8

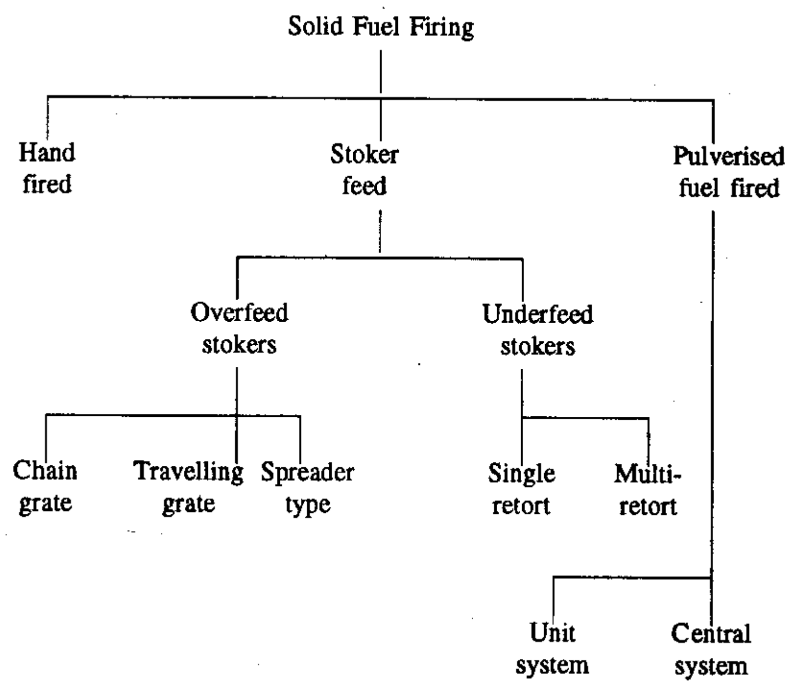
Burning of Fuels

8.1. COAL BURNING METHODS

The efficient combustion of fuel in the combustion chamber and efficient transfer of heat energy to the water for steam generation are essential for the economical working of power plant. The two commonly methods used for burning coal are stoker firing and pulverised fuel firing. The stoker firing method is used for solid fuel and pulverised firing method is used for pulverised coal. The selection of firing method adopted for a particular power plant depends upon the following factors :

(1) The characteristics of the available coal. (2) Capacity of the plant. (3) Load factor of the power plant. (4) Nature of load fluctuation, and (5) Reliability and efficiency of the various combustion equipments available.

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



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

Overfeed supply of coal. In case of overfeed stoker, the coal is fed on to the grate above the point of air admission as shown in Fig. 8.1.

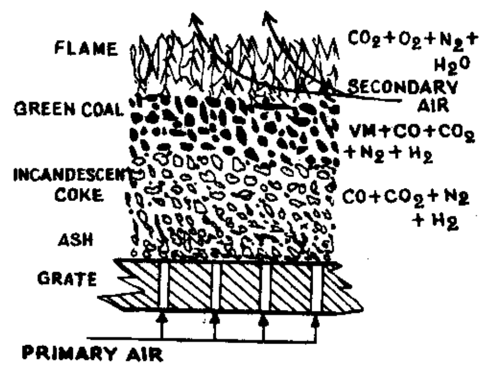


Fig. 8.1. Principle of overfeed stoker.

The mechanics of combustion in overfeed stoker is described below :

(1) The pressurised air coming from F.D. fan enters under the bottom of the grate. The air passing through the grate is heated by absorbing the heat from the ash and grate itself, whereas the ash and grate are cooled. The hot air then passes through a bed of incandescent coke. As the hot air passes through incandescent coke, the O_2 reacts with C to form CO_2. The rate of carbon-oxidation in this part of fuel bed depends entirely on the rate of air supply. Generally, for a fuel bed of 8 cm deep, all the O_2 in the air disappears in the incandescent region. The water vapour carried with air also reacts with C in incandescent zone and forms CO, CO_2 and H_2. Part of CO_2 formed reacts with C passing through incandescent zone and converts into CO. The gases leaving the incandescent region of fuel bed consist of N_2, CO_2, CO, H_2 and H_2O.

(2) The raw coal is continuously supplied on the surface of the bed. Here it loses its volatile matter by distillation. The heat required for the distillation of coal is given by incandescent coke below the fresh fuel, hot gases diffusing through the surface of the bed and hot gases and flame in the furnace above. The ignition zone lies directly below the raw fuel undergoing distillation.

(3) The gases leaving the upper surface of the fuel bed contain combustible volatile matter formed from the raw fuel, N_2, CO_2, CO, H_2 and H_2O. Additional secondary air is supplied at the top of the bed to burn the remaining combustible gases (volatile matter + CO + H_2). The secondary air is supplied at a very high speed to create turbulence which is required for complete combustion of unburned gases. The combustion of the remaining combustible gases is completed in the combustion chamber.

(4) The burned gases entering the boiler contain N_2, CO_2, O_2 and H_2O and some CO if the burning is incomplete.

(5) During incandescence, the fuel continuously loses its carbon by oxidation until only the ash remains. The primary air supplied from the bottom cools the ash until it rests on a plane immediately adjacent to the grate.

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

(1) Air after passing through the holes in the grate as shown in Fig. 8.2 meets the raw coal. As it diffuses through the bed of raw coal, it meets with the volatile matter generated by the raw-coal. The heat for distillation comes by conduction from the mass of incandescent fuel bed which exists above the raw coal. The air mixes with the formed volatile matter and passes through the ignition zone and then enters into the region of incandescent coke.

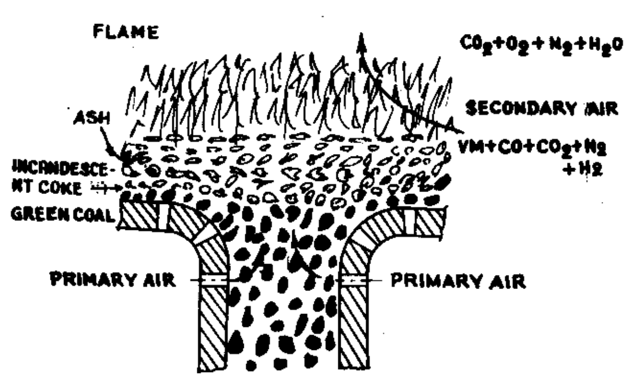


Fig. 8.2.

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

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

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

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

The rate of air supply has a marked effect on the speed of ignition in case of under-feed burning as the rising air cools the raw fuel prior to ignition. At low rate of air fuel, the heat flow by conduction from the incandescent fuel bed downward is faster than the removal of heat by air. This pushes the ignition plane down below the bed surface and creates a maximum depth of incandescent zone. As the air flow rate increases, it removes the heat from the fuel bed at a rapid rate and raises the ignition zone nearer the fuel bed surface and reduces the depth of incandescent fuel.

The action cannot take place in over-feed method of fuel supply, as the air has to pass through the incandescent zone before reaching the ignition plane.

The under-feed method of fuel supply is best for semi-bituminous and bituminous coals high in volatile matter. The volatile matter gets heated to a high temperature as it passes through incandescent region of coal. The volatile matter being at a higher temperature before entering the furnace burns quickly when mixed with secondary air.

In case of over-feed burning, the volatile matter will be somewhat cooler than the furnace gases and therefore it requires longer time for complete burning. This may create a tendency to form smoke.

8.2. OVERFEED STOKERS

These types of stokers are used for large capacity boiler installations where the coal is burned without pulverisation. The overfeed stokers are of mainly two types (*a*) Travelling grate stoker, and (*b*) Spreader stoker.

Travelling Grate Stoker. The travelling stoker may be chain grate type or bar grate type. These two differ only in the details of grate construction.

The grate surface of a chain grate stoker is made of a series of cast iron links connected by pins to form an endless chain.

The grate surface of a bar grate stoker is made of a series of cast iron sections mounted on carrier bars. The carrier bar rides on two endless type drive chains.

A travelling type chain grate is shown in Fig. 8.3. The chain grate stoker consists of an endless chain which forms a support for the fuel bed. The chain travels over two sprocket wheels one at the front and other at the rear of furnace as shown in figure. The front sprocket is connected to a variable speed drive mechanism.

The coal is fed by gravity from a hopper located in front of the stoker. The depth of the fuel on the grate is regulated by hand adjusted gate as shown in figure. The speed of the grate varies at the rate at which the coal is fed to the furnace. The combustion control automatically regulates the speed of the grate to maintain the required steam generation rate. The ash containing a small amount of combustible material is carried over the rear end of the stoker and deposited in the ashpit as shown in figure.

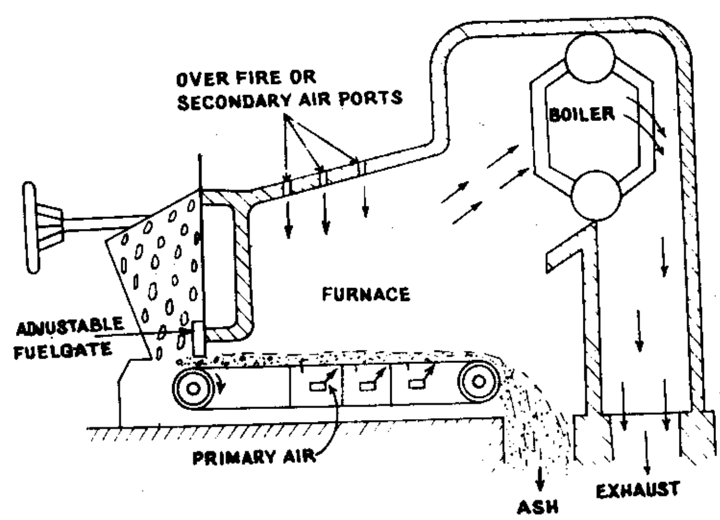


Fig. 8.3. Chain Grate Stoker.

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

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

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

Advantages. 1. It is simple in construction and its initial cost is low.

2. It is more reliable in service therefore maintenance charges are low.

3. It is self-cleaning stoker.

4. The heat release rates can be controlled just by controlling the speed of chain.

5. It gives high heat release rates per unit volume of the furnace.

Disadvantages. 1. The amount of coal carried on the grate is small as the increase in grate size creates additional problems. This cannot be used for high capacity boilers 200 tons/hr or more.

2. The temperature of preheated air is limited to 180°C.

3. The clinker troubles are very common.

4. Ignition arches are required.

5. There is always some loss of coal in the form of fine particles carried with the ashes.

Another type of travelling stoker is vibrating grate stoker. It operates in a manner similar to that of chain grate stoker except that the fuel feed and fuel bed movement are accomplished by vibration. The vibration and the inclination of the grate cause the fuel bed to move through the furnace towards the ash pit. The rate of fuel feed is automatically controlled by varying the off and on cycle of the vibrating mechanism. The vibrating condition of the fuel bed promotes uniform air distribution and better mixing. This action of vibrating bed permits the use of wider range of fuels.

Chain grate stokers are best suited for non-caking, high volatile and high ash coals. The bar grate stokers burn lignite and small size anthracite coals successfully. Vibrating grate stokers are suitable for medium volatile bituminous coals and lignites but at reduced burning rates. The travelling stokers are not suitable for caking coal at it requires agitation during burning.

Igni-Fluid Boilers

In this arrangement, advantages of stoker and FBC systems are taken. In this system, a conventional chain grate stoker is used as shown in Fig. 8.3 except the width of the grate is only about 10% of the conventional chain stoker of similar capacity. The grate is tilted to horzontal by 8 to 12°. Another outstanding difference is the variation of the pressure in the wind box compared with the wind-box used with chain grate stoker. The wind box pressure in this system varies from 20 cm to 2 cm of water head above atmosphere, highest in the first wind box and lowest in last. Air passages provided with stoker are quite small and assist in maintaining high air pressure under the grate.

In this system, 50% of the total air is supplied as primary air through grate at a velocity of 15 – 20 m/sec and remaining 50% is admitted as secondary air over the fuel bed. The primary air helps to suspend the fuel over the grate and simultaneously sustains the primary combustion ($C \rightarrow CO$) and secondary air completes the combustion of CO and volatile matter released from the coal in the primary zone. The primary air is heated to 250°C whereas secondary air is heated to a much higher temperature. The preheat temperature of primary air is limited to 250°C to reduce the maintenance cost of the stoker. The quantity of air supplied to different compartments of wind box is controlled by the dampers.

Operating advantages of ignifluid boiler over stoker are listed below.

(1) Automatic spreading of coal.

(2) Intimate reaction of fuel and air.

(3) Any type of coal or of any size can be used. There is less loss through air holes as closed grate links are used.

(4) High combustion efficiency of the order of 90% can be easily obtained.

(5) Forced outages due to clinkering of stoker are less.

Spreader Type or Sprinkler Stoker. This is a overfeed type stoker. The coal burns on this stoker remains partly in suspension and partly on the grate. The arrangement of the stoker is shown in Fig. 8.4.

The spreader stoker installation consists of variable feeding device, a mechanism for throwing the coal uniformly on the grate and with suitable openings for admitting the air. The coal feeding and distributing mechanism is located in the front wall above the grate as shown in figure. A portion of coal supplied which contains fine particles of coal burns in suspension and remaining falls to the grate. The air supplied by F.D. fan enters the furnace through the openings provided in the grate. A portion of this air is used to burn the

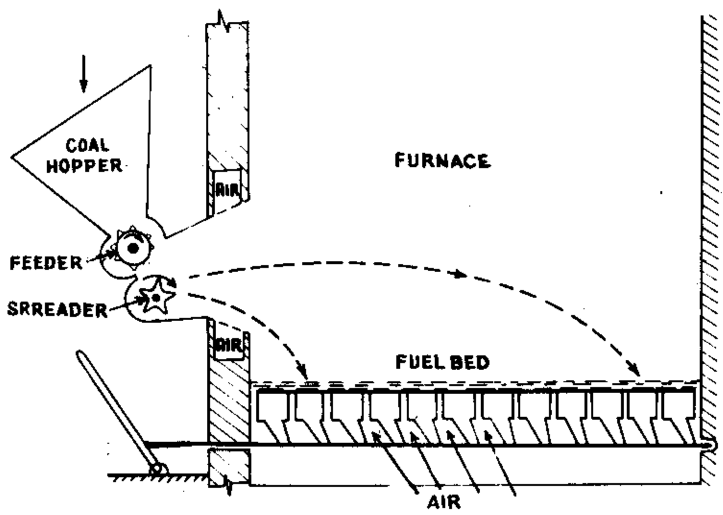


Fig. 8.4. Spreader Stoker.

fuel on the grate and remaining air is utilised to burn the volatile matter and fine particles in suspension. Overfire or secondary air is supplied through the nozzle as shown in figure. The secondary air creates high turbulence and completes the combustion of volatile matter and fine particles of the coal. The unburnt coal and ash are deposited on the grate which is removed periodically. Both stationary as well as moving grates are used with spreader stoker. Stationary grates are used upto 10 MW capacity plant while moving grates are used in the range of 10 to 30 MW capacity plant.

The feeder is a slow speed rotating drum on which large number of small blades are mounted. It supplies coal to the spreaders in a continuous stream. The speed of the feeder can be changed as per the load on the plant. The feeders may be reciprocating ram, endless belt or spiral worm. The feeders are operated with variable speed drive to control the combustion as per requirement.

Spreader consists of a rapidly rotating shaft carrying blades as shown in figure. These blades are twisted to provide uniform distribution of the coal over the grate. The fast rotating blades hit the coal particles coming from the feeder and throw it into the furnace. The distribution of coal over the grate depends on the rotating speed of the spreader and on the size of the coal. Variations in performance of the spreader owing to the changes in coal size and moisture content are corrected by means of an external hand adjustment of the mechanism.

The selection of the size of the coal used in spreader stoker is very important. The coal size used should be in between 6 cm and 36 cm.

The spreader stoker has wide applications with respect to the fuels used as well as to the boiler sizes. A wide variety and poor quality coal can be burnt efficiently with this type of stoker. This type of stoker can be used for boiler capacities from 80 tons to 150 tons of steam per hour. The heat release rate of 40×10^6 kJ/m^2-hr is possible with stationary grate and 80×10^6 kJ/m^2-hr is possible with travelling grate.

The advantages and disadvantages of this stoker are listed below :

Advantages. 1. A wide variety of coal varying from lignite to semi-anthracite as well as high ash coal can be burnt easily.

2. The clinkering difficulties are reduced even with coals which have high clinkering tendencies, by the nature of the spreading action.

3. The coking tendency of the coal is reduced before it reaches the grate by the release of volatile gases which burn in suspension.

4. The use of high temperature preheated air is possible.

5. It gives quick response to load change similar to pulverised fuel system because there is only a small amount of fuel on the grate at any time and most of heat is released during burning of the coal in suspension.

6. This form of fixing provides thin and even firebed and results in high rate of combustion (350 kg/m^2-hr). Therefore, it gives quick response to the load change and with less sensitivity to the swelling characteristics of the fuel.

7. This fire bed gives equal pressure drop and proper air distribution so that combustion can be completed with minimum quantity of excess air.

8. Its operation cost is considerably low, as 0.6 kW per ton per hour fired.

Disadvantages. 1. It is always difficult to operate spreader with varying sizes of a coal and with varying moisture content.

2. A natural result of suspension burning of fine fuel particles is the entrainment of ash in the products of combustion. To avoid the nuisance of fly ash, a dust collector is almost a necessary with this stoker.

3. Many fine unburnt carbon particles are also carried with the exhaust gases and it is necessary to trap these and return to the furnace for burning. Otherwise it would add as a loss to the combustion system.

8.3. UNDERFEED STOKERS

In underfeed stokers, the fuel is fed from underneath the fire and moves gradually upwards. The primary air is supplied just below the level at which combustion takes place. The fuel releases the volatile matter as it passes through the initial fuel bed from bottom. The released volatile matter mixes with fresh air and enters into the combustion zone. Therefore, the entire combustion process is highly efficient and gives high rates of heat release.

Bituminous and semi-bituminous coals with small ash content and fusing temperature above 1300°C (caking or non-caking) can be burnt very effectively in these stokers.

The underfeed stokers fall into two main groups, the single retort and multiple retort storkers.

Single Retort Stoker. The arrangement of single retort stoker is shown in Figs. 8.5 (*a*) and 8.5 (*b*)

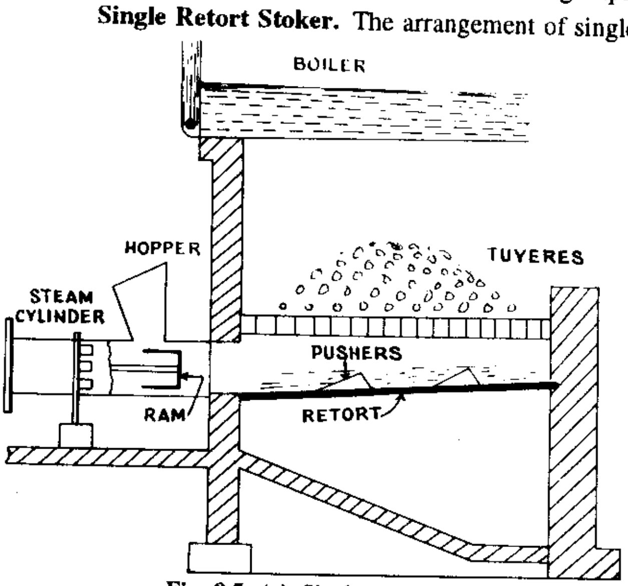


Fig. 8.5. (*a*) Single retort stoker.

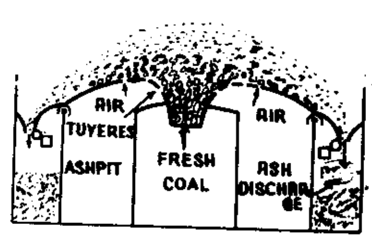


Fig. 8.5. (*b*) Single retort type stoker.

in form of two views. The fuel is placed in large hopper on the front of the furnace, and then it is further fed by reciprocating ram or screw conveyor into the bottom of the horizontal trough. The air is supplied through the tuyeres provided along the upper edge of the grate as shown in Fig. 8.5 (*b*). The ash and clinkers are collected on the ash plate provided with dumping arrangement. The coal feeding capacity of a single retort stoker varies from 100 to 2000 kg per hour.

The increase of capacity in an underfeed cannot be obtained simply by building larger single retort stoker. The size of retort for increasing the capacity is limited by virtue of inability of obtaining even air distribution from the sides of retorts. Multi-retort stokers are generally used for increasing the burning capacity of the stoker.

Multi-retort Stoker. The multi-retort stoker is shown in Fig. 8.6. It consists of a series of alternate retorts and tuyere boxes for supply of air. Each retort is fitted with a reciprocating ram for feeding and pusher plates for the uniform distribution of coal. The coal falling from the hopper is pushed forward during the inward stroke of the stoker ram. Then the distributing rams (pushers) push the entire coal down the length of the stoker. The ash formed is collected at the other end as shown in figure. The number of retorts may vary from 2 to 20 with local burning capacity ranging from 300 kg to 2000 kg per hour per retort.

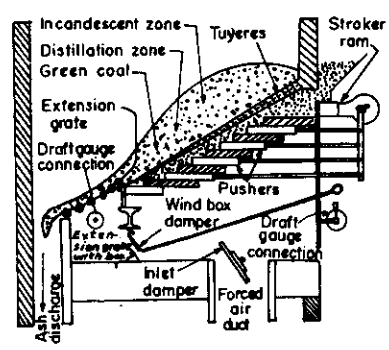


Fig. 8.6. Underfeed multi-retort stoker.

Underfeed stokers are supplied with forced draft for maintaining sufficient air flow through the fuel bed. The primary air is supplied to the fuel bed from main wind box situated below the stoker. The partly burnt coal moves on to the extension grate. The low pressure air entering into the extension grate, wind from main wind box is supplied to the thinner fuel bed on the extension grate. The quantity supplied is regulated by an air damper as shown in figure.

The air pressure in the main wind box under the stoker is also varied to meet the variable load. Means are also provided for varying the air pressure under the different sections of the stoker in order to correct for irregular fuel-bed conditions. The use of forced draft causes rapid combustion and it also becomes necessary to introduce 'overfire air' when high volatile coals are used to prevent the smoke formation. Combustion control is introduced into the stoker drive either by varying the ram stoke or by changing the rate of reciprocation ; usually the latter. On-off control is used on motor driven stokers. A throttling of steam control is used in case of steam engine driven stokers.

The advantages and disadvantages of the underfeed stokers are listed below.

Advantages. 1. This gives higher thermal efficiency compared with chain grate stokers.

2. The part load efficiency is high with multiple retort stoker.

3. The combustion rate is considerably higher.

4. Sufficient amount of coal always remains on the grate so that the combustion is continued in the event of temporary breakdown of the coal supply system.

5. The grate is self-cleaning.

6. Different varieties of coals can be used with this type of stoker.

7. Tuyeres, grate bars and retorts are not subjected to high temperature as they remain always in contact with fresh coal.

8. The use of forced draft and relatively large quantity of fuel on the stoker make them responsive to rapid changes in load.

9. The coal is continuously agitated by the plunger and pusher plates and due to this, the fuel bed remains porous and free from clinkers.

10. Smokeless operation is possible even at very light load.

11. It can be used with all refractory furnaces because of non-exposure of stoker mechanism to the furnace. Under the existing conditions in the furnace of this type, it would not be possible to use other types.

12. Underfeed stokers are suitable for non-clinkering, high volatile and low ash content coals.

Disadvantages. 1. The initial cost of the unit is high.

2. It requires large building space.

3. The clinker troubles are usually present.

4. Low grade fuels with high ash content cannot burn economically. The anthracite coals with relative low ash fusion temperatures are not suited to the underfeed stoker.

Loading of the Grates. Rate of loading the grate, J(kg/m^2) and rate of burning j(kg/m^2-hr) are independent with each other, J determines the height of the fuel bed (H_b) over the grate and it is given by

$$H_b = 0.15 \text{ J cm.}$$

J value is limited merely to see that the bed height does not exceed more than certain amount and it is not fixed as per the ash content in the coal. If bed height exceeds 15 cm, clinker formation increases due to fusion of ash. To avoid this chronic trouble, fuel bed height should not exceed over 15 cm. The bed height should not fall below 10 cm to avoid undue cooling of furnace and imperfect combustion. If the ash content of coal is low, the coal burns at faster rate and vice versa even the bed height is same. Therefore, *the grate loading (J)* is dictated by consideration of clinker formation and *burning rate (j)* is dictated by the ash content in the coal.

For stoker firing boilers, the feeding of coal must be carefully controlled to give bed height 10 to 15 cm. However the rate of burning of coal on the grate should be controlled as per ash content in the coal by adjusting the speed of grate in chain grate stoker and adjusting the speed of coal movement in ram type stoker. The cam shaft speed can be adjusted in accordance with ash content of coal for governing the coal movement on the grate.

Efficient Burning of coal on Grate. Indian coals used for power generation contain 30-35% of volatiles and 30-40% carbon. The average calorific value of the coal is 22000 kJ/kg, the minimum may be 18000 kJ/kg and maximum 25000 kJ/kg. Presently, the boilers are designed to burn coal containing ash greater than 20% and having ash fusion temperature not below 1400°C.

If a coal having 22000 kJ/kg heat value is used in the power plant, the carbon gives 11000 kJ and volatile gives 11000 kJ if all the coal and volatiles are burned. If the boiler using above coal, burns 80% volatiles and 5% carbon is left unburnt, then the actual heat release would be 18000 kJ/kg. This indicates an inability of burning complete volatiles and to prevent unburnt carbon. This also reduces steam generation rate or increases coal consumption for the same steam generation rate.

For complete burning of volatiles and to prevent unburnt carbon going with ash, adequate quantity of secondary air and its entry with high turbulence at proper location over the grate are essential requirements. Excessive secondary air will chill the hydro-carbon gases and thus forms smoky exhaust. Too low secondary air, wrongly directed with inadequate turbulence will result in partial burning of volatiles, with heavy soot formation. In either case, substantial amount of heat is lost.

The flames over the bed are due to the burning of volatile gases, lower the *volatile content in the coal, shorter will be the flame.* The burning of coal over the grate causes only glow and not the flame. The glow may be white, dazzling, orange or red depending on the temperature at the top of the bed. If the volatiles burn intensely, high temperature is generated over the bed and helps to burn the carbon completely and vice versa.

Any failure to burn volatiles efficiently will also effect the burning of carbon and unburned carbon percentage increases. Effective burning of volatile is essential for effective burning of carbon and with minimum loss.

If the volatiles contain H_2 and CH_4, we get blue, non-luminous short flame. The heavier hydrocarbons take longer time to oxidise, so the flame moves up and unburned carbon within the flame glows. As soon as this unburnt carbon burns out, the flame vanishes. Therefore, volatiles containing heavy hydrocarbon give long luminous orange colour flames. These long flames may touch the boiler tube surfaces and unburned carbon in the flame gets chilled and is deposited on the tube surfaces and reduces the steam generation capacity of the boiler. To avoid such deposition, it is necessary to provide adequate quantity of secondary air with sufficient turbulence.

Advantages and disadvantages of stoker firing over pulverised system of firing

Advantages. 1. There is no necessity of coal preparation plant as the coal obtained from mines can be directly used. Sometimes it is necessary to size (crush) the coal in order to suit the furnace conditions.

2. This can be used for medium capacity plant more economically.

3. It is free from danger of explosion.

4. The building space requirement compared with pulverised system is less.

5. The capital investment as compared to pulverised system is less.

6. The maintenance and operating costs are less.

7. The auxiliary plant required is considerably reduced.

8. It also works for few hours in the event of coal handling plant failure as large amount of coal is stored on the grate.

9. The dust collection problems are less severe compared with pulverised system as most of the ash is removed from the grate.

10. The stoke firing systems are more reliable.

Disadvantages. 1. The loss of coal is more through riddlings.

2. There is heavy wear and tear of moving parts due to abrasive action of coal.

3. The troubles of clinkering of combustion chamber walls are very common.

4. Sudden variations of load cannot be met to the same degree of efficiency as in the case of pulverised fuel firing.

5. The furnaces need fire arches which increase the construction cost and create troubles during operation.

6. Stand-by losses are considerably more.

8.4. PULVERISED FUELS AND THEIR ADVANTAGES

The pulverised fuel firing system was used for generating the steam in the early 1920s. The conventional fuel firing methods (stoke firing) were found to be unable to take the fluctuating loads on the plant due to limited capacity of combustion. Further, these conventional methods were found unsuitable for large capacity (100 MW and more) plants and coals containing high percentage of ash due to the difficulties experienced in removing large quantities of ash and interference of the formed ash in the combustion process. The pulverised fuel systems are nowadays universally used for large capacity plants and using low cost (low grade) fuel as it gives high thermal efficiency and better control as per the load demand.

In a 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 through 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 amount of primary air may vary from 10% to almost the entire combustion air requirements as per the type of pulveriser used and load on it.

The efficiency of 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 98% through 50 mesh sieve.

Many modern thermal power plants use pulverised fuel systems when the available coal is cheap and is not suitable for stoke firing. The advantages and disadvantages of pulverised system over stoke-firing system are listed below :

Advantages. (1) The success of the pulverised firing system lies in the fact that by breaking, a given mass of coal into smaller pieces exposes more coal surface area for combustion. For example, 0.1 inch diameter sphere has 60 in^2 surface area per cu. inch volume and at 0.01 inch, it has 600 in^2/cu. inch and at 0.001 inch it has 6000 in^2/cu. inch. The increase of surface area exposed per unit volume with the decreasing diameter of coal particle is shown in Fig. 8.7. This increase varies rapidly after 0.01 inch diameter of the coal particle and there is no substantial increase after 0.001 inch diameter.

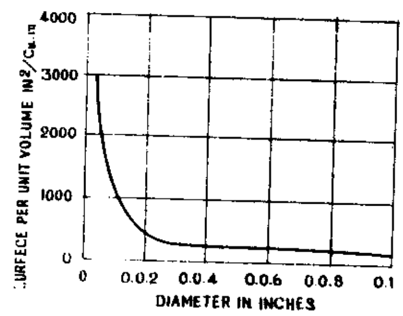


Fig. 8.7.

(2) Greater surface area of coal per unit mass of coal allows faster combustion as more coal surface is exposed to heat and oxygen. This reduces the excess air required to ensure complete combustion and the fan power also.

(3) Wide variety and low grade coal can be burnt more easily.

(4) It gives fast response to load changes as rate of combustion can be controlled easily and immediately. Automatic control applied to pulverised fuel fired boilers is effective in maintaining an almost constant steam pressure under wide load variations.

(5) The system is perfectly free from clinker and slagging troubles.

(6) This system works successfully with or in combination with gas and oil.

(7) It is possible to use highly preheated secondary air (350°C) which helps for rapid flame propagation.

(8) The pulverising system can be repaired without cooling the unit as the pulverising equipment is located outside the furnace.

(9) Large amount of heat release is possible and with such rate of heat generation, each boiler of pulverised fuel fired system can generate as large as 2000 tons of steam per hour.

(10) The banking losses are low compared with stoke firing system.

(11) The boilers can be started from cold very rapidly and efficiently. This is highly important during emergency.

(12) The external heating surfaces are free from corrosion and fouling as smokeless combustion is possible.

(13) There are no moving parts in the furnace subjected to high temperature, therefore the life of system is more and the operation is troubleless.

(14) Practically no ash handling problems.

(15) The furnace volume required is considerably less as the use of burners which produce turbulence in the furnace makes it possible to complete combustion with minimum travel of flame length.

Disadvantages. (1) The capital cost of the pulverised system is considerably high as it requires many additional equipments. Its operation cost is also high compared with stoke firing.

(2) This system produces fly-ash (fine dust) which requires special and costly fly-ash removal equipments as electrostatic precipitators.

(3) The flame temperatures are high and the conventional types of refractory lined furnaces are inadequate. It is always necessary to provide water cooled walls for the safety of the furnace. The maintenance cost is also high as working temperature is high which causes rapid deterioration of the refractory surface of the furnace.

(4) The possibilities of explosion are more as coal burns like a gas.

(5) The storage of powdered coal requires special attention and high protection from fire hazards.

(6) The fine grinding of fuel at all loads is not possible particularly in unit system.

(7) The building space required is large particularly for central system.

(8) The skilled operators are required.

(9) Special starting-up equipments are required.

(10) Nuisance (high air pollution) is caused by the emission of very fine particles of grit and dirt as they remain in suspended condition in air for a considerable long period.

(11) The removal of liquid slag formed from low fusion temperature ash requires special equipments and creates additional problems of its removal.

Adoption of Pulverised Fuel Firing. The pulverised coal firing has been widely accepted and universally used for large thermal power plants. The choice of pulverised fuel firing system in preference to the other firing methods depends upon the size of the boiler unit, the type of coal available, the cost of coal, the kind of load on the power plant (constant or fluctuating), the load factor and the availability of trained personnel.

The pulverised fuel equipment is not generally adopted to small capacity plants, because benefits in efficiency and flexibility do not warrant the complications in equipment and operating cost.

The characteristics of coal are very important in the selection of coal when stoke firing is used but need less considerations in the pulverised coal firing plant. The most suitable coal that can be successfully used in pulverised form should contain about 20% of volatile matter and should not have more than medium coking power. In general, high volatile coals are harder to grind than low volatile coals, requiring large mill for the same capacity, more power per ton and more maintenance. The disadvantages of high volatile coal are partly compensated by the fact that the gases are more easily distilled and burned and ignition can be easily maintained owing to the presence of volatile gases.

The capital and operating costs of pulverised fuel system are more than other methods and difference in cost must be repaid in decreased maintenance and increased thermal efficiency. The use of low cost fuel frequently justifies the increased cost of pulverising system provided the system must be used at high rating and for large percentage of time.

The satisfactory performance of pulverised system largely depends to a large extent upon the pulverising mill performance. The pulveriser should deliver the rated tonnage of coal, with minimum consumption of power and produce a pulverised fuel of satisfactory fineness over a wide range of operation. Further, it must be quiet in operation, must give service with a minimum outage time and operate with low maintenance cost.

Problems encountered with burning of High Ash Coal. Coal is one single factor which directly affects the generation in the thermal power plants. It is unfortunate that poor quality of coal and that too of a varying nature results in colossal loss of generation from thermal stations in this country.

The Indian coals contain high ash (30-40%) and this type of coal will be only available for power generation. Use of such high ash coal creates some burning problems as the ash interferes in the combustion process and affects the thermal efficiency as shown in Fig. (8.8).

The problem of using high ash coal is two-fold.

(1) Solution of the problem for the existing plants which are designed for low ash coal (20%).

(2) Solution for the forthcoming power stations.

The second problem can be solved with proper design modifications as listed below :

* The velocity of the flue gases is limited to 10 m/sec to avoid erosion.
* The coal pipes should be lined with ceramic glass.
* Higher size ID fan should be used so that it can run at lower speed without affecting output.
* Increase the capacity of electrostatic precipitater to improve the collection efficiency.
* Low speed ball mill should be used for pulverising as it provides constant size output over a longer time period.
* Flame stabilization should be achieved by one of the following methods.

(*a*) Increase area/volume ratio of the furnace.

(*b*) Increase primary air temperature.

(*c*) Ensure longer retention time of the coal particle in the ignition area.

The problem for existing plants is more difficult as major design modifications are not possible. The difficulties of erosion of I.D. fans, pulverisers and flue gas pipes and reduction in thermal efficiency are experienced at Khaparkheda, Parli, Nasik and Koradi power plants in Maharashtra due to use of higher ash coal.

To avoid the above problems, the size of ID fan and use of low speed mills should be incorporated. These modifications do not change the ash level but reduce abrasive material content from coal and reduces the erosion problem.

The rated generation level can be attained by benefication. Considerable improvement in the availability is experienced with proper maintenance practices and procedures. Monceau-Sur Sambre Power station in Belgium using coal containing 55% ash and Renusagar power station in India using coal containing 50% ash are the examples which provide 90% availability of the power plant by proper maintenance.

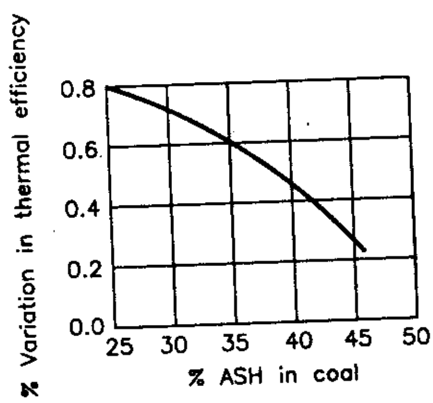


Fig. 8.8. Effect of ash content in coal on thermal efficiency.

8.5. PULVERISED FUEL BURNERS

The efficient utilization of pulverised coal depends to a large extent upon the ability of the burners to produce uniform mixing of coal and air and turbulence within the furnace. The air which carries the pulverised fuel in the furnace through the burner is primary air and remaining secondary air required for complete combustion is admitted separately around the burner or elsewhere in the furnace. The pulverised coal burners should satisfy the following requirements :

(1) It should mix the coal and primary air thoroughly and project the same in the furnace properly with secondary air which is generally added around the burner.

(2) It should create proper turbulence and maintain stable combustion of coal and air throughout the operating range of the plant.

(3) It should control the flame shape and its travel in the furnace. This is generally done by the secondary air vanes and other control adjustments provided in the burner.

(4) The mixture of coal and air should move away from the burner at a rate equal to flame travel to avoid the flash back with the burner.

(5) The burner should also be provided with adequate projection against overheating, internal fires and excessive abrasive wear.

The factors which affect the performance of the pulverised fuel burner are, the characteristics of the fuel used, fineness of the powdered coal, volatile matter, the geometry of the burner, place of mixing the fuel and air, proportions of primary and secondary airs, furnace design and patterns of load changes.

The classification of burners is made on the rapidity of burning the coal and air in the furnace.

(1) Long-Flame or U-Flame or Streamlined Burners. The arrangement of primary air and coal flow and the supply of secondary air is shown in Fig. 8.9. Tertiary air is supplied around the burner to form an envelope around the primary air and fuel to provide better mixing. The burner discharges air and fuel mixture vertically in thin flat streams with practically no turbulence and produces a long flame. Heated secondary air is introduced at right angles to the flame which provides necessary mixing for better and rapid combustion.

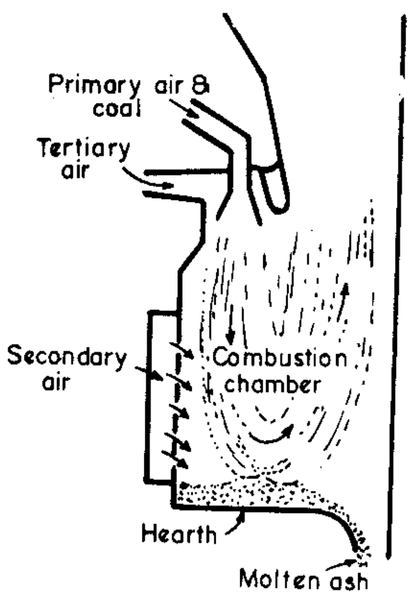


Fig. 8.9. Long flame burner.

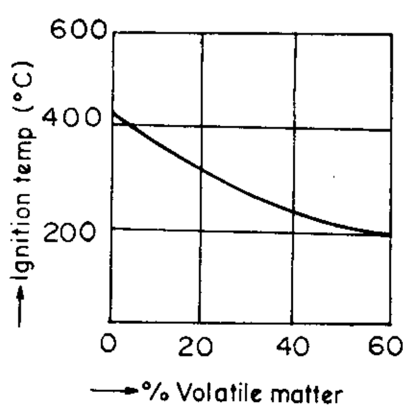


Fig. 8.10.

Furnaces for low volatile coal are equipped with such burners to give a long flame path for slower burning of coal particles. The longer path provides more time to burn and it is necessary to control the velocity in this zone (tip velocity is limited to 25 m/s). Less heat of ignition is available due to low volatile content and it is necessary to reduce the cooling effect from the wall tubes in the ignition zone by using a refractory belt round the furnace or by a refractory front wall. Generally low volatile coals have higher fusion temperature than bituminous coal and therefore higher furnace ratings are permissible.

Lower volatile matter increases the ignition temperature of the coal as shown in Fig. 8.10.

(2) Short flame or turbulent burner. The turbulent burners are usually set into furnace walls and project the flame horizontally into the furnace as shown in Fig. 8.11. 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 a short distance. This burner gives high rate of combustion compared with other types. The velocity at the burner tip is as high as 50 m/sec. The bituminous coal is successfully used with this burner. By proper adjustments, a long penetrating flame or short intensely hot flame can be produced. All modern plants use this type of burner. This is generally preferred for high volatile coals.

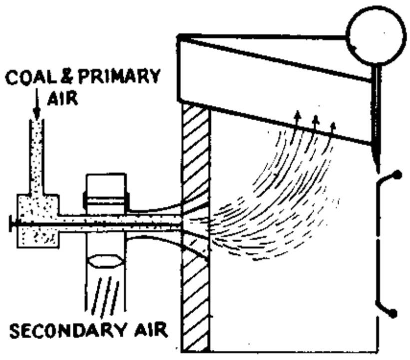


Fig. 8.11. Turbulent burner.

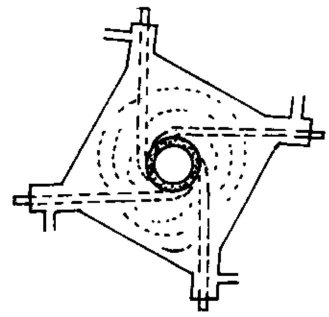


Fig. 8.12. Plan of furnace tangential firing.

(3) **Tangential burners.** The tangential burners are set in the furnace as shown in Fig. 8.12 and discharge the fuel-air mixture tangentially to an imaginary circle in the centre of the furnace. The swirling action produces sufficient turbulence in the furnace to complete the combustion in a short period and avoids the necessity of producing high turbulence at the burner itself. High heat release rates are possible with this method of firing.

This type of burner is sometimes constructed with tips that can be angled through a small vertical arc (± 30) so as to raise or lower the position of the turbulent combustion region in the furnace. This arrangement controls the temperature of the gases at the furnace aperture and maintains constant superheat temperature of the steam as the load varies. When the burners are tilted downward, the furnace gets filled completely with the flame and the furnace exit gas temperature is reduced as the furnace absorption is greater. This reduces the heat given to the superheater. The reverse is also true when the burners are tilted upwards. The usual limit of tilt ± 30° is sufficient to provide 100°C difference in the furnace gas exit temperature.

In a pulverised fuel firing system, the fluid ash carried in the gas stream is likely to be deposited on exposed metal surfaces and solidify thereon as slag. Sufficient heat absorbing surface must be provided to cool the molten ash by radiation below its softening temperature before it comes into contact with metallic surfaces. Thus, in the large units, a tall furnace is used and in very large units, it becomes economical to sub-divide the furnace either by water-cooled division walls or by arranging side-by-side separately cased furnaces.

One of the main problems in pulverised fuel firing is to shorten the time required for combustion. The development of combustion chamber design has been marked throughout its history by the endeavour to burn the maximum amount of coal dust with minimum space and in minimum time.

For the given fineness of coal, shortening of combustion time is mainly the aerodynamic problem of bringing of air and fuel together within the furnace as quickly as possible. This means that air and fuel particles must be in violent motion (turbulence) relative to each other. Early designers sought to achieve this through the use of burners causing a turbulent or whirling motion, skilfully introducing primary, secondary and tertiary air. Such burners promote quick ignition but it is a characteristic of pulverised fuel firing that it is extremely difficult to influence the tail of combustion. This cannot be done by burner agitation or by introducing secondary air at point farther along in the path of the burning dust. The intense motion needed is secured in modern practice by multiple burners in the corners of combustion chamber or by tilting burners which are adjustable, all are so arranged that the streams of burning fuel and air impinge violently on one another.

The heat generating rates of 1.5×10^6 kJ/m^3/hr are achieved with such types of burners.

(4) Cyclone Burner. The major disadvantages of utilising pulverised coal as fuel are : (1) the capital and running cost of pulverised mills are considerable, and (2) nearly 70% of the ash in coal goes with exhaust gases in form of 'fly-ash' and it requires expensive dust collectors in the gas circuit.

The cyclone burner is a new method of burning coal particles in suspension which overcomes the disadvantages associated with pulverised fuel system as mentioned above.

Basically, this burner was designed to burn crushed low grade bituminous coal that normally have a high content of low fusing temperature ash. The first commercial cyclone furnace boiler was designed to burn bituminous coal and was installed at Calument Station of the Commonwealth Edison Company in 1944. Since then this method of burning has been incorporated in many units throughout U.S.A. and U.K.

The cyclone burner is a horizontal cylinder of water-cooled construction 2 to 3 metres in diameter and 2.5 m in length as shown in Fig. 8.13. The inside part of the cyclone cylinder is lined with chrome ore. The horizontal axis of the burner is slightly deflected towards the boiler. It is externally arranged to the boiler furnace and equipped with a single scroll type inlet at one end and a gas discharge throat into the boiler at the other end.

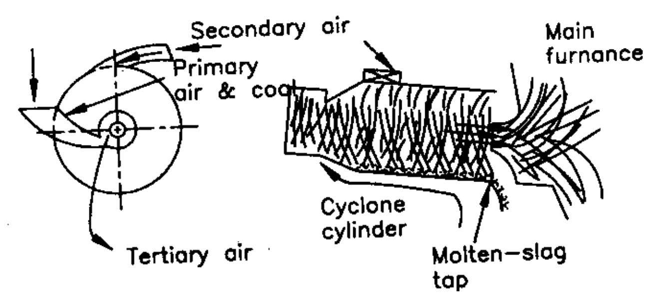


Fig. 8.13. Cyclone burner.

The coal used in cycline burner is crushed to 6 mm maximum size and blown into a cylindrical 'cyclone furnace'. Air at 80 cm water pressure and coal admitted tangentially to the cylinder at outer end creates strong and highly turbulent vortex. As the coal with air moves from the front to rear, secondary air is introduced tangentially as shown in figure to complete the combustion. Extremely high heat liberation rate and the use of preheated air cause high temperatures (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. The molten ash flows to an appropriate disposal system as the horizontal axis of the burner is tilted.

The merits of the cyclone burner over the other types are listed below :

(1) Simplified coal crushing equipments can be used instead of costly pulverised mills.

(2) All the incombustibles are retained in cyclone burner therefore the boiler fouling and all problems associated with it are reduced. A comparison between cyclone burner and pulverised coal firing equipment on the basis of 75 MW capacity plant shows 25% reduction in floor area ; 33% reduction in building volume, 22% reduction in weight and 80% reduction in maintenance charges. This is because of the high furnace heat release rates.

(3) As the forced draught is used with this type of burner, it can be operated with less excess air. Excess air required can be reduced to 15% minimum using forced draught fan.

(4) Combustion rate 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.

(5) It is seen from the performance of the burner that the slag recovery is 82% and dust passing to the stack is 8% whereas in pulverised system, the percentages of slag and dust formation are exactly opposite. Therefore there is a considerable simplification of equipment required for the removal of dust from flue gases.

(6) The cyclone furnace can use low grade fuels, reduces the size of steam generator and limits the fly-ash emission so that excessive furnace cleaning and precipitators are not required.

The heat release rates of the order of 16×10^6 to 20×10^6 kJ/m^3/hr and coals with high ash melting temperatures are successfully used in this type of burner.

The cyclone furnace gives best results with low grade fuels and high silica ratio (80%). Majority of the Indian coals can be straight away burned in cyclone furnace very successfully. A few percentage of Indian coals are such that can be used in cyclone furnace directly but it is possible to use with addition of limestone to reduce silica ratio from 97 to 84 and fusion temperature from 1400°C to 1300°C.

8.6. SPECIAL TYPE BURNERS

Sonic Burner. A sonic burner is basically a pressure jet burner as shown in Fig. (8.14). Provision is made for connecting either compressed air or steam supplied to the burner. Air or steam passing through burner head gains very high velocity which produces resonance in the vicinity. This brings about the creation of powerful *sonic energy* and controlled amount of fuel is fed in this region. The interaction of the sonic energy and fuel results in uniformly atomised droplets of fuel. The size of each droplet surrounded by a layer of air is of the order of 5 – 10 microns.

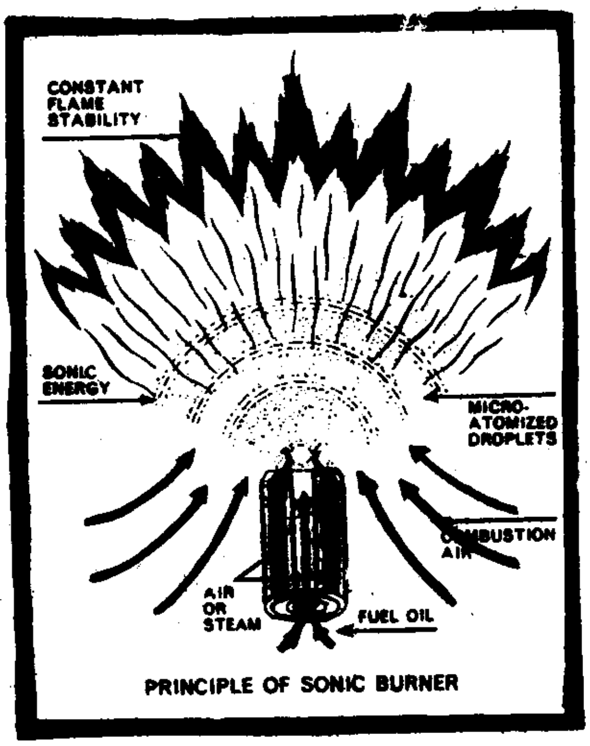


Fig. 8.14.

The advantages are listed below :

(1) Better control of flame temperature and bright flame can be produced.

(2) Highest degree of combustion can be achieved at stoichometric ratio.

(3) Higher operating temperature as well as better heat transfer can be achieved.

(4) Very low energy is required for atomization and head is cleaned automatically due to scrubbing effect of sonic energy.

(5) Very high turn-down ratio can be achieved.

Hydrotherm System

A pulse type combustion principle developed by Hydrotherm Inc. is shown in Fig. (8.15). It requires no burner, no pilot light, no chimney.

The operating principle is comparable to an internal combustion engine. On the first cycle only, a small blower forces outside air into a sealed chamber where it is mixed with gas and then ignited by a spark plug. Thereafter, combustion occurs automatically at a pulsating combustion rate (25 cycles/sec). The hot gases are forced down through the heat exchanger at a high velocity and with high turbulence which is surrounded by the boiler water. On subsequent cycles, the residual heat in the chamber eliminates the need of spark plug also. As no chimney is required so chimney heat losses are eliminated.

The boiler can reduce gas consumption by 30%. First cost is double that of a conventional boiler but the savings can pay the difference in less than a year.

It has been suggested that in India, a thermal power plant of 50 MW capacity and above could be installed preferably on cyclone type furnace for the production of cheap power in our country.

8.7. BURNING OF COAL WASHERY WASTE DISPOSAL

A new type of incinerator—a *fluidised bed combustor*—has been developed by the CRIRO division of process technology as an attempt to overcome the worsening problem of coal washery waste disposal.

Every year in Australia, some 58 coal washeries discard about 15 million tonnes of waste. The raw washery refuse consists mainly of coal bearing shale containing coal-like organic material. While this organic

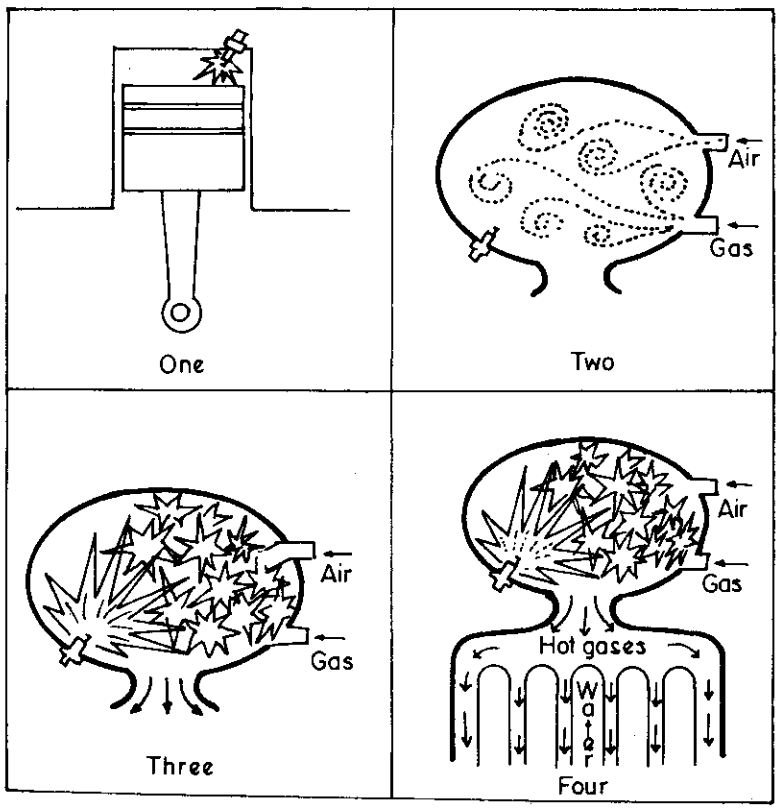


Fig. 8.15.

material will burn in conventional incinerators. Therefore, it (washery refuse) is dumped in consolidated heaps and remaining slurry of fine coal and dust is usually pumped into settling ponds. The disposal cost of this waste lies between $2 to $4 per tonne.

The fluidised bed incinerator developed by CSIRO is able to burn coarse refuse containing upto 80% ash and slurries containing as much as 60% water. Crushed waste is fed into a hot fluidised bed where it is suspended along with previously burned and burning material in upward jets of air. A special device thickens the slurry to a point where they can burn independentally.

EXERCISES

8.1. What is meant by 'overfeed' and 'underfeed' principles of coal firing ? Which is preferred for high volatile coal and why ?

8.2. Describe the burning sequence of coal in 'overfeed' and 'underfeed' stokers. Which type is suitable and why to burn (*a*) high ash clinkering coals, (*b*) high volatile matter coal, and (*c*) low ash content coals ?

8.3. Describe different types of overfeed stokers and discuss the merits and demerits of each over others.

8.4. Draw a neat diagram of multi-retort underfeed stoker and explain its working. Discuss its merits over other types of stokers.

8.5. What are the advantages of burning the fuels in pulverised form ?

8.6. What are the requirements of the burners used for firing pulverised coal ? Describe the various types of burners used and their relative merits and demerits.

8.7. Draw a neat diagram of cyclone burner and describe its working. What are its outstanding features compared with other burners ? Why such burners are useful for Indian coals ?

8.8. What is the necessity of a good combustion control in furnaces ? Draw a neat diagram of Hagan automatic control combustion system and explain its working.

□□□

9

Ash Handling and Dust Collection

9.1. INTRODUCTION

The disposal of ashes from a large capacity power station is of some importance as it is 10 to 20% of the coal used. A 200 MW capacity power plant using Indian coals produces as large as 60,000 tons of ash per annum. This quantity of ash is equivalent of a height of 1.5 metres covering four hectares area. This shows that a power plant of 200 MW capacity requires 160 hectares area during its life time if the ashes produced are dumped at the site of the plant. The ashes should be discharged and dumped at a sufficient distance from the power plant because of following reasons :

(1) The ash is dusty, therefore irritating and annoying to handle.

(2) It is sufficiently hot when it comes out of the boiler furnaces.

(3) It produces poisonous gases and corrosive acids when mixed with water.

The ash-handling is a difficult problem and sufficient attention should be given to design the ash handling plant. The difficulties encountered in the ash-handling plant layout are listed below :

(1) It forms clinkers by fusing together in large lumps which must be broken before given to any reasonably sized conveying equipment.

(2) The ash produced is abrasive and will wear out the conveyor parts on contact with it therefore special conveyors must be designed to handle the ashes.

(3) The ashes must be cooled before carrying from the furnace collecting hoppers as it is very difficult to carry hot ashes.

The following places can be used for dumping the ashes as huge amount of ash is to be handled per day (150 to 200 tons per day) :

(1) The barges may be used for dumping ashes in the sea where sea-borne coals is used.

(2) Disused quarries are worth for disposing of ashes as they are capable of dumping the ashes over a number of years provided quarries are within reasonable distance.

(3) The ash can be used for the road making or to fill the low lying areas. Therefore the collected ash can be discharged at the required site from the sump.

(4) Deep ponds may be constructed and the ash can be dumped into these ponds.

(5) Land for ash tripping at plant site is necessary unless there is a large demand for ashes for building, roadmaking and similar purposes.

The ash handling problem is further aggravated in indian thermal power plants due to use of low grade coal. The ash percentage in the majority of Indian coals lies between 24 to 50%. The ash handled in Indian power plants is of the order of 20 to 40 kg per million kJ of heat generated whereas in America, the ash handled is hardly 4 to 10 kg per million kJ of heat generated. Another problem to be faced in Indian thermal power plants is the silica content in the ash as high as 60 to 65% against 40 to 50% in American coals which causes the erosion. The large quantities of ash to be handled and its erosive characteristics are posing a big problem today for the design of ash handling system and boilers in India.

Any ash handling system comprises the following operations :

(1) To remove the ashes from the furnace ash hopper.

(2) To convey the ashes from furnace ash-hopper to a storage or fill with the help of conveyors.

(3) To dispose the ashes from the storage.

In every ash handling plant, the quenching of ashes before carrying to the sump is desirable and necessary as it offers the following advantages :

(1) It reduces the temperature of ashes and it is always easier to handle cold ashes than hot.

(2) The quencing of ash tends to disintegrate large clinker and reduce it to more manageable proportions.

(3) It reduces the ashes to a dustless condition.

(4) It also reduces the corrosive action of ashes on the equipments used to carry it.

(5) The water is used as a seal to prevent uncontrolled air entering the boiler and so upsetting combustion condition.

The modern thermal power stations run at high load factors and burn large quantities of low grade coal having high percentage of ashes. Therefore proper attention should be given to the design of ash-handling plant if reliable and economic operation is to be maintained.

The principal requirements of a good ash handling plant are listed below :

1. The plant should be able to handle large clinkers, boiler refuse, soot and dust with minimum attention of operators.

2. The plant should be able to handle requisite quantity of ash daily.

3. The capital investment should be minimum and operating and maintenance charges should also be minimum.

4. The plant should operate uninterrupted for a long period. This can be achieved by designing the equipments of the plant which are hardly affected by the abrasive action of the ashes.

5. The plant should have high rate of handling in order to deal adequately with any sudden change in boiler operating conditions.

6. In case of addition of units, it should need minimum changes in the original layout of the plant.

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

8. The plant must be able to operate effectively and efficiently in case of variation in ash characteristics due to change of fuel used.

9. The plant should be able to operate efficiently under all variable load conditions.

10. It should also deal effectively with hot and wet ashes.

9.2. ASH HANDLING SYSTEM

The ever increasing capacities of boiler units together with their ability to use low grade high ash content coals have been responsible for the development of modern ash handling systems.

The general layout of the components used in modern ash handling and dust collection plant is shown in Fig. 9.1.

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. The mechanical handling system is generally used for low capacity power plants using coal as fuel. The arrangement of the system is shown in Fig. 9.2.

The hot ash coming out of boiler furnace is made to fall over the belt conveyor through a water seal as shown in figure. The cooled ash falls on the belt conveyor and it is carried continuously to the dumping site or overhead bunker. The ash is carried to the dumping site from the ash bunker with the help of trucks.

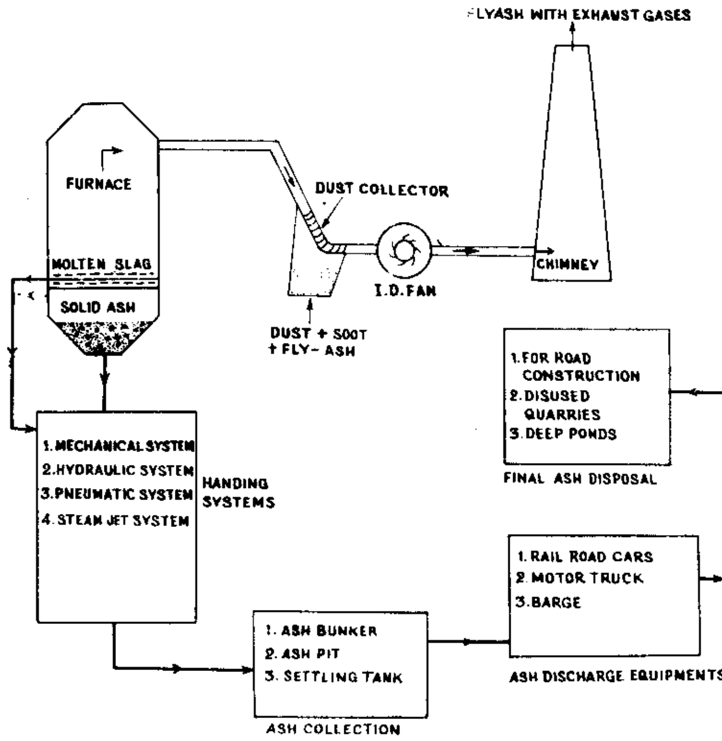


Fig. 9.1. General layout of ash handling and dust collection system.

The control valve is opened and closed manually to load the truck. This type of ash handling system is used at Khapaskheda power station which is near Nagpur.

The life of this system is 5 to 10 years. The maximum capacity of this system is limited to 5 tons per hour. The major advantage of this system is low power consumption.

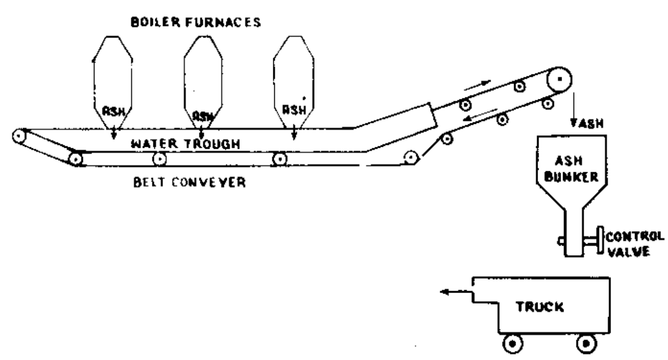


Fig. 9.2. Mechanical ash handling system.

2. Hydraulic Ash Handling System. The hydraulic ash handling system carries the ash with the flow of water with high velocity through a channel and finally dumped to the sump. The hydraulic system is subdivided as low velocity system and high velocity system.

Low Velocity System. The arrangement of the system is shown in Fig. 9.3 (*a*). In this system, ash from the furnace grate falls into the system of water possessing low velocity and carried to sump with water. The velocity of water in the water-trough is usually between 3 to 5 m/sec. With the use of higher water velocity, the abrasion is reduced as the ash tends to ride on the water instead of scouring along the bottom. The ash is separated from water when it reaches to the sump. The separated water is used again while the ash collected in the sump is sent out through carriages. The ash carrying capacity of this system is 50 tons/hr and distance covered is 500 metres.

High Velocity System. The arrangement of the system is shown in Fig. 9.3 (*b*). The hoppers below the boilers are fitted with water nozzles at the top and on the sides as shown in figure. The top nozzles

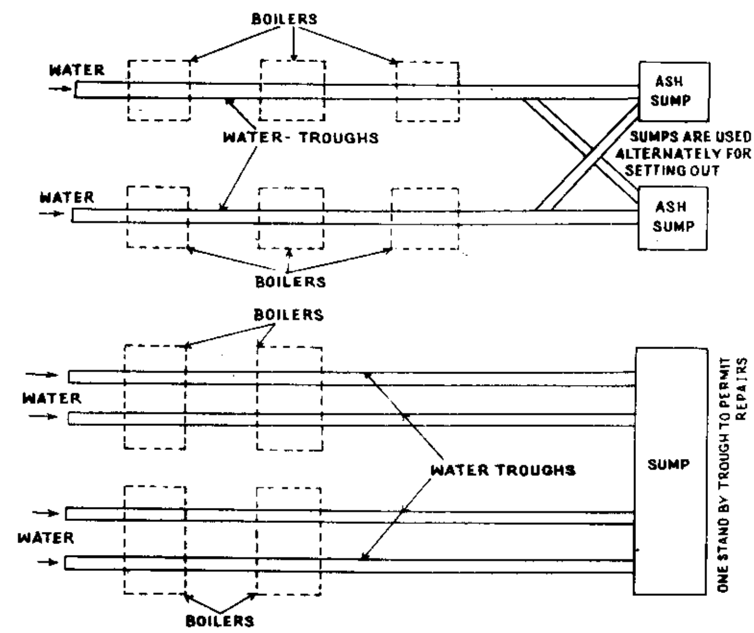


Fig. 9.3. (*a*) Low-pressure Ash Handling Hydraulic System.

quench the ash and the side nozzles provide the driving force to carry the ash through a trough. The cooled ash with high velocity water is carried to the sump through the trough as shown in figure. The water is again separated from ash and recirculated. The ash carrying capacity of this system is as large as 120 tons per hour and the distance covered is as large as 1000 metres.

Sometimes the ash and water is pumped to the sump with the help of the pump through the pipe to increase the ash carrying capacity of the system. The only disadvantage is, the pump must be made of special wear resisting material.

The troughs and sumps used in the conveying ash are made of corrosion and wear resistant material as ash carried with water contains many corrosive acids and salts in dissolved form.

The molten slag produced in the pulverised fuel systems can also be carried with the help of high pressure hydraulic system. The cooling nozzles, located near the top of the hopper, direct high pressure water jets against continually running molten stream and disintegrate the slag into small particles as it strikes the surface of water. The formed slag particles fall into a sluice and second set of nozzles transports the slag particles to downcomers discharging into main sluiceway. The slag with water is again discharged to the sump as usual.

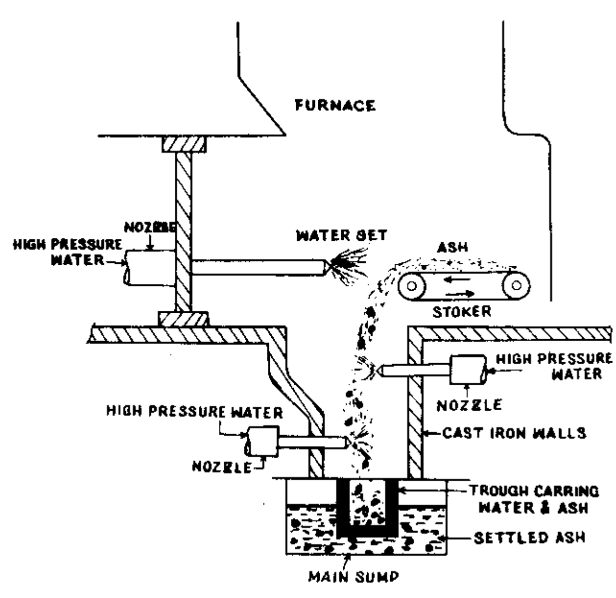


Fig. 9.3. (*b*) High pressure Ash Handling Hydraulic System.

In some cases, the water jet pump-type (high pressure high velocity hydraulic system) system is used to pump the ashes or slag to an elevated storage bin installed over a railroad or roadway. The bin is so constructed that the water is drained out and ash or slag is discharged from the bin by gravity flow to rail cars or trucks.

Advantages of Hydraulic System

1. It is clean, dustless and totally enclosed.
2. Its ash carrying capacity is considerably large therefore it is more suitable for large thermal power plants.
3. It can discharge the ash at a considerable distance (1000 m) from the power plant.
4. It can also be used to handle a stream of molten ash.
5. The unhealthy aspects of ordinary ash basement work is eliminated.
6. The whole system is clean and healthy.
7. The important feature of the systems is the absence of working parts in contact with the ash.

Low velocity hydraulic system is gaining more popularity in modern thermal power stations as it is simple, able to handle large ash quantities, clean and comparatively economical.

It is always difficult to compare low and high velocity systems without detailed particulars of the two types of plants with water quantities and power requirements.

The water required for low velocity system is two or three times for an equivalent high pressure plant and exact opposite would be the case for the power required to drive the pumps. The high power requirement of high pressure system is considered a disadvantage but it handles high ash concentrated fluid and reduces the danger of choking the sluice. This high rate of ash handling allows the plant to operate intermittently (25 to 20% of the time required to continuous low velocity system). Therefore, the power required to handle per ton of ash by a high pressure system would be 33% to 50% of an equivalent low presure system. It is always difficult to decide the economy of one plant over the other without all required details.

3. Pneumatic Ash Handling System. The arrangement of the system is shown in Fig. 9.4. This system has been developed for handling abrasive ash as well as fine dusty materials such as fly-ash and soot. This is more suitable to the boiler plants from which ash and soot must be transported some considerable distance for final disposal.

The ash and dust from all discharge points are picked up by a high velocity air stream created by an exhauster at the discharge end. The ash collected in the ash hopper is passed through the ash crushers

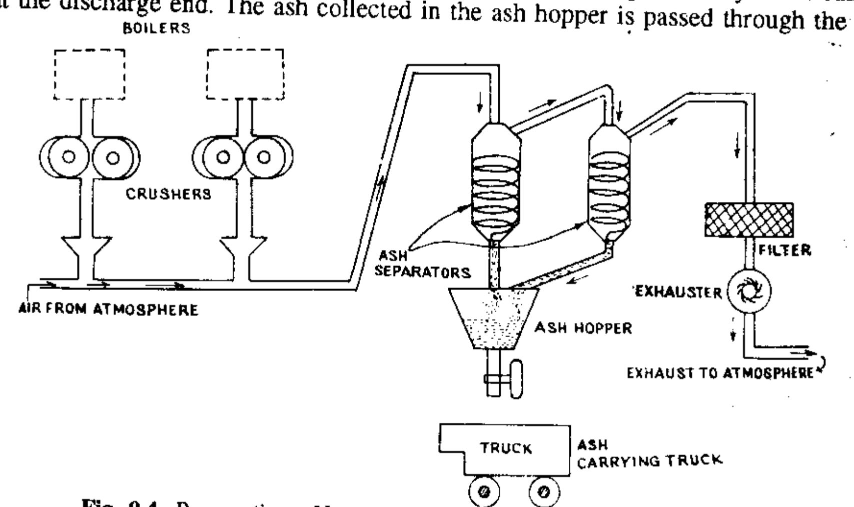


Fig. 9.4. Pneumatic or Vacuum Extraction Ash Handling System.

into the air stream as shown in figure. The ash carried by the air is separated into the primary and secondary separators working on cyclone principle and is collected in ash hopper as shown in figure. The clean air is discharged from the top of the secondary air-separator into the atmosphere through exhauster. The exhauster used may be mechanical as I.D. fan or stream jet type or water jet type. If the mechanical exhauster is used, then it is necessary to use filter or air-washer before the air enters into the exhauster to ensure the clean air exhaust to atmosphere. The mechanical exhauster is preferred where large tonnages of material are to be conveyed. The power requirement of mechanical exhauster is approximately 3 kW per ton of material. The steam-jet exhauster is commonly used for small and medium-sized plant. The steam consumption of this system is approximately 120 kg per ton of material discharged. The water-jet exhauster may be used more economically where large quantities of water are easily and cheaply available. The ash carrying capacity of this system varies from 5 to 30 tons per hour.

The advantages and disadvantages of this system are listed below :

Advantages. 1. With the use of this system, all dust nuisance is eliminated in the handling of flyash and dust. The dustless operation is possible as the materials are handled totally in an enclosed conduit.

2. There is no spillage and rehandling.

3. The materials are conveyed in a dry state and delivered to the storage bin in the same condition. Therefore, there is no chance of ash freezing or sticking in the storage bin and material can be discharged freely by gravity.

4. The system has great flexibility and thus can be made to fit varying physical plant conditions.

5. The conveyor pipeline requires little space in the boiler plant and therefore the cost of the plant per ton of ash discharged is less than the other systems.

The system suffers only from the disadvantage of wearing out the pipe line and therefore the maintenance charges are high. It is also more noisy than other systems.

4. Steam Jet System. In this system of ash handling, the steam is passed through a pipe at sufficiently high velocity which is capable of carrying dry solid materials of considerable size along with it. The high velocity is given to the steam by forcing the steam through the pipe under pressure greater than that of atmospheric.

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 hoppers is fed. The ash is deposited in the ash hopper.

The advantages and disadvantages of this system are listed below :

Advantages. 1. The steam generated by the boiler is used, therefore, it does not require any sort of auxiliary drive.

2. Ash can be removed economically by this system through a horizontal distance of 200 metres and through a vertical distance of 30 metres.

3. The capital cost of this system per ton of ash handled is less than other systems.

4. It requires less space.

5. The equipment can be installed in awkward position too.

Disadvantages. 1. There is greater wear of pipes carrying the ash due to abrasive action of ash. Therefore the pipe is lined with nickel alloy.

2. The operation of the system is noisy.

3. The capacity of this system is limited to 15 tons per hour therefore continuous operation of the system is necessary.

9.3. DUST COLLECTION AND ITS DISPOSAL

The subject of fuel gas cleaning has become a problem of prime importance in the design of large thermal power stations using coal as fuel as the atmospheric pollution is highly restricted. The major emissions from thermal power stations are fly ash, carbon ash (known as cinder), smoke, dust and irritating vapours like CO, SO_2 and nitrogen oxides. The emissions from the power stations are objectionable if the content extends a particular limit (0.5 gram/m^3) because it has bad effects on the human and animal healths as well as bad effects on crops and destroying, spoiling and damaging actions on the public property. A power station near the city or large residential area must not be a nuisance as far as the discharge of soot, grit and sulphur from the boiler chimney is concerned. The cleaning of gas before discharge to the atmosphere has become essential with the introduction of pulverised fuel boilers, because 80% of the ash in coal is carried with the exhaust gases in a very fine form. A 400 MW capacity power plant using pulverised Indian coal as fuel discharges as large as 500 tons of ash per day with the exhaust gases if proper care is not taken to remove the particulates before exhaust. The above example is sufficient to explain the effects of fly ash and the necessity to remove it. Another aggravated problem in the gas cleaning is, the size of particulates carried with the gas. The size of these particulates varies from 1 to 80 microns [1 (μ) micron = 10^{-3} mm].

The cleaning of flue gases using coal as fuel in India has become important due to the following reasons :

(1) Most of the Indian coals contain more percentage of ash (30 to 45%), therefore ash carried with the gases per ton of coal burned is large.

(2) The Indian coals contain only 1 to 1.5% of sulphur and if it is emitted to the atmosphere in the form of sulphur dioxide, it is highly objectionable as it has very bad effects on human, animal and crop health. Therefore, the use of high sulphur content coal for thermal power plant is already restricted.

The cleaning of gas, particularly in India, poses a difficult problem and requires special design due to following reasons :

(1) The ash from the Indian coal contains large percentage of silica (60 to 65%) and if it is carried with gases, it has abrasive action on the equipments.

(2) The fineness of typical fly-ash from a pulverised coal fired boiler is so great that the collection problem is very difficult. There are cases where 95% of the fly ash passed through 325 mesh (43 μ) screen. (A 325 mesh screen will hold water). This fact itself indicates the minuteness of the particles.

Therefore, it is always necessary to clean the gas strems contaminated with particulate matters before the gas is discharged to the atmosphere. The gas cleaning devices take the advantage of certain physical or electrical properties of the particulate matter of the gas stream. The selection of the gas cleaning devices will be influenced by the efficiency required, characteristics of the particulate matter, cost of device, availability of space, power and water requirements. Other basic considerations include maintenance, dependability and waste disposal system.

The type of the gas cleaning devices used and their classification are listed ahead.

Gas cleaning devices

- Mechanical
  - Dry type
    - Gravitational separators
    - Cyclone separator
  - Wet-type (scrubbers)
    - Spary type
    - Packed type
    - Impingement type
- Electrical
  - Rod-type
  - Plate type

Any type of gas cleaning device used should satisfy the following conditions :

(1) The equipment should be simple and sound in construction. (2) It must give high operating efficiency at all loads on the power plant. (3) They should have long life. (4) It should occupy minimum of building space. (5) It should require little attention. (6) The operating and maintenance charges should be as low as possible. (7) The capital investment should be minimum. (8) The draught loss must be as small as possible. (9) It should permit its insertion before induced draught fans. (10) It must be able to remove very fine ash particles if their removal is essential.

The principles of different types of dust collectors are discussed below :

9.4. MECHANICAL DUST COLLECTORS (DRY TYPE) AND FABRIC FILTERS

The power engineer can choose from cyclonic collectors, fabric filters, electronic precipitators, wet scrubbers and combinations of these equipments to reduce the particulate emissions from coal fired boilers. All of them have countless years of successful operating experience. Selection of optimum system for the power plant involves careful analysis of pollution control equipments and of capital and operating costs of the equipments.

Gravitational Separators. The basic principles used in separating the dust particles are shown in Fig. 9.5.

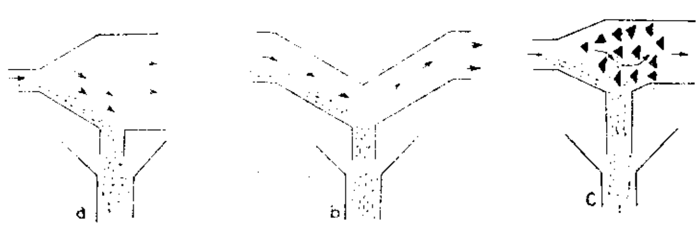


Fig. 9.5. Gravitational separator.

By increasing the cross-sectional area of duct as shown in Fig. 9.5 (*a*) through which dust laden gases are passed, the gas velocity is reduced and dust particles are allowed to fall down.

Changing the direction of the gas flow as shown in Fig. 9.5 (*b*), allows the heavier particles to settle out as rapid change of direction can be followed by heavier particles.

The larger dust particles may be knocked out of the gas steam by impingement on baffles as shown in Fig. 9.5 (*c*). These are used to drop the large cinders from the gases.

Bag House Dust Collector. Increased use of low sulphur coal coupled with the necessity of higher efficiency of particulate collection devices has made equipment designers to consider fabric filters as an alternative when electrostatic collection problems are anticipated.

As a rough thumb rule, low sulphur coal (less than 1%) and temperature under 300°C favour a bag house collector. Higher sulphur content and higher temperatures favour an electrostatic precipitator. The glass-bags are successfully used as dust collectors from many years. The first high temperature glass bag house collector was installed in 1958 by Joy Co. (California). With continued development in bag fabric design and bag tensioning, the bag life has been extended for a considerable long time. The loss of bags due to wear of bag-house collector (oldest) installed on a coal fire boiler by Joy Co. handling 8,80,000 CFM at 160°C at Eastern utility installation is hardly 1% over three years period.

A reverse flow cleaning design adds further to the life of the collector. In this type of design, flue gas is sent inside of the bags, then through the cloth into the house and then out. A gentle reverse flow of air periodically cleans the bags with a minimum of bag flexing, avoiding exceess fabric friction that increases the bag life.

A well designed and maintained bag-house collector (particle size above 1 μ) will collect 99.9% of dust and the efficiency is independent of the amount of dust in the flue gas. However, the baghouses are more sensitive to condensation of objectionable gases than other types of collectors and generally require more maintenance due to periodic bag changing.

The formed SO_3 combines with the water-vapour and forms H_2SO_4. The temperature of the flue gases should not drop below DPT of sulphuric acid as filters are highly susceptible to H_2SO_4 attack. Therefore, it is always necessary to maintain operating temperature above DPT of the exhaust gases.

The temperature of the gas leaving the air-preheater is the temperature entering the baghouse filter. This temperature mostly depends on the boiler load and type of fuel used as shown Fig. 9.6A. It can be seen from figure that the sulphur content in the coal has a major effect on the baghouse design. The acid DPT increases with increasing sulphur percentage in the coal. Usually the acid DPT varies from 60 to 170°C. Continued operation of baghouse at or below DPT shortens the bag life.

The temperature of the hot gases passing through baghouse can be controlled by cold air bypass of the air preheater, preheating of the gas before entering the baghouse by steam or bypassing of hot flue gases around the economiser.

The presently used bag fabric filters are impregnated with Teflon which assists in the lubrication of the glass fibres and resists possible deterioration which could be experienced if gas temperatures were to fall below dew point temperature (DPT).

Some other factors which affect the performance of the baghouse filter are listed below :

1. Type of Boiler Combustion. Each type of steam generator-stoker fired, pulverised coal-fired and cyclone-fired produces different quantities of flyash and bottom ash as shown in Fig. 9.6B that affect the baghouse performance very much. Stoker-fired boilers produce a coarse abrasive flyash which tends to accelerate the wear of baghouse. The ash from stoker fired boiler contains significant amount of coal which increases the chances of fire danger. Flyash produced from cyclone furnace is considerably less in quantity and finer than the stoker-fired boiler. The pulverised coal boiler produces large quantity of flyash and does not contain carbon. Therefore, it increases the load on the baghouse but eliminates the danger of fire.

2. Type of coal. Higher percentage of moisture and H_2 in the coal increases the flue gas DPT. A 20% moisture can increase the flue gas DPT by 15°C. The chemical nature of the flyash also affects the baghouse performance which is dependent on the ash size, handling characteristics, abrasiveness and fluidity. Ash slagging characteristics can vary the amount of flyash produced by as much as 30%.

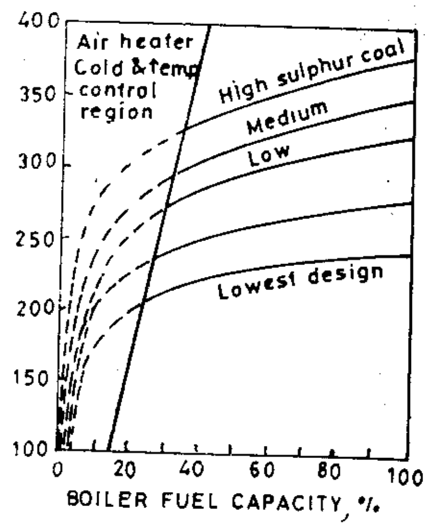


Fig. 9.6A.

3. Boiler operation. The boiler variables that affect the operation of the baghouse are load change, fuel change, trips and shutdowns. Boiler startups and shutdowns present unique problems to baghouse operation. During cold restart, moisture from the auxiliary fuel will condense on cold surfaces of baghouse. In addition to this, heavy hydrocarbon vapours also condense on the baghouse surfaces. This can cause some fabric blinding but even more serious, accumulated hydrocarbon may ignite in the baghouse.

Types of Baghouse Filters. There are mainly three designs of fabric filter baghouse construction :

1. Open Pressure Type. An open pressure baghouse, in which the fan is located to the dust loaded side, can be operated with open sides as long as protection is provided from weather. This type is normally constructed with corrugated steel or asbestos cement walls. It may have open grating at the cell plate level and may not require hopper insulation. The Fig. (9.7 *a*), shows the arrangement of the system.

2. Closed Pressure Type. It is a closed air-light structure and fan is located to the inlet side of the baghouse similar to open system. This arrangement is generally used for gases having high DPT. The floor of the unit is closed and structure walls and hopper are insulated. The Fig. (9.7 *b*) shows the arrangement of the system.

3. Closed Suction Type. This is just similar to closed pressure type arrangement except the fan is located to the outlet of baghouse clean gas side. This is generally used for gases having DPT between 75 to 85°C. The floor, walls and hopper of this unit are insulated. Blower maintenance is cheaper as it is located to clean side of the gas. The Fig. (9.7 *c*) shows the arrangement of the system.

Advantages of the Baghouse Filters. (1) Baghouses are not sensitive to flyash resistivity. Its efficiency remains constant irrespective of gas resistivity as cleaning mechanism is not electrostatic in nature like electrostatic precipitator.

(2) Baghouses are recognized for their high collection efficiency usually in excess of 99.9%.

(3) The outlet loading (grains/m^3) of the gas is not affected by the inlet parameters like flow volume, particle size, grain loading and temperature.

(4) They are less costly than electrostatic precipitators.

(5) Baghouses easily comply with capacity requirements.

Baghouse fabrics are very sensitive to fluctuations in gas temperature. Blinding of the bags cannot occur unless the unit is operated below acid DPT. Continued operation at or below acid DPT lead to corrosion of metal parts and reduces the bag life.

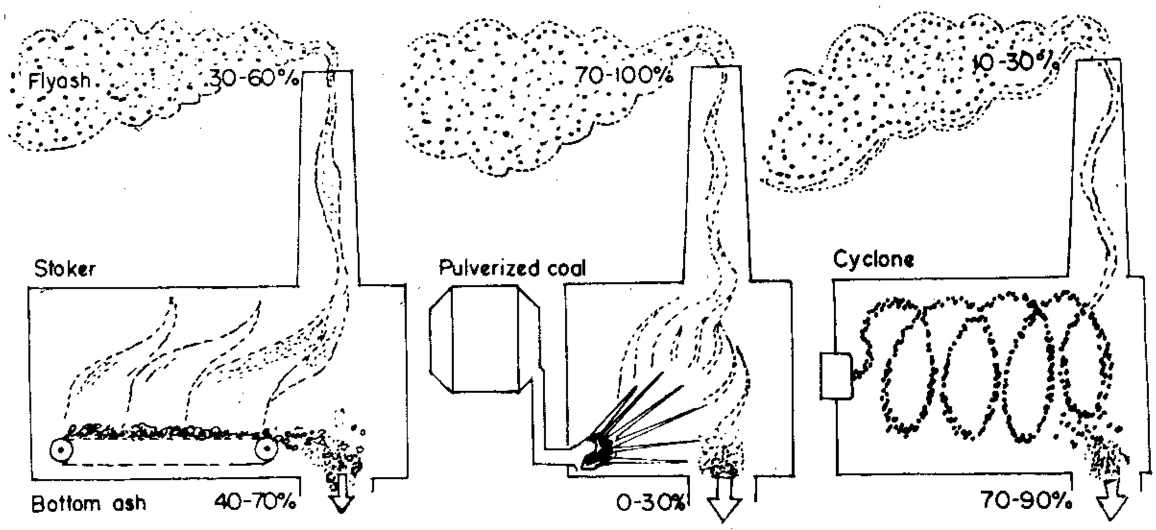
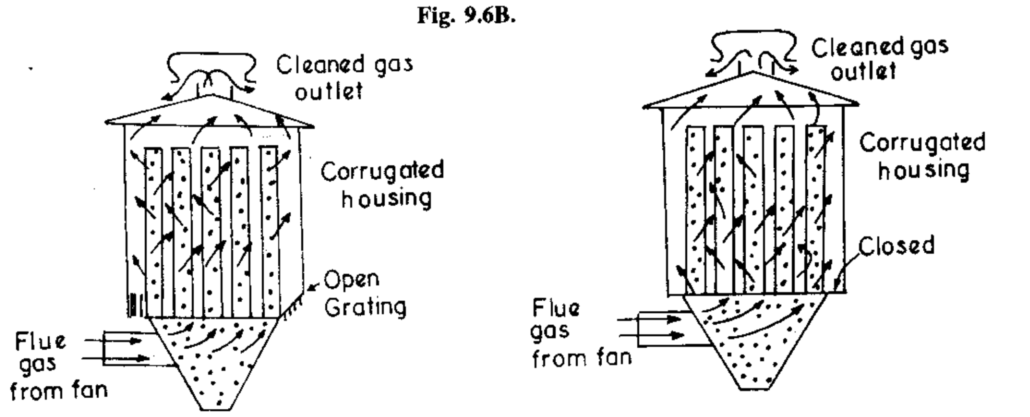
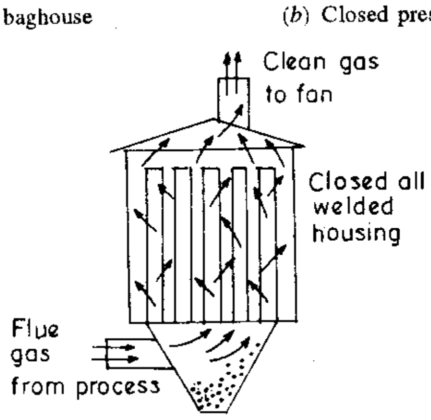


Fig. 9.6B.



(*a*) Open pressure baghouse (*b*) Closed pressure baghouse



(*c*) Closed suction baghouse.

Fig. 9.7.

Pulse-Jet Dust Collector

Fabric filters are capable of operating only in low temperature gas streams. For high temperature applications (above 120°C), it is necessary to cool the gas stream to an acceptable temperature before it enters the fabric filter. Presently, fabric filters are developed for high temperatures also.

Among three types of fiters (shaker, reverse-air and pulse-jet), the pulse jet is considered most newest technology which can be used for high temperature applications in coal-fired boilers.

The fabric filters consist of large box with suspended filter bags. Gas flows into the box and passes through the bags. The particulates are captured on the bag surfaces, forming a cake that acts as an additional filter. What changes in pulse jet is, the bags are cleaned online by the application of short bursts of compressed air into the bag. The pulses dislodge the particles collected on the bag surfaces.

Both shaker and reverse gas systems must be taken offline for cleaning. Whereas, the pulse jet system, which has no moving parts, can be used online for cleaning. This is the major advantage of the system.

The pulse jet system is capable to collect fine particles with efficiency of 99.9%. They are simple in construction so they offer an additional advantage of operational and maintenance ease. The viscosity of the gas has prodominant effect on the operation of the unit.

The particulate characteristics can affect the design and performance of the unit. These include temperature, dew point and moisture content in the gas, the particulate size, chemical composition of dust and operating pressure of the system. Among all, the temperature of the gas is controlling factor for successful high temperature dust collection. The temperature of the gas should be 30°C above DPT of the gas. Any moisture allowed to form within the collector can promote corrosion and cause deterioration and fouling of the filter elements.

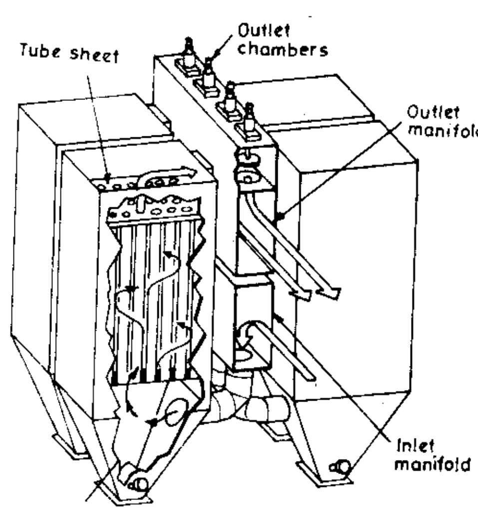


Fig. 9.8. Pulse jet collector.

Condensation of the gases is a primary concern during startup and shutdown. For system to startup, a heating system should be incorporated for preheating the collector to its normal operating temperature. This is necessary to prevent formation of acidic condensate on the cool surfaces of the collector. Generally, clean fuel as propane or natural gas is burned to preheat the equipment.

Moisture also affects the selection of the fabric filter material, internals and housing, since corrosion rates tend to rise when moisture is combined with elevated temperatures. The potential for corrosion is especially acute when condensed water vapour combines with acid forming gas components.

A pulse jet collector's operation may be affected because of lower density of the gas at higher temperatures. Shock waves generated by the pulse jet are generally less effective in low density gas. Therefore higher gas velocities are needed, otherwise, particulates in low density gas streams tend to imbed the particles deeper into the filter, making cleaning more difficult.

The fabric materials used for different temperature ranges are listed in the table given below.

The equipment, itself, such as the jet pump used for generating the air pulses, must be designed for high-temperature cleaning. Because, shock waves are less effective with low density cleaning air produced by high temperatures, the pulse system and its air supply may require upsizing.

OPERATION & MAINTENANCE

FIRE	OPERATING TEMPERATURE (DRY HEAT) CONTI-NUOUS	MAXIMUM (SHORT TIME)				SPECIFIC DENSITY	SUPPORTS COMBUSTION	RESISTANCE TO ALKALIES	ACIDS	ORGANIC ACIDS	OXIDIZING AGENTS	ORGANIC SOLVENTS
Cotton	82°C	94°C	82°C	None, if not treated	8.5%	1.50	Yes	Good	Poor	Poor	Fair	Very good
Wool	94°C	110°C	88°C	None, if not treated	15%	1.31	No.	Poor	Good	Good	Fair	Very good
Polymide Nylon 66	94°C	121°C	94°C	No effect	4 – 4.5%	1.14	Yes	Good	Poor	Poor	Fair	Very good
Polypropylene Herculon	94°C	107°C	94°C	Excellent	0.1%	0.9	Yes	Excellent	Excellent	Excellent	Good	Excellent
Polyester Dacron	132°C	150°C	94°C	– 5	0.4%	1.38	Yes	Fair	Fair +	Fair	Good	Good
Acrylic Copolymer Orlon	120°C	120°C	110°C	Very Good	1.0%	1.16	No	Fair	Good	Good	Good	Very good
Homopolymer acrylic Dralon	140°	140°C	125°C	Very good	1.0%	1.17	Yes	Fair	Very good	Excellent	Good	Very good
Aramid Nomex	204°C	232°C	177°C	– 5	4.5%	1.38	No	Good	Fair	Fair +	Poor	Very good
Glass Fiberglass	260°C	290°C	260°C	– 5	0%	2.54	No	Fair	Very good	Very good	Excellent	Very good
PTFE Teflon	260°C	290°C	260°C	– 5	0%	2.3	No	Excellent	Excellent	Excellent	Excellent	Excellent
Polyphenylene Sulfide Nylon	190°C	232°C	190°C	– 5	0.6%	1.38	No	Excellent	Excellent	Excellent	– 4	Excellent
Polybenz-imidazole PBI	260°C	343°C	260°C	– 5	14%	1.43	No	Good	Excellent	Excellent	Fair	Excellent

WATER VAPOR, SATURATED CONDITION (MOIST HEAT) | BIOLOGICAL RESISTANCE (BACTERIA, MILDEW) | RELATIVE MOISTURE REGAIN (68°F AND 65%°F)

TEMPERATURE FILTRATION | **LOW & MEDIUM-TEMPERATURE FILTRATION**

TEMPERATURE FILTRATION | **LOW AND MEDIUM-TEMPERATURE FILTRATION**

Materials Used for Baghouse. Baghouse collectors can be used even with gases at 260°C and in either caustic or acidic environments depeding on the type of cloth used. Cotton is used for most applications upto 100°C. Nylon offers high abrasive resistance and can withstand caustic conditions. The synthetics orlon and decron can withstand in acidic conditions and at temperatures of 120°C. Fiberglass cloth can be used even for gases at 300°C. The teflon bags are claimed to be superior in abrasion resistance and strength to glass bags but they cost 6 to 10 times more than glass bags. The majority of the baghouse installations utilise fiberglass bags treated with either teflon or silicon graphite.

Cyclone Separator. In this type of mechanical collector, a high velocity gas stream carrying the dust particles enters at high velocity and tangential to the conical shell as shown in Fig. 9.8A. This produces a whirling motion of the gas within the chamber and throws heavier dust particles to the sides and fall out of gas stream and are collected at the bottom of the collector. The gas from the conical shell is passed through the secondary chamber as shown in figure for final dust separation.

Sometimes multi-cyclone dust collectors are used instead of single cyclone unit. The cyclone collectors are commonly used with stoker and with pulverised fuel fire installations.

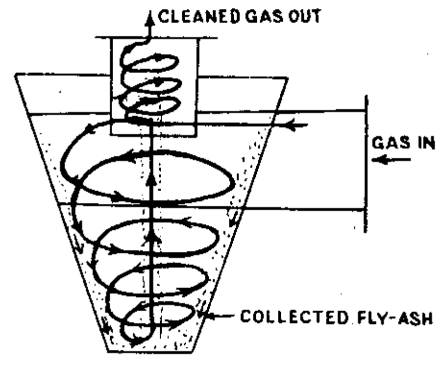


Fig. 9.8A. Cyclone dust collector.

Cyclone dust collectors of multitubular type have been used extensively in power plants. In some areas, this equipment meets even prevailing air pollution codes, in others, it must be supplemented with additional equipment, generally an electrostatic precipitator or wet scrubber.

The overall collection efficiency of the cyclone is related directly to the quantity of particulate less than ten microns in size and the design pressure loss across the unit in the direction of gas flow. The flyash particles less than 10 μ size comprises only 20% of emissions from spreader stoker boilers but for pulverised coal fire unit, the figure is 42% and for boilers with cyclone burners 65%. Collection efficiencies for these firing methods are 90 – 95%, 75 – 90% and 55 to 65% respectively. The range of collection efficiencies for a particular firing method is indicative of the variations in pressure drops and of the collecting tube diameter. The relationship of particle size to pressure drop is given below :

Particle Size in microns.	*Collection Efficiency*		
	Pressure drop 2.5 cm	*Pressure drop 5 cm*	*Pressure drop 7.5 cm*
0-10	62.5	67.0	70.0
10-20	95.8	97.8	98
20-45	98.6	99.1	99.3
Over 45	99.3	99.5	99.6

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

The advantages and disadvantages of cyclone collector are listed below :

Advantages. 1. It is more rugged therefore maintenance costs are relatively low.

2. Its efficiency is higher for bigger size particles and therefore it is easy to remove bigger size particles by this collector than any other.

3. Its efficiency increases with increasing the load.

Disadvantages. 1. It is incapable of removing dust and ash particles which remain in suspension with still air.

2. It requires more power than other collectors as very high velocity is required to create the vortex motion in the cyclone chamber.

3. This type of collector is not very flexible in terms of volume handled.

4. The pressure loss is comparatively high. This is 2 cm to 15 cm of water.

5. The collection efficiency decreases as the fineness of the dust particle increases.

6. This type of collector requires considerable headroom and it must be placed outside the boiler room.

9.5. ELECTROSTATIC PRECIPITATORS (ESP)

This electrical equipment was first introduced by Dr. F.G. Cottell in 1906 and was first economically used in 1937 for the removal of dust and ash particles carried with the exhaust gases of the thermal power plants.

The electrostatic precipitators are extensively used in removal of flyash from electric utility boiler emissions. The use of this collector is growing rapidly because of the new strict air quality codes. An electrostatic precipitator can be designed to operate at any desired efficiency for use as a primary collector or as a supplementary unit to a cyclone collector. It is often considered worthwhile to retain an existing cyclone as primary collector in cases where collection efficiencies must be upgraded especially where there is large amount of ***unburnt*** carbon in flyash (about 15%) because the presence of large quantities of carbon in the gas can adversely affect the collection efficiency of a precipitator.

The working principle of electrostatic precipitator is illustrated in Fig. 9.9 (*a*) and the actual layout of all components is shown in Fig. 9.9 (*b*).

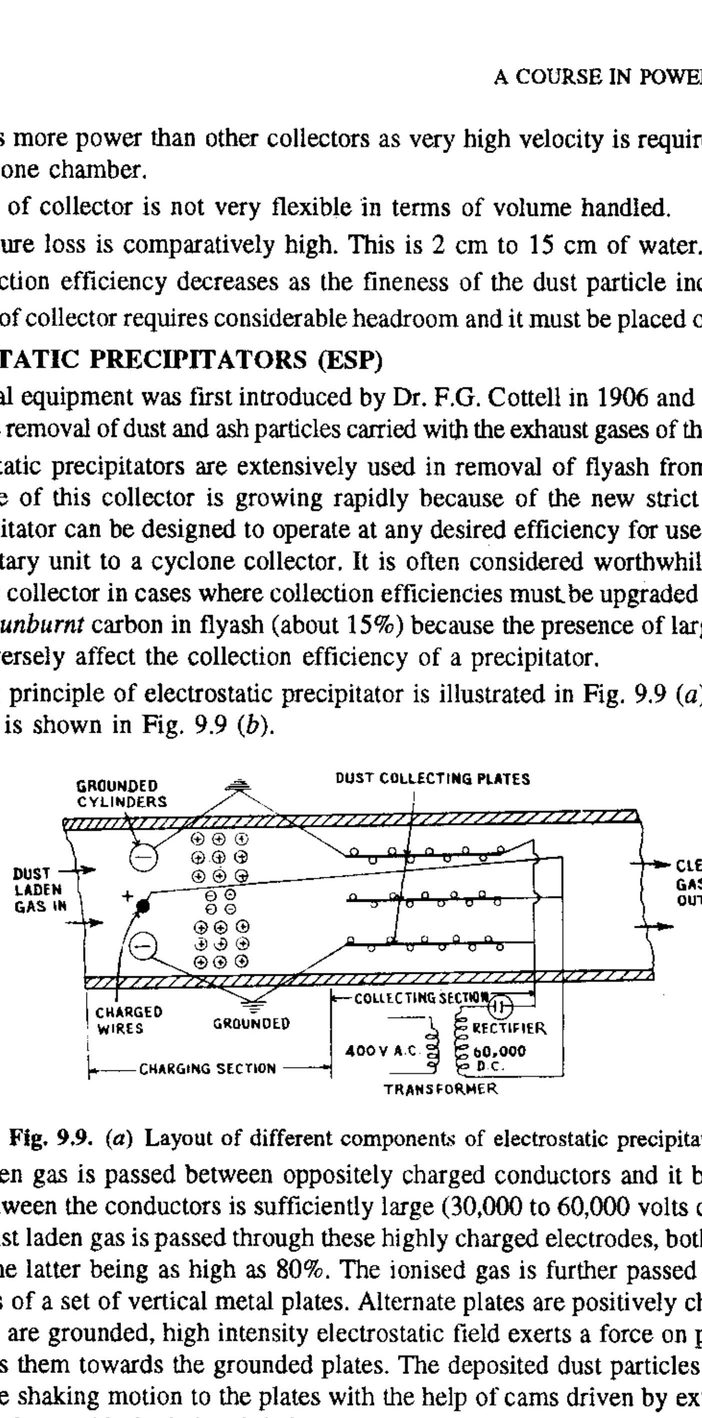


Fig. 9.9. (*a*) Layout of different components of electrostatic precipitator.

The dust laden gas is passed between oppositely charged conductors and it becomes ionised as the voltage applied between the conductors is sufficiently large (30,000 to 60,000 volts dependent on electrode spacing). As the dust laden gas is passed through these highly charged electrodes, both negative and positive ions are formed, the latter being as high as 80%. The ionised gas is further passed through the collecting unit which consists of a set of vertical metal plates. Alternate plates are positively charged and earthed. As the alternate plates are grounded, high intensity electrostatic field exerts a force on positively charged dust particles and drives them towards the grounded plates. The deposited dust particles are removed from the plates by giving the shaking motion to the plates with the help of cams driven by external means. The dust removed from the plates with the help of shaking motion is collected in the dust hoppers. Care should be taken that the dust collected in the hopper should not be entrained in the clean gas.

The advantages and disadvantages of this collector are listed below :

Advantages. 1. This is more effective to remove very small particles like smoke, mist and flyash. Its range of dust removal is sufficiently large (0.01 μ to 1.00 μ). The small dust particles below 10 μ cannot be removed with the help of mechanical separators and wet scrubbers cannot be used if sufficient water is not available. Under these circumstances, this type is very effective.

2. This is also most effective for high dust loaded gas (as high as 100 grams per cu metre). Its efficiency is as high as 99.5%.

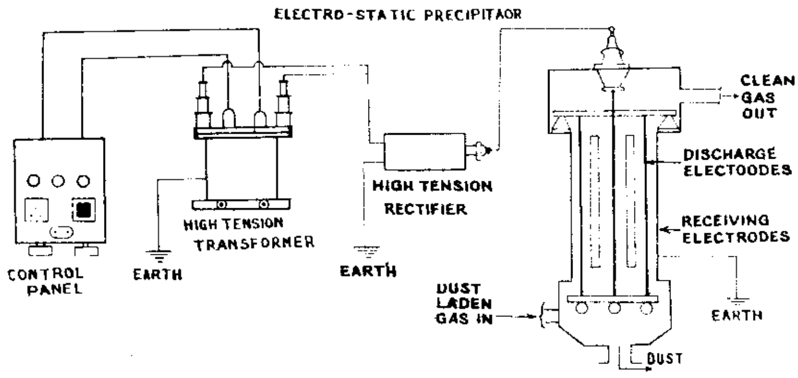


Fig. 9.9. (b) General arrangement of an electrostatic precipitator.

3. The draught loss of this separator is the least of all forms (1 cm of water).

4. The maintenance charges are least among all separators.

5. It provides ease of operation.

6. The dust is collected in dry form and can be removed either dry or wet.

Disadvantages. 1. The direct current (D.C.) is not available with the modern power plants, therefore, considerable electrical equipment is necessary to convert low voltage (400 V) A.C. to high voltage (60,000) D.C. This increases the capital cost of the equipment as high as 40 to 60 cents per 1000 kg of rated installed steam generating capacity.

2. The running charges are also considerably high as the amount of power required for charging is considerably large.

3. The space required is larger than wet system.

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

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

However, in spite of costs it is frequently used with pulverised coal-fired stations for its effectiveness on fine ash particles compared with other types of collectors.

The Factors Affecting the Performance of Electrostatic Precipitators. The present trend in adopting the gas cleaning device is to discharge the clean gas without containing SO_2 to the atmosphere. One solution to this problem is to burn fuels containing less sulphur, but unfortunately low sulphur fuels are costly to use. However, in most cases burning low sulphur fuel increases the electrical resistivity of fly ash, particularly at relatively low temperatures. This higher and unpredictable resistivity at lower temperatures coupled with high collection efficiencies (99.5 to 99.9%) demanded by pollution control codes can spell troubles for low temperature precipitators. That's why pollution control engineers are leaning towards precipitators operating at about 345°C where resistibility is not dependent on sulphur level in the flue gases.

The principle of electrostatic precipitator is described in three basic steps as charging of the suspended particles, collection of particulates under the influence of electrostatic field and removal of the precipitate from the collection plate. Many factors influence these three fundamental steps but they are critical to the reliability and performance of high temperature precipitators which are described below :

1. Corona Characteristics. Initiation of corona depends upon free electrons supplied by random sources such as natural radioactivity. Under the influence of an electrical field, these electrons are accelerated to a terminal velocity. The rapidly moving electrons produce additional free electrons by colliding with the orbital electrons of gas molecules and by ionization. At higher temperatures, flue-gas density is reduced, resulting in a reduced starting potential. Thus, at high temperatures, lower voltages initiate the corona to start the precipitation process, resulting in more collection for a given voltage than at lower temperatures.

Electrostatic precipitators operated at maximum power input have steep corona characteristics ; that is, the rate of change of corona current is much greater than the concurrent charge in precipitator-circuit voltage. The steeply rising corona current is further enhanced by increasing temperature of the stack gases. The net effect is to maximize power levels to achieve high efficiency.

2. Resistivity of the Particles. Particulate resistivity is probably the most important basic variable influencing the precipitator performance and therefore is an important design consideration.

A too high level of electrical resistivity or too low level causes collection difficulty. A high resistivity dust, such as sulphur, does not readily give up its negative charge to the collection to rodes. Carbon, a low resistivity particulate readily gives up its negative charge and assumes a positive large. This causes the particulate to be repelled back into the gas stream of negatively charged particles. A low resistivity dust can be collected and repelled in this manner many times before finally being emitted to the atmosphere. Therefore, the presence of large quantities of carbon in the ash can adversely affect the collection efficiency of a precipitator. One thumb-rule followed by designer is to downgrade the efficiency of the unit by 1% for every 1% of carbon in the gas over 15%. Therefore, one always wishes a medium resistivity for a good collection efficiency. In coal-fired boilers, sulphur in the form of SO_2 affects resistivity. Figure 9.10 shows these effects for three different sulphur percentages.

When resistivity is plotted against the temperature taking sulphur content as parameter, a typical U curve results as shown in Fig. (9.11). The resistivity has maximum value between 150 to 200°C. The nature of U-curve is explained below.

Resistivity has two components, one related to the bulk of the material (known as volume condition) and another is related to the surface of the particle, absorbed layer of gas (surface conduction known as chemical conditioning). As the temperature increases, the absorbed surface contaminants evaporate and surface resistivity increases. And with all insulating materials, the volume resistivity increases with decreasing temperature

$$R_t = \overset{\uparrow}{\underset{\downarrow}{R_v}} + R_s \text{ (with increasing temperature)}$$

where R_v is volume resistance and R_s is surface resistance.

Surface conduction dominates below 150°C and volume conduction dominates above 250°C. Between the two, the composite conductivity is the sum of both.

Surface resistivity depends mainly on the chemistry of flue gas, especially on the water and sulfuric acid dewpoints. By contrast, volume resistivity depends on the chemical composition of the particle itself.

Flyash resistivities below 2×10^{10} ohm-cm do not generally limit corona-current density and ESP-voltage to the point of affecting performance. Above this value, sparking can occur at lower voltage and severe back corona is experienced when resistivity exceeds 10^{12} ohm-cm. Referring to the figure and considering 2×10^{10} ohm-cm is a critical resistivity, ESP can be operated at any flue gas temperature without considering the problem of resistivity related performance if low resistivity ash is handled by ESP.

But high resistivity flash suffers from power limitations at temperatures below 600°F. And this is the basis for adopting ***high-side*** ESP installation. The curve for moderate resistivity flkyash intersects the critical valve at 300°F, close to the normal operating temperature of most *cold side* installations. This explains why such units are sensitive to temperature of the flue gas. During the operation of ESP, it is experienced that flyash emission increases ten times the flue gas entering temperature changes by as little as 10°F (5°C). ESP installations many times operate below optimum collection efficiency, and inlet gas temperature is one of the main reasons which is generally overworked by the operator.

There is hardly any difference in the performance of ESPs designed by different companies with similar specific collection areas and geometries. But differences are more likely to be found in components life, ease of service and price. Therefore, the basic design is usually less a factor in performance of ESP than the operation of unit itself. The problem of bad operation can be solved mainly by routine maintenance rather than design of ESP unit.

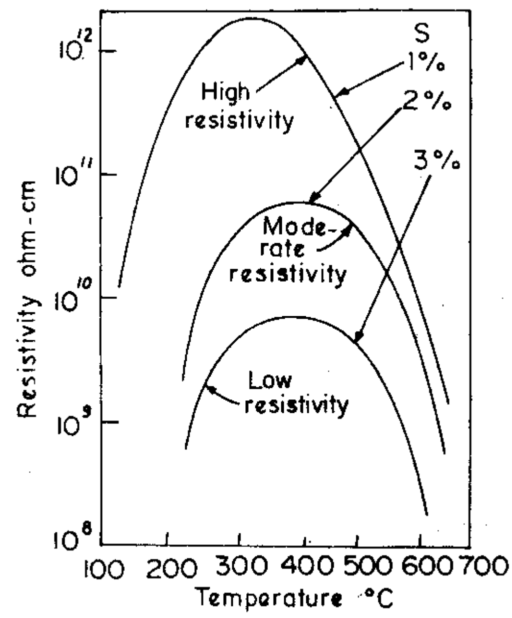


Fig. 9.10. Effects of sulphur content on ash resistivity at various temperatures (resistivity in ohm-cm).

The range of resistivity for good collection efficiency is 10^9 to 10^{10} Ω-cm. When lower sulphur fuels were required by regulations, precipitators began operating at much lower than design operating efficiencies. In many cases, a higher precipitator operating temperatures were used to mitigate the effects of high resistivity. Alternative to higher operating temperatures is an addition of moisture or other conditioning agents (NH_3, SO_3, triethylamine). The effects of temperature of the gas and moisture content on resistivity are shown in Fig. 9.11.

The most widely used reagent is H_2SO_4. It is injected in the flue gases as vapour. Only 10-20 ppm is sufficient for adequate conditioning. Through mixing of H_2SO_4 vapour is an important objective because the ESP will react unfavourably if the unconditioned flyash remains in just one gas passage.

3. Rapping Behaviour. This is perhaps the most complex among the three performance steps. Non-electrical adhesive forces which play a significant role in plate rapping, vary inversely with particle diameter, but depend generally on the chemical and physical nature of the particle. Moisture can increase adhesion at lower temperatures. Particle resistivity has a critical effect on the electrical force causing particles to slick to the collection plates : the more resistive the particle, the greater the force. Operation at low temperatures and high resistivity requires considerably more rapping acceleration on the collection plates

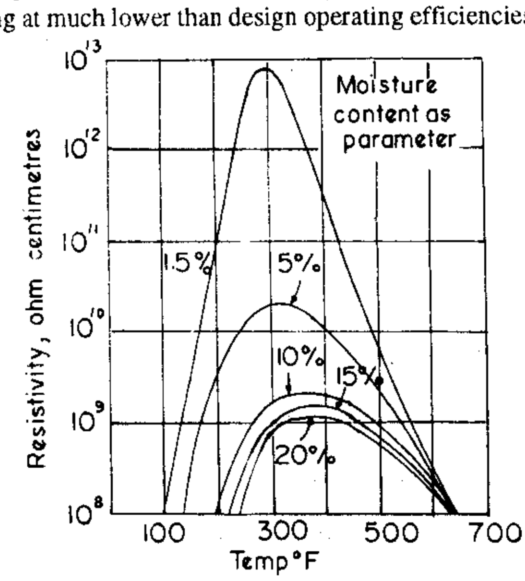


Fig. 9.11. Effects of temperature and moisture content on resistivity of gas carrying ash content.

than it does under normal resistivity, and high temperatures. Conventional practice limits maximum average gas velocity in high-resistivity and low temperature operation to approximately 1.2 m/sec. This limit avoids losses due to re-entrainment of particles which can occur when the dust layer is dislodged violently. In contrast, precipitators commonly run at 1.7 m/sec gas velocity at higher temperature.

4. Gas Velocity. There are two forces acting on a particle having direction right angles to each other as shown in Fig. 9.12. First is due to the flow of gas and second is produced by the electric force on the ionised particle perpendicular to the motion of the gas. The path followed by the particle will take direction which is resultant of the two forces mentioned above. The resultant of these two forces which moves the particle across the space between the electrode plates and the path followed is similar to the path shown in the figure. If the particle is ionised at point A, it will be collected at point b on the plate as shown in figure. If the gas velocity is too high or conversely the voltage is too low, the particle will follow the path Ac and it will be carried beyond the end of the plate. Therefore, the efficiency of the collector decreases with an increase in velocity which can be compensated by increasing the voltage supplied to the plates.

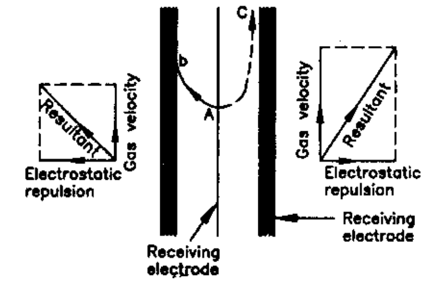


Fig. 9.12. Path of dust particle through electrostatic precipitators.

5. Particle Size and Field Strengths. The performance of a precipitator (collection efficiency) is governed by the following equations :

$$\text{Collection efficiency} = 1 - [e]^{(-A\omega/V)}$$

$$\text{Migration velocity } (\omega) = \frac{r\,E_1 E_2}{2\pi\mu}$$

where A = Effective precipitator collecting electrode area. V = Gas flow through the precipitator.

r = Radius of the particle. E_1 = Strength of particle charging field. (volts)

E_2 = Strength of particle collecting field. (volts) μ = Viscosity or frictional coefficient of the gas.

Collection efficiency increases with an increased collection area, migration velocity and decreases with an increase in quantity of gas flow. Migration velocity proportionally increases with particle size, precipitation field strengths (E_1, E_2) and decreases proportionally with gas velocity. Small increase in field strength causes a much larger increase in ω. But the field voltage cannot be increased above that at which electric arc is formed between the electrodes and ground. All ESPs are equipped with electrical circuitry that maintains the highest possible voltage with arc formation, arcs occur any way at locations of minimum electrical clearance within the ESP. Even in well designed ESPs, the maximum voltage applied to the electrodes without arcing is limited by the properties of flyash. When the voltage is abnormally low, the precipitator performance is drastically reduced. It has been found that the calculated ω's tend to be several times larger than those measured in actual field operation. Uneven gas flow, particle re-entrainment and other factors not anticipated in an idealized formula are responsible for these differences.

6. Performance During Operation. During operation, a layer of flyash is deposited on the collecting plates. Corona currents now must pass through this deposited layer to reach the grounded plates. But this layer increases electrical resistance, a voltage drop occurs across the layer as shown in Fig. (9.13). This reduces the voltage potential between emitting and passive electrodes and ultimately reduces the collection rate (kg/hr). In order to restore the field to full original strength, the voltage applied to the electrodes must be increased.

A more critical effect is the voltage gradient in the dust layer. If it exceeds the dielectric strength of the dust layer at any location, the layer will break down at that location and arcing will result.

If the flyash resistivity is high, the corona current density must be low. When resistivity is very high, breakdown of the dust layer occurs at very low current densities, causing a condition known as back Corona. Here positive ions are generated in the flyash layer and migrate towards the emitting electrodes, neutralizing negatively charged particles along the route. The corona current in ESP depends on the applied voltage as shown in Fig. (9.14). The difference between the clean plate and dirty plate curves represents the voltage drop through the ash layer collected on the plates.

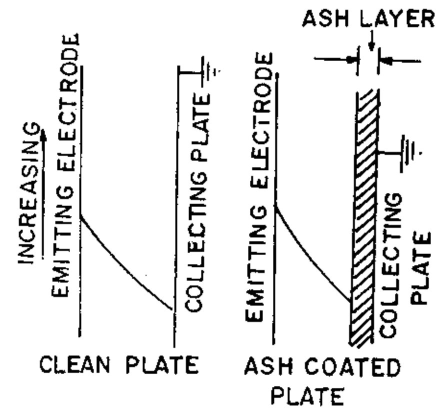


Fig. 9.13. Ash layer changes the voltage gradient between electrode and plate.

Coromax Pulse—A New Precipitator. The requirements for the reduction of the flyash emission from the coal-fired power plants and at the same time use of low sulphur coal producing high resistivity fly ash have created the troubles for successful operation of ESPs. The performance of the ESP can be improved with low sulphur coal by pulse energization.

Principle of Its Operation. The voltage applied to a pulse energized precipitator consists of short duration high voltage pulses repeatedly superimposed on a base DC-voltage as shown in Fig. (9.15). The pulse duration is of the order of 100 μ seconds and pulse frequency is 200/sec.

As the gas passes through the precipitator,

(1) the gas is ionised by the high voltage corona at the discharge electrode.

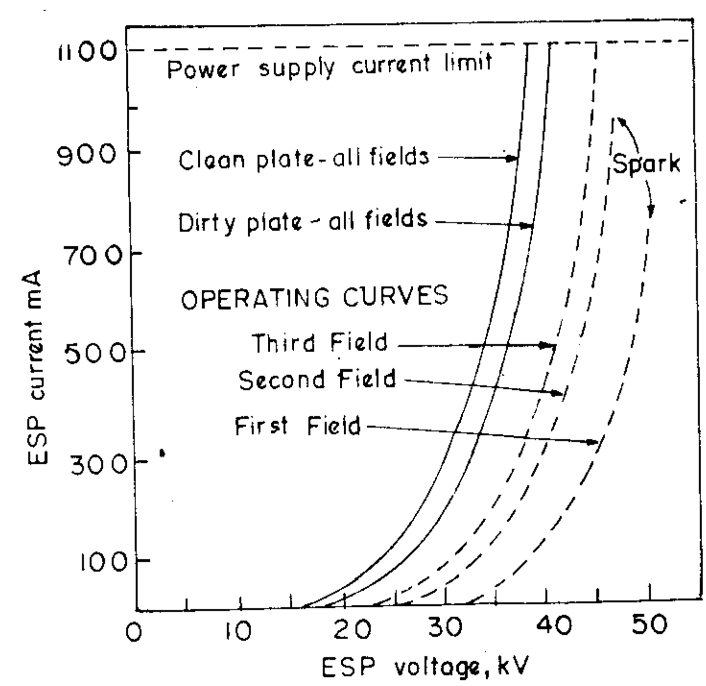


Fig. 9.14. Studying abnormal operating conditions.

(2) the gas ions and electrons collide with dust particles that become negatively charged.

(3) as the particle's charge reaches the limit, (called saturation charge) the electrostatic field between the electrodes causes the particle to migrate to the collecting electrode.

(4) the particle gives up its charge to the grounded collecting electrode.

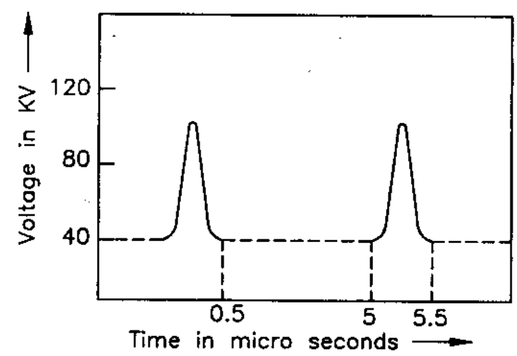


Fig. 9.15. Precipitator voltage wave form.

The last operation depends on the resistivity of the dust particle. If the resistivity is too low, the particle will give up its charge too easily and re-enter in the gas stream. If the resistivity is greater than 10^9 Ω-cm, a build-up of negative charge will occur at the surface of dust layer on the collecting electrode. When the resulting increase in the potential difference across this dust layer becomes a considerable portion of the applied voltage, the precipitator's electric field strength is lowered and current flow is impeded. This interferes with particle charging and collection.

The arrangement of the components is shown in Fig. (9.16*a*) and the circuit diagram is shown in Fig. (9.16*b*).

The advantages of this system are listed below :

(1) Current control capability is independent of precipitator voltage.

(2) It provides enhanced peak field strength between discharge and collecting electrodes.

(3) It improves the particle charging and collection efficiency of the precipitator.

(4) The size of the precipitator can be reduced significantly in cases with high resistivity dust if pulse energization is used instead of conventional DC-energization.

(5) The specific precipitation power (W/m^2) may be reduced to 50-75% of the value with DC-energization, depending on the factors such as dust resistivity and gas temperature.

The first pulse energised precipitator for a coal fired boiler was commissioned in 1982 at a power station-Aalborg (Denmark) where a unit of 135 MW capacity was converted from oil to coal. Another unit for 150 MW capacity was also commissioned in 1983 at Stigsneess Power plant in Denmark.

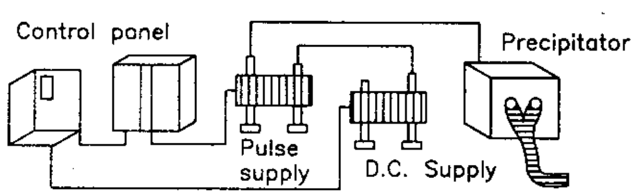


Fig. 9.16. (*a*) Coromax pulse system.

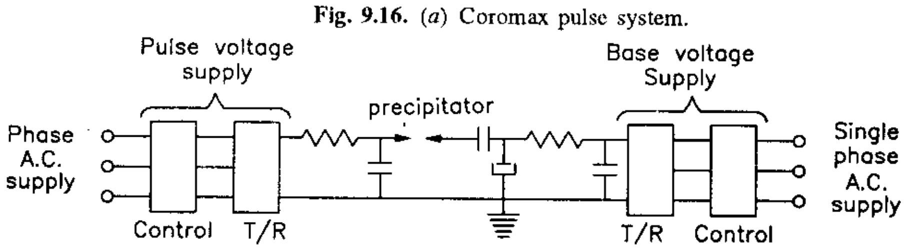


Fig. 9.16. (*b*) Pulse Energizing circuit (T/R)-Transformer/Rectifier.

If this system is to be incorporated at the existing ESP, the existing transformer/rectifier may be used as DC-supply. The only modifications necessary are that transformer/rectifier has to be tied in with the controls of the pulse system.

9.6. GAS CONDITIONING

Today's fuel situation in the world particularly in USA, and strict codes for gas emission create further problems for the electric power industry. The switching from higher sulphur to low sulphur coals helps to meet sulphur dioxide restrictions, but they generate more ash and flue gas per MW, therefore, they require collector of higher collection efficiency. Compounding the problem is that resistivity of the dust is several orders of magnitude greater than that of higher sulphur coals.

Gas conditioning is defined here as injection of small quantities of SO_3 into the flue gas. This reduces electrical resistivity of fly ash and thus makes the dust more amenable to collection in the electrical precipitator. In other words, it increases the collection efficiency of the precipitator. In short, gas conditioning significantly improves precipitator performance, eliminating the need for overdesigning the precipitator and reduces the capital cost.

About 10^{-10} ohm of dust conductivity (or 10^{10} ohm-cm-resistivities) is required for efficient operation of the precipitator. This level of resistivity is regarded as the critical in precipitator design. Higher resistivity causes excessive sparking. This limits the allowable applied voltage and impairs precipitator performance.

Dust resistivity is a function of its chemical composition and conditions of temperature and humidity. Humidity lowers resistivity (mentioned earlier) because conductive condensation collects on the particulate surface. Its effects may be increased by the presence of small quantities of conditioning agents. The condensed water film thickens with water vapour in the gas and also with lower flue gas temperature.

As discussed earlier, the precipitator does not work satisfactorily (with high efficiency) when low sulphur coal is used in the boiler. Because, the flue gas resistance increases due to low sulphur content (higher the sulphur, higher is conductivity and lower is the resistivity). Therefore, it becomes necessary to add some compounds in the form of spray in the flue gases before entering into the precipitator. This increases the efficiency of the precipitator as the overall gas resistance decreases.

Gas Conditioning Compounds. Typical conditioning compounds for each specific type of dust are found by modified trial and error. The most commonly used conditioning agents are H_2SO_4 and NH_3. Generally H_2SO_4 is used with low sulphur coals which exhibit high resistivity while NH_3 is used with high sulphur coals which may have too low a resistivity value.

The resistivity of fly ash also depends on the sulphate level on the surface of the gases and ash. The research has indicated that the critical sulphate level is estimated at 0.5% of the gas. Higher values are sufficient to insure good electrical operation and precipitator performance whereas lower values (higher resistivity and poor electrical operation) reduces the precipitator performance.

During combustion, most of the sulphur in the coal is converted into SO_2 and 1 or 2% is further oxidized to SO_3. Small traces of SO_3 in the gas (10 to 20 ppm) are sufficient to maintain the resistivity of the fly-ash below the critical value. Generally, the higher resistivity ashes (formed from burning low sulphur coal of 1%) are deficient in sulphates. This can be corrected by adding SO_3 to the flue gas stream ahead of the precipitator. High sulphur coals (above 3%) pose the reverse problem. Their dust exhibits low resistivity due to excesses of SO_3 on the absorbed dust particles. Anhydrous NH_3 in combination with steam has corrected this problem.

Adding SO_3 to high resistivity ash ahead of the precipitator significantly improves electrical operation and therefore precipitator performance and efficiency. There are several types of commercial SO_3, gas conditioning systems as direct injection of liquid SO_3, vaporization of H_2SO_4 ; and sulphur burning followed by the catalytic conversion of SO_2 to SO_3. Among all mentioned above, sulphur burning finds extensive use as it is more economical and safe.

Sulphur Burning Method for Flue Gas Conditioning. Molten sulphur is pumped from a steam jacketed storage tank to the sulphur burner through steam jacketed transfer lines. Liquid sulphur is atomized with high velocity air and completely burned to SO_2 in the combustion chamber. The effluent SO_2 air mixture flows out of the sulphur burner at about 950°C. After cooling to 350°C in an air cooler, the gas is converted catalytically in a one-stage of vanadium oxide bed to SO_3. The dilute SO_3 gas after heating to 600°C in electric heater is transported to the precipitator distribution manifold for gas conditioning purposes. The line diagram of the above described system is shown in Fig. 9.17.

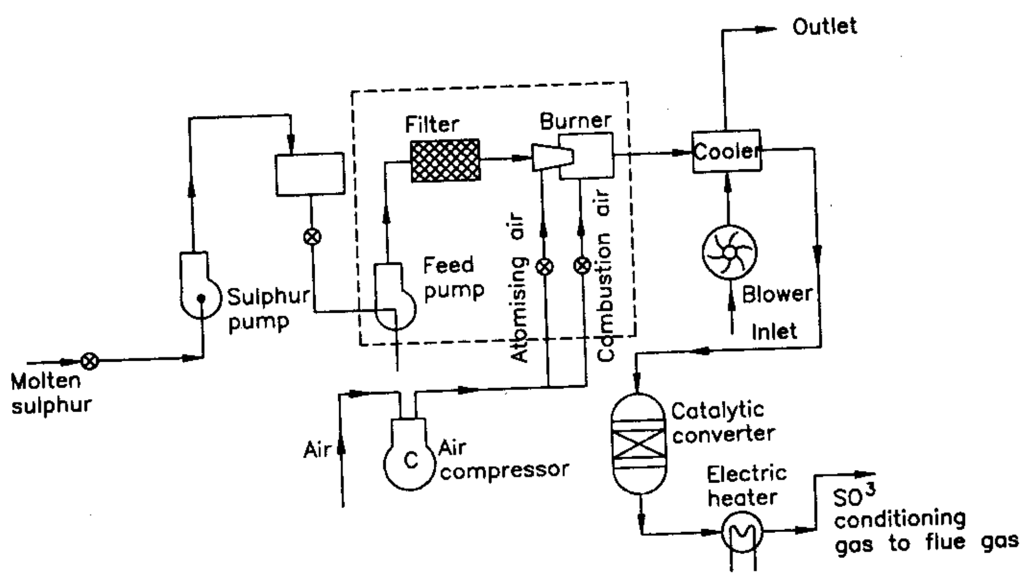


Fig. 9.17. Sulphur burning method for flue gas conditioning.

Comparing the performance of hot and cold precipitators on the past experience reveals that, in a number of cases, hot precipitators can be built in smaller sizes than cold units for the same application.

The electrostatic precipitators are specified on empirically derived data rather than being designed from theoretical principles. It is fair to say that the precipitator application or design is much more an art than a science.

9.7. WET-TYPE MECHANICAL DUST COLLECTORS

During the last decade, trend towards the nuclear steam supply system, large oil-fired systems and light oil-fired combined cycle threatened the coal-fired steam generator market for electric power production. The ever increasing lead time and environmental restrictions on nuclear systems, ever decreasing supply of oil and gas reversed this trend with the consequent increased use of coal during the present decade. Tightening restrictions on pollutant emissions during this decade, particularly those of SO_2, fostered increased use of low sulphur oil and coal.

Nevertheless, rigid air pollution control laws (in western countries) have placed great emphasis on the need for reduced emissions from coal-fired units. The pollution control laws compelled the electric utility systems to use low content sulphur coal to control the emission level of SO_2 in the atmosphere. But low sulphur fuel is too expensive and not available in the required quantity. The use of low sulphur coal has caused still difficult sulphur pollution problems. Fly-ash from low sulphur coal presents a high resistivity problem to electrostatic precipitators when gases are to be treated at temperatures of 150°C to 200°C. As a result, precipitators can become prohibitively large and expensive.

The control of SO_2 in the exhaust gas emission using low sulphur fuel can be better controlled with the use of scrubbers (wet dust collection system) as the problem of resistibility of flue gases does not arise for the efficient working the wet dust collector. The difficulty of particulate matter collection by conventional precipitation techniques when burning low sulphur coal, moved wet scrubbing to the forefront. The use of wet scrubbing offers a means for making high sulphur coal an environmentally acceptable source of energy.

Most utilities planning new power generation systems for future installations (in part of U.S.A.) must choose wet scrubbers and low sulphur coal. The straight air quality laws in some of the western states of U.S.A., New Mexico, Utah, Nevada Wyoming, Colorado and Montana preclude the low sulphur fuel option as ample low sulphur fuel is available locally and utilities have no choice other than to install scrubbers. Therefore, it is anticipated that central and southern Utah may become a scrubber centre because of the several large power stations are planned in this area.

The fumes, smokes and soluble gases as SO_2 and H_2S carried with the flue gases using low sulphur coals can be economically removed with the help of wet type mechanical collectors. The gases and fumes and very fine dust are dissolved in the liquid (water + lime) which is spread in the dust collector and mixture in the form of thick fluid from the bottom of the collector and cleaned flue gasees go out from the top.

All wet collectors operate on the same basic principle. Fine slow moving liquid droplets collide with the wet dust particles. Wetted particles agglomerate until heavy enough to drop out of the gas stream. In general, greater the difference in relative velocities between the dust particles and water droplets and finer the droplets, the higher the collector's efficiency.

9.8. COMBINED OPERATION OF DIFFERENT COLLECTORS

(*a*) **Combined Cyclone and Baghouse Collector.** A Danish firm has introduced a combined cyclone and bag filter which is automatically cleaned while operating by means of scavenging with pressurised air. The largest volume of the particles is separated in the cyclone and the remaining micro-size dust is removed in bag filters.

The system incorporates an electrically controlled scavenging providing high reliability of operation. The filter bags are cleaned by means of powerful pressurized air blasts. The scavenging system does not incorporate any built-in electrical components, therefore risk of dust explosion is totally removed. The scavenging intervals are selected between 3 to 60 seconds, depending upon filter size and load.

This system is suitable for suction or pressure filters and resists negative pressure upto 500 cm of water head. This is used in connection with dust extraction plants and drying plants.

(*b*) **Combined dry mechanical and electrical collector.** The combination of mechanical with electrical collectors is used commonly to reduce the initial cost of the collector system. The electrical collector is very costly and gives falling efficiency characteristics with increasing load. The mechanical collector gives increasing efficiency characteristics as shown in Fig. 9.18. The combination of the two gives the efficiency characteristics as shown in figure which shows the constant efficiency irrespective of load on the system.

The mechanical collector is usually installed first with the electrical collector following, the former removes the heavier particles and the latter the samll particles. This combination is more preferable and economical because mechanical collector gives high collector efficiency with the larger particle size and electrical collector efficiency is least affected with the size of the particles.

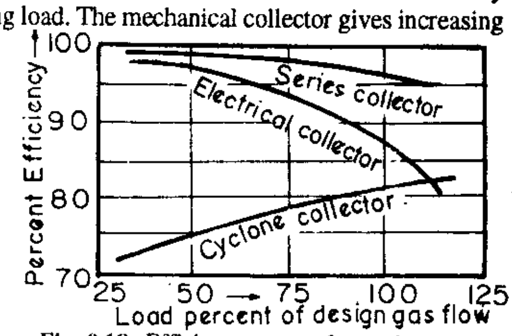


Fig. 9.18. Efficiency curves for cyclone, and electric combined dust collectors.

(*c*) **Combined Wet Mechanical and Electrical Collector.** Alone wet scrubber requires higher operating energy input in terms of operating pressure drop. Typical pressure drops range between 15 to 40 cm of H_2O to obtain clean stack outlet. The trend of thinking for wet scrubbing processes has been toward providing as electrostatic precipitator for removal of most of the fly ash ahead of the scrubber, instead of relying upon the scrubber for particulate control. This is because, fly ash can interfere with both scrubber chemistry and mechanical operation.

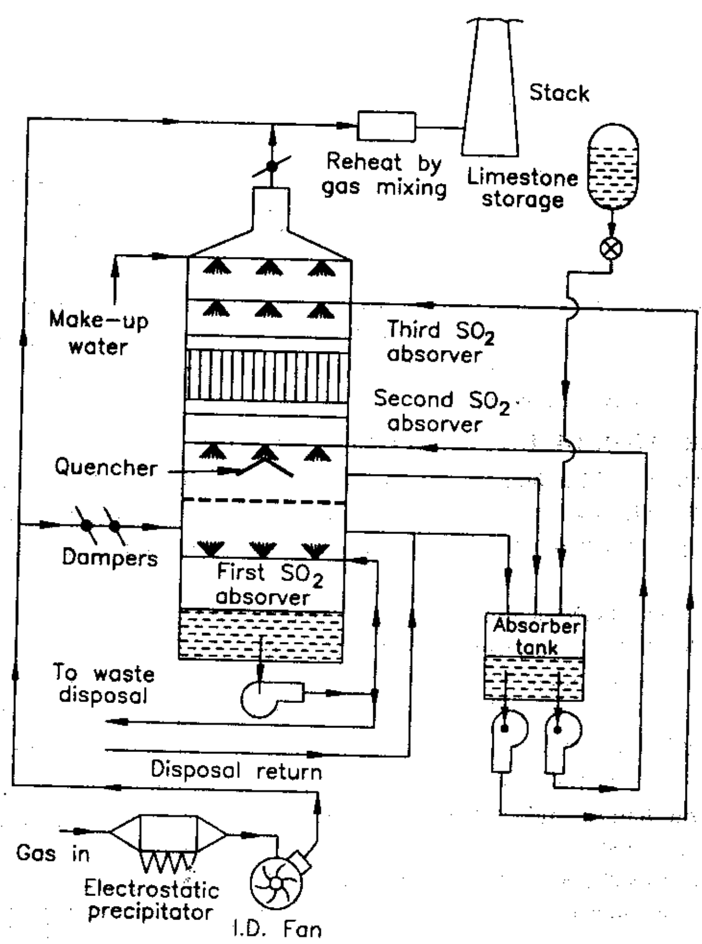


Fig. 9.19. An Electrostatic Precipitator followed by an absorbing tower scrubber used for Kansas Power and Energy Centre.

A combined system designed for Kansas Power Energy Centre is shown in Fig. 9.19. Flue gase leaving the air heater enters a cold electronic precipitator designed to meet particulate emission requirements. After leaving the precipitator, the flue gas enters the induced draft fans. The SO_2 absorbers (spany towers) are located downstream of the fan. After the flue gases are treated in the scrubbers, it is mixed with a portion of the flue gases that has bypassed the scrubber. This hot gas at 140°C heats the wet flue gases leaving the scrubber to about 80°C before it enters the stack. This is necessary to maintain the gas temperature above dew-point temperature of the gas otherwise the acid would condense passing through the stack and deteriorate the stack within no time. Sometimes, electric heaters are used to heat the gas coming out of scrubber instead of bypassing the gas coming out of precipitator.

The dry sulphur extraction process from coal or sulphur oxides from flue gases are not yet developed to the commercial stage but research is still proceeding in this direction.

The power engineer has to choose from cyclone collectors, ESPs, fabric filters, wet scrubbers and combination of these, to reduce particulate emissions from coal-fired plants. All of them have countless years of successful operating experience. Selection of optimum system for the required plant involves careful analysis of pollution control requirements and of capital and operating costs of the equipments.

9.9. PERFORMANCE OF DUST COLLECTORS

The performance of the collectors includes the effect of particle size and its velocity on the collection efficiency and the power requirement with an increase in load on the collectors.

Mechanical Collectors (Dry). 1. The efficiency of the mechanical collectors increases with an increase in dust particle size.

2. The efficiency increases with an increase in gas velocity or load on the plant. This is due to the increase in intensity of the centrifugal force acting on the particles which is responsible to settle them out.

3. The draught loss increases with an increase in gas velocity and power required also increases.

Wet Collectors

1. The efficiency of the collector increases with an increase in relative velocity between water and gas and quantity of water.

2. The efficiency of this decreases with an increase in size of the dust particles because there is every possibility of clogging passages through which the effluent flows down.

3. The power requirement increases with an increase in relative velocity.

Electrostatic Precipitator

1. The efficiency of this collector is least affected by the size of the particle.

2. Its efficiency is highy affected due to increase in gas velocity. The cause for the same is explained earlier.

3. The power requirement increases with an increase in voltage supplied as well as with an increase in gas loading.

The use of collectors for different sizes of particles is shown in Fig. 9.20 and their comparison concerning cost, space requirement and power requirement is given in table shown below.

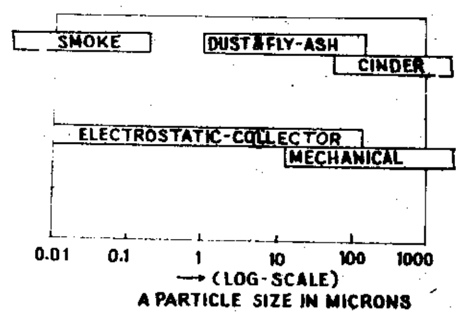


Fig. 9.20. Range of Collectors for dust collection.

Type of Collector	*Costs*			*Space occupied*		*Draught loss*
	Capital	*Operating*	*Maintenance*	*Area*	*Volume*	
Water film with settling tank	1	1	1	1	1	1
Water spray type with filter plant	2	2	2	0.9	2.5	1.3
Multi-cyclone	1.1	1	0.6	0.4	3.5	2.8
Electrostatic	1.9	2	0.5	0.45	3	0.33

The effect of particle size on the collection efficiency on different collectors is shown in Fig. 9.20A.

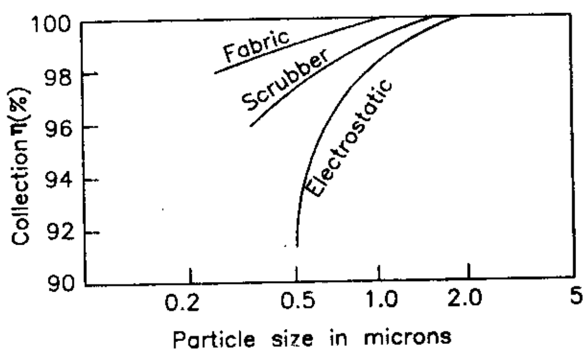


Fig. 9.20A.

9.10. INSTALLATION OF COLLECTORS

The installation of collectors (particularly electrostatic) either before air-heater or after air-heater is remained a problem of dispute.

Dust collectors are generally installed between the boiler outlet and the chimney ; usually on the chimney side of the air-heater. There is definite advantage in keeping the collector before air-heater because it maintains the air-heater more clean and reduces the cleaning charges. However the practice is to keep the collectors after the air-heater and use soot blowers to keep the heater surfaces clean.

In first case, the charges of cleaning the air-heater are reduced but in the second case the heat utilised for heating the air is more as there is no loss of heat in collectors as heaters are earlier the collector. But more collection of soot on heating surfaces also reduces the rate of heat transfer. The problem of installation is left with the engineer with his past experiences as operating difficulties are concerned and cost evaluation. Because this again depends upon the type of coal used, type of combustion system used and the capacity of the plant.

Presently, it is claimed that the installation of electric collector to hot-side as shown in Fig. 9.21 is more preferable and economical for the reasons mentioned below.

The performance of electric-collector depends mostly on the sulphur content of the fuel. It is better with higher percentage of sulphur. The present legislation is forcing the use of low sulphur content coal for power plants to reduce the SO_2 emission. As the sulphur content in the fuel approaches to 1%, the performance of the collector deteriorates because of the increased electrical resistance of the fly-ash to be collected.

It has been found in many thermal plants that with the reduction in SO_2 emission, the emission of solid particulates have increased. The electrostatic precipitators do not function well with the Western power plants which use coal of low sulphur content (0.4 to 0.8%) because of increased electrical resistance of the ash to be collected.

To overcome the above-mentioned difficulty, the electrostatic collector should be designed to operate at higher temperatures, thus avoiding the high resistivity range. When the precipitator operates at temperatures in excess of 270°C (500°F) ; the resistivity decreases to normal range and performance improves. This arrangement can handle low resistivity fly-ash from low sulphur coals.

The 'hot side' electrostatic precipitators were never favoured in past because the gas volume passing through these collectors is nearly 50% greater than normal at this temperature and increases the size required. The proportional increase in size also increases the capital cost required and its operation at this temperature demands special materials which further adds in cost. Even then for special situation, it is always advisable for power plant engineers to consider the hot side electrostatic precipitators.

Most fly ash precipitators are located downstream of the air-preheater where gas temperatures are 130 to 180°C. The small changes in gas condition or sulphur content of the coal have marked effect on the collection efficiency of the precipitator in this range of temperature. Because, at lower temperatures, the gaseous vapour enveloped around the particle must provide the conductive medium. The amount of SO_2 in the emission effects this gaseous envelop.

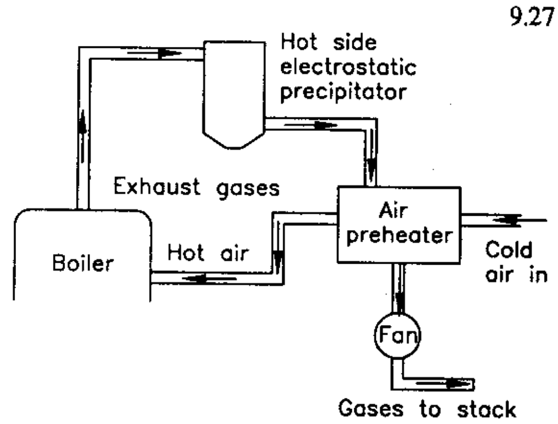


Fig. 9.21. Hot-side Electrostatic Precipitator.

The installation of the collector upstream of the air-preheater, where gas temperature exceeds 350°C, the precipitator is less effected by the changes in the gas or coal composition. At higher temperatures, the mass conductivity is substantially higher and the particle itself becomes the medium for the necessary electron flow.

The installation of '*hot side*' electrostatic precipitator at Akron Power Station in Ohio (U.S.A.) in 1967 is the example for its best performance. It has given the rated efficiency of 99% during the operation for 1967 to 1970 and it has also been observed that the tubes of the air-heater were very clean. The collector handles 3280 m^3 of gas per minute at 353°C. Mechanical rapping of the collecting plates removes the dust and it falls into the hoppers and then it is removed through a vacuum system. Flexibility in the design of the rapping controls permits changing of the intensity and timing of rappers to match boiler operations.

Optimization of heat recovery from exhaust gases is the main aim of the system arrangement. The ESPs efficiency drops at lower temperature if more heat is extracted in the heat recovery system (cold ESP). This drop in ESP's efficiency can be compensated by higher sulphur content in the coal. Therefore, cold side arrangement can be used for higher sulphur content coal provided the exit gas temperature should not fall below acid dew point temperature. Therefore in any of the systems, one objective (getting more heat recovery) cannot be achieved without impairing the other objective (losing ESP collection efficiency). Any fuel saving through waste heat recovery will offset by the high capital and higher operating costs of the precipitator.

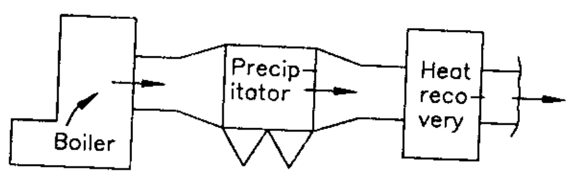


Fig. 9.22. (*a*) Hot-side Arrangement (> 600°F).

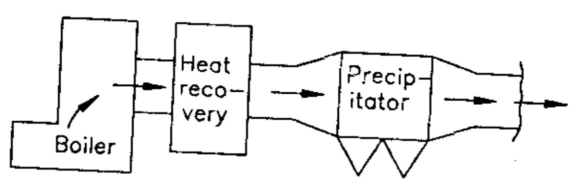


Fig. 9.22. (*b*) Cold-side Arrangement (< 300°F).

9.11. ASH DISPOSAL

The various methods are used for disposing the ash from collected hopper to the discharged site or discharged hopper which are located far away from the power plant.

1. Vacuum Extraction Plant. This system of disposal is used on both stoker and pulverised fuel intallations and gives good service. The arrangement of the system is exactly same as shown in Fig. 9.9. The crushers are not required if it is used with pulverised coal-fired boilers.

2. Water Ejector System. This system also can be used with stoker as well as with pulverised fuel-fired boilers with equal efficiency. Its adaption is more economical if the higher pressure water is used for the system.

The dust is periodically extracted from the dust hoppers by the water ejector and discharged into a sluiceway in the form of slurry. Its capacity lies between 60 to 80 tons per hour.

3. Steam Ejector System. This system is also used to carry the dust to the disposal site. The working principle is already discussed.

4. Mechanical Conveyors. The dust is also carried with the help of mechanical conveyors like screw and belt provied it is wetted before carrying.

The ash and dust is transported either using wet system or dry system. In the wet system, ash is transported to ash ponds in the form of slurry. As ash settles in the pond, the part of the water evaporates and the remainder is either recycled or impounded. This system requires installation of pipelines and construction of embankments.

In dry system, ash is transported to the disposal site in a relatively dry state (in the form of paste). Water is added only to compact the ash. It does not require embankments to hold ash. Compacted ash surfaces are covered with top soil and seeded.

Combinations of these two basic types also exist. Ash slurry may be pumped to a pond and after dewatering, it may be excavated and transported to a dry site for final disposal. For boiler bottom ash, combination systems are commonly used. The bottom ash slurry is often dewatered and transported by trucks to a dry disposal site.

If the final disposal area for flyash is beyond economic pneumatic conveying distance but is not more than 10 km from the power station, it is generally less costly to transfer the flyash to the disposal area by mixing with water and pumping as a slurry. The fly ash can be pumped as a low concentration slurry (containing 20% ash by weight) or can be pumped as a high concentration (50% or more). High concentration is more economical in terms of power consumption as the amount of water pumped is much reduced, but to avoid the possibility of blockages occurring in the disposal pipeline, close control of the slurry concentration and of pumping velocity becomes necessary.

It is not desirable to pump the furnace bottom ash over long distances because firstly it has to be carried in water suspension at a higher velocity than dust and secondly, its abrasive qualities cause wear of pipelines.

The ash slurry can also be directly discharged to river (as used earlier for Koradi plant in Maharashtra), or to natural pond (as used for Singrauli* plant in U.P.) or to the sea (as used for Ennore plant near Madras). The consumption of this station is 5000 tons of low grade coal per day producing 1870 tons of fly-ash and 700 tons of slag per day. A mixture of ash and sea water is pumped into the sea about 3.5 km to the South of tidal inlet. The outfall has been located at 4 m depth by carrying ash disposal pipes on a jetty 150 m long. This system is working very satisfactorily provided if it is environmentally acceptable. The ash discharged in the river should not be carried in the farms which will affect the crops. This was very much experienced when the slurry was discharged to Koradi river by Koradi power plant in Maharashtra. The pond bottom is also very much affected by the ash slurry of the Singrauli power plant. Leaching may introduce ash into the underground water, thus affecting drinking well water around the area. The discharge in the sea may also affect the fish life.

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*Rihand reservoir in Mirzapur district is the country's largest man-made lake 50 kilometer long. 2500 tons of ash in the form of slurry from Singrauli plant of 1000 MW capacity is discharged to this pond daily.

The arrangements of wet and dry discharge systems are shown in Fig. 9.23 (*a*) and Fig. 9.23 (*b*).

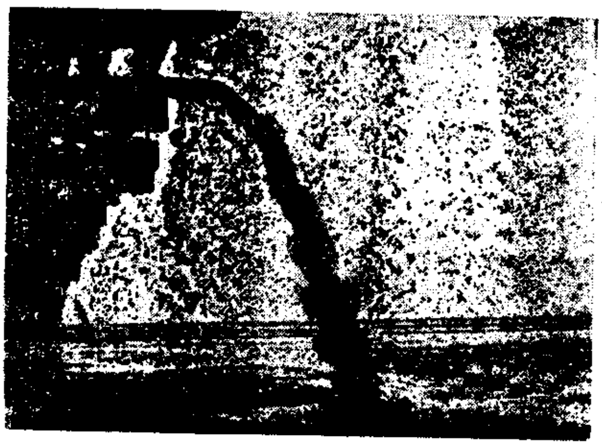

Fig. 9.23. (*a*) Ash slurry discharged into Rihand reservoir.

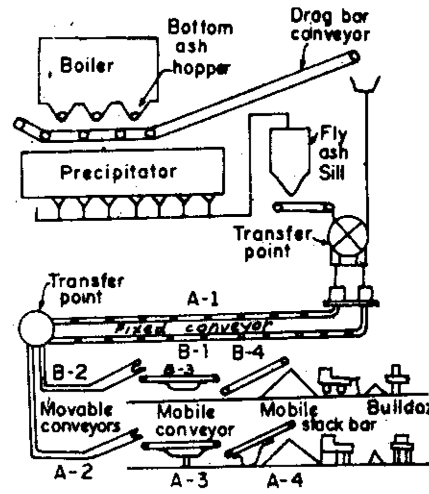

Fig. 9.23. (*b*)

The advantages and disadvantages of wet and dry system are listed below :

Wet System

Advantages. (1) Transportation of ash by pipelines eliminates noise, dust and traffic problem.

(2) Use of manned equipment is eliminated.

(3) The system is unaffected by transportation strikes.

Disadvantages. (1) Large quantities of leachate under a positive pressure head in pond pose a constant threat to ground water quality. This is prevented by surface preparation and artificial lining which are very costly.

(2) The transport water is normally recycled. This requires additional pipelines, pumping equipment, treatment facilities and substantial operating and maintenance costs.

(3) Larger area is required. Area of wet system may be twice of the dry system.

(4) Water requirements are very large.

(5) Scaling and cementation within pipeline, particularly when the slurry contains calcium, magnesium and sulphate ashes, may render this system unsuitable in certain cases.

(6) It is not flexible to relocate the other discharged site.

Dry System

Advantages. (1) Leachate quantities are significantly reduced. Linear to disposal area can be eliminated by fixation of ash. Ash piles can be designed to provide drainage at different levels.

(2) Water and power requirements are considerably less.

(3) Compacted ash is a structural material which can be sold.

(4) Required storage volume and area is reduced considerably. The density of compacted ash is 1400 kg/m^3 against 900 kg/m^3 of loose ash.

(5) The ash disposal site has wider choice of land after closure.

(6) This system offers greater flexibility in operation as ash is transported by vehicles to different sites.

Disadvantages. (1) Use of trucks makes this system totally dependent.

(2) It presents increased visual impact along transportation route.

(3) Wetting of ash containing calcium and magnesium forms lumps which may stick to conveying belt. Larger lumps must be broken before transportation.

Dry ash removal system often has the advantage of reduced water demand, reduced risk of ground water contamination, reduced energy requirements and reduced storage volume.

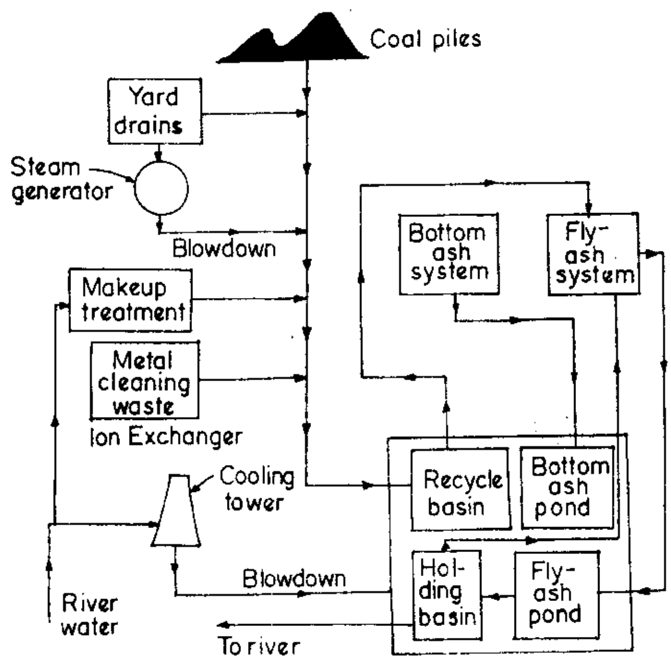

Fig. 9.24. Ash and dust removal system—wet type.

The pond system for ash and dust removal at the coal burning power plant is shown in Fig. (9.24).

100 MW-Coal fired plant (fresh water makeup).

Waste streams	*Flow *gpd/MW*	*Dissolved solid mg/litre*	*Waste streams*	*Flow gpd/MW*	*Dissolved solid mg/litre*
Boiler cleaning	4	3000	Ash Handing	300	3000
Fireside cleaning	5	3000	Wet Scrubber	20	2000
Air precheater cleaning	100	8000	Ion exchange	88	6000
Lab drains	10	200	Miscellaneous	3.2	300
Boiler Blowdown	100	50	Floor drains	30	300
			Total	660	3668

*Gallons per day per MW.

Lagoons

In cases where local sites are not available, it becomes necessary to creeate artificial storage areas called lagoons. For a power plant of 2000 MW capacity, the size of lagoon required is 1 km × 1 km × 15 m size and it is very costly to provide such artificial site. Therefore lagoons are used only in cases of emergency.

The lagoons consist of holes dug into the ground and surrounded by walls known as bunds. The bunds are usually made of material excavated from holes. The larger lagoons (required for 2000 MW) are concrete faced to give necessary strength to resist the pressure which may be of the order of 270 kN/m^2 applied by the huge water content of 2100 million litres.

9.12. ASH AND ITS EFFECTS ON BOILER OPERATION AND PERFORMANCE

With pulverised coal, all the ash particles are formed in suspension and tend to remain in suspension in the furnace. In slag type furnace, a portion of that (20 to 30%) is drained to the furnace bottom in a molten state. The portion of ash which tends to escape towards the stack is called **fly-ash** and a portion which is collected at the bottom of the furnace and is removed either in dry or wet state is called **bottom ash.**

A 500 MW power plant boiler consumes 300 tons of coal per hour and produces 120 tons of total ash per hour in India. Out of this 20% (24 tons/hr) comes out in the form of clinkers and removing 80% (96 tons/hr) is carried in the gas stream and is collected in the hoppers beneath the economiser, air-preheater, mechanical collector and electronic precipitator. The chemical composition of ash varies as per the source of coal and its origin.

The broad composition of ash is given below :

	Content in Ash (%)	*Content in Ash (%)*	*Content in Ash (%)*
Silica (SiO_2)	50	38	48
Alumina (Al_2O_3)	40	20	26
Iron oxide (Fe_3O_3)	16	6	10
Calcium (CaO)	10	2	4
Magnesium	3.5	1.0	2.0
Sulphate (SO_3)	2.5	0.5	1.2
Alkalies (Na_2O, K_2O)	5.5	2.0	4.5

The ash produced is abrasive and will wear out the conveying parts on contact with it. Another form of ash is clinker which is formed by fusing in the forms of lumps.

The burning of coal is very much hampered due to presence of ash, because, it becomes soft and sticky in the furnace. When it forms clinkers, it is very difficult to remove from the grate. The molten ash may also accumulate on the walls of furnace and on boiler surface which corrodes the boiler parts and also hampers heat transfer. The deposition of this ash on heat transfer surfaces choke the flow and it cant be removed during running of the boiler.

The temperature of gas leaving the furnace and entering into the convection surfaces must be low enough to prevent the fouling. This temperature is dictated by the ash fusion temperature which is dependent on the content of alkalies and have direct bearing on slagging tendencies. Therefore, these ingredients should be kept at minimum by washing the coal before use.

9.13. USES OF ASH AND DUST

Use of ash in the production of concrete is technically established. 20% flyash and 30% bottom ash are presently used constructively in USA.

Coal source, quality, degree of grinding, combustion characteristics and boiler design are some of the factors which affect chemical and physical quality of the ash and its potential use. Combustion conditions as percentage of air and furnace temperature are important for the ash quality as they influence the degree of oxidation of the metals. Use of additives to control boiler corrosion or to aid in collecting ash in ESP also affect the ash quality.

Ash is widely used in the production of cement. Flyash is pozzolanic and develops self-hardering characteristics. Concrete made of ash has showed improved workability and strength greater than all cement-based concrete. The pozzolanic quality of ash lime mixture creates a healing of cracks in the pavement themselves.

Due to their better alkali values, they are used for treating acidic soils. Its use for agricultural purposes has been recently experimented in Japan and it is found that it supplies essential nutrients such as sulphur, boron, calcium and zinc. It also adjusts pH to optimum levels for plant growth. It is also found that if the ash is used in limited quantity in soil, it increases the yield of corn, turnip, white clover and asfalfa.

9.14. UTILISATION OF FLY-ASH

The disposal of ash using low grade coal (30–50% ash content) in thermal power plants in India has created lot of problems as large land-area and huge quantity of water are required for the same. The fly-ash generation is estimated (in 1998) to be 60 million tons per year from 75 coal-fired thermal plants which may increase to 90 million tons per year by 2000 and 110 million tons by 2010. Delhi alone contributes 5600 tons of fly-ash every day from its 3 thermal power plants.

India's current total installed capacity (as per 1996 estimate) of power plants is 83288 MW out of which, coal-fired thermal plants contribute 53819 MW (65% of total). The World Bank estimates coal based power generation to increase by another 81000 MW by 2010 which will further increase flyash load of 56 million tons per year.

About 20% of coal ash in the coal is converted into bottom ash and 80% flyash.

India utilises only 3 – 4% of flyash generated as compared to 40% utilisation in France and U.K. The Govt. of India wants to achieve 50% flyash utilisation in coming five years.

According the Ninth Plan, we will have a shortage of 6.6 million houses in the urban areas and 12.76 million houses in the rural areas by the end of 2001. This canot be achieved inspite of all the efforts of Govt. of India because of the cost factor of construction.

Fly ash is essentially a waste material which can be converted to a resource with a minimum amount of investment. This gives fly ash an edge over other construction material, as it is very environment firendly. This also helps in increasing both the speed and quality of construction.

Govt. of India is not fully prepared to appreciate the magnitude of the fly ash problem. Disposal of fly ash is extremely water and land intensive, leading to diversion of fertile land and unsustainable water usage. It also causes displacement of people since large tracts of land are acquired for fly ash disposal, besides leading to air, water and soil contamination. Disposal of fly ash is equally costly as 2% of the cost of the plant goes into disposal of fly ash. Transportation is a main component. The Govt. alone spent Rs. 700 crores in 1995 for moving fly-ash from the site of generation to the disposal site. In addition to this, the water required to remove and transport the fly-ash in the form of slurry is considerably high. Approximately 1 m^3/hr is required per MW generating capacity.

Because of building the problem of disposal of fly-ash, many utilities are considered. Flyash can be used for making a variety of building products.

(1) Mixing with Cement

10 to 25% dry flyash can be used as clinker during manufacture of cement or blended with finished Portland cement to produce Portland Pozzolana cement whose strength is higher. The major drawback of this cement is its high cost and it requires more setting time.

(2) Cellular Light Weight Concrete

This can be manufactured by a process involving the mixing of flyash, cement, coarse sand, fine sand and a foaming agent and the slurry formed is poured in moulds and allowed to set. The blocks are then removed and are cured by spraying water on the stack. The bulk density of the products varies from 400 to 1800 kg/m^3 against ordinary brick bulk density of 1600 to 1920 kg/m^3. The blocks are specially useful in high rise construction reducing the dead weight of the structure. DLF Universal Ltd., New Delhi, is using these blocks in their construction projects for the last eight years.

(3) Sintered Light Weight Aggregates

This is produced by pelletisation or nodulisation of flyash and sintering them at 1000°C to 1300°C. Unburnt fuel in the flyash modules supports ignition. Sintered light weight aggregate substitutes stone chips in concrete reducing dead weight. The process know-how developed by CBRI, Roorkee, has yet to go in for commercial production.

(4) Cast-in-Situ Flyash Walls

Using high flyash mix comprising of cement, lime, flyash and sand in appropriate proportions depending upon the quality of flyash with pre-measured water-cement ratio, cast-in-situ walls can be built. These can be cast to any thickness using steel shuttering. By using this system, we can achieve 20% economy, quicker construction, good finish on both sides of wall and more carpet area.

(5) Flyash-Stone Powder-Cement Bricks

This type of bricks are manufactured by mixing weighted flyash, cement and stone powder in a mixture and moulded and pressed in brick making machine. The compacted bricks are water-cured for 28 days. The compressive strength of these bricks varies from 70 to 110 bar depending upon the cement content.

Recently CFRI-Dhanbad has developed a process to manufacture bricks using dry-flyash. This process is chemically bounded. The brick material contains 83% fly-ash, 10% sand, 7% lime stone and 0.2% accelerator. The mixture of the above constituents is subjected to formation as per required shape in the mould and then naturally cured for 2 to 3 days. Then these bricks are steam cured at 2 to 5 bar pressure for giving the strength. The brick can bear 125 bar compressive load.

The Govt. of Maharashtra has entered in contract with a British firm Derk European Holding to prepare cement like binding material in Aug. 2000. This project is going to start at Nasik and company will be able to produce the product from Dec. 2000 titled as Pozocret.

This project will produce 1000 tons/hr initally and Electricity Board of Maharashtra will get Rs. 30/ton of flyash which will yield Rs. 90 lacs to the Board. Presently, 70,000 tons of coal is used and 21000 tons of ash is produced per day in Maharashtra from Thermal Power Plants only.

The metals such as Al, Fe, Si and titanium can be recovered from the ash. An average class flyash contains 44% Silica (SiO_2), 21% alumina (Al_2O_3) and 17% ferric oxide (Fe_2O_3). Most of the iron oxide is not chemically bounded and can be separated magnetically. One plant in operation today that removes magnetite from flyash is at Hatfield Ferry Power Plant in Greensburg. But only laboratory scale processes have been operated to separate the other minerals.

EXERCISES

9.1. Why ash and dust handing problem is more difficult than coal handling problems ?

9.2. How the ash produced carries the importance in the selection of thermal power plant site ?

9.3. What are the different ash handling systems ? Discuss the relative merits and demerits.

9.4. Draw a line diagram of hydraulic ash handling system used for modern capacity power plant. Discuss its merits with other systems.

9.5. Draw a line diagram of pneumatic ash handling system. Explain the difficulties encountered in its design and operation. When this system is preferred over other system ?

9.6. How dust collection system differs from ash collection ? Why it is more serious in case of pulverised coal-fired boilers ?

9.7. What do you understand by wet type mechanical dust collector ? Explain with the neat diagrams the working of different types of wet type mechanical dust collectors. When such type of collector is preferred and why ?

9.8. Explain the working of electrostatic precipitator with a neat diagram and list out its outstanding features over other collectors.

9.9. In modern thermal plants, mechanical collector with electrostatic precipitator is preferred over single unit. Why ?

9.10. What do you understand by the term 'performance of a dust collector'.

Explain the effect on the following variables on the performance of electrostatic precipitator giving necessary causes :

(*a*) The load of the plant.

(*b*) Voltage supplied to the collector.

(*c*) Size of the particles.

9.11. In most of the cases, the electrostatic precipitator is installed to the cold side. Why ?

9.12. Electrostatic precipitator works better with high percentage sulphur coal when installed to cold side, but it is necessary to install to hot side for its better performance when used with coal of low sulphur content. Justify your answer for the above statement ?
Why hot side installation is more perferable and economical in India ?

9.13. What factors are considered in evaluating the performance of electrostatic precipitator ?
Why this collector does not operate efficiently with power plants using low sulphur coal ?

9.14. What do you understand by flue gas conditioning ? When it is used and why ?

9.15. What are the different methods used for flue gas conditioning ? Describe one which is commonly used giving its advantages over the other systems.

9.16. Discuss the advantages and disadvantages of electrostatic precipitator and scrubber when it is to be used in power plant (*a*) using coal of high ash content and high sulphur (*b*) high ash content and low sulphur (*c*) low ash content and low sulphur.
Give an example of each type from Indian power plant specifying the reasons.

9.17. When combined operation of the different collectors is preferred, why ?
Under what circumstances (1) combination of electrostatic precipitator, with scrubber is preferred ? (2) a combination of cyclone with electrostatic precipitator is preferred ?

9.18. Specify the type of flue gas cleaning method for the following type of power generating systems giving specific reason :

1. Power plant using high sulphur coal and negligible ash.
2. Power plant using high ash coal with negligible sulphur.
3. Power plant using high ash and high sulphur coal.
4. Power plant using low ash and low sulphur coal.
5. Power plant using low ash and high sulphur coal but (*a*) the load is fluctuating (*b*) the load is stationary.
6. Power plant using low ash low sulphur coal but (*a*) the load is fluctuating (*b*) the load is stationary.

9.19. Why wet scrubbers are generally preferred with oil-fired power stations even if the sulphur content in oil is considerably high ?
What is the difficulty in using an electrostatic precipitator ?

9.20. What are the advantages of spary type scrubber over packed type scrubber ? When packed type is more preferable over spary type ?

□□□

10
Scrubber Technology

10.1. INTRODUCTION

Coal is re-emerging as the dominant fuel for power generation for the intermediate term (15-20 years). Use of coal today requires emission control devices different from those used in the last era of coal dominance. The main objectionable emission among all is SO_2 which is highly injurious to human, animal and agricultural life. The present strict restrictions on emissions by the Government have forced this industry to remove SO_2 from exhaust gases to a permissible level. The flue gas desulfarization (FGD) has become the basic necessity of the power plant as most of the inferior coal available for power generation throughout the world contains 3 to 4% sulphur. The equipment used for removing SO_2 is known as scrubber, a major equipment feature of coal-fired power plant design and construction.

Sulphur in coal cannot be destroyed, it can only be converted to one form or other. The technology of FGD is therefore one of conversion. The technology used is generally split according to the type of end product generated, rather than by the exact chemical route used. This technology is generally classified as *Non-Regenerable* or throwaway process which produces sulphate salts which are worthless and discharged and *Regenerable process* which produces sulphur or H_2SO_4 from the collected material.

The throwaway system has been developed and most widely used type today. As per 1978 estimates, nearly 94% of the total generation used this type of scrubbing system for an effective removal of SO_2. The basic attraction is the requirement of simple equipment, easy pH control and cheap raw materials used makes this system most popular and economic among all the presently available techniques. Therefore, this chapter will deal with this type of system in more detail and other systems will be just introduced as they are not yet used on commercial basis.

Fundamentally, all flue gas desulfurization processes rely upon absorption or adsorption. Absorption is the transfer of a substance, such as SO_2 from a mixture of gases into a liquid with which, the gas phase is brought into intimate contact. This phenomenon is the one on which most of the today's FGD technology is used. Adsorption is the adhesion of very thin film of substance on another substance with which it is contacted. The capture of SO_2 by activated carbon is an example of this process which is rarely used for SO_2 removal from flue gases.

The common methods which are used are of absorption type. The materials used for absorption include lime, lime-stone, MgO, duel alkali and carbonates. All these materials are dissolved in water and then they are sprayed in a box like tower where the flue gases enter. By making the intimate contact of both, the efficiency of absorption is increased. The absorption capacity depends upon the surface of absorption exposed to flue gases, relative velocity of two and recidance time and many others. This process is made more effective if a material with which SO_2 can react chemically is present in the phase into which it is transferred. If alkali is present in water with which the flue gas is contacted, the absorption of SO_2 is greatly enhanced.

10.2. NON-GENERATIVE OR THROWAWAY SYSTEM (LIME OR LIME STONE ABSORPTION TYPE SCRUBBER)

Presently 95% scrubbers used in the power industry fall under this category as this technique and design are very well developed during last 20 years.

The concern of the designer of a utility, FGD system today is two-fold. He must design a system to satisfy all local emission levels ; while simultaneously meeting waste disposal requirements. In addition to this, he must also find ways to minimise the energy requirements of an essentially this non-productive process.

The basic closed-loop scrubber system commonly used is shown in Fig. 10.1. Flue gas, after fly ash has been removed in electrostatic precipitator, enters the bottom of the absorber and exists at the top. A water slurry of an alkali reagent, such as lime stone, is sprayed down against the gas through a series of nozzles. This slurry falls to bottom, absorbing SO_2 as it travels down. It drains out of the bottom of the tower into, a reaction tank to complete the conversion to calcium sulphate ($CaSO_4$) popularly known as gypsum and then recycled back to the nozzles for another pass.

Some type of packing is often built into the tower to improve the gas-liquid contacting. This could be either a mobile packing, such as plastic balls or glass marbles or a fixed packing, such as plastic punch plates.

The flue gas coming out of absorber after removing SO_2, the gas is reheated in order to protect the booster fans, provide added buoyancy to the plume and increase visibility. The reheating is generally achieved with an extraction steam. Soot-blowers are also provided to keep the heat exchangers clean.

Limestone slurry is supplied from a storage and grinding facility. Waste slurry is periodically blown down from each absorber, concentrated in thickeners and then pumped to a pond–an ultimate disposal area. Water is recovered and recycled back into the system at several locations as shown in figure 10.1. Some make-up water is always required to overcome the losses in the system. The scrubbing system includes reagent preparation, water treatment and waste disposal.

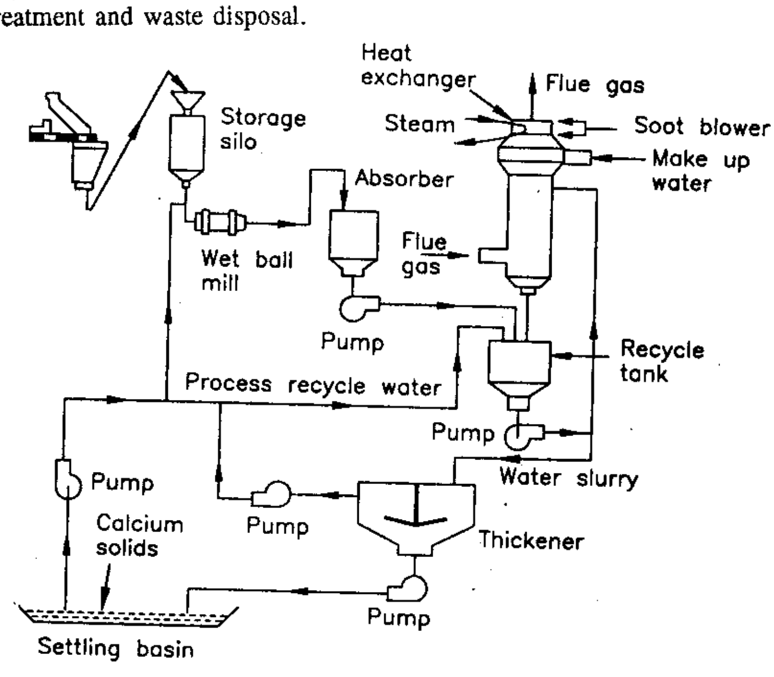

Fig. 10.1. Schematic diagram for closed loop operation.

Lime-stone ($CaCO_2$) is not as reactive as lime (CaO) and a higher stoichiometric (mole ratio of $CaCO_3$: SO_2) addition is necessary which affects solid disposal problem as well as raw materical costs. Even though lime-stone is favoured because of its relative simplicity and major development work has been done with lime-stone.

The degree of SO_2 removal which can be achieved with lime-stone is limited by the cost of stages, spraying rates, fineness of limestone grind, gas side pressure drop and slurry retention time, both in the scrubber and holding tanks.