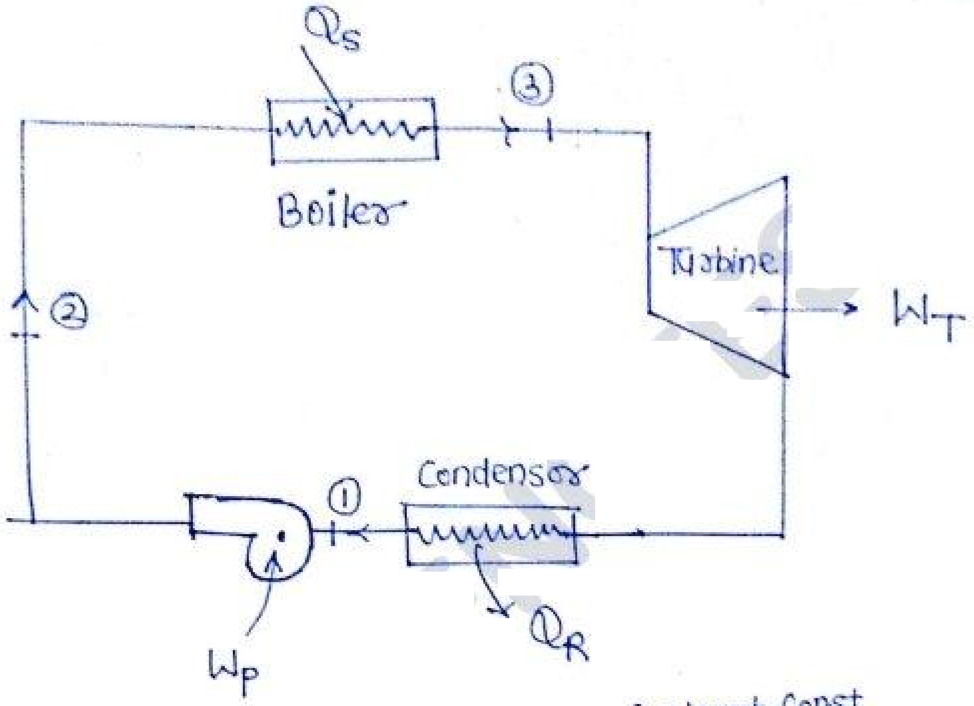
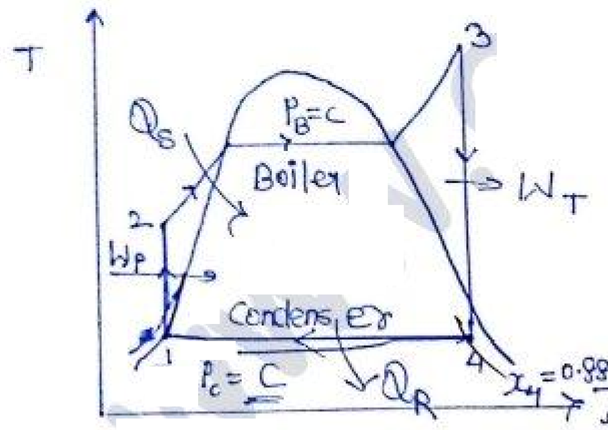
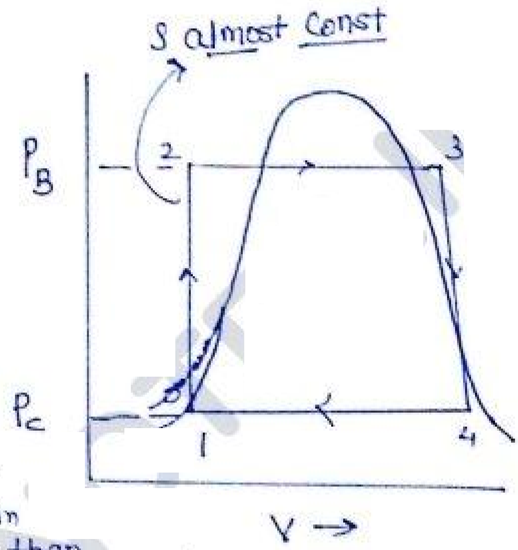
Rankine / Vapour Power Cycle :-







$v_g >> v_f$ can't directly Pump $W_p = \int v\,dp$

$x_4 = 0.88$ to 0.9 it cannot be less than this if less than this turbine blade erosion

Rankine Cycle Consist of four process

1-2 :- Reversible adiabatic compression of liquid from condenser to boiler pressure in boiler feed pump.

2-3 :- constant pressure heat addition process ~~from~~ to convert liquid into superheated steam in boiler.

3-4 : reversible adiabatic expansion from boiler to condensor pressure in steam turbine.

4-1 : Constant pressure heat rejection process in the condensor to get saturated water

$$\begin{cases} n = 1.3 \rightarrow \text{superheated steam} \\ n = 1.135 \rightarrow \text{saturated steam} \\ n = 1.035 + 0.1x \rightarrow \text{wet steam} \end{cases}$$

Turbine work $W_T = h_3 - h_4$

Pump work $W_P = h_2 - h_1 = v_f \cdot (P_B - P_C)$

$Q_S = h_3 - h_2$

$Q_R = h_4 - h_1$

$W_{net} = W_T - W_P = (h_3 - h_4) - (h_2 - h_1)$

$W_{net} = (h_3 - h_2) - (h_4 - h_1)$

$$\boxed{W_{net} = Q_S - Q_R = W_T - W_P}$$

Specific steam Consumption or steam Rate:-

It is the mass flow rate of steam require to produce 1 KW power output

$$SSC = \frac{\dot{m}_s \rightarrow kg/s}{P \rightarrow KW}$$

$$SSC = \frac{\dot{m}_s}{\dot{m}_s \cdot W_{net}} \qquad P = \dot{m} \cdot W_{net}$$

$$SSC = \frac{1}{W_{net}} \text{ kg/KJ or kg/KWS}$$

$$\boxed{SSC = \frac{3600}{W_{net}}} \text{ kg/KWh}$$

Heat Rate (HR):-

It is the ~~heat~~ rate of heat input require to produce 1 KW power output.

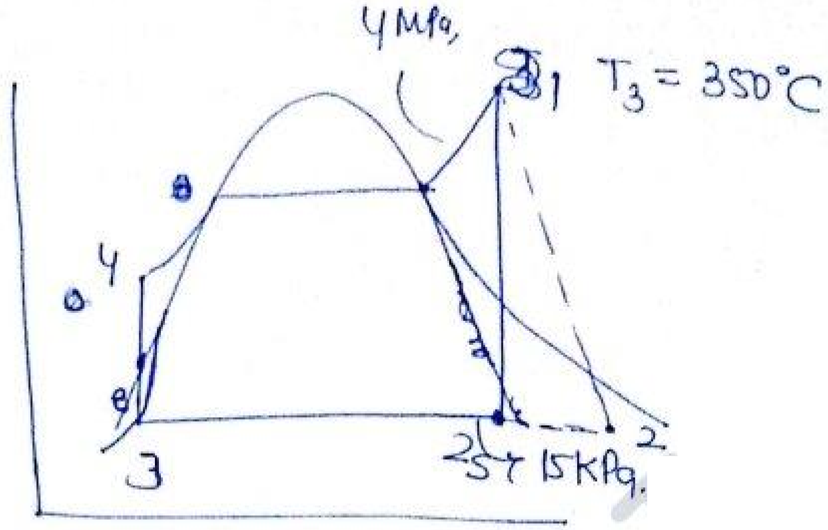
$$HR = \frac{Q_S}{W_{net}} = \frac{\text{Heat in KW}}{\text{Power in KW}} = \frac{\dot{m}_s \cdot Q_s}{\dot{m}_s \cdot W_{net}}$$

$$\boxed{HR = \frac{Q_S}{W_{net}} = \frac{1}{\eta}}$$

P.27

P.931

W.B



4×10^6 Pa

15×10^3 Pa

$$\eta_T = \frac{T_3 - T_4}{T_{4s} - T_4}$$

$$\left(\frac{T_3}{T_{4s}}\right) = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_{4s} = \frac{623}{4.93}$$

$$T_{4s} = 126.28$$

$$T_{4s} = -146.71$$

$h_1 = h_3 = 3092.5$ KJ/kg

$$S_1 = 6.5821 = S_{2s} = S_f + x_{2s}(S_g - S_f)\Big|_{15KPa}$$

$$6.5821 = 0.7549 + x_{2s}(8.0085 - 0.7549)$$

$$x_{2s} = 0.803$$

$$h_{2s} = h_f + x_{2s} \cdot (h_g - h_f)$$

$$h_{2s} = 225.94 + 0.803(2599.1 - 225.94)$$

$$h_{2s} = 2132.29 \text{ KJ/kg}.$$

$$\eta = 0.9 = \frac{h_1 - h_2}{h_1 - h_{2s}} \Rightarrow h_2 = 2228.3 \text{ KJ/kg}$$

$$h_3 = 225.94 \text{ KJ/kg}$$

$W_p = v_{f_1} \times (4000 - 15) = 4.04$

$h_4 - h_3 = 4.04$

$h_4 = 230 \text{ kJ/kg}.$

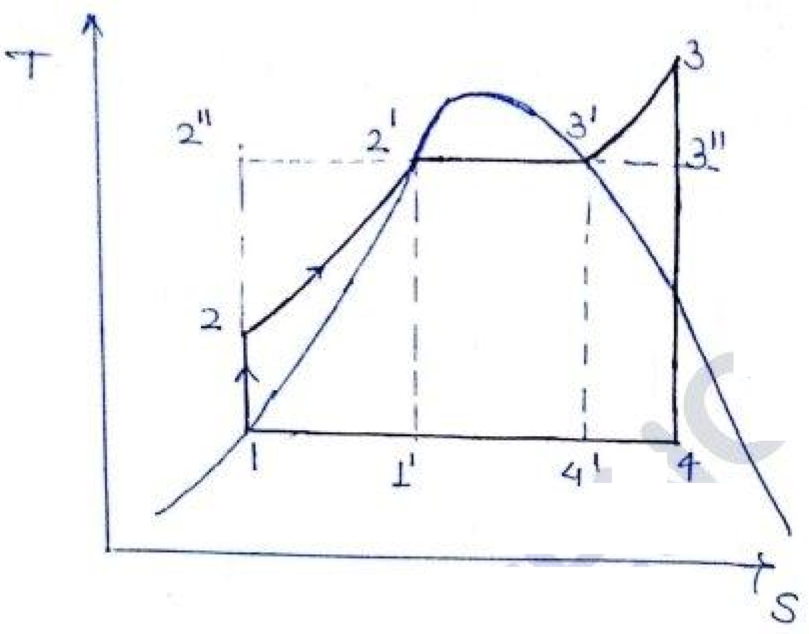
$W_{net} = (h_1 - h_2) - W_p$

$W_{net} = 860.06 \text{ kJ/kg}$

$Q_s = h_1 - h_4 = 2862.5 \text{ kJ/kg}$

$\eta = \underline{30\%}$

Carnot cycle thermal power plant:-



Rankine cycle → 1-2-3-4

Carnot → 1'-2'-3-4 or 1-2''-3'-4' or 1'-2'-3''-4

→ Carnot cycle is not practicle in thermal power plant due to following reasons.

1) The dryness fraction at the lower stage of turbine expansion will be less if expansion takes place by 3'-4'.

2) it is not possible to control condensation process in such a manner to get desired quality of steam as given by state 1'

3) it is not possible to design a pump which can handle liquid vapour mixture phase.

(4). Pump work is always more for carnot cycle.

(5). It is not possible to add heat at const. temp but with continuously decreasing pressure

$\Rightarrow$ Q $\eta_{Carnot} > \eta_{Rankine}$

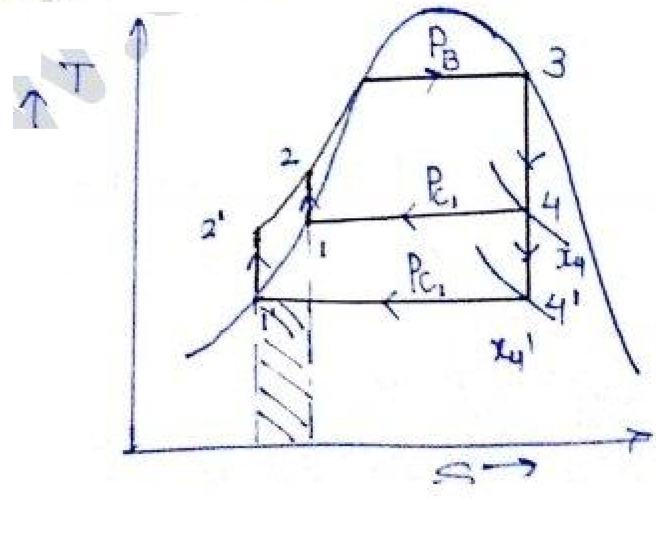
$\Rightarrow (W_{net})_{rankine} > (W_{net})_{Carnot}$

$\Rightarrow (W_P)_{Carnot} > (W_P)_{rankine}$.

Efficiency of Rankine Cycle :-

Efficiency can be increased by either increasing mean temp. of heat addition or by decreasing mean temp of heat rejection and it can be obtained by i) Decreasing Condensor pressure

1) Decreasing Condensor pressure:-



(i) W_p - Can not say (but marginally it increases)

(ii) W_T - ↑↑

(iii) W_{net} - ↑

(iv) Q_S - ↑

(v) Q_R - Cannot say (↑)

(vi) T_{mA} - ↓

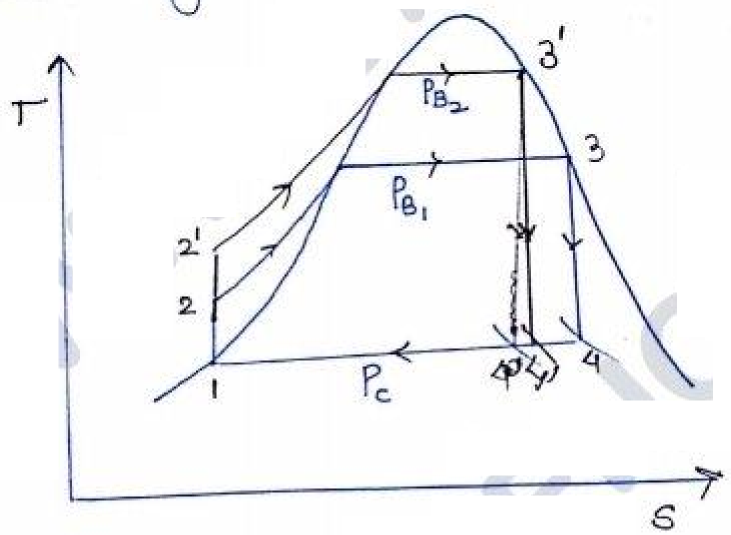
(vii) T_{mR} - ↓↓

(viii) η - ↑

(ix) x - ↓

(x) Moisture ↑

② Increasing Boiler Pressure :-



(i) W_P - ↑

(ii) W_T - ↑↑

(iii) W_{net} - ↑

(iv) Q_S - Cannot say (↓)

(v) Q_R - ↓

(vi) T_{mA} - ↑

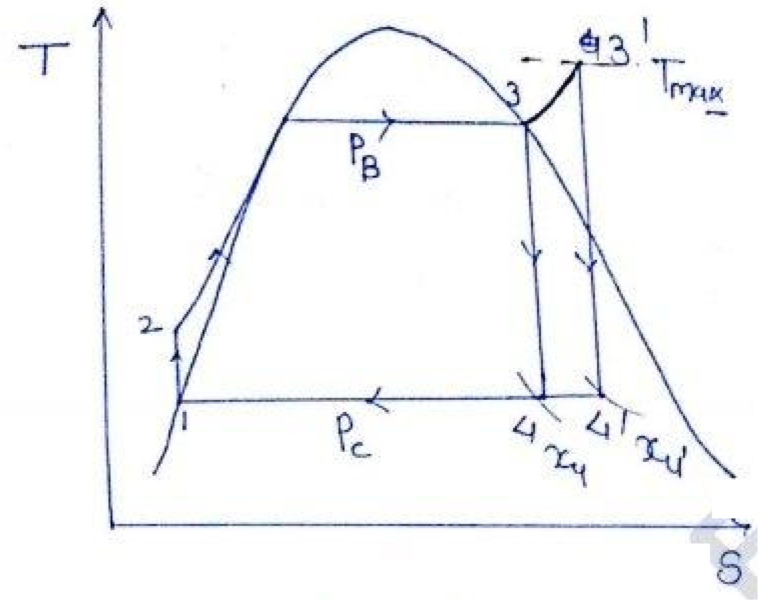
(vii) T_{mR} - Same

(viii) η - (↑)

(ix) x - (↓)

(x) Moisture (↑)

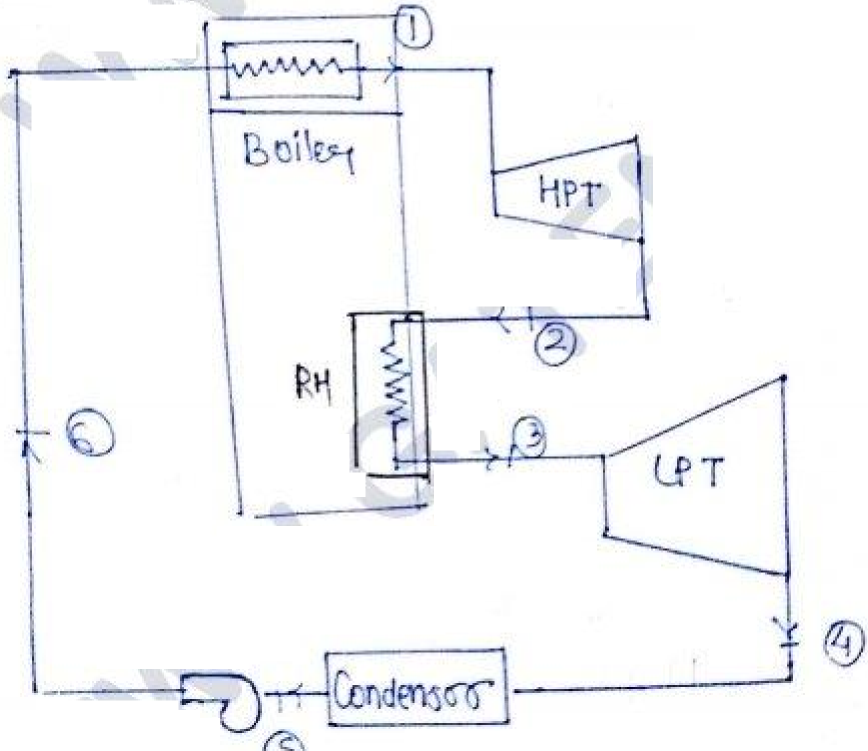
③ By Superheating

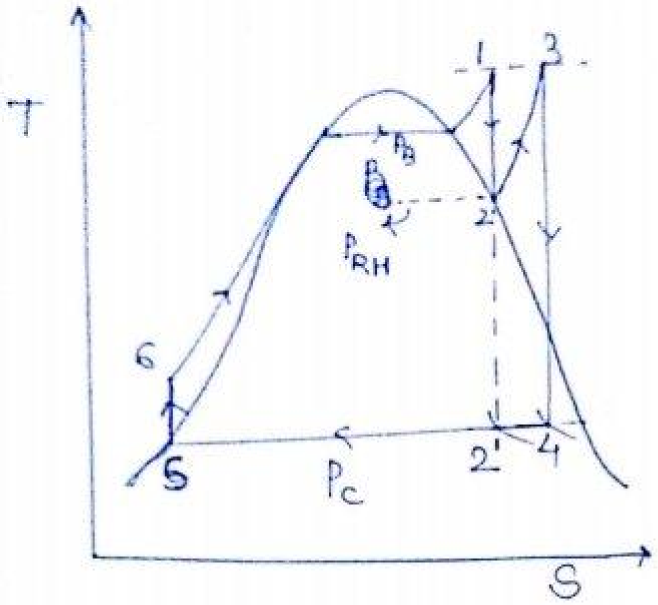


(i) W_p - Same
(ii) W_T - ↑
(iii) W_{net} - ↑
(iv) Q_S - ↑
(v) Q_R - ↑
(vi) T_{mA} - ↑ , T_{mR} - Same
(vii) η ↑
(viii) x ↑ , Moisture ↓

→ Most preferred
→ T_{max} is only one constraint (depends on Metalargical Condn)

Reheat Cycle :-



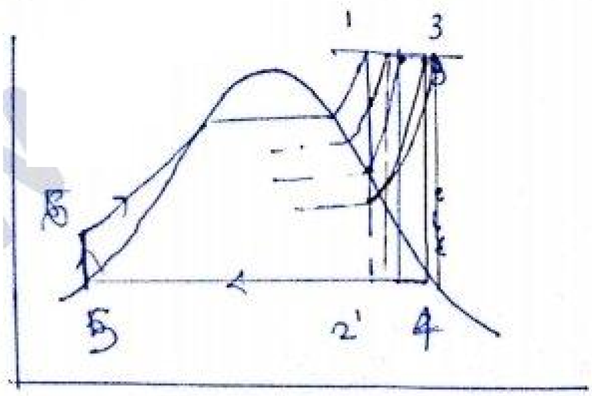


(i) W_P – Same
(ii) W_T – ↑
(iii) W_{net} – ↑
(iv) Q_S – ↑
(v) Q_R – ↑
(vi) T_{mA} – (↑) cannot say (↑) T_{mR} – Same
~~(vii) η – ↑~~
(viii) x ↑, Moisture ↓
(vii) $\eta \propto T_{m.A.}$

Reason behind using Reheat Cycle is to increase dryness fraction (x) & temp limit.

→ In Reheat cycle the total expansion of steam from boiler to condenser pressure takes place in more than one stages with reheating of steam in b/w stages.

The main advantages of Reheat Cycle is that it increases the dryness fraction at lower stages and makes it possible to use higher pressure



P_{RH} = 20% to 25% of P_B

till this pressure η↑ but after this η↓

$$W_T = (h_1 - h_2) + (h_3 - h_4)$$

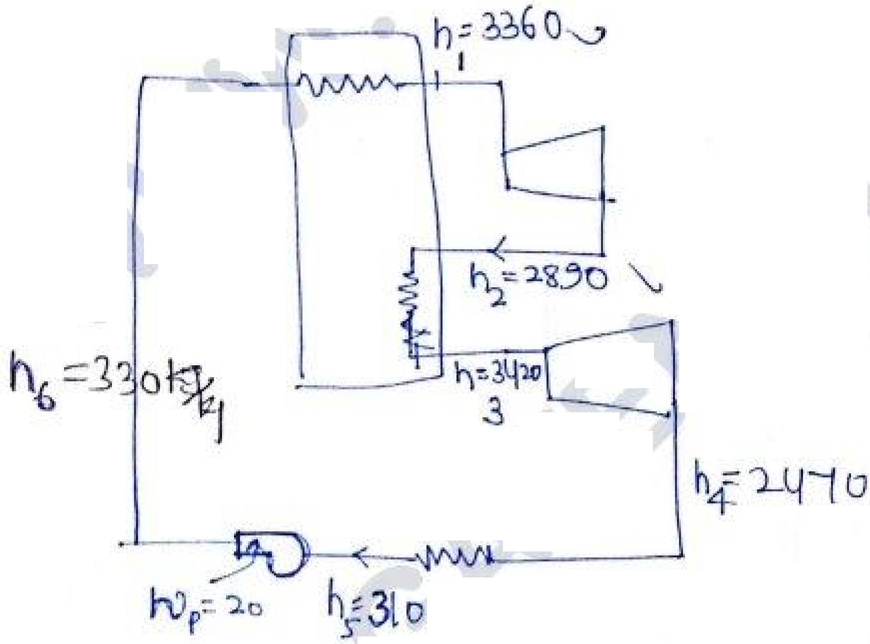
$$W_p = (h_6 - h_5)$$

$$Q_S = Q_{S_1} + Q_{S_2}$$

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

$$Q_R = h_4 - h_1$$

Ques For the reheat cycle as shown below find η & W_{net}. When steam flow rate is 300 kg/min. Pump work is 20 kJ/kg.



$W_p = 20\ kJ/kg$

$h_6 = 310 + 20$

$h_6 = 330.$

$$\eta = \frac{(h_1 - h_2) + (h_3 - h_4) - 20}{(h_1 - h_4) + (h_3 - h_2)} = 39.32\%$$

$$P = \dot{m}_s((h_1 - h_2) + (h_3 - h_4) - W_p) = 7\ MW$$

Ques Steam is working fluid in Rankine cycle with superheat and reheat. Steam enters 1^{st} stage of turbine at 8 MPa, 480°C and expands to 0.7 MPa. It is reheated at constant P to 440°C before entering 2^{nd} stage turbine where it expands to condensor of 0.008 MPa the net power output is 100MW then determine
(i) η_{th} (ii) mass flowrate of steam (kg/hr.
(iii) rate of heat rejected in condensor (MW)

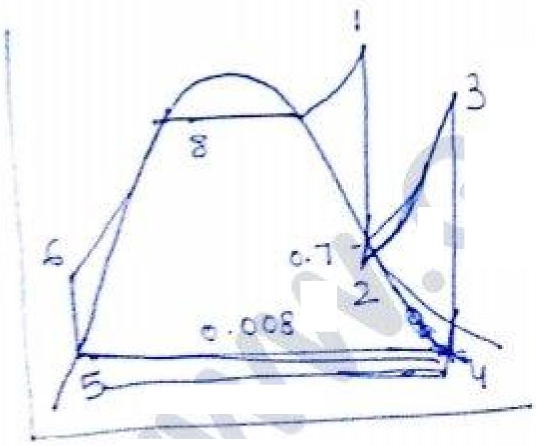
8 MPa, 480°C $h = 3348$, $S = 6.6586$

0.7 MPa, 440°C $h = 3353$, $S = 7.757$

0.7 MPa $h_f = 697.22$, $h_{fg} = 2066.3$ $S_f = 1.992$, $S_g = 6.708$

0.008 MPa $S_f = 0.5926$, $S_g = 8.2287$

$h_f = 173.88$ $h_{fg} = 2403.1$ $v_f = 1.0085 \times 10^{-3}\ m^3/kg$



$h_1 = 3348$

$S_1 = S_2$

$6.6586 = 1.992 + x(6.708 - 1.992)$

$x = 0.98$

$h_2 = h_f + x\, h_{fg}$

$= 697.22 + 0.989 \times (2026.3)$

$h_2 = ~~2740.39~~$

$\doteq 2741.87$

$h_3 = 3353$

$s_3 = s_4$

$7.757 = 0.5926 + x(8.2287 - 0.5926)$

$x = 0.9382$

$h_4 = 173.88 + 0.9382(2403.1)$

$= 2428.5$

$h_5 = 173.88$

$W_p = 1.0085\times10^{-3}(8 - 0.008)\times10^3$

$W_p = 8.08\ kJ/kg = h_6 - h_5$

$h_6 = 181.96\ kJ/kg$

$W_{net} = (h_1 - h_2) + (h_3 - h_4) - W_p$

$W_{net} = 1524.24$

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

$Q_S = 3779.4\ kJ/kg$

$\eta = \frac{W_{net}}{Q_s} = \frac{1524.24}{3779.4} = 40.3\%$

(3) $Q_R = \dot{m}_s(h_4 - h_5)$

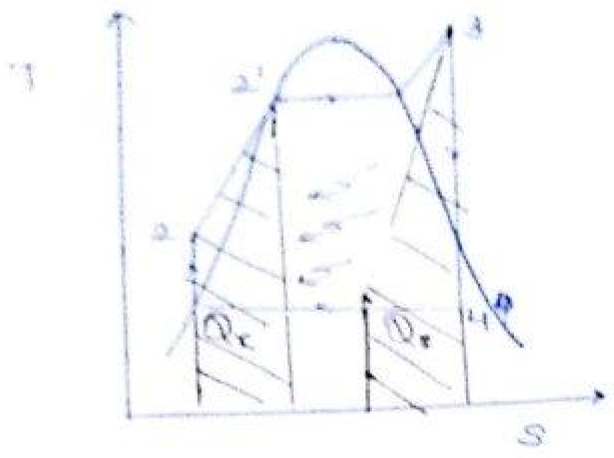
$Q_R = 147.27 MW$

$P = \dot{m}_s \cdot W_{net}$

$100\times10^6 = \dot{m}_s \cdot 1524.24$

$M_s = 2.36\times10^5\ kg/hr$

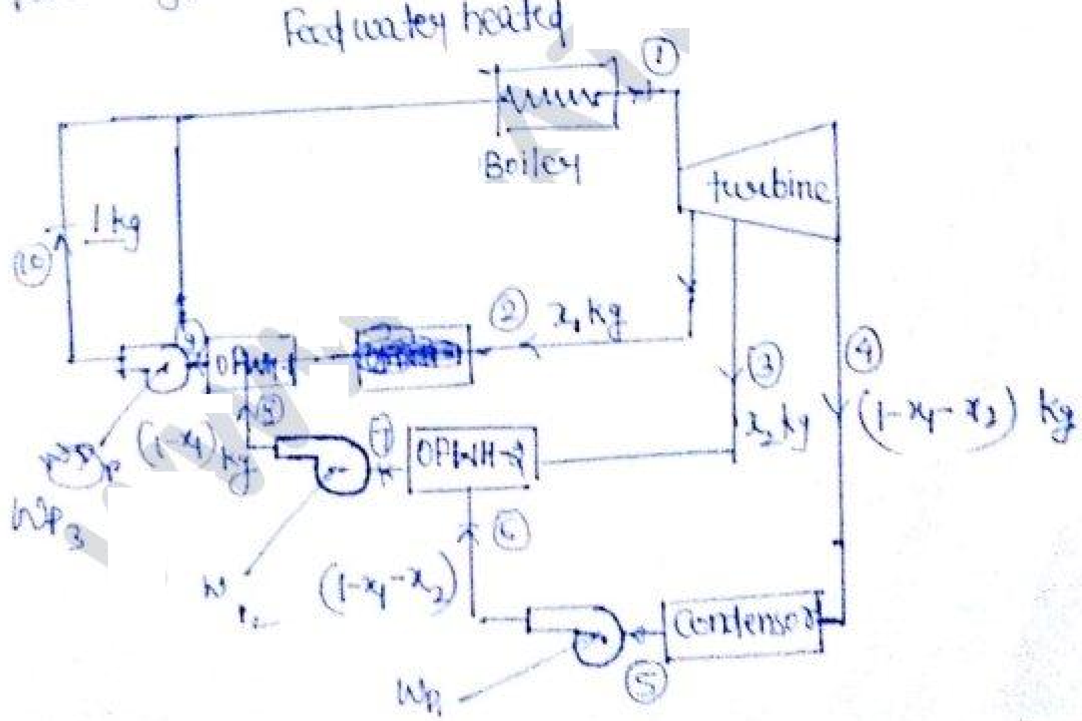
Regeneration :—

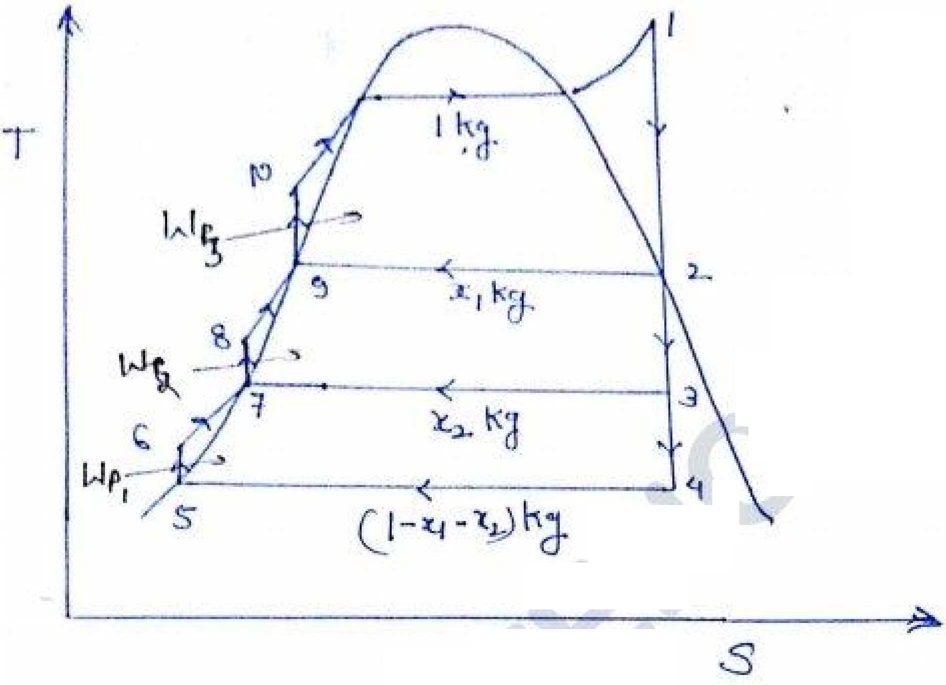


The ideal regenerative cycle heat is exchange internally b/w high temp steam expanding in turbine and the feed water before entering in the boiler

ideal regerative cycle is not possible as heat exchange inside the turbine can not be designed and if possible then also the problem of blade erosion will be higher (x less)

In actual working high temp. Steam is extracted from intermidiate stages which is utilised for feed water heating. There are two types of FWH (i) open or direct contact type FWH



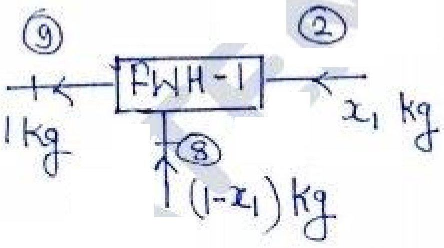


$$W_T = (h_1-h_2) + (1-x_1)(h_2-h_3) + (1-x_1-x_2)(h_3-h_4) \ \frac{kJ}{kg} \text{ of stea}$$

$$W_P = (1-x_1-x_2)W_{P_1} + (1-x_1)W_{P_2} + W_{P_3}$$

$$Q_S = h_1 - h_{10}$$

For OFWH-1



$$E_{in} = E_{out}$$

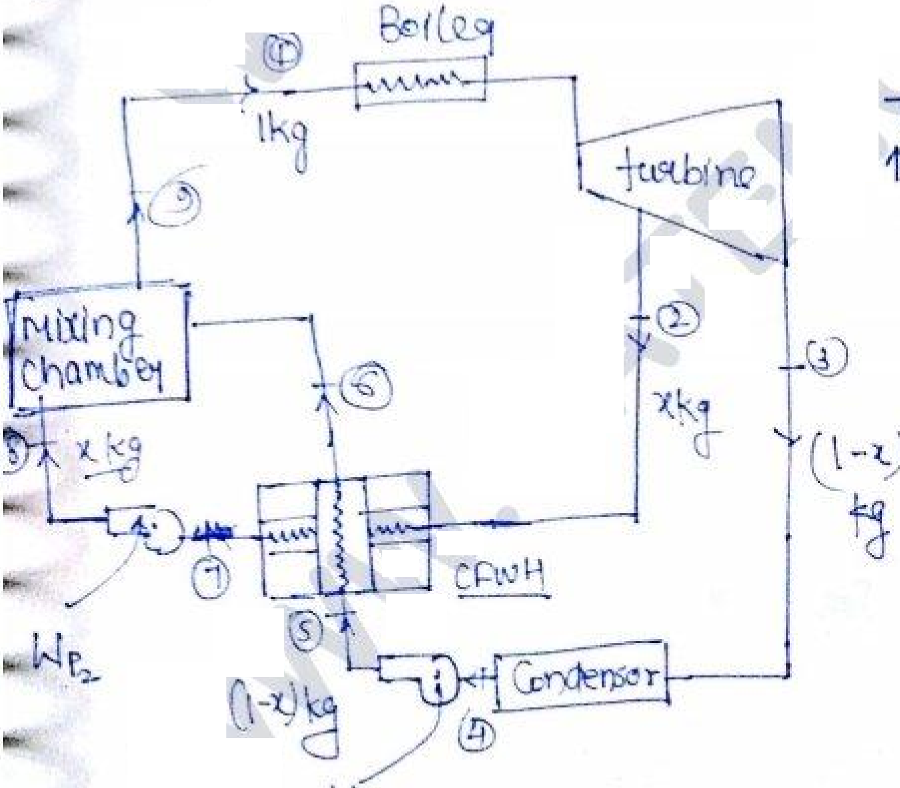
$$\boxed{x_1 h_2 + (1-x_1)h_8 = h_9}$$

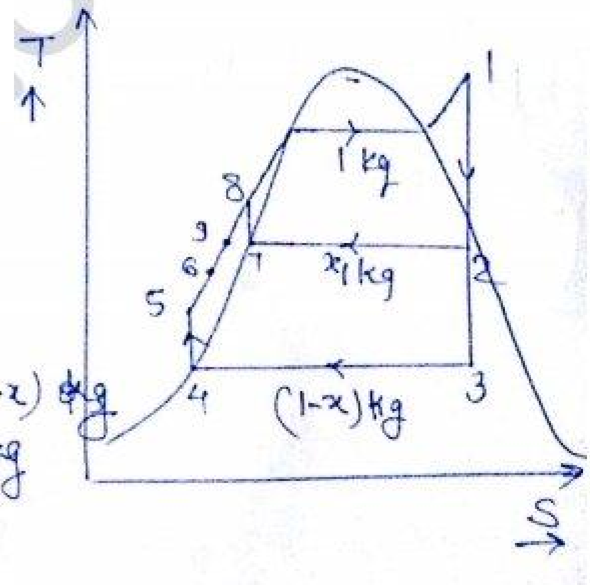
For OFWH-2

$$\boxed{x_2 \cdot h_3 + (1-x_1-x_2)h_6 = (1-x_1)h_7}$$

i) Open feed water heater:- it is basically a mixing chamber where high temp steam is mixed with feed water to get equilibrium Condition. There is always loss of energy due to mixing. Therefore two steams are mixed at equal pressure these are not preferred as the number of box required will be more along with losses due to mixing. Now a days only one OFWH is used known as deaerator and it's purpose is to remove the air from the feed water at that get mixed with feed water in condensor.

(ii) Closed feed water heater:-(indirect contact type)





These FWH are proper heat exchanger where heat is transferred from ~~extracted~~ expanded steam to the feed water without mixing taking place. As the two steam do not mix they can be kept at different pressure

$$W_T = (h_1 - h_2) + (1-x)(h_2 - h_3) \ \frac{kJ}{kg} \text{ of steam}$$

$$W_p = (1-x) W_{p_1} + x \cdot W_{p_2}$$

$$Q_s = h_1 - h_9$$

for CFWH $E_{in} = E_{out}$

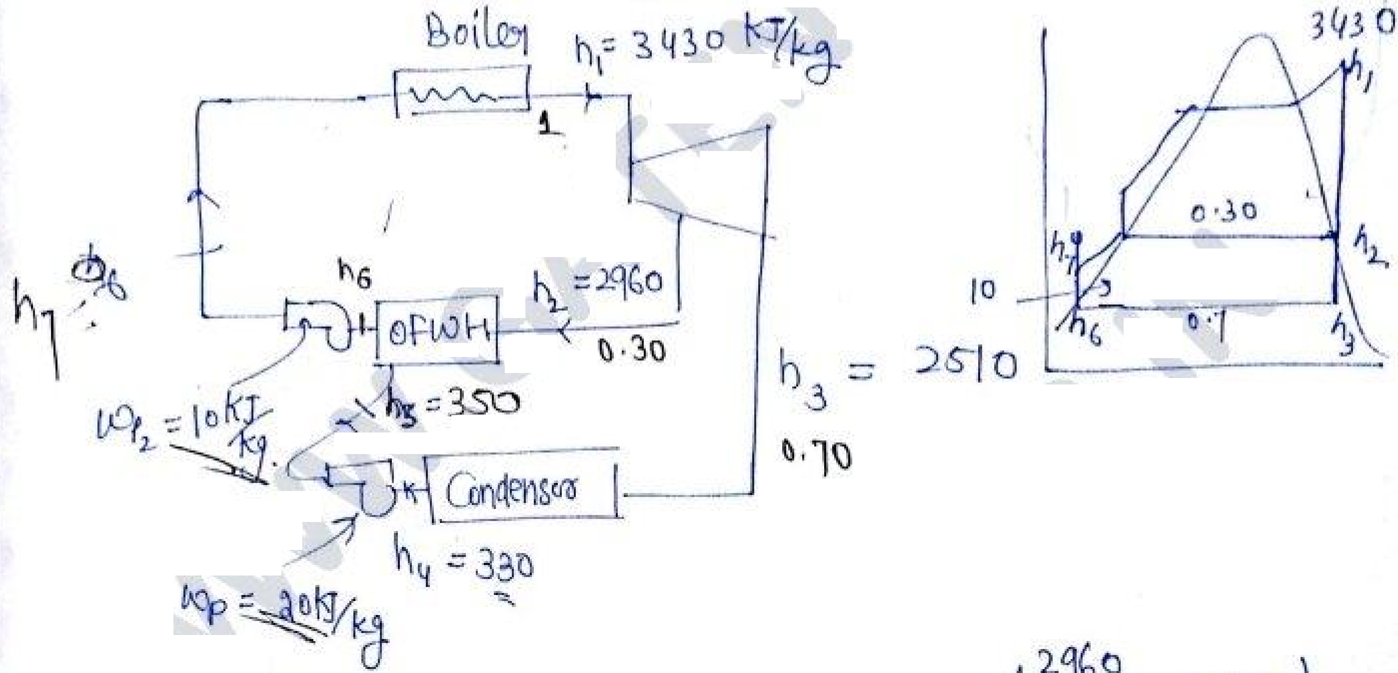
$$x \cdot h_2 + (1-x) h_5 = x \cdot h_7 + (1-x) h_6$$

Effects of Regeration :—

1. cycle efficiency increase (heat rate decrease).
2. for the same steam flow rate turbine output decreases.
3. It decrease steam flow to the condensor thus requiring smaller condensor.
4. for the same power output steam flow rate required increase thus requiring bigger boiler.
5. it provides ~~the~~ a convenient method of removing air from fee water.

⑥ it helps to control large volume flow rate at the lower stages of turbine expansion.

Ques for the regenerative cycle as shown below find the efficiency when the steam extracted is 30% of total steam generator. Also find efficiency without regenerator.



~~$W_T = 0.3(2960 - 3430 - 2960) + 0.70(3430 - 2510)$~~

~~$W_T = 785$ KJ/kg~~

with regen $\quad x h_2 + (1-x) h_5 = h_6$

$$0.3 \times 2960 + 0.7 \times 350 = h_6$$

$$h_6 = 1133 \text{ KJ/kg.} \qquad h_7 = 1143 \text{ KJ/kg.}$$

$$W_T = (h_1 - h_2) + (1-x)(h_2 - h_3)$$

$$= (3430 - 2960) + 0.7(2960 - 2510) = 785 \text{ KJ/kg}$$

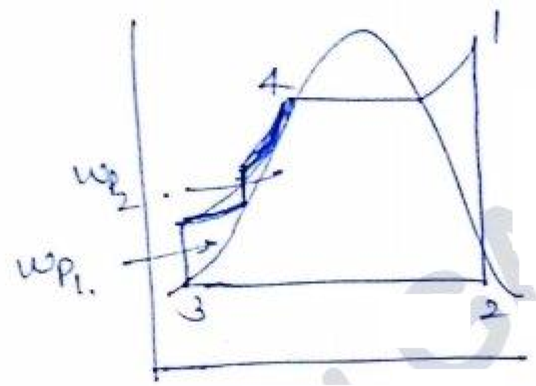
$W_p = 0.7 \times 20 + 10 = 24 \text{ KJ/kg}$

$Q_s = h_1 - h_7 = 3430 - 1143$

$Q_s = 2287 \text{ KJ/kg}$

$\eta = 33.27\%$

without regeneration



$$\eta = \frac{(h_1 - h_2) - 30}{h_1 - h_4}$$

$$\eta = \frac{(3430 - 2510) - 30}{3430 - 360}$$

$\eta = 29\%$

Q.34
Pg 32
WB

at OFWH

$z \cdot h_{12} + (1-y-z) h_2 = (1-y) h_3$ — (1)

at CFWH $(1-y) h_4 + y\, h_{10} = (1-y) h_5 + y \cdot h_6$ (2)

$(1-y)\, 643.92 + y \times 3155 = (1-y)\, 1087.4 + y \times 1087.4$

$643.92 - 643.92y + 3155y = 1087.4 - 1087.4y + 1087.4y$

$y = 0.176 \text{ kg/kg stm}$

$$Z(3014.5) + (1 - 0.176 - Z)\,192.30 = (1 - 0.176)\,640.1$$

$$3014.5\,Z + 0.823 \times 192.30 - Z\,192.30 = 526.87$$

$$Z = 0.1306 \text{ kg/kg stem}$$

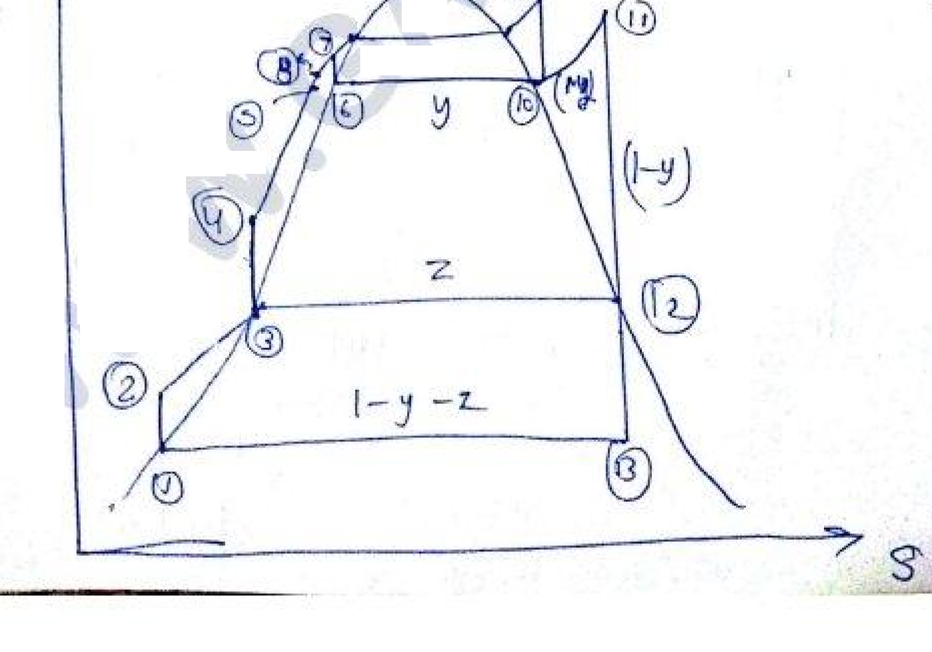
$$W_T = (h_9 - h_{10}) + (1-y)(h_{11} - h_{12}) + (1-y-z)(h_{12} - h_{13})$$

$$= 1444. \text{ kJ/kg}$$

$$W_p = (1-y-z)\,w_p + (1-y)\,w_p + y\,w_p = 5.92 \text{ kJ/kg}$$

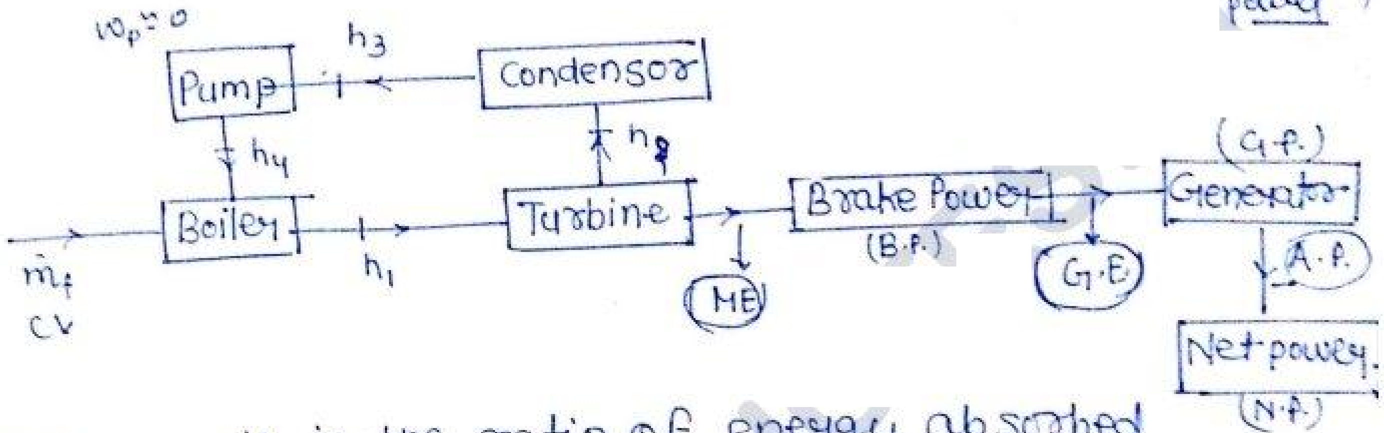
$$Q_s = (h_9 - h_8) + (1-y)(h_{11} - h_{10}) = 2924.2$$

$$\eta = \frac{W_T - W_p}{Q_s} = 49.2\%$$



Efficiency in steam power plant:

Ap - Auxiliary power



1) η_{boiler}: it is the ratio of energy absorbed by water to get converted in vapour to the energy release by Combustion of Fuel

$$\eta_{boiler} = \frac{\dot{m}_s(h_1 - h_4)}{\dot{m}_f \cdot CV}$$

$\eta_{boiler} \simeq 92\%$

2) Cycle efficiency:– it is the ratio of net work output to the heat supplied.

$$\eta_{cycle} = \frac{\dot{m}_s(h_1 - h_2)}{\dot{m}_s(h_1 - h_4)}$$

$\eta_{cycle} \simeq 40 \text{ to } 44\%$

3) Mechanical efficiency:– $\eta_{mech} = \frac{\text{Brake power output}}{\text{Net work of Cycle}}$

$$\eta_{mech} = \frac{B.P.}{\dot{m}_s(h_1 - h_2)}$$

$\eta_{mech} \simeq 95\%$

4) Generator efficiency :-

$$\eta_{gen} = \frac{G.P.}{B.P.} \qquad \eta_{gen} \simeq 92 \text{ to } 95\%$$

5) Auxiliary efficiency :

$$\eta_{auxiliary} = \frac{\text{Net Power}}{G.P.} \qquad \eta_{aux} \simeq 95\% \text{ to } 96\%$$

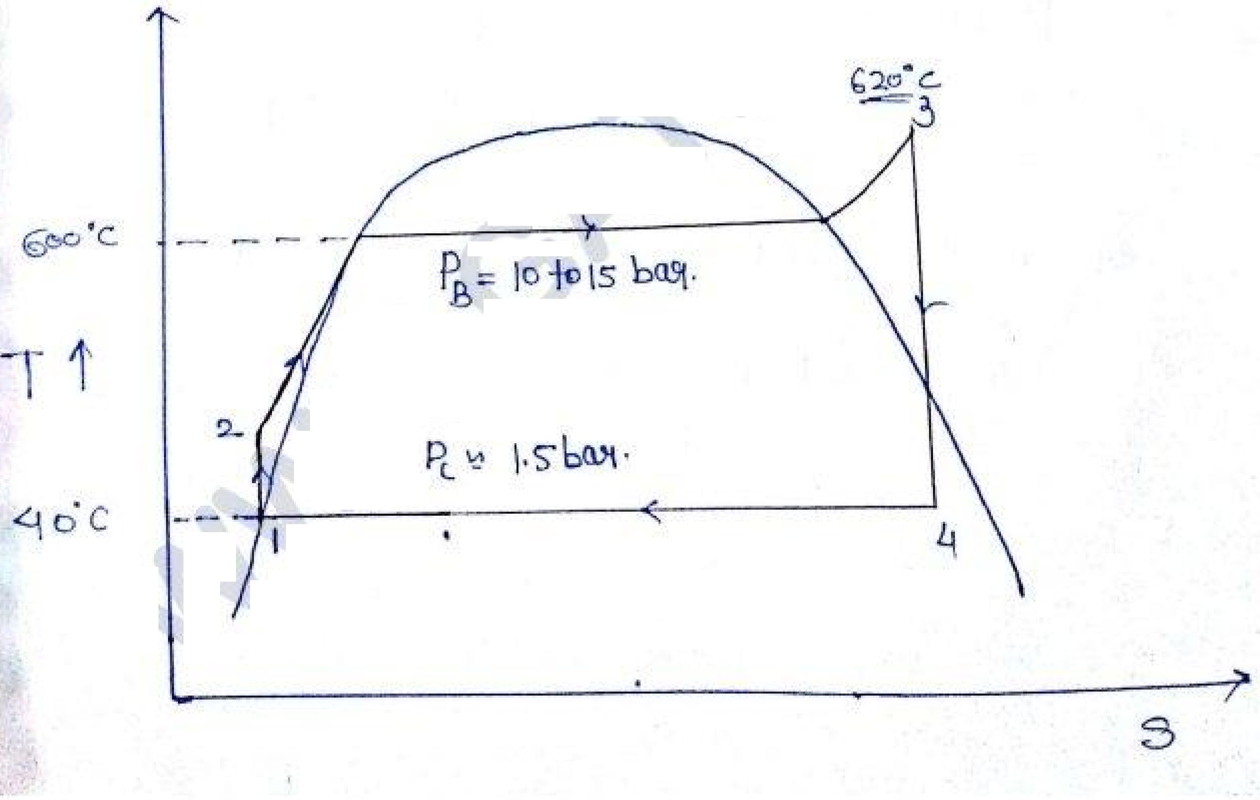
6) $$\eta_{overall} = \frac{\text{Net power of plant}}{\text{energy released by Fuel}}$$

$$\eta_{over} \simeq 35\% - 37\%$$

$\eta_{aux} = 1$ (if not given)

$$\boxed{\eta_{overall} = \eta_{boiler} \times \eta_{cycle} \times \eta_{mech} \times \eta_{gen} \times \eta_{aux}}$$

Characteristics of ideal working Fluid :-



→ specific heat of liquid should be small in order to decrease heat transfer require to raise liquid to boiling point.

→ it should have high critical temp. so that the saturation pressure at the max. temp. should be low.

→ it should have large enthapy of vapourisation

→ saturation pressure at the temp. of heat rejection should be above atmospheric pressure to avoid the need of maintaining vaccume in condenser.

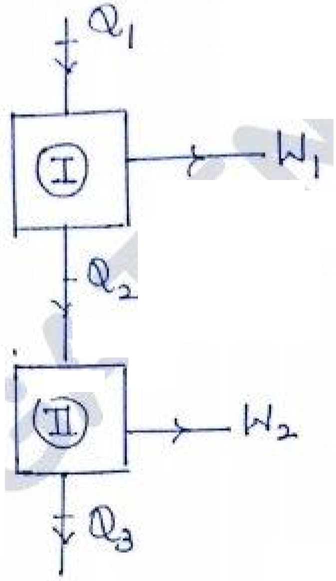
→ Fluid should have steam saturated vapour line to reduce moisture in the lower stage.

→ freezing point of fluid should be below room temp. so that it does not get solidified while ~~going~~ flowing through the pipe line.

→ Fluid should be chemically stable, No-toxic, non-corrosive, easily available and cheap.

Binary or 2-Fluid Cycle :-

Two ~~worki~~ different working fluid cycles are coupled in series such that heat rejected by one cycle works as source of energy for other cycle:



$$\eta_I = 1 - \frac{Q_2}{Q_1}$$

$$\boxed{Q_2 = (1-\eta_I)\cdot Q_1}$$

$$\eta_{II} = 1 - \frac{Q_3}{Q_1}$$

$$\boxed{Q_3 = (1-\eta_{II})\cdot Q_2}$$

overall eff. of cycle.

$$\eta = 1 - \frac{Q_3}{Q_1}$$

$$\eta = 1 - \frac{(1-\eta_{II})\cdot Q_2}{Q_1} = 1 - \frac{(1-\eta_I)(1-\eta_{II})\,Q_1}{Q_1}$$

$$\boxed{(1-\eta) = (1-\eta_I)(1-\eta_{II})} \; ---$$

Note: Total losses will be equal to product of losses of all the cycle in series.

$$\Rightarrow ** \quad \boxed{\eta = \eta_I + \eta_{II} - \eta_I\cdot\eta_{II}}$$