UNIT I

COAL BASED THERMAL POWER PLANTS

INTRODUCTION TO THERMAL POWER PLANTS :-

Steam is an important medium for producing Mechanical energy. A steam power plant continuously converts the energy stored in fossil fuels (coal, oil and natural gas) in the form of heat energy. Steam has the advantage that it can be raised from water which is available in abundance. The steam power stations are very much suitable where the coal is abundantly available. The pressure ranges from 10kg/cm^2 to super critical pressure and the temperature varies from 250°C to 650°C

Thermal plants are not suitable for supplying fluctuating loads because any change in the load demand requires the corresponding change in output energy. In thermal power plants, the input energy is produced by burning the coal. So, there is always a large time lapse between the change in energy output and input which is not desirable. Therefore, such power stations are used only as base load stations and it supplies constant power.

Factors to Decide the unit size of power plants :-

(i) Required amount of power

(ii) Cost

(iii) Availability of resources

(iv) Technological aspects.

Sources of Energy Available for power Generation :-

1. Steam
2. Gas or air
3. Diesel and petrol
4. Nuclear
5. Renewable energy sources such as solar, wind, geothermal, tidal, wave, MHD etc.

RANKINE CYCLE :-

Rankine cycle is the theoretical cycle on which the steam turbine works. Rankine cycle is an ideal cycle for vapour power cycles. The line diagram of the plant working on the cycle is shown as. Rankine cycle has the following processes.

Processes :-

1-2 => Reversible adiabatic expansion in the turbine

2-3 => constant pressure heat transfer in the condenser.

3-4 => Reversible adiabatic pumping process in the feed pump.

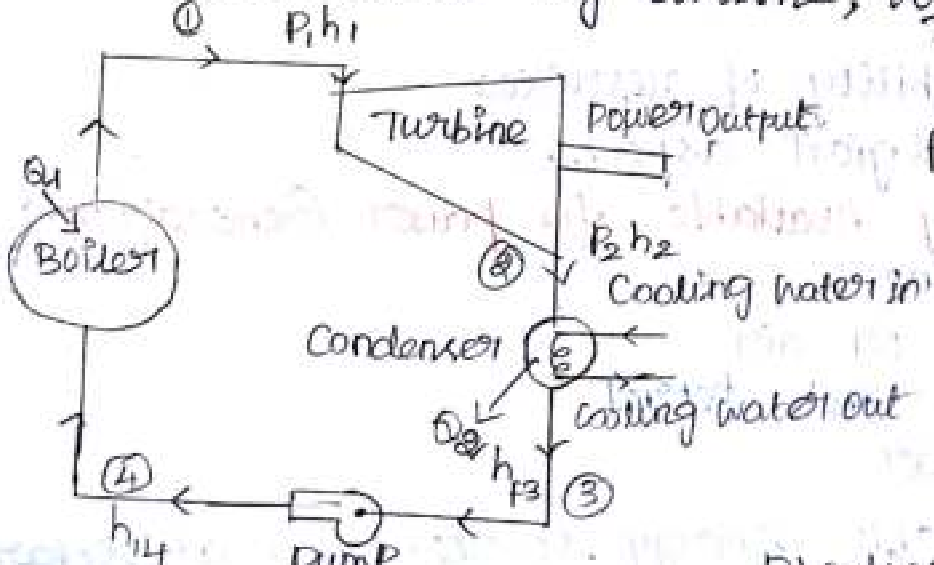
4-1 => Constant pressure heat transfer in the boiler.

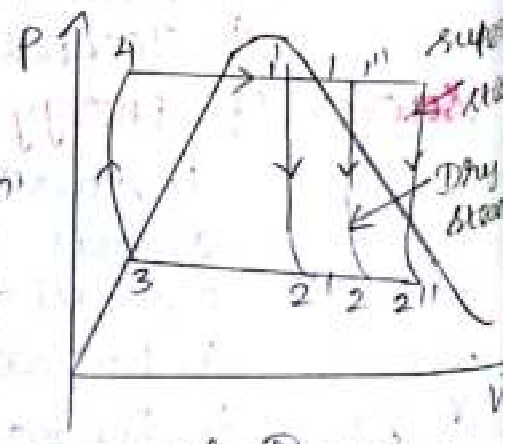
To analyse the cycle, 1 kg of fluid is taken and the steady flow energy equation is applied to boiler, turbine, condenser and pump.

Process 1-2 (Turbine)

The dry saturated steam from boiler (point 1) is isentropically expanded in the turbine (up to point 2) for developing mechanical work and hence, the pressure of steam falls from P_1 to P_2. The temperature at the end of expansion is T_2 which is the saturated temperature at condenser pressure P_2. The steam after expansion is in wet condition with dryness faction x_2

Work done by turbine, $W_T = h_1 - h_2$





PV diagram of Rankine cycle

process 2-3 (Condenser) :-

The wet steam is then condensed in a condenser isothermally and isobarically. The wet steam is converted into water in the condenser. This process is a heat rejection process but the heat is rejected from wet steam to atmosphere..

Heat rejected in the condenser $Q_R = h_2 - h_3 = h_2 - h_{f_2}$

(ie) $h_3 = h_{f_2}$

process 3-4 (pump) :-

The water from the condenser is isentropically pumped from pressure P_3 to the boiler pressure P_4. There is a slight rise in temperature from T_3 to T_4. The enthalpy of water increases due to the pump work.

work done by pump, $W_p = h_4 - h_3 = v_3 (P_4 - P_3)$

$W_p = v_{f3} (P_4 - P_3) = v_{f_2} (P_1 - P_2)$

(ie) $P_4 = P_1$; $P_3 = P_2$; $v_3 = v_{f_2}$

process 4-1 (Boiler) :-

The heat is supplied by the boiler to raise the temperature of water to saturated temperature of T_5 at pressure of P_5.

Heat supplied during 4-1

$Q_{S_{4-1}} = h_1 - h_4$

heated
n

$Q_S = h_1 - h_4 = h_1 - h_{f4}$ $\therefore h_4 = h_{f4}$

$Q_S = h_1 - (h_3 + W_p)$

Net work output, $W = W_T - W_p$ $[\because h_4 = h_3 + W_p = h_{f_2} + W_p]$

$= (h_1 - h_2) - W_p$

$= h_1 - (h_{f_2} + W_p)$

Efficiency of the cycle $\eta = \frac{W}{Q_S}$

$$= \frac{(h_1-h_2)-W_p}{h_1-(h_{f_2}+W_p)}$$

Otherwise, $\eta = \frac{Q_S - Q_R}{Q_S}$

$$= \frac{(h_1-h_4)-(h_2-h_3)}{h_1-h_4} = \frac{(h_1-h_2)-(h_4-h_3)}{h_1-h_4}$$

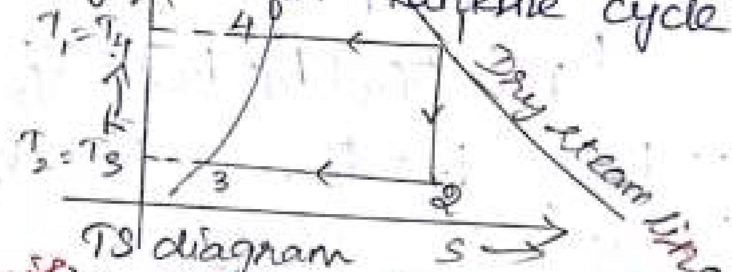
$$\eta = \frac{(h_1-h_2)-W_p}{h_1-(h_{f_2}+W_p)}$$

The pump work is too small when compared expansion work. Hence, it may be neglected for the low-pressure operation. But, it should be included for high-pressure operation

If the pump work is neglected, then the efficiency equation is reduced to

$$\eta = \frac{h_1-h_2}{h_1-h_3} = \frac{h_1-h_2}{h_1-h_{f_2}} \quad (h_3 = h_{f_2})$$

T-s diagram for Rankine cycle without feed pump



(i) Specific steam consumption (SSC) :-

It is defined as the mass flow of steam required to develop 1 unit of power output.

$$SSC = \frac{3600}{W} \text{ in kg/Kh.}$$

Where W be the network output

$W = (h_1-h_2)-W_p$ → for cycle with pumb work

$W = h_1-h_2$ → without pump work

$W = h_1-h_2$ → without pump work

(ii) Specific steam flow rate (SSF) :-

It is defined as the steam flow in kg required to develop 1 unit of power output

$$SSF = \frac{3600}{W} \text{ in kg/kWh}$$

(iii) Work ratio :-

It is defined as the ratio of network to the gross work

$$\text{Work ratio} = \frac{\text{Net work}}{\text{Gross work}} = \frac{W_T - W_P}{W_T}$$

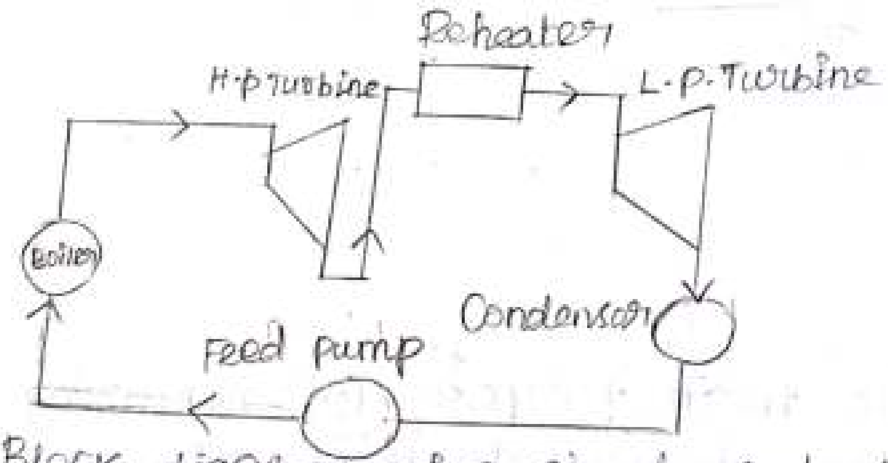
IMPROVISATIONS OF RANKINE CYCLE :-

Rankine can be improved in three ways such as

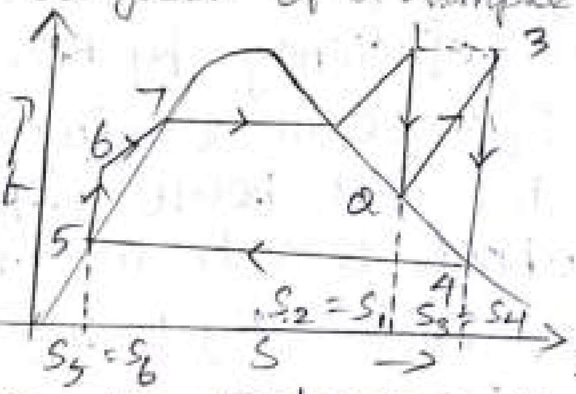
(i) Reheating
(ii) Regeneration
(iii) Combined reheating and regeneration.

Reheat Rankine cycle :-

It is desirable to increase the average temperature and pressure of steam at which the heat is supplied and also to keep the steam as dry as possible at the end of turbine. If the pressure increases, the expansion ratio in the turbine will also increase and the steam becomes wet at the end of expansion. Increasing the moisture of steam will cause the erosion of turbine blades and increase in turbine losses.



Block diagram of a simple reheat Rankine cycle



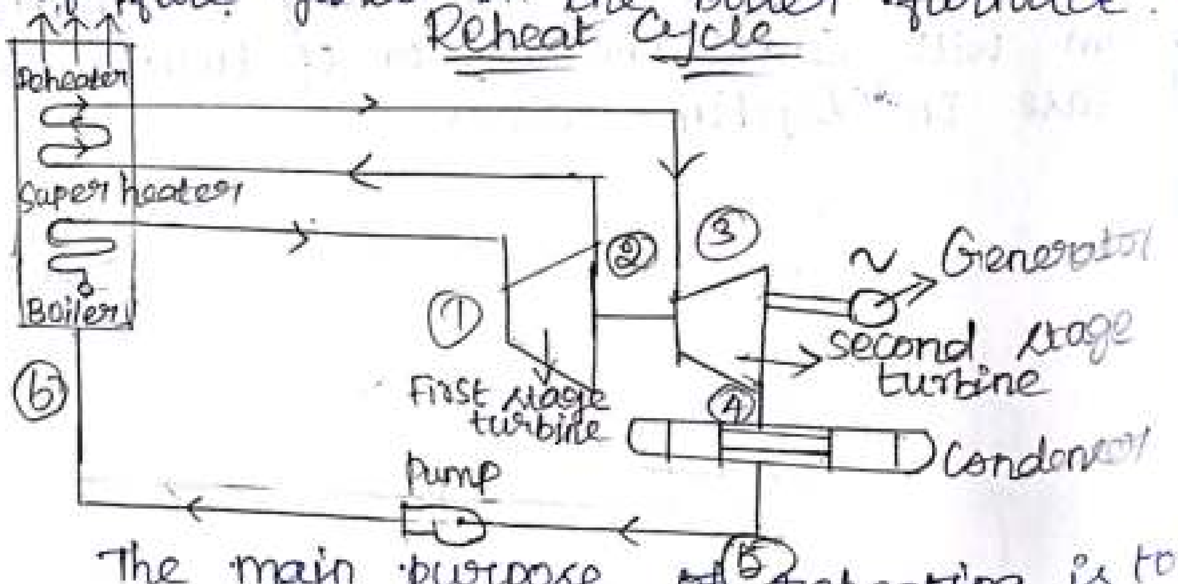
Reheat Rankine cycle

In the reheat cycle, the expansion is being carried out in two stages. The steam is initially expanded in H.P. turbine to some

help of ... expanded in L.P ...
steam is expanded in L.P ... The main purpose of reheat...
Condenser pressure. The main purpose of reheat...
is to increase the dryness fraction of the steam
passing through the turbine and it should
never fall below 0.88. The thermal efficiency is
increased with the reheat cycle but the specific
steam consumption is reduced, But, the thermal
efficiency of the reheat cycle may be decreased
if it is used at low pressures. T-S diagram
for reheat cycle :

The efficiency of the ordinary Rankin cycle can be improved by increasing the pressure and temperature of steam entering into the turbine. 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 Cycle



The main purpose of reheating is to increase the dryness fraction of steam and improve the cycle efficiency by 5%. but the dryness fraction of steam coming out of turbine should not fall below 0.92. The cost of reheat cycle is about 5% to 10% more than a simple Rankine cycle. By using the reheat cycle, the specific steam consumption decreases and thermal efficiency increases.
Normally, the reheat pressure is ...% of the

Initial pressure of the steam.

The process 1-2 represents the isentropic expansion in high pressure turbine and 3-4 represents the isentropic expansion in low pressure turbine. The steam is reheated at constant pressure process 2-3. The reheat can be carried out by returning the steam to the boiler and passing it through a heat exchanger placed in the boiler at constant pressure. Other processes are similar to a simple Rankine cycle

$$\text{Heat supplied } Q_S = Q_{S_{1-6}} - Q_{S_{2-3}}$$

$$= (h_1 - h_6) + (h_3 - h_2)$$

$$\text{Work output, } W = (W_{1-2} + W_{3-4} - W_p)$$

$$= (h_1 - h_2) + (h_3 - h_4) - (h_6 - h_5)$$

Therefore, the efficiency of the reheat Rankine cycle is

$$\eta_{reheat} = \frac{(h_1 - h_2) + (h_3 - h_4) - W_p}{h_1 - (h_{f_4} - W_p) + (h_3 - h_2)}$$

where $W_p = v_{f_4}(P_1 - P_4)$

If the pump work is neglected

$$\eta_{reheat} = \frac{(h_1 - h_2) + (h_3 - h_4)}{(h_1 - h_{f_4}) + (h_3 - h_2)}$$

Where $h_1 \Rightarrow$ enthalpy of super heated steam

$= h_{g_1} + c_{pg}(T_{sup} - T_{sat})$

$h_2 \Rightarrow$ enthalpy of steam at intermediate pressure P_2

If $s_2 = s_1$, the steam is in dry condition, then $h_2 = h_{g_2}$

If $s_2 < s_1$, the steam is in super heated condition then

$h_2 = h_{g_2} + c_{pg}(T_{sup} - T_{sat})$

$s_2 > s_1$, the steam is in wet condition $h_2 = h_{f_2} + x_2 h_{fg_2}$

$h_3 \Rightarrow$ Enthalphy of super heated steam at pressure $P_3 = P_2$

$h_4 \Rightarrow$ Enthalpy of steam at pressure P_4

(ie) Condenser pressure

h_6 => Enthalpy of steam at pump ...

$$h_6 = h_5 + W_p$$

$$W_p = (P_6 - P_5) \times V_5$$

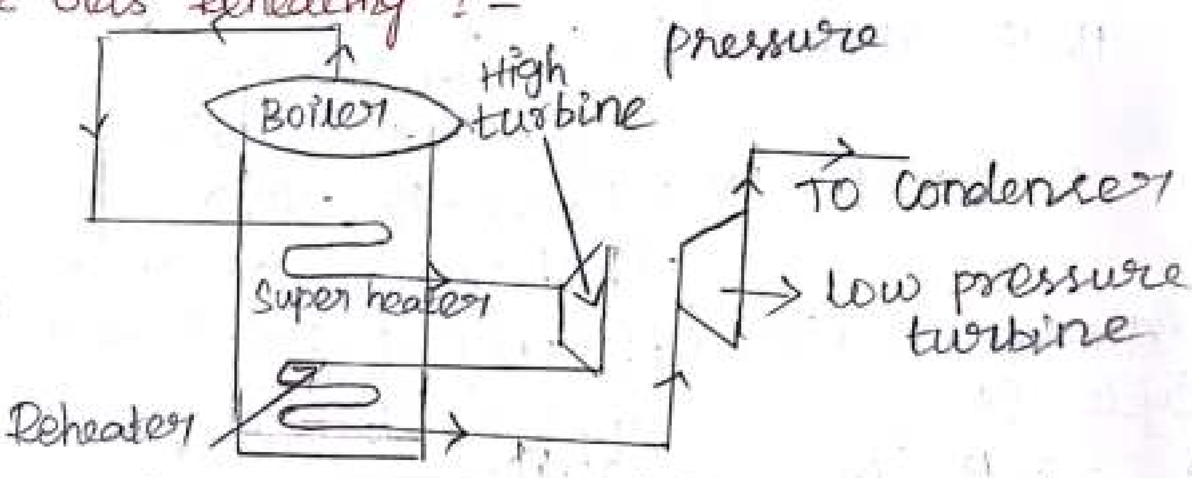
$$W_p = (P_1 - P_4) \times V_{f4} \quad [\because P_6 = P_1 \quad P_5 = P_4]$$

$V_5 = V_f$ at condenser pressure.

Types of reheating :-

1. flue gas reheating
2. Live steam reheating
3. Combined flue gas and live steam reheating

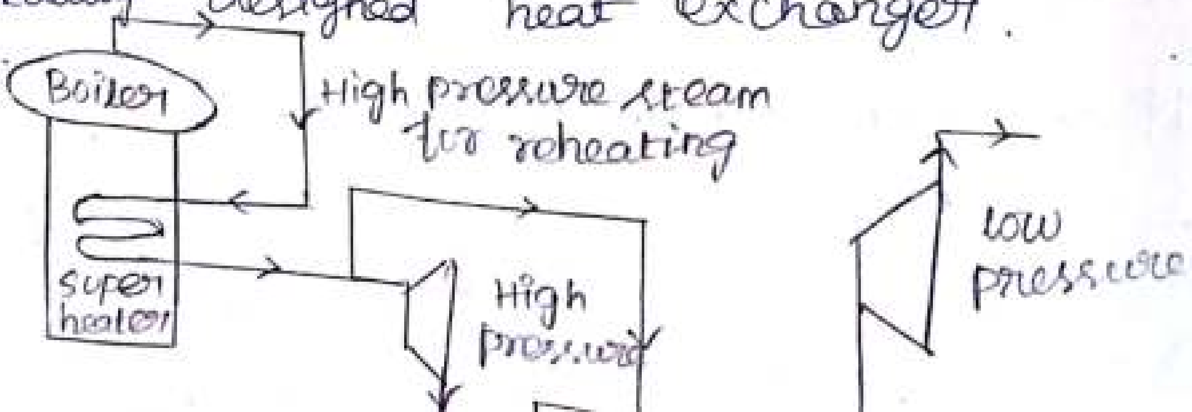
Flue Gas Reheating :-



In this method, the flue gas coming out from boiler is used to heat the steam. The reheater is always placed behind the high-pressure super-heater. The steam can be reheated to initial throttle temperature as reheating is normally employed by using a counter flow heat exchanger.

Live-steam Reheating :-

In this process, the high-pressure steam from the boiler is used for reheating the steam coming out from H.P turbine in a specially designed heat exchanger.



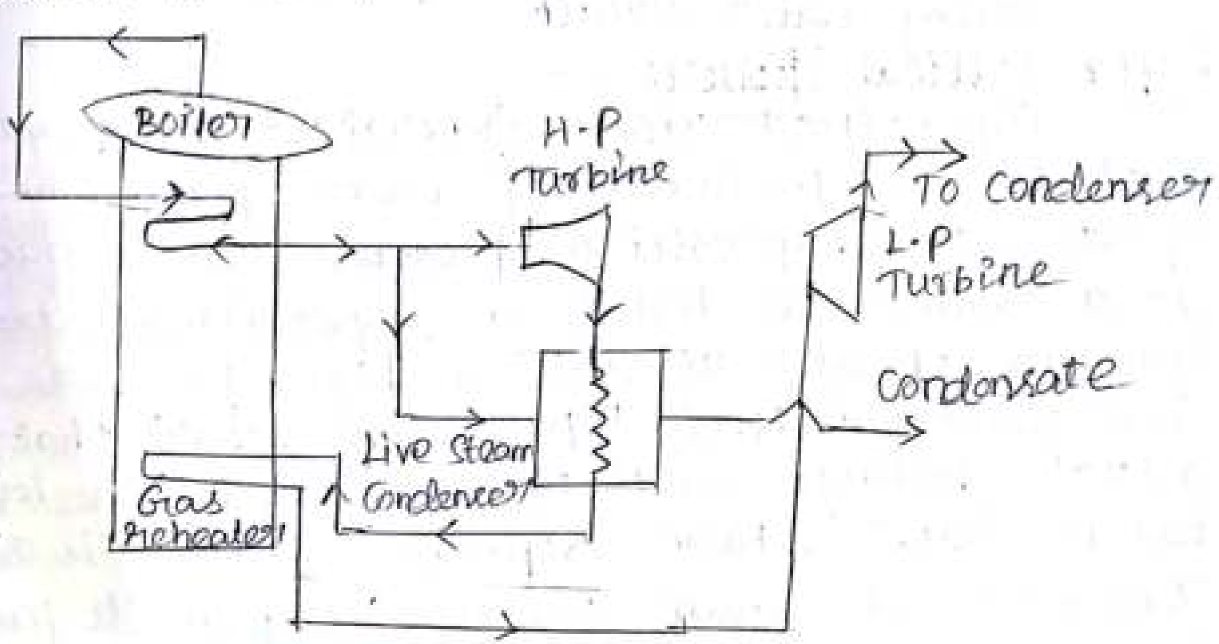
The main advantages in this process are as follows

1. The reheater can be placed near the turbine Therefore, it avoids the use of large piping.

2. It is simple in operation.

Combined Gas and Live steam Reheating :-

In the combined heating system it limits the steam reheated to its Initial throttle temperature and the live steam reheating is eliminated. The steam coming out from H.P turbine is first passed through the live steam reheated and then it goes to a gas reheated. After reheating the steam in the gas reheated the steam is put through the low-pressure turbine. Initially, the steam from the boiler is superheated in the super heater.



THERMAL POWER PLANT :-

A thermal power station is a power plant in which the prime mover is steam driven. Water is heated, turns into steam and spins a steam turbine which drives an electrical generator. After it passes through the turbine, the steam is condensed in a condenser and recycled to where it was heated; this is known as a Rankine cycle. The greatest variation in the design of thermal power stations is due to the different fuel sources. some

prefer to use the term energy center bec
such facilities convert forms of heat energ

into electricity. Some thermal power plants
also deliver heat energy for industrial purpo
for district heating or for desalination of
water as well as delivering electrical powe
Large proportion of CO_2 is produced by the ho
fossil fired thermal power plants, efforts t
reduce these outputs are various and wides

The four main circuits one would come across in any thermal power plant layout ar

- Coal and Ash circuit
- Air and Gas circuit
- feed water and steam circuit
- cooling water circuit

Super critical Boilers :-

Supercritical steam generators are freq. used for the production of electric power. Th operate at "supercritical pressure". In contra to a "subcritical boiler" a supercritical ste generator operates at such a high pressure (over 3,200 psi/22.06 Mpa or 220.6 bar) that actual boiling ceases to occur, and the b has no water-steam separation. There is generation of steam bubbles can form. It pa below the critical point as it does work in the high pressure turbine and enters t generator's condenser. This is more efficient resulting in slightly less fuel use. The te "boiler" should not be used for a super critical pressure steam generator, as no "boiling" actually occurs in this device

FLUIDIZED BED BOILERS :-

The major portion of the coal availabl

low calorific value, high ash content and ... The traditional grate fuel firing systems have got limitations and are techno-economically unviable to meet the challenges of future. Fluidized bed combustion has emerged as a viable alternative and has significant advantages over conventional firing system and offers multiple benefits - compact boiler design, fuel flexibility, higher combustion efficiency and reduced emission of noxious pollutants such as SOx and NOx. The fuels burnt in these boilers include coal, washery rejects, rice husk, bagasse & other agricultural wastes. The fluidized bed boilers have a wide capacity range - 0.5 T/hr to over 100 T/hr

SURFACE CONDENSER :-

Surface condenser is the commonly used term for a water-cooled shell and tube heat exchanger installed on the exhaust steam from a steam turbine in thermal power stations. These condensers are heat exchangers which convert steam from its gaseous to its liquid state at a pressure below atmospheric pressure. Where cooling water is in short supply, an air-cooled condenser is often used. An air-cooled water condenser is however significantly more expensive and cannot achieve as low a steam turbine exhaust pressure as a water cooled surface condenser.

Surface condensers are also used in applications and industries other than the condensing of steam turbine exhaust in power plants.

In thermal power plants, the primary purpose of a surface condenser is to condense the exhaust steam from a steam turbine to obtain maximum efficiency and also to convert the turbine exhaust steam into pure water (referred to as steam condensate), so that it may be reused in the steam generator or boiler as boiler feed water.

STEAM TURBINE

The steam turbine itself is a device convert the heat in steam to mechanical p. The difference between the heat of steam per unit weight at the inlet to the turbine a the heat of steam per unit weight at the outlet to the turbine represents the heat which is converted to mechanical power. There the more the conversion of heat per pound kilogram of steam to mechanical power in turbine, the better is its efficiency. By cond. the exhaust steam of a turbine at a pressure below atmospheric pressure, the st. pressure drop between the inlet and exhaus of the turbine is increased, which increases the amount of heat available for conver. to mechanical power. Most of the heat libe due to condensation of the exhaust stea, is carried away by the cooling medium used by the surface condenser.

fuel and ash handling :-

Ash Handling systems is the none/un combusted portion or residue, after taking combustion of any solid fuel is usually coal. And any coal contains some non combust-ible portion which is called ash. Content of that coal.

There are different types of ashes :

- Bottom ash
- fly ash

Bottom ash is the residue which remains in the solid from at the bottom and fly ash is the light particle which goes out al. with exhaust gases and usually they are collected in chimneys.

Taking their so formed ash away from the plant / Boiler is called - "ASH HANDLING SYSTEM"

This is done in either.

- Mechanical conveying
- Pneumatic conveying

DRAUGHT SYSTEMS :-

Most boilers now depend on mechanical draught equipment rather than natural draught. This is because natural draught is subject to outside air conditions and temperature of flue gases leaving the furnace, as well as the chimney height. All these factors make proper draught hard to attain and therefore make mechanical draught equipment much more economical.

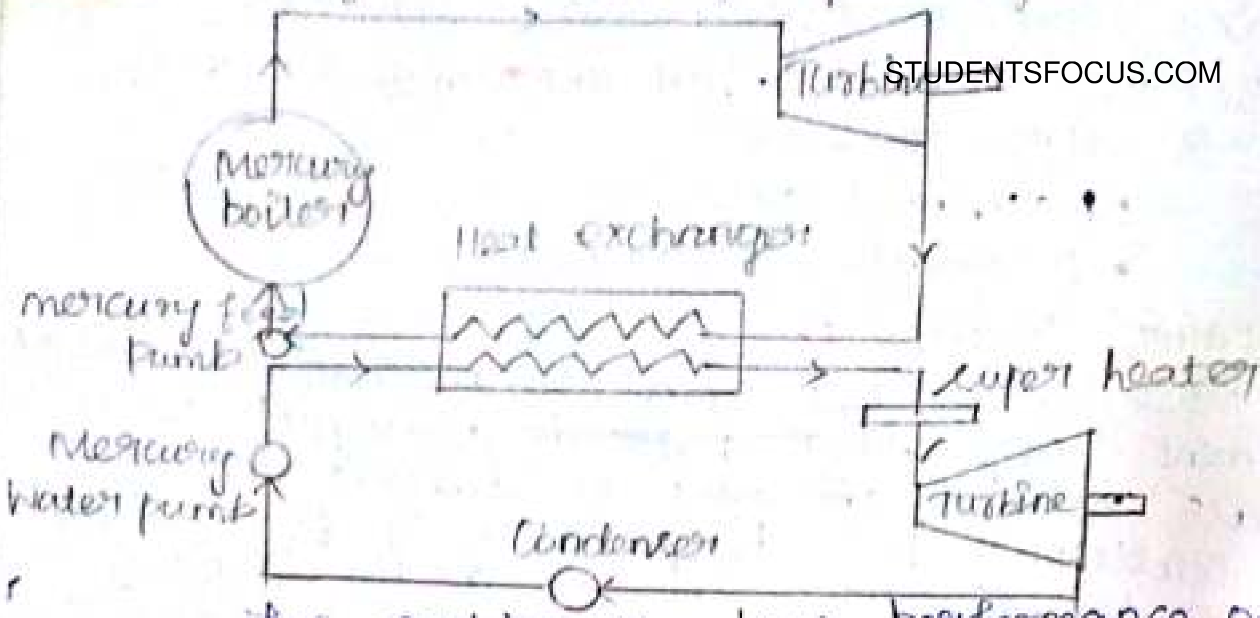
Feed water and steam circuit :-

The steam produced in the boiler is supplied to the turbines to generate power. The steam that is expelled by the prime mover in the thermal power plant layout is then condensed in a condenser for re-use in the boiler. The condensed water is forced through a pump in to the feed water heaters where it is heated using the steam from different points in the turbine. To make up for the lost steam and water while passing through the various components of the thermal power plant layout, feed water is supplied through external sources. feed water is purified in a purifying plant to reduce the dissolve salts that could scale the boiler tubes.

BINARY VAPOUR CYCLE :-

It is one type of combined cycles in which usually two working fluids mercury and water are used to improve the overall thermal efficiency of the power plant

Layout of binary vapour cycle :



For getting the best performance of vapour power cycle, the working fluid should have the following characteristics.

1. High enthalpy of vaporization
2. Good heat transfer characteristic
3. High critical temperature with a low corresponding saturation temperature.
4. High condenser temperature.
5. freezing temperature should be below room temperature and 5-7. The process 7-8 represents the pumping process of feed water in the feed pump.

Let m = Mass of mercury in the mercury cycle / kg of steam circulated

Heat supplied $(Q_s) = m \times (h_1 - h_4) + (h_5 - h_9)$

Workdone by mercury turbine / kg of steam Generated ; $W_{T_m} = (h_1 - h_2)$

Workdone by the steam turbine / kg of steam generated

$$W_{T_s} = h_5 - h_6$$

Heat rejected $Q_R = h_6 - h_7$

Total workdone in binary cycle

$$W_T = W_{T_m} + W_{T_s}$$

pump work $W_P = m(h_4 - h_3) + (h_8 - h_7)$

Overall efficiency of the binary cycle

$$\eta_{binary} = \frac{W_{Tm} + W_{St}}{Q_s}$$

Specific steam rate,

$$SSR = \frac{3600}{W_T - W_P} \ kg/kWh$$

Thermal efficiency of the mercury cycle,

$$\eta_{binary} = \frac{m \times W_{Tm}}{m.h_1} = \frac{W_{Tm}}{h_1}$$

Efficiency of steam cycle,

$$\eta_{binary} = \frac{W_{Ts}}{h_5 - h_8}$$

The value of m can be determined from energy balance equation.

$$m(h_2 - h_3) = (h_9 - h_8)$$

Mass flow rate of mercury required/kg of steam flow rate

$$m = \frac{h_9 - h_8}{h_2 - h_3}$$

COGENERATION SYSTEMS :-

Cogeneration is also called Combined heat power. Cogeneration works based on the concept of producing two different form of energy by using a single source of fuel. Out of these two forms one must be heat or thermal energy and other one is either electrical or Mechanical energy. Cogeneration is the most optimum, reliable clean and efficient way of utilizing fuel. The fuel used may be natural gas, oil, diesel, propane, wood, bagasse, coal etc.

It working principle is simple. In this case, the fuel is used to generate electricity and. this electricity produces heat and this heat is used to boil the water to produce steam for space heating and