1.7 LAYOUT AND EQUIPMENT OF ASH HANDLING SYSTEM

Boilers burning pulverized coal (PC) have dry bottom furnaces. The large ash particles are collected under the furnace in a water-filled ash hopper. Fly ash is collected in dust collectors with either an electrostatic precipitator or a bag house. A PC boiler generates approximately 80% fly ash and 20% bottom ash. Ash must be collected and transported from various points of the plants as shown in Fig.1.7.1. Pyrites, which are the rejects from the pulverizers, are disposed with the bottom ash systems. Three major factors should be considered for ash disposal systems.

1. Plant site
2. Fuel source
3. Environmental regulation

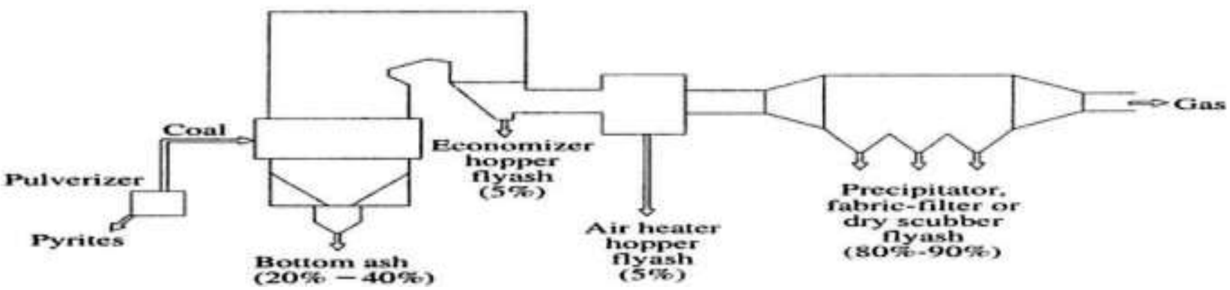
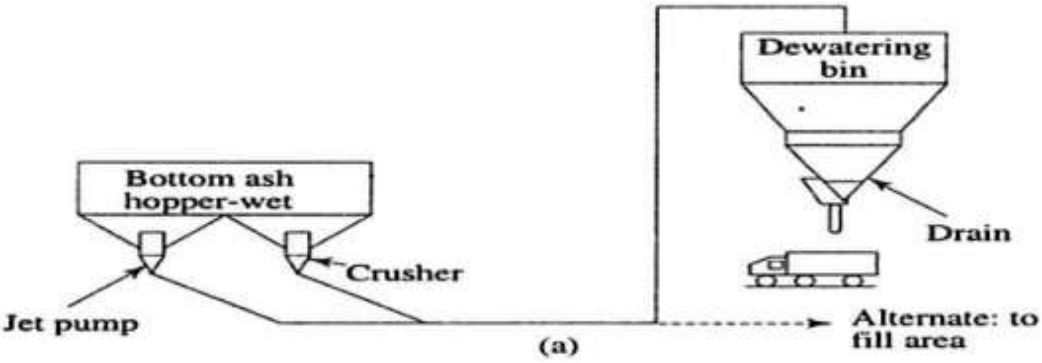


Figure 1.7.1 Ash collection and Transportation
[Source: "power plant Engineering" by Anup Goel ,Laxmikant D.jathar,Siddu :47]

The sluice conveyor system It is the most widely used for bottom ash handling, while the hydraulic vacuum conveyor it is the most frequently used for fly ash systems.



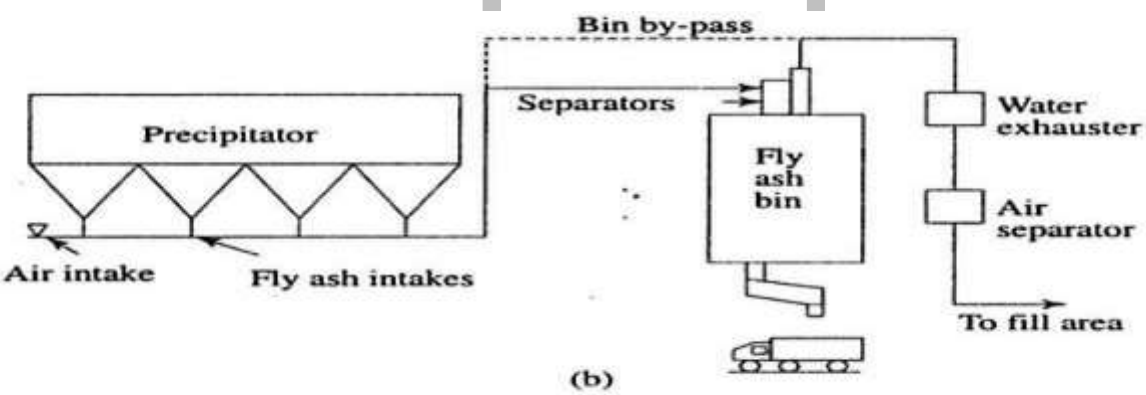


Figure 1.7.2 fly ash hydraulic vacuum conveyor

[Source: "power plant Engineering" by Anup Goel ,Laxmikant D.jathar,Siddu :38]

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

1.10 BINARY CYCLES AND COGENERATION SYSTEMS

No single fluid can meet all the requirements as mentioned above. Although in the overall evaluation water is better than any other working fluid, at high temperatures, however, there are a few better fluids and notable among them are:

(a) Diphenyl ether $(C_6H_5)_2O$

(b) Aluminium bromide $AlBr_3$

(c) Liquid metals like mercury, sodium, potassium and so on. Among these only mercury has actually been used in practice.

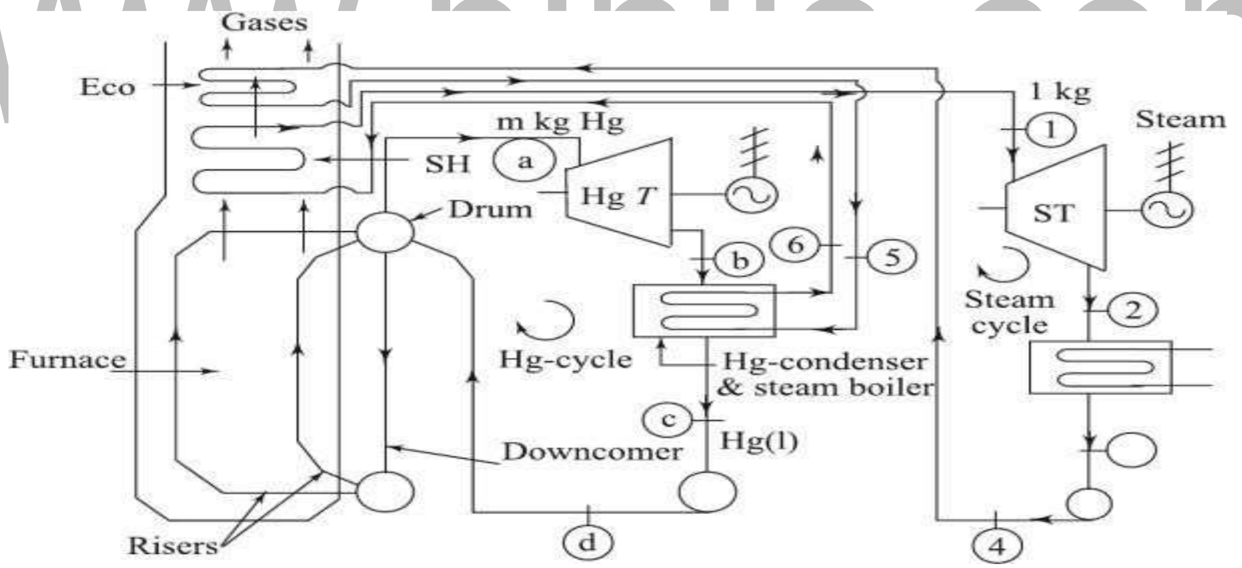


Figure 1.10.1 Mercury-steam Binary cycle

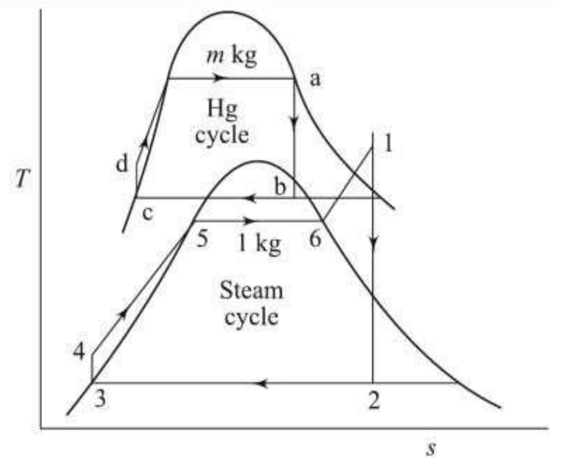
[Source: "power plant Engineering" by Anup Goel ,Laxmikant D.jathar,Siddu :11]

Diphenyl ether could be considered but it has not yet been used because like most organic substances, it decomposes gradually at high temperatures. Aluminium bromide is a possibility and yet to be considered.

As at pressure of 12 bar, the saturation temperatures for water, aluminium bromide and mercury are 187˚C,482.5˚C and 560˚C, its vaporization pressure is relatively low. Its critical pressure and temperature are 1080 bar and 1460˚C respectively.

But in the low temperature range, mercury is unsuitable because its saturation pressure becomes exceedingly low, and it would be impractical to maintain such a high vacuum in the condenser.

At 30˚C the sayturation pressure of mercury is only $2.7x10^{-4}$cm Hg. Its specific volume at such a low pressure is very large, and it would be difficult to accommodate such a large volume flow.



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T-S diagram of mercury-steam binary cycle

For this reason, to make advantage o f the beneficial features of mercury in the high temperature range and to get rid of its deleterious effects in the low temperature range, mercury vapour leaving the mercury turbine is condensed at a higher temperature and pressure, and the heat released during the condensation of mercury is utilized in evaporating water to form steam to operate on a conventional turbine.

Thus, in the binary (or two fluid) cycle, two cycles with different working fluids are coupled in series, the heat rejected by on being utilized in the other.

The flow diagram of mercury-steam binary cycle and the corresponding T-S diagram are given in Fig.32&33 respectively.

The mercury cycle a-b-c-d is a simple rankine cycle saturated vapour. The heat rejected by mercury during condensation (process b-c) is transferred to boil water and form saturated vapour (process 5-6).

The saturated vapour is heated from the external source (furnace) in the super heater(process 6-1). Super heated steam expands in the turbine and is then condensed. The condensate is then pumped to the economizer where it is heated till it becomes saturated liquid by the outgoing flue gases (process4-5).

The saturated liquid then goes to the mercury condenser-steam boiler , where the latent heat is absorbed. In an actual plant, the steam cycle is always a regenerative cycle with feed water heating, but for the sake of simplicity, this complication has been omitted.

Let m represent the flow rate of mercury in the mercury cycle per kg of steam circulating in the steam cycle. Then , for 1 kg of steam,

$Q_1 = m(h_a-h_d)+(h_1-h_6)+(h_5-h_4)$

$Q_2 = h_2-h_3$ ....-(1)

$W_T = m(h_a-h_b)+(h_1-h_2)$

$W_P = m(h_d-h_c)+(h_4-h_3)$

$$\eta_{cycle} = \frac{Q_1 - Q_2}{Q_1} = \frac{W_T - W_P}{Q_1} \text{ and}$$

$$\text{steam rate (SSC)} = \frac{3600}{W_T - W_P} \text{ Kg/kWh}$$

COGENERATION SYSTEMS

There are several industries such as paper mills, textile mills, chemical factories, jute mills, sugar factories, rice mills and so on where saturated steam at the desired temperature is required for heating, drying etc.

For constant temperature heating (or drying), steam is a very good medium since isothermal condition can be maintained by allowing saturated steam to condensate at that temperature and utilizing the latent heat released for heating purposes.

Apart from the process heat, the factory also needs power to drive various machines, for lighting and other purpose.

Earlier, steam of power purposes was generated at a moderate pressure and saturated steam of process work was generated separately at a pressure which gave the desired heating temperature.

Having two separate units for process heat and power is wasteful, for the total heat supplied to the steam generator for power purposes, a greater part will normally be carried away by the cooling water in the condenser.

Back pressure Turbine

By modifying the initial steam pressure and exhaust pressure, it is possible to generate the required power and make available the required quantity of exhaust steam at the desired temperature for process work.

In Fig.34, the exhaust steam from the turbine is utilized for process heating, the process heater replacing the condenser of the ordinary rankine cycle.

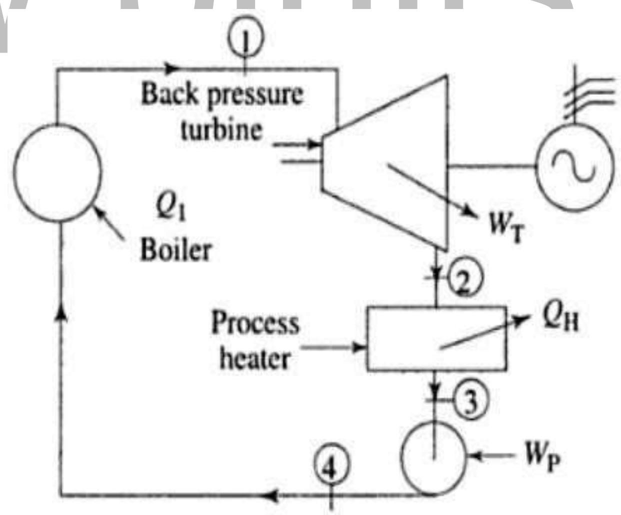


Figure 1.10.2 Cogeneration plant

[Source: "power plant Engineering" by Anup Goel ,Laxmikant D.jathar,Siddu :11]

The pressure at exhaust form the turbine is the saturation pressure corresponding to the temperature desired in the process heater such a turbine is called a back pressure turbine.

A plant producing both electrical power and process heat simultaneously is called a **cogeneration plant**.

When the process steam is the basic need, and the power is produced incidentally as a by- produce the cycle is often called a byproduct power cycle.

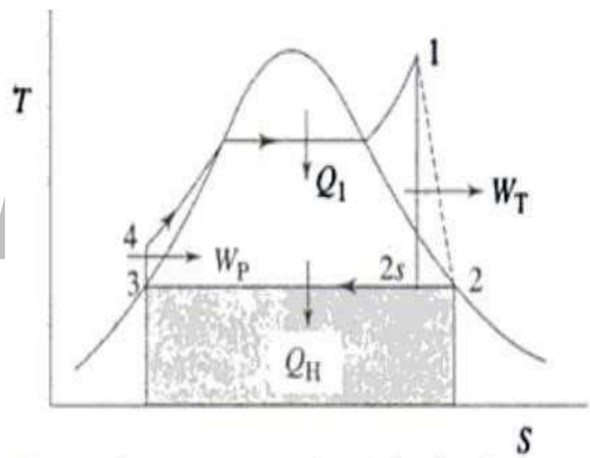


Figure 1.8.1 power cycle with a back pressure turbine

[Source: "power plant Engineering" by Anup Goel ,Laxmikant D.jathar,Siddu :12]

Figure shows the T-S plot for such a cycle. If W_T is the turbine output in kW, Q_H is the process heat required in kJ/h, and w_s are the steam flow rate in kg/h.

$$\times 3600 = (h_1 - h_2)$$

$$Q_H = (h_2 - h_3)$$

$$W_T \times 3600 = \frac{Q_H}{h_2 - h_3}(h_1 - h_2$$

$$Q_H = \frac{W_T \times 3600 \times (h_2 - h_1)}{(h_1 - h_2)} \frac{KJ}{h} \ldots\ldots\ldots\ldots (1)$$

Total energy input Q_1 (as heat) to the co-generation plant, W_T part of it only is converted into shaft work or electricity.

The remaining energy (Q_1-W_T), which would otherwise have been a waste, as in the rankine cycle, by second law, it is utilized as process heat.

The co-generation plant efficiency η_{co} is

$$\eta_{co} = \frac{W_T + Q_H}{Q_1} \ldots\ldots\ldots (2)$$

1.6 FUEL HANDLING SYSTEM (COAL HANDLING)

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

Coal Delivery

The coal from supply points is delivered by ships or boats to power stations situated near to sea or river whereas coal is supplied by rail or trucks to the power stations which are situated away from sea or river.

Unloading

The type of equipment to be used for unloading the coal received at the power station depends on how coal is received at the power station. If coal is delivered by trucks, there is no need of unloading device as the trucks may dump the coal to the outdoor storage. Coal is easily handled if the lift trucks with scoop are used.

In case the coal is brought by railway wagons, ships or boats, the unloading may be done by car shakes, rotary car dumpers, cranes, grab buckets and coal accelerators. Rotary car dumpers although costly are quite efficient for unloading closed wagons.

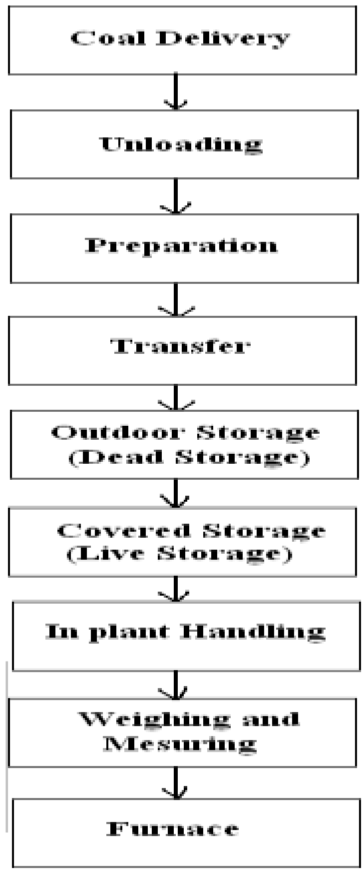


Figure 1.6.1 Steps in coal Handling

[Source: "power plant Engineering" by Anup Goel ,Laxmikant D.jathar,Siddu :38]

3. Preparation

When the coal delivered is in the form of big lumps and it is not of proper size, the preparation (sizing) of coal can be achieved by crushers, breakers, sizers driers and magnetic separators.

Figure 1.6.1 Steps in coal Handling

[Source: "power plant Engineering" by Anup Goel ,Laxmikant D.jathar,Siddu :38]

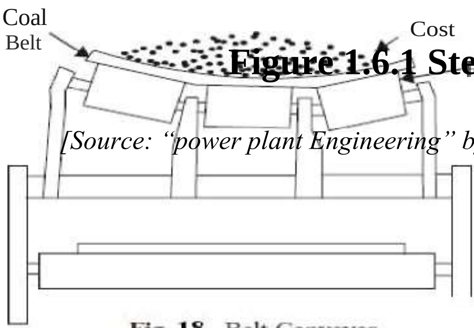


Fig. 18 . Belt Conveyor.

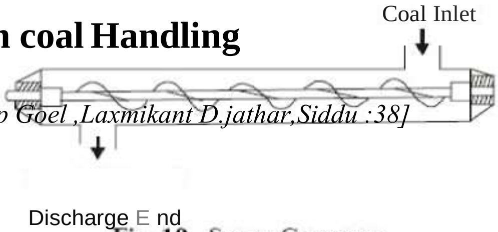


Fig. 19 Screw Conveyor.

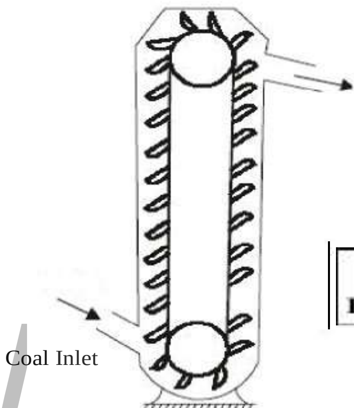
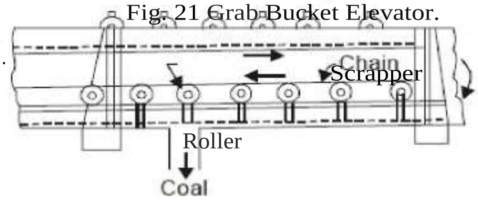
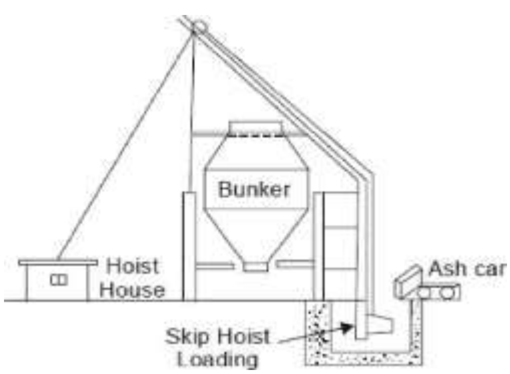


Fig. 21 Grab Bucket Elevator.



F . 20 bucket Els



rig. 22 Skip Hoist.

Fig. 23 Flight Conveyor.

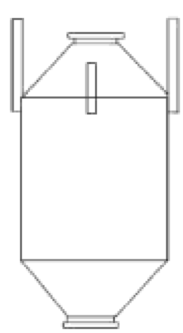


Fig. 2 4 Cyliuclricul Bucket

1. Transfer

After preparation of coal is transferred to the dead storage by means of the following systems:

(a) Belt conveyors

(b) Screw conveyors

(c) Bucket elevators

(d) Grab bucket elevators

(e) Skip hoists

(f) Flight conveyor

Belt conveyor

Figure shows a belt conveyor. It consists of an endless belt moving over a pair of end drums (rollers). At some distance a supporting roller is provided at the center.

The belt is made up of rubber or canvas. Belt conveyor is suitable for the transfer of coal over long distances. It is used in medium and large power plants. The initial cost of the system is not high and power consumption is also low.

The inclination at which coal can be successfully elevated by belt conveyor is about 20. Average speed of belt conveyor varies between 200-300 rpm. This conveyor is preferred than other types.

Advantages of belt conveyor:

(1) Its operation is smooth and clean

(2) It requires less power as compared to other types of systems.

(3) Large quantities of coal can be discharged quickly and continuously.

(4) Material can be transported on moderate inclines

Screw Conveyor

It consists of an endless helicoids screw fitted to a shaft The screw while rotating in a trough transfers the coal from feeding end to the discharge end.

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

Bucket elevator

It consists of buckets fixed to a chain figure. The chain moves over two wheels.The coal discharged at the top.

Grab bucket elevator

It lifts and transfers coal on a single rail or track from one point to the other. The coal lifted by grab buckets is transferred to overhead bunker or storage. This system requires less power for operation and requires minimum maintenance.The grab bucket conveyor can be used with crane or tower as shown in Figure although the initial cost of this system is high but operating cost is less.

Skip hoist

It consists of a vertical or inclined hoist way a bucket or a car guided by a frame and cable for hoisting the bucket. It is simple and compact method of elevating coal or ash Figure shows a skip hoist.

Flight Conveyor

It consists of one or two strands of chain to which steel scrapes or flights are attached, which scrap the coal through a trough having identical shape. This coal is discharged in the bottom of trough. It is low in first cost but has large energy consumption. There is considerable water.

Skip hoist and bucket elevators lift the coal vertically while belts and flight conveyors move the coal horizontally or on inclines.figure shows a flight conveyor. Flight conveyors posses the following

Advantages

(i) They can be used to transfer coal as well as ash.

(ii) The speed of conveyor can be regulated easily.

(iii) They have a rugged construction

(iv) They need little operational care.

Disadvantages:

(i) There is more wear due to dragging action.

(ii) Power consumption is more

(iii) Maintenance cost is high

(iv) Due to abrasive nature of material handle the speed of conveyors is low (10 to 30m/min).

Storage of coal

It is desirable that sufficient quantity of coal should be stored. Storage of coal gives protection against the interruption of coal supplies when there is delay in transportation of coal or due to strikes in coal mines.

Also when the prices are low, the coal can be purchased and stored for future use. The amount of coal to be stored depends on the availability of space for storage, transportation facilities, the amount of coal that will whether away and nearness to coal mines of the power station. Usually coal required for month operation of power plant is stored in case of power stations situated at longer distance from the collieries whereas coal need for about 15 days is stored in case of power station situated near to collieries. Storage of coal for longer periods is not advantageous because it blocks the capital and results in deterioration of the quality of coal.

The coal received at the power station is stored in dead storage in the form of piles laid directly on the ground. The coal stored has the tendency to whether (to combine with oxygen of air) and during this process coal has some of its heating value and ignition quality

Due to low oxidization the coal may ignite spontaneously. This is avoided by storing coal in the form of piles which consists of thick and compact layers of coal so that air cannot pass through the coal piles. This will minimize the reaction between coal and oxygen.

The other alternative is to allow the air to pass through layers of coal so that air may remove the heat of reaction and avoid burning. In case the outer coal is to be stored for longer periods the outer surface of piles may be sealed with asphalt or fine coal.

The coal is stored by the following methods.

Stocking the coal in heats

The coal is piled on the ground up to 10-12m height. The pile top should be given a slope in the direction in which the rain may be drained off.

The sealing of stored pile is desirable in order to avoid the oxidation of coal after packing an air tight layer of coal.Asphalt, fine coal dust and bituminuous coating are the materials commonly used for this purpose.

Under water storage

The possibility of slow oxidation and spontaneous combustion can be completely eliminated by storing the coal under water.Coal should be stored at a site located on solid ground, well drained, free of standing water preferably on high ground not subjected to flooding

In plant Handling

From the dead storage the coal is brought to covered storage (live storage)(bins or bunkers). A cylindrical bunker shown in Figure In plant handling may include the equipment such as belt conveyors, screw conveyors, bucket elevators etc., to transfer the coal. Weigh lorries hoppers and automatic scales are used to record the quantity of coal delivered to the furnace.

Coal weighing methods

Weigh lorries, hoppers and automatic scales are used to weigh the quantity of coal. The commonly used methods to weigh the coal are as follows:

(i) Mechanical (ii) Pneumatic (iii) Electronics

The mechanical method works on a suitable lever system mounted on knife edges and bearing connected to a resistance in the form of a spring of pendulum.

The pneumatic weighters use a pneumatic transmitted weight head and the corresponding air pressure determined by the load applied.The electronic weighing machines make use of load cells that produce voltage signals proportional to the load applied.

The important factors considered in selecting fuel handling surface systems are as follows:

(i) Plant flue rate

(ii) Plant location in respect to fuel shipping

(iii) Storage area available

1.8 NATURAL DRAUGHT WITH ADVANTAGES AND DISADVANTAGES

APPLICATIONS IN NATURAL DRAUGHT:

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

Where H- Height of the Chimney (m)

pa –Atmospheric pressure (N/m^2)

p1 –Pressure acting on the grate from chimney side (N/m^2)

p2 –Pressure acting on the grate from atmospheric (N/m^2)

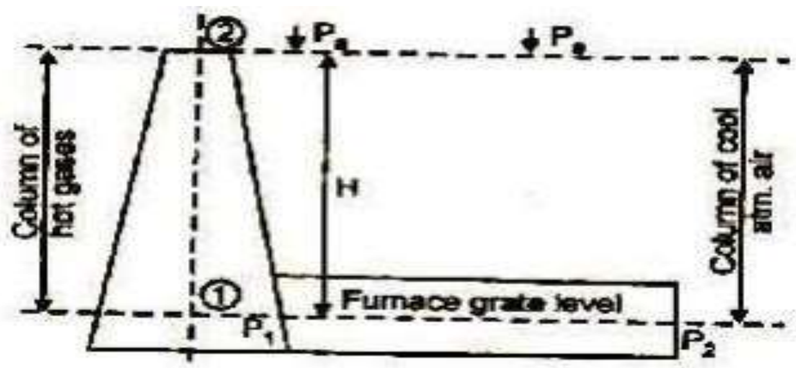


Figure: Natural draught

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

Merits of Natural Draught

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

Demerits of natural draught

- . Maximum pressure available for producing draught by the chimney is less.
- Flue gases have to be discharged at high temperature since draught increases with the increase in temperature of flue gases.

Heat cannot be extracted from the flue gases for economizer, superheater, air pre-heater, etc. since the effective draught will be reduced if the temperature of the flue gases is decreased.

4. Overall efficiency of the plant is decreased since the fluid gases are discharged at higher temperatures.

6. Poor combustion and specific fuel consumption is increased since the low velocity of air affects thorough mixing of air and fuel.

7. Not flexible under peak loads since the draught available for a particular height

8. A considerable amount of heat released by the fuel (about 20%) is lost due to

Applications

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

A) FORCED DRAUGHT B) INDUCED DRAUGHT C) BALANCED DRAUGHT

ARTIFICIAL DRAUGHT

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

A chimney of an reasonable height would be incapable of developing enough draft to remove the tremendous volume of air and gases (400×10^3 m^3 to 800×10^3 m^3 per minutes). The further advantage of fans is to reduce the height of the chimney needed.

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

Forced Draught

In a forced draught system, a blower is installed near the base of the boiler and air is forced to pass through the furnace, flues, economizer, air-preheater and to the stack. This draught system is known as positive draught system or forced draught system because the pressure and air is forced to flow through the system.

The arrangement of the system is shown in figure. A stack or chimney is also in this system as shown in figure but its function is to discharge gases high in the atmosphere to prevent the contamination. It is not much significant for producing draught therefore height of the chimney may not be very much.

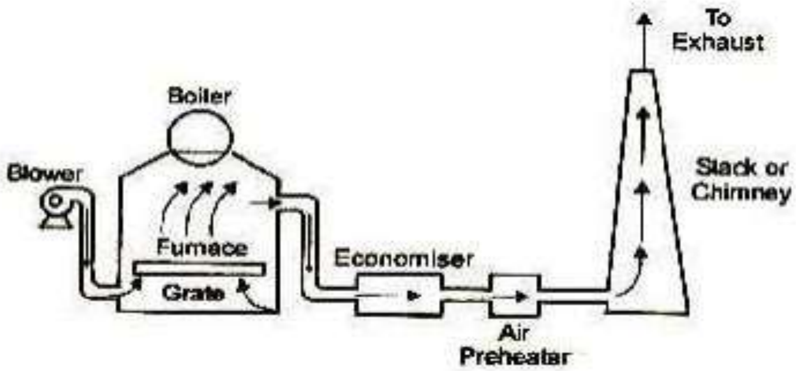


Figure: Forced draught

Figure: Forced draught

Figure 1.8.2 Forced Draught

[Source: "power plant Engineering" by Anup Goel ,Laxmikant D.jathar,Siddu :57]

Induced Draught:

In this system, the blower is located near the base of the chimney instead of near the grate. The air is sucked in the system by reducing the pressure through the system below atmosphere. The induced draught fan sucks the burned gases from the furnace and the pressure inside the furnace is reduced below atmosphere and induces the atmospheric air to flow through the furnace. The action of the induced draught is similar to the action of the chimney.

The draught produced is independent of the temperature of the hot gases therefore the gases may be much heat as possible in air-preheater and an izer and air-preheater are incorporated in the hat the temperature of the gas handled by the em and its function is similar as mentioned in forced draught but total draught produced in induced draught system is the sum of the draughts produced by the fan and chimney.

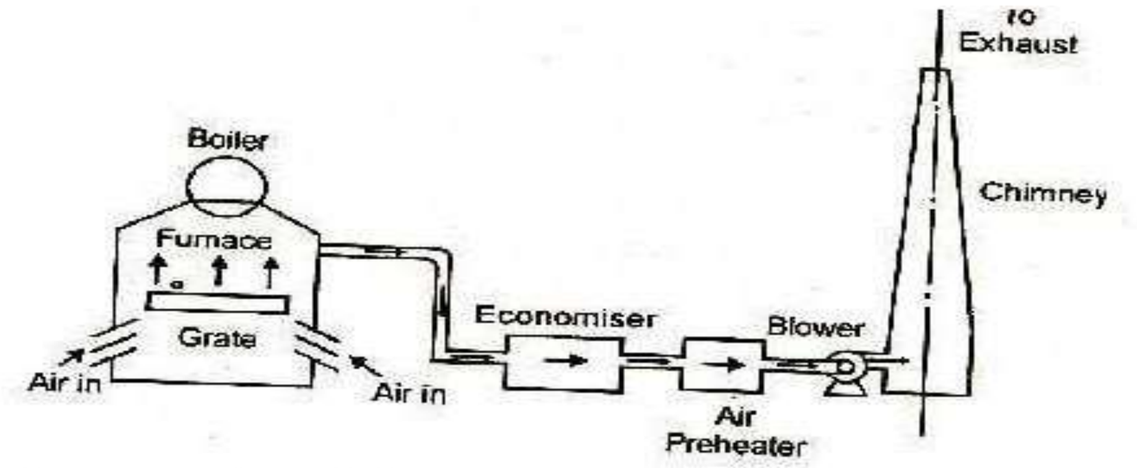


Figure: Induced draught

Figure 1.8.3 Induced Draught

[Source: "power plant Engineering" by Anup Goel ,Laxmikant D.jathar,Siddu :57]

Balanced Draught:

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

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

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

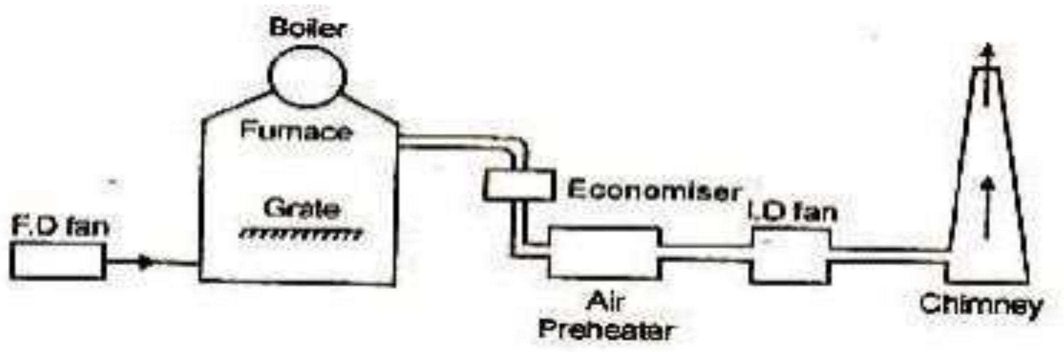


Figure 1.8.4 Natural Draught

[Source: "power plant Engineering" by Anup Goel ,Laxmikant D.jathar,Siddu :57]

To overcome both the difficulties mentioned above either using forced draught or induced draught alone, a balanced draught is always preferred.

The balanced draught is a combination of forced and induced draught. The forced draught overcomes the resistance of the fuel bed therefore sufficient air is supplied to the fuel bed for proper and complete combustion. The induced draught fan removes the gases from the furnace maintaining the pressure in the furnace just below atmosphere. This helps to prevent the blow –off of flames when the doors are opened as the leakage of air is inwards.

1.4 FLUIDIZED BED COMBUSTION BOILERS

Fluidized bed boilers produce steam from fossil and waster fuels by using a technique called fluidized bed combustion. These can be of two types:

1. Bubbling fluidized bed (BFB) boilers
2. Circulating fluidized bed (CFB) boilers

BUBBLING FLUIDIZED BED (BFB) BOILERS

In BFB boilers, crushed coal (6-20mm) is injected into the fluidized bed of limestone just above an air-distribution grid at the bottom of the bed

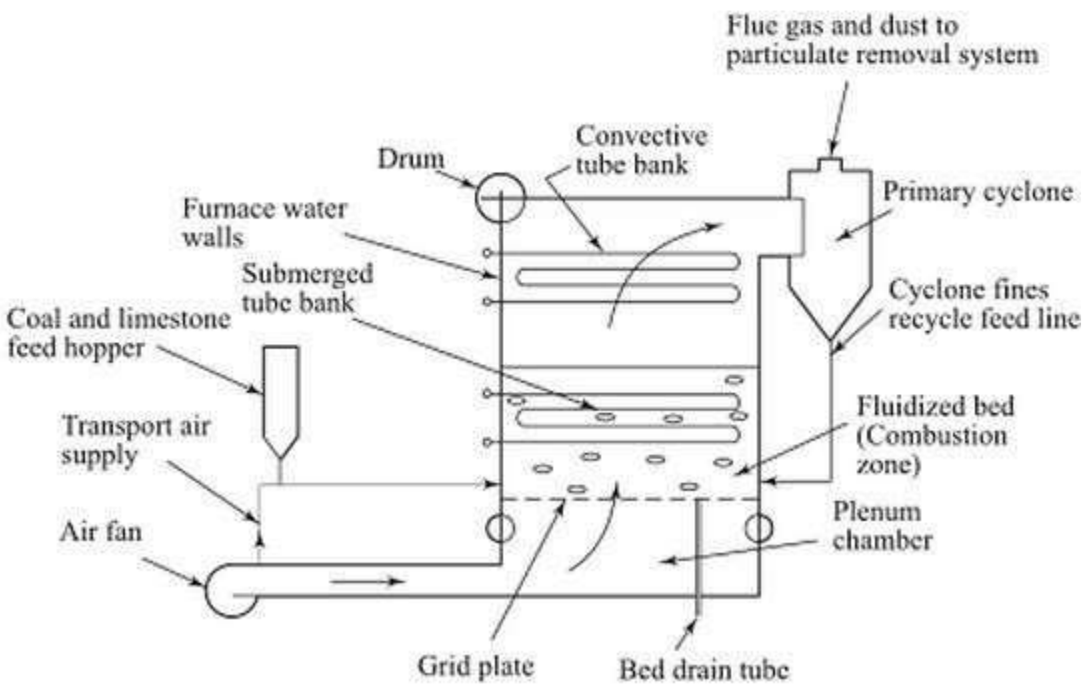


Figure 1.4.1 Bubbling FBC boiler system

[Source: "power plant Engineering" by by Anup Goel ,Laxmikant D.jathar,Siddu :3page:18]

The air flows upwards through the grid from the air plenum into the bed, where combustion of coal occurs. The products of combustion leaving the bed contain a large proportion of un burnt carbon particles which are collected in cyclone separator and fed back to the bed. The boiler water tubes are located in the furnace.

Since most of the sulphur in coal is retained in the bed by the material used (limestone), the gases can be cooled to a lower temperature before leaving the stack with less formation of acid (H_2SO_4). As a result of low combustion temperatures (800-900˚C), inferior gases of coal can be used without slagging problems and there is less formation of NO_x.

Cheaper alloy materials can be used, resulting in economy of construction. Further economies are achieved since no pulverizer is required. The volumetric heat release rates are 10 to 15 times higher and the surface heat transfer rates are 2 to 3 times higher than a conventional boiler. This makes the boiler make compact.

Figure shows a bubbling bed boiler system operating at atmospheric pressure, similar to the one of 160 MWe Tennessee Valley Authority (TVA) project at Shawnee, USA, recently installed (1993).

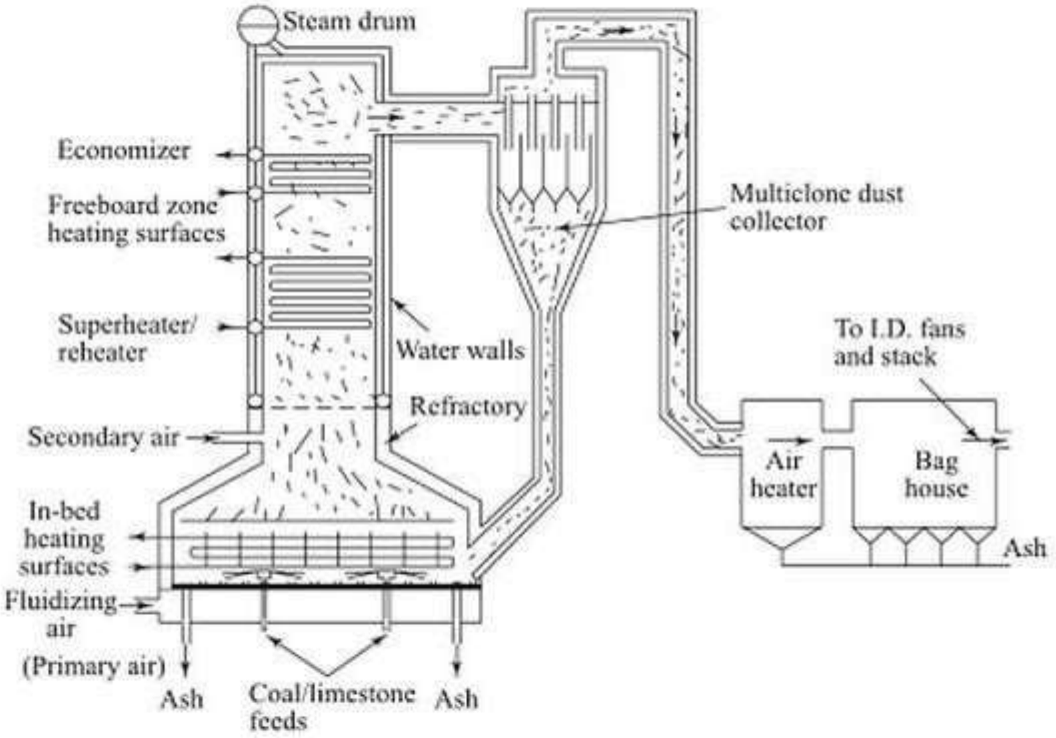


Figure 1.4.2 Atmospheric bubbling FBC boiler system

[Source: "power plant Engineering" by by Anup Goel ,Laxmikant D.jathar,Siddu :3page:19]

CIRCULATING FLUIDIZED BED (CFB) BOILERS

The CFB boiler is said to be the second generation fluidized bed boiler Figure. It is divided into two sections. The first section consists of

(a) Furnace or fast fluidized bed

(b) Gas-solid separator (cyclone)

(c) Solid recycle device (loop seal or L-value)

(d) External heat exchanger

These components from a solid circulation loop in which fuel is burned. The furnace enclosure of a CFB boiler is generally made of water tubes as in pulverized coal fired (PC)boilers. A fraction of the generated heat is absorbed by these heat transferring tubes. The second section is

Schematic of a circulating fluidized bed boiler

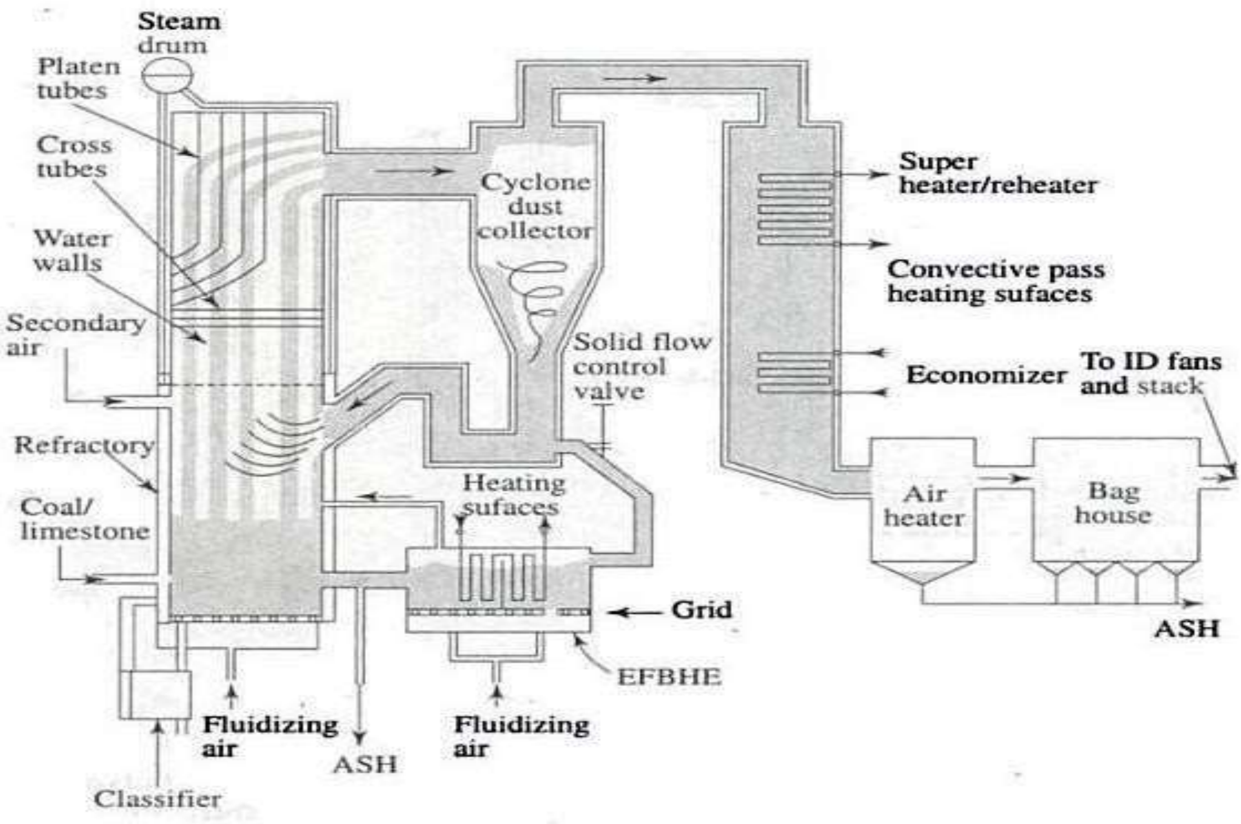


Figure 1.4.3 Circulating FBC boiler system

[Source: "power plant Engineering" by by Anup Goel ,Laxmikant D.jathar,Siddu :3page:19]

the back-pass, where the remaining heat from the glue gas is absorbed by the reheater, , economizer and air preheater surfaces (as in a conventional boiler)

The lower part o f the first section (furnace) is often tapered. Its walls are lined with refractory up to the level of secondary air entry. Beyond this the furnace walls are generally cooled by evaporative, superheater, or reheater surfaces. The gas-solid separator and the non- mechanical valve are also lined with refractory. In some designs, a part of hot solids recycling between the cyclone and the furnace is diverted through an external heat exchanger, which is a bubbling fluidized bed with heat transfer surfaces immersed in it to remove heat from the hot solids.

Coal is generally injected into the lower section of the furnace. It is sometimes fed into the loop-seal, from which it enters the furnace along with returned solids. Limestone is fed into the bed in a similar manner. Coal burns when mixed with hot bed solids.

The primary combustion air enters the furnace through an air distributor or grate at the furnace floor. The secondary air is injected at some height above the grate to complete the combustion. Bed solids are well mixed throughout the height of the furnace. Thus, the bed temperature is nearly uniform in the range 800-900˚C, though heat is extracted along its height.

Relatively coarse particles of sorbent (limestone) and unburned char, larger than the cyclone cut-off size, are captured in the cyclone and are recycled back near the base of the furnace. Finer solid residues (ash and spent sorbents) generated during combustion and desulphurization leave the furnace, escaping through the cyclones, but they are collected by a bag-house or electrostatic precipitator located further downstream.

1.9 FEEDWATER TREATMENT

Boiler make-up water to the extent of 1.5—2 percent of the total flow rate is required to replenish the losses of water through leakage from fittings and bearings, boiler blow down, escape with non-condensable gases in the deaerator, turbine glands, and other causes.

1. Prevention of hard scale formation on the heating surfaces
2. Elimination of corrosion
3. Control of carry-over to eliminate deposition on superheater tubes, and
4. Prevention of silica deposition and corrosion damage to turbine blades.

Raw water is, therefore, first pre-treated and then demineralized. For once through boilers and boiling water nuclear reactors, which require high water purity, a condensate polishing system is used to further polish the water. Raw water contains a variety of impurities, such as (a) Suspended solids and turbidity, (b) organics, (c) hardness (salts of calcium and magnesium), (d) alkalinity (bicarbonates, carbonates, and hydrates), (e) other dissolved ions (sodium, sulphate, chloride, etc.,), (f) silica and (g) dissolved gas(O_2, CO_2). The extent of pre- treatment depends on the source of raw water.

<u>External treatment</u>

The first step of pre-treatment of boiler feed water is clarification, in which the water is chlorinated to prevent biofouling of the equipment. The suspended solids and turbidity are coagulated by adding special chemicals (like aluminiumsulphate, $Al_2(SO_4)_3$) and agitated. The coagulated matter settles at the bottom of the clarifier and is removed.

If the turbidity of clarified effluent is high, positive filtration is needed. Both gravity filters and pressure-type filters are used, but the latter is preferred. A granular medium like sand is commonly used for filtration. The pressure difference across the filtering medium is an indication of solid accumulation. When it reaches a given limit,the solids are removed from the bed by backwashing. Further filtration by activated carbon can absorb organics and remove residual chlorine from the chlorination process.

The dissolved salts of calcium and magnesium give to water a quality called hardness. Hardness is characterized by the formation of insoluble precipitates or curds with soaps, and is usually measured with a standard soap test. All natural waters are hard and contain scale-forming impurities which are mainly the salts of calcium and magnesium in the form of carbonates, bicarbonates, chlorides and sulphates. The hardness is expressed in ppm of dissolved salts. Softening of water, i.e removal of hardness from water, can be done by lime-soda process, phosphates process, zeolite process and demineralization.

Lime—soda process

In lime—soda softening, calcium and magnesium salts are removed using lime (calcium hydroxide) and soda ash (sodium carbonate). When this process is carried out at normal raw-water temperature, it is called a "cold process" softening; and when carried out at or near the boiling point, it is referred to as a "hot process" softening. Since heating greatly accelerates the necessary reactions, the hot process is preferred for boiler water treatment, where most of the energy used in heating the water may be retained in the cycle. The representative reactions are given below:

$$Ca(HCO_3)_2+Ca(OH)_2 =2CaCO_3+2H_2O$$

$$MgCl_2+Ca(OH)_2=Mg(Oh)_2+CaCl_2$$

$$MgSO_4+Ca(OH)_2=Mg(OH)_2+CaSO_4$$

$$CaSO_4+Na_2CO_3=CaCO_3+Na_2SO_4$$

$$CaCl_2+Na_2CO_3=CaCO_3+2NaCl$$

The products, calcium carbonate and magnesium hydroxide are insoluble in water and settle to the bottom of the vessel. The softened effluent is then passed through sand or charcoal filters before usage.

Hot phosphate Softening

In the hot phosphate softening process, calcium and magnesium hardness is removed using phosphate and caustic soda, Tricalcium phosphate ($Ca_3(PO_4)_2$) and magnesium hydroxide are precipitated. The process is carried out at a temperature of 100˚C or above. Since the hot phosphate process requires more expensive chemicals than the lime—soda process, it is used where the initial water hardness is 60 ppm or less. Where hardness is greater than this, a lime soda process may be used first, followed by a phosphate clean-up. The representative reactions are given below:

$3Ca(HCO_3)_2+6NaOH=2CaCO_3+2Na_2CO_3+6H_2O$

$CaCO_3+2Na_3PO_4=Ca_3(PO_4)_2+2Na_2CO_3$

$g(HCO_3)_2+4NaOH=Mg(OH)_2+2Na_2CO_3+2H_2O$

$3CaSO_4+2Na_3PO_4=Ca_3(PO_4)_2+3Na_2SO_4$

Sodium Zeolite Softening

Water can be softened by passing it through a bed of sodium zeolite, which may be natural compounds of sodium aluminium silicate, with the cations of calcium and magnesium removed in the process.

$CaCO_3+Na_2A=CaZ+Na_2CO_3$

$MgSO_4+Na_2Z=MgZ+Na_2SO_4$

$Ca(HCO_3)_2+Na_2Z=CaZ+NaHCO_3)_2$

The softening capacity of the bed gets exhausted in course of time, and the bed can be regenerated by flushing it with brine (NaCl),

$CaZ+2NaCl=Na_2Z+Ca$

$MgZ+2NaCl=Na_2Z+MgCl_2$

Zeolite softening is not ideal for the following reasons: (i) Water of high or low pH have a deleterious effect on zeolites, (ii) high temperatures also have a bad effect,(iii) turbid waters coat the zeolite material, reducing its efficiency, (iv) there is no reduction in alkalinity or total solids, (v) there can be silica gain in water from the zeolite,(vi) with low content of calcium, the water can be corrosive, sodium zeolite softening in conjunction with the use of evaporating may be more effective.

Hydrogen Zeolite softening

When water containing calcium, magnesium and sodium ions is passed through a hydrogen zeolite, these ions are exchanged for hydrogen and the bicarbonate, sulphate, chloride and nitrate radicals are converted to their respective acids.

When the hydrogen zeolite becomes exhausted, it is backwashed and regenerated with acid. After being rinsed, it is ready for use again. Sulphuric acid is generally used for regeneration because of its relatively low cost.

$$MgZ+H_2SO_4=H_2Z+MgSO_4$$

$$CaZ+H_2SO_4=H_2Z+CaSO_4$$

Anion exchangers

Anion exchangers can remove the anions like chlorides, sulphates and nitrates (acid forms) present in hydrogen zeolite effluent by resinous materials which absorb them. Typical reactions are:

$$2HCl+RCO_3=RCl_2+H_2CO_3 \quad H_2SO_4+RCO_3=RSO_4+H_2CO_3$$

$$2HNO_3+RCO_3=R(NO_3)_2+H_2CO_3$$

Carbonic acid is removed by aeration. When the acidic water is sprayed in a shower to expose large surface area, the carbon dioxide gas is released.

$H_2CO_3 = CO_2 + H_2O$

When the anion exchanger is exhausted, it is regenerated by backwashing with soda ash

$RCl_2 + Na_2CO_3 = RCO_3 + 2NaCl$

$RSO_4 + Na_2CO_3 + RCO_3 + Na_2SO_4$

Demineralizing plant

The process of removing dissolved solids in water by ion exchange is called demineralization. Two types of resins, cation and anion, are used. The cation resin is the hydrogen zeolite where the hydrogen ion is exchanged for the cations calcium, magnesium and sodium, and the anion resin adsorbs the anions chlorides, nitrates and sulphates, as discussed above. Both ion-exchange processes are reversible, and the resins are restored to their original form by regeneration.

A typical Demineralizing plant consisting of a cation exchanger, an anion exchanger, a degasfier and a silica adsorber in series is shown in Fig.31. In the degasifier, carbon dioxide gas is removed by aeration. Silica in water is very detrimental at high pressure. It vaporizes at high pressure and flows with steam, condenses on turbine blades in the form of hard glassy scales which are difficult to remove. Magnesium hydroxide is often used to adsorb silica from water.

The membrane treatment for removing the total dissolved solids from make-up water is also an energy efficient process and is gradually gaining more acceptances. It uses the principle of either reverse osmosis or electro dialysis. The driving force for reverse osmosis is the application of counter pressure to normal osmotic pressure, driving water molecules through the membranes in preference to dissolved salts.

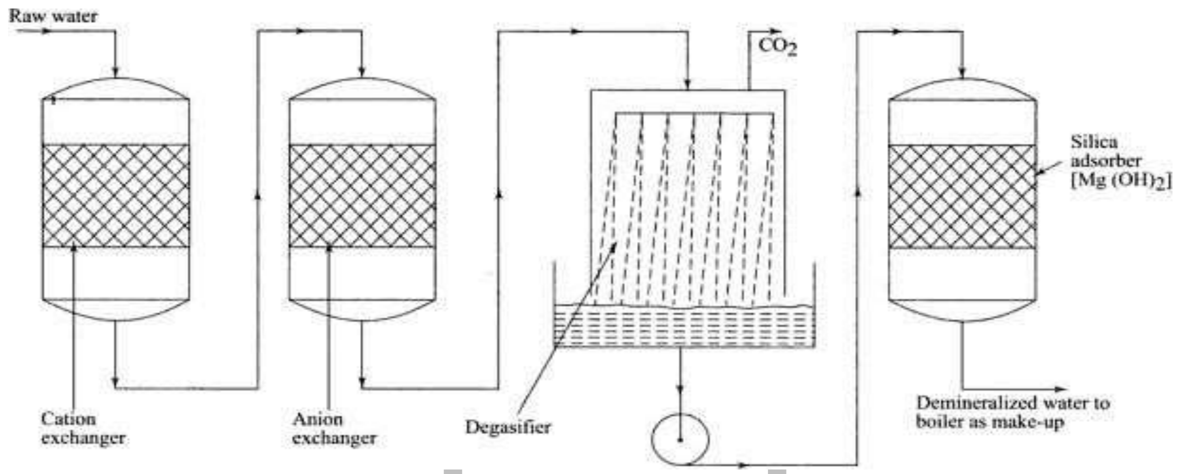


Figure 1.8.1 A typical Demineralizing plant

[Source: "power plant Engineering" by Anup Goel ,Laxmikant D.jathar,Siddu :65]

Condensate polishing

A high quality make-up water can be produced for the plant by using Demineralizing systems as discussed above. However, this treated water while flowing through the cycle can pick up impurities due to condenser leakage from the circulating water through the tubes as well as metallic ions, such as iron and copper, from pipelines.

Condensate polishing is accomplished by passing the condensate through large Demineralizing vessels, called mixed bed units, which contain both cation and anion resins. The resins not only remove dissolved salts in the above manner, but also act as filters for impurities or suspended solids. Power plants using once-through boilers and nuclear reactors generally require high quality water and use condensate polishing systems.

1.2 LAYOUT OF MODERN COAL POWER PLANT

Layout of steam power plant:

Steam is an important medium for producing mechanical energy. Steam is used to drive steam engines and steam turbines. Steam has the following advantages.

1. Steam can be raised quickly from water which is available in plenty.
2. It does not react much with materials of the equipment used in power plants.
3. It is stable at temperatures required in the plant.

Equipment of a Steam Power Plant

A steam power plant must have the following equipment.

1. A furnace for burning the fuel the development of power in any country depends upon the available resources in that country. The hydel power totally depends upon the natural sites available and hydrological cycle in that country. New sites cannot be humanly created for hydel power plants.
2. A steam generator or boiler for steam generation.
3. A power unit like an engine or turbine to convert heat energy into mechanical energy.
4. A generator to convert mechanical energy into electrical energy.
5. Piping system to carry steam and water.

The development of nuclear power in a country requires advanced technological developments and fuel resources. This source of power generation is not much desirable for the developing countries as it is dependent on high technology and they are highly capital based systems.

Many times, hydel power suffers if draught comes even once during a decade and the complete progress of the nation stops. The calamity of rain draught on power industry has been experienced by many states of this country.

To overcome this difficulty, it is absolutely necessary to develop thermal plants in the country which are very much suitable for base load plants.The general layout of the thermal power plant consists of mainly four circuits as shown in Figure the four main circuits are:

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

1. Coal and ash circuit

This includes coal delivery, preparation, coal handling, boiler furnace, ash handling and ash storage. The coal from coal mines is delivered by ships, rail or by trucks to the power station. This coal is sized by crushers, breakers etc. The sized coal is then stored in coal storage (stock yard). From the stock yard, the coal is transferred to the boiler furnace by means of conveyors, elevators etc.

The coal is burnt in the boiler furnace and ash is formed by burning of coal, Ash coming out of the furnace will be too hot, dusty and accompanied by some poisonous gases. The ash is transferred to ash storage. Usually, the ash is quenched to reduced temperature corrosion and dust content.

There are different methods employed for the disposal of ash. They are hydraulic system, water jetting, ash sluice ways, pneumatic system etc. In large power plants hydraulic system is used

2. Air and Gas circuit

It consists of forced draught fan, air pre heater, boiler furnace, super heater, economizer, dust collector, induced draught fan, chimney etc. Air is taken from the atmosphere by the action of a forced draught fan. It is passed through an air pre-heater. The air is pre-heated by the flue gases in the pre-heater. This pre-heated air is supplied to the furnace to aid the combustion of fuel. Due to combustion of fuel, hot gases (flue gases) are formed.

The flue gases from the furnace pass over boiler tubes and super heater tubes. (In boiler, wet steam is generated and in super heater the wet steam is superheated by the flue gases.) Then the flue gases pass through economizer to heat the feed water. After that, it passes through the air pre-heater to pre-heat the incoming air. It is then passed through a dust catching device (dust collector). Finally, it is exhausted to the atmosphere through chimney

Feed water and Steam circuit

The steam generated in the boiler is fed to the steam prime mover to develop the power. The steam coming out of prime mover is condensed in the condenser and then fed to the boiler with the help of the pump.

The condensate is heated in the feed-heaters using the steam tapped from different points of the turbine. The feed heaters may be of mixed type or indirect heating type.

Some of the steam and water is lost passing through different components of the system; therefore, feed water is supplied from external source to compensate this loss. The feed water supplied from external sourced is passed through the purifying plant to reduce the dissolved salts to an acceptable level. The purification is necessary to avoid the scaling of the boiler tubes.

4.Cooling water circuit

The circuit includes a pump, condenser, cooling tower etc. the exhaust steam from the turbine is condensed in condenser. In the condenser, cold water is circulated to condense the steam into water. The steam is condensed by losing its latent heat to the circulating cold water.

Thus the circulating water is heated. This hot water is then taken to a cooling tower, In cooling tower, the water is sprayed in the form of droplets through nozzles. The atmospheric air enters the cooling tower from the openings provided at the bottom of the tower. This air removes heat from water. Cooled water is collected in a pond (known as cooling pond). This cold water is again circulated through the pump, condenser and cooling tower. Thus the cycle is repeated again and again. Some amount of water may be lost during the circulation due to vaporization etc. Hence, make up water is added to the pond by means of a pump. This water is obtained from a river or lake. A line diagram of cooling water circuit is shown in figure separately.

Working of the thermal power

Steam is generated in the boiler of thermal power plant using the heat of the fuel burned in the combustion chamber. The steam generated is passed through steam turbine where part of its thermal energy is converted into mechanical energy which is further used for generating electric power.

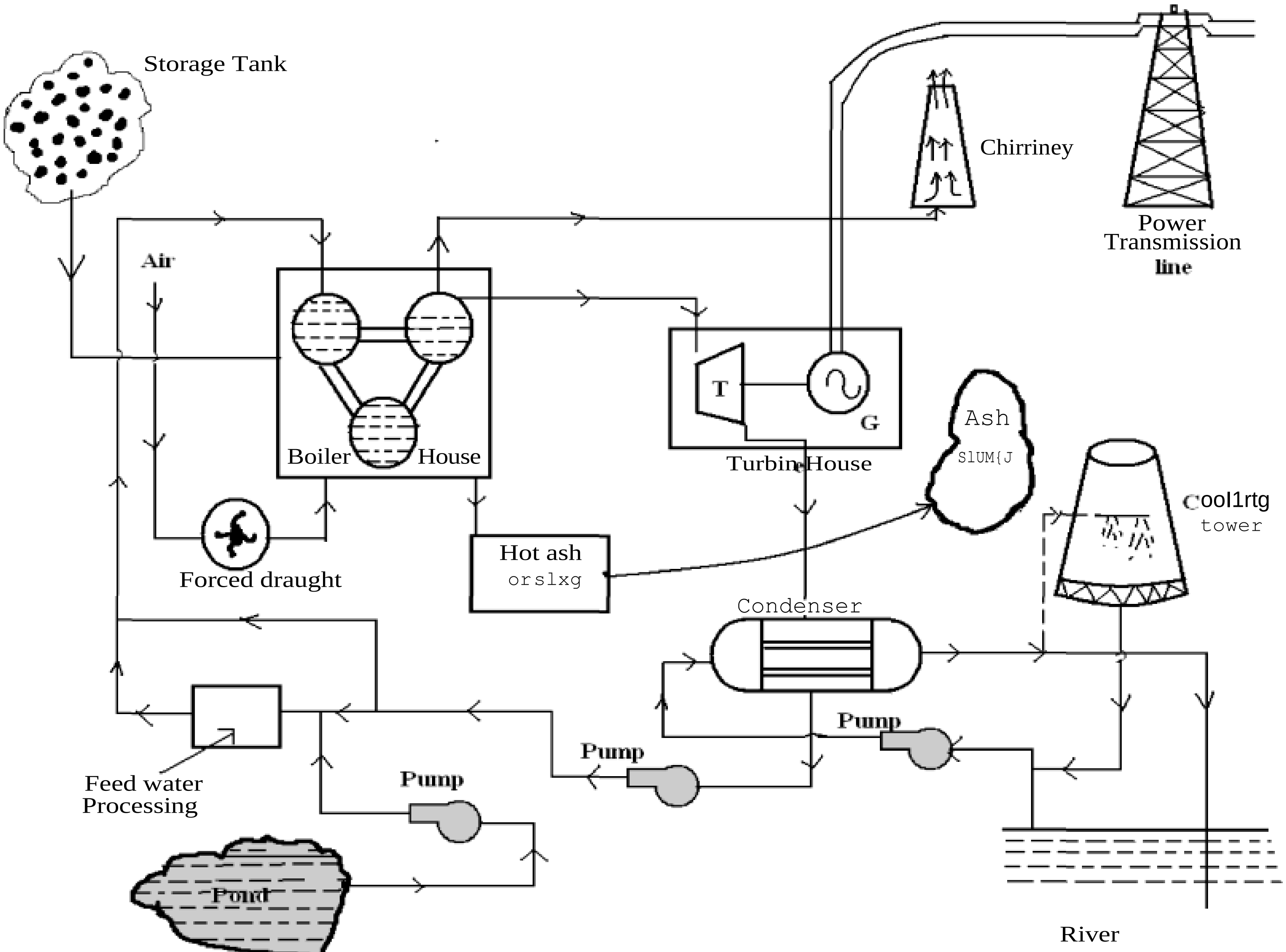


Fig.5 General layout of thermal power plant

Figure 1.2.1 Layout of Thermal power plant

[Source: "power plant Engineering" by Anup Goel ,Laxmikant D.jathar,Siddu :13]

Merits (Advantages) of a Thermal Power Plant

1. The unit capacity of a thermal power plant is more. The cost of unit decreases with the increase in unit capacity.
2. Life of the plant is more (25-30 years) as compared to diesel plant (2-5 years).
3. Repair and maintenance cost is low when compared with diesel plant.
4. Initial cost of the plant is less than nuclear plants.
5. Suitable for varying load conditions.
6. No harmful radioactive wastes are produced as in the case of nuclear plant.
7. Unskilled operators can operate the plant.
8. The power generation does not depend on water storage.
9. There are no transmission losses since they are located near load centres.

Demerits of thermal power plants

1. Thermal plant are less efficient than diesel plants
2. Starting up the plant and bringing into service takes more time.
3. Cooling water required is more.
4. Space required is more
5. Storage required for the fuel is more
6. Ash handling is a big problem.
7. Not economical in areas which are remote from coal fields
8. Fuel transportation, handling and storage charges are more
9. Number of persons for operating the plant is more than that of nuclear plants. This increases operation cost.
10. For large units, the capital cost is more. Initial expenditure on structural materials, piping, storage mechanisms is more.

1.1 RANKINE CYCLE

The Rankine cycle is a model used to predict the performance of steam turbine systems. It was also used to study the performance of reciprocating steam engines. The Rankine cycle is an idealized thermodynamic cycle of a heat engine that converts heat into mechanical work while undergoing phase change. The heat is supplied externally to a closed loop, which usually uses water as the working fluid. It is named after William John Macquorn Rankine, a Scottish polymath and Glasgow University professor.

There are four processes in the Rankine cycle. These states are identified by numbers (in brown) in the above T–s diagram.

Process 1–2: The working fluid is pumped from low to high pressure. As the fluid is a liquid at this stage, the pump requires little input energy.

Process 2–3: The high-pressure liquid enters a boiler, where it is heated at constant pressure by an external heat source to become a dry saturated vapour. The input energy required can be easily calculated graphically, using an enthalpy–entropy chart (h–s chart, or Mollier diagram), or numerically, using steam tables.

Process 3–4: The dry saturated vapour expands through a turbine, generating power. This decreases the temperature and pressure of the vapour, and some condensation may occur. The output in this process can be easily calculated using the chart or tables noted above.

Process 4–1: The wet vapour then enters a condenser, where it is condensed at a constant pressure to become a saturated liquid.

In an ideal Rankine cycle the pump and turbine would be isentropic, i.e., the pump and turbine would generate no entropy and hence maximize the net work output. Processes 1–2 and 3–4 would be represented by vertical lines on the T–s diagram and more closely resemble that of the Carnot cycle. The Rankine cycle shown here prevents the vapor ending up in the superheat region after the expansion in the turbine, [1] which reduces the energy removed by the condensers.

The actual vapor power cycle differs from the ideal Rankine cycle because of

irreversibilities in the inherent components caused by fluid friction and heat loss to the surroundings; fluid friction causes pressure drops in the boiler, the condenser, and the piping between the components, and as a result the steam leaves the boiler at a lower pressure; heat loss reduces the net work output, thus heat addition to the steam in the boiler is required to maintain the same level of net work output.

$$\eta_{th} = \frac{W_T - W_P}{Q_{in}} = \frac{(h_1 - h_2) - (h_4 - h_3)}{(h_1 - h_4)} = 1 - \frac{(h_2 - h_3)}{(h_1 - h_4)}$$

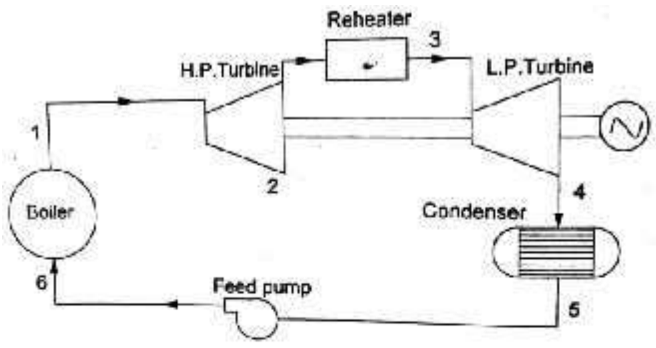
IMPROVISATIONS OF RANKINE CYCLE

Rankine cycle efficiency can be improved by using the following three methods.

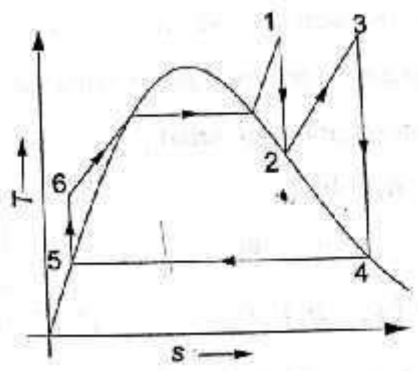
1. Reheating
2. Regeneration
3. Combined reheating and regeneration

Reheat Rankine Cycle

In the reheat cycle, the steam is extracted from a suitable point in the turbine and it is reheated with the help of flue gases in the boiler furnace.



Reheat Rankine cycle



T-s diagram for reheat Rankine cycle

Figure 1.1.1 Rankine cycle

[Source: "power plant Engineering" by Anup Goel ,Laxmikant D.jathar,Siddu :3]

The purpose of a reheating cycle is to remove the moisture carried by the steam at the final stages of the expansion process. In this variation, two turbines work in series. The first accepts vapor from the boiler at high pressure

After the vapor has passed through the first turbine, it re-enters the boiler and is reheated before passing through a second, lower- pressure, turbine. The reheat temperatures are very close or equal to the inlet temperatures, whereas the optimal reheat pressure needed is only one fourth of the original boiler pressure.

Among other advantages, this prevents the vapor from condensing during its expansion and thereby reducing the damage in the turbine blades, and improves the efficiency of the cycle, because more of the heat flow into the cycle occurs at higher temperature.

The reheat cycle was first introduced in the 1920s, but was not operational for long due to technical difficulties. In the 1940s, it was reintroduced with the increasing manufacture of high-pressure boilers, and eventually double reheating was introduced in the 1950s. The idea behind double reheating is to increase the average temperature.

It was observed that more than two stages of reheating are unnecessary, since the next stage increases the cycle efficiency only half as much as the preceding stage. Today, double reheating is commonly used in power plants that operate under supercritical pressure.

REGENERATIVE CYCLE

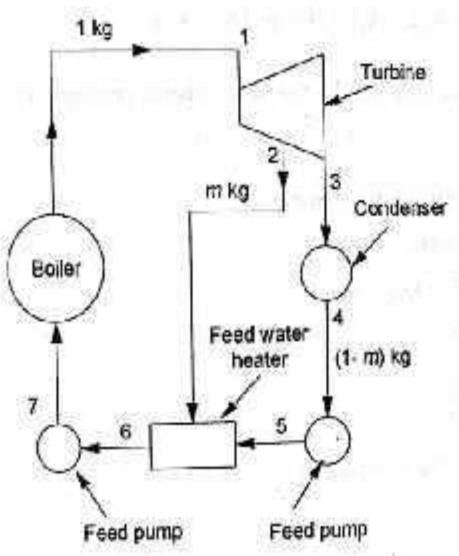


Figure 1.1.2 Regenerative cycle

[Source: "power plant Engineering" by Anup Goel ,Laxmikant D.jathar,Siddu :8]

SINGLE STAGE REGENERATIVE RANKINE CYCLE

The regenerative Rankine cycle is so named because after emerging from the condenser (possibly as a sub cooled liquid) the working fluid is heated by steam tapped from the hot portion of the cycle. On the diagram shown, the fluid at 2 is mixed with the fluid at 4 (both at the same pressure) to end up with the saturated liquid at 7. This is called "direct-contact heating". The Regenerative Rankine cycle (with minor variants) is commonly used in real power stations.

Another variation sends *bleed steam* from between turbine stages to feedwater heaters to preheat the water on its way from the condenser to the boiler. These heaters do not mix the input steam and condensate, function as an ordinary tubular heat exchanger, and are named "closed feedwater heaters".

Regeneration increases the cycle heat input temperature by eliminating the addition of heat from the boiler/fuel source at the relatively low feed water temperatures that would exist without regenerative feed water heating. This improves the efficiency of the cycle, as more of the heat flow into the cycle occurs at higher temperature.

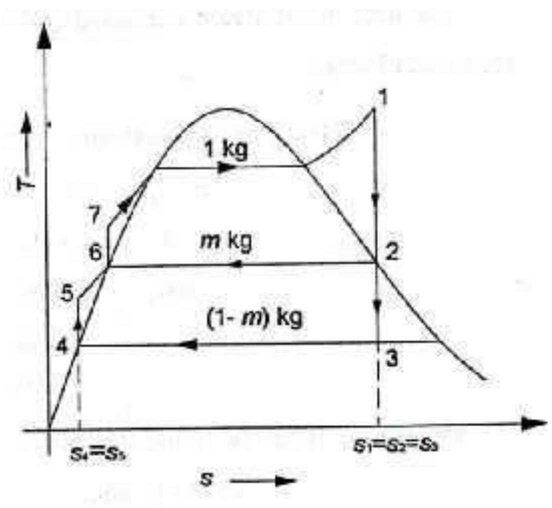


Figure 1.1.3 T-S Diagram of Regenerative cycle

[Source: "power plant Engineering" by Anup Goel ,Laxmikant D.jathar,Siddu :8]

1.3 SUPER CRITICAL BOILERS

Boiler is an apparatus to produce steam. Thermal energy released by combustion of fuel is transferred to water, which vaporizes and gets converted into steam at the desired temperature and pressure.

The steam produced is used for:

- Producing mechanical work by expanding it in steam engine or steam turbine.
- Heating the residential and industrial buildings.
- Performing certain processes in the sugar mills, chemical and textile industries.
- Boiler is a closed vessel in which water is converted into steam by the application of heat. Usually boilers are coal or oil fired.

A BOILER SHOULD FULFIL THE FOLLOWING REQUIREMENTS

Safety. The boiler should be safe under operating conditions.

Accessibility. The various parts of the boiler should be accessible for repair and maintenance.

Capacity. The boiler should be capable of supplying steam according to the requirements.

Efficiency. To permit efficient operation, the boiler should be able to absorb a maximum amount of heat produced due to burning of fuel in the furnace.

It should be simple in construction and its maintenance cost should be low. Its initial cost should be low. The boiler should have no joints exposed to flames. The boiler should be capable of quick starting and loading. The performance of a boiler may be measured in terms of its evaporative capacity also called power of a boiler. It is defined as the amount of water evaporated or steam produced is in kg per hour. It may also be expressed in kg per kg of fuel burnt.

The increasing fuel costs with decreasing fuel quantity have constantly persuaded power engineers to search for more economical methods of power generation. The most recent method to produce economical thermal power is by the use of super-critical steam cycle.

Between the working ranges of 125 bar and 510°C to 300 bar and 600°C, large numbers of steam generating units are designed which are basically characterized as sub-critical and super-critical. Usually a sub-critical boiler consists of three distinct sections as preheater (economizer), evaporator and superheater and in case of super- critical boiler, the only preheated and superheaters are required.

The constructural layouts of both types of boilers otherwise practically identical. With the recent experiments gained in design and construction of super-critical boilers, it has become a rule to use super-critical boilers above 300 MW capacity units.

The **advantages** of supercritical boilers over critical types are listed below:

The heat transfer rates are considerably large compared with sub-critical boilers. The steam side heat transfer coefficient for sub-critical is 16500 kJ/m^2-hr°C when the steam pressure and temperature are 180 bar and 538°C whereas the steam side heat transfer, coefficient for super-critical boiler is 220000 kJ/m^{2}hr-°C when the steam is generated at 240°C.The pressure level is more stable due to less heat capacity of the generator and therefore gives better response. Higher thermal efficiency (40-42%) of power station can be achieved with the use of super critical steam. The problems of erosion and corrosion are minimized in super-critical boilers as two phase mixture does not exist. The turbo generators connected to super critical boilers can generate peal loads by changing the pressure of operation. There is a great ease of operation and their comparative simplicity and flexibility make them adaptable at load fluctuations.

1.5 TURBINES

Steam turbine is a heat engine which uses the heat energy stored in steam and performs work. The main parts of s steam turbine are as follows:

A rotor on the circumference of which a series of blades or buckets are attached. To a great extent of performance of the turbine depends upon the design and construction of blades. The blades should be so designed that they are able to withstand the action of steam and the centrifugal force caused by high speed.

As the steam pressure drops the length and size of blades should be increased in order to accommodate the increase in volume. The various materials used for the construction of blades materials used for the construction of blades depend upon the conditions under which they operated steel or alloys are the materials generally used.

(i) Bearing to support the shaft.

(ii) Metallic casing which surrounds blades, nozzles, rotor etc.

(iii) Governor to control the speed.

(iv) Lubricating oil system.

Steam from nozzles is directed against blades thus causing the rotation. The steam attains high velocity during its expansion in nozzles and this velocity energy of the steam is converted into mechanical energy by the turbine.

As a thermal prime mover, the thermal efficiency of turbine is the usual work energy appearing as shaft power presented as a percentage of the heat energy available.

High pressure steam is sent in through the throttle valve of the turbine. From it comes torque energy at the shaft, exhaust steam, extracted steam, mechanical friction and radiation.

Depending upon the methods of using steam arrangement and construction of blades, nozzle and steam passages, the steam turbines can be classified as follows:

1. According to the action of steam
   (i) Impulse turbine
   (ii) Reaction turbine
   (iii) Impulse and reaction turbine.

In impulse turbine the steam expands in the stationary nozzles and attains high velocity. The resulting high velocity steam impinges against the blades which alter the direction of steam jet thus changing the momentum of jet and causing impulsive force on the blades.

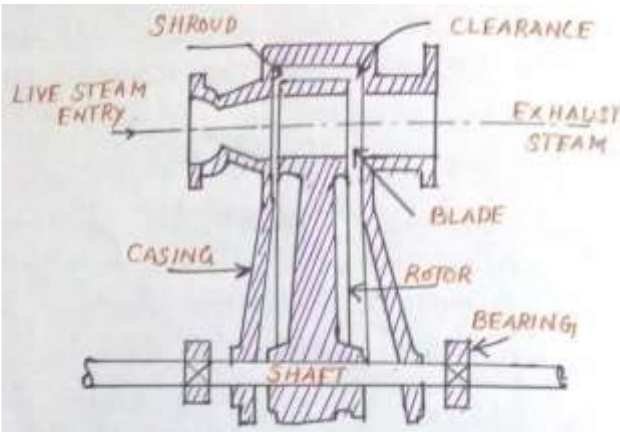


Figure 1.5.1 Impulse Turbine

[Source: "power plant Engineering" by by Anup Goel ,Laxmikant D.jathar,Siddu :3page:27]

In reaction turbine steam enters the fast moving blades on the rotor from stationary nozzles. Further expansion of steam through nozzles shaped blades changes the momentum of steam and causes a reaction force on the blades.

Commercial turbines make use of combination of impulse and reaction forces because steam can be used efficiently by using the impulse and reaction blading on the same shaft. Figure shows impulsed reaction turbine.

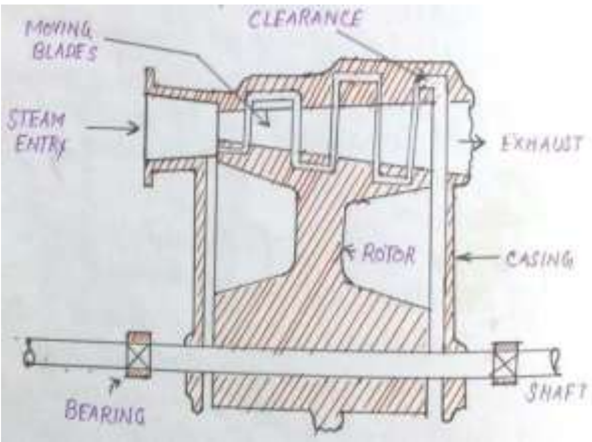


Figure 1.5.2 Reaction turbine
[Source: "power plant Engineering" by P.K.Nag page:28]

2. According to the direction of steam flow
   (i) Axial
   (ii) Radial
   (iii) Mixed
3. According to pressure of exhaust
   (i) Condensing
   (ii) Non-condensing
   (iii) Bleeder
4. According to pressure of entering steam
   (i) Low pressure
   (ii) High pressure
   (iii) Mixed pressure

5. According to step reduction

    (i) Single stage

    (ii) Multi-stage

6. According to method of drive such as

    (i) Direct connected

    (ii) Geared

CONDENSERS

The thermal efficiency of a closed cycle power developing system using steam as working fluid and working on carnot cycle is given by an expression $(T_1-T_2)/T_1$. This expression of efficiency shows that the efficiency increases with an increase in temperature T_1 and decrease in temperature T_2.The maximum temperature T_2(temperature at which heat is rejected) can be reduced to the atmospheric temperature if the exhaust of the steam takes place below atmospheric pressure. If the exhaust is at atmospheric pressure, the heat rejection is at 100˚C.

Low exhaust pressure is necessary to obtain low exhaust temperature. But the steam cannot be exhausted to the atmosphere if it is expanded in the engine or turbine to a pressure lower than the atmospheric pressure. Under this condition, the steam is exhausted into a vessel known as condenser where the pressure is maintained below the atmosphere by continuously condensing the steam by means of circulating cold water at atmospheric temperature.

A closed vessel in which steam is condensed by abstracting the heat and where the pressure is maintained below atmospheric pressure is known as a condenser. The efficiency of the steam plant is considerably increased by the use of a condenser. In large turbine plants, the condensate recovery becomes very important and this is also made possible by the use of condenser.

The steam condenser is one of the essential components of all modern steam power plants. Steam condensers are of two types:

1. Surface condenser
   (a) Down flow type
   (b) Central flow condenser
   (c) Evaporation condenser
2. Jet condenser
   (a) Low level jet condensers (parallel flow type)
   (b) High level or barometric condenser
   (c) Ejector condenser

Surface condensers

In surface condensers there is no direct contact between the steam and cooling water and the condensate can be re-used in the boiler. In such condenser even impure water can be used for cooling purpose whereas the cooling water must be pure in jet condensers.

Although the capital cost and the space needed is more in surface condensers but it is justified by the saving in running cost and increase in efficiency of plant achieved by using this condenser. Depending upon the position of condensate extraction pump, flow of condensate and arrangement of tubes the surface condensers may be classified as follows:

(a) Down flow type

Figure shows a sectional view of down flow condenser. Steam enters at the top and flows downward. The water flowing through the tubes in one direction lower half comes out in the opposite direction in the upper half. figure shows a longitudinal section of a two pass down- flow condenser.

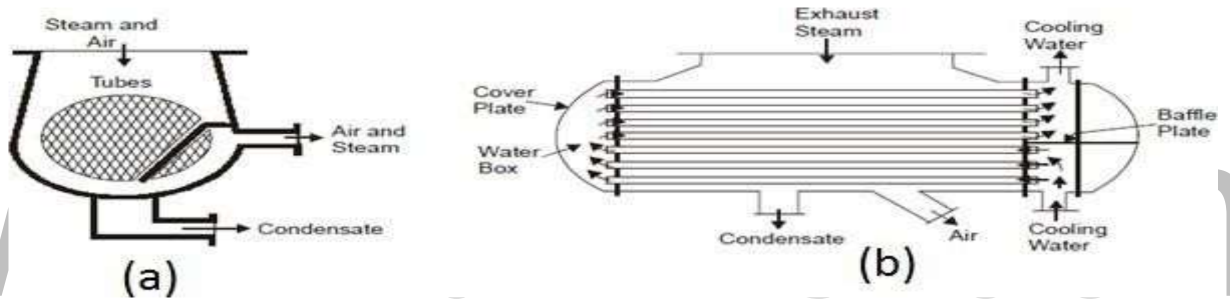


Figure 1.5.3 Surface condenser

[Source: "power plant Engineering" by by Anup Goel ,Laxmikant D.jathar,Siddu :3page:35]

(b) Central flow condenser

Figure shows a central flow condenser. In this condenser the steam passages are all around the periphery of the shell. Air is pumped away from the center of the condenser.

The condensate moves radially towards the center of tube nest. Some of the exhaust steam which moves towards the center meets the undercooling condensate and pre-heats it thus reducing under cooling.

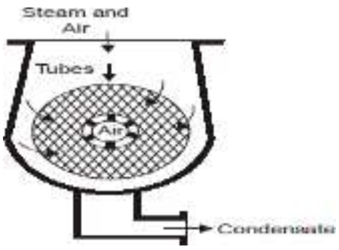


Figure 1.5.4 Down flow condenser

[Source: "power plant Engineering" by by Anup Goel ,Laxmikant D.jathar,Siddu :3page:35]

(c) Evaporation condenser.

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

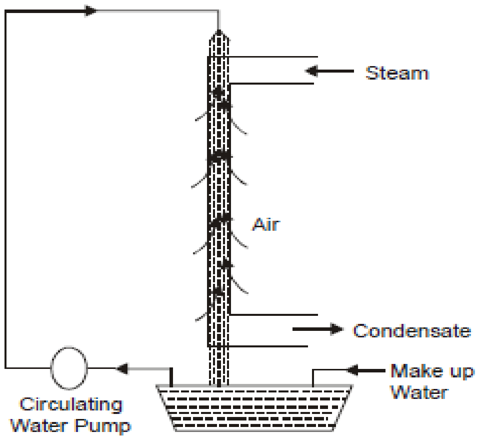


Figure 1.5.5 Evaporation condenser

[Source: "power plant Engineering" by by Anup Goel ,Laxmikant D.jathar,Siddu :3page:35]

Advantages

(i) The condensate can be used as boiler feed water.

(ii) Cooling water of even poor quality can be used because the cooling water does not come in direct contact with steam.

(iii) High vacuum (about 73.5 of Hg) can be obtained in the surface condenser. This increasing the thermal efficiency of the plant.

Disadvantages

(i) The capital cost is more

(ii) The maintenance cost and running cost this condenser is high

(iii) It is bulky and requires more space.

Jet condensers

In jet condensers the exhaust steam and cooling water come in direct contact with each other. The temperature of cooling water and the condensate is same when leaving the condensers.

Elements of the jet condenser are as follows:

(i) Nozzles or distributors for the condensing water.

(ii) Steam inlet

(iii) Mixing chambers: They may be (a) Parallel flow type (b) Counter flow type depending on whether the steam and water move in the same direction before condensation or whether the flows are opposite

(iv) Hot well

In jet condensers the condensing water is called injection water.

(a) Low level jet condensers (Parallel flow type)

In this condenser Figure water is sprayed through jets and it mixes with steam.

The air is removed at the top by an air pump.

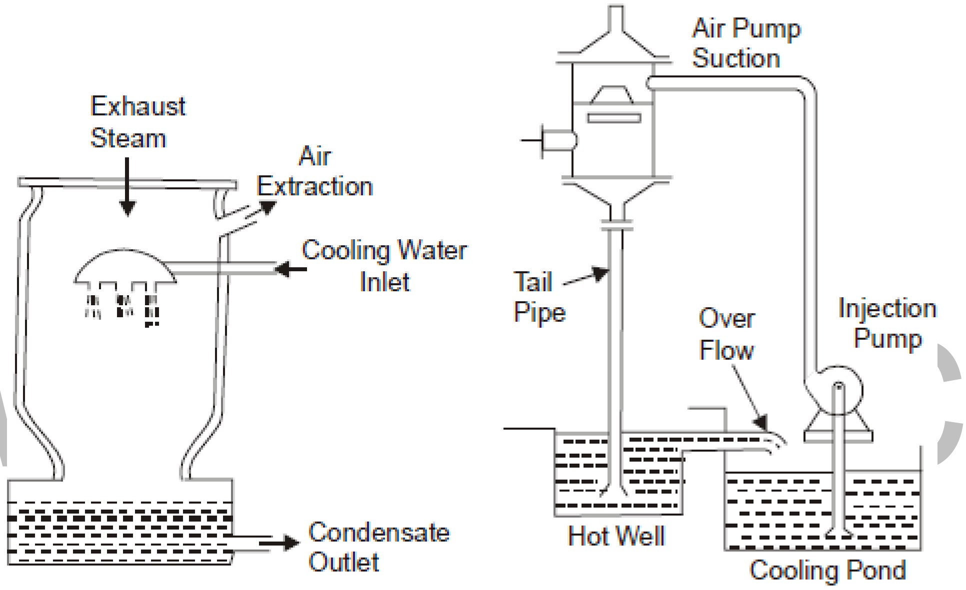


Fig.14 Fig.15

Figure 1.5.6 Low level and High level Jet condenser

[Source: "power plant Engineering" by by Anup Goel ,Laxmikant D.jathar,Siddu :page:36]

High level or Barometric condenser

Figure shows a high level jet condenser. The condenser shell is place at a height of 10.33m (barometric height) above the hot well. As compared to low level jet condenser this condenser does not flood the engine if the water extraction pumps facts. A separate air pump is used to remove the air.

Ejector condenser

Figure shows an ejector condenser. In this condenser cold water is discharged under a head of about 5 to 6m through a series of convergent nozzles. The steam and air enter the condenser through a non-return valve.

Steam gets condensed by mixing with water. Pressure energy is partly converted into kinetic energy at the converging cones. In the diverging cone the kinetic energy is partly converted into pressure energy and a pressure higher that atmospheric pressure is achieved so as to discharge the condensate to the hot well.

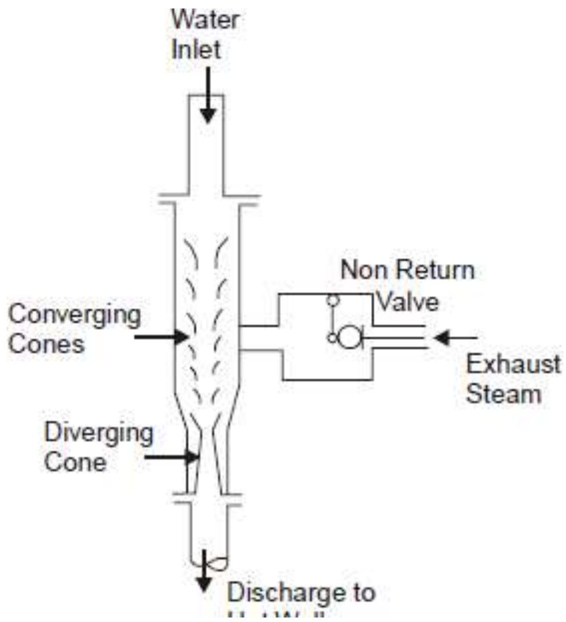


Figure 1.5.7 Ejector Condenser

[Source: "power plant Engineering" by by Anup Goel ,Laxmikant D.jathar,Siddu :page:36]