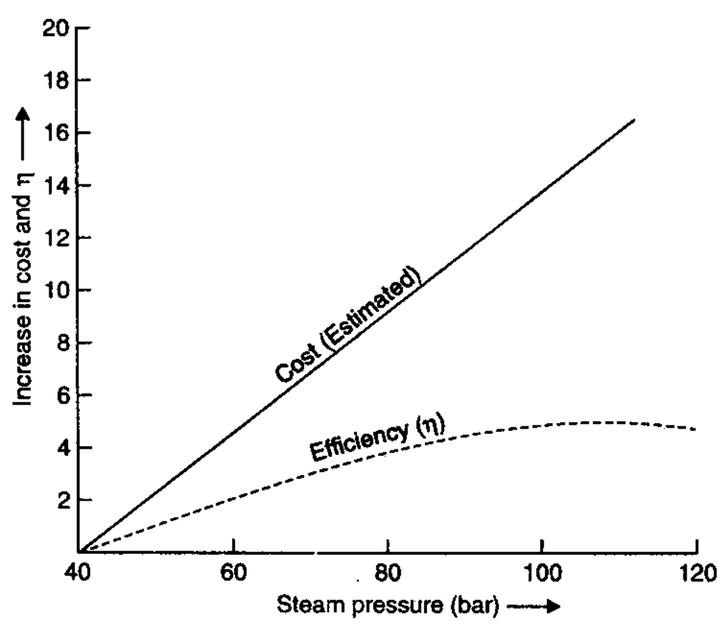


Fig. 3.4. Effect of steam pressure on cost and η (efficiency)

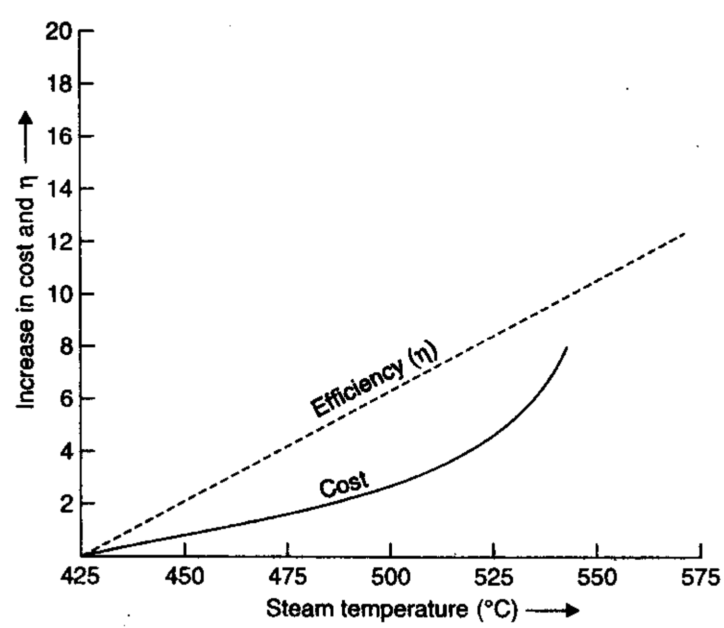


Fig. 3.5. Effect of steam temperature on cost and η (efficiency).

Fig. 3.6 shows that *as the average output of plant units increases the percentage total capital cost decreases.*

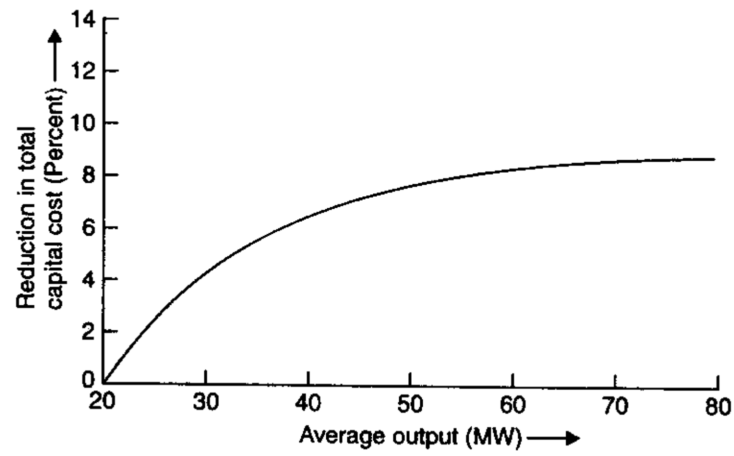


Fig. 3.6

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

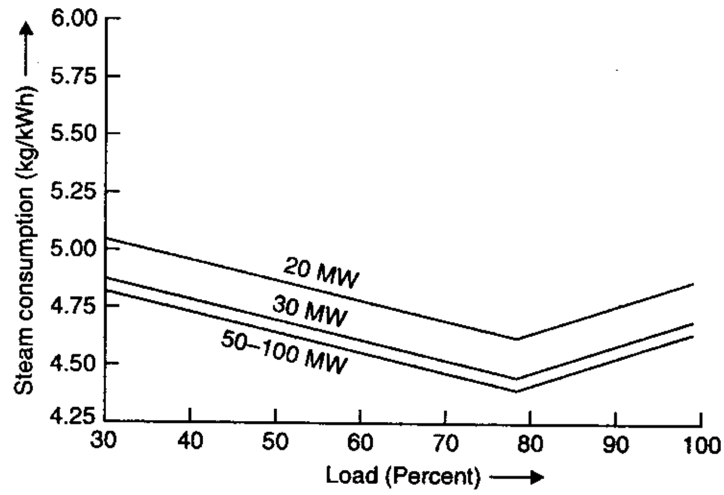


Fig. 3.7

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.

Fuel handling plant needs extra attention, while designing a thermal power station, as almost 50 to 60 percent of the total operating cost consists of fuel purchasing and handling. *Fuel system is designed in accordance with the type and nature of fuel.*

Continuously increasing demand for power at lower cost calls for setting up of higher capacity power stations. Rise in capacity of the plant poses a problem in coal supply system from coal mines to the power stations. The coal from coal mines may be transported by the following means :

1. Transportation by sea or river,
2. Transportation by rail,
3. Transportation by ropeways,
4. Transportation by road, and
5. Transportation of coal by pipeline.

The pipeline coal transport system offers the following *advantages* :

1. It provides simplicity in installation and increased safety in operation.
2. More economical than other modes of transport when dealing with large volume of coal over long distances.
3. This system is continuous as it remains unaffected by the vagaries of climate and weather.
4. High degree of reliability.
5. Loss of coal during transport due to theft and pilferage is totally eliminated.
6. Manpower requirement is low.

3.8.2. Requirements of Good Coal Handling Plant

1. It should need minimum maintenance.
2. It should be reliable.
3. It should be simple and sound.
4. It should require a minimum of operatives.
5. It should be able to deliver requisite quantity of coal at the destination during peak periods.
6. There should be minimum wear in running the equipment due to abrasive action of coal particles.

3.8.3. Coal Handling Systems

"*Mechanical handling*" of coal is preferred over "*manual handling*" due to the following *reasons* :

1. Higher reliability.
2. Less labour required.
3. Economical for medium and large capacity plants.
4. Operation is easy and smooth.
5. Can be easily started and can be economically adjusted according to the need.
6. With reduced labour, management and control of the plant becomes easy and smooth.
7. Minimum labour is put to unhealthy condition.
8. Losses in transport are minimised.

Disadvantages :

1. Needs continuous maintenance and repair.
2. Capital cost of the plant is increased.
3. In mechanical handling some power generated is usually consumed, resulting in less net power available for supply to consumers.

3.8.4. Coal Handling

Refer Fig. 3.8.

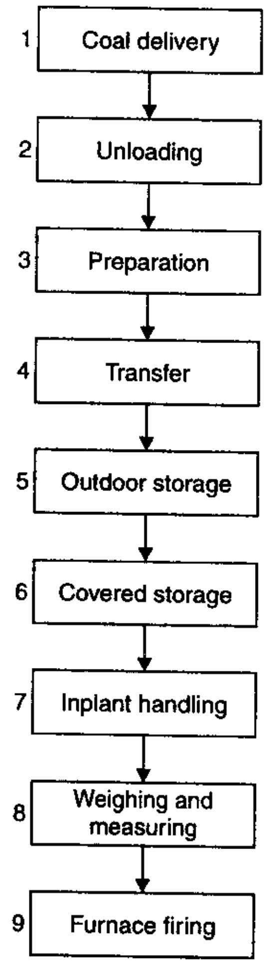


Fig. 3.8. Various stages in coal handling.

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.

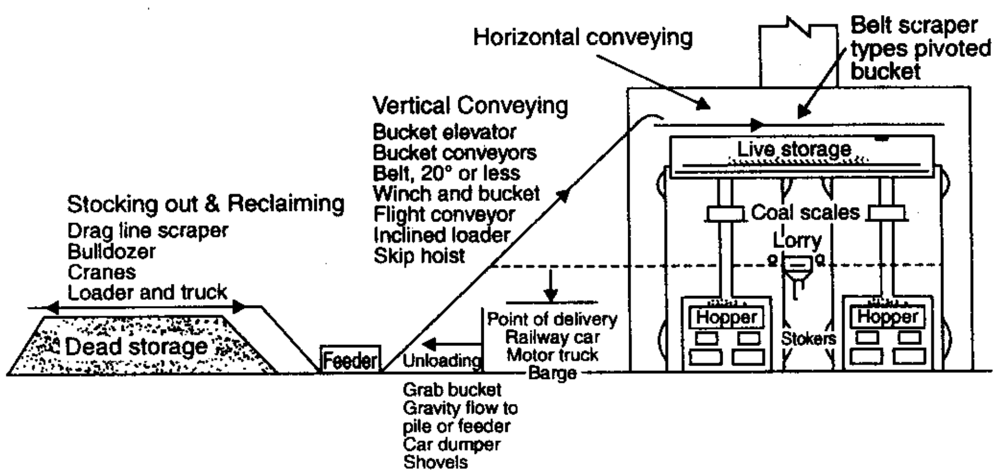


Fig. 3.9. Outline of coal handling equipment.

— Stations which cannot make use of navigation facilities may be supplied coal either by rail or trucks. Transportation of coal by *trucks* is usually used in case the *mines are not far off* or when the necessary *railway facilities are not available.* In case rail transport is to be adopted, the necessary siding for receiving the coal should be brought as near the station as possible.

2. **Unloading.** The type of coal unloading equipment used in the plant depends upon the type of out-plant handling mode as road, rail or ship. If coal is delivered by trucks, there is no need of unloading device as the trucks may dump the coal to the outdoor storage. Coal is easily handled if the lift trucks with scoop are used (see Fig. 3.10).

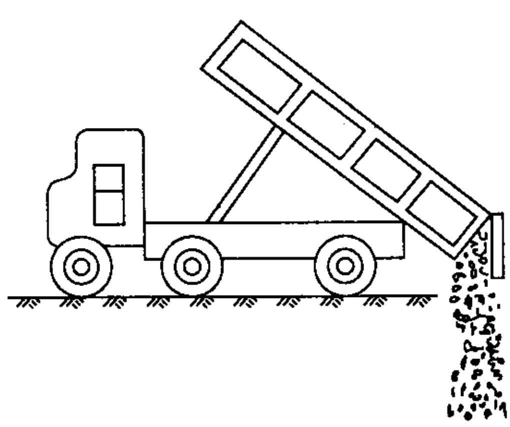


Fig. 3.10. Lift truck with scoop.

When the coal is transported by sea, the unloading equipment normally used is given below :

(*i*) Portable conveyors

(*ii*) Coal accelerators

(*iii*) Coal towers

(*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 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.*

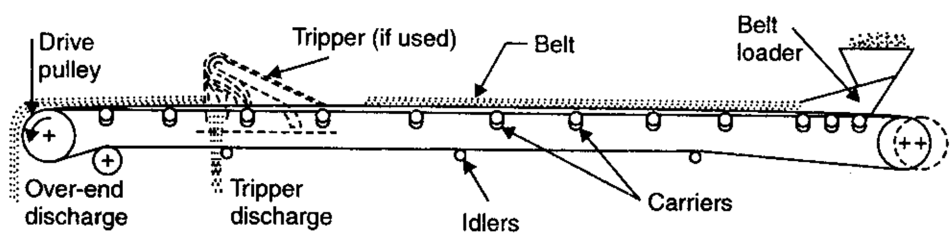


Fig. 3.11. Belt conveyor.

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.

2. As the maximum inclination at which coal can be transferred by this arrangement is limited, in order to transfer coal at considerable heights as involved in modern stations, the *length of the conveyor becomes excessive.*

(*ii*) **Screw conveyor.** Refer Fig. 3.12. It consists of an endless helicoid screw fitted to a shaft. The driving mechanism is connected to one end of the shaft and the other end of the shaft is supported in an enclosed ball bearing. The screw while rotating in a trough/housing transfers coal from one end to the other end. The following particulars relate to this conveyor.

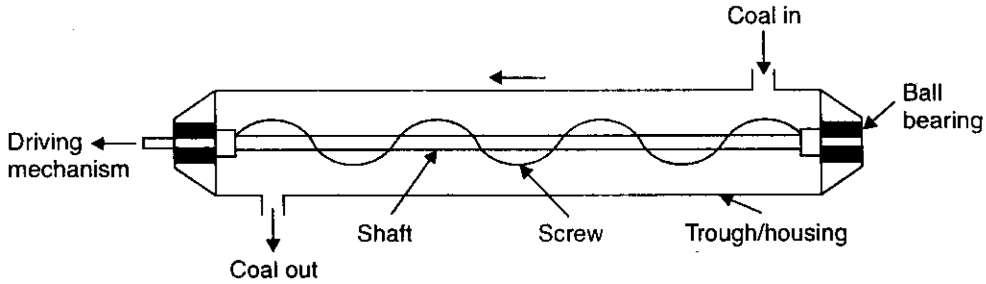


Fig. 3.12. Screw conveyor.

Diameter of the screw	......15 to 50 cm
Speed	......70 to 120 r.p.m.
Maximum capacity	......125 tonnes/hour.

(*iii*) **Vee bucket elevator.** In this type of elevator, steel V-shaped buckets are rigidly fastened to an endless chain going round sprockets. The buckets are equally spaced on the chain, and receive their load by dipping into coal pocket at the lower end of the system. The material elevated in V-buckets is discharged either by centrifugal force at the top of the elevator or by drawing back the buckets on the discharged side.

Advantages :

1. Less power is required for operating the equipment (as the coal is carried not dragged).
2. Coal can be discharged at elevated places.
3. Less floor area is required.

Disadvantages :

Its capacity is limited and hence *not suitable for large capacity stations.*

Fig. 3.13 shows a '**bucket elevator**' which is used for moderate lifts. The material is continuously handled and can be both hoisted and conveyed.

(*iv*) **Pivoted bucket conveyor.** This conveyor consists of malleable iron buckets suspended by pivots midway between the joints of two endless chains, which are driven by a motor located at some convenient point, usually at the top of a vertical rise. While travelling horizontally, buckets maintain their position due to gravity and support the joints. The conveyor is loaded by passing below a crusher. The coal is charged into the bunker by a tripping device.

Advantages :

1. Low operational cost.
2. High capacity.
3. Less floor area requirement.

Disadvantages :

High initial cost of the equipment.

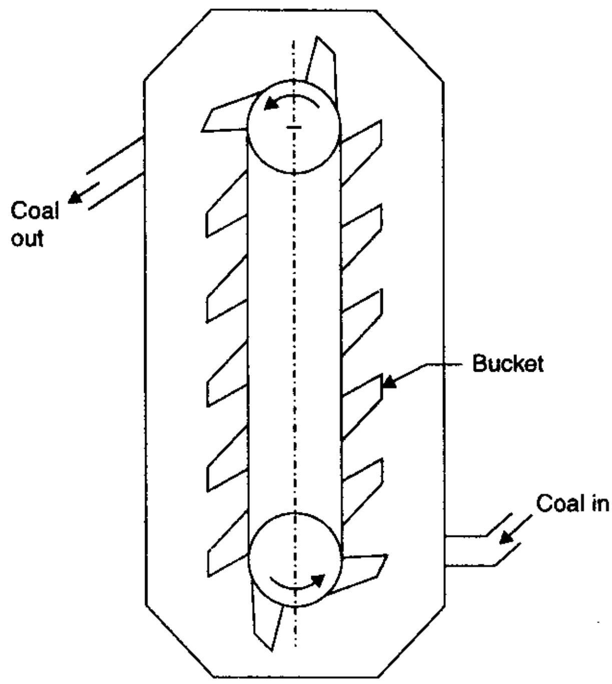


Fig. 3.13. Bucket elevator.

(*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.

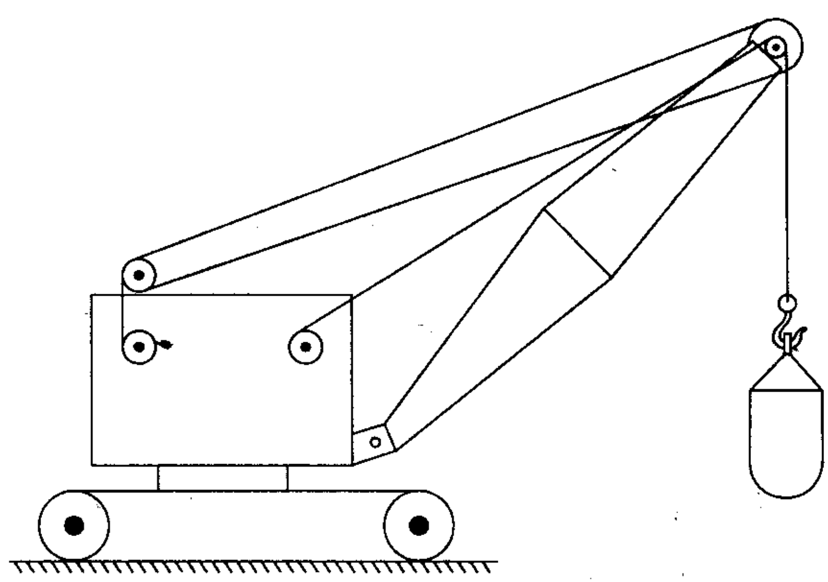


Fig. 3.14. Grab bucket conveyor.

(*vi*) **Flight conveyor (or Scraper).** It is generally used for transfer of coal when filling of number of storage bins situated under the conveyor is required. It consists of one or two strands of chain, to which steel scrapers are attached. The scraper scraps the coal through a trough and the coal is discharged in the bottom of the trough as shown in Fig. 3.15. Capacity of a conveyor of this type may range from 10 to 100 tonnes per hour. It is used extensively for conveying coal horizontally and for inclinations up to 35°.

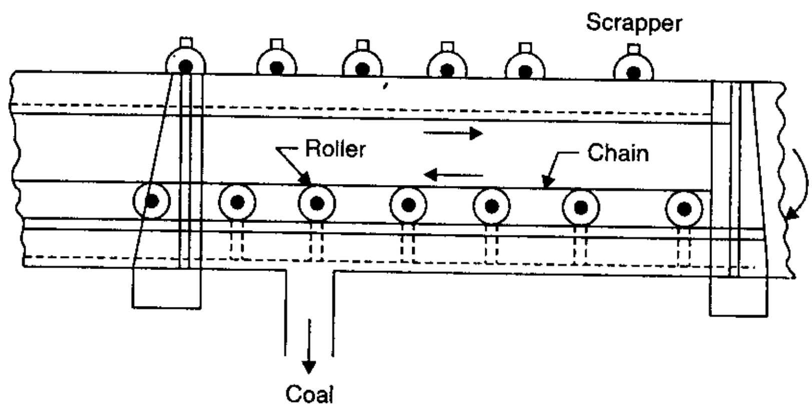


Fig. 3.15. Flight conveyor.

Advantages :

1. It has a rugged construction.
2. Requires little operational care.
3. It can be used for transfer of coal as well as ash.
4. Its speed can be easily regulated.
5. It needs small headroom.

Disadvantages :

1. Excessive wear due to dragging action.
2. High maintenance cost.
3. The speed is limited to 30 m/min. to reduce the abrasive action of material handled.
4. Power consumption is more (due to dragging action).

(*vii*) **Skip hoist.** Refer Fig. 3.15 (*a*). It is used for high lifts and handling is non-continuous. This arrangement is simple and cheap and operation costs including labour and maintenance are low. The skip hoist is the oldest and simplest means of elevating coal or ash and is favourite of engineers particularly in ash handling.

5. Storage of coal. It is very essential that adequate quantity of coal should be stored. Storage of coal gives protection against the interruption of coal supplies when there is delay in transportation of coal or due to strikes in coal mines. In regard to storage of coal the following points should be considered :

(*i*) There should be no standing water near the storage area.

(*ii*) At a place where a well-drained area is not available, drainage ditches should be installed.

(*iii*) Storage area should be solid and not loos[illegible]ous.

(*iv*) Piles should be built up in successive layers and as far as possible compact.

(*v*) Conical piling should be avoided.

(*vi*) In order to protect against wind erosion, piles should be sealed.

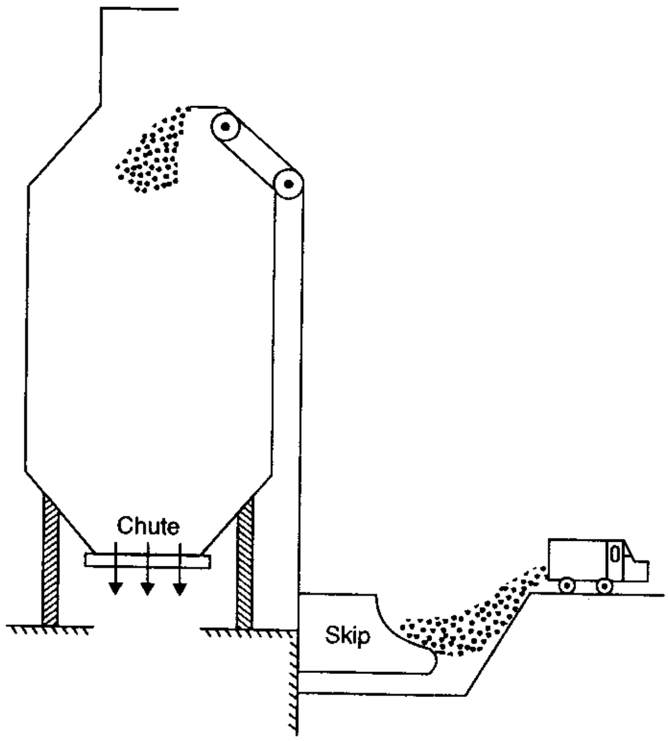


Fig. 3.15. (a) Skip hoist.

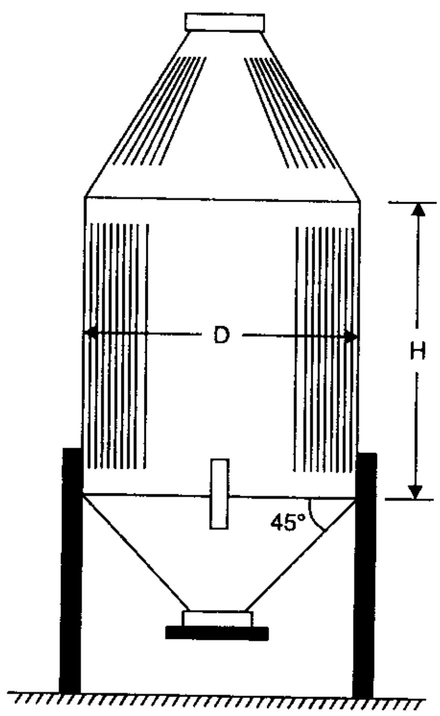


Fig. 3.16. Cylindrical bunker.

(*vii*) Storage should be done in such a way that the handling cost is minimum.

(*viii*) At storage site fire fighting equipment should be easily available.

'Live storage' is a covered storage provided in plants, sufficient to meet one day requirement of the boiler. Bunkers (Fig. 3.16) made of steel or reinforced concrete are used to store the coal ; from here the coal is transferred to the boiler grates.

6. Inplant handling. It may refer to any one of the following :

(*i*) Coal handling between the final storage and the firing equipment.

(*ii*) A conveying system to feed coal from any bunker section to any firing unit and to move coal from one bunker section to another.

(*iii*) Inplant handling may mean no more than chutes to direct flow into individual firing units and gates or valves to control the flow.

Inplant handling may include the equipment such as belt conveyors, screw conveyors, bucket elevators etc. to transfer the coal. Weigh lorries, hoppers and automatic scales are used to record the quantity of coal delivered to the furnace.

7. Weighing and measuring. To weigh the quantity of coal the following equipment is used :

(*i*) Weigh bridge
(*ii*) Belt scale
(*iii*) Weigh lorry
(*iv*) Automatic scale.

8. Furnance firing. Refer Articles 3.9 and 3.10.

3.8.5. Layout of a Fuel Handling Equipment

Fig. 3.17 shows a schematic layout of a fuel handling equipment of a modern steam power plant where coal (a solid fuel) is used. Brief description is given below :

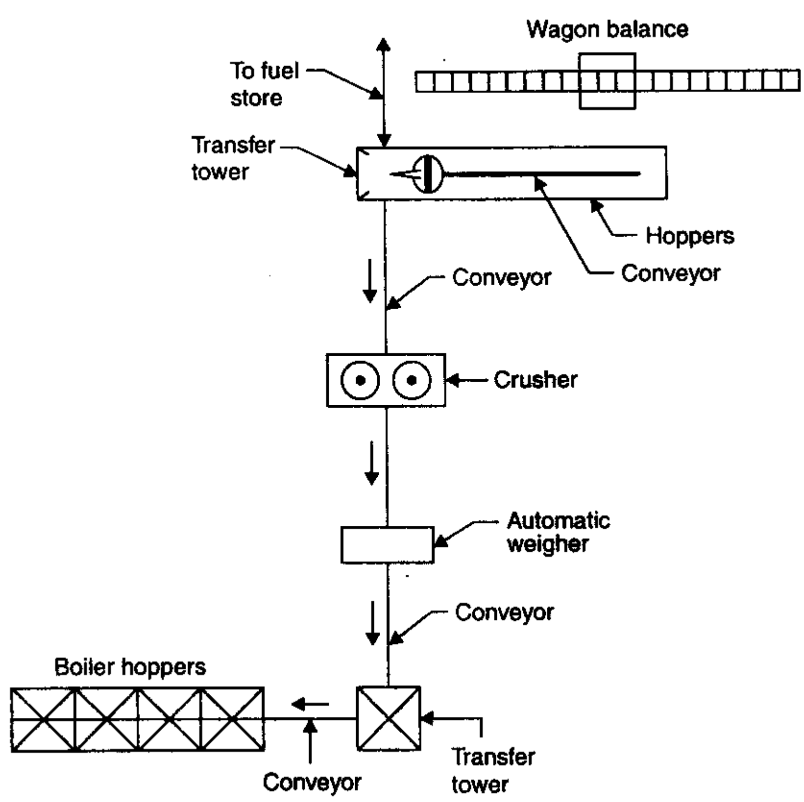


Fig. 3.17. Layout of a fuel handling equipment.

— 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 than coal per kg of steam generated, many operators select fuel oil burners rather than stokers because of the simplicity and cleanliness of storing and transporting the fuel from storage to burner.

Depending on the type of combustion equipment, boilers may be classified as follows :

1. Solid fuels fired :

(*a*) Hand fired

(*b*) Stoker fired

(*i*) Overfeed stokers

(*ii*) Underfeed strokers.

(*c*) Pulverised fuel fired

(*i*) Unit system

(*ii*) Central system

(*iii*) Combination of (*i*) and (*ii*).

2. Liquid fuel fired :

(*a*) Injection system

(*b*) Evaporation system

(*c*) Combination of (*a*) and (*b*).

3. Gaseous fuel fired :

(*a*) Atmospheric pressure system

(*b*) High pressure system.

3.9.2. Combustion Equipment for Solid Fuels—Selection Considerations

While selecting combustion equipment for solid fuels the following considerations should be taken into account :

1. Initial cost of the equipment.
2. Sufficient combustion space and its ability to withstand high flame temperature.
3. Area of the grate (over which fuel burns)
4. Operating cost
5. Minimum smoke nuisance.
6. Flexibility of operation.
7. Arrangements for thorough mixing of air with fuel for efficient combustion.

3.9.3. Burning of Coal

The two most commonly used methods for the burning of coal are :

1. Stroker firing
2. Pulverised fuel firing.

The selection of one of the above methods depends upon the following factors :

(*i*) Characteristics of the coal available.

(*ii*) Capacity of the boiler unit.

(*iii*) Load fluctuations.

(*iv*) Station load factor.

(*v*) Reliability and efficiency of the various types of combustion equipment available.

3.9.3.1. Stoker Firing

*A "**stoker**" is a power operated fuel feeding mechanism and grate.*

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 coal 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 fuel.
3. There is always a certain amount of loss of coal in the form of riddling through the grates.
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 for 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 and in case of underfeed stokers, the coal is admitted into the furnace *below* the point of air admission.

1. Overfeed stokers

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

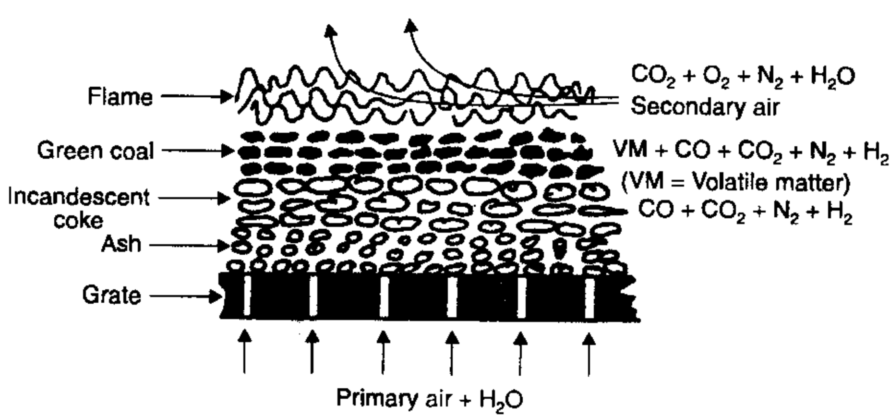


Fig. 3.18. Principle of overfeed stoker.

The fuel bed section receives fresh coal on top surface. The ignition plane lies between green coal and incandescent coke.

The air (with its water vapour content from atmosphere) enters the bottom of the grate under pressure. In flowing through the grate opening the air is heated while it cools the grate. The warm air then passes through a layer of hot ashes and picks up the heat energy.

The region immediately above the ashes contains a mixture of incandescent coke and ash, coke content increasing in upward direction. As the air comes in contact with incandescent coke, the oxygen reacts with carbon to form carbondioxide. Water vapour entering with the air reacts with coke to form CO_2, CO and free H_2. Upon further travel through the incandescent region some of the CO_2 reacts with coke to form CO. Hence no free O_2 will be present in the gases leaving the incandescent region.

Fresh fuel undergoing distillation of its volatile matter forms the top-most layer of the fuel bed. Heat for distillation and eventually ignition comes from the following *four sources* :

(*i*) By conduction from the incandescent coke below.

(*ii*) From high temperature gases diffusing through the surface of the bed.

(*iii*) By radiation from flames and hot gases in the furnace.

(*iv*) From the hot furnace walls.

The ignition zone lies directly below the raw fuel undergoing distillation.

To burn the combustible gases, additional secondary air must be fed into the furnace to supply the needed oxygen. The secondary air must be injected at considerable speed to create turbulence and to penetrate to all parts of the area above the fuel bed. The combustible gases then completely burn in the furnace.

Fuel, coke and ash in the fuel bed move in direction opposite to that of air and gases. Raw fuel continually drops on the surface of the bed. The rising air feed cools the ash until it finally rests in a plane immediately adjacent to the grate.

Types of overfeed stokers

The "overfeed stokers" are used for large capacity boiler installation where the coal is burnt with pulverisation.

These stokers are mainly of following two types :

1. Travelling grate stoker

(*a*) Chain grate type (*b*) Bar grate type

2. Spreader stoker.

1. Travelling grate stoker

These stokers may be *chain grate type or bar grate type*. These two differ only in the details of grate construction.

Fig. 3.19 shows a **"Chain grate stoker"**.

A chain grate stoker consists of flexible endless chain which forms a support for the fuel bed. The chain travels over two sprocket wheels one at the front and one at the rear of furnace. The front sprocket is connected to a variable speed drive mechanism. The speed of the stroker is 15 cm to 50 cm per minute.

The coal bed thickness is shown for all times by an index plate. This can be regulated either by adjusting the opening of fuel grate or by the speed control of the stoker driving motor.

The air is admitted from the underside of the grate which is divided into several compartments each connected to an air duct. The grate should be saved from being overheated. For this, coal should have sufficient ash content which will form a layer on the grate.

Since there is practically no agitation of the fuel bed, non-coking coals are best suited for chain grate stokers.

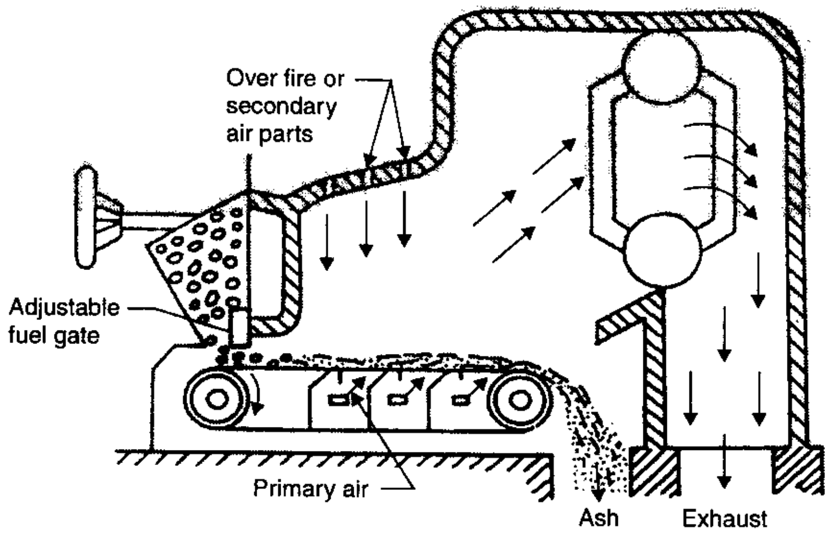


Fig. 3.19. Chain grate stoker.

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.*

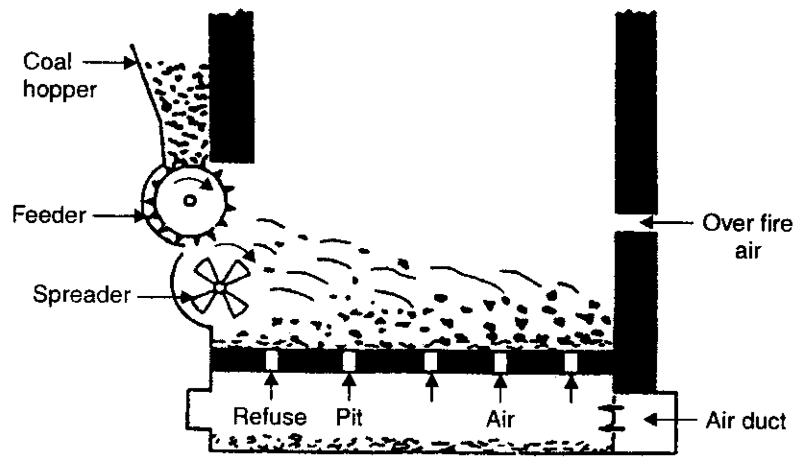


Fig. 3.20. Spreader stoker.

— This type of stoker can be used for boiler capacities from 70000 kg to 140000 kg of steam per hour. The heat release rate of 10×10^6 k cal/m^2-hr is possible with *stationary grate* and of 20×10^6 k cal/m^2-hr is possible with *travelling grate.*

Advantages :

1. A wide variety of coal can be burnt.
2. This stoker is simple to operate, easy to light up and bring into commission.
3. The use of high temperature preheated air is possible.
4. Operation cost is considerably low.
5. The clinking difficulties are reduced even with coals which have high clinkering tendencies.
6. Volatile matter is easily burnt.
7. Fire arches etc. are generally not required with this type of stokers.
8. As the depth of coal bed on the grate is usually limited to 10 to 15 cm only, fluctuating loads can be easily met with.

Disadvantages :

1. It is difficult to operate spreader with varying sizes of coal with varying moisture content.
2. Fly-ash is much more.
3. No remedy for clinker troubles.
4. There is a possibility of some fuel loss in the cinders up the stack because of the thin fuel bed and suspension burning.

2. Underfeed feeders

Principle of operation. Refer Fig. 3.21 (*a*).

— *The underfeed principle is suitable for burning the semi-bituminous and bituminous coals.*

— Air entering through the holes in the grate comes in contact with the raw coal (green coal). Then it passes through the incandescent coke where reactions similar to overfeed system take place. The gases produced then pass through a layer of ash. The secondary air is supplied to burn the combustible gases.

The underfeed stokers fall into two main groups, the *single retort* and *multi-retort stokers.*

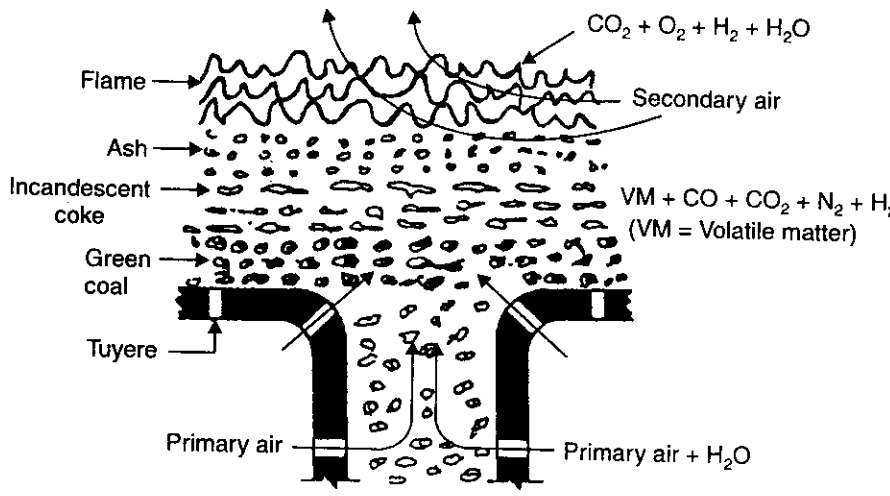


Fig. 3.21. (*a*) Principle of underfeed feeders.

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

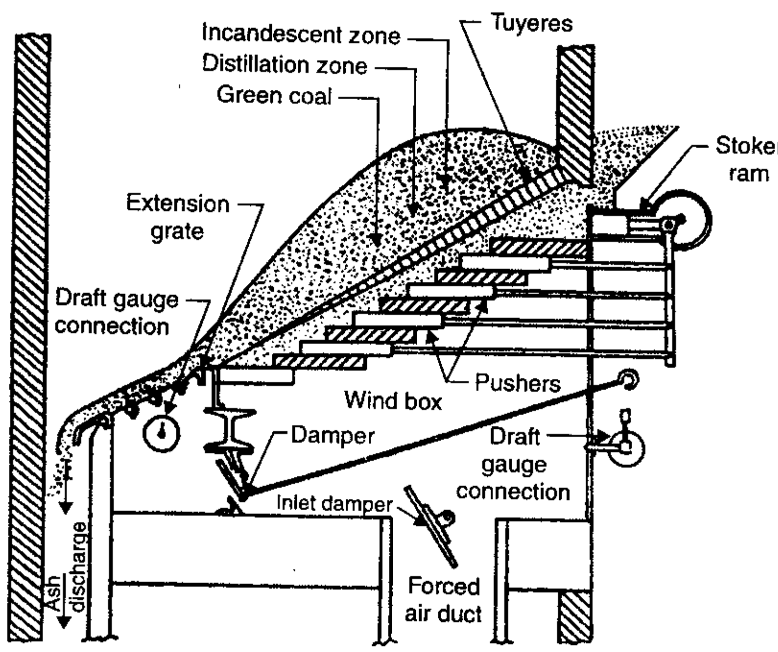


Fig. 3.21. (*b*) Multi-retort underfeed stokers.

— 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.

— The height and profile of the fuel bed is controlled by *secondary*, or *distributing rams*. These rams oscillate parallel to the retort axes, the length of their stokes can be varied as needed. They slowly move the entire fuel bed down the length of the stoker.

— At the rear of the stoker the partly burned fuel bed moves onto an *extension grate* arranged in sections. These sections also oscillate parallel to the fuel-bed movement. The sharp slope of the stoker aids in moving the fuel bed. Fuel-bed movement keeps it slightly agitated to break up clinker formation. From extension grate the ash moves onto ash dump plate. Tilting the dump plate at long intervals deposits the ash in the ashpit below.

— *Primary air* from the wind box underneath the stoker enters the fuel bed through holes in the vertical sides of the tuyeres. The extension grate carries a much thinner fuel bed and so must have a lower air pressure under it. The air entering from the main wind box into the extension-grate wind box is regulated by a *controlling air damper*.

In this stoker the number of retorts may vary from 2 to 20 with coal burning capacity ranging from 300 kg to 2000 kg per hour per retort.

Underfeed stokers are *suitable for non-clinkering, high voltatile coals having caking properties and low ash contents.*

Advantages :

1. High thermal efficiency (as compared to chain grate stokers).
2. Combustion rate is considerably higher.
3. The grate is self cleaning.
4. Part load efficiency is high particularly with multi-retort type.
5. Different varieties of coals can be used.
6. Much higher steaming rates are possible with this type of stoker.
7. Grate bars, tuyeres and retorts are not subjected to high temperature as they remain always in contact with fresh coal.
8. Overload capacity of the boiler is high as large amount of coal is carried on the grate.
9. Smokeless operation is possible even at very light load.
10. With the use of clinker grinder, more heat can be liberated out of fuel.
11. Substantial amount of coal always remains on the grate so that the boiler may remain in service in the event of temporary breakdown of the coal supply system.
12. It can be used with all refractory furnaces because of non-exposure of stoker mechanism to the furnace.

Disadvantages :

1. High initial cost.
2. Require large building space.
3. The clinker troubles are usually present.
4. Low grade fuels with high ash content cannot be burnt economically.

3.9.3.2. Pulverised fuel firing

In pulverised fuel firing system the *coal is reduced to a fine powder with the help of grinding mill and then projected into the combustion chamber with the help of hot air current.* The amount of air required (known as *secondary air*) to complete the combustion is supplied separately to the combustion chamber. The resulting turbulence in the combustion chamber helps for uniform mixing of fuel and air and thorough combustion. *The amount of air which is used to carry the coal and to dry* *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.

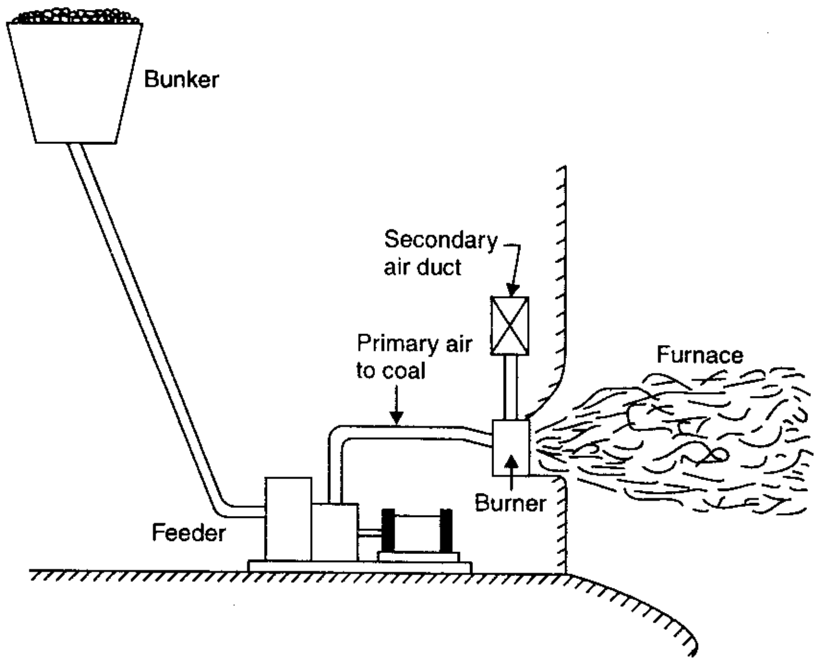


Fig. 3.22. Elements of pulverised coal system.

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 evaporation 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 flame propagation.
14. The furnace volume required is considerably less.

Disadvantages :

1. High capital cost.
2. Lot of fly-ash in the exhaust, which makes the removing of fine dust uneconomical.
3. The possibility of explosion is more as coal burns like gas.
4. The maintenance of furnace brickwork is costly.
5. Special equipment is needed to start this system.
6. The skilled operators are required.
7. A separate coal preparation plant is necessary.
8. High furnace temperatures cause rapid deterioration of the refractory surfaces of the furnace.
9. Nuisance is created by the emission of very fine particles of grit and dust.
10. Fine regular grinding of fuel and proper distribution to burners is usually difficult to achieve.

Pulverised Fuel Handling

Basically, pulverised fuel plants may be divided into the following *two systems* :

1. Unit system
2. Central system.

Unit system :

A unit system is shown in Fig. 3.23.

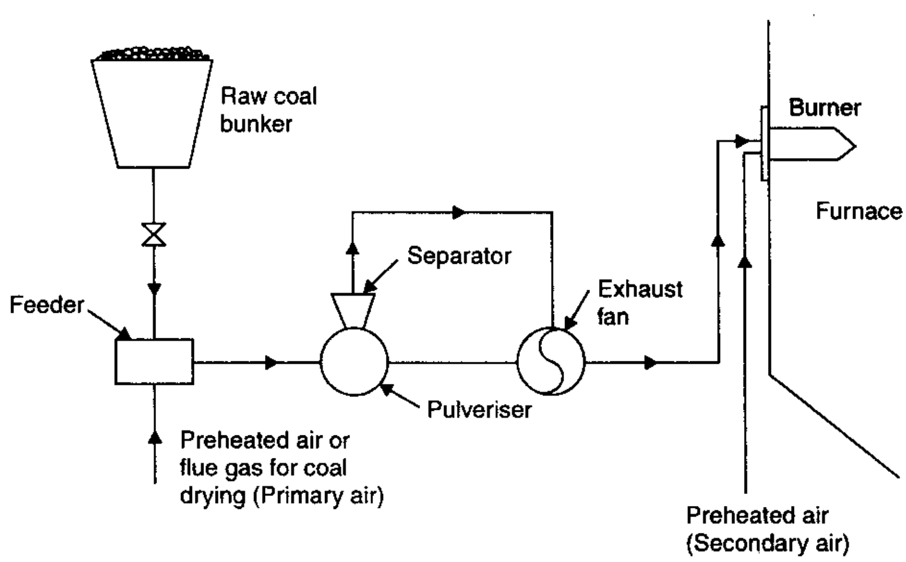


Fig. 3.23. Unit system.

Most pulverised coal plants are now being installed with unit pulveriser.

The *unit system* is so called from the fact that each burner or burner group and the pulveriser constitute a unit. Crushed coal is fed to the pulverising mill at a variable rate governed by the combustion requirements of the boiler and furnace. Primary air is admitted to the mill and becomes the transport air which carries the coal through the short delivery pipe to the burner. This air may be preheated if mill drying is desirable.

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.

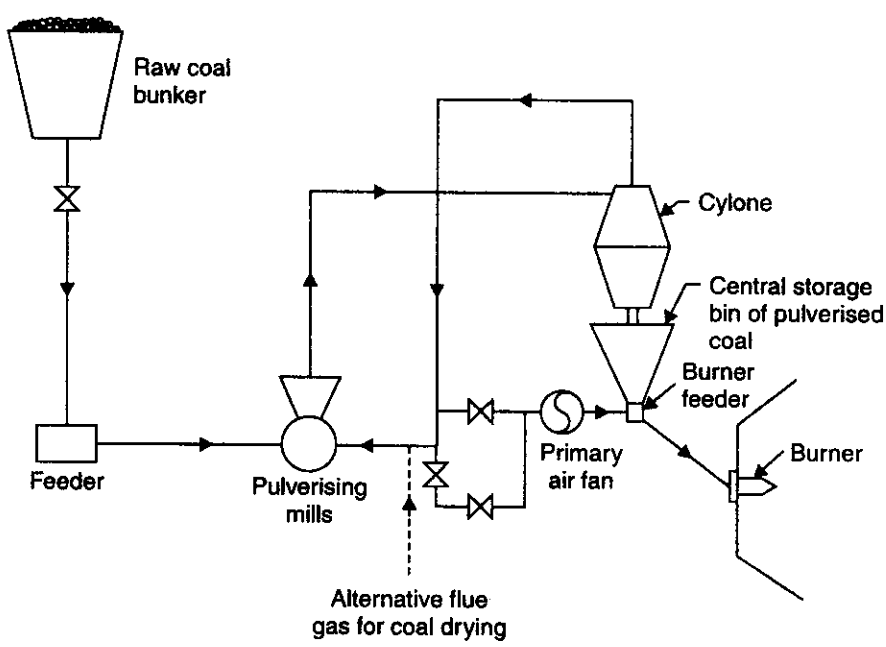


Fig. 3.24. Central system.

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 pulverisers 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 hours supply of pulverised coal. From the bin the coal is metered to the burners by motor-driven feeders of varied design. Primary air, added at the feeders, floats the coal to the burners.

Advantages :

1. Offers good control of coal fineness.
2. The pulverising mill may work at constant load because of the storage capacity between it and the burners.
3. The boiler aisels are unobstructed.
4. More latitude in the arrangement and number of burners is allowed to the designers.
5. The large storage is protection against interruption of fuel supply to the burners.
6. Less labour is required.
7. Power consumption per tonne of coal handled is low.
8. Burners can be operated independent of the operation of coal preparation plant.
9. Fans handle only air, as such, there is no problem of excessive wear as in case of unit system, where air and coal both are handled by the fan.

Disadvantages :

1. Driers are usually necessary.
2. Fire hazard of quantities of stored pulverised coal.
3. Central preparation may require a separate building.
4. Additional cost and complexity of coal transportation system.
5. Power consumption of auxiliaries is high.

Pulveriser. Coal is pulverised in order to increase its surface exposure, thus promoting rapid combustion without using large quantities of excess air. A pulveriser is the most important part of a pulverised coal system. Pulverisers (sometimes called *mills*) are classified as follows :

1. Attrition mills
   (*i*) Bowl mills
   (*ii*) Ball and race mills.
2. Impact mills
   (*i*) Ball mills
   (*ii*) Hammer mills.

Pulverisers are driven by electric motors with the feeders either actuated by the main drive or by a small d.c. motor, depending upon the control used.

Ball and race mill. This a low speed unit in which grinding pressure is maintained by adjustable springs. The coal passes between the two rotating elements again and again until it has been pulverised to the desired degree of fineness. Fig. 3.25 shows a ball and race mill. Mill, feeder and fan require up to 14 kWh per tonne of coal pulverised.

Bowl mill. The bowl mill grinds the coal between a whirling bowl and rolls mounted on pivoted axes. Coal fed into the centre is thrown by centrifugal force against the sides of the bowl where it is pulverised between the sides of the bowl and the grinding ring. The fine and intermediate sizes are picked up from the top by an air current and carried into the separator above for classification. It consumes about 5 kWh of electricity per tonne of coal.

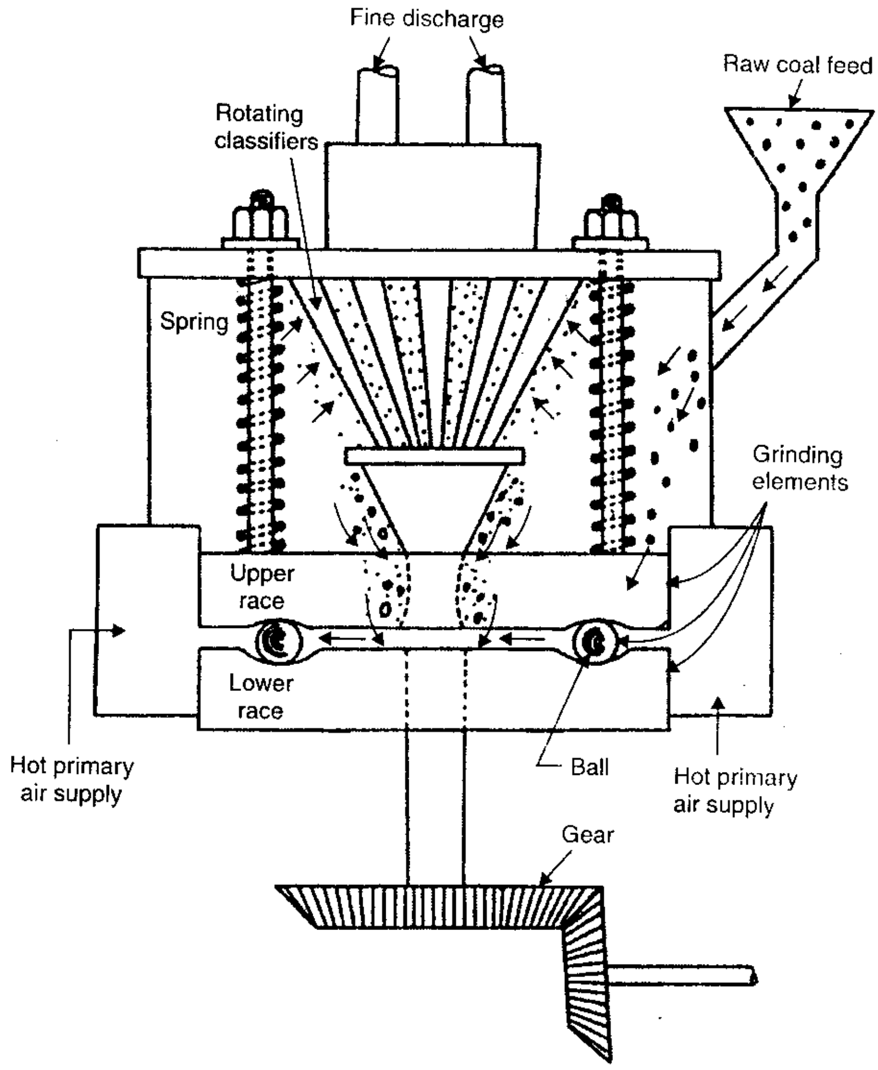


Fig. 3.25. Ball and race mill.

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. 3.27 shows the *principle of impact mill.*

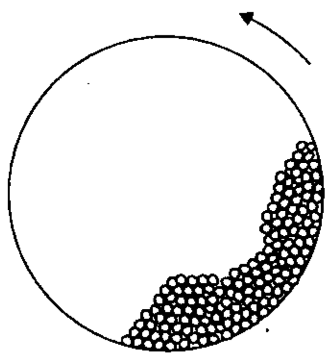


Fig. 3.26. Principle of ball mill.

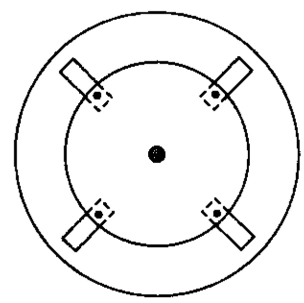


Fig. 3.27. Principle of impact mill.

3.9.4. Burners

Primary air that carries the powdered coal from the mill to the furnace is only about 20% of the total air needed for combustion. Before the coal enters the furnace, it must be mixed with additional air, known as *secondary air,* in burners mounted in the furnace wall. *In addition to the prime function of mixing, burners must also maintain stable ignition of fuel-air mix* and *control the flame shape and travel in the furnace.* Ignition depends on the rate of flame propagation. To prevent flash back into the burner, the coal-air mixture must move away from the burner at a rate equal to flame-front travel. *Too much secondary air can cool the mixture and prevent its heating to ignition temperature.*

The *requirements of a burner* can be summarised as follows :

(*i*) The coal and air should be so handled that there is stability of ignition.

(*ii*) The combustion is complete.

(*iii*) In the flame the heat is uniformly developed avoiding any superheat spots.

(*iv*) Adequate protection against overheating, internal fires and excessive abrasive wear.

3.9.4.1. Pulverised fuel burners

Pulverised fuel burners may be *classified* as follows :

1. Long flame burners
2. Turbulent burners
3. Tangential burners
4. Cyclone burners.

1. Long flame burners. These are also called U-flame or steamlined burners. In this type of burner coal is floated on a portion of air supply (primary air) and supplied to the burner in one stream. Secondary and tertiary air supplies are maintained as shown in Fig. 3.28. The length of flame is increased in the combustion chamber by downward initial flow of the flame. The flame produced is stable, long and intense but it can be made short and intense by adding much secondary air. Tertiary air enters through the burner and forms an envelope around the primary air and fuel and provides better mixing.

Furnaces for low volatile coal are equipped with such burners to give a long flame path for slower burning particles.

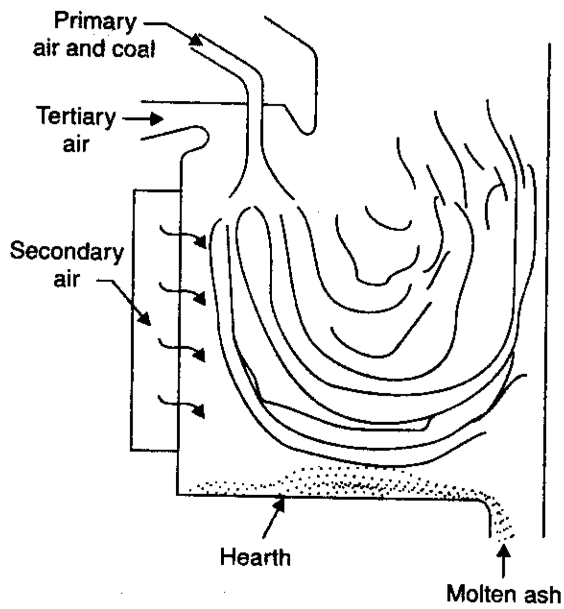


Fig. 3.28. Long flame burner.

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.

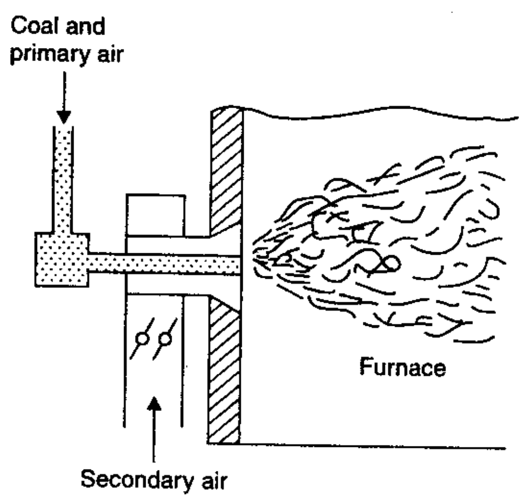


Fig. 3.29. Turbulent burner.

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 tangential to an imaginary circle formed at the centre. The swirling action produces adequate turbulence in the furnace to complete the combustion in a short period and avoids the necessity of producing high turbulence at the burner itself.

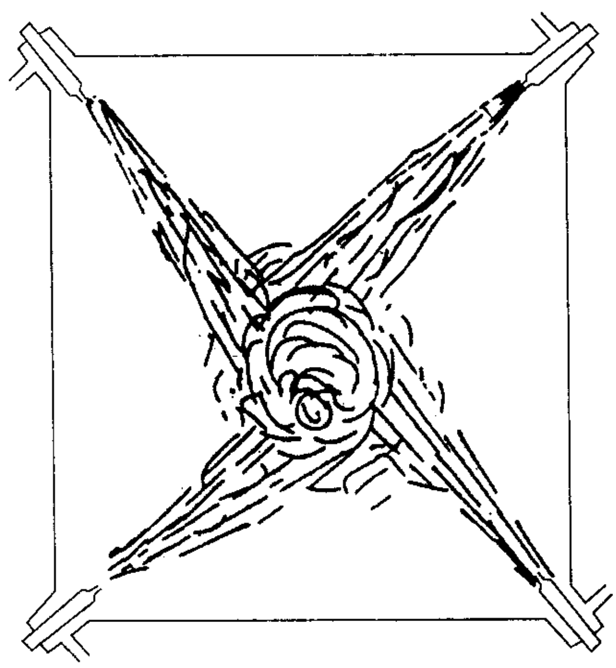


Fig. 3.30. Plan of furnace with tangential firing.

The tangential burners have the following *advantages* :

1. The parts of the burner are well-protected by furnace wall tubes.
2. The operation of these burners is very simple.
3. High heat release with complete and effective utilisation of furnace volume is possible.
4. The completeness of combustion is exceptionally good and a maximum degree of turbulence exists throughout the furnace.
5. Liquid, gaseous and pulverised fuels can be readily burned either separately or in combination.

4. Cyclone burners. Two main *disadvantages* associated with pulverised coal firing are :

(*i*) High cost.

(*ii*) 70% of the ash escapes as fly-ash which requires expensive dust collectors in the flue gas path.

These disadvantages are offset by a *cyclone burner.* In a cyclone burner coal is crushed to a maximum size of 6 mm and blows into a cylindrical cyclone furnace. The fuel is quickly consumed and liberated ash forms a molten film flowing over the inner wall of the cylinder. Owing to *inclination of the furnace*, the molten ash flows to an appropriate disposal system.

The description of a cyclone burner (developed by M/s Babcock and Wilcox) is given below : Refer Fig. 3.31.

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.

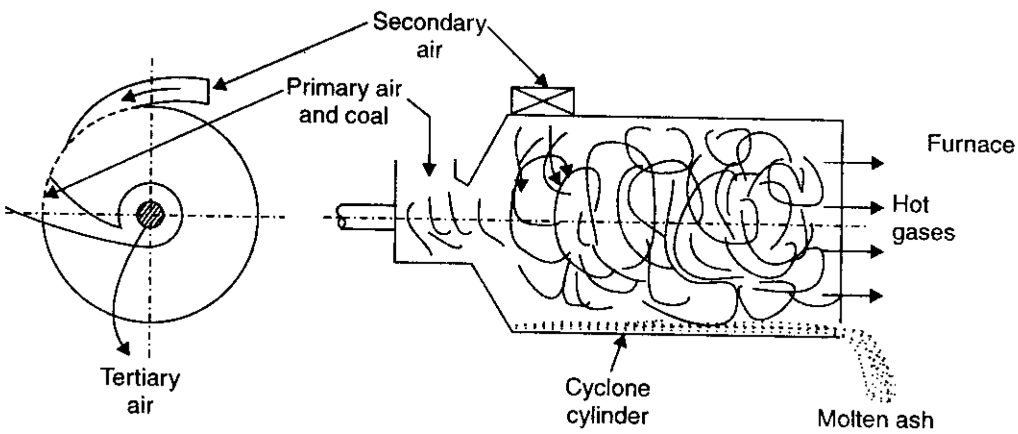


Fig. 3.31. Cyclone burner.

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.

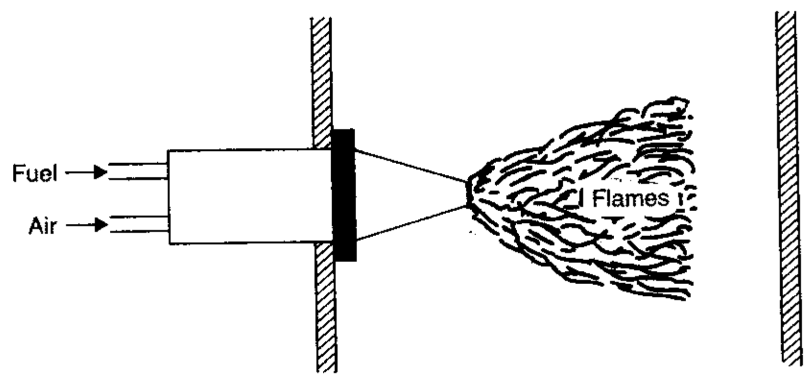


Fig. 3.32. Principle of oil burning.

Classification of oil burners. The oil burners may be *classified* as :

1. *Vapourising oil burners :*
   (*a*) Atmospheric pressure atomising burner
   (*b*) Rotating cup burner
   (*c*) Recirculation burner
   (*d*) Wick type burner
2. *Atomising fuel burners :*
   (*a*) Mechanical or oil pressure atomising burner
   (*b*) Steam or high pressure air atomising burner
   (*c*) Low pressure air atomising burner.

1. Vapourising oil burners

Following are the requirements of a vapourising/evaporation oil burner :

(*i*) To vapourise the fuel before ignition.
(*ii*) To mix the vapourised fuel thoroughly with the air.
(*iii*) To minimise the soot formation.
(*iv*) To give high heat release by burning large quantity of oil per hour.
(*v*) To allow for efficient combustion of fuel at part load operation.

(*a*) ***Atmospheric pressure atomising burner.*** This burner makes use of highly volatile liquid fuels such as neptha, volatile gasoline etc. Here the *fuel at low pressure* is passed through a tube adjacent to the flame before being released through an orifice. While passing through the hot tube, most of the fuel is vapourised so that the fluid ejected from the orifice is more or less a vapour. The required quantity of primary air is supplied to burn the vapour stream in a cylindrical tube.

(*b*) ***Rotating cup burner.*** These burners are used on low as well as medium capacity boilers.

In this type of burner, the fuel oil flows through a tube in the hollow shaft of the burner and into the cup at the furnace end. An electric motor or an air turbine runs the shaft and the cup at high speeds (3000 to 10000 r.p.m.). As a result of centrifugal force fuel is split into small droplets. About 10 to 15 percent of air is supplied as primary air. This air is supplied from a blower surrounding the cup. The shape of the flame is governed by the sharp edge of the cup and the position of air nozzle.

(*c*) ***Recirculating burner.*** The part of the combustion products may be recirculated in order to heat up the incoming stream of fuel and air. Low ratio of the mass of recirculated combustion products to the mass of unburnt fuel-air mixture results in less temperature rise of the mixture, 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.*

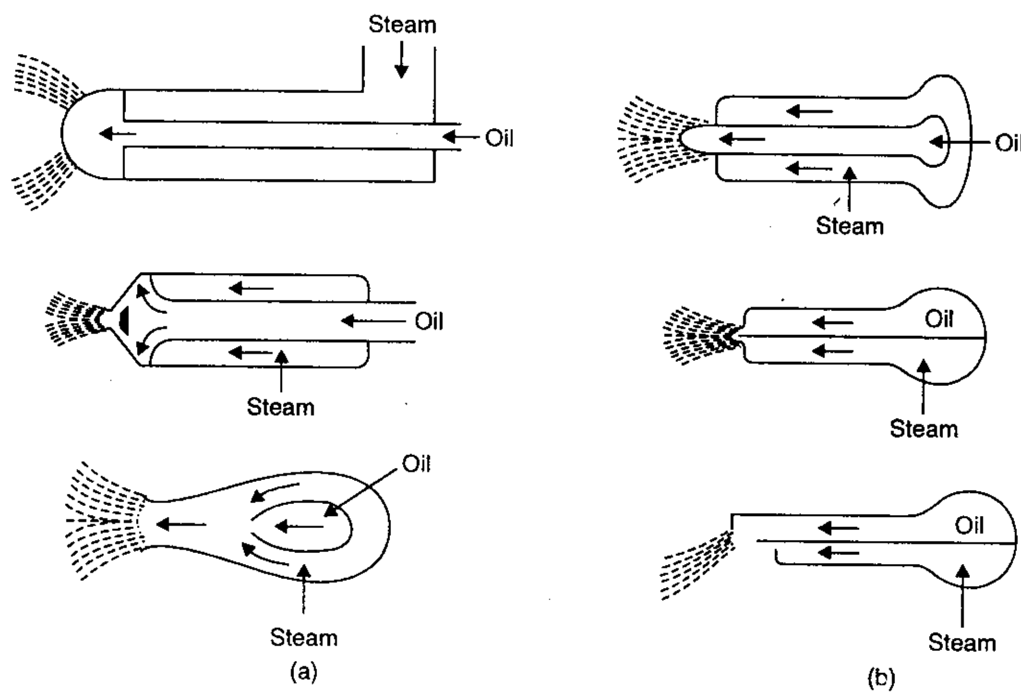


Fig. 3.33. (*a*) Inside mixing (*b*) Outside mixing.

In case of *inside mixing type burners* steam and oil are *mixed inside the burner* before the mixture is projected in the furnace in either a flat spray or in a hollow cone. *These burners provide high efficiency at the high firing rates and flexible flame shape.* In this type of burner instead of steam high pressure air can also be used.

(*c*) ***Low pressure air atomising burners.*** They operate on the same principle as for burners described earlier. In this case air pressure required ranges from 0.015 bar to 0.15 bar.

These are the simplest and most versatile atomising type of burners and usually give troublefree service for long interrupted periods.

3.9.4.3. Gas burners

Gas burning claims the following ***advantages*** :

(*i*) It is much simpler as the fuel is ready for combustion and requires no preparation.

(*ii*) Furnace temperature can be easily controlled.

(*iii*) A long slow burning flame with uniform and gradual heat liberation can be produced.

(*iv*) Cleanliness.

(*v*) High chimney is not required.

(*vi*) No ash removal is required.

For generation of steam, natural gas is invariably used in the following cases :

(*i*) Gas producing areas.

(*ii*) Areas served by gas transmission lines.

(*iii*) Where coal is costlier.

Typical gas burners used are shown in Fig. 3.34 to 3.36.

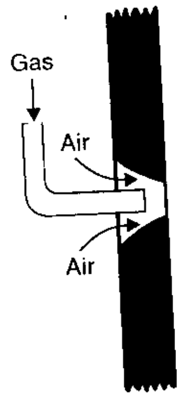


Fig. 3.34

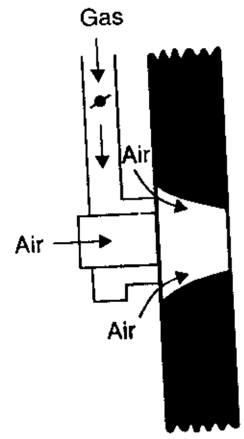


Fig. 3.35

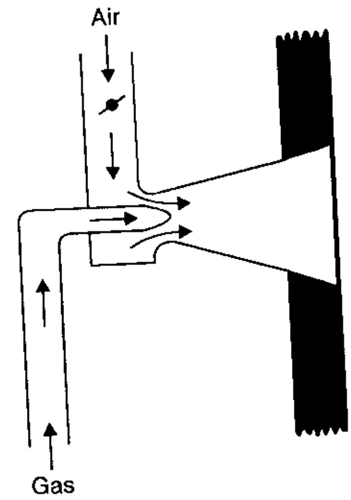


Fig. 3.36

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.

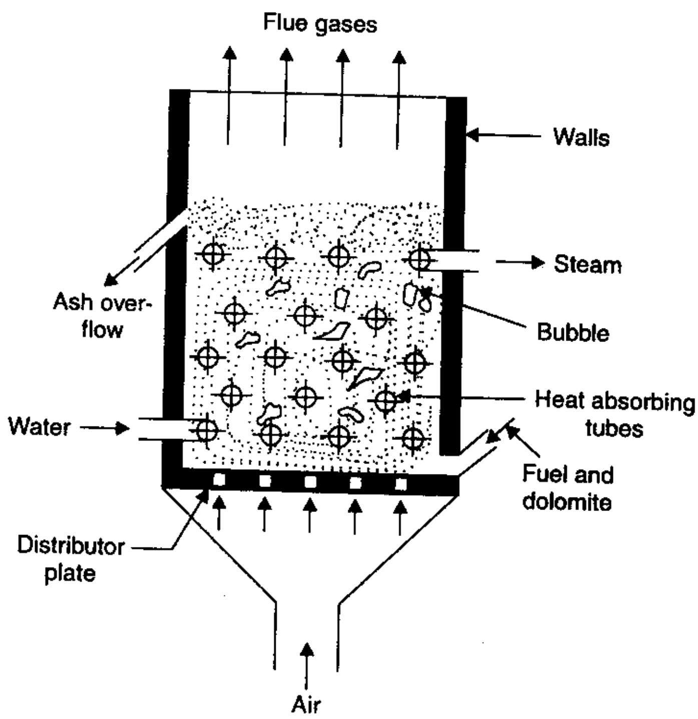


Fig. 3.37. Basic FBC system.

The cost economic shows that a saving of about 10% in operating cost and 15% capital cost could be achieved for a unit rating of 120 MW and it may be still higher for bigger units.

Advantages :

1. As a result of better heat transfer, the unit size and hence the *capital costs are reduced.*

2. It can respond rapidly to changes in load demand (since thermal equilibrium between air and coal particles in the bed is quickly established).

3. Low combustion temperatures (800 to 950°C) inhibits the formation of nitrogen oxides like nitric oxide and nitrogen dioxide.

4. Since combustion temperatures are low the fouling and corrosion of tubes is reduced considerably.

5. As it is not necessary to grind the coal very fine as is done in pulverised fuel firing, therefore, the cost of coal crushing is reduced.

6. Pollution is controlled and combustion of high-sulphur coal is possible.

7. FBC system can use solid, liquid or gaseous fuel or mix as well as domestic and industrial waste. Any variety of coal can be used successfully.

8. Combustion temperature can be controlled accurately.

9. The system can be readily designed for operation at raised combustion pressure, owing to the simplicity of arrangement, small size of the plant and reduced likelihood of corrosion or erosion of gas turbine blades.

10. The combustion in conventional system becomes unstable when the ash exceeds 48% but even 70% ash containing coal can be efficiently burned in FBC.

11. The large quantity of bed material acts as a thermal storage which reduces the effect of 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 every day in large power stations and mechanical devices become indispensable. A station using low grade 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 off by sale or otherwise.

Handling of ash is a problem because ash coming out of the furnace is too hot, it is dusty and irritating to handle and is accompanied by some poisonous gas. Ash needs to be *quenched* before 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 disintegrate.

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 a station.

2. It should be able to handle large clinkers, boiler refuse, soot etc. with little personal attention 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 nuisance 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 plant.

10. The plant should have high rate of handling.

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

(*i*) Bucket elevator

(*ii*) Bucket conveyor

(*iii*) Belt conveyor

(*iv*) Pneumatic conveyor

(*v*) Hydraulic sluicing equipment

(*vi*) Trollies or rail cars etc.

Fig. 3.38 shows the outline of ash disposal equipment.

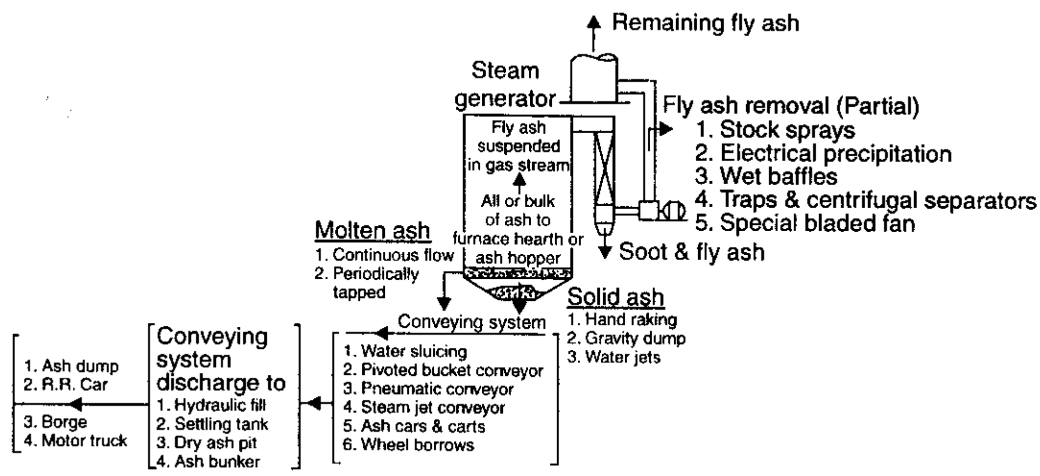


Fig. 3.38. Outline of ash disposal equipment.

3.11.2. Ash Handling Systems

The modern ash-handling systems are mainly classified into four groups :

1. Mechanical handling system
2. Hydraulic system
3. Pneumatic system
4. Steam jet system.

1. Mechanical handling system

Fig. 3.39 shows a mechanical handling system. This system is generally employed for *low capacity power plants* using coal as fuel.

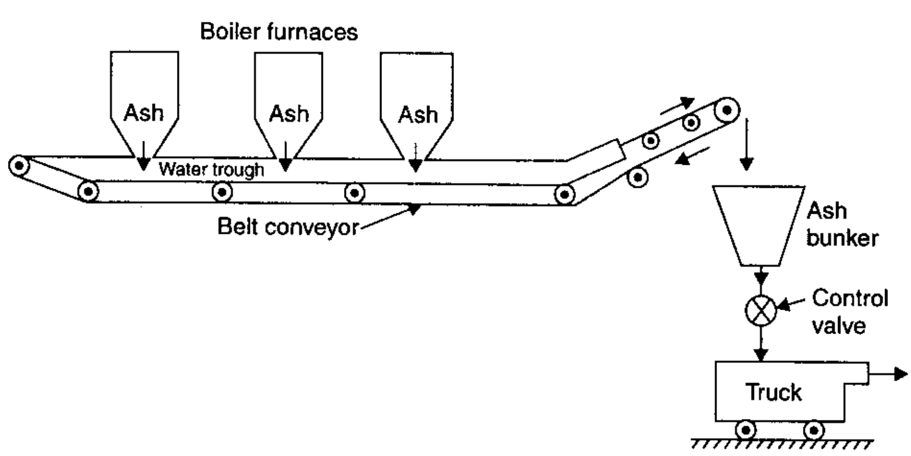


Fig. 3.39. Mechanical handling system.

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.

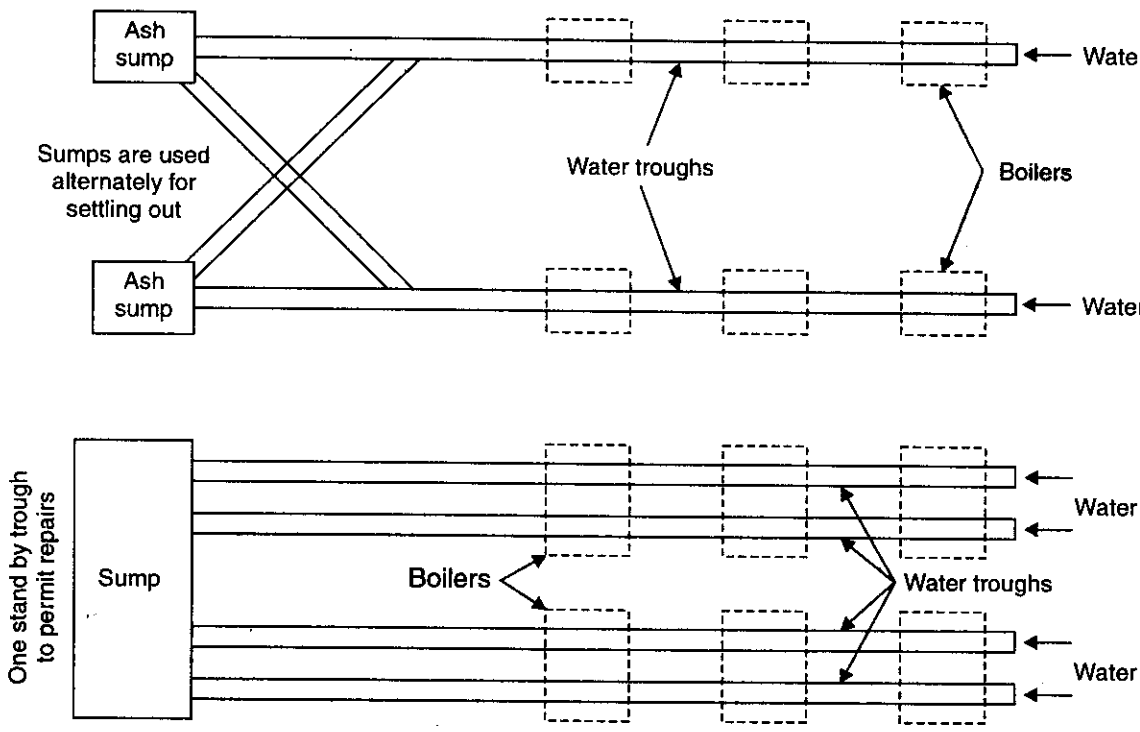


Fig. 3.40. Low pressure system.

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.

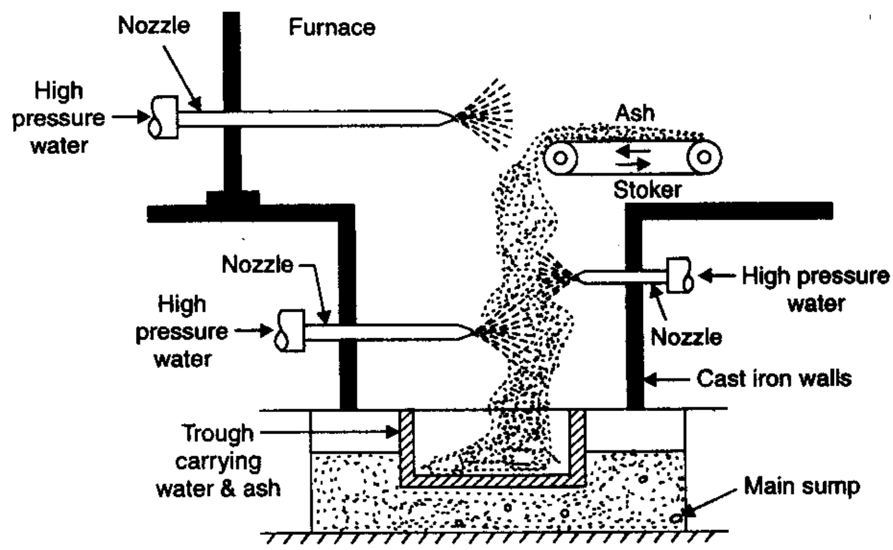


Fig. 3.41. High pressure system.

Advantages of hydraulic system :

1. The system is clean and healthy.
2. It can also be used to handle stream of molten ash.
3. Working parts do not come into contact with the ash.
4. It is dustless and totally closed.
5. It can discharge the ash at a considerable distance (1000 m) from the power plant.
6. The unhealthy aspects of ordinary ash basement work is eliminated.
7. Its ash carrying capacity is considerably large, hence suitable for large thermal power plants.

3. Pneumatic system

Fig. 3.42 shows the schematic of a pneumatic ash handling system. This system can handle abrasive ash as well as fine dusty materials such as fly-ash and soot. It is preferable for the boiler plants from which ash and soot must be transported some far off distance for final disposal.

The exhauster provided at the discharge end creates a high velocity stream which picks up ash and dust from all discharge points and then these are carried in the conveyor pipe to the point of delivery. Large ash particles are generally crushed to small sizes through mobile crushing units which are fed from the furnace ash hopper and discharge into the conveyor pipe which terminates into a separator at the delivery end.

The *separator* working on the *cyclone principle* removes dust and ash which pass out into the ash hopper at the bottom while clean air is discharged from the top.

The *exhauster* may be mechanical or it may use steam jet or water jet for its operation. When a *mechanical exhauster* is used it is usually essential to use a filter or washer to ensure that the exhauster handles clear air. Such type of exhauster may be used in a large station as the power requirements are less. *Steam exhauster* may be used in small and medium size stations. Where large quantities of water are easily and cheaply available *water exhauster* is preferred.

The ash carrying capacity of this system varies from 25 to 15 tonnes per hour.

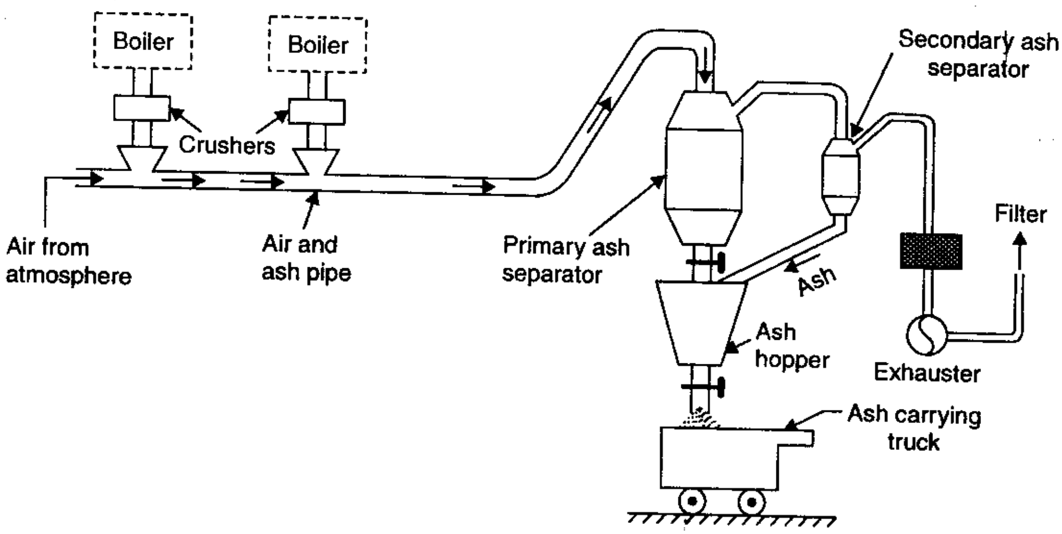


Fig. 3.42. Pneumatic or vacuum extraction ash handling system.

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.

3. Due to abrasive action of ash the pipes undergo greater wear (and to reduce this wearing action the pipes are lined with nickel alloy).

3.12. DUST COLLECTION

3.12.1. Introduction

The products of combustion of coal-fed fires contain particles of solid matter floating in suspension. This may be smoke or dust. If *smoke*, the indication is that combustion conditions are faulty, and the proper remedy is in the design and management of the furnace. If *dust*, the particles are mainly fine ash particles called *"Fly-ash"* intermixed with some quantity of carbon-ash material called *"cinder"*. *Pulverised coal and spreader stoker firing units are the principle types causing difficulty from this source.* Other stokers may produce minor quantities of dust but generally not enough to demand special gas cleaning equipment. The two mentioned are troublesome because coal is burned in suspension—in a turbulent furnace atmosphere and every opportunity is offered for the gas to pick up the smaller particles and sweep them along with it.

The size of the dust particles is measured in *microns*. The micron is one millionth of a metre. As an indication of the scale of this measure, the diameter of a human hair is approximately 80 microns. Typical classification of particles by name is given in Fig. 3.43, but the limits shown are, for the most part, arbitrary. A critical characteristic of dust is its *"Settling Velocity"* in still air. *This is proportional to the product of the square of micron size and mass density.*

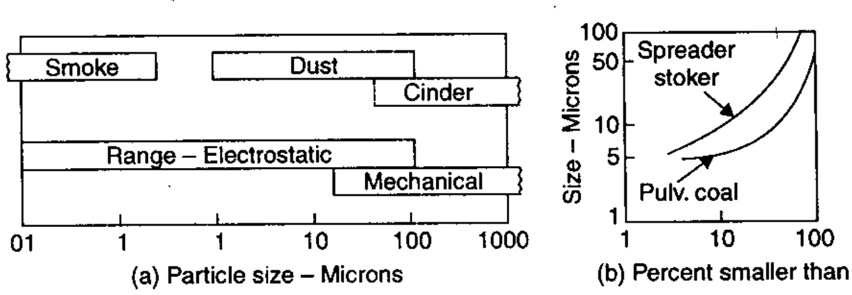


Fig. 3.43. Typical particle sizes : (*a*) Flue gas particles and ranges of collecting equipment. (*b*) Typical distribution of particle size in products of combustion.

3.12.2. Removal of Smoke

Smoke is produced due to the incomplete combustion of fuels. Smoke particles are less than 1 micron in size. The smoke disposal to the atmosphere is not desirable due to the following *reasons* :

(*i*) Smoke is produced due to incomplete combustion of coal. This will create a big economic loss due loss of heating value of coal.

(*ii*) A smoky atmosphere is unhealthy.

(*iii*) Smoke corrodes the metals, darkens the paints and gives lower standards of cleanliness.

In order to check the nuisance of smoke the coal should be completely burnt in the furnace. *The presence of dense smoke indicates poor furnace conditions and a loss in efficiency and capacity of a boiler plant.*

3.12.3. Removal of Dust and Dust Collectors

The removal of dust and cinders from flue gas can usually be effected to the required degree by commercial dust collectors.

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.

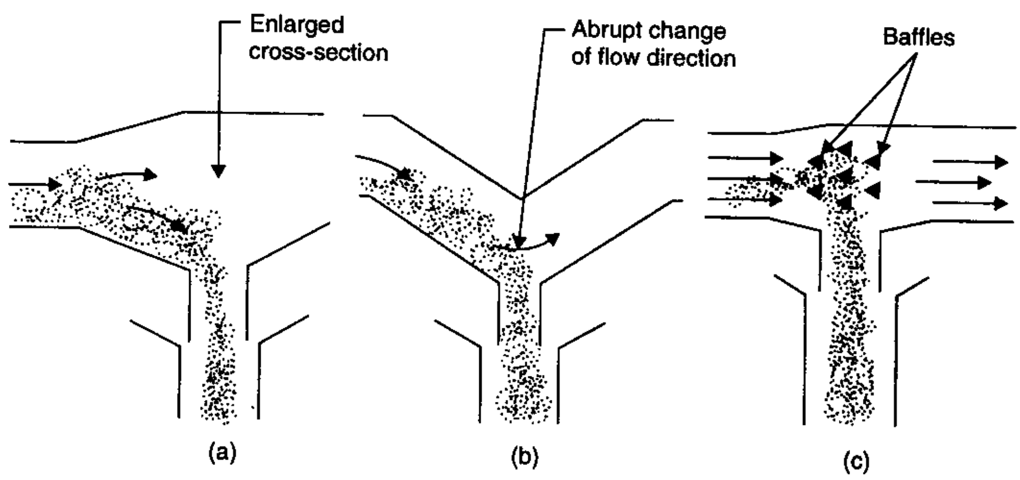


Fig. 3.44. Principles used in dust collection.

(*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.

(b) The cyclone is a separating chamber wherein high-speed gas rotation is generated for the purpose of "*centrifuging*" the particles from the carrying gases. Usually, there is an outer downward flowing vertex which turn into an inward flowing vertex. Involute inlets and sufficient velocity head pressure are used to produce the vortices. As multiple, small-diameter vortices with high pressure drops appear to have high cleaning efficiency, that type is now being exploited. Skimming cyclones shave off the dust at the periphery of the vortex along with a small portion of the gas flow. This concentrated flow is then led to a secondary chamber for final separation.

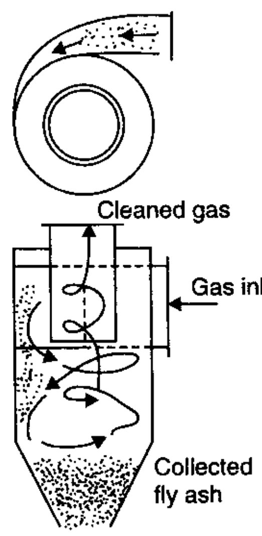


Fig. 3.45. Cyclone separator.

The factors which affect the performance of this collector are *gas volume, particulate loading, inlet velocity, temperature, diameter to height ratio of cyclone and dust characteristics.*

The advantages and disadvantages of cyclone collectors are given below :

Advantages :

1. Rugged in construction.
2. Maintenance costs are relatively low.
3. Efficiency increases with increase in load.
4. Easy to remove bigger size particles.

Disadvantages :

1. Requires more power than other collectors.
2. Incapable to remove dust and ash particles which remain in suspension with still air.
3. Less flexible (in terms of volume handled).
4. High pressure loss comparatively (from 2 cm to 15 cm of water).
5. Requires considerable head room and must be placed outside the boiler room.
6. As the fineness of the dust particle increases its collection efficiency decreases.

2. Electrical dust collector

Electrostatic precipitators. This type, also called "Cottrell precipitators", works effectively on the finer flue dusts. Fig. 3.46 shows the basic elements of an electrostatic precipitator. These are :

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

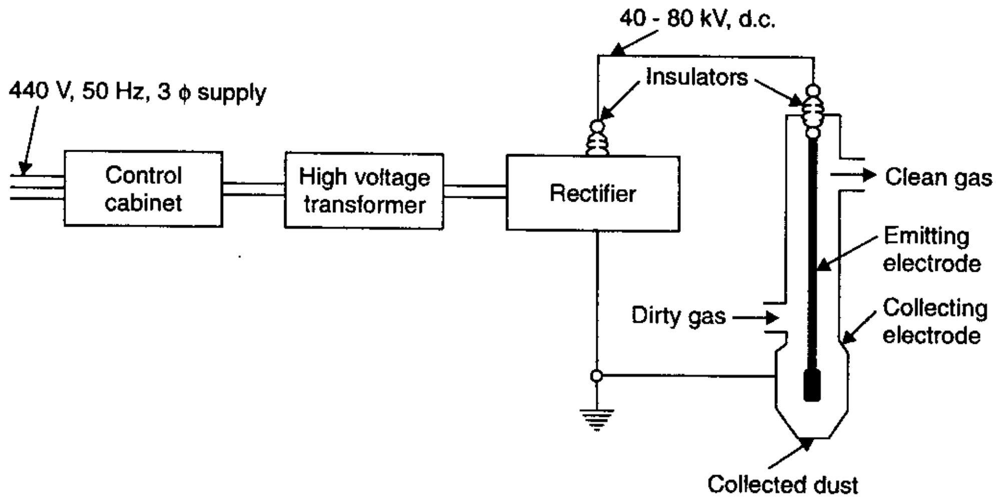


Fig. 3.46. Basic elements of electrostatic precipitators.

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.

3.12.4. Efficiency of Dust Collectors

The *'collection efficiency'* of a dust separator is the amount of dust removed per unit weight of dust. *Though dust collectors remove contaminants, they increase draught losses and hence the fan power.*

The *'absolute efficiency'* of a dust collector is the percentage of entering solids that will be removed by the collector. Some manufactures prefer to rate their equipment on efficiency curves as illustrated in Fig. 3.47.

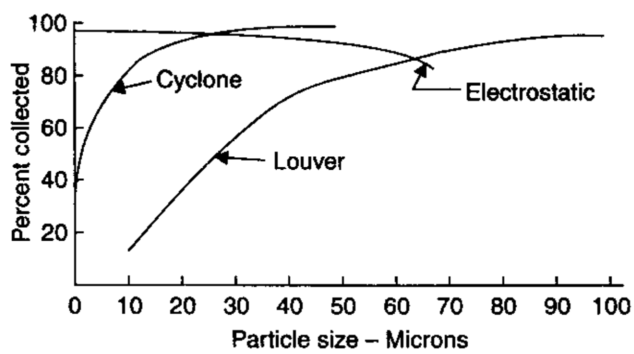


Fig. 3.47. Typical fractional efficiencies of dust collectors.

Bag test dust sampler. Refer Fig. 3.48.

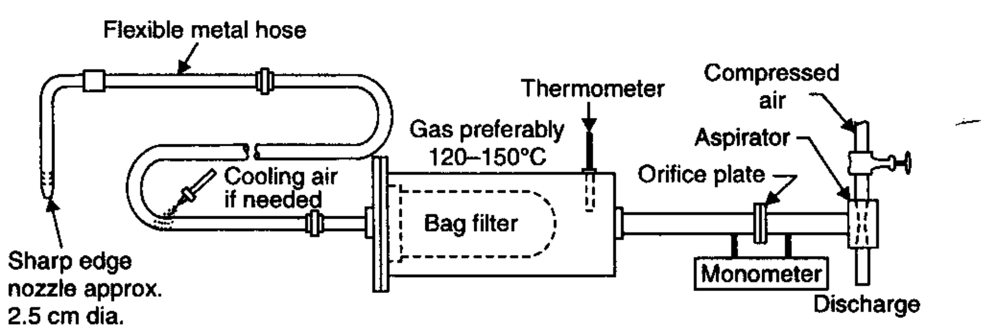


Fig. 3.48. Dust sampler.

This is an apparatus for *withdrawing a sample of dusty gas and filtering out the dust.* Weighing of the filter before and after a timed collection period, together with the data on relative area of sampling nozzle to flue gas passage, will suffice to establish the *collection efficiency* if the gas passage is traversed both at the inlet and discharge of the dust collector, load remaining steady meanwhile.

In order to obtain average samples the duct cross-sectional area must be subdivided into elements and a reading taken at the geometrical centre of each. Furthermore in a true sample the gas velocity into sampling tube must be the same as that of the surrounding gas flow. This considerably complicates the testing, for preliminary pitot-static traverse must be made and then the rate of flow into the sample nozzle adjusted for the same velocity. This explains the reason for some of the components shown on the sampler.

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.

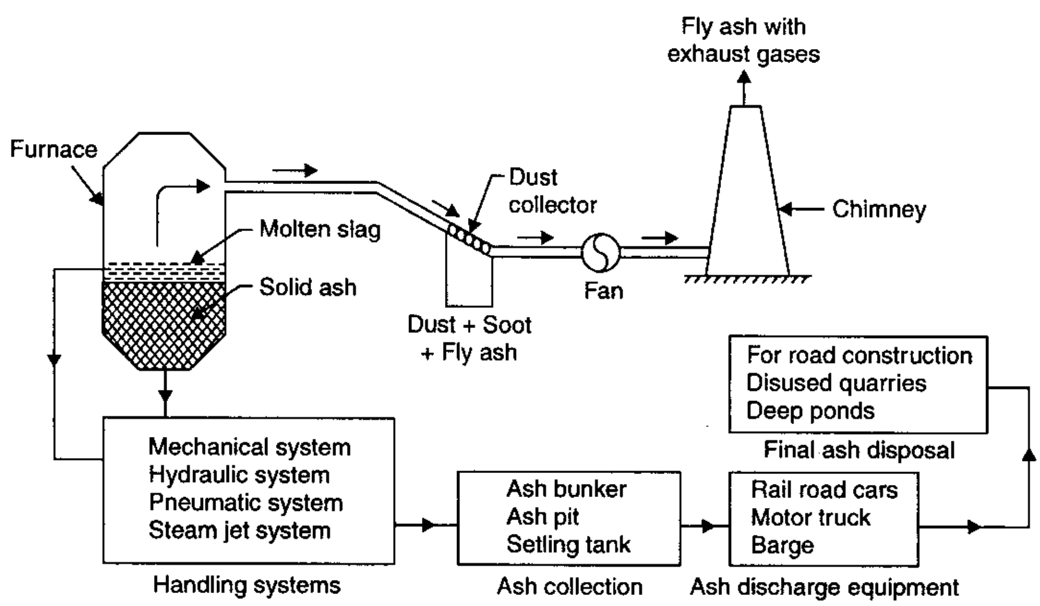


Fig. 3.49. General layout of ash handling and dust collection system.

3.12.8. Flyash—Its Composition, Disposal and Applications

3.12.8.1. Composition :

- The **fly-ash** *is the residue from the combusion of pulverized coal collected by the mechanical or electrostatic separators from the flue gases of thermal power plants.* The fly-ash obtained from electrostatic precipitators is finer than Portland cement, whereas that obtained from cyclone separators is comparatively coarser and may contain large amounts of unburnt fuel.
- It consists mainly of spherical glassy particles ranging from 1 to 150 μm in diameter, of which the bulk passes through a 45-μm sieve.
- The fly-ash, like portland cement, contains oxide of calcium, aluminium and silicon, but the amount of calcium oxide is considerably less.

The ***constituents*** of fly-ash are : *Silicon dioxide* (SiO_2) = 30 to 60% ;

Aluminium oxide (Al_2O_3) = 15 to 30% ; *Unburnt fuel* (carbon) = Up to 30% ;

Calcium oxide (CaO) = 1 to 7% ; *Magnesium oxide* (MgO) = Small amounts ;

Sulphur trioxide (SO_3) = Small amounts.

In fly-ash, the carbon content *should be as small as possible,* whereas *the silicon content should be as high as possible.*

The composition of fly-ash varies with the *type of fuel burnt, load on boiler* and *type of separator* etc.

3.12.8.2. Disposal of fly-ash :

Presently, the fly-ash is disposed off in the following two ways :

1. ***Dry system.*** Here the fly-ash is transferred into an overhead silo or a bunker at the plant *penumatically*. The use of mechanical means (*e.g.,* screw conveyors etc.) for the removal of fly-ash is restored to only if the quantity of flash to be handled is small.

2. ***Wet system.*** In this system of disposal of fly-ash, the *fly-ash is mixed with water and sluiced to the settling ponds or dumping areas near the plant.* The system, however, will work satisfactorily if the following *conditions* are satisfied : (*i*) The water supply is available continuously ; (*ii*) Large areas of wasteland for ponding are available ; and (*iii*) The filled-up ponds are emptied regularly.

The present system of fly-ash disposal causes the following *problems :*

1. The region's ecology is disturbed.
2. Wastage of costly land (due to dumping of fly-ash) in the vicinity of thermal power stations.
3. The fly-ash causes health hazard to the people living near the thermal power stations.
4. The transport of fly-ash to the selected ash ponds entails heavy expenditure.
5. Soil, vegetation, under ground-water resources etc. get polluted.

3.12.8.3. Applications of Fly-ash

The fly-ash may be *used* in the following ways :

1. The fly-ash may be used in ***concrete*** as an *admixture* or *in-part replacement of cement.* The fly-ash is generally used in the following three ways :

- As a *part replacement of cement.*
- As a *part replacement of fine aggregate.*
- As a *simultaneous replacement of cement and fine aggregate.*

2. Cellular concrete blocks :

These blocks are light in weight and are produced by *autoclaving a set mix of a fine silicous material such as fly-ash and binder in the form of lime.*

Advantages :

(*i*) Low thermal conductivity.

(*ii*) Stable against temperature and humidity variations.

(*iii*) Better sound insulation.

(*iv*) Better strength to weight ratio.

(*v*) Since the cellular concrete blocks are machine finished and uniform in size, therefore, less quantity of cement mortar is required. Further as the blocks are smooth and uniformly coloured, plaster can be avoided completely.

3. Fly-ash building bricks :

- To manufacture fly-ash building bricks, the *fly-ash, sand* and *lime* are mixed approximately in the ratio of 80 : 13 : 7. The bricks are made by using *hydraulic press and the semi-dried bricks are cured in a steam chamber at an appropriate temperature and pressure.*
- As compared to conventional bricks, these bricks are :

— *superior in shape, technical specifications, impermeability* and *compressive* strength ;

— *light in weight* (20 percent) ; and

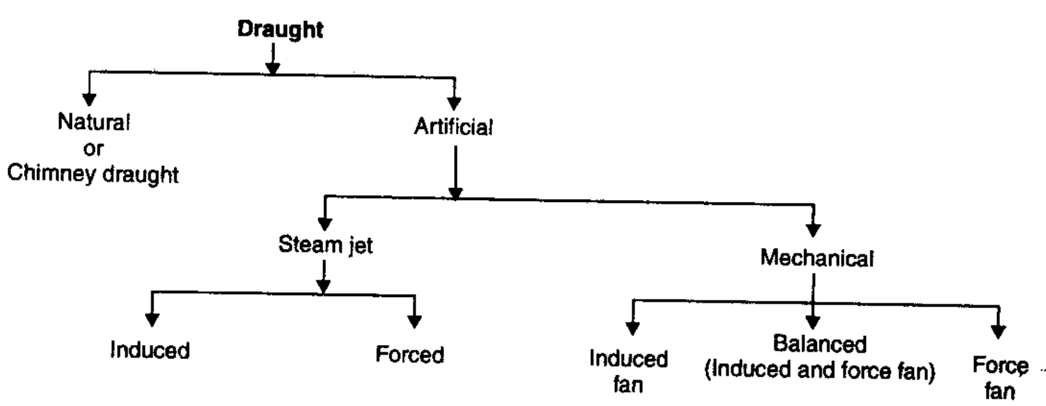
— *cheaper* (about 10 to 15 percent).

3.13. CHIMNEY DRAUGHT

3.13.1. Definition and Classification of Draught

The small pressure difference which causes a flow of gas to take place is termed as a **draught.** The function of the draught, in case of a boiler, is to force air to the fire and to carry away the gaseous products of combustion. In a boiler furnace proper combustion takes place only when sufficient quantity of air is supplied to the burning fuel.

The draught may be classified as :



3.13.2. Natural Draught

Natural draught is obtained by the use of a chimney. The chimney in a boiler installation performs one or more of the following functions : (*i*) *It produces the draught whereby the air and* *gas are forced through the fuel bed, furnace, boiler passes and settings ; (ii) It carries the* products of combustion to such a height before discharging them that they will not be objectionable or injurious to surroundings. A *chimney* is vertical tubular structure built either of masonry, concrete or steel. *The draught produced by the chimney is due to the density difference between the column of hot gases inside the chimney and the cold air outside.*

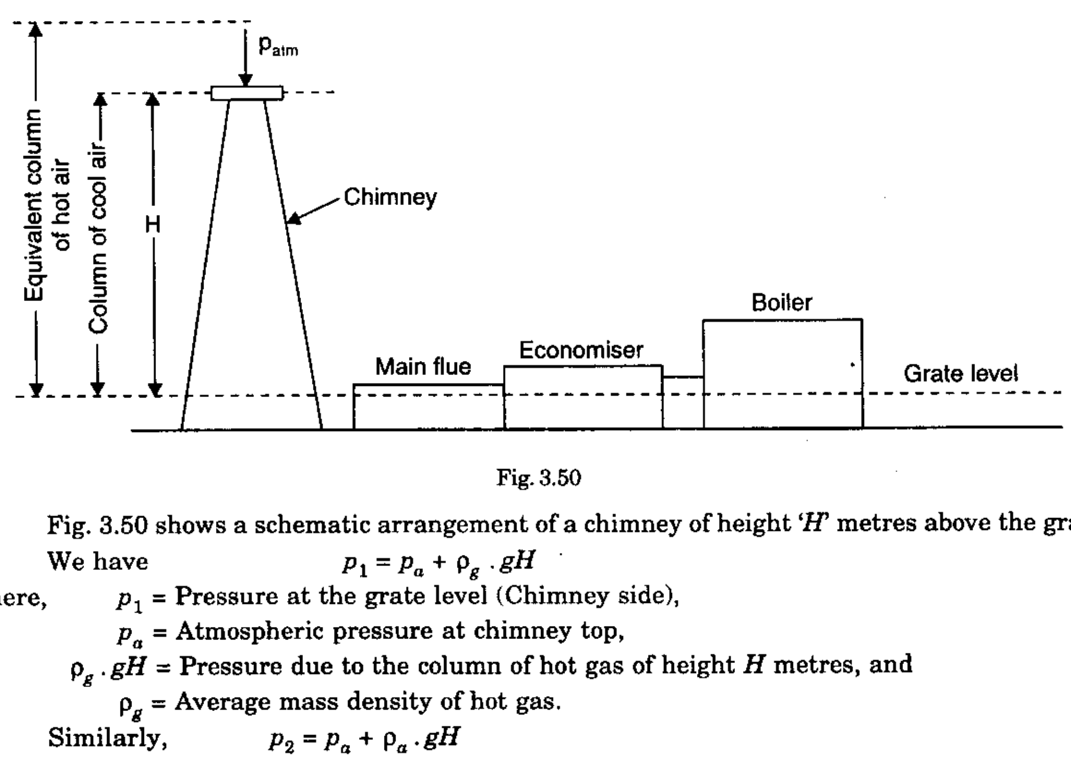


Fig. 3.50

Fig. 3.50 shows a schematic arrangement of a chimney of height '*H*' metres above the grate.

We have $$p_1 = p_a + \rho_g \cdot gH$$

where, p_1 = Pressure at the grate level (Chimney side),

p_a = Atmospheric pressure at chimney top,

$\rho_g \cdot gH$ = Pressure due to the column of hot gas of height H metres, and

ρ_g = Average mass density of hot gas.

Similarly, $$p_2 = p_a + \rho_a \cdot gH$$

where, p_2 = Pressure acting on the grate on the *open side.*

$\rho_a \cdot gH$ = Pressure exerted by the column of cold air outside the chimney of height H metres

ρ_a = Mass density of air outside the chimney.

∴ Net pressure difference causing the flow through the combustion chamber,

$$\Delta p = p_2 - p_1 = (\rho_a - \rho_g)\, gH \quad ...(3.1)$$

This *difference of pressure causing the flow of gases is known as* **'static draught'**. Its value is small and is generally *measured by a water manometer.*

It may be noted that this pressure difference in chimney is generally *less* than 12 mm of water.

3.13.3. Chimney Height and Diameter

Let us assume that the volume of products of combustion is equal to the volume of air supplied both reduced to the same temperature and pressure conditions.

Let, m_a = Mass of air supplied per kg of fuel,

T_a = Absolute temperature of atmospheric air, and

T_g = Average absolute temperature of chimney gases.

Also, $\frac{\text{Mass of hot gases}}{\text{Mass of air}} = \frac{m_a + 1}{m_a}$, temperature and pressure being same.

The mass density of air at atmospheric conditions is given by (using gas equation) :

$$\rho_a = \frac{p}{RT_a} = \frac{1.01325 \times 10^5}{287} \cdot \frac{1}{T_a} = 353 \cdot \frac{1}{T_a} \quad \text{...(3.2)}$$

The mass density of hot gases at temperature T_g is given by :

$$\rho_g = \frac{p}{RT_g} \cdot \left(\frac{m_a+1}{m_a}\right) = \frac{1.01325 \times 10^5}{287} \cdot \frac{1}{T_g} \cdot \left(\frac{m_a+1}{m_a}\right)$$

$$= 353 \cdot \frac{1}{T_g} \cdot \left(\frac{m_a+1}{m_a}\right) \quad \text{...(3.3)}$$

Inserting the values of ρ_a and ρ_g into eqn. (3.1), we get

$$\Delta p = 353\, gH \left[\frac{1}{T_a} - \frac{1}{T_g} \cdot \left(\frac{m_a+1}{m_a}\right)\right] \quad \text{...(3.4)}$$

Assuming that the draught pressure Δp produced is equivalent to H_1 metre height of burnt gases, we have

$$\Delta p = \rho_g \cdot gH_1 = 353 \left(\frac{m_a+1}{m_a}\right) \cdot \frac{1}{T_g}\, g\, H_1 \quad \text{...(3.5)}$$

Equation (3.4) and (3.5), we get

$$353 \left(\frac{m_a+1}{m_a}\right) \frac{1}{T_a}\, g.\, H_1 = 353\, g\, H \left[\frac{1}{T_a} - \frac{1}{T_g}\left(\frac{m_a+1}{m_a}\right)\right]$$

$$\frac{353}{T_a}\left(\frac{m_a+1}{m_a}\right) g\, H_1 = \frac{353}{T_g}\, g\, H - \frac{353}{T_g}\, g\, H \left(\frac{m_a+1}{m_a}\right)$$

$$\frac{353}{T_a}\left(\frac{m_a+1}{m_a}\right) g\, H_1 = \frac{353}{T_g}\left(\frac{m_a+1}{m_a}\right) g\, H \left[\left(\frac{m_a}{m_a+1}\right)\frac{T_g}{T_a} - 1\right]$$

$$\therefore \quad H_1 = H \left[\left(\frac{m_a}{m_a+1}\right)\frac{T_g}{T_a} - 1\right] \quad \text{...(3.6)}$$

Due to losses at various sections along the path of the flue gas, the actual draught available is *always less* than that given by the eqn. (3.4).

If h_w is the height, in mm of a column of water which will produce the pressure Δp, then

$$h_w = 353\, H \left[\frac{1}{T_a} - \frac{1}{T_g}\left(\frac{m_a+1}{m_a}\right)\right] \quad \text{...(3.7)}$$

(1 mm of water = 9.81 *Pa*)

The height h_w would be shown by the use of a U-tube manometer.

Note. The formula as expressed by eqn. (3.7) is used for numerical calculation work only.

Chimney diameter :

Assuming no loss, the velocity of the gases passing through the chimney is given by

$$C = \sqrt{2gH_1}$$

If the pressure loss in the chimney is equivalent to a hot-gas column of h' metres, then

$$C = \sqrt{2g(H_1 - h')} = 4.43\sqrt{H_1 - h'} \qquad ...(3.8)$$

$$= 4.43\sqrt{H_1}\sqrt{1 - \frac{h'}{H_1}} = K\sqrt{H_1} \qquad ...(3.9)$$

where $K = 4.43\sqrt{1 - \frac{h'}{H_1}}$

The value of K : 0.825 .... For *brick chimneys*, and
1.1 .... For *steel chimneys*.

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

$$\dot{m}_g = \rho_g \,.\, A \,.C \text{ kg/s}$$

or

$$\dot{m}_g = \rho_g \,.\, \frac{\pi}{4} D^2 . C$$

$\therefore$

$$D^2 = \frac{\dot{m}_g}{\rho_g . C} \times \frac{4}{\pi}$$

or

$$D = 1.128\sqrt{\frac{\dot{m}_g}{\rho_g . C}} \qquad ...(3.10)$$

3.13.4. Condition for Maximum Discharge through a Chimney

The chimney draught is most effective when the maximum weight of hot gases is discharged in a given time, and it will be shown that this occurs when the absolute temperature of the chimney gases bears a certain relation to the absolute temperature of the outside air.

We know that the velocity of gas through the chimney, assuming the losses to be negligible, is given by :

$$C = \sqrt{2gH_1}, \quad \text{where } h' = 0$$

Inserting the value of H_1 from eqn. (3.6)

$$C = \sqrt{2gH\left[\left(\frac{m_a}{m_a + 1}\right)\frac{T_g}{T_a} - 1\right]} \qquad ...(3.11)$$

The density of the hot gas is given by

$$\rho_g = \frac{p}{RT_g} \qquad ...(3.12)$$

The mass of gas discharged per second,

$$m_g = A \times C \times \rho_g$$

Inserting the values of C and ρ_g from eqns. (3.11) and (3.12), we get

$$m_g = A\sqrt{2gH\left[\left(\frac{m_a}{m_a + 1}\right)\frac{T_g}{T_a} - 1\right]}\;\frac{p}{RT_g}$$

$$m_g = \frac{K}{T_g}\sqrt{\left(\frac{m_a}{m_a + 1}\right)\frac{T_g}{T_a} - 1} \qquad ...(3.13)$$

where constant $K = \frac{A \times p \times \sqrt{2gH}}{R}$

The value of m_g will be *maximum*, if

$$\frac{dm_g}{dT_g} = 0 \text{ as } T_a \text{ and } m_a \text{ are fixed quantities}$$

$$\therefore \quad \frac{d}{dT_g}\left[\frac{K}{T_g}\sqrt{\left(\frac{m_a}{m_a+1}\right)\frac{T_g}{T_a} - 1}\right] = 0$$

or $$\frac{d}{dT_g}\left[\frac{1}{T_g}\sqrt{\left(\frac{m_a}{m_a+1}\right)\frac{T_g}{T_a} - 1}\right] = 0$$

or $$\frac{d}{dT_g}\left[\frac{(ZT_g - 1)^{1/2}}{T_g}\right] = 0$$

where $Z = \frac{m_a}{m_a+1} \cdot \frac{1}{T_a}$

or $$\frac{d}{dT_g}\left[(ZT_g - 1)^{1/2} \times T_g^{-1}\right] = 0$$

or $$(Z \cdot T_g - 1)^{1/2} \cdot (-1)(T_g)^{-2} + T_g^{-1} \times \tfrac{1}{2}(ZT_g - 1)^{-1/2} \times Z = 0$$

or $$\frac{-(ZT_g - 1)^{1/2}}{T_g^{\,2}} + \frac{Z}{2T_g(ZT_g - 1)^{1/2}} = 0$$

or $$\frac{-2(ZT_g - 1) + ZT_g}{2(T_g)^2 (ZT_g - 1)^{1/2}} = 0$$

or $$-2(ZT_g - 1) + ZT_g = 0$$

or $$-2ZT_g + 2 + ZT_g = 0$$

or $$ZT_g = 2$$

or $$\frac{m_a}{m_a+1} \cdot \frac{T_g}{T_a} = 2$$

i.e., $$\frac{T_g}{T_a} = 2\left(\frac{m_a+1}{m_a}\right) \qquad ...(3.14)$$

Thus we see that the *absolute temperature of the chimney gases bears a certain ratio to the absolute temperature of the outside air.*

Putting the value of $\frac{T_g}{T_a}$ in eqn. (3.6), we get

$$(H_1)_{max} = H\left[\left(\frac{m_a}{m_a+1}\right) \times 2\left(\frac{m_a+1}{m_a}\right) - 1\right] = H(2-1) = H$$

i.e., $$(H_1)_{max} = H \qquad ...(3.15)$$

The draught in mm of water column for maximum discharge can be evaluated by inserting the value of T_g / T_a in eqn. (3.7)

$$\therefore \quad (h_w)_{max} = 353\, H \left(\frac{1}{T_a} - \frac{1}{2\,T_a}\right) = \frac{176.5H}{T_a} \text{ mm of water} \quad ...(3.16)$$

3.13.5. Efficiency of a Chimney

The temperature of the flue gases leaving a chimney, in case of *natural draught,* is higher than that of flue gases leaving it in case of *artificial draught* system because a certain minimum temperature is needed to produce a given draught with the given height of a chimney. As far as steam generation is concerned, in case of a natural draught system the heat carried away by flue gases is more due to *higher* flue gas temperature. This indicates that the draught is created at the cost of thermal efficiency of the boiler plant installation since a portion of the heat carried away by the flue gases to produce the required draught could have been used either in heating the air going to furnace or in heating the feed water going to boiler ; thereby improving the thermal efficiency of the installation. Let,

T' = Absolute temperature of flue gases leaving the chimney to create the draught of h_w mm of water,

T'' = Absolute temperature of flue gases leaving the chimney in case of artificial draught of h_w mm of water, and

c_p = Mean specific heat of flue gases.

The extra heat carried away by 1 kg of flue gas due to higher temperature required to produce the natural draught

$= c_p\,(T' - T'')$, since T' is greater than T''.

The draught pressure produced by the natural draught system in height of hot gases column,

$$H_1 = H\left[\left(\frac{m_a}{m_a+1}\right) \times \frac{T_g}{T_a} - 1\right] \text{ metre}$$

The maximum energy this head would give to 1 kg of flue gas which is at the expense of extra heat carried away from the boiler plant

$$= H\left[\left(\frac{m_a}{m_a+1}\right) \times \frac{T_g}{T_a} - 1\right] \quad \text{...Energy units}$$

$$= \frac{H}{J}\left[\left(\frac{m_a}{m_a+1}\right) \times \frac{T_g}{T_a} - 1\right] \quad \text{...Heat units}$$

$$\therefore \text{ Efficiency of chimney, } \eta_{ch} = \frac{\frac{H}{J}\left[\left(\frac{m_a}{m_a+1}\right) \times \frac{T_g}{T_a} - 1\right]}{c_p\,(T' - T'')} \quad ...(3.17)$$

In the equation, $T' = T_g$.

(In S.I. units J = 1)

- The efficiency of a chimney is proportional to the height but even for a very tall chimney the efficiency will be *less than 1%* and thus we see that chimney is *very inefficient as an instrument for creating draught.*

3.13.6. Draught Losses

The loss in a draught may be due to the *reasons* mentioned below :

(*i*) The frictional resistance offered by the flues and gas passages to the flow of flue gases.

(*ii*) Loss near the bends in the gas flow circuit.

(*iii*) Loss due to friction head in equipments like grate, economiser, superheater etc.

(*iv*) Loss due to imparting velocity to the flue gases.

The loss in draught in a chimney is 20 per cent of the total draught produced by it.

3.13.7. Artificial Draught

In the boiler installations of today the total static draught required may vary from 30 to 350 mm of water column.

It may not be possible to build a chimney high enough to produce draught of such a large magnitude. To meet this requirement artificial draught system should be used. It may be a *mechanical draught* or a *steam jet draught.* The former is used for central power stations and many other boiler installations while the latter is employed for small installations and in locomotives.

3.13.8. Forced Draught

In a mechanical draught system, the draught is produced by a fan. In a forced draught system, a blower or a fan is installed *near or at the base of the boiler* to force the air through the cool bed and other passages through the furnace, flues, air preheater, economiser etc. It is a *positive pressure draught. The enclosure for the furnace etc. has to be very highly sealed so that gases from the furnace do not leak out in the boiler house.*

3.13.9. Induced Draught

In this system a fan or blower is located *at or near the base of the chimney.* The pressure over the fuel bed is reduced below that of the atmosphere. By creating a partial vacuum in the furnace and flues, the products of combustion are drawn from the main flue and they pass up the chimney. *This draught is used usually when economisers and air preheaters are incorporated in the system.* The draught is similar in action to the natural draught.

3.13.10. Balanced Draught

It is a *combination of the forced and induced draught systems.* In this system, the *forced draught fan overcomes the resistance in the air preheater and chain grate stoker while the induced draught fan overcomes draught losses through boiler, economiser, air preheater and connecting flues.*

The *forced draught* entails following *advantages over induced draught* :

1. Forced draught fan does not require water-cooled bearings.
2. Tendency to air leak into the boiler furnace is reduced.
3. No loss due to inrush of cold air through the furnace doors when they are opened for fire and cleaning fires.
4. Fan size and power required for the same draught are 1/5 to 1/2 of that required for an induced draught fan installation because forced draught fan handles cold air.

3.13.11. Advantages of Mechanical Draught

The mechanical draught possesses the following *advantages* :

1. Easy control of combustion and evaporation.
2. Increase in evaporative power of a boiler.
3. Improvement in the efficiency of the plant.
4. Reduced chimney height.
5. Prevention of smoke.
6. Capability of consuming low grade fuel.
7. Low grade fuel can be used as the intensity of artificial draught is high.

8. The fuel consumption per kW due to artificial draught is 15% less than that for natural draught.
9. The fuel burning capacity of grate is 200 to 300 kg/m^2-hr with mechanical draught, whereas, it is hardly 50 to 100 kg/m^2-hr with natural draught.

3.13.12. Steam Jet Draught

Steam jet draught is a simple and easy method of producing artificial draught. It may be of forced or induced type depending upon where the steam jet to produce draught is located. If the steam jet is *directed into the smoke box* near the stack, the air is *induced* through the flues, the grate and ash pit to the smoke box. If the jet is *located before the grate,* air is *forced* through the fuel bed, furnace and flues to the chimney.

The steam jet draught entails the following *advantages* :

(*i*) Very simple and economical.
(*ii*) Occupies minimum space.
(*iii*) Requires very little attention.
(*iv*) In forced type steam jet draught, the steam keeps the fire bars cool and prevents the adhering of clinker to the fire bars.
(*v*) Several classes of low grade fuels can be used with this system.

WORKED EXAMPLES

Example 3.1. *Calculate the mass of flue gases flowing through the chimney when the draught produced is equal to 1.9 cm of water. Temperature of flue gases is 290°C and ambient temperature is 20°C. The flue gases formed per kg of fuel burnt are 23 kg. Neglect the losses and take the diameter of the chimney as 1.8 m.*

Solution. Draught in mm of water, h_w = 1.9 cm = 19 mm

Temperature of flue gases, T_g = 290 + 273 = 563 K

Ambient temperature, T_a = 20 + 273 = 293 K

Flue gases formed per kg of fuel burnt, $(m_a + 1)$ = 23 kg

Diameter of the chimney, D = 1.8 m

Mass of flue gases, m_g :

Using the relation, $$H_1 = H\left[\left\{\frac{m_a}{m_a+1}\times\frac{T_g}{T_a}\right\}-1\right]$$

where H_1 is the head in terms of gas column.

Also $$h_w = 353\ H\left[\frac{1}{T_a}-\frac{1}{T_g}\times\left(\frac{m_a+1}{m_a}\right)\right]$$

$$19 = 353\ H\left(\frac{1}{293}-\frac{1}{563}\times\frac{23}{22}\right) \qquad \left(\begin{array}{ll}\because & m_a+1 = 23 \text{ kg (given)}\\ i.e. & m_a = 22 \text{ kg}\end{array}\right)$$

$$19 = 353\ H\ (0.00341 - 0.00185) = 0.548\ H$$

or $$H = 34.67 \text{ m}$$

$$\therefore \quad H_1 = 34.67\left(\frac{22}{23}\times\frac{563}{293}-1\right) = 29.05 \text{ m of air.}$$

Velocity of gases, $C = \sqrt{2gH_1} = \sqrt{2 \times 9.81 \times 29.05} = 23.87$ m/s.

Now, mass of flue gases, $m_g = A \times C \times \rho_g$

where $\rho_g = 353 \left(\frac{m_a + 1}{m_a}\right) \cdot \frac{1}{T_g} = 353 \times \frac{23}{22} \times \frac{1}{563} = 0.655$ kg/m³

$\therefore$ $m_g = \pi/4 \times (1.8^2) \times 23.87 \times 0.655 =$ **39.8 kg/s. (Ans.)**

Hence *mass of flue gases passing through the chimney* = **39.8 kg/s. (Ans.)**

Example 3.2. *A chimney of height 32 m is used for producing a draught of 16 mm of water. The temperatures of ambient air and flue gases are 27°C and 300°C respectively. The coal burned in the combustion chamber contains 81% carbon, 5% moisture and remaining ash. Neglecting losses and assuming the value of burnt products equivalent to the volume of air supplied and complete combustion of fuel find the percentage of excess air supplied.*

Solution. Height of the chimney, $H = 32$ m

Draught in mm of water $= 16$ mm

Ambient air temperature, $T_a = 27 + 273 = 300$ K

Temperature of flue gases, $T_g = 300 + 273 = 573$ K

Percentage of carbon in the fuel $= 81\%$

Percentage of excess air supplied :

Using the relation, $h_w = 353\, H \left[\frac{1}{T_a} - \frac{1}{T_g}\left(\frac{m_a+1}{m_a}\right)\right]$ mm of water

$$16 = 353 \times 32 \left[\frac{1}{300} - \frac{1}{573}\left(\frac{m_a+1}{m_a}\right)\right]$$

$$\frac{16}{353 \times 32} = \frac{1}{300} - \frac{1}{573}\left(\frac{m_a+1}{m_a}\right)$$

$$\frac{m_a+1}{m_a} = 573\left(\frac{1}{300} - \frac{16}{353 \times 32}\right) = 573\,(0.003333 - 0.001416) = 1.0984$$

$\therefore$ $m_a = 10.16$ kg/kg of fuel

Again, $C + O_2 = CO_2$

$12 + 32 = 44$

Thus 1 kg of carbon requires $\frac{32}{12} = \frac{8}{3}$ kg of oxygen and $\frac{8}{3} \times \frac{100}{23} = 11.6$ kg of air. One kg of fuel contains only 0.81 carbon.

$\therefore$ Air required for complete combustion $= 11.6 \times 0.81 = 9.396$ kg/kg of fuel.

Hence, *percentage excess air supplied* $= \frac{10.16 - 9.396}{9.396} \times 100 =$ **8.13%. (Ans.)**

Example 3.3. *Determine the height and diameter of the chimney used to produce a draught for a boiler which has an average coal consumption of 1800 kg/h and flue gases formed per kg of coal fired are 14 kg. The pressure losses through the system are given below :*

Pressure loss in fuel bed = 7 mm of water, pressure loss in boiler flues = 7 mm of water, pressure loss in bends = 3 mm of water, pressure loss in chimney = 3 mm of water.

Pressure head equivalent to velocity of flue gases passing through the chimney = 1.3 mm of water.

The temperatures of ambient air and flue gases are 35°C and 310°C respectively.

Assume actual draught is 80% of theoretical.

Solution. Average coal consumption = 1800 kg/h

Flue gases formed per kg of coal fired = 14 kg

Temperature of ambient air, $T_a = 35 + 273 = 308$ K

Temperature of flue gases, $T_g = 310 + 273 = 583$ K.

Height of chimney, H :

Draught required is equivalent to overcome the losses and velocity head

$$= 7 + 7 + 3 + 3 + 1.3 = 21.3 \text{ mm of water.}$$

Actual draught to be produced,

$$h_w = \frac{21.3}{0.8} = 26.62 \text{ mm of water}$$

$$h_w = 353\, H \left(\frac{1}{T_a} - \frac{1}{T_g} \cdot \frac{m_a + 1}{m_a} \right)$$

$$26.62 = 353\, H \left(\frac{1}{308} - \frac{1}{583} \times \frac{14}{13} \right) = H\,(1.146 - 0.652) = 0.494\, H$$

$$H = 53.88 \text{ m}$$

$$\rho_g = \frac{353}{T_g} \left(\frac{m_a + 1}{m_a} \right) = \frac{353}{583} \times \frac{14}{13} = 0.652 \text{ kg/m}^3$$

Flue gases formed per second $= \dfrac{1800 \times 14}{3600} = 7$ kg

$$m_g = A \times C \times \rho_g \qquad \ldots(i)$$

But $\quad C = \sqrt{2gH_1}$

where H_1 is the equivalent velocity expressed in m of gas

$$H_1 \rho_g = h_w \rho_w$$

where h_w is the water head equivalent to velocity head responsible for giving velocity to the gas,

$$\therefore \quad H_1 = \frac{h_w \rho_w}{\rho_g} = \frac{1.3 \times 1000}{1000 \times 0.652} = 1.993 \text{ m}$$

$$\therefore \quad C = \sqrt{2 \times 9.81 \times 1.993} = 6.25 \text{ m/s}$$

Substituting this value in eqn. (*i*), we get

$$7 = \frac{\pi}{4} D^2 \times 6.25 \times 0.625 \quad \text{or} \quad D^2 = \frac{7 \times 4}{\pi \times 6.25 \times 0.652}$$

$\therefore$ $\quad$ **D = 1.478 m. (Ans.)**

Example 3.4. *Calculate power of a motor required to drive a fan which maintains a draught of 54 mm of water under the following conditions for (i) induced draught fan, (ii) forced draught fan :*

Temperature of flue gases leaving the boiler in each case = 240°C

Temperature of air in the boiler house = 20°C

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 $V_o = 0.7734$ m³ at 0°C and 760 mm of Hg)

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

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

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

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

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

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, m³/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, $V_o = \dfrac{m_a M}{\rho}$

$$\therefore \quad V = \frac{T_a V_0 m_a M}{273} \text{ m}^3\text{/h}$$

Substituting in eqn. (3.18), we get

Power of F.D. fan, $$P_{FD} = \frac{2.725 \times 10^{-6}}{273} \left(\frac{h V_0 m_a M T_a}{\eta_f} \right) \text{kW}$$

$$= 0.998 \times 10^{-8} \left(\frac{h V_0 m_a M T_a}{\eta_f} \right) \text{kW}$$

(*ii*) ***Induced draught (I.D.) fan power, P_{ID} :***

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

Then $m_a + 1$ = Mass of the products of combustion.

At the same temperature

$$\frac{\rho_g}{\rho_a} = \frac{m_a + 1}{m_a}$$

But $$\rho_a = \frac{273}{T_g} \times \frac{1}{V_0}$$

$$\therefore \quad \rho_g = \frac{273}{T_g} \times \frac{1}{V_0}$$

$$\text{Volume handled by I.D. fan} = \frac{\text{Total mass handled by I.D. fan}}{\text{Density of gases}}$$

$$= \frac{M(m_a + 1)}{\rho_g} = \frac{M(m_a + 1) T_g V_0 m_a}{273\,(m_a + 1)} = \frac{M m_a T_g V_0}{273}$$

Substituting in eqn. (3.18), we get

Power of I.D. fan, $$P_{ID} = \frac{2.725 \times 10^{-6} \times h M m_a T_g V_0}{273 \times \eta_f}$$

$$= 0.998 \times 10^{-8} \, \frac{h V_0 m_a M T_g}{\eta_f}$$

Assuming *same efficiency*, for the *same draught* (neglecting leakage), we have

$$\frac{\text{Power of I.D. fan}}{\text{Power of F.D. fan}} = \frac{T_g}{T_a}.$$

3.14. BOILERS

3.14.1. Introduction

In simple a ***boiler*** *may be defined as a closed vessel in which steam is produced from water by combustion of fuel.*

According to American Society of Mechanical Engineers (A.S.M.E.) a *'steam generating unit'* is defined as :

"A combination of apparatus for producing, furnishing or recovering heat together with the apparatus for transferring the heat so made available to the fluid being heated and vapourised".

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).

7. Single tube and multi-tube boilers

The fire tube boilers are classified as single-tube and multi-tube boilers, depending upon whether the fire tube is one or more than one. The examples of the former type are cornish, simple vertical boiler and rest of the boilers are multi-tube boilers.

3.14.3. Comparison between 'Fire-tube and Water tube' Boilers

S. No.	*Particulars*	*Fire-tube boilers*	*Water-tube boilers*
1.	*Position of water and hot gases*	Hot gases inside the tubes and water outside the tubes.	Water inside the tubes and hot gases outside the tubes.
2.	*Mode of firing*	Generally internally fired.	Externally fired.
3.	*Operating pressure*	Operating pressure limited to 16 bar.	Can work under as high pressure as 100 bar.
4.	*Rate of steam production*	Lower	Higher.
5.	*Suitability*	Not suitable for large power plants.	Suitable for large power plants.
6.	*Risk on bursting*	Involves lesser risk on explosion due to lower pressure.	Involves more risk on bursting due to high pressure.
7.	*Floor area*	For a given power it occupies more floor area.	For a given power it occupies less floor-area.
8.	*Construction*	Difficult	Simple
9.	*Transportation*	Difficult	Simple
10.	*Shell diameter*	Large for same power	Small for same power
11.	*Chances of explosion*	Less	More
12.	Treatment of water	Not so necessary	More necessary
13.	*Accessibility of various parts*	Various parts not so easily accessible for cleaning, repair and inspection.	Various parts are more accessible.
14.	*Requirement of skill*	Require less skill for efficient and economic working.	Require more skill and careful attention.

3.14.4. Selection of a Boiler

While selecting a boiler the following *factors* should be considered :

1. The working pressure and quality of steam required (*i.e.*, whether wet or dry or superheated).
2. Steam generation rate.
3. Floor area available.
4. Accessibility for repair and inspection.
5. Comparative initial cost.
6. Erection facilities.
7. The probable load factor.
8. The fuel and water available.
9. Operating and maintenance costs.

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.

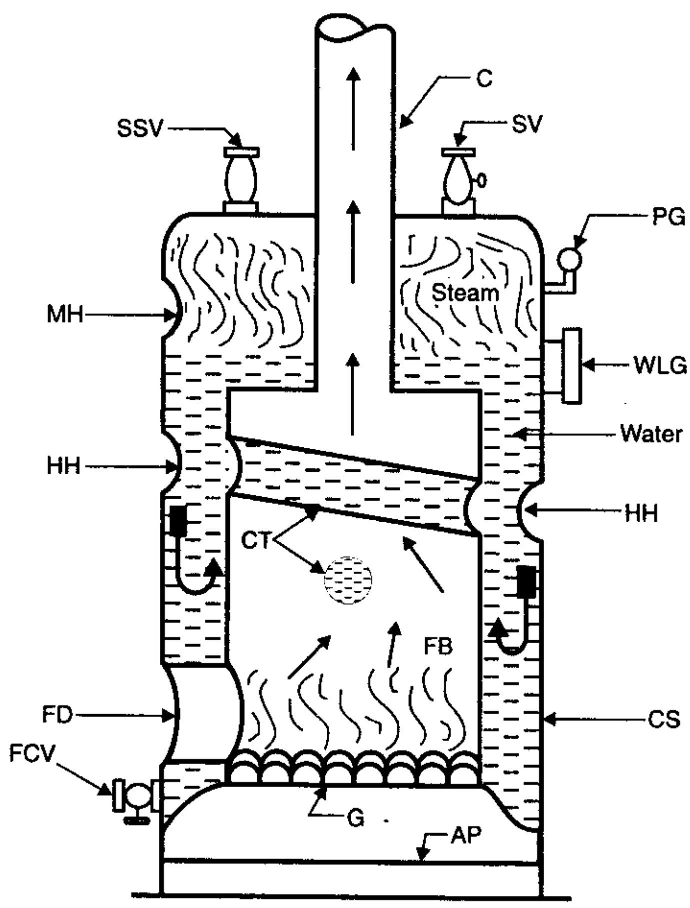
Refractory. A heat insulation material, such as fire brick or plastic fire clay, used for such purposes as lining combustion chambers.

3.14.7. Fire Tube Boilers

The various fire tube boilers are described as follows :

3.14.7.1. Simple vertical boiler

Refer Fig. 3.51. It consists of a cylindrical shell, the greater portion of which is full of water (which surrounds the fire box also) and remaining is the steam space. At the bottom of the fire box is grate on which fuel is burnt and the ash from it falls in the ash pit.



CS = Cylindrical shell
MH = Man hole
CT = Cross tubes
FB = Fire box
AP = Ash pit
PG = Pressure gauge
SV = Safety valve
WLG = Water level gauge
C = Chimney
HH = Hand hole
FD = Fire door
G = Grate
SSV = Steam stop valve
FCV = Feed check valve

Fig. 3.51. Simple vertical boiler.

The fire box is provided with two cross tubes. This increases the heating surface and the circulation of water. The cross tubes are fitted inclined. This ensures efficient circulation of water.

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.

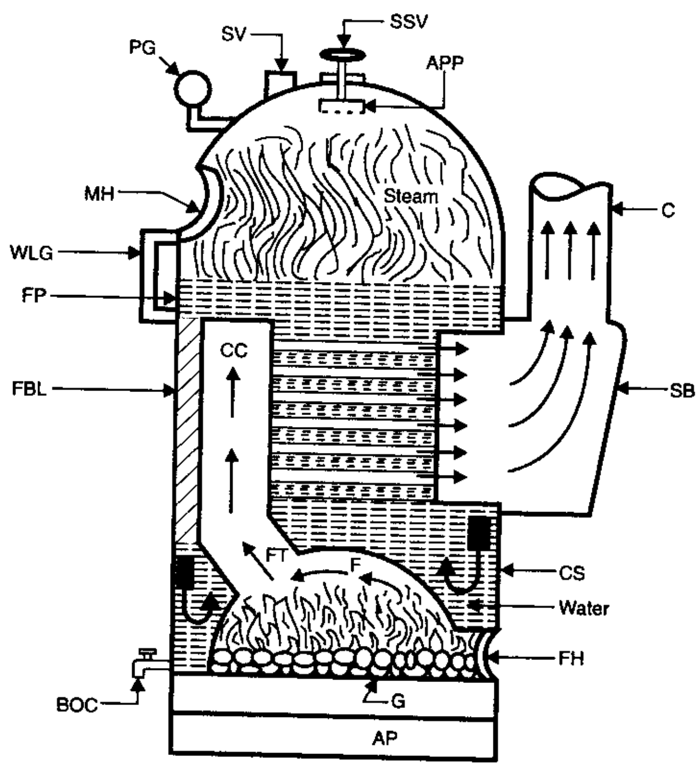
Flow of combustion gases and circulation of water in water jackets are indicated by arrows in Fig. 3.51.

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

Fig. 3.52. Cochran boiler.

Dimensions, working pressure, capacity, heating surface and efficiency are given below :

Shell diameter	...... 2.75 m
Height	...... 5.79 m
Working pressure	...... 6.5 bar (max. pressure = 15 bar)
Steam capacity	...... 3500 kg/h (max. capacity = 4000 kg/h)
Heating surface	...... 120 m^2
Efficiency	...... 70 to 75% (depending on the fuel used)

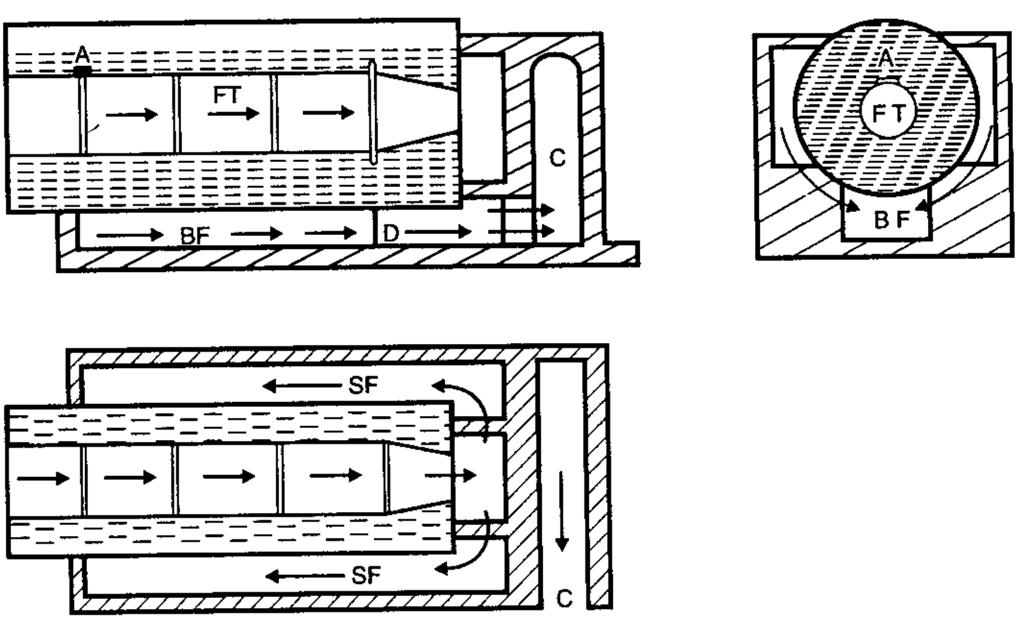
Cochran boiler consists of a cylindrical shell with a dome shaped top where the space is provided for steam. The furnace is one piece construction and is seamless. Its crown has a hemispherical shape and thus provides maximum volume of space. The fuel is burnt on the grate and ash is collected and disposed of from ash pit. The gases of combustion produced by burning of fuel enter the combustion chamber through the flue tube and strike against fire brick lining which directs them to pass through number of horizontal tubes, being surrounded by water. After which the gases escape to the atmosphere through smoke box and chimney. A number of hand-holes are provided around the outer shell for cleaning purposes.

The various boiler mountings shown in Fig. 3.52 are : (*i*) Water level gauge, (*ii*) Safety valve, (*iii*) Steam stop valve, (*iv*) Blow off cock, (*v*) Manhole, and (*vi*) Pressure gauge.

The path of combustion of gases and circulation of water are shown by arrows in Fig. 3.52.

3.14.7.3. Cornish boiler

This form of boiler was first adopted by Trevithick, the Cornish Engineer, at the time of introduction of high-pressure steam to the early Cornish engine, and is still used.



A = Fusible plug
BF = Bottom flue
D = Damper
FT = Flue tube
SF = Side flue
C = Passage to chimney

Fig. 3.53. Cornish 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 where larger reserve of water and steam are needed.

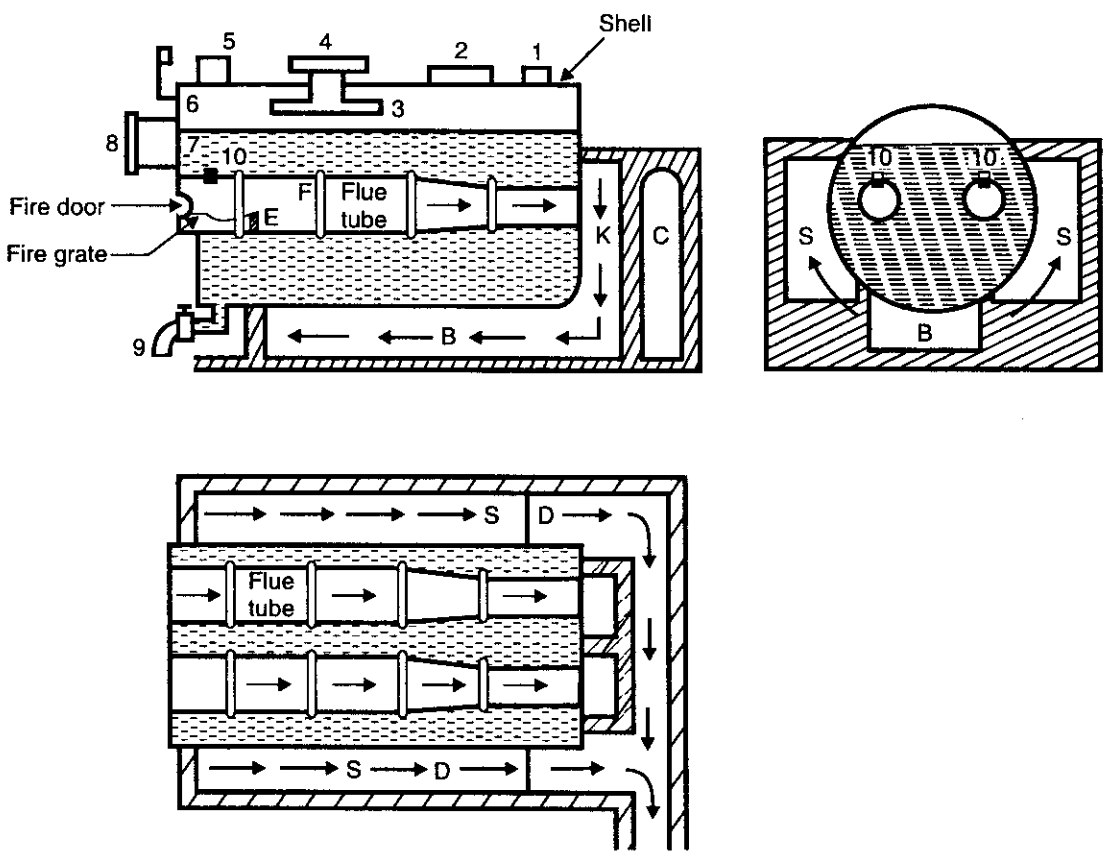
The *specifications* of Lancashire boiler are given below :

Diameter of the shell	...... 2 to 3 m
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 control the flow of hot gases to the chimney, dampers (in the form of sliding doors) are provided. As a result the flow of air to the grate can be controlled. The various mountings used on the boiler are shown in Fig. 3.54.

Note. In Cornish and Lancashire boilers, conical shaped cross tubes known as galloway tubes (not shown) may be fitted inside the furnace tubes to increase their heating surfaces and circulation of water. But these tubes have now become absolute for their considerable cost of fitting. Moreover, they cool the furnace gases and retard combustion.



B = Bottom flue
C = Chimney
D = Dampers
E = Fire-bridge
F = Flue tube
K = Main flue
S = Side flue

1. High steam low water safety valve
2. Manhole
3. Antipriming pipe
4. Steam stope valve
5. Safety valve
6. Pressure gauge
7. Feed check valve
8. Water gauge
9. Blow down cock
10. Fusible plug

Fig. 3.54. Lancashire boiler.

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%

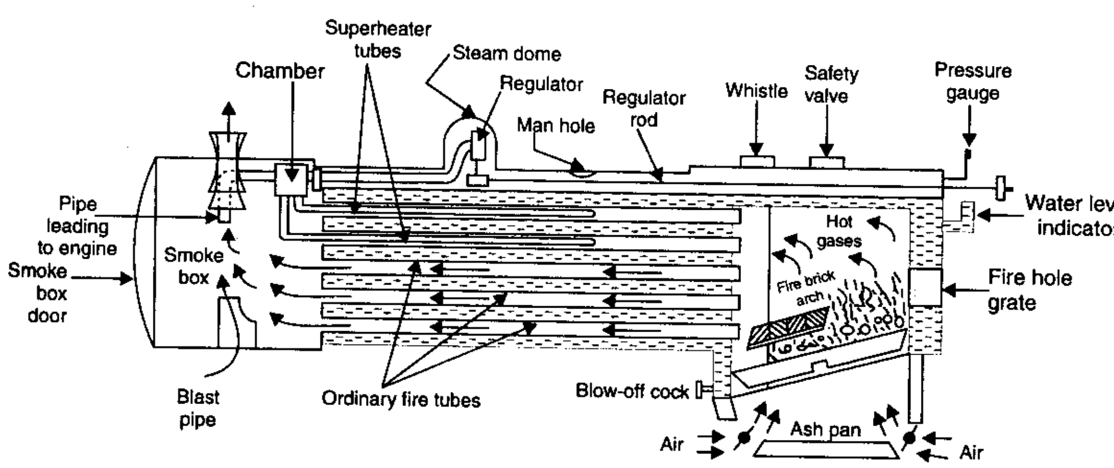


Fig. 3.55. Locomotive boiler.

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.

A dome shaped chamber known as *steam dome* is fitted on the upper part of the barrel, from where the steam flows through a steam pipe into the chamber. The flow of steam is regulated by means of a regulator. From the chamber it passes through the superheater tubes and returns to the superheated steam chamber (not shown) from which it is led to the cylinders through the pipes, one to each cylinder.

In this boiler natural draught cannot be obtained because it requires a very high chimney which cannot be provided on a locomotive boiler since it has to run on rails. Thus some artificial arrangement has to be used to produce a correct draught. As such the draught here is *produced by exhaust steam* from the cylinders which is discharged through the blast pipe to the chimney. When the locomotive is *standing* and no exhaust steam is available from the engine *fresh steam* from the boiler is used for the purpose.

The various boiler mountings include :

Safety valves, pressure gauge, water level indicator, fusible plug, man hole, blow-off cock and feed check valve.

A locomotive boiler entails the following *merits* and *demerits* :

Merits :

1. High steam capacity.
2. Low cost of construction.
3. Portability.
4. Low installation cost.
5. Compact.

Demerits :

1. There are chances to corrosion and scale formation in the water legs due to the accumulation of sediments and the mud particles.
2. It is difficult to clean some water spaces.
3. Large flat surfaces need bracing.
4. It cannot carry high overloads without being damaged by overheating.
5. There are practical constructional limits for pressure and capacity which do not meet requirements.

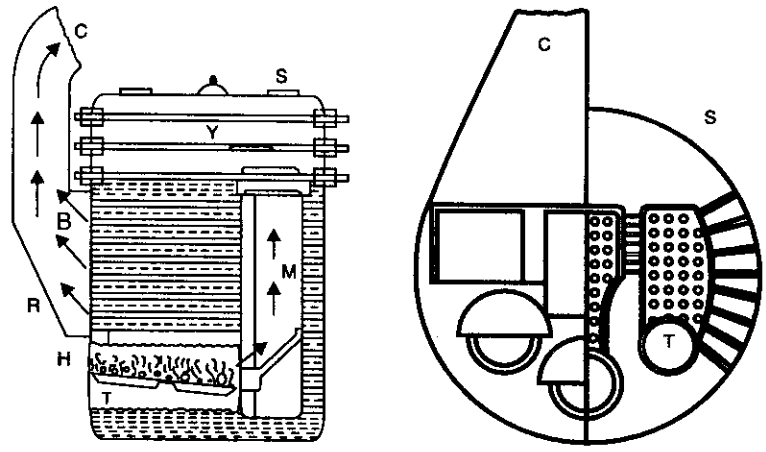
3.14.7.6. Scotch boiler

The scotch type marine boiler is probably the *most popular* boiler for steaming capacities upto about 1000 kg/h and pressure of about 17 bar. It is of compact size and occupies small floor space.

Fig. 3.56 shows a single ended scotch type marine boiler. It consists of a cylindrical shell in which are incorporated one to four cylindrical, corrugated steel furnaces. The furnaces are internally fired and surrounded by water. A combustion chamber is located at the back end of the furnace and is also surrounded by water. Usually, each furnace has its own combustion chamber. A nest of fire tubes run from the front tube plate to the back tube plate.

The hot gases produced due to burning of fuel move to the combustion chambers (by means of the draught). Then they travel to the smoke box through the fire tubes and finally leave the boiler *via* uptake and the chimney.

In a double-ended scotch boiler furnaces are provided at each end. They look like single-ended boilers placed back to back. A double-ended boiler for same evaporation capacity, is cheaper and occupies less space as compared to single-ended boiler.

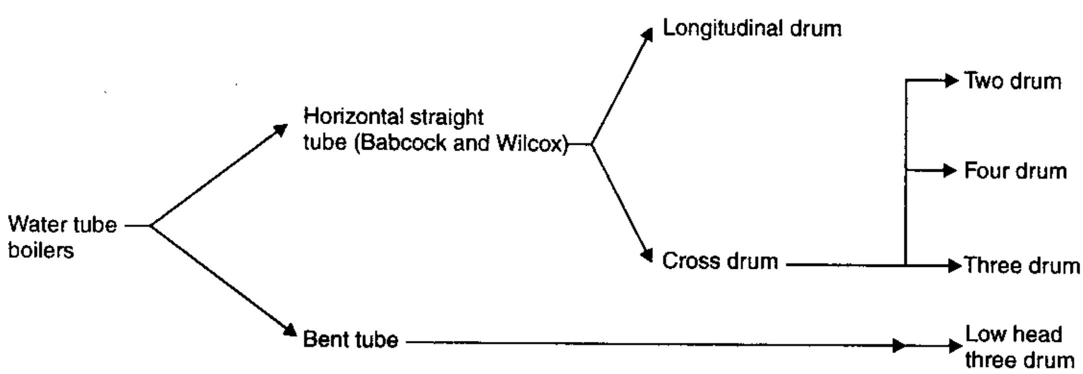


T = Furnace tube
H = Fire hole
M = Combustion chamber
B = Smoke box
R = Smoke box door
C = Chimney
S = Shell
Y = Bar stays.

Fig. 3.56. Scotch boiler.

3.14.8. Water Tube Boilers

The types of water tube boilers are given below :



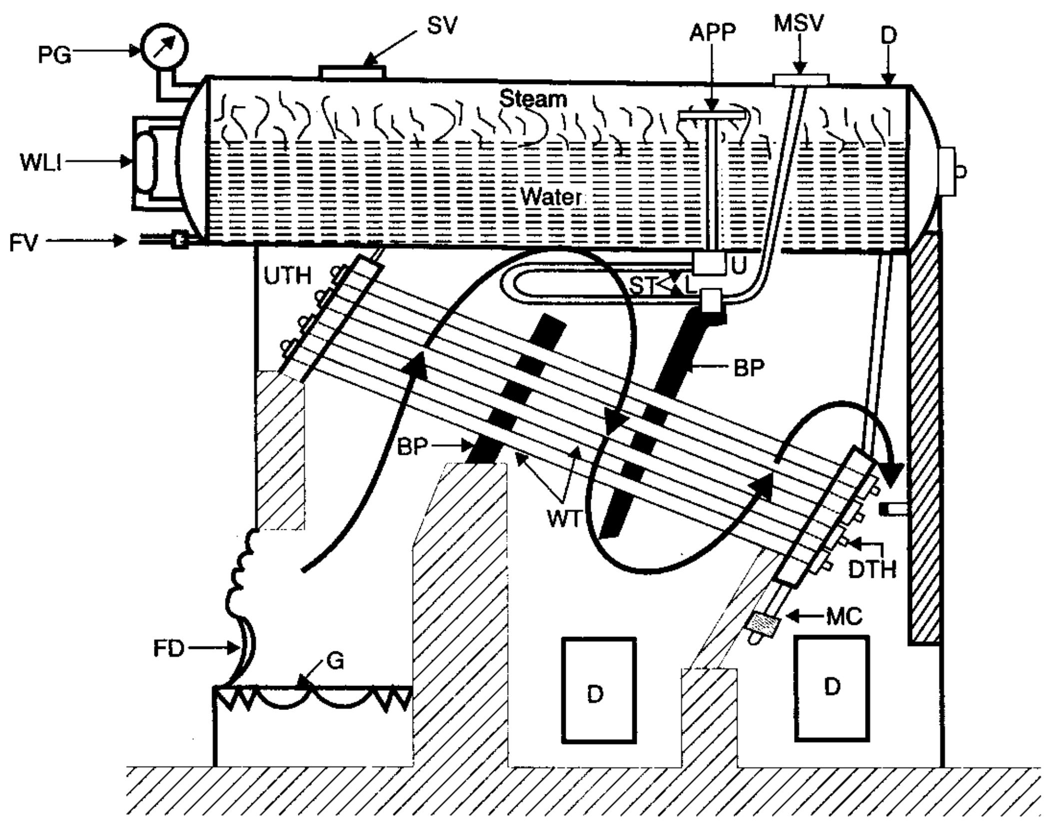
3.14.8.1. Babcock and wilcox water-tube boiler

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%

Fig. 3.57 shows a Babcock and Wilcox boiler with longitudinal drum. It consists of a drum connected to a series of front end and rear end headers by short riser tubes. To these headers are connected a series of inclined water tubes of solid drawn mild steel.



D = Drum	PG = Pressure gauge
DTH = Down take header	ST = Superheater tubes
WT = Water tubes	SV = Safety valve
BP = Baffle plates	MSV = Main stop valve
D = Doors	APP = Antipriming pipe
G = Grate	L = Lower junction box
FD = Fire door	U = Upper junction box
MC = Mud collector	FV = Feed valve.
WLI = Water level indicator	

Fig. 3.57. Babcock and Wilcox boiler.

The angle of inclination of the water tubes to the horizontal is about 15° or more. A hand hole is provided in the header in front of each tube for cleaning and inspection of tubes. A feed valve is provided to fill the drum and inclined tubes with water the level of which is indicated by the water level indicator. Through the fire door the fuel is supplied to grate where it is burnt. The hot gases are forced to move upwards between the tubes by baffle plates provided. The water from the drum flows through the inclined tubes *via* downtake header and goes back into the shell in the form of water and steam *via* uptake header. The steam gets collected in the steam space of the 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

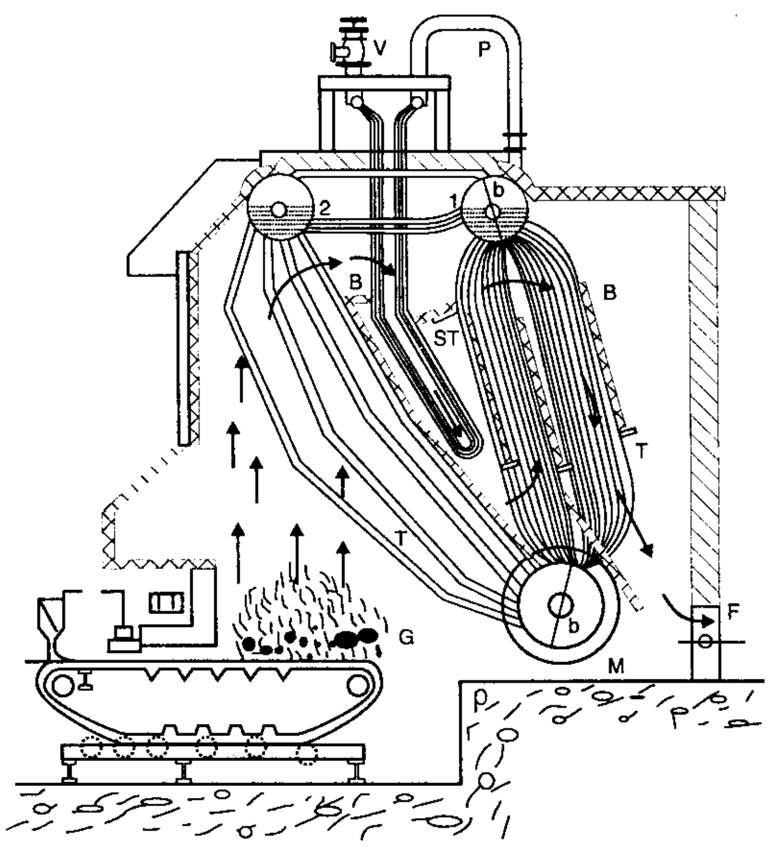
Stirling water-tube boiler is an example of *bent tube* boiler. The main elements of a bent type water tube boiler are essentially drum or drums and headers connected by bent tubes. For large central power stations these boilers are very popular. They have steaming capacities as high as 50,000 kg/h and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



V = Stop valve	ST = Superheater tubes
P = Steam pipe	T = Water tubes
b = Water baffle	G = Grate
B = Baffle wall	M = Mud drum

Fig. 3.58. Stirling boiler.

3.14.9. High Pressure Boilers

3.14.9.1. Introduction

In applications where steam is needed at pressure, 30 bar, and individual boilers are required to raise less than about 30000 kg of steam per hour, *shell boilers are considerably cheaper than the water-tube boilers.* Above these limits, shell boilers (generally factory built) are difficult to transport if not impossible. There are no such limits to water-tube boilers. These can be site erected from easily transportable parts, and moreover the pressure parts are of smaller diameter and therefore can be thinner. The geometry can be varied to suit a wide range of situations and furnace is not limited to cylindrical form. Therefore, *water tube boilers are generally preferred for high pressure and high output, whereas, shell boilers for low pressure and low output.*

The modern high pressure boilers employed for power generation are for steam capacities 30 to 650 tonnes/h and above with a pressure up to 160 bar and maximum steam temperature of about 540°C.

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.

11. A very rapid start from cold is possible if an external supply of power is available. Hence, the boiler can be used for carrying peak loads or standby purposes with hydraulic station.
12. Use of high pressure and high temperature steam is economical.

3.14.9.4. LaMont boiler

This boiler works on a forced circulation and the circulation is maintained by a centrifugal pump, driven by a steam turbine using steam from the boiler. For emergency an electrically driven pump is also fitted.

Fig. 3.59 shows a LaMont steam boiler. The feed water passes through the economiser to the drum from which it is drawn to the circulation pump. The pump delivers the feed water to the tube evaporating section which in turn sends a mixture of steam and water to the drum. The steam in the drum is then drawn through the superheater. The superheated steam so obtained is then supplied to the primemover.

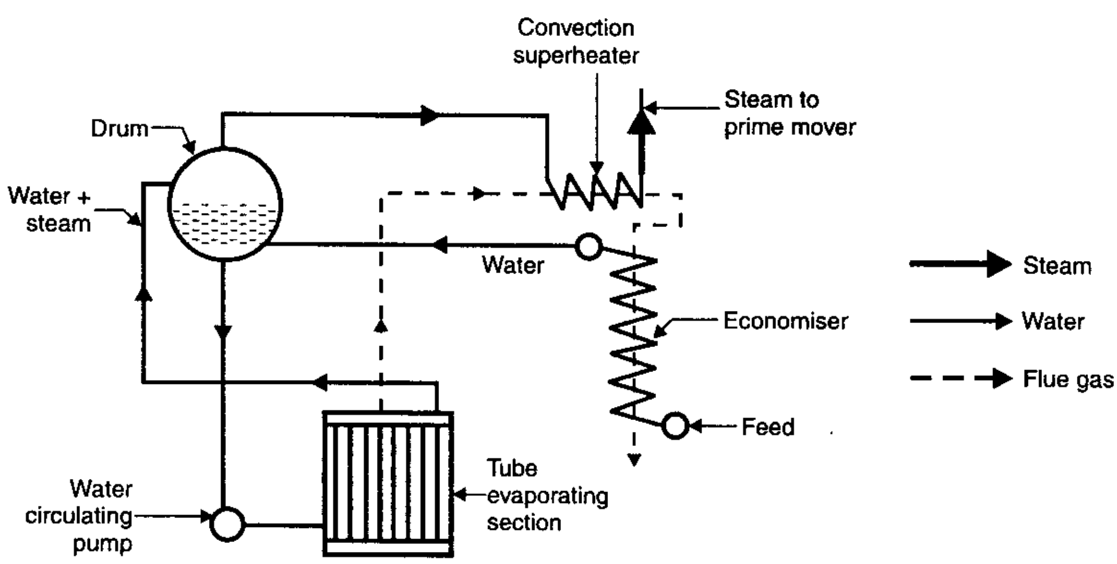


Fig. 3.59. LaMont boiler.

These boilers have been built to generate of 45 to 50 tonnes of superheated steam at a pressure of 130 bar and at a temperature of 500°C.

3.14.9.5. Loeffler boiler

In a LaMont boiler the major difficulty experienced is the deposition of salt and sediment on the inner surfaces of the water tubes. The deposition reduces the heat transfer and ultimately the generating capacity. This further increases the danger of overheating the tubes due to salt deposition as it has high thermal resistance. This difficulty was solved in Loeffler boiler by *preventing the flow of water into the boiler tubes.*

This boiler also makes use of forced circulation. Its novel principle is *the evaporating of the feed water by means of superheated steam from the superheater, the hot gases from the furnace being primarily used for superheating purposes.*

Fig. 3.60 shows a diagrammatic view of a Loeffler boiler. The high pressure feed pump draws water through the economiser (or feed water heater) and delivers it into the evaporating 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.

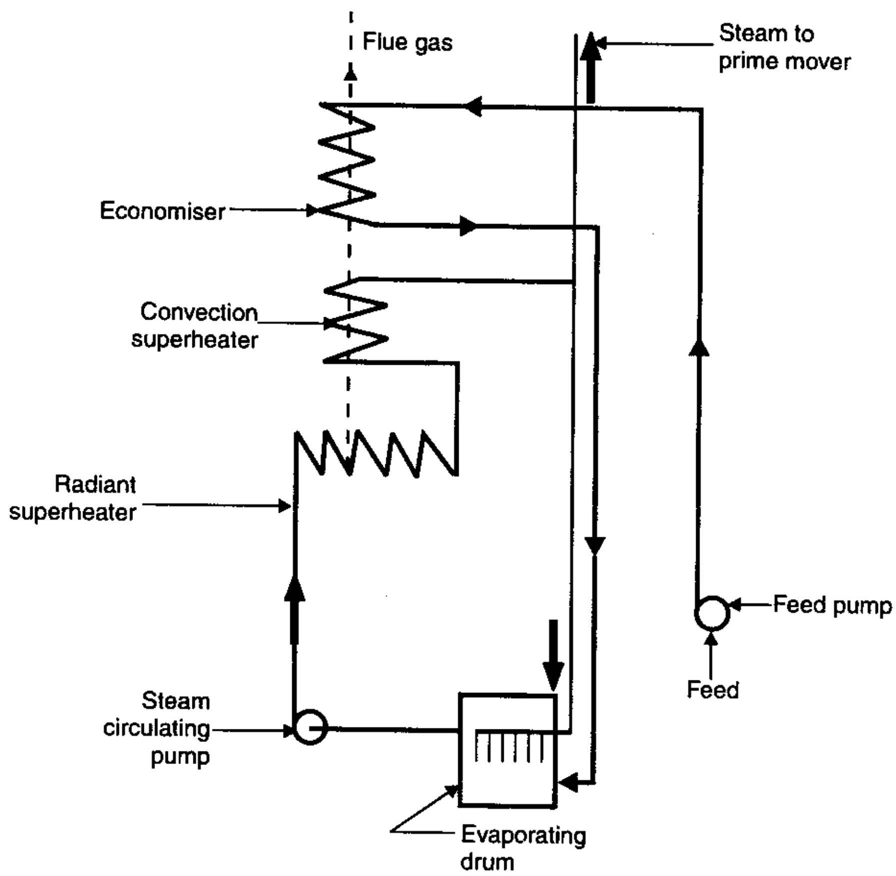


Fig. 3.60. Loeffler boiler.

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.*

As the steam pressure increases, the *differential* between the specific weight of saturated water in down-comers and specific weight of steam-water mixture in furnace wall tubes, which *causes natural circulation* in boiler, goes on *decreasing. Sluggish circulation causes film boiling.* In film boiling, the tube metal remains in contact with steam bubbles which provide high thermal resistance for heat flow and therefore tube metal sharply deteriorates due to high metal temperature leading to failure of the boiler tubes.

It is *not possible to prevent "film boiling"* in the upper furnace tubes for pressures above *180 bar* with *natural circulation.* Therefore, generally above 160 bar pressure, *controlled circulation* in water walls is used by providing *boiler circulating pump* between down-comers and lower water distributing heaters and the water walls. In such controlled circulation boilers, it is possible to utilize high steam pressure upto 200 bar but beyond this, the effectiveness of Boiler drum in separating the saturated steam from water is reduced. Therefore, *beyond 200 bar, drumless boiler is envisaged.* In *sub-critical range* (< 225.65 bar), a **separator vessel** is utilised to separate out salts from steam water mixture, but in *supercritical range* (> 225.65 bar), the separate vessel cannot function and only **once through** (monotube) is adopted.

- Fig. 3.61 shows a *once through or monotype boiler* (a design adopted by Sulzers Brothers Ltd). In this design there is a separator vessel with sub-critical pressures ; the *once through circulation is provided by a "feed pump".*

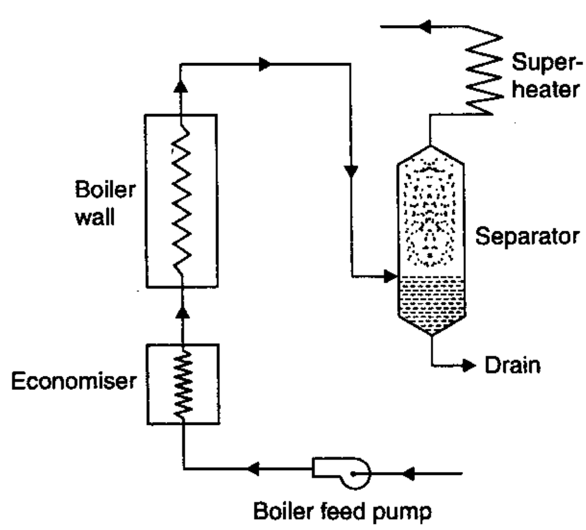


Fig. 3.61. Once through (or Monotype) boiler.

- Fig. 3.62 shows a combined circulatory boiler (a design adopted by M/S Combustion Engineering Co.). In this design a *"Mixing vessel"* provides suction to boiler circulating pumps at sub-critical pressures and inlet saturated steam to superheater and serves as a receiving header for steam-water mixture from evaporator suction. The boiler circulating pumps are required to function in the start-up or low pressure conditions but when the pressure goes above critical pressure then these are stopped and once through circulation is provided by boiler feed pump.

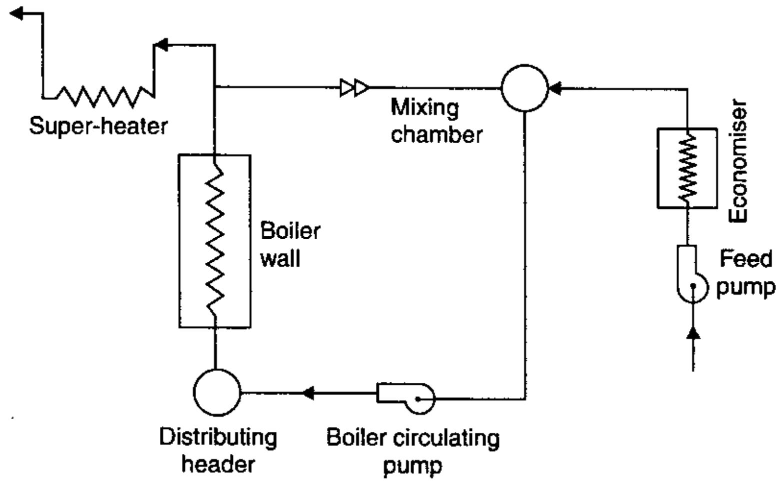


Fig. 3.62. Combined circulatory pump.

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 surfaces* *reduce the heat flow and steam generation as it offers high thermal resistance than water film. Benson in 1922 argued that if the boiler pressure was raised to critical pressure (225 atm.), the steam and water have the same density and therefore, the danger of bubble formation can be easily eliminated.* The first high pressure Benson boiler was put into operation in 1927 in West Germany.

This boiler too makes use of forced circulation and uses oil as fuel. It chief novel *principle is that it eliminates the latent heat of water by first compressing the feed to a pressure of 235 bar, it is then above the critical pressure and its latent heat is zero.*

Fig. 3.63 shows a schematic diagram of a Benson boiler. This boiler does not use any drum. The feed water after circulation through the economic tubes flows through the radiant parallel tube section to evaporate partly. The steam water mixture produced then moves to the transit section where this mixture is converted into steam. The steam is now passed through the convection superheater and finally supplied to the prime mover.

Boilers having as high as 650°C temperature of steam had been put into service. The maximum working pressure obtained so far from commercial Benson boiler is 500 atm. The Benson boilers of 150 tonnes/h generating capacity are in use.

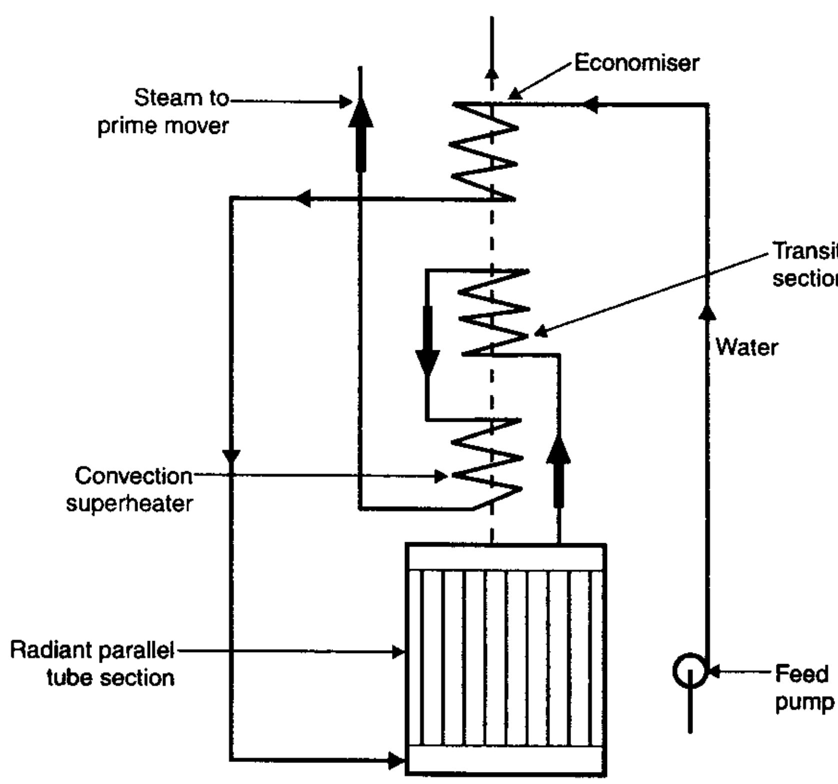


Fig. 3.63. Benson boiler.

Advantages of a Benson Boiler

The Benson boiler possesses the following *advantages* :

1. It can be erected in a comparatively smaller floor area.
2. The total weight of a Benson boiler is 20% less than other boilers, since there are no drums. This also reduces the cost of the boiler.

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.

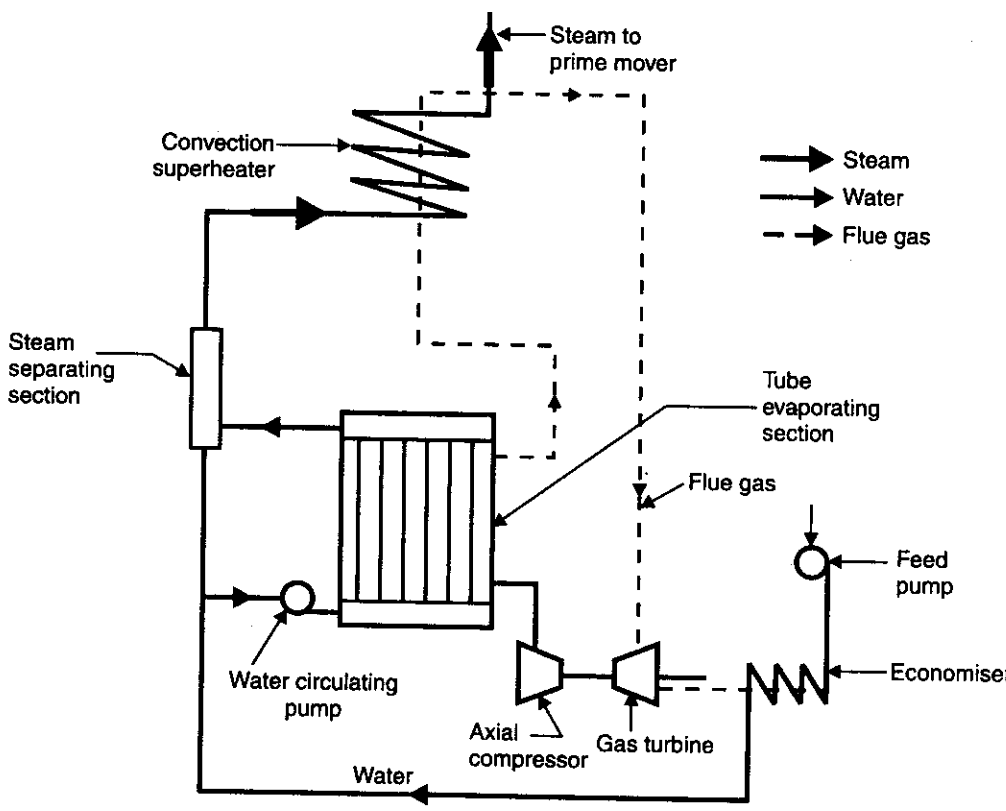


Fig. 3.64. Velox boiler.

This boiler makes use of ***pressurised combustion.***

The gas turbine drives the axial flow compressor which raises the incoming air from atmosphere pressure to furnace pressure. The combustion gases after heating the water and steam flow through the gas turbine to the atmosphere. The feed water after passing through the economiser is pumped by a water circulating pump to the tube evaporating section. Steam separated in steam separating section flows to the superheater, from there it moves to the prime mover.

The size of the Velox boiler is limited to 100 tonnes/h because 600 B.H.P. is required to run the air compressor at this output. The power developed by the gas turbine is not sufficient to run the compressor and therefore some power from external source power must be supplied.

Advantages :

1. The boiler is very compact and has greater flexibility.
2. Very high combustion rates are possible.
3. It can be quickly started.
4. Low excess air is required as the pressurised air is used and the problem of draught is simplified.

3.14.9.8. Super-critical boilers

A large number of steam generating plants are designed between working ranges of 125 atm. and 510°C to 300 atm. and 660°C ; these are basically characterised as *sub-critical and super-critical.*

Usually, *a sub-critical boiler* consists of three distinct section as *preheater* (economiser), *evaporator* and *superheater.*

A *super-critical boiler* requires only *preheater* and *superheater.*

The constructional layout of both the above types of boilers is, however, practically identical.

These days it has become a rule to use *super-critical boilers above 300 MW capacity units.*

The super-critical boilers claim the following *advantages* over critical type :

1. Large heat transfer rates.
2. Owing to less heat capacity of the generator the pressure level is more stable and therefore gives better response.
3. Because of absence of two phase mixture the problems of erosion and corrosion are minimised.
4. More adaptable to load fluctuations (because of great ease of operation, simplicity and flexibility).
5. The turbo-generators connected to super-critical boilers can generate peak loads by changing the pressure of operation.
6. Higher thermal efficiency.

Presently, 246 atm. and 538°C are used for unit size above 500 MW capacity plants.

3.14.9.9. Supercharged boiler

In a supercharged boiler, the combustion is carried out under pressure in the combustion chamber by supplying the compressed air. The exhaust gases from the combustion chamber are used to run the gas turbine as they are exhausted to high pressure. The gas turbine runs the air compressor to supply the compressed air to the combustion chamber.

Advantages :

1. Owing to very high overall heat transfer co-efficient the heat transfer surface required is hardly 20 to 25% of the heat transfer surface of a conventional boiler.
2. The part of the gas turbine output can be used to drive other auxiliaries.

3. Small heat storage capacity of the boiler plant gives better response to control.
4. Rapid start of the boiler is possible.
5. Comparatively less number of operators are required.

Corrosion in boilers and its prevention

For the safety and performance of fossil fired boilers proper selection of tube material is very essential.

It is of paramount importance to keep the tubes clean internally and externally free of deposits that could impair heat transfer and lead to corrosion, ultimately causing tube failures. Corrosion damage is always experienced inside tubes of the boiler, economiser and superheater when water chemistry is not maintained within limit as recommended by the manufacturers.

Materials commonly used for various parts/sections of the boilers are given below :

Parts/Sections	**Materials**
1. *Furnace walls and economisers*	Carbon steels and ferric alloys with small percentages of chromium (5–10%).
2. *Superheater and reheater tubes*	— Carbon steels... upto 500°C temp. — Alloy steels ... temp. > 500°C. — Carbon-molybdenum steel is used at *inlet section.* — Ferritic alloy steel with high percentage of chromium is used for downstream section of superheater. — Stainless steel and high chromium steels are recommended for *hotter sections* (560–600°C).

Composite tubes (consisting of an outer layer of 50% Cr, 15% Ni steel, metallurgically bonded to inner layer of 800 H) are used when coal-ash attack is severe.

Following are the few important phenomena which contribute to corrosion :

(*i*) Hydrogen induced brittle fracture.
(*ii*) Bulk deposit corrosion.
(*iii*) Corrosion fatigue.
(*iv*) Stress corrosion cracking.
(*v*) Oxidation.
} Water-side problems

(*vi*) Fouling.
(*vii*) Slagging.
} Fireside problems

If inspite of design efforts high temperature corrosion occurs then the problem can be solved by using any one of the following methods :

1. Using the fuels having more favourable characteristics.
2. Replacing the damaged tubes with tubes containing high chromium content.
3. Providing stainless steel tube shields at the cost of reduced efficiency.

3.15. ACCESSORIES

***Accessories** are the auxiliary plants required for steam boilers for their proper operation and for the increase of their efficiency.*

Commonly used accessories are discussed as follows :

3.15.1. Feed Pumps

The feed pump is a pump which is used to *deliver feed water to the boiler.* It is desirable that the quantity of water supplied should be at least equal to that evaporated and supplied to the engine. Two types of pumps which are commonly used as feed pumps are : (*i*) *Reciprocating pump*, and (*ii*) *Rotary pump.*

The reciprocating pump consists of a pump cylinder and a piston. Inside the cylinder reciprocates a piston which displaces water. The reciprocating pump may be of two types :

1. Single-acting pump 2. Double-acting pump.

In a single-acting pump the water is displaced by one side of the piston only and so the water is discharged in alternate strokes.

In a double-acting pump, the water is discharged in each stroke of the piston since the water is displaced by both the sides of the piston.

The reciprocating feed pumps are continuously run by steam from the same boiler to which water is to be fed.

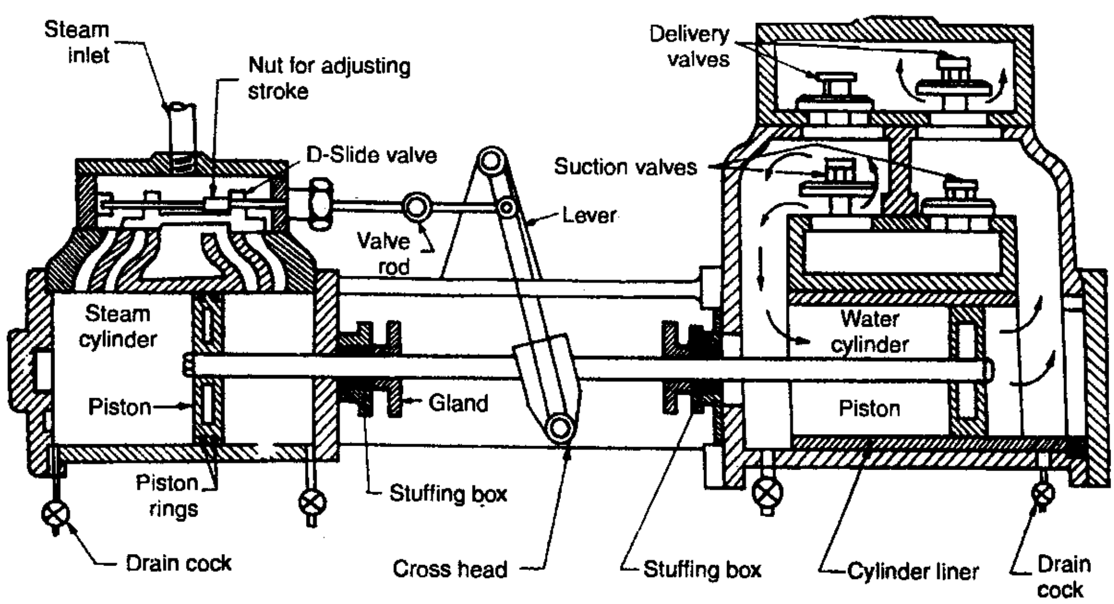


Fig. 3.65. Feed pump.

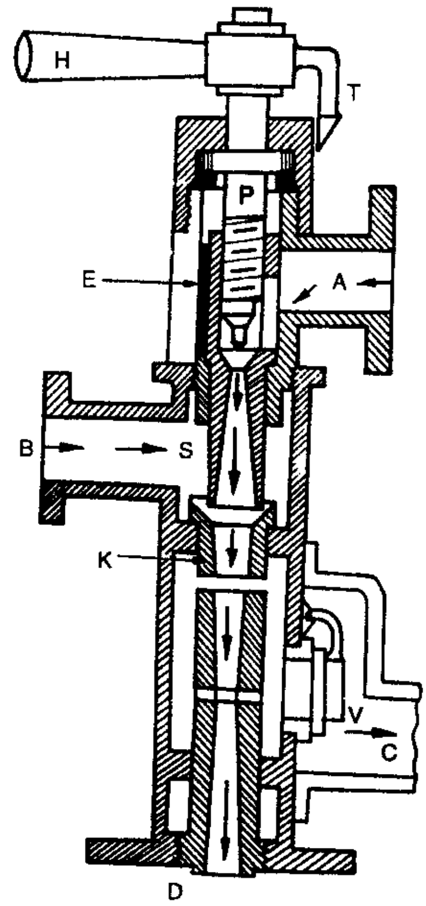
Fig. 3.65 shows a duplex direct acting steam pump. Here there are two single steam cylinders placed side by side. Slide valves distribute the steam in each cylinder. The slide valve in each cylinder steam chest is operated by the crosshead on the piston rod of the opposite cylinder, through an arrangement of rods and rocker arms. The feed pump is generally double-acting. On each side of the pump plunger there are suction and discharge valves. The pumps work alternately and consequently continuous flow of water is maintained. ***Double feed pump is commonly employed for medium size boilers.***

Rotary feed pumps are of centrifugal type and are commonly run either by a small steam turbine or by an electric motor. A rotary pump consists of a casing and a rotating element known as impeller which is fitted over a shaft. It utilises the centrifugal force of the rotating impeller for pumping the liquid from one place to the other.

3.15.2. Injector

The function of an injector is to feed water into the boiler. It is commonly employed for vertical and locomotive boilers and does not find its application in large capacity high pressure boilers. It is also used where the space is not available for the installation of a feed pump.

In an injector the water is delivered to the boiler by steam pressure ; the *kinetic energy of steam is used to increase the pressure and velocity of the feed water.*



S = Steam cone
K = Combining cone
D = Delivery cone
P = Spindle
A = Steam pipe
B = Water pipe
E = Key
H = Handle
T = Pointer
V = Valve
C = Overflow pipe

Fig. 3.66. Injector.

Fig. 3.66 shows an injector. It consists of a spindle P, a steam cone S, a combining cone K, a delivery cone D, and a handle H, with a pointer T. The spindle's upper end is provided with a handle while the lower end serves the purpose of a valve. The pointer on the handle indicates the 'shut' and 'open' position of the valve. The lower part of the spindle has a screw which works in a nut which is integral part of the steam cone. The key E checks the rotation of steam cone. With the rotation of the handle steam cone moves up or down and consequently the valve controls the steam flow through the steam cone. The steam enters through the steam pipe A, while the feed water enters through the water pipe B. The flow of water is also regulated due to sliding motion of the steam cone by its lower end. The water mixes with the steam at the combining cone where it is condensed. The mixture then passes through the delivery cone and there its kinetic energy is converted into pressure energy. The final pressure must be greater than the steam pressure of boiler otherwise water will not enter into the boiler. The excess water finds its way through the overflow pipe.

Advantages of an injector :

1. Low initial cost.
2. Simplicity.
3. Compactness.
4. Absence of dynamic parts.
5. Thermal efficiency very high (about 99%).
6. Ease of operation.

Disadvantages :

1. Pumping efficiency is low.
2. It cannot force very hot water.
3. Irregularity of operation under extreme variation in steam pressure.

Note. An injector is more efficient than a feed pump because all the heat in the operating steam is returned to boiler and in addition to performing the work of a pump, the injector acts as a feed water heater. But when a large quantity of feed water is involved (*e.g.* marine and large installations) feed pumps are employed because they have greater reliability and require lesser amount of attention.

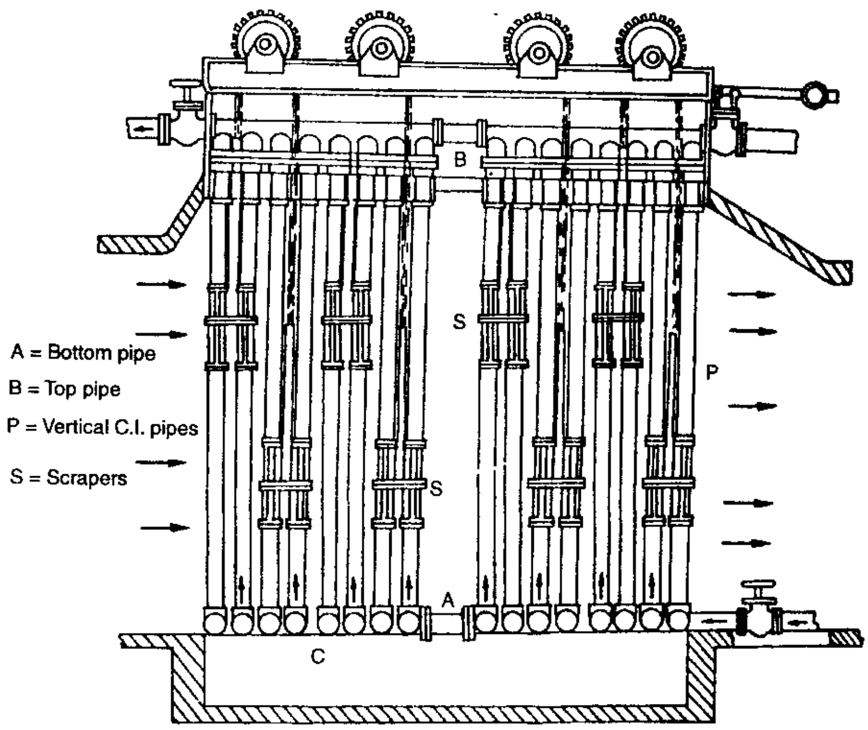
3.15.3. Economiser

An economiser is a device in which the waste heat of the flue gases is utilised for heating the feed water.

Economiser are of the two types : (*i*) *Independent type*, and (*ii*) *Integral type*. *Former* is installed in chamber apart from the boiler setting. The chamber is situated at the passage of the flow of the flue gases from the boiler or boiler to the chimney. *Latter* is a part of the boiler heating surface and is installed within the boiler setting.

Fig. 3.67 shows an independent type vertical tube economiser (called Green's economiser). It is employed for boilers of medium pressure range upto about 25 bar. It consists of a large number of vertical cast iron pipes P which are connected with two horizontal pipes, one at the top and the other at the bottom. A is the bottom pipe through which the feed water is pumped into the economiser. The water comes into the top pipe B from the bottom pipe (*via.* vertical pipes) and finally flows to the boiler. The flue gases move around the pipes in the direction opposite to the flow of water. Consequently, heat transfer through the surfaces of the pipes takes place and water is thereby heated.

A blow-off cock is provided at the back of end vertical pipes to remove sediments deposited in the bottom boxes. The soot of the flue gases which gets deposited on the pipes reduces the efficiency of the economiser. To prevent the soot deposit, the scrapers S move up and down to keep the external surface of the pipe clean (for better heat transfer).



A = Bottom pipe
B = Top pipe
P = Vertical C.I. pipes
S = Scrapers

Fig. 3.67. Economiser.

By-pass arrangement (Fig. 3.68) *enables to isolate or include the economiser in the path of flue gases.*

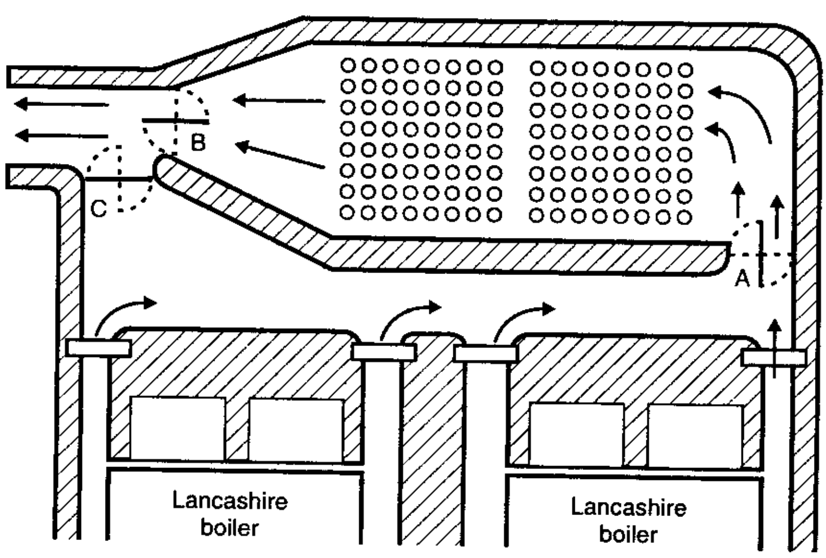


Fig. 3.68. By-pass arrangement of flues.

The use of an economiser entails the following *advantages* :

1. The temperature range between various parts of the boiler is reduced which results in reduction of stresses due to unequal expansion.
2. If the boiler is fed with cold water it may result in chilling the boiler metal. Hot feed water checks it.
3. Evaporative capacity of the boiler is increased.
4. Overall efficiency of the plant is increased.

3.15.4. Air Preheater

The function of the air pre-heater is to increase the temperature of air before it enters the furnace. It is generally placed after the economiser ; so the flue gases pass through the economiser and then to the air preheater.

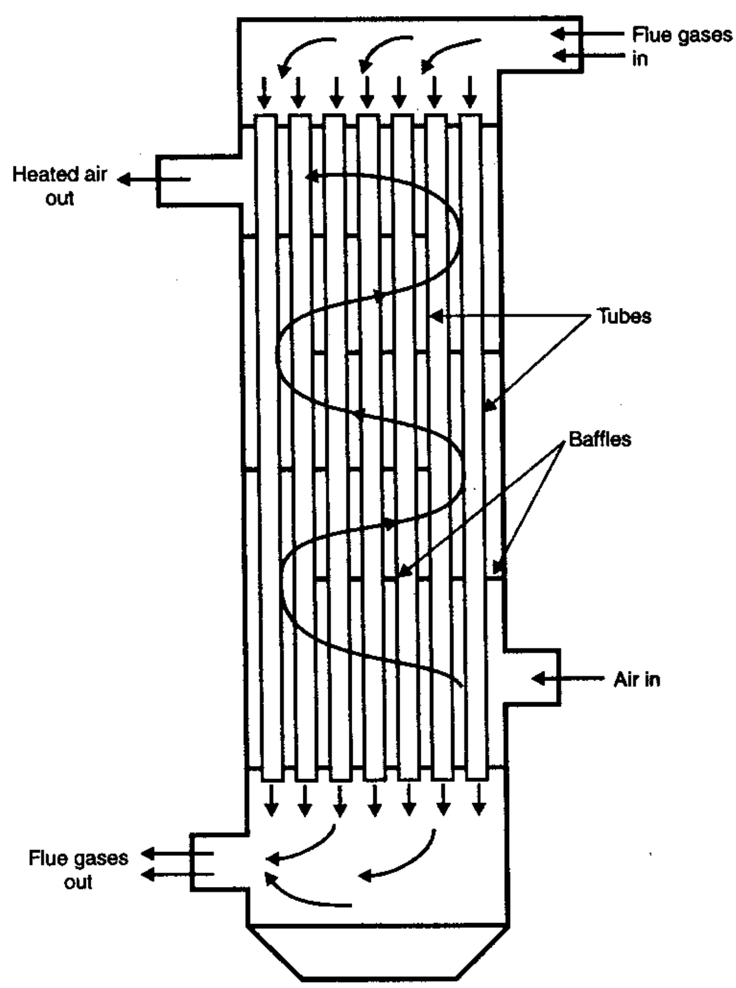


Fig. 3.69. Tubular type air preheater.

An air-preheater consists of plates or tubes with hot gases on one side and air on the other. It preheats the air to be supplied to the furnace. Preheated air accelerates the combustion and facilitates the burning of coal.

Degree of preheating depends on :

(i) Type of fuel,

(ii) Type of fuel burning equipment, and

(iii) Rating at which the boiler and furnace are operated.

There are *three* types of air preheaters :

1. Tubular type
2. Plate type
3. Storage type.

Fig. 3.69 shows a *tubular type air preheater*. After leaving the boiler or economiser the gaseous products of combustion travel through the inside of the tubes of air preheater in a direction opposite to that of air travel and transfer some of their heat to the air to be supplied to the furnace. Thus the air gets initially heated before being supplied to the furnace. The gases reverse their direction near the bottom of the air heater, and a soot hopper is fitted to the bottom of air heater casing to collect soot.

In the *plate type air preheater* the air absorbs heat from the hot gases being swept through the heater at high velocity on the opposite side of a plate.

Fig. 3.70 shows a self explanatory sketch of a *storage type air preheater* (heat exchanger).

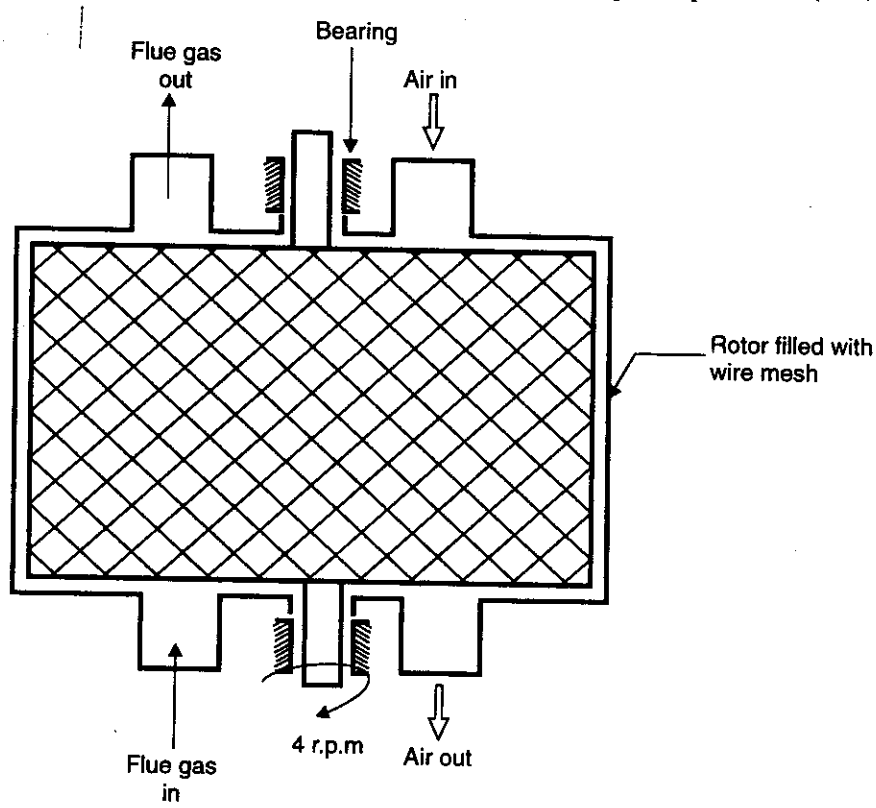


Fig. 3.70. Storage type air preheater.

Finally the gases escape to the atmosphere through the stack (chimney). The temperature of the gases leaving the stack should be kept as low as possible so that there is minimum loss of heat to the stack.

3.15.5. Superheater

The function of a superheater is to increase the temperature of the steam above its saturation point. The superheater is very important accessory of a boiler and can be used both on fire-tube and water-tube boilers. The small boilers are not commonly provided with a superheater.

Superheated steam has the following *advantages* :

(*i*) Steam consumption of the engine or turbine is reduced.

(*ii*) Losses due to condensation in the cylinders and the steam pipes are reduced.

(*iii*) Erosion of turbine blade is eliminated.

(*iv*) Efficiency of the steam plant is increased.

Superheaters are located in the path of the furnace gases so that heat is recovered by the superheater from the hot gases.

There are two types of superheaters :

1. Convective superheater
2. Radiant superheater.

Convective superheater makes use of heat in flue gases whereas a *radiant superheater* is placed in the furnace and wall tubes receives heat from the burning fuel through radiant process. The *radiant type of superheater is generally used where a high amount of superheat temperature is required.*

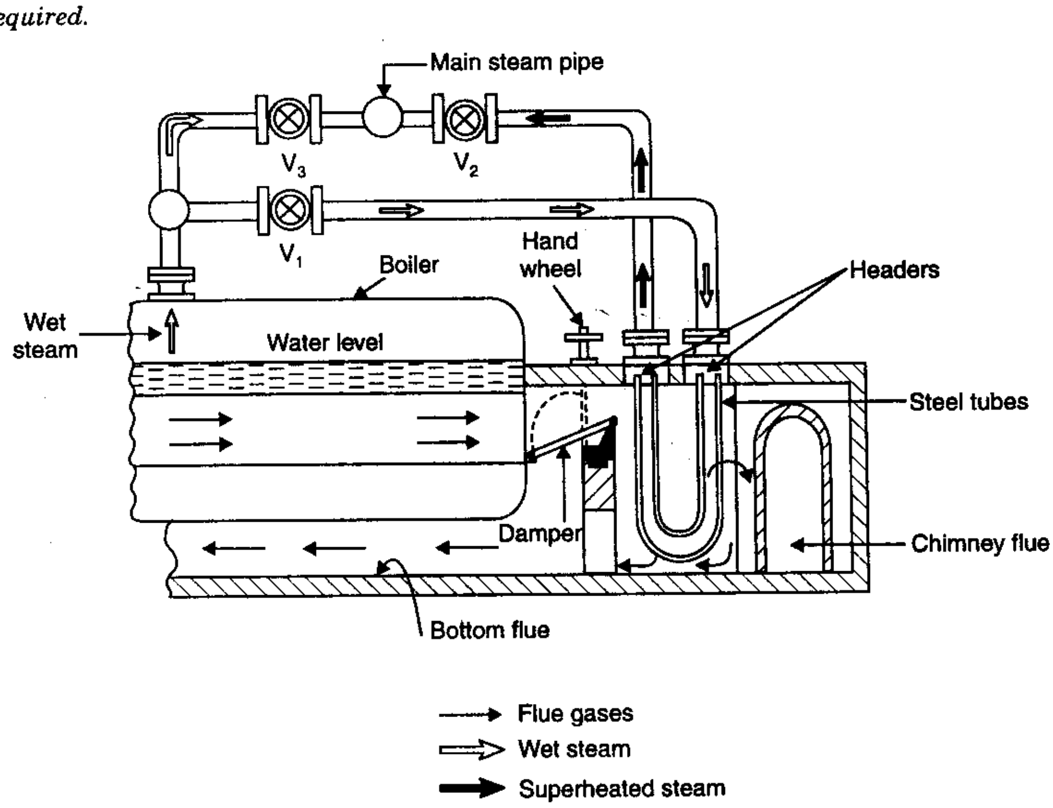


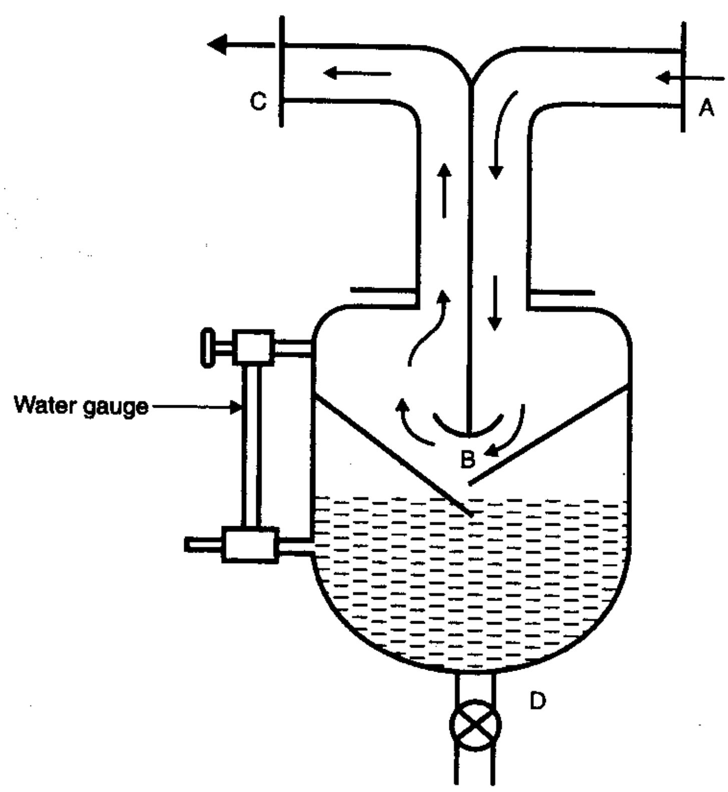
Fig. 3.71. Sugden's superheater.

Fig. 3.71 shows Sugden's superheater installed in a Lancashire boiler. It consists of two steel headers to which are attached solid drawn 'U' tubes of steel. These tubes are arranged in groups of four and one pair of the headers generally carries ten of these groups or total of forty tubes. The steam from the boiler enters and leaves the headers as shown by the arrows. Fig. 3.71 also shows how the steam pipes may be arranged so as to pass the steam through the superheater or direct to the main steam pipe. When the steam is taken from the boiler direct to the main steam pipe, the valves V_1 and V_2 are closed and V_3 is opened ; when the steam is passed through the superheater *i.e.*, when the superheater is in action the valve V_3 is closed the valve V_1 and V_2 are opened.

The path of the gases is controlled by the damper which is operated by the hand wheel.

3.15.6. Steam Separator

The steam available from a boiler may be either wet, dry ; or superheated ; but in many cases there will be loss of heat from it during its passage through the steam pipe from the boiler to the engine tending to produce wetness. The use of wet steam in an engine or turbine is uneconomical besides involving some risk ; hence it is usual to endeavour to separate any water that may be present from the steam before the latter enters the engine. This is accomplished by the use of a steam separator. Thus *the function of a steam separator is to remove the entrained water particles from the steam conveyed to the steam engine or turbine.* It is installed as close to the steam engine as possible on the main steam pipe from the boiler.



A, C = Flanges D = Drain pipe
B = Baffles

Fig. 3.72. Baffle plate steam separator.

According to the *principle of operation* the steam separators are *classified* as follows :

1. Impact or baffle type
2. Reverse current type
3. Centrifugal type.

Fig. 3.72 shows *baffle plate steam separator.* The steam enters the flange *A* and flows down. In its passage it strikes the baffles *B* ; as a result it gets deflected, but water particles having greater density and greater inertia fall to the bottom of the separator. The drier steam discharges through the flange *C*. To see the level of water collected a water gauge is provided. The water collected in the vessel is removed at intervals through the drain pipe *D*.

3.16. FEED WATER HEATERS AND EVAPORATORS

The main condensate in most of the power plants returns to the steam generator as feed water. Some make-up water may be added to replace losses in the cycle. In a few plants the boiler feed water may be 100 percent make-up, in this case the plant turbines exhaust at back pressures above atmospheric to supply steam for other purposes. Feed water is heated by bleeding steam to heaters as in a regenerative cycle from the main turbine, or by using exhaust steam from auxiliary-drive turbines, or by by-product steam from processes. *Feed water heating with steam at a lower pressure than boiler pressure usually raises overall plant efficiency.*

3.16.1. Feed Water Heaters

The feed water heaters may be classified as follows :

1. Open or contact heaters

(*i*) Tray type (*ii*) Jet type.

2. Closed or surface heaters

Heated feed water enables steam generators to produce more kg of steam and avoids severe thermal stressing by cold water entering a hot drum. Preheating feed water also causes scale-forming dissolved salts to precipitate outside the boiler and removes dissolved O_2 *and* CO_2, *which corrode boiler material.*

3.16.1.1. Open heaters

(*i*) ***Tray type open heater.*** The construction of an open heater employs a shell of rolled steel plates riveted or welded along a longitudinal seam. Dished steel ends are joined to the shell at two ends through riveting or welding. In the *tray type heater* (Fig. 3.73), the upper half of the shell contains two tray sections and the spray distributor, while the lower half is mostly empty and serves as a storage for heated water. Above the shell is placed a vent condenser. Feed water after passing through the vent condenser flows into the spray distributor from where it cascades over the staggard trays. Exhaust steam from auxiliaries or low pressure steam from a suitable point in the turbine is passed into the heater, entering opposite the tray sections and flowing upward counter to the direction of water, through the heating section. The flow of two liquids through the heater, thus, results in thorough mixing up so that heat of steam is transferred to water, the steam itself also being condensed. O_2, CO_2 and NH_3 are also removed by this type of heater.

In addition to the heating of feed water, the *contact type heater* is often constructed for *deaerating action.* The only difference between the simple heater and a deaerating open heater is *in the addition of a section of air removing trays* below the heating trays. After the water has been heated in the heating section, it is made to pass over the air separating trays which provide a complete separation of air and water. Water then flows down while air and non-condensable gases together with water vapour pass to the top of the shell and from there to the vent condenser. The vent condenser is a small surface condenser of U-type. The vapour content is condensed here and drained to the air separating section while air and gases are vented to the atmosphere. *The interior of the shell of deaerating heat, as also the trays, is made of corrosion resistant material such as stainless steel.*

(*ii*) ***Jet type open heaters.*** In this type of deaerating contact heater spring loaded spray valves atomise the feed water coming from the vent condenser and spray it upwards against a baffle. The low pressure steam enters a conical steam jacket fitted in the upper part of the shell, and is allowed to expand in the same direction as the water spray, mixes with water, and the mixture falls down to the lower part of the shell which serves as a storage. The non-condensing gases travel upwards as in the tray type heater and are passed on to the vent condenser. *It is mainly used in marine where tray type of heaters do not work well due to the pitching and rolling of the vessel. They can handle water containing scaling impurities and are lighter in weight. These heaters do not work well at low pressures, specially at sub-atmospheric pressure.*

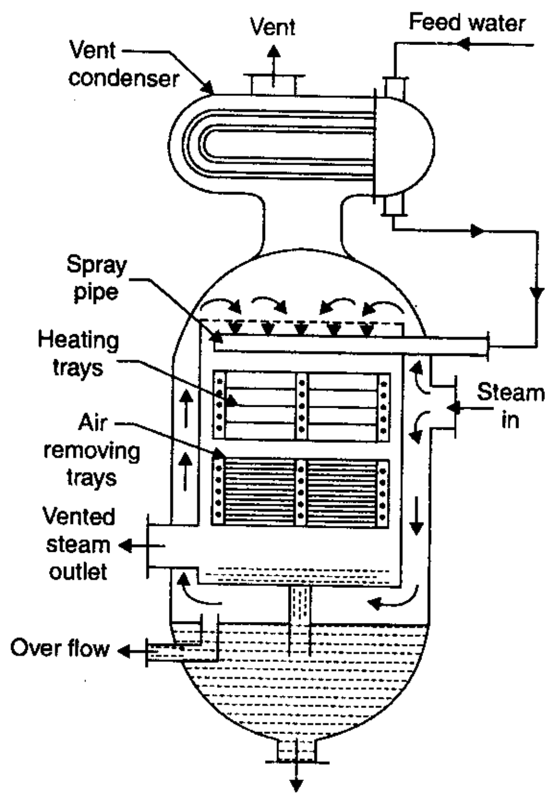


Fig. 3.73. Tray type open heater.

3.16.1.2. Closed or Surface feed heaters

These heaters usually have shell and tube construction and may be made *horizontal* and *vertical*. The construction of a closed heater and a surface condenser are identical *except that the heater is designed for higher temperatures and pressures and has greater strength than the condenser.*

Fig. 3.74 shows a *closed feed water heater*. It consists of a shell (made of a steel plate of suitable thickness) which has a welded longitudinal seam. To each end of the shell is welded a steel flange for fitting the covers, and on the top and bottom connections are provided for inlet of steam and exit of condensate. A baffle plate is provided below the steam inlet to spread the steam evenly over the tubes. The water tubes (16 to 25 mm diameter) of admiralty brass or other suitable material, are stretched between two end sheets of Muntz metal or soft steel, one of these being fixed and the other *'floating'* to take up expansion strain in tubes. The floating tube sheet is covered with a head cover bolted on to it and prevents the leakage of water into space.

The heater may have single pass or the water box may be divided to give two-pass design. A pair of air pockets provided at the bottom of the shell permits the withdrawal of air.

The flow of steam and water through the heater is usually counter to each other. Low pressure heaters may use steam under vacuum and high-pressure heaters at pressures above 40 bar. Steam and water need not be at the same pressure, and one pump may push water through several heaters in series. Water pressure may be as high as 250 bar.

For good performance heaters must be *drained* and *vented.*

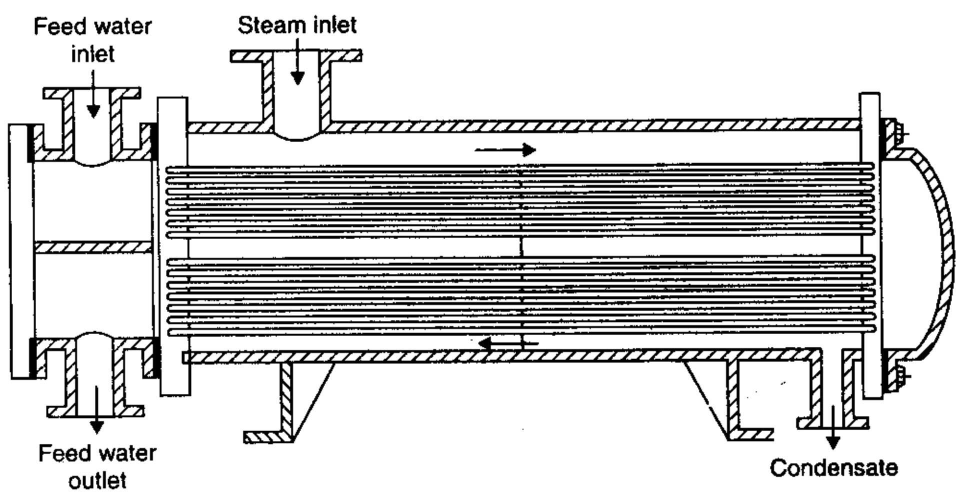


Fig. 3.74. Closed feed water heater.

3.16.2. Miscellaneous Heaters

Water may also be heated by *"waste heat"* in a variety of heater arrangements, some of which are as listed below :

1. The blow off heat exchanger.
2. The turbine tube oil cooler.
3. Generator air and hydrogen coolers.
4. The steam-jet air-ejector condenser.
5. The deaerating vent condenser.
6. The evaporator condenser.
7. The drain cooler.

3.16.3. Evaporators

These are used to give a supply of pure water as make-up feed for the boilers. Raw water is evaporated by using extracted steam and then condensed to give distilled and pure feed water.

Two main classes of evaporators are :

1. The film type evaporators. In this type water is sprayed on the surface of tubes through which steam is passed. As the water falls on the surface of heated tubes it evaporates.

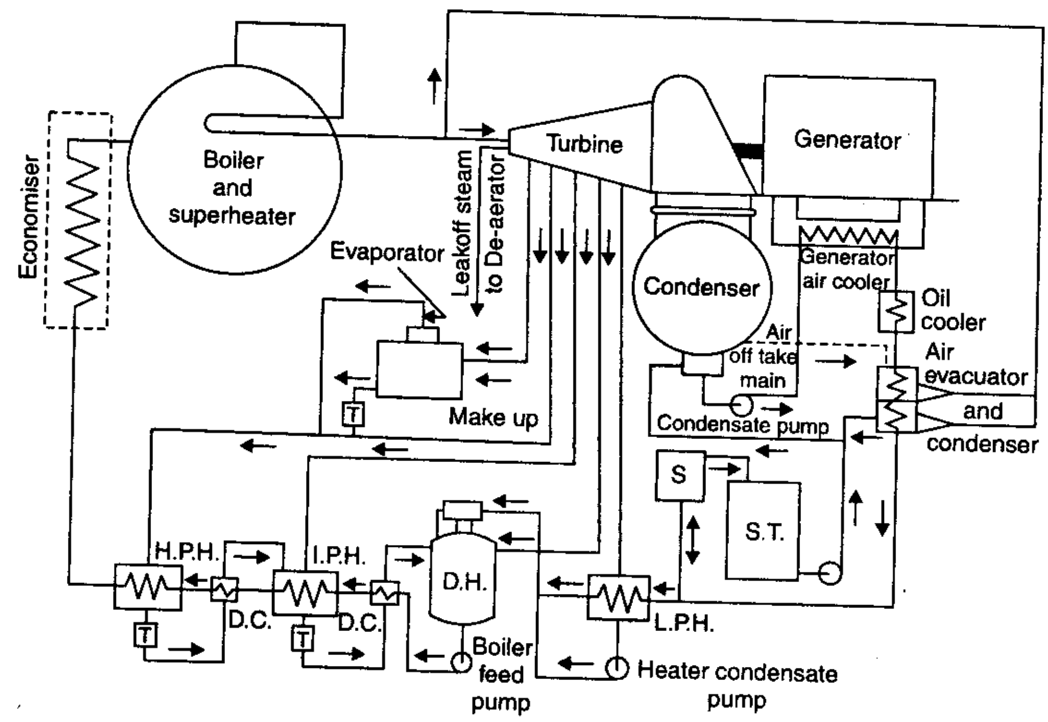
2. The submerged type evaporators. In this case the bundle of tubes is submerged in water. Vapours formed in the shell pass out of the shell through a moisture separator and enter a feed water condenser or water heater where these condense and mix with feed water.

In practice, two or more evaporators may be connected in parallel or in series.

The raw water used causes sludge and scale formation in the evaporator drum and on the surface of the tubes. Regular blow-downs keep the sludge concentration low. Scales from the outer surface of tubes are removed by cracking them with sprays of cold water, steam flow inside the tubes being continued.

3.16.4. Typical Utility Cycle Layout

Fig. 3.75 shows a typical utility cycle layout with four feed water heater, an evaporator, and miscellaneous heat exchangers.



H.P.H. = High pressure heater
I.P.H. = Intermediate pressure heater
L.P.H. = Low pressure heater
D.H. = De-aerating heater
D.C. = Drain cooler
T. = Trap
S. = Surge tank
S.T. = Storage tank

Fig. 3.75. Shcematic layout of a central station to illustrate general relationship of equipment used in feed heating cycle.

Industrial plant layouts vary widely depending on the following :

(*i*) The product of the manufacturing plant.

(*ii*) Need for electric power and steam at various pressures.

3.17. PERFORMANCE OF BOILERS

3.17.1. Evaporative Capacity

The evaporative capacity of a boiler may be expressed in terms of :

(*i*) kg of steam/h

(*ii*) kg of steam/h/m^2 of heating surface

(*iii*) kg of steam/kg of fuel fired.

3.17.2. Equivalent Evaporation

Generally the output or evaporative capacity of the boiler is given as kg of water evaporated per hour but as different boilers generate steam at different pressures and temperatures (from feed water at different temperatures) and as such have different amounts of heat ; the number of kg of water evaporated per hour in no way provides the exact means for comparison of the performance of the boilers. Hence to compare the evaporative capacity or performance of different boilers working under different conditions it becomes imperative to provide a common base so that water be supposed to be evaporated under standard conditions. The *standard conditions* adopted are : *Temperature of feed water 100°C and converted into dry and saturated steam at 100°C.* As per these standard conditions 1 kg of water at 100°C necessitates 2257 kJ (539 kcal in MKS units) to get converted to steam at 100°C.

Thus the ***equivalent evaporation*** *may be defined as the amount of water evaporated from water at 100°C to dry and saturated steam at 100°C.*

Consider a boiler generating m_a kg of steam per hour at a pressure p and temperature T.

Let, h = Enthalpy of steam per kg under the generating conditions, and

$$\begin{bmatrix} h = h_f + h_{fg} \text{ ...... dry saturated steam at pressure } p \\ h = h_f + xh_{fg} \text{ ...... wet steam with dryness fraction } x \text{ at pressure } p \\ h = h_f + h_{fg} + c_p\,(T_{sup} - T_s) \text{ ...... superheated steam at pressure } p \text{ and temperature } T_{sup} \end{bmatrix}$$

h_{f_1} = Specific enthalpy of water at a given feed temperature.

Then heat gained by the steam from the boiler per unit time

$$= m_a\,(h - h_{f_1})$$

The equivalent evaporation (m_e) from the definition is obtained as :

$$m_e = \frac{m_a\,(h - h_{f_1})}{h_{fg}} = \frac{m_a\,(h - h_{f_1})}{2257} \quad \text{...(3.19)}$$

The evaporation rate of the boiler is also sometimes given in terms of *kg of steam / kg of fuel*.

The presently accepted standard of expressing the capacity of a boiler is in terms of the total heat added per hour.

3.17.3. Factor of Evaporation

It is defined as *the ratio of heat received by 1 kg of water under working conditions to that received by 1 kg of water evaporated from and at 100°C.* It is denoted by F_e.

∴ Factor of evaporation, $$F_e = \frac{h - h_{f_1}}{2257} \quad \text{...(3.19(a))}$$

3.17.4. Boiler Efficiency

'Boiler efficiency' *is the ratio of heat actually utilised in generation of steam to the heat supplied by the fuel in the same period.*