Power Plant Engineering

Introduction:-

→ Electricity is the only form of energy which is easy to produce, easy to transport easy to use & easy to control. The terminal form of energy for transmission & distribution. Electricity consumption per capita is the index of living standard of people of a place or country.

→ Electricity in bulk quantities is produced in power plants which can be of following types

(a) Thermal (b) Nuclear (c) Hydraulic (d) Gas turbine (e) Geothermal.

→ Thermal, Nuclear, ~~Hydraulic~~ Geothermal power plant work with steam as working fluid. & have similarity in ther cycle & structure.

Gas turbine plants are often used as peak units they run for short time in a day to meet peak load demand.

→ Hydraulic power plants are esentially multipurpose. Besides generating power they also cater for irrigation, flood control, Fisheries, afforestation, navigation etc.

Geothermal power plants can be built only in certain geographical locations.

→ Thermal Power plants generate more than 65% of electricity produced in world. Fossil Fuel (viz) coal are energy source. Steam as working fluid. steam is also used in many industries for process heat.

→ It is found that demand for electricity bears linear relationship with gross national product (GNP) of a country. Projection of future demand of electricity is thus tied to economic growth of concerned region. with increase in economic growth, the consumption of electricity also increases.

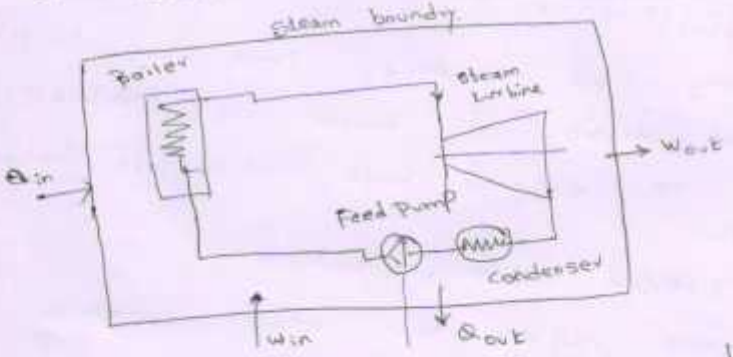
→ Growing energy demand related to expanding industrialization & improving standards of living make the world dependent mainly upon fossil fuels as mentioned earlier. oil, natural gas & coal are of primary source of energy for transportation as well as electricity generati..

Rankine cycle:-

→ It is a thermodynamic cycle used to generate electricity in many Power station & is the real world approach to carnot cycle

→ super heating steam generated in boiler & expand in steam turbine

→ steam turbine → Generator → Electricity



→ Power plant generate electricity by using Fuels like coal, oil, natural gas

→ Power plant Consist boiler, turbine, Condenser & Pump.

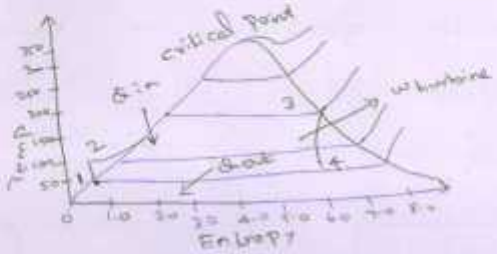
→ Fuel burned burns in boiler & super heater heats water to generate steam & then steam convert in to super heated stake in super heater then super heated steam is used to rotate the turbine which Powers the generator After that the steam leaves the turbine is cooled in to liquid stake in the Condenser liquid is Pressurized by pump prior to going back to boiler

Process of Rankine cycle:-

→ Heat engine with vapour Power cycle

working Fluid is water

→ Four states in Rankine cycle



Process 1-2 - working fluid pumped from L.P to H.P

Process 2-3 - liquid enters a boiler is heated at const. pressure by an external heat source to become dry saturated vapour

Process 3-4 - Expand through turbine.

Process 4-1 - wet vapour then enters condenser where it condensed at const pressure & temp to be come saturated liquid.

In ideal rankine cycle pump & turbine → Isentropic

work o/p of cycle steam turbine. $W_1 = m(h_1 - h_2)$

work i/p " pump $W_2 = m(h_4 - h_3)$

m - Mass flow of cycle

Heat supply to cycle (boiler) $Q_1 = m(h_1 - h_4)$

Heat rejected from cycle $Q_2 = m(h_2 - h_3)$ (condenser)

net work o/p $W = W_1 - W_2$

Thermal η - $\eta = W/Q_1$

2

→ 5% of Rankine cycle is not as high as Carnot cycle but the cycle has less Practical difficulties

→ Regeneration helps improve the Rankine cycle 5%

→ In open feed water heaters, a Fraction of steam exiting a high pressure turbine is mixed with feed water at same pressure

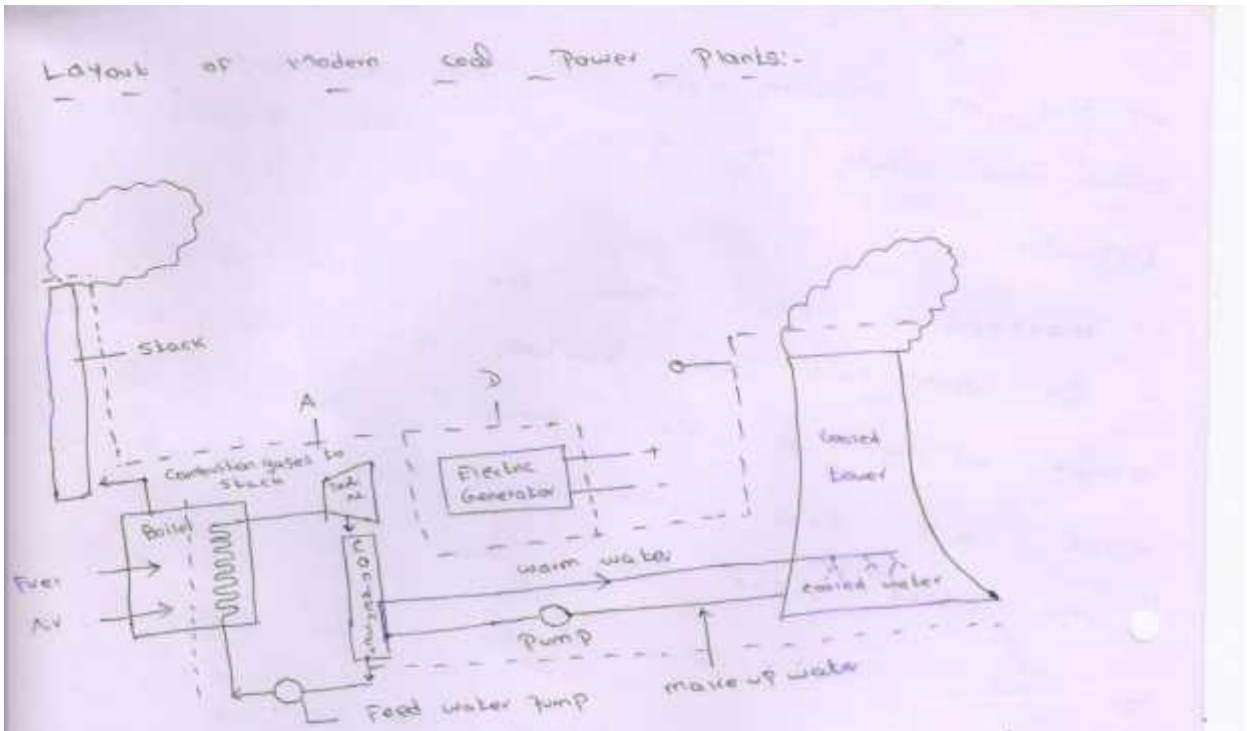
In closed system, bled steam from the turbine is not directly mixed with feed water, so there fore the two streams can be at different pressures

Organic Rankine cycle:-

'organic' is a term used in chemistry to describe a class of chemicals that includes freon & most of other common refrigerants. rankine cycle is a closed circuit in steam cycle

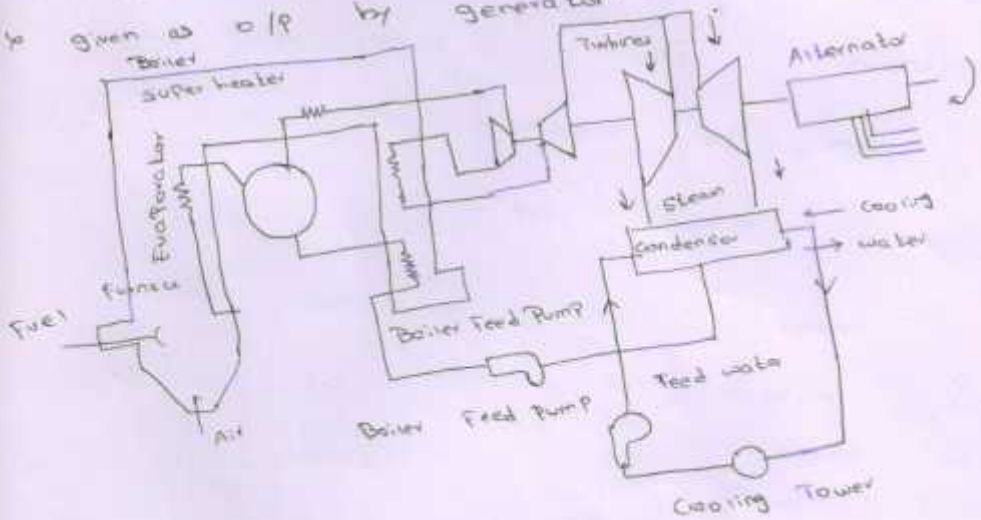
'organic' Rankine cycle uses heated chemical instead of steam as found in Rankine cycle

Layout of modern coal Power Plants:-



→ In thermal P.P fuel is used to heat the boiler to convert water in to steam. steam is used to turn a turbine which is connect to generator

↳ when turbine turns electricity is generated to given as o/p by generator



1) water intake:-

- water is taken in to boiler through water source. water is plenty then source is river.
- If scarce then it is recycled & same water is used over & over again.

2) Boiler heating:-

- Boiler is heated with coal. Furnace is used to heat fuel & supply heat produced to boil. Increase in temp helps in transformation of water in to steam.

3. steam turbine:-

- Steam generated in boiler is sent through steam turbine. The turbine has blades that rotate when high velocity steam flows through them. This rotation of turbine used to generate electricity.

4. Generator:-

- Generator connect to turbine
- Turbine rotates, Generator produces electricity when passed on to power distribution system.

5 Special fittings:-

- Economizer uses the heat from exhaust gas to heat Feed water
- Air preheater heats air sent in to the combustion chamber to improve η.

Ash Collection System:-

→ Ash collection system in place to collect all waste particles from combustion process to prevent them from escaping in to atmosphere

→ other monitoring devices to track the functioning of all devices

Main parts of the plant:-

→ coal conveyor → stoker → Pulverizer
→ Boiler → coal ash → Air preheater
→ Electro static precipitator → smoke stack
→ Turbine → condenser → Transformer
→ cooling Tower → Generator → High voltage power lines

Smoke stack:-

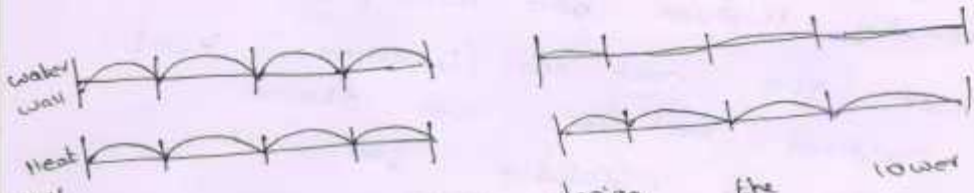
→ A chimney from a boiler used to venting smoke to outside atmosphere
→ Almost vertical to . hot gas flow smoothly, drawing air in to combustion through chimney.
→ space inside a chimney called Flue. Chimneys found in buildings, steam locomotives & ships.

Super critical boilers

→ with PC technology the once through boiler is only type for super critical pressure operation above (221.2 bar), because there is no latent heat of vaporization involved to water on being heated at constant super critical pressure. Suddenly Flash in to vapour, there is no saturation temp as such to vapour is further heat to desired temp in super heaters.

→ Although there is no drum but there is a transition section where the water is likely to flash. Before the transition, the water is in liquid phase after the transition the water is in vapour Phase. Although $v_f \approx v_g$ during Flashing heat transfer coefficient of water in liquid Phase is greater than in a vapour Phase or $h_f > h_g$. The surface areas require for certain heat transfer would be different since the tube diameter is the same before to after transition in once through mode the length of the 2 phase

To avoid this spiral membrane wall design is adopt for super critical boiler. The temperature profile of wall tube of vertical & spiral type are shown below.

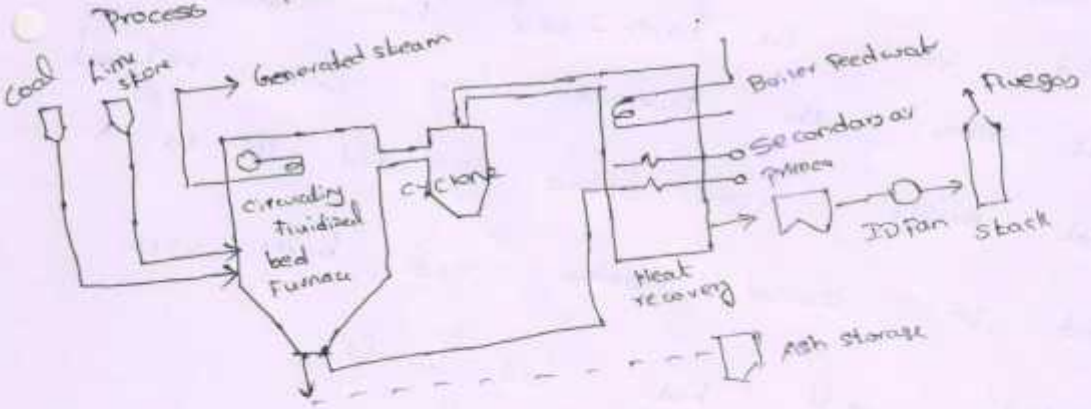


In spiral design the lower portion of Furnace is arranged in spiral configuration such that steam circulate in tube around boiler as it travel up the Furnace Every tube is part of all four walls so temp diff b/w tubes is minimized & heat absorption by individual tube is approximately same. The spiral water wall system does not require any flow adjusting device to be attached at Furnace inlet An intermediate header is used to make Furnace wall vertical at upper region of Furnace. As Furnace wall tubes are at an angle the spiral tubes are not self support the supporting load is transfer to upper section vertical tube

The boiler water tubes are located in Furnace Another view of atmospheric Fluidized bed combustor

since most of the sulphur in coal is retain in bed by bed material used the gases can cooled to low temp before leaving stack with less formation of acid. As a result of low combustion temp ; - Ferial gases of coal can be used with out slagging problem & there is less Formation of NO_x. cheaper alloy material can be used result in economy of Construction. Further economies are achieved since no pulverizer is required

Process Flow of circulating Fluidized bed boiler



The lower part of the first section is often tapered. Its walls are lined with refractory up to level of secondary air entry. Beyond this the Furnace walls are generally cooled by evaporative, Super heater. The gas Solid seperator & non mechanical valve are also lined with refractory.

In some design a part of hot Solid recycle b/@ cyclone & Furnace is divert through external heat excharger which is bubbling Fluidized bed with heat transfer surface immersed in to it remove heat from hot Solids

Coal is generally injected in to lower section of Furnace. It is some times fed in to the loop-seal. From which its entes the Furnace along with returned hot solids. Lime stone is fed in to bed in similar manner coal burns with mixed with hot bed solids.

Condenser:-

Need:-

Condenser were exhaust steam from turbine is condensed operates at pressure lower than atmosphere

1. To reduce turbine exhaust pressure so as to ↑ the specific o/p of turbine. If circulating cooling water temp in a condenser is low enough this pressure is equal to saturation pressure

A condenser by lowering its back pressure say from 1.013 to 0.074 bar.

Types:-

(a) Direct contact type condenser:- where condensate & cooling water directly mix & come out as single stream

(b) Surface condenser which are shell tube heat exchanger where two fluid do not come in direct contact & heat released by condensation of steam is transfer through walls of tube in to the cooling water continuously circulating inside them.

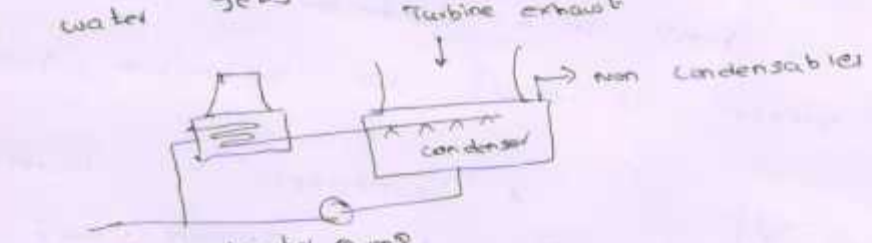
Direct contact Condensers

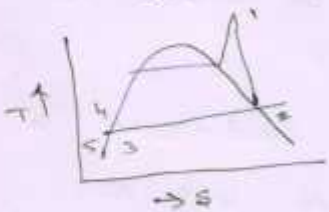
(a) Spray Condenser

(b) Barometeric condenser

(c) Jet condenser

→ In spray condenser cooling water sprayed in to steam. Steam by mixing directly with cold water gets condensed.





→ Part of condensate (ω_4) equal to turbine exhaust flow

ω_2 is sent back to plant as feed water

In geo thermal OTEC plant only vacuum is req. to be maintain in condenser

& no Feed water

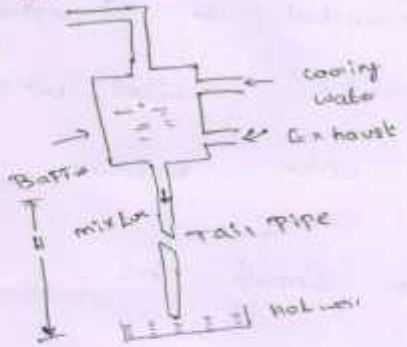
$$\omega_2 = \omega_1 \qquad \omega_3 = \omega_2 + \omega_5$$

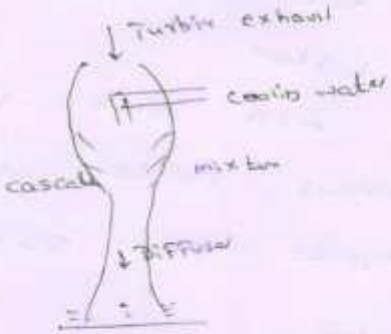
$$\omega_2 h_2 + \omega_5 h_5 = \omega_3 h_3$$

$$\frac{\omega_5}{\omega_2} = \frac{h_2 - h_3}{h_3 - h_5}$$

$h_2 - h_3$ is much greather than $h_3 - h_5$ the circulating water Flow is much larger than Steam Flow.

In barometric condenser cooling water is made to Fall in series of baffles to expose large surface area for steam fed from below to come in direct contact





In barometric condenser the cooling water is made to Fall in series of buffles to expose large surface area steam fed From below to come in direct contact.

$P_{atm} - P_{cld} + \Delta P_f = \rho g H$

ρ : density of mixture H - height of tail pipe

For low value of ΔP_f H is around 9.5m

Higher value higher Friction - Friction lower by increase tail pipe diameter which result in tall & heavy system

Ash Handling system:-

Boilers burning pulverized coal have dry bottom Furnaces. The large ash particles are collected under Furnace in water filled ash hopper. Fly ash is collected in dust Collectors with either an electrostatic precipitator. A pc boiler generate appx 80% fly ash 20% bottom

- Ash must be collected & transport from various points of plants. pyrites which are rejects from pulverizes with bottom ash system.

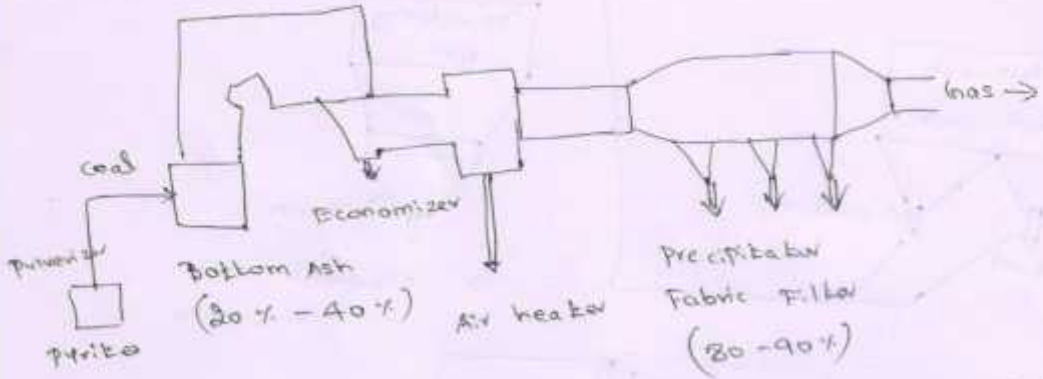
Three major Factor should be Considered

1) plant site
2) Fuel Source
3) Environmental regulation.

→ Need of water is land important Consideration For many ash handling System depend on kind of Fuel Source

→ Ash quantity to be disposed

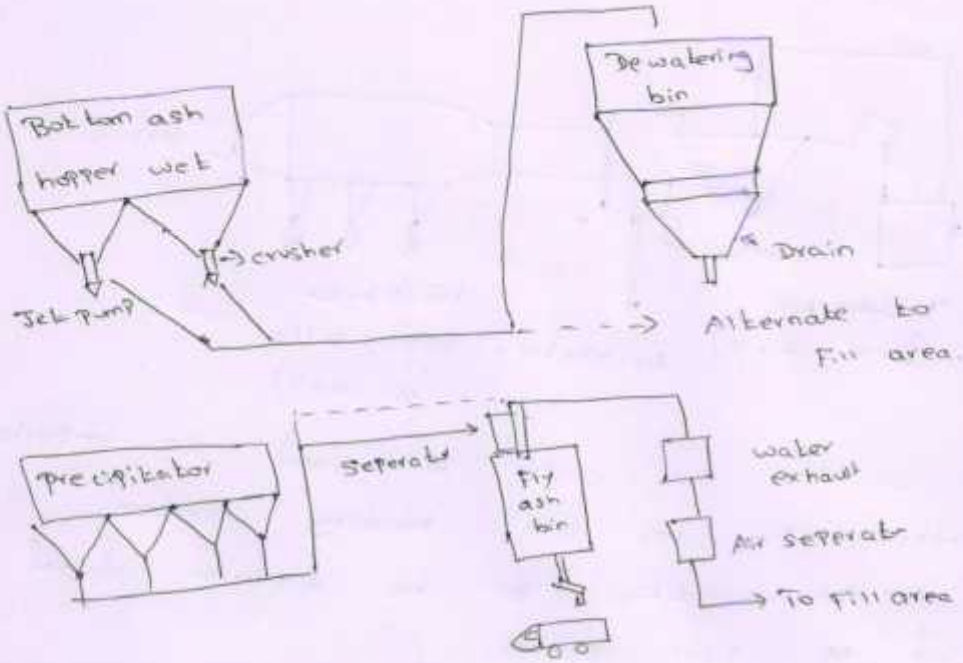
→ Ash storage & disposal sites are guided by environment regulations



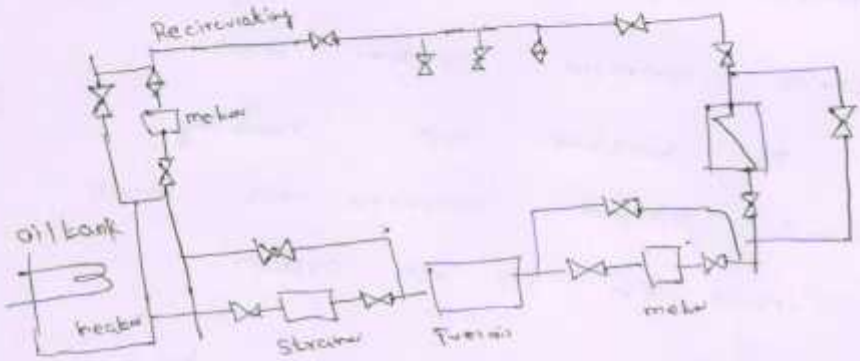
- Need for water & land are important consideration for any ash handling system.
- Ash quantities to be disposed depend on kind of fuel source.
- Ash storage & disposal sites are guided by environmental regulation.

Sluice conveyor system most widely used for bottom ash handling. while hydraulic vacuum conveyor is most frequently used for fly ash system.

- Bottom ash & slag may be used as filling material for road construction.
- Fly ash can partly replace Cement for making concrete. Bricks can made with fly ash. These are durable & stron



Combustion of Fuel oil



Draught system:-

→ Large amount of air needed for combustion gaseous combustion products in huge quantity have removed continuously from boiler Furnace

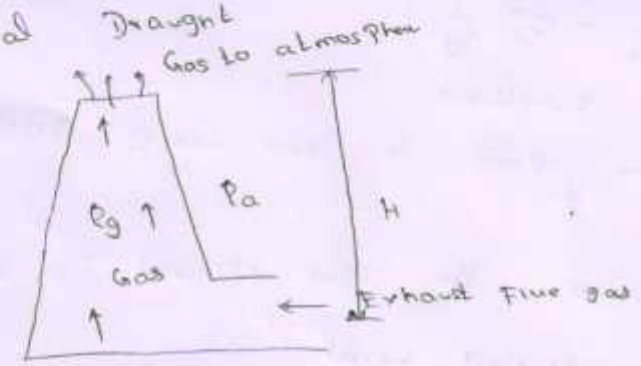
→ To produce required flow of either air or combustion gas pressure differential needed.

→ Draught is used to define static pressure in Furnace. The Function of draught system are

(i) To supply to the furnace the required quantity of air for complete combustion of fuel

(ii) To remove gaseous product of combustion from Furnace to throug these chimney.

Natural Draught



$$\Delta p = gH(\rho_a - \rho_g)$$

ρ_a - density of atmospheric air kg/m³

ρ_g - avg gas density in chimney kg/m³

g - acceleration due to gravity 9.81 m/s²

$$v_a = \frac{0.287 \times 273}{101.325} = 0.7733 \ m^3/kg$$

$$v_a = 0.7733 \ m \times \frac{T_a}{273}$$

$$\rho_a = \frac{1}{0.7733} \times \frac{273}{T_a} = 1.293 \left(\frac{273}{T_a}\right) kg/m^3$$

$$\rho_g = \frac{m+1}{0.7733 \times m \times T_g/273}$$

$$= 1.293 \left(\frac{273}{T_g}\right)\left(\frac{m+1}{m}\right) = \frac{353}{T_g}\left(\frac{m+1}{m}\right)$$

$$\Delta P = 1.293 \times 273 \left\{\frac{1}{T_s} - \frac{m+1}{m}\frac{1}{T_g}\right\} gH$$

$$= 353 \ gH \left[\frac{1}{T_a} - \frac{m+1}{m}\frac{1}{T_g}\right]$$

$$\Delta P = 10^3 gh \times 10^{-3}$$

$$= 353 \ gH \left\{\frac{1}{T_a} - \frac{m+1}{m}\frac{1}{T_g}\right\}$$

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

Stacks have two functions

1. To assist the Fans in over coming Pressure loss
2. To help disperse the gas effluent in to atmosphere in to sufficient height

$$\Delta P_{act} = \Delta P - \rho_g \frac{\bar{v}^2}{2}\left(1 + \frac{fH}{D}\right)$$

f - Friction factor

H - stack height, m

D - stack inside diameter

v - Stack exit velocity

ρ_g - avg gas density

Feed water treatment:

Boiler makeup water to extent of 1.5 - 2 % of total flow rate is req to replenish the loss of water through leakage from fitting, bearings, boiler blow down. The make up water needs to be treated prior to feeding it to boiler for

- Prevention of hard scale formation on heating surfaces
- Elimination of corrosion
- control of carry over to eliminate deposit on super heater tubes.
- Prevention of silica deposition & corossion damage to turbine blades.
- Raw water is first pretreated to demineralized
- For once through boilers & boiling water nuclear reactor which require high water purity a condensate polishing system is used to further polish the water.
- Raw water contain a variety of impurities.

(a) suspend solid & turbidity (b) organics
(c) hardness (d) alkalinity. (e) other dissolved ion
(f) silica (g) dissolve gases

Binary vapour cycle :-

→ No single fluid can meet all requirements as mentioned above.

→ Although in overall evaluation water is better than any other working fluid at high temp. however there are few better liquids notable among them are

a) diphenyl ether b) aluminium bromide

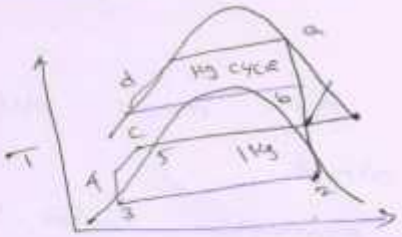
c) liquid metal like mercury sodium, potasium, so on.

Diphenyl ether could be considered but it has not yet been used becz like most organic substance it decompose gradually at high temperature.

Aluminium bromide is possibility yet so considered.

As at pressure of 1 bar the saturation temp for water, aluminium bromide mercury are 187°C, 482.5°C, 560°C

High cyclic temp consistent with best avail material for use in PPF is 560°C



But in low temp range mercury is unsuitable becz its saturation pressure exceed low & it would be impractical to maintain such high vacuum in condenser

For this reason to take advantage of beneficial measure of mercury very high temp to get rid of its deleterious effect in low temp range. mercury vapour leaving mercury turbine is condensed at high temp & pressue & heat released during condensation of mercury is utilized in evaporating vapour.

The flow diagram of mercury steam binary cycle & corresponding T-S diagram shown The mercury cycle a-b-c-d is a simple rankine cycle using saturated vapour.

Heat reject by mercury duriy

Condensation is transfer to boil water to form saturated water vapour.

- The saturated vapour is heated from external source in super heater
- The super heated steam expand in turbin and then condensed.
- The condensate is then pumped to economiser where it is heated until it become saturated liquid by outgoing gases
- The saturated liquid then goes to mercury condense steam boiler where the latent heat absorbed.

In actual plant the steam cycle alway regeneration

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

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

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

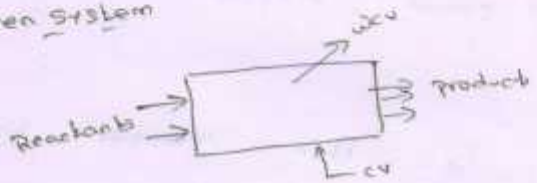
$$\text{heycle} = \frac{Q_1 - Q_2}{Q_1} = \frac{W_T - W_P}{Q_1}$$

$$\text{steam rate} = \frac{3600}{W_T - W_P} \quad \text{kg/kWh}$$

Steam & Heat rate:-

The First law of thermodynamic was treated so far ignoring such energy term as chemical, electrical & magnetic in energy balance of system

open system



For chemically reactive the steady state flow energy can as

$$H_g + Q_{cv} = H_p + W_{cv}$$

ignoring changes in kinetic & Potential energy.

Here H_g & H_p are the enthalpies of reactants & Products, respectively evaluated for their constituent at their respective Pressure & temp

$$\frac{\Sigma}{R} + Q_{cv} = \frac{\Sigma}{P} + W_{cv}$$

$$C_2H_6 + 3.5O_2 + (3.5)(3.76)N_2 \rightarrow 2CO_2 + 3H_2O + (3.5)(3.76)N_2$$

Enthalpies of various reactant

Product are those that start at same datum of composition, temperature & pressure which are arbitrarily chosen as the elemental substance at 25°C & 1atm respectively

This reaction may written as

$2C + 3H_2 \longrightarrow C_2H_6 + 2817.3$ KJ/Kg C_2H_6

$C + O_2 \rightarrow CO_2 + 8946.8$ KJ/Kg CO_2

The quantities 2817.3 & 8946.8 leave system & hence -ve. They are called enthalpies of formation

h_F° for various substances at 25°C, 1atm the enthalpy of all element at standard reference state is assigned the value of zero

Because of chemical reaction are balanced in terms of moles not masses

$m = nM$ n = number of moles.

M = molecular weight

$\sum_R n_i \bar{h}_i + Q_{cv} = \sum_P n_e h_e + W_{cv}$

$h_{1,P} = (h_f^\circ)_{298K\ 1atm} + (\bar{\Delta h})_{298K\ 1atm}$

$h_P = h_F^\circ + \Delta T_n$

Closed system:

$U_R + Q = U_P + W$ W → non flow work, For gas

$H = U + PV = U + n\bar{R}T$ $\bar{R}$ universal gas constant

Subsystem of thermal Power Plant:-

coal :-

→ It is principal energy source particularly in india becz of its large deposit & availability

→ coal originated from veg matter which grew million of yrs ago trees & plant fall in to decayed & later produced peat bogs huge geological upheal buried these bogs under layers of silt. According to geological order of formation coal type

(1) Peat (ii) Lignite (3) Subbituminous
(4) Bituminous (5) Subanthracite (6) Anthracite

Bituminous is largest group

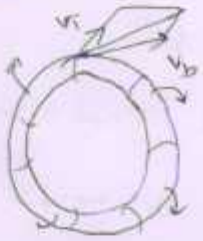
Draught system:-

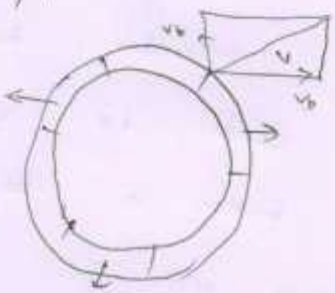
Large amount of air needed for Combustion of Fuel the gaseous combustion Product in huge quantity have also to be removed continously from boiler furnace

To produce req flow of either air or combustion gas pressure differential needed

Fans:-

FD & ID Fans operate continuously for long periods 1 or 1½ yrs. so these can be well designed ruggedly constructed well balanced, highly ⅁. over wide range of ⅁/p



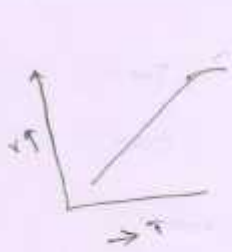


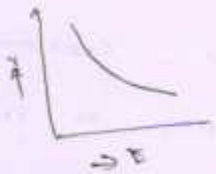
Kinetics of Combustion:-

Combustion of fuel in a furnace determine by number of physical & chemical factor The physical factor include process of mix fuel & air size of fuel particles & surface area exposed for reaction.

-the chemical factors are related to temp & concentration of reactant

The complex field of velocity, temp & concentration together determin kinetics of chemical reactio





Crusher:-

It carried in conveyor belt passes through a magnetic seperator to remove tramp iron pieces. When coal is taken to crusher for being broken in to red Feed size which in pulverizing mill is 30mm or below

Two types are common:-

(i) Ring crusher & hammer mill

Coal is Fed at top & is crushed by action of ring that pivot off centre or rotor & by swing hammer attach to it There is another type of crusher called Bard ford breaker which is used for large capacity work.

Unit-I completed
Sign