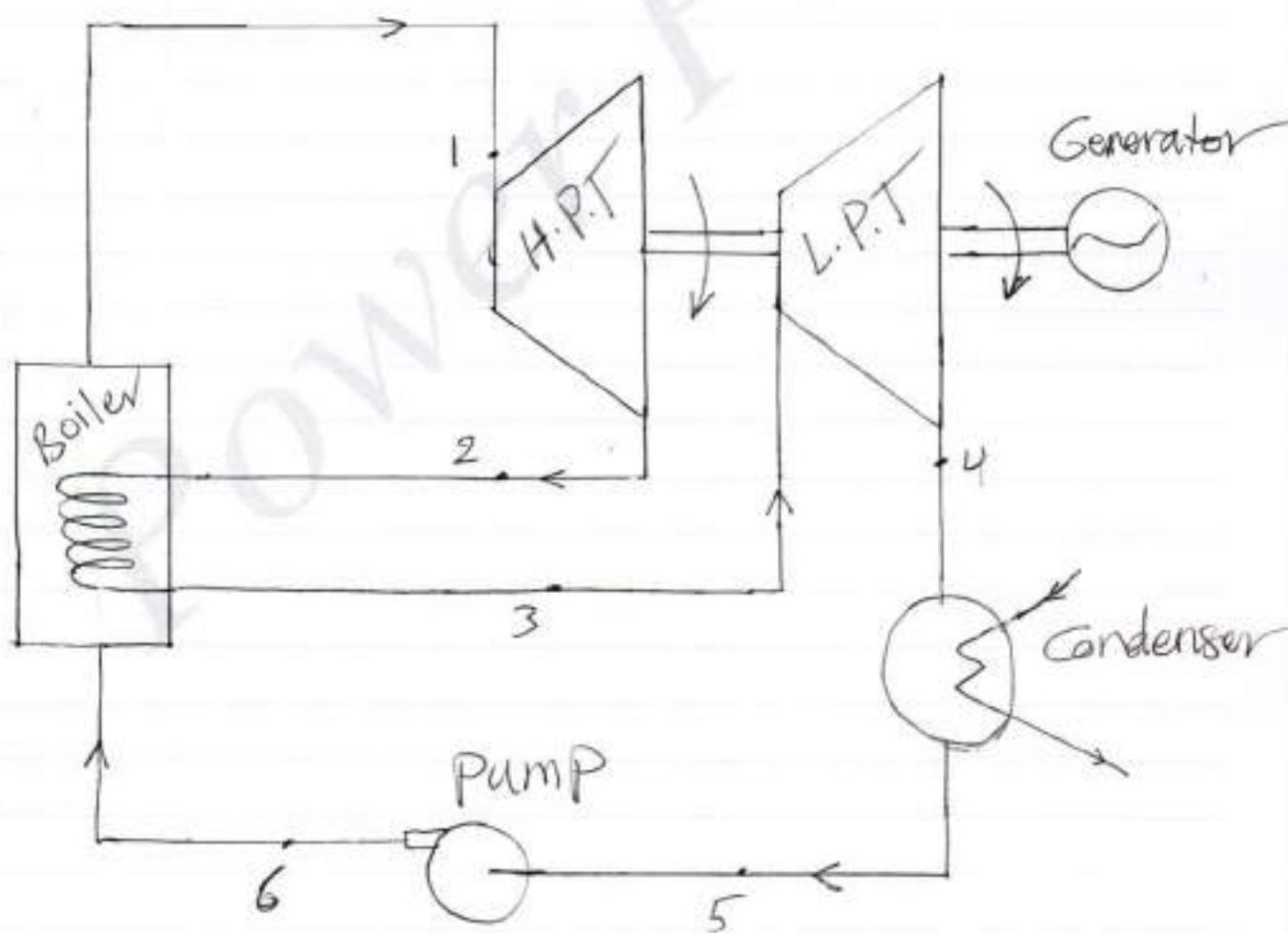


Power Plants

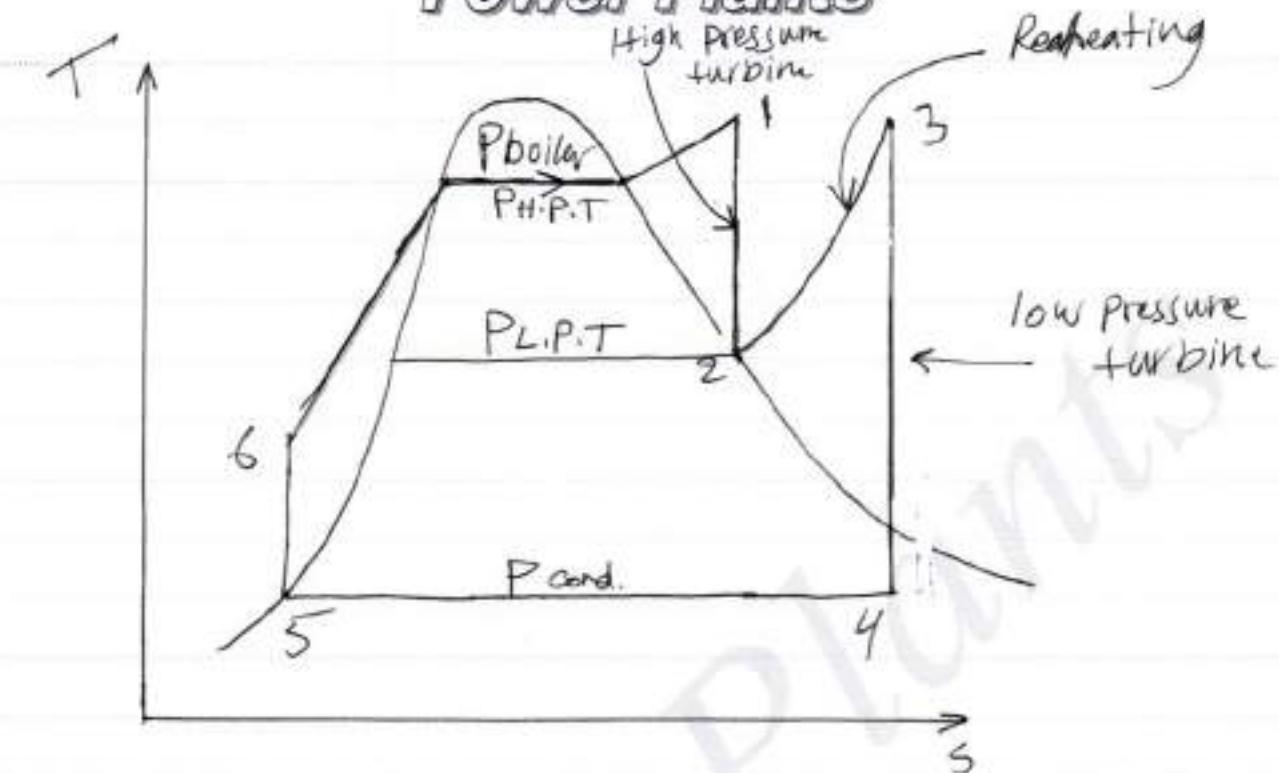
* Reheat Rankine Cycle

It is desirable to increase the temperature at which heat is supplied to the steam, and also to keep the steam as dry as possible in the lower stages of the turbine.

The ideal Rankine cycle differs from the simple ideal Rankine cycle in that the expansion process takes place in two stages.



Power Plants



(1-2) : high-pressure turbine stage, Steam is expanded isentropically to an intermediate pressure

(2-3) : Intermediate pressure , Steam is sent back to the boiler where it is reheated at constant pressure

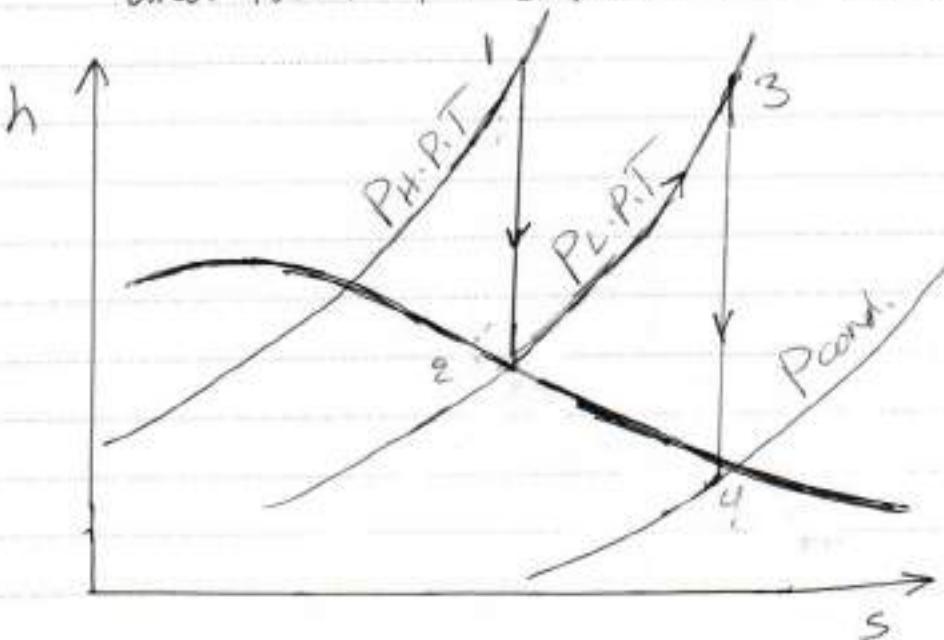
(3-4) : Low-pressure turbine stage , Steam is expanded isentropically to the condenser pressure.

(4-5) : Condenser pressure , Steam is cooled down to saturated liquid

(5-6) : Pump, water is pumped from condenser pressure to boiler Pressure.

Power Plants

(6-1) % Boiler pressure , heat is added to water and turn it to superheated steam.



Thermodynamic analysis of reheat cycle as shown on T-s and h-s representation are carried out as follows ~

$$W_{H.P.T} = h_1 - h_2$$

$$W_{L.P.T} = h_3 - h_4$$

$$W_{\text{pump}} = h_5 - h_6$$

$$W_{\text{net}} = (W_{H.P.T} + W_{L.P.T}) - W_{\text{pump}}$$

Power Plants

$$W_{net} = (h_1 - h_2) + (h_3 - h_4) - (h_5 - h_6)$$

$$Q_{add} = Q_{boiler} + Q_{reheating}$$

$$Q_{add} = (h_1 - h_6) + (h_3 - h_2)$$

$$\gamma = \frac{W_{net}}{Q_{add}}$$

$$\gamma = \frac{(h_1 - h_2) + (h_3 - h_4) - (h_5 - h_6)}{(h_1 - h_6) + (h_3 - h_2)}$$

Output Power of the Plant = $\dot{m}_s \cdot W_{net}$

\dot{m}_s = mass flow rate of the steam

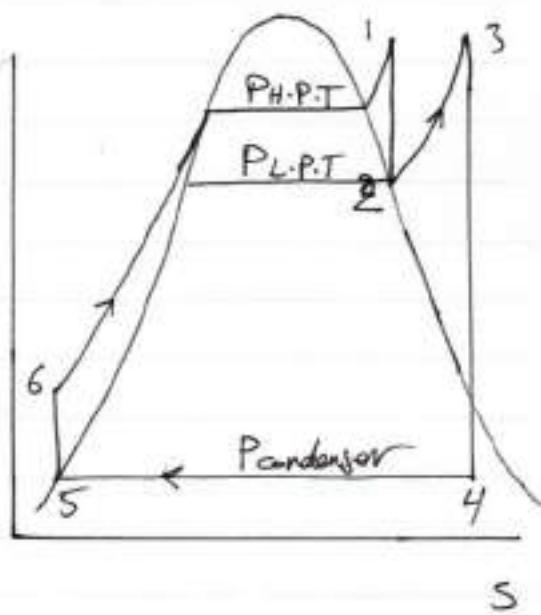
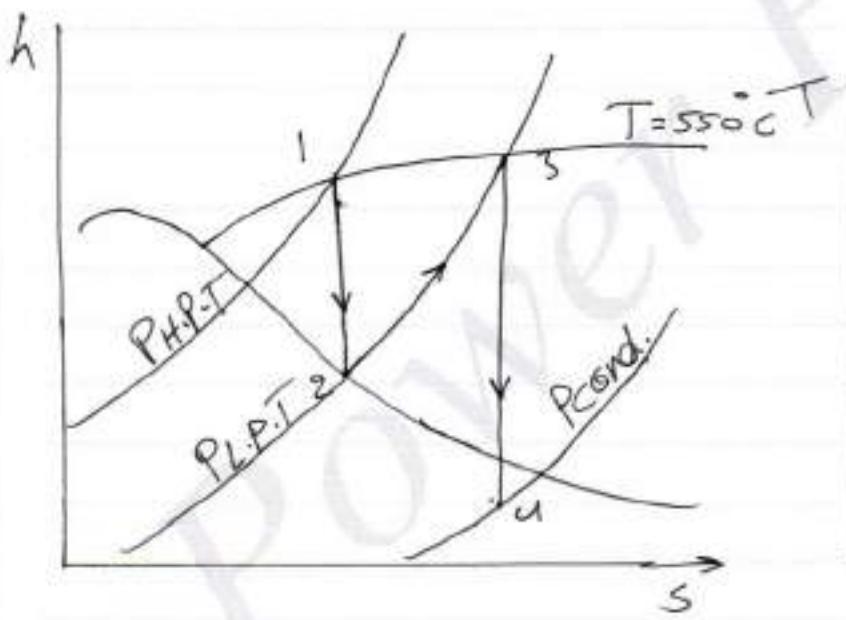
$$P_{out} = \dot{m}_s \cdot W_{net}$$

Power Plants

Ex/ In a steam power plant, Steam enters HPT at 150 bar and 550°C and leaves as saturated vapor. the Condenser Pressure is 0.1 bar. Assume that the reheating occurs up to the original temperature. Determine

- Work done
- heat added
- Output Power if the mass flow rate of steam is 50 kg/s
- Thermal efficiency of the cycle

Solution ~



Power Plants

From Mollier chart

At 150 bar and 550 °C

$$h_1 = 3455 \text{ kJ/kg}$$
$$h_2 = 2785 \text{ kJ/kg}$$

reheating pressure is 1.25 MPa

$$h_3 = 3585 \text{ kJ/kg}$$

$$h_4 = 2965 \text{ kJ/kg}$$

From Steam table

At 0.1 bar $h_5 = 191.83 \text{ kJ/kg}$

$$\dot{V}(P_2 - P_1) = h_6 - h_5$$

$$0.001(15000 - 10) = h_6 - 191.83$$

$$h_6 = 206.82 \text{ kJ/kg}$$

$$W_T = W_{H.P.T} + W_{L.P.T}$$

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

Power Plants

$$= (3455 - 2785) + (3585 - 2465)$$
$$= 1790 \text{ kJ/kg}$$

$$W_p = h_6 - h_5$$
$$= 206.82 - 191.83$$
$$= 15 \text{ kJ/kg}$$

$$W_{done} = W_T - W_P$$
$$= 1790 - 15$$
$$= 1775 \text{ kJ/kg}$$

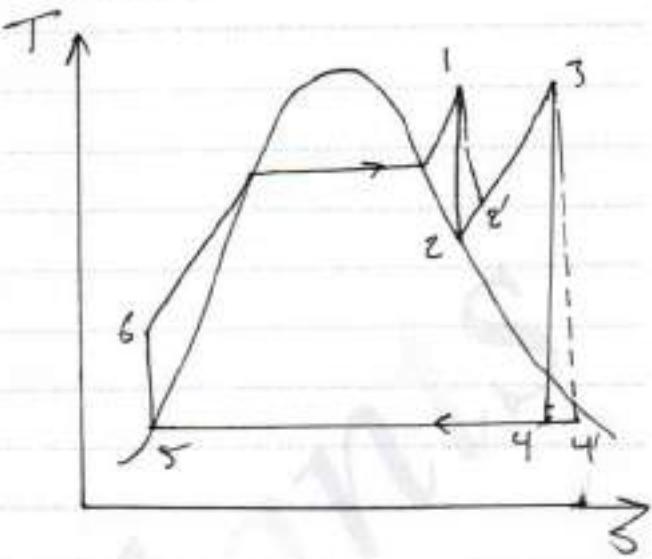
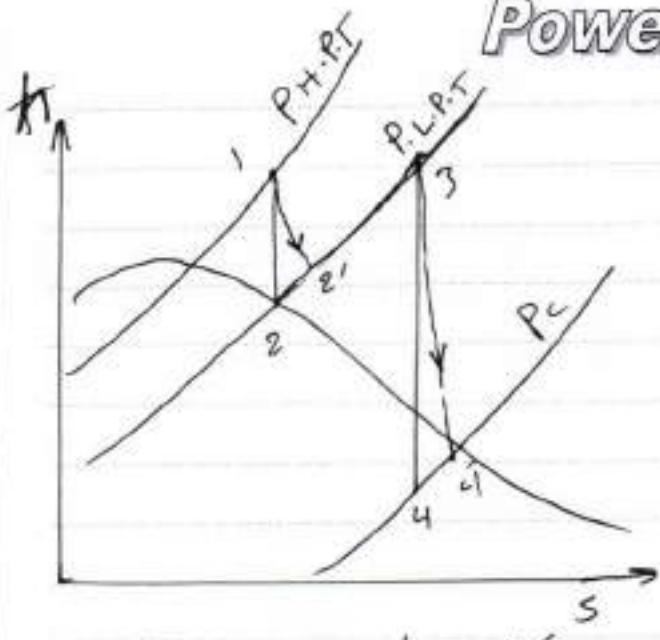
$$\dot{Q}_{add} = (h_1 - h_6) + (h_3 - h_2)$$
$$= (3455 - 206.82) + (3585 - 2785)$$
$$= 4048.18 \text{ kJ/kg}$$

$$\eta_{ideal} = \frac{W_{done}}{\dot{Q}_{add}} = \frac{1775}{4048.18} = 43.84\%$$

→ If the isentropic efficiency of the two turbines are 85%, Find the new efficiency?

$$P_{output} = m_s \cdot W_D$$
$$= 50 * 1775 = 88.75 \text{ MW}$$

Power Plants



$$\gamma_{\text{ise. H.P.T}} = \frac{h_1 - h_2'}{h_1 - h_2}$$

$$0.85 = \frac{3455 - h_2'}{3455 - 2785} \Rightarrow h_2' = 2885.5 \text{ KJ/kg}$$

$$\gamma_{\text{ise. L.P.T}} = \frac{h_3 - h_4'}{h_3 - h_4}$$

$$0.85 = \frac{3585 - h_4'}{3585 - 2465} \Rightarrow h_4' = 2633 \text{ KJ/kg}$$

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

$$= (3455 - 2885.5) + (3585 - 2633) - 15$$

$$= 1506.5 \text{ KJ/kg}$$

Power Plants

$$\begin{aligned}Q_{\text{add}} &= (h_1 - h_6) + (h_3 - h_2') \\&= (3455 - 266.82) + (3585 - 2885.5) \\&= 3947.7 \text{ kJ/kg}\end{aligned}$$

$$\eta = \frac{W_{\text{done}}}{\text{actual } Q_{\text{add}}} = \frac{1506.5}{3947.7} = 38.16\%$$

$$\begin{aligned}\Delta\eta &= \eta_{\text{ideal}} - \eta_{\text{actual}} \\&= 43.89\% - 38.16\% \\&= 5.68\%\end{aligned}$$

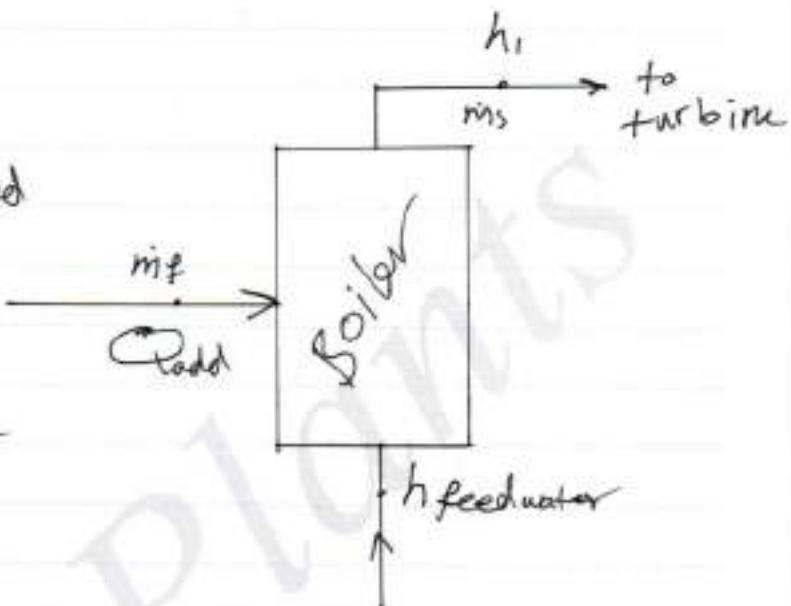
You can notice that the cycle efficiency has decreased 5.68% when taking into account isentropic efficiency of the H.P.T and L.P.T.

Power Plants

* Efficiencies in Steam Power Plant

- Boiler efficiency

It is the heat supplied to the steam in the boiler expressed as a percentage of the chemical energy of the fuel which is available in the combustion.



i.e.,

$$\eta_b = \frac{(h_1 - h_{fw}) m_s}{m_f * C.V}$$

where, h_1 = Enthalpy of steam entering the turbine (kJ/kg)

h_{fw} = Enthalpy of feed water (kJ/kg)

m_s = steam mass flow rate (kg/s)

m_f = fuel mass flow rate (kg/s)

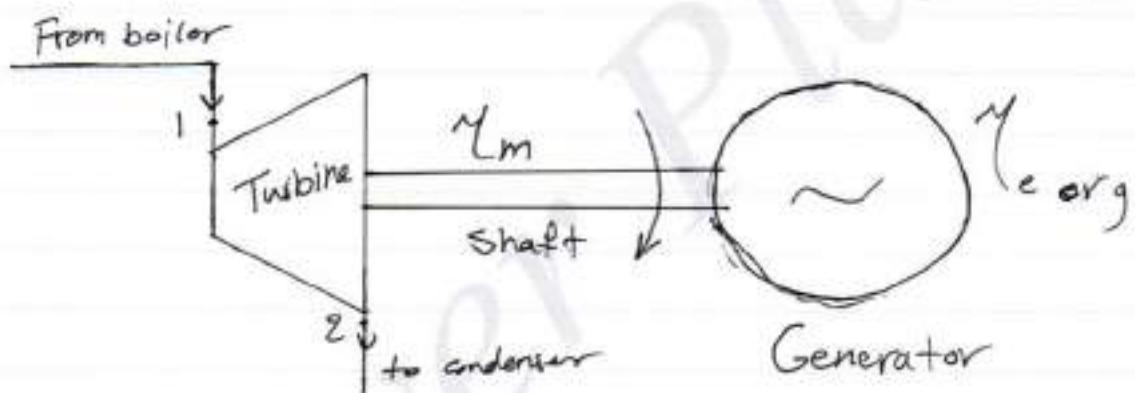
C.V = Calorific value of the fuel (kJ/kg)

Power Plants

- Mechanical and electrical (generator) efficiency

In steam plants, the work done by turbine is transferred to the generator to generate electricity by a shaft.

Due to friction losses in the shaft and iron losses in the generator, there are going to be two efficiencies mechanical efficiency and electrical efficiency



So, the output Power of Plant in this case
called "terminal power"

$$\text{Terminal Power} = m_s \times \text{WD} \times \eta_g \times \eta_m$$

Power Plants

- Cycle efficiency

Cycle efficiency which is explained well previously takes into account equipment of the cycle: turbine, condenser, pump and boiler

$$\eta_{\text{cycle}} = \frac{W.D}{Q_{\text{add}}}$$

- Specific steam consumption

When taking into account mechanical and electrical efficiency of the shaft and the generator, S.S.C will be as follows,

$$S.S.C = \frac{3600}{W.D + (\eta_g \times \eta_m)} \text{ kg}_{\text{fuel}}/\text{kw.hr}$$

- Plant efficiency

Plant efficiency includes cycle equipment and both mechanical and electrical efficiencies along with boiler efficiency :-

$$\eta_{\text{plant}} = \eta_{\text{cycle}} + \eta_{\text{boiler}} + \eta_m + \eta_g$$

Power Plants

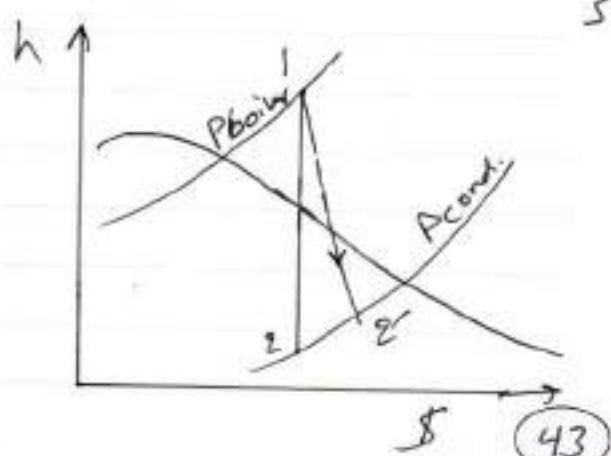
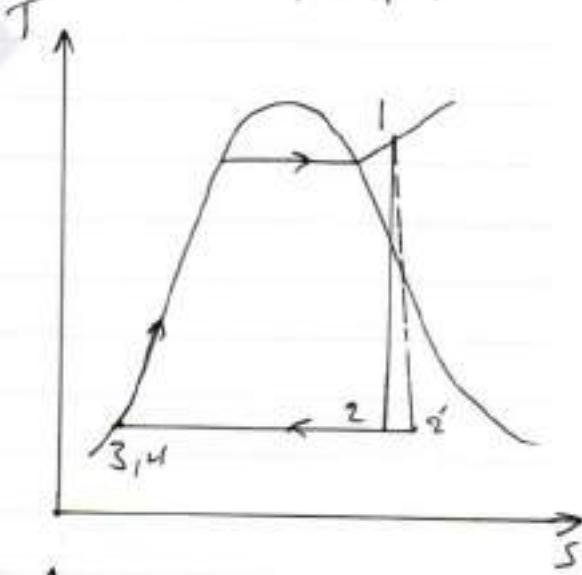
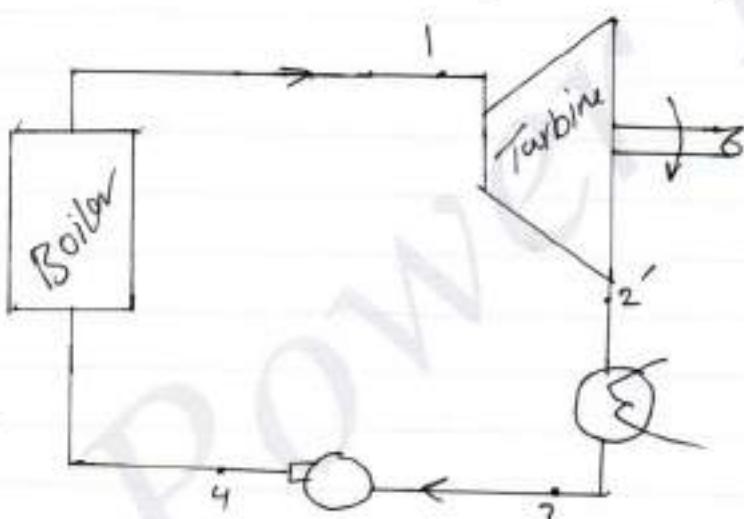
Ex/ Steam power plant has the following data:-
 Steam condition at turbine $6 \text{ MPa}, 450^\circ\text{C}$
 Condenser pressure 0.008 MPa

$$\eta_{\text{turbine}} = 0.83, \eta_m = 0.92, \eta_g = 0.96, m_s = 40 \text{ kg/s}$$

$$CU \text{ of fuel} = 37000 \text{ kJ/kg}, m_f = 4 \text{ kg/s}$$

Neglect Pump work. Find

- a) Work done
- b) heat added
- c) boiler efficiency
- d) cycle efficiency
- e) plant efficiency
- f) terminal Power



Power Plants

Solutions~

From Mollier charts

$$h_1 = 3305 \text{ kJ/kg}$$

$$h_2 = 2105 \text{ kJ/kg}$$

$$\eta_t = \frac{h_1 - h_2'}{h_1 - h_2} \Rightarrow 0.83 = \frac{3305 - h_2'}{3305 - 2105}$$

$$h_2' = 2881.7 \text{ kJ/kg}$$

From Steam table

$$\text{at } 0.008 \text{ MPa}, h_3 = h_4 = h_f = 173.7 \text{ kJ/kg}$$

$$\begin{aligned} W.D. &= h_1 - h_2' \\ &= 3305 - 2105 \\ &= 1200 \text{ kJ/kg} \end{aligned}$$

$$\begin{aligned} Q_{\text{add}} &= h_1 - h_4 \\ &= 3305 - 173.7 \\ &= 3131.3 \text{ kJ/kg} \end{aligned}$$

$$\begin{aligned} \eta_b &= \frac{(h_1 - h_4)_{\text{mis}}}{m_f \cdot CV} \\ &= \frac{(3305 - 173.7) + 40}{4 \times 37000} = 89.6\% \end{aligned}$$

Power Plants

$$\begin{aligned}\text{Cycle efficiency} &= \frac{W.D}{Q_{add}} \\ &= \frac{1200}{3131.3} = 38.3\%\end{aligned}$$

$$\begin{aligned}\eta_{\text{Plant}} &= \eta_{\text{cycle}} + \eta_b + \eta_m + \eta_e \\ &= 0.383 * 0.846 + 0.92 + 0.96 \\ &= 28.6\%\end{aligned}$$

You can notice that $\eta_{\text{Plant}} < \eta_{\text{cycle}}$

$$\begin{aligned}\text{Terminal Power} &= m_s * W.D + \eta_g + \eta_m \\ &= 40 * 1200 + 0.92 + 0.96 \\ &= 42.4 \text{ MW}\end{aligned}$$