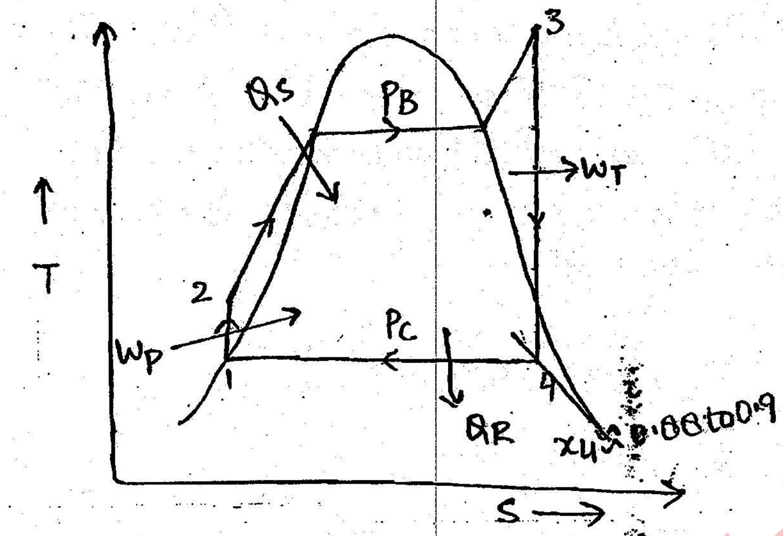
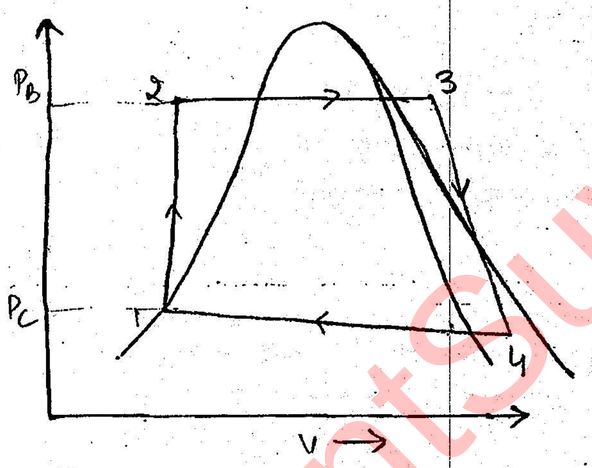
VAPOUR POWER CYCLE OR RANKINE CYCLE

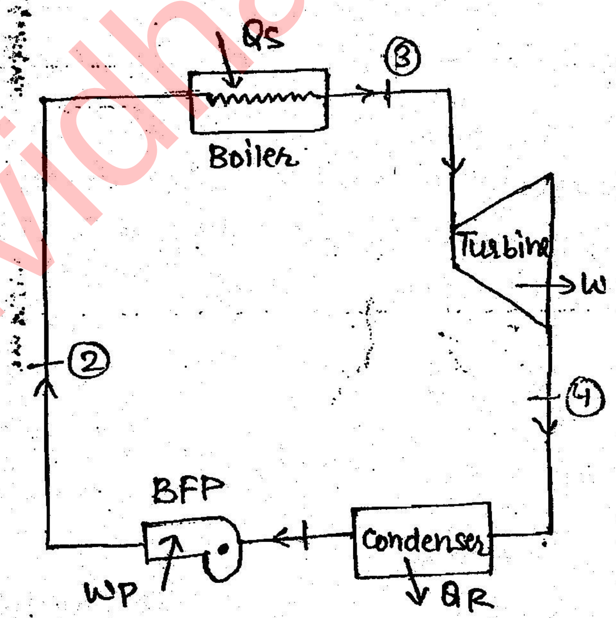


$n = 1.3$ → superheated steam.

$n = 1.135$ → saturated steam

$n = 1.035 + 0.1x$ → wet





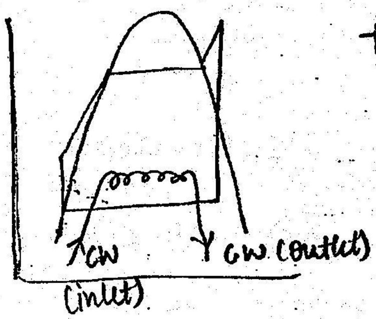
Rankine cycle is a practical working cycle for thermal power plant and it consist of four process.

Process 1-2 → isentropic compression of liquid from condenser to Boiler pressure in Boiler Feed pump.

Process 2-3 → Constant pressure heat addition process in the boiler to convert liquid into superheated steam.

Process 3-4 → isentropic expansion in the turbine from boiler to condenser pressure

Process 4-1 → Constant pressure heat rejection process in the condenser to get saturated water.



जितना temp कम होगा condenser में की saturation pressure भी कम होगा। जिससे volume increase होजाएगा (from P-V diagram) और workdone = vdp जिससे ज्यादा ही ज्यादा work मिलेगा। This is the reason thermal power plant is more efficient in winter than summer.

But limiting condition of decreasing pressure → $x = 0.9$ [Because of inertia]
dryness fraction never less than 0.9
) temp can't be less than the CW temp.

Why should we decreased Q_R (Rejection) in condenser $Q_s \times 0.6 = Q_R$
Because there is no pump which work on (vapour and liquid)
Volume at the exit of turbine is more ∴ pump work is more
Condenser decrease volume = 16000 गुना कम कर देता है।
• Air infilteration • cavitation.

$W_T = h_3 - h_4$

$\boxed{W_{net} = Q_s - Q_R = W_T - W_p}$

$W_p = h_2 - h_1 = v_{f1}(P_B - P_c)$

$h_3 = 3240\ kJ/kg$

$Q_s = h_3 - h_2$

Take Triple point of water as a refrence to a required temp → given energy to 1 kg.

$Q_R = h_4 - h_1$

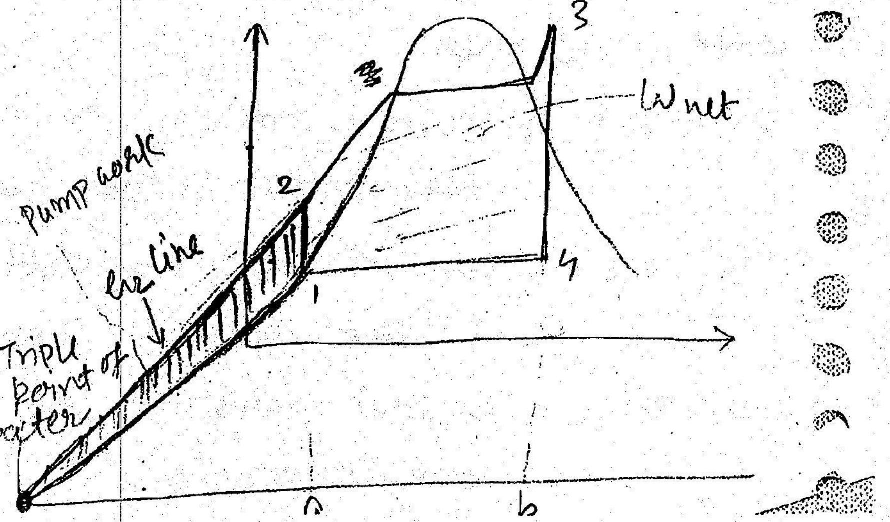
$W_{net} = W_T - W_p$

$$\boxed{\eta = \frac{W_{net}}{Q_s}}$$

$W_{net} = W_T - W_p$

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

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



Steam Rate OR Specific steam consumption :-

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It is the mass flow rate of steam required to produce 1 kw net power output.

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

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

$$\boxed{SSC = \frac{1}{W_{net}}} \ kg/kws \text{ or } kg/kJ \qquad \boxed{SSC = \frac{3600}{W_{net}}} \ kg/kwh$$

Heat Rate :-

It is the rate of Heat input required to produce 1 kw power output.

$$HR = \frac{\text{Heat input in kw}}{\text{Power Output in kw}}$$

$$HR = \frac{\dot{m}_s Q_s}{\dot{m}_s W_{net}}$$

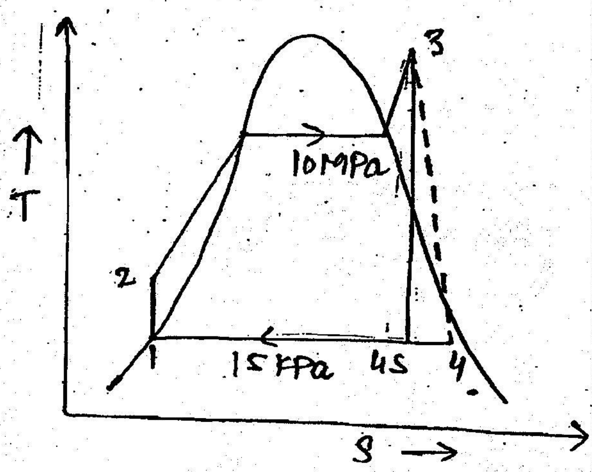
$$\boxed{HR = \frac{Q_s}{W_{net}} = \frac{1}{\eta}}$$

PB:- In a thermal power plant operating on Rankine cycle steam enter the turbine at 10MPa, 400°C and exit at a pressure of 15 KPa then it enters a condenser and exit as saturated water. next the pump feed the water back to the boiler. The η of turbine is 90% and the enthalpy of water and steam is as given below. The flow rate is 120kg/min then find -

(1) Net power output of the cycle in MW
(2) Efficiency of the cycle.

	h (kJ/kg)	s (kJ/kg K)	v (m³/kg)
Steam 10 MPa, 400°C	3092.5	6.5821	0.06645

water 15 kPa	h_f	h_{fg}	s_f	s_g	v_f	v_g
	225.94	2599.1	0.7549	8.0085	0.001014	10.02



$S_3 = S_{4s}$

$6.5821 = S_f + x_{4s}(S_g - S_f)$

$x_{4s} = 0.803$

$h_{4s} = h_f + x_{4s}(h_{fg} - h_f)$

$h_{4s} = 2132.42 \text{ KJ/Kg}$

$\eta_T = \dfrac{h_3 - h_4}{h_3 - h_{4s}} = 0.9$

$h_4 = 2228.4 \text{ KJ/Kg}$

$h_3 = 3092.5 \text{ KJ/Kg}$

$h_1 = 225.94$

$W_p = h_2 - h_1 = V_{f_1}(P_B - P_c)$

$= 0.001014(10 \times 10^3 - 15)$

$W_p = 10.12 \text{ KJ/Kg}$

Now $h_2 = 236 \text{ KJ/Kg}$

① $P = \dot{m}[(h_3 - h_4) - W_p]$

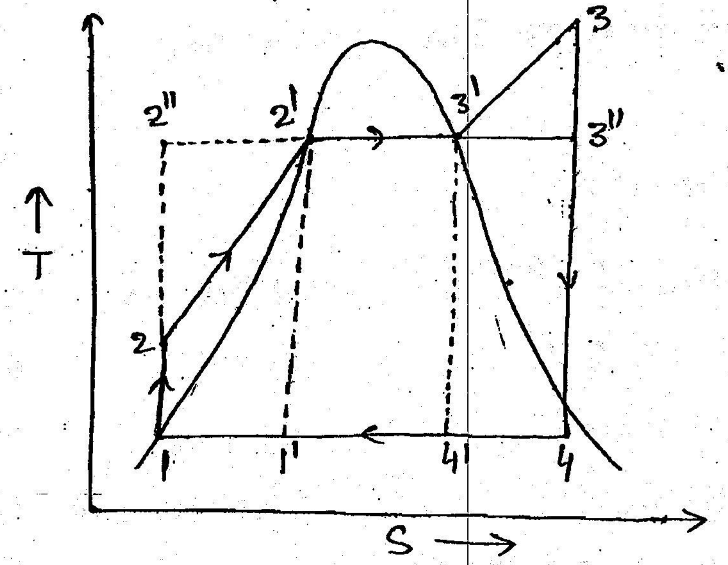
$P = 2[(h_3 - h_4) - W_p]$

$\boxed{P = 1.707 \text{ MW}}$

② $\eta = \dfrac{(h_3 - h_4) - W_p}{(h_3 - h_2)}$

$\boxed{\eta = 29.89\%}$

CARNOT CYCLE IN THERMAL POWER PLANT :-



Rankine → 1-2-3-4

carnot cycle → 1'-2'-3'-4'

OR

1-2''-3'-4'

OR

1'-2''-3''-4

Carnot cycle is not practical in thermal power plant due to following reason –

- The dryness fraction at the end of turbine expansion will be very less and there will be problem of blade erosion. (process 3'-4')
- It is not possible to control condensation process in such a manner to get the desired quality of steam as given by state 1'.
- It is not possible to design a pump which can handle liquid vapour mixture phase.
- pump work is always more for carnot cycle.
- It is not possible to add heat at constant temp. but with decreasing pressure.

$\eta_{carnot} > \eta_{Rankine}$

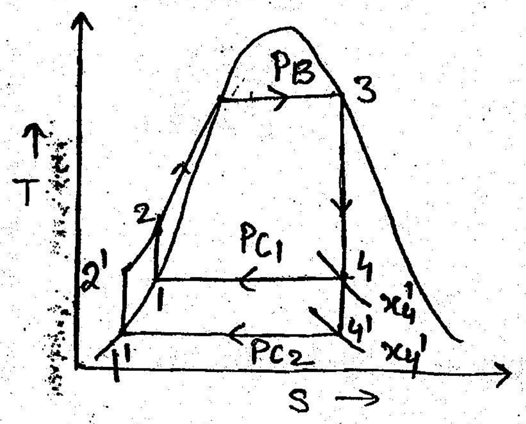
$W_{net\,Rankine} > W_{net\,carnot}$

$(W_{pump})_{carnot} > (W_{pump})_{Rankine}$

Efficiency of Rankine cycle :-

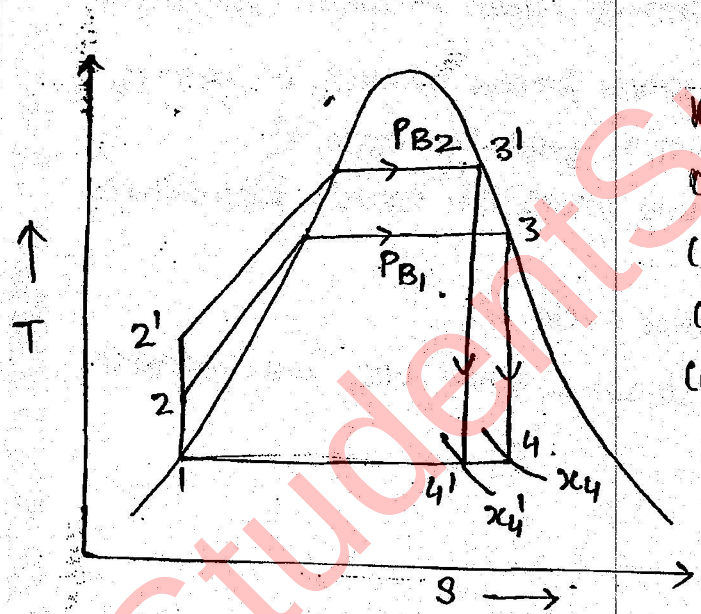
η can be increased by either increasing mean temp. of heat addition or by decreasing mean temp. of heat rejection and it can be obtained by →

1) Decreasing the condenser pressure. ($P_c \downarrow$)



(1) $w_p \uparrow$ (can not say)
(2) $w_T \uparrow\uparrow$
(3) $w_{net} \uparrow$
(4) $Q_S \uparrow$
(5) $Q_R \uparrow$ (can not say)
(6) $T_{mA} \downarrow$
(7) $T_{mR} \downarrow\downarrow$
(8) $\eta \uparrow$
(9) $x \downarrow$
(10) Moisture $\uparrow$

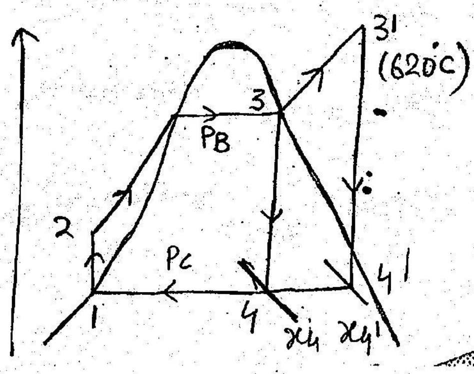
2) Increasing Boiler pressure ($P_B \uparrow$)



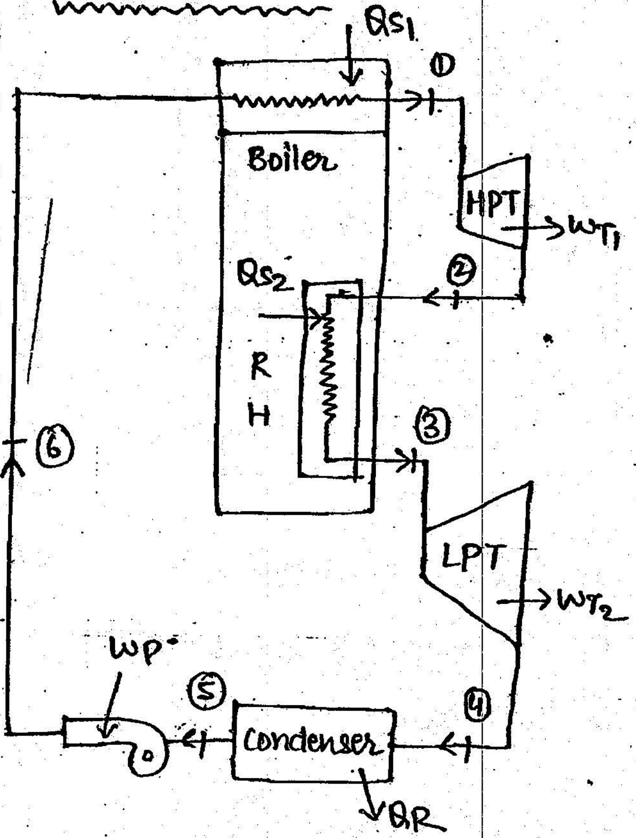
(1) $w_p \uparrow$
(2) $w_T \uparrow\uparrow$
(3) $w_{net} \uparrow$ ($\dot{m}_s \downarrow$)
(4) $Q_S \downarrow$ (Can not say)
(5) $Q_R \downarrow$
(6) $T_{mA} \uparrow$
(7) T_{mR} Same
(8) $\eta \uparrow$
(9) $x \downarrow$ (10) Moisture $\uparrow$

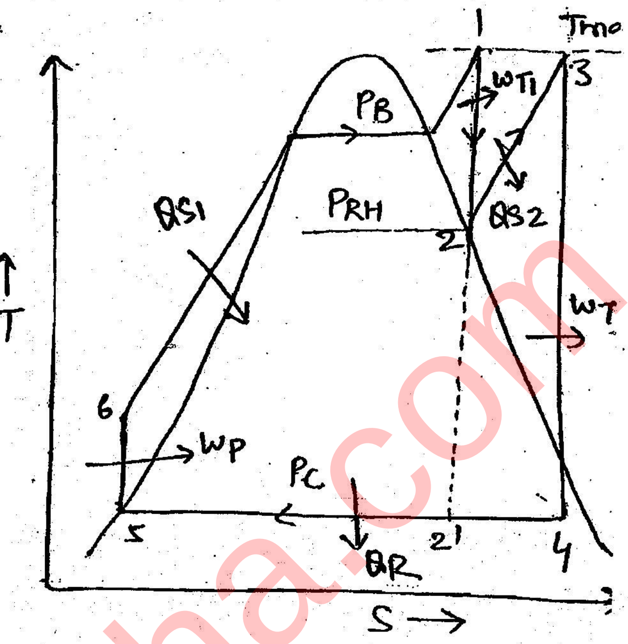
3) Superheating :- (max^m temp. 620°C)

1) w_p same
2) $w_T \uparrow$
3) $w_{net} \uparrow$
4) $Q_S \uparrow$ (3-3')
(5) $Q_R \uparrow$ (4-4')
(6) $T_{mA} \uparrow$
(7) T_{mR} same
(8) $\eta \uparrow$
(9) $x \downarrow \uparrow$
(10) Moisture $\uparrow\downarrow$



REHEAT CYCLE :-





Pressure of Reheat = 20% to 25% of PB

(1) Wp – same
(2) WT → ↑
(3) Wnet – ↑
(4) Qs – ↑
(5) QR – ↑
(6) TmA – ↑ (upto 20% to 25% of PB)
(7) TmR – same
(8) $\eta \propto T_{mA}$
(9) x ↑
(10) moisture ↓

Reheating is the process in which the total expansion of steam from boiler to condenser pressure takes place in more than one stages with reheating of steam in b/w the stages.

The main advantage of Reheat cycle is that it increases the dryness fraction at lower stages and makes it possible to use higher boiler pressure. With the reheater pressure we can regulate the dryness fraction required at the lower stages of turbine expansion and is normally preferred during initial design.

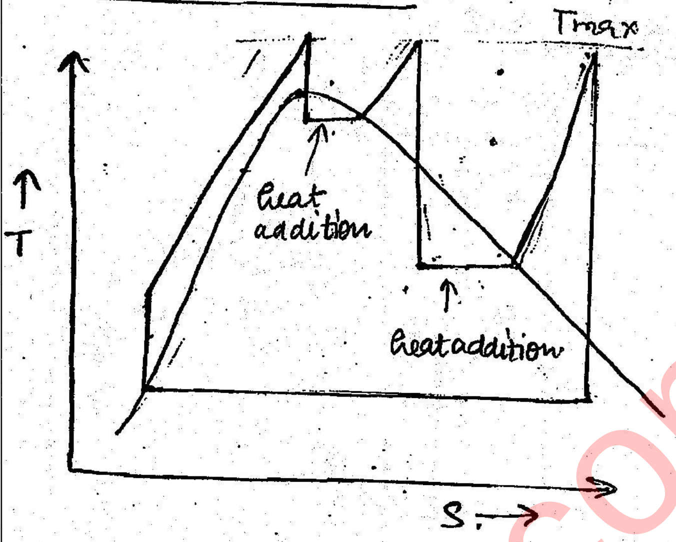
$$\boxed{\begin{array}{l} P_{RH}\downarrow \rightarrow x\uparrow \\ P_{RH}\uparrow \rightarrow x\downarrow \end{array}}$$

$$W_{net} = W_{T_1} + W_{T_2} - W_p$$

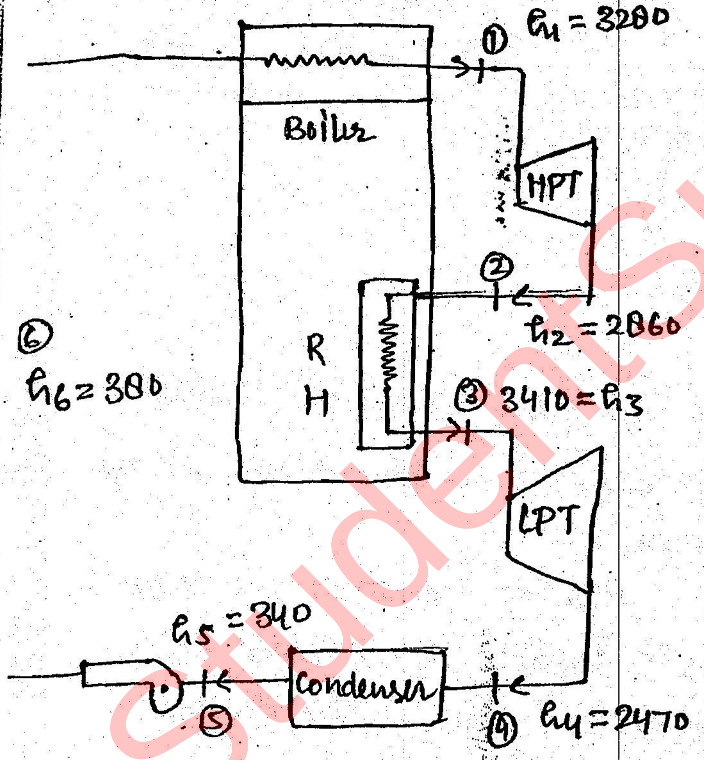
$$Q_s = Q_{s_1} + Q_{s_2}$$

$$\boxed{\eta = \frac{W_{net}}{Q_s}}$$

Super critical Boiler



B. For the reheat cycle as shown below find the η and the net power output when steam flow rate is 800 kg/min and the enthalpy are given in kJ/kg. Take pump work as 40 kJ/kg.



(1) $$\eta = \frac{W_{T_1} + W_{T_2} - W_p}{Q_{s_1} + Q_{s_2}}$$

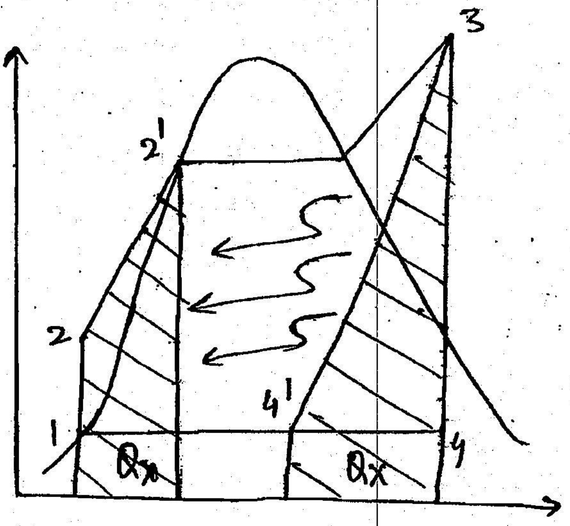
$$= \frac{(h_1 - h_2) + (h_3 - h_4) - 40}{(h_1 - h_6) + (h_3 - h_2)}$$

$$\boxed{\eta = 38.26\%}$$

$$P = \dot{m}_s [W_{net}]$$

$$\boxed{P = 6.6\ MW}$$

REGENERATION :-

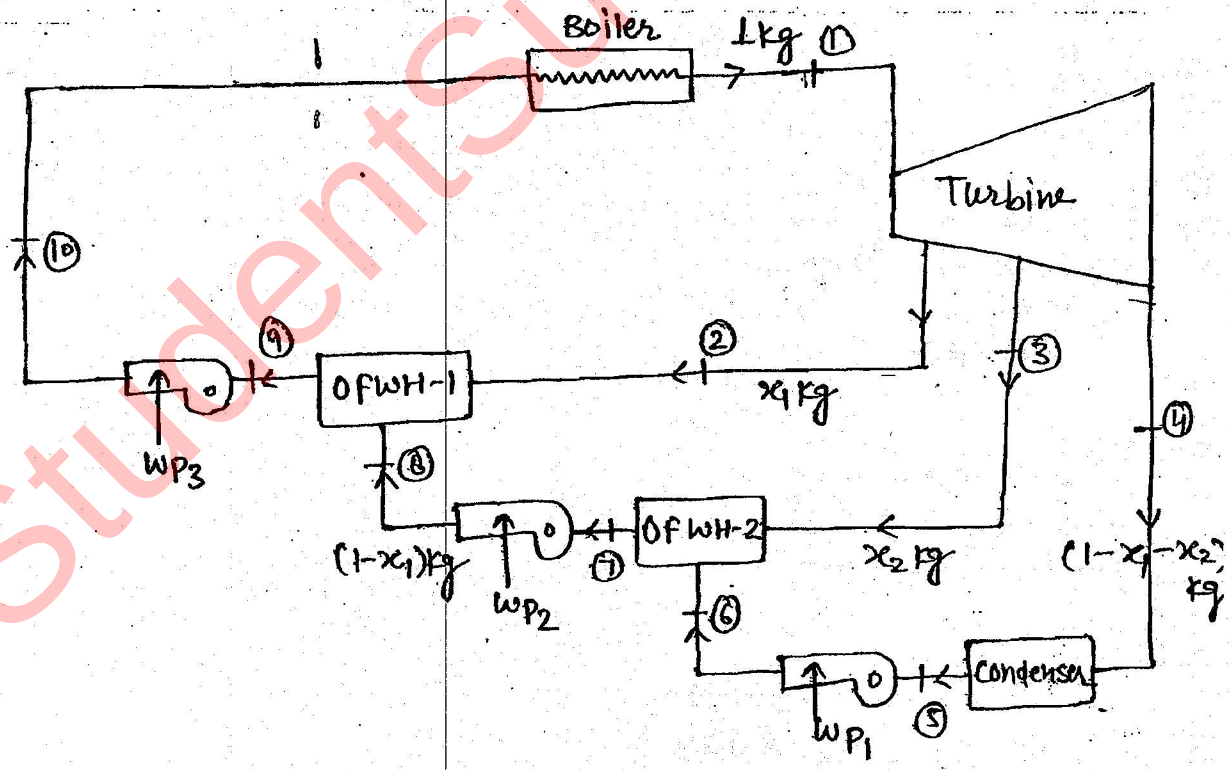


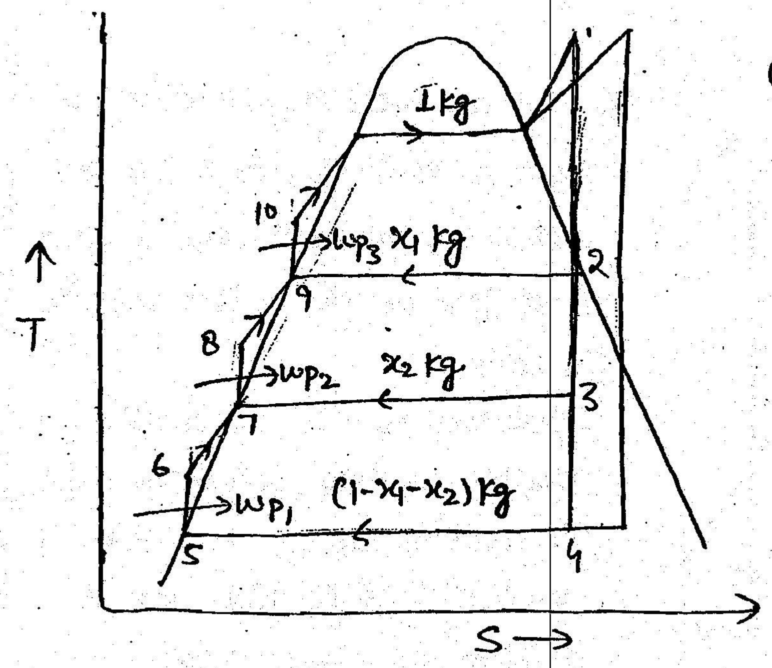
⊛ In an ideal Regenerative cycle heat is exchange internally b/w steam expanding in the turbine and feed water before entering the boiler.

Ideal cycle is not practically possible as heat exchanger inside the turbine can not be designed and if possible then also a problem of blade erosion will be higher.

⊙ In actual working High temp. steam is extracted from intermediate stage which is utilized for feed water heating which gives two types of feed water heater (FWH)

Open or Direct contact type FWH :-



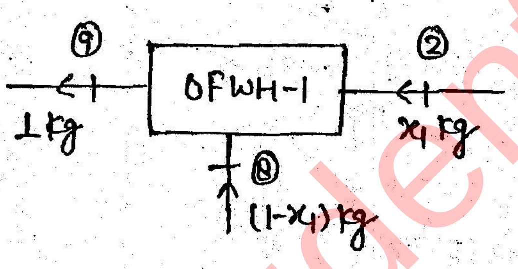


(*) This is not used because there is loss of energy and No. of pumps required to maintain the same pressure.

These FWH are basically mixing chamber where high temp. steam is mixed with feed water to get equalibrium condition. There is always loss of pressure due to mixing and to minimize the loss there is always mixed at equal pressure. (with the help of pump).

Now-a-days only one OFWH is used known as deaizator and its main purpose is to remove air from the feed water.

For OFWH-1



$E_{in} = E_{out}$

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

For OFWH-2

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

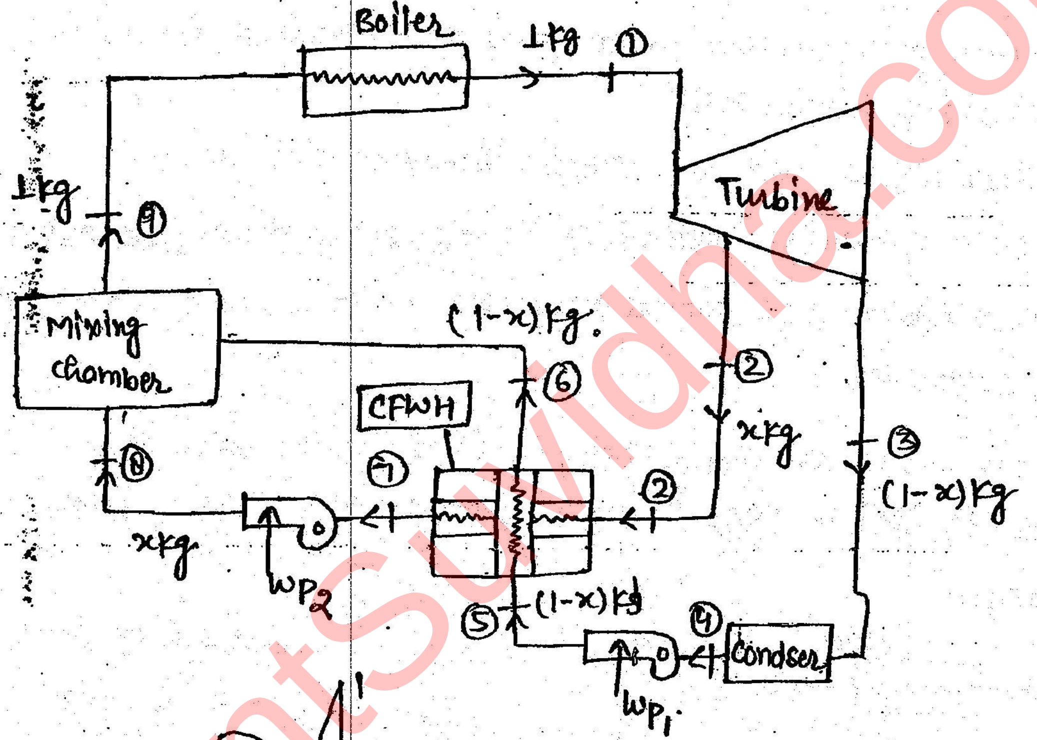
$$W_T = (h_1-h_2) + (1-x_1)(h_2-h_3) + (1-x_1-x_2)(h_3-h_4) \text{ KJ/kg of steam}$$

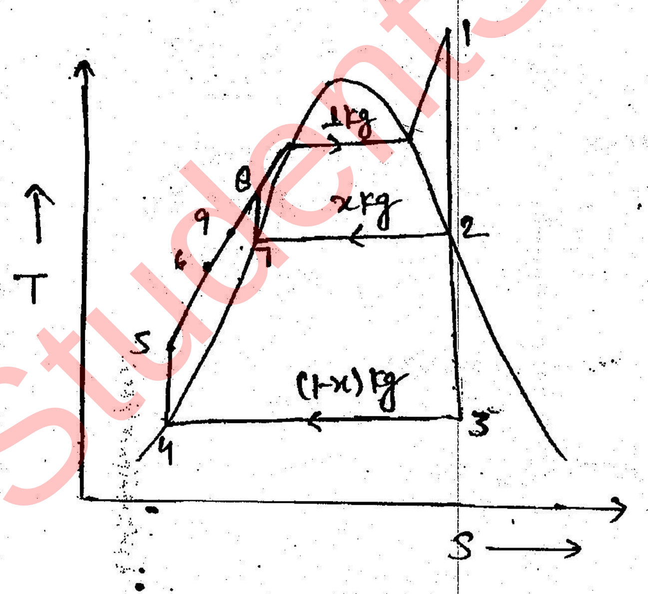
$$W_P = (1-x_1-x_2)W_{P_1} + (1-x_1)W_{P_2} + W_{P_3}$$

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

$\boxed{\eta \uparrow}$

Closed Feed water Heater :-





* These FWH are proper heat exchanger where high temp. steam is used to heat up the feed water without mixin taking place b/w the two steam. As they do not mix they can be kept at differen pressure.

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

$$W_P = (1-x)W_{P_1} + xW_{P_2}$$

$Q_s = h_1 - h_9$

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

$$\boxed{x h_2 + (1-x) h_5 = x h_7 + (1-x) h_6}$$

Effects of Regeneration :-

Cycle η increases. (heat rate decreases)

For the same steam flow rate turbine output decreases.

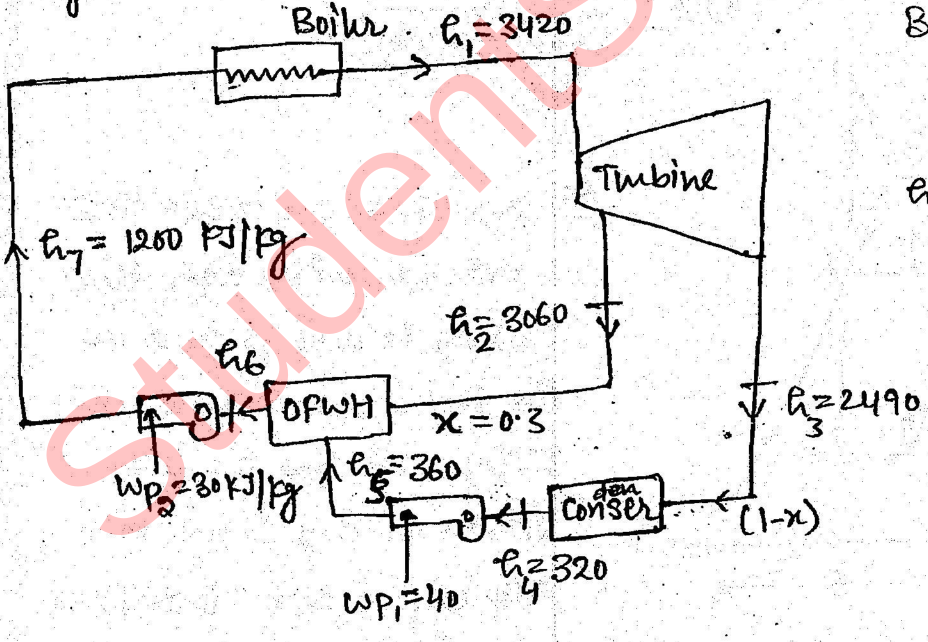
For the same power output steam flow rate required increases, thus requiring bigger boiler.

For the steam flow rate we require smaller condenser

It provides a convenient method of removing air from feed water

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

Q: For an OFWH as shown below. Find the η when steam extracted is 30% of total steam generated. Also find η without regeneration.



Because of 30%

$\therefore x = 0.3$

$h_7 = h_6 + wp_2$
$= 1170 + 30$
$= 1200$

With Regeneration

$x h_2 + (1-x) h_5 = 1 h_6$

$h_6 = 1170$ kJ/kg

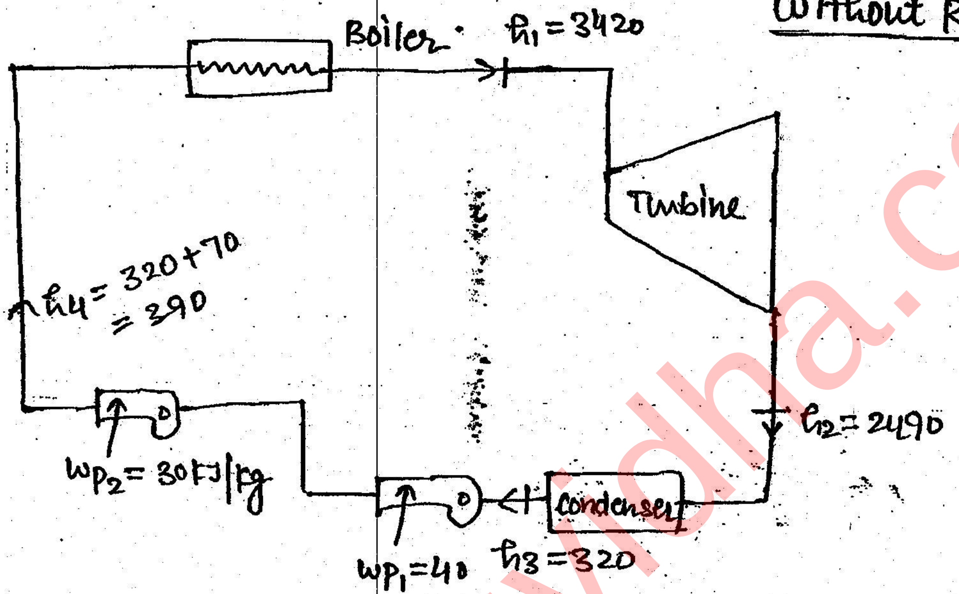
$$W_{net} = (h_1-h_2) + (1-x)(h_2-h_3) - (1-x)W_{P_1} - W_{P_2}$$

$$W_{net} = 701 \text{ KJ/kg}$$

$$Q_S = h_1 - h_7 = 2220 \text{ KJ/kg}$$

$$\eta = \frac{701}{2220} = 31.57\%$$

Without Regeneration



$$\eta = \frac{(h_1-h_2)-70}{(h_1-h_4)}$$

$$\boxed{\eta = 28.38\%}$$

Characterstic of Ideal working working fluid :-

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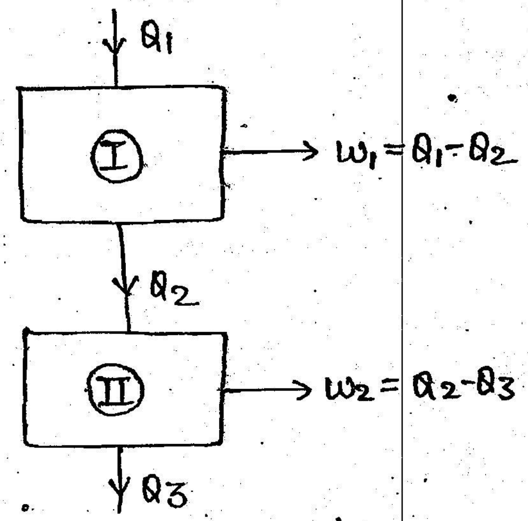
21/09/2016

Binary or two Fluid cycle :-

When two cycle with different working Fluid are coupled in series in such a manner that the heat rejected by one cycle is utilised by other.



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

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

$$\eta_{II} = 1 - \frac{Q_3}{Q_2}$$

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

combined cycle η

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

putting Q_3

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

putting value of Q_2

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

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

for Binary :-

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

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

$$\boxed{\eta = \eta_I + \eta_{II} - \eta_I \eta_{II}}$$

for n cycles in series

$$\boxed{(1-\eta) = (1-\eta_I)(1-\eta_{II})(1-\eta_{III}) \cdots\cdots (1-\eta_n)}$$