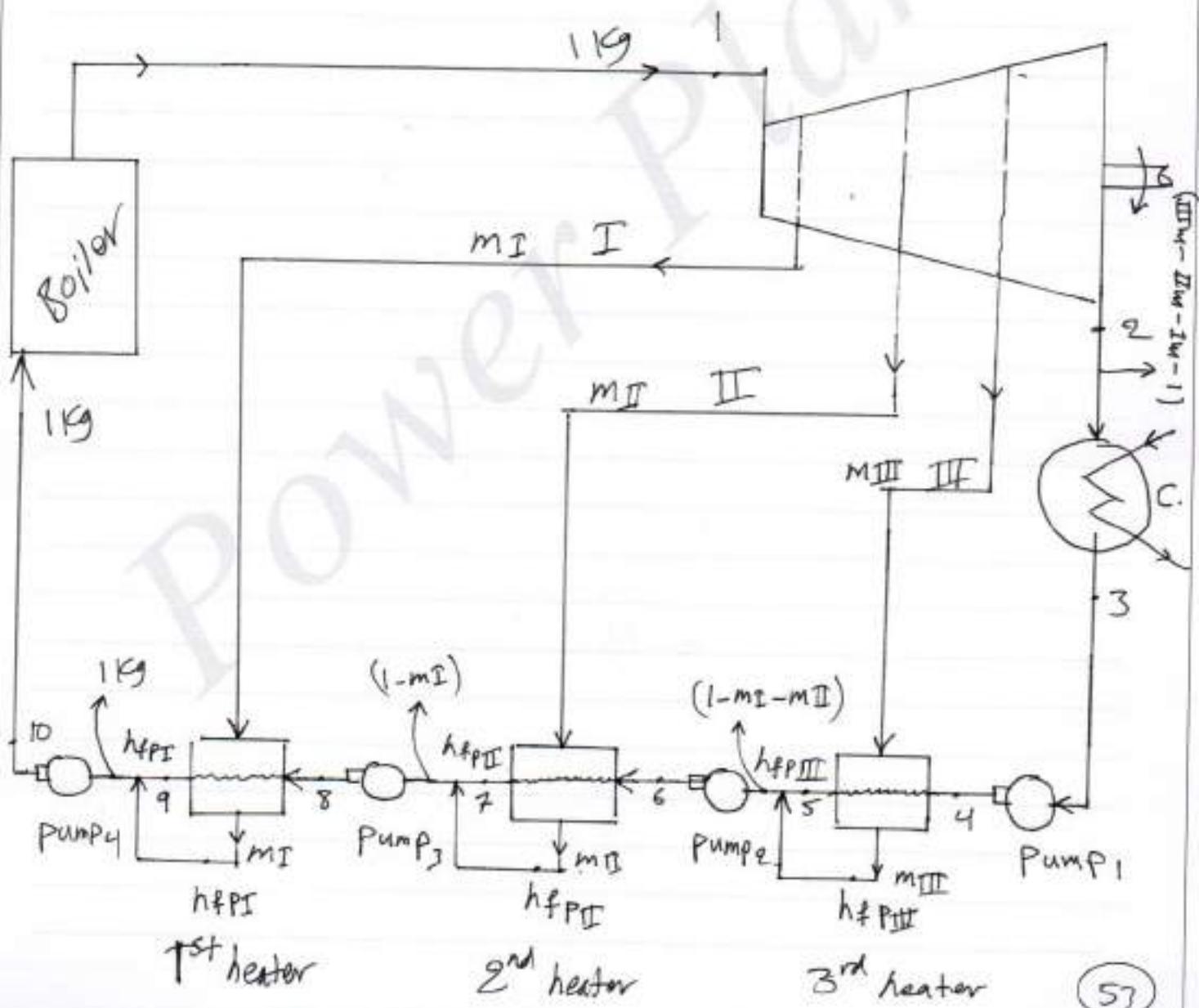


Power Plants

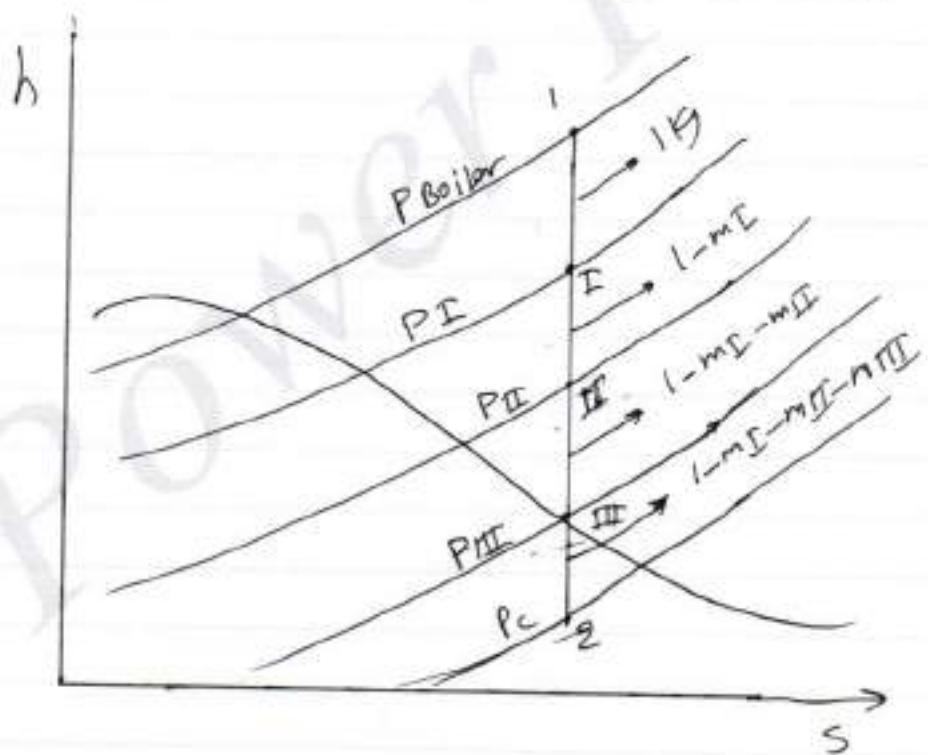
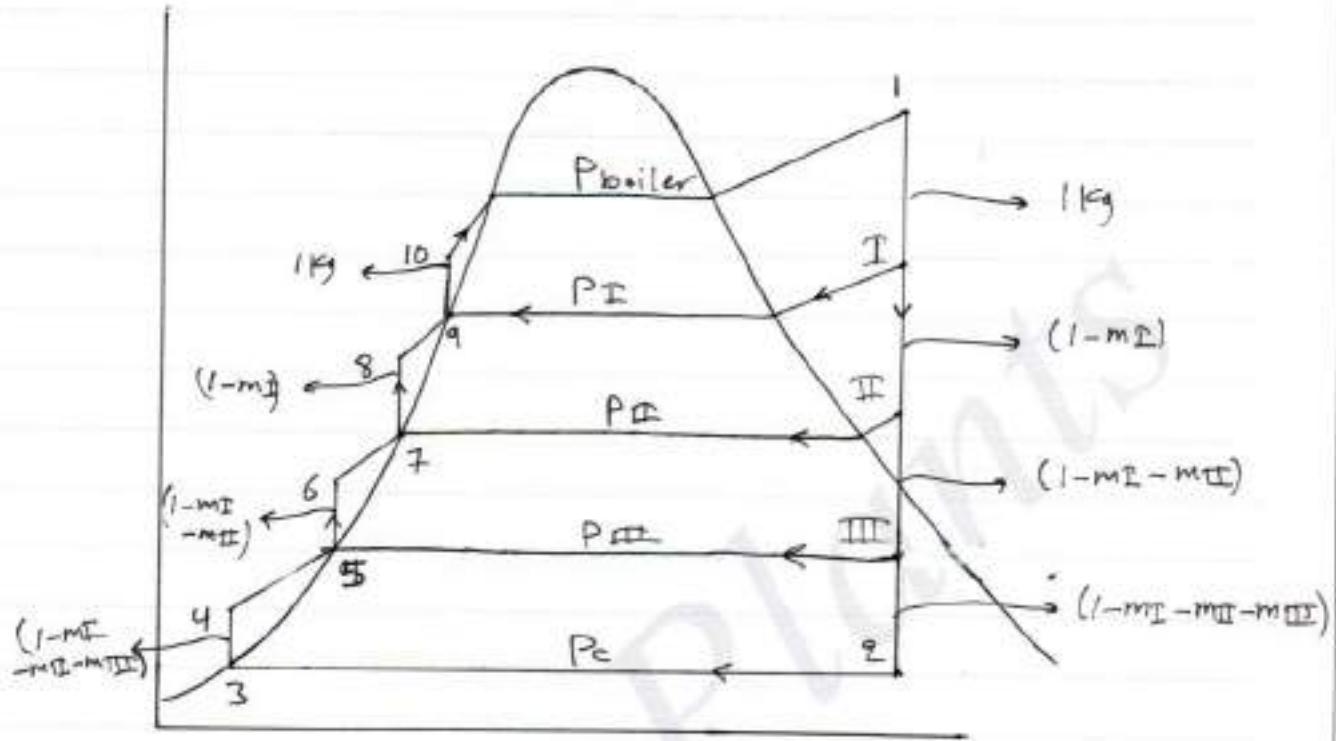
- Closed feed water heaters

In this type, the heat is transferred from the extracted (bledded) steam to the feed water without mixing taking place. The two streams can be at different pressure since they do not mix.

- Forward flow heaters:-

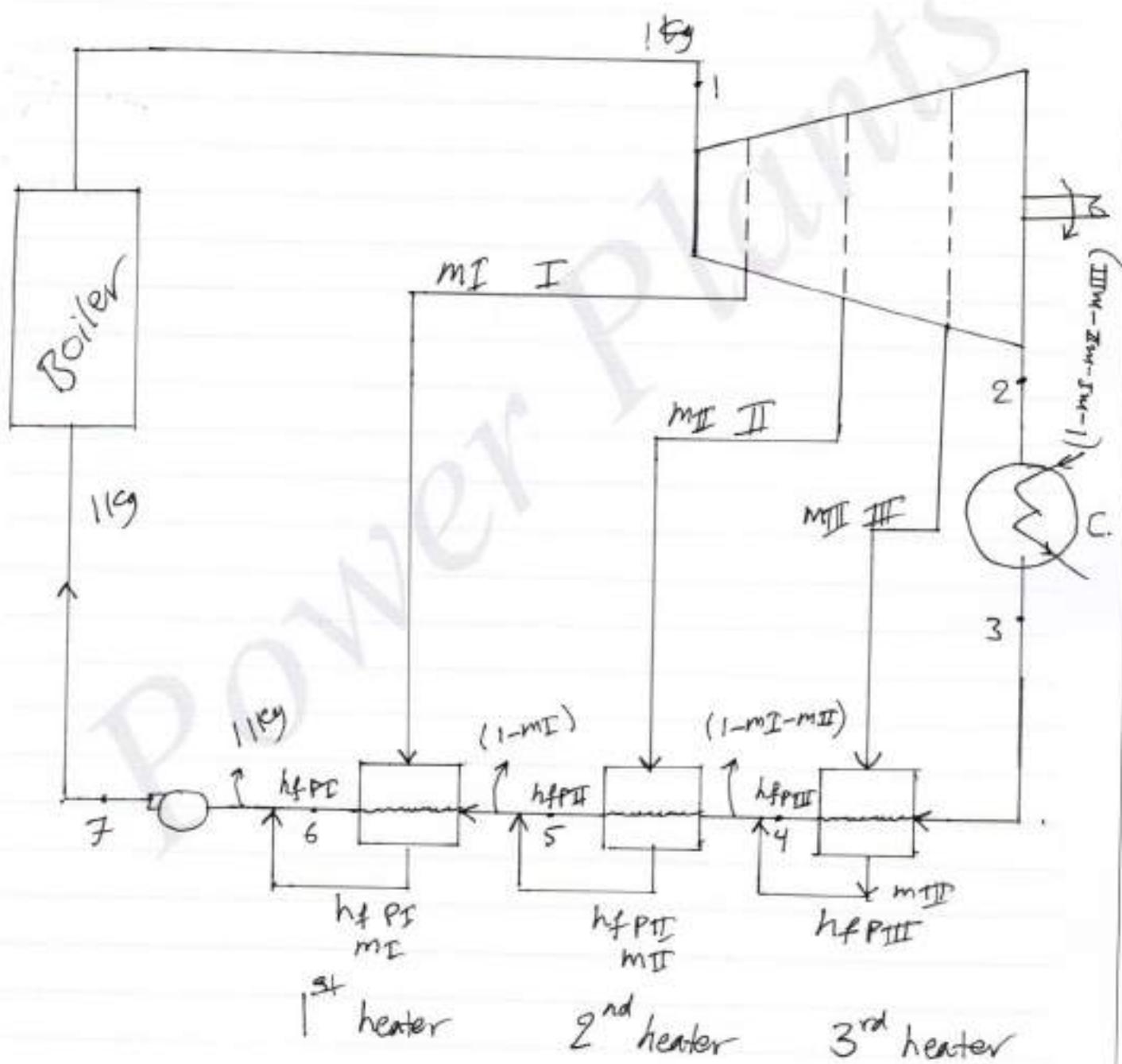


Power Plants

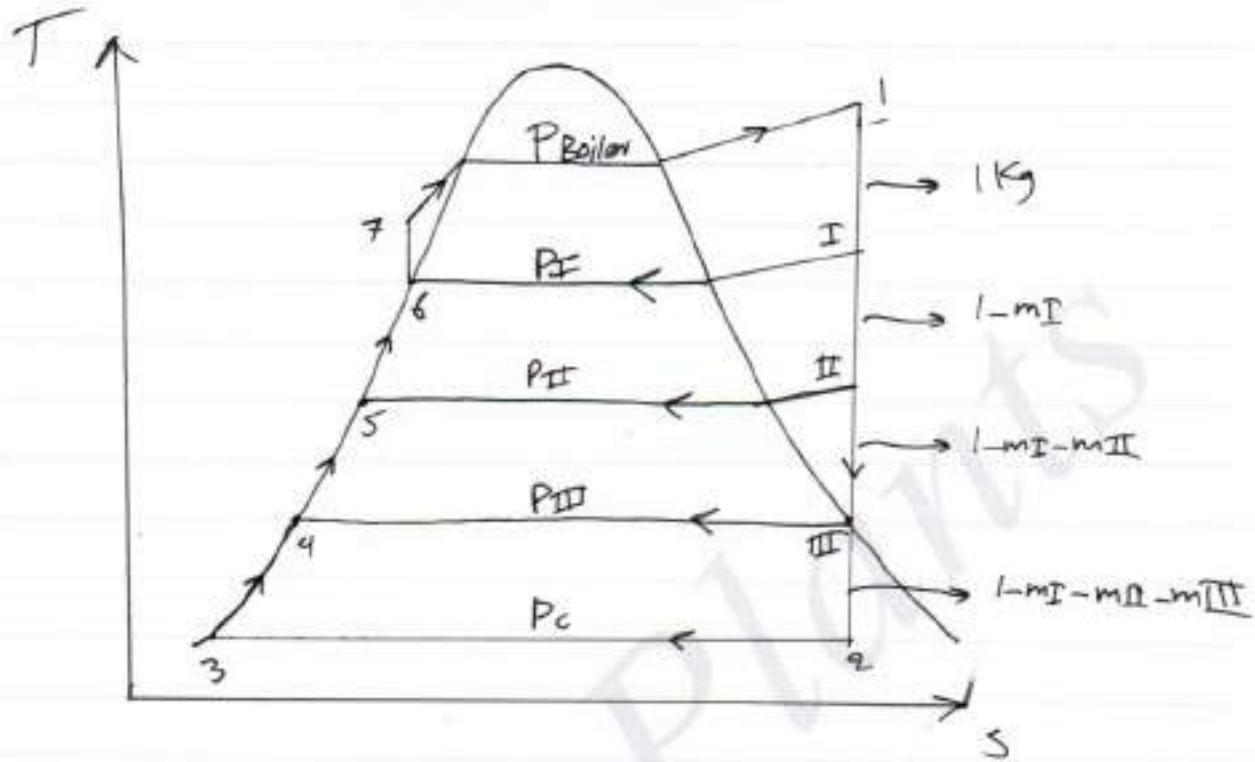


Power Plants

In order to make the calculations easier, we can neglect work of pump₁, pump₂, pump₃, so the new cycle is as follows:-



Power Plants



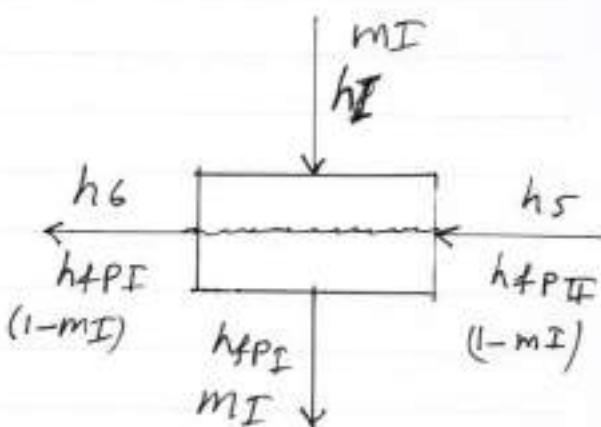
* Calculations :-

- 1st heater

Heat rejected = heat gained

$$m_I (h_I - h_{fP_I}) = (1-m_I) * (h_6 - h_5)$$

$$m_I (h_I - h_{fP_I}) = (1-m_I) (h_{fP_I} - h_{fP_{II}})$$



Then, m_I is calculated from the equation above

Power Plants

- 2nd heater

Heat rejected = Heat gained

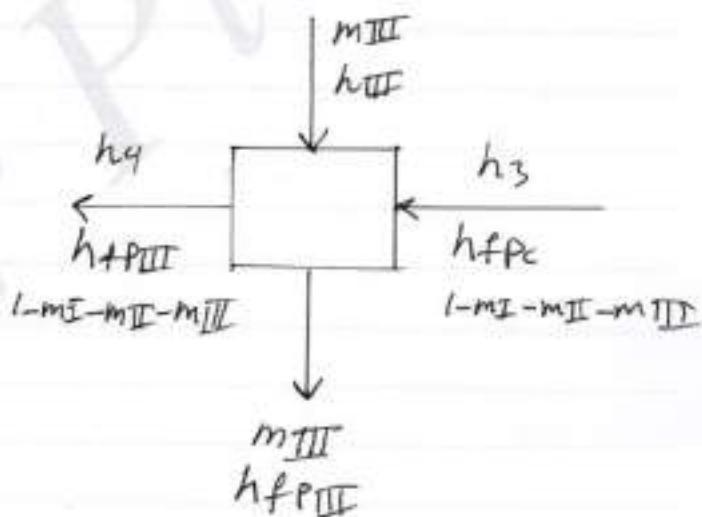
$$m_{II}(h_{II} - h_{fP_{II}}) = (1-m_I-m_{I'}) (h_5 - h_4)$$

$$m_{II}(h_{II} - h_{fP_{II}}) = (1-m_I-m_{II}) (h_{fP_{II}} - h_{fP_{III}})$$

Then, m_{II} is calculated from equation above.

- 3rd heater

Heat rejected = heat gained



$$m_{III}(h_{III} - h_{fP_{III}}) = (1-m_I-m_{II}-m_{III})(h_4 - h_3)$$

$$m_{III}(h_{III} - h_{fP_{III}}) = (1-m_I-m_{II}-m_{III})(h_{fP_{III}} - h_{fP_C})$$

m_{III} is also calculated from equation above.

Power Plants

Now, after all extracted masses are evaluated,
we can calculate the cycle efficiency :-

$$\begin{aligned} W.D &= W_{I-II} + W_{II-III} + W_{III-I} - W_{T-C} \\ &= (h_1 - h_I) + 11g + (h_I - h_{II}) \times (1-m_I) + (h_{II} - h_{III}) + \\ &\quad (1-m_I - m_{II}) + (h_{III} - h_2) + (1-m_I - m_{II} - m_{III}) \end{aligned}$$

$$Q_{add} = (h_1 - h_T) * 1 \text{ kg}$$

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

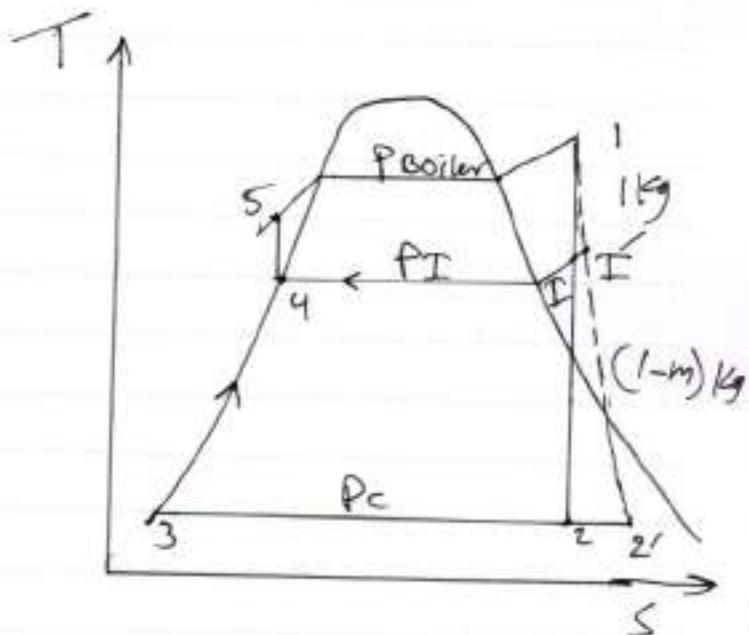
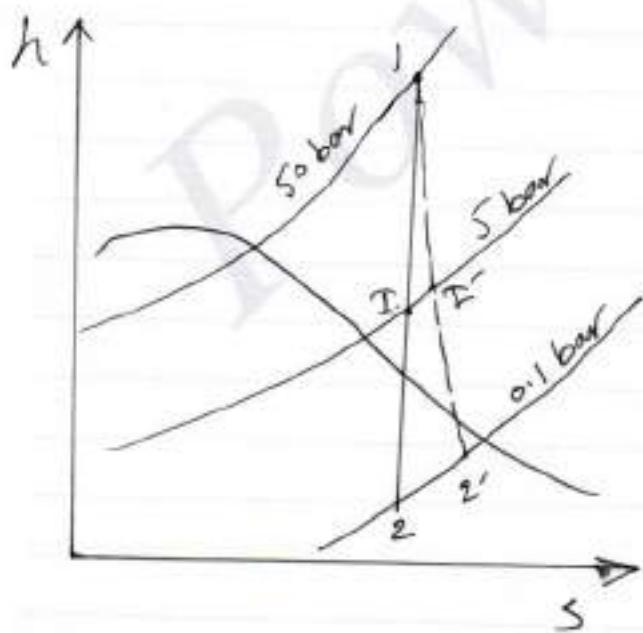
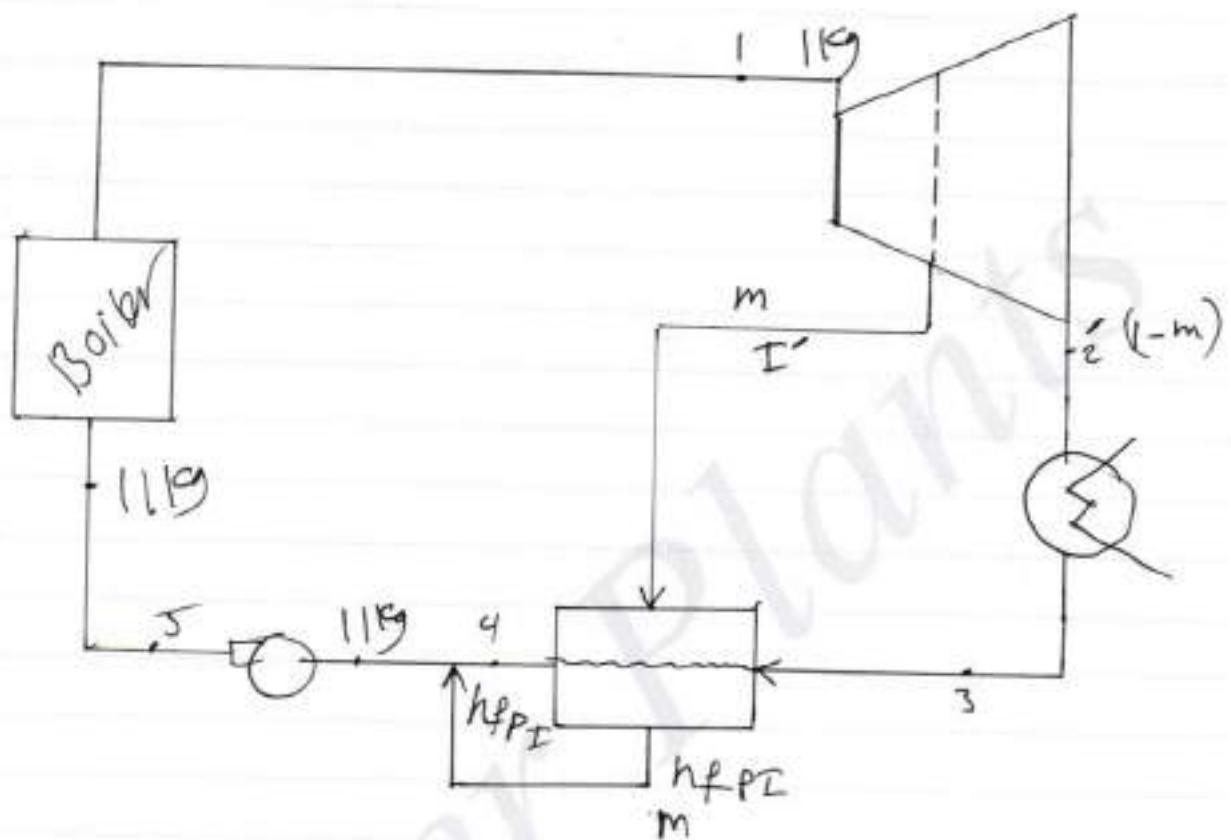
Ex/ For example on Page 50 , use the same conditions . The feed water heater is closed type (forward) . Calculate

- amount of mass used for bleeding
- m_c

turbine efficiency is 85 %

Power Plants

Solutions



59

Power Plants

From chart : $h_1 = 3230 \text{ kJ/kg}$
 $h_I = 2790 \text{ kJ/kg}$
 $h_e = 2190 \text{ kJ/kg}$

From steam table : $h_3 = h_f = 191.8 \text{ kJ/kg}$
 $h_4 = h_{fP_I} = 640.1 \text{ kJ/kg}$

$$\eta_t = \frac{h_1 - h_2'}{h_1 - h_2} \Rightarrow 0.85 = \frac{3230 - h_2'}{3230 - 2190}$$

$$h_2' = 2346 \text{ kJ/kg}$$

$$0.85 = \frac{h_1 - h_I'}{h_1 - h_I} \Rightarrow 0.85 = \frac{3230 - h_I'}{3230 - 2790}$$

$$h_I' = 2856 \text{ kJ/kg}$$

$$h_5 = 642.6 \text{ kJ/kg}, \quad \eta_t(P_b - P_I) = h_5 - h_4$$

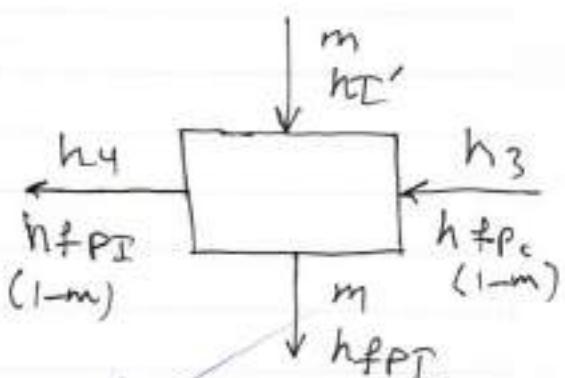
Heat balance for heater

$$m(h_I' - h_{fP_I}) = (1-m)(h_4 - h_3)$$

$$m(2856 - 640.1) = (1-m)(640.1 - 191.8)$$

$$\therefore 2664.2 m = 448.3$$

$$m = 0.1682 \text{ kg}$$



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Power Plants

$$\begin{aligned}W.D &= 1 \text{ kg } (h_1 - h_t') + (h_I' - h_e') (1-m) - (h_S - h_u) \\&= 1 * (3230 - 2856) + (2856 - 2346)(1 - 0.1682) - (642.6 - 640.1) \\&= 795.7 \text{ kJ/kg}\end{aligned}$$

$$\begin{aligned}Q_{add} &= (h_1 - h_S) \text{ kg} \\&= (3230 - 642.6) * 1 \\&= 2587.4 \text{ kJ/kg}\end{aligned}$$

$$\eta_{cycle} = \frac{795.7}{2587.4} = 30.75\%$$

Ex/ The output power of a steam plant is 100 MW. The turbine consists of high and low pressure cylinders with a reheating between them using boiler flue gases. There are three forward flow feed water heaters (closed type) located in the cycle and use bleed steam from the low pressure turbine.

Bleedings occur at 20 bar, 5 bar, 0.7 bar

Boiler steam pressure and temperature are 100 bar, 550°C
high pressure turbine exhausts at 40 bar.

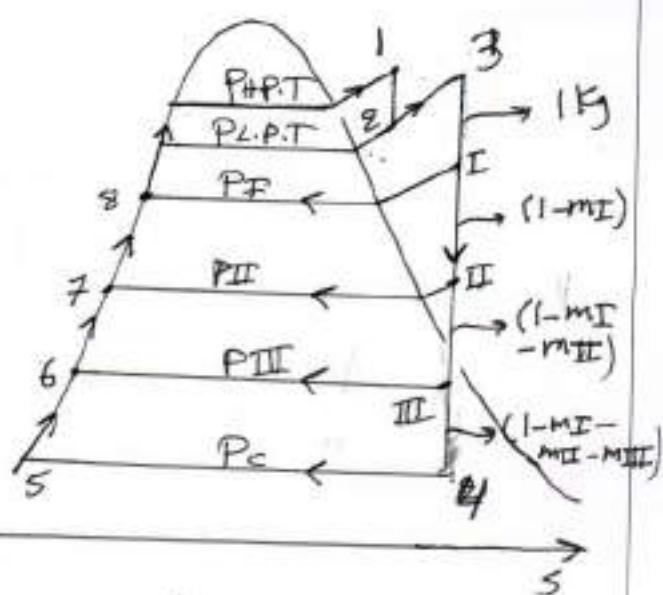
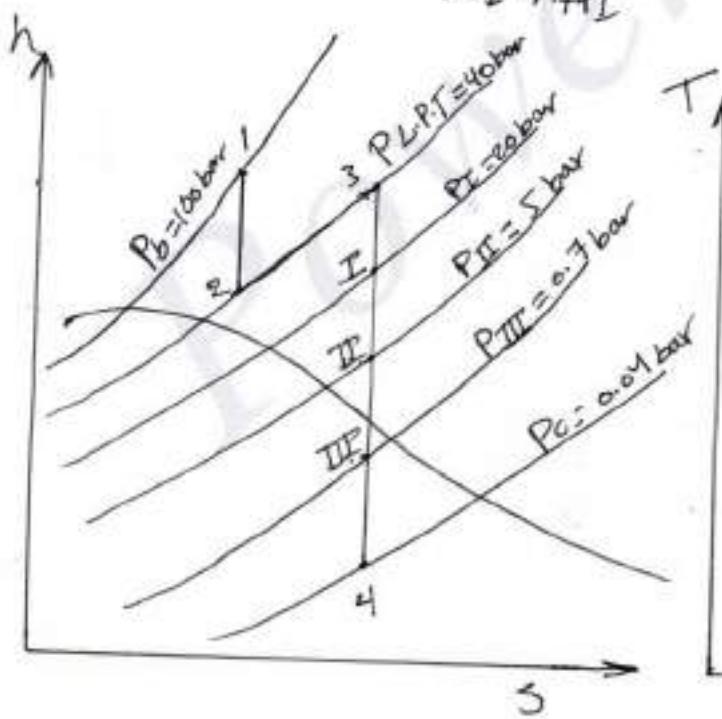
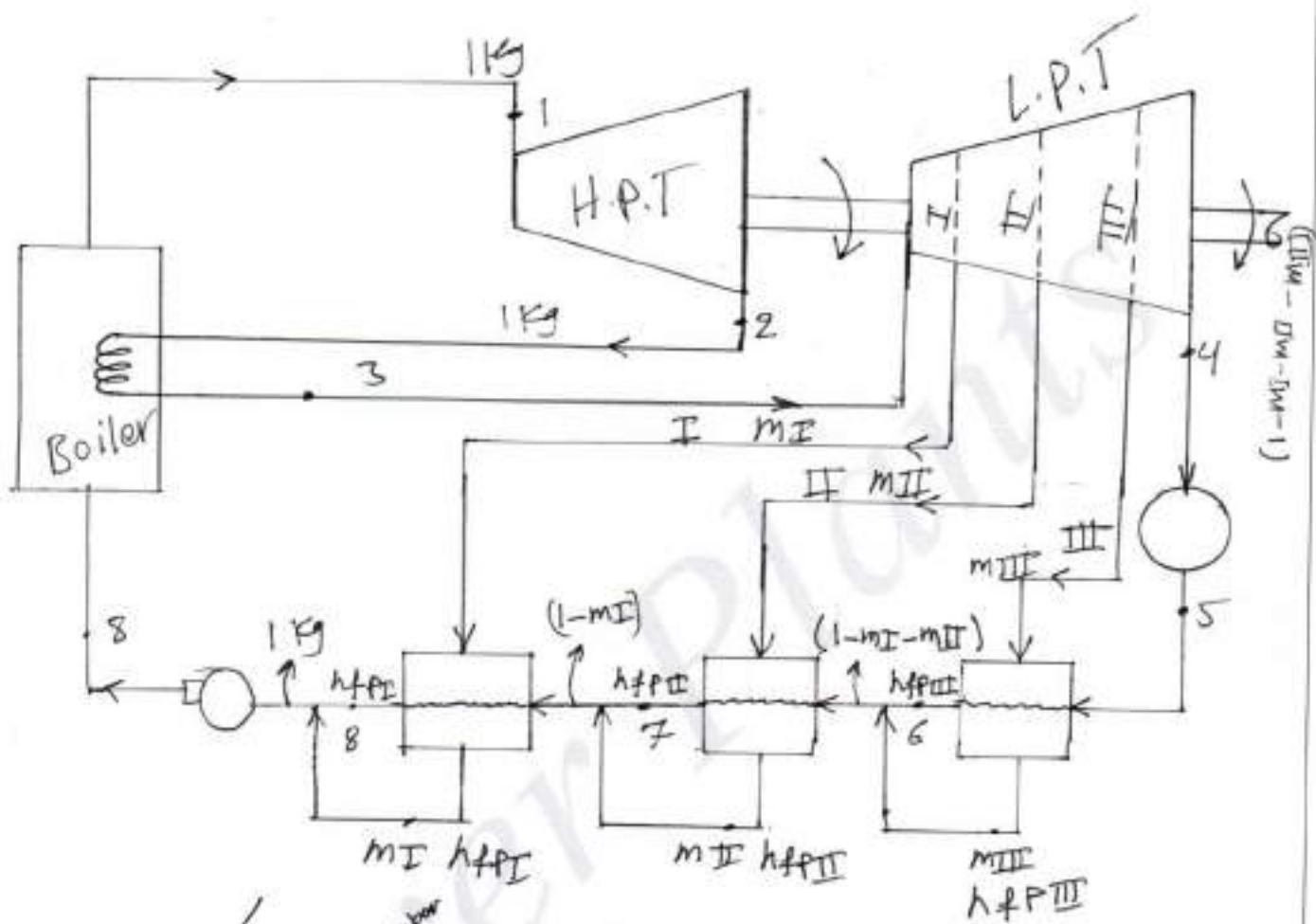
Steam admitted to low pressure turbine at 40 bar, 510°C
Steam exhausts from low pressure turbine at 0.01 bar

- Find: a) amounts of steam used for bleeding
b) mass flow rate of steam
c) cycle efficiency

Neglect all pumps work.

Power Plants

Solutions~



Power Plants

From h-s Chart 8 $h_1 = 3500 \text{ kJ/kg}$

$$h_2 = 3200 \text{ kJ/kg}$$

$$h_3 = 3470 \text{ kJ/kg}$$

$$h_I = 3250 \text{ kJ/kg}$$

$$h_{II} = 2880 \text{ kJ/kg}$$

$$h_{III} = 2527 \text{ kJ/kg}$$

$$h_4 = 2135 \text{ kJ/kg}$$

From Steam table: $h_5 = h_f P_c = 121.4 \text{ kJ/kg}$

$$h_6 = h_f P_{II} = 376.8 \text{ kJ/kg}$$

$$h_7 = h_f P_{I\!I\!I} = 640.1 \text{ kJ/kg}$$

$$h_8 = h_f P_I = 968.6 \text{ kJ/kg}$$

Heat balance

- 1st heater

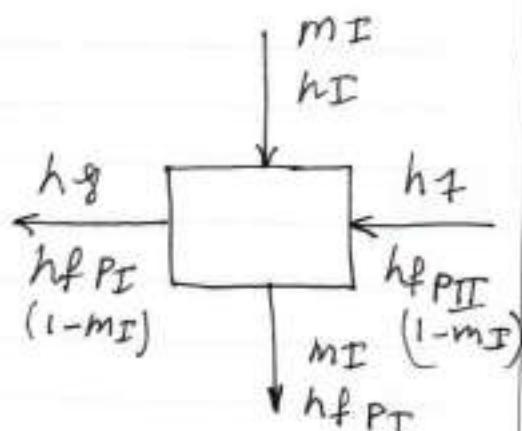
$$m_I (h_I - h_f P_I) = (1-m_I)(h_8 - h_7)$$

$$m_I (3250 - 968.6) = (1-m_I)(968.6 - 640.1)$$

$$2341.4 m_I = (1-m_I) \downarrow 268.5$$

$$2609.9 m_I = 268.5$$

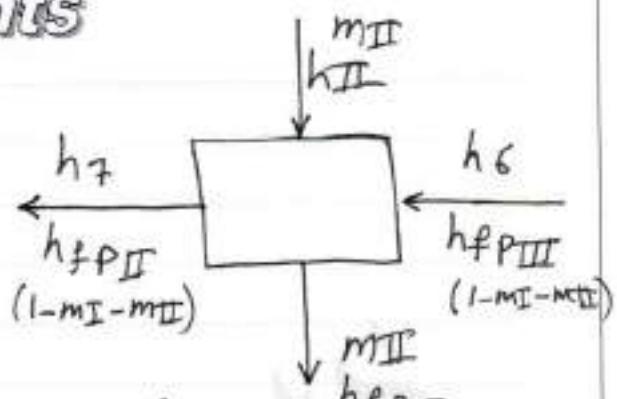
$$m_I = 0.1028 \text{ kg}$$



Power Plants

- 2nd heater

$$m_{II}(h_{II} - h_{fP_{II}}) = (1-m_I-m_{II}) \times (h_7 - h_6)$$



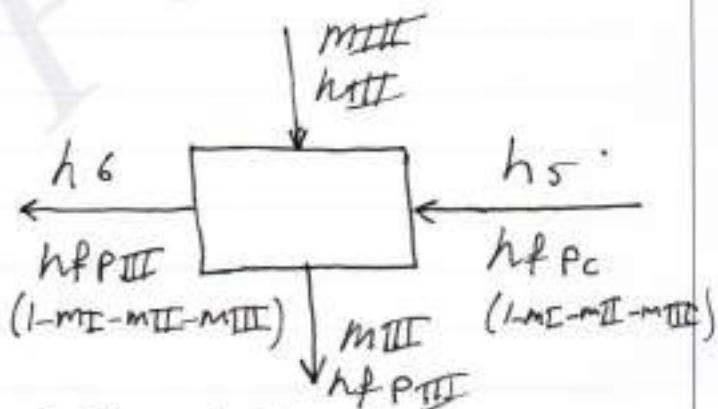
$$m_{II}(2880 - 640.1) = (1 - 0.1028 - m_{II})(640.1 - 376.8)$$

$$2239.9 m_{II} = (0.8972 - m_{II}) \times 263.3$$

$$2503.2 m_{II} = 236.237$$

$$m_{II} = 0.0943 \text{ kg}$$

- 3rd heater



$$m_{III}(h_{III} - h_{fP_{III}}) = (1-m_I-m_{II}-m_{III})(h_6 - h_5)$$

$$m_{III}(2527 - 376.8) = (1 - 0.1028 - 0.0943 - m_{III})(376.8 - 121.4)$$

$$2150.2 m_{III} = (0.8029 - m_{III}) \times 255.4$$

$$m_{III} \times 2405.6 = 205.06$$

$$m_{III} = 0.0852 \text{ kg}$$

Power Plants

$$\begin{aligned} W.D &= W_{H.P.T} + W_{L.P.T} \\ &= W_{H.P.T} + W_{I-I} + W_{II-II} + W_{III-IV} \\ &= 1kg(h_1-h_2) + 1kg(h_3-h_I) + (1-m_I)(h_I-h_{II}) + \\ &\quad + (1-m_I-m_{II})(h_{II}-h_{III}) + (1-m_I-m_{II}-m_{III})(h_{III}-h_4) \\ &= (3500 - 3200) + (3470 - 3250) + (1-0.1027)(3250 - 2880) \\ &\quad + (1-0.1027-0.0943)(2880 - 2527) + (1-0.1027-0.0943-0.0852) \\ &\quad * (2527 - 2135) \\ &= 1416.7 \text{ kJ/kg} \end{aligned}$$

$$\begin{aligned} Q_{add} &= 1kg(h_1-h_8) + 1kg(h_3-h_2) \\ &= (3500 - 908.6) + (3470 - 3200) \\ &= 2861.4 \text{ kJ/kg} \end{aligned}$$

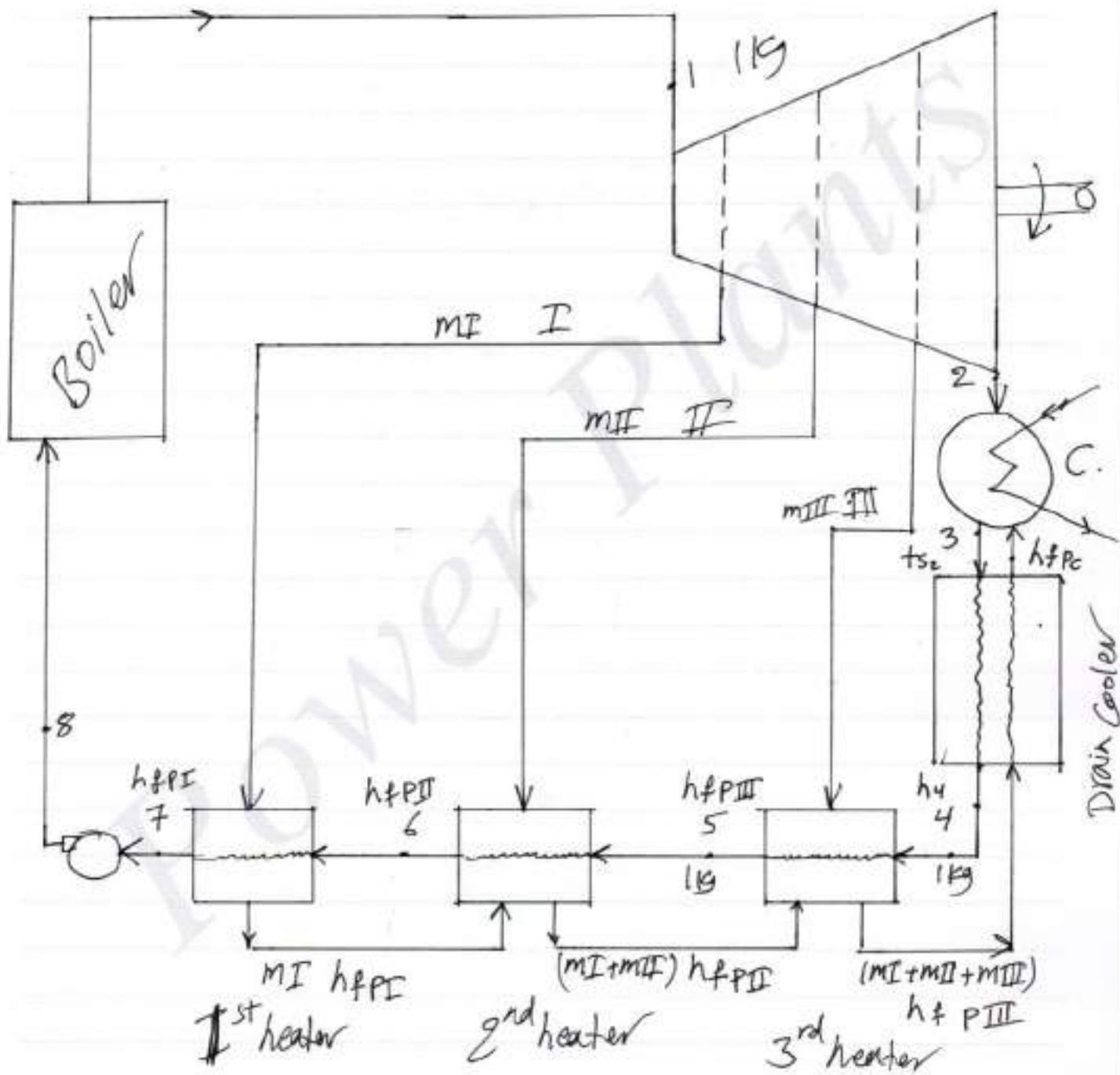
$$\begin{aligned} P_{output} &= \dot{m}_s * W.D \\ 100000 &= \dot{m}_s * 1416.7 \end{aligned}$$

$$\dot{m}_s = 70.58 \text{ kg/s}$$

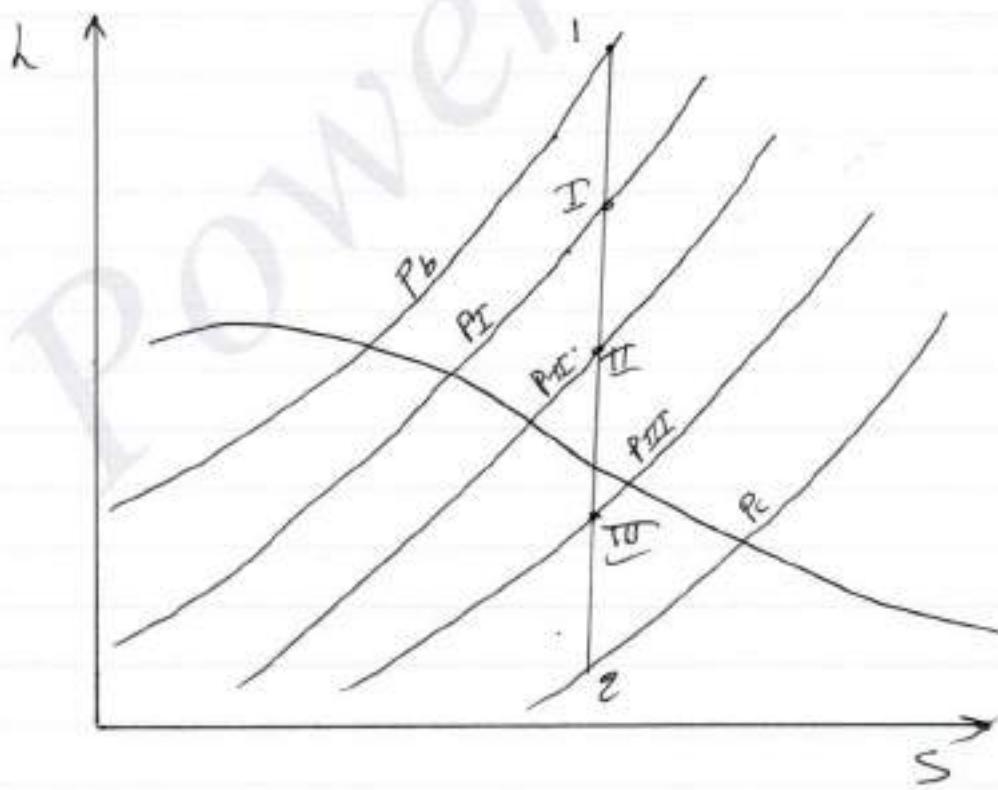
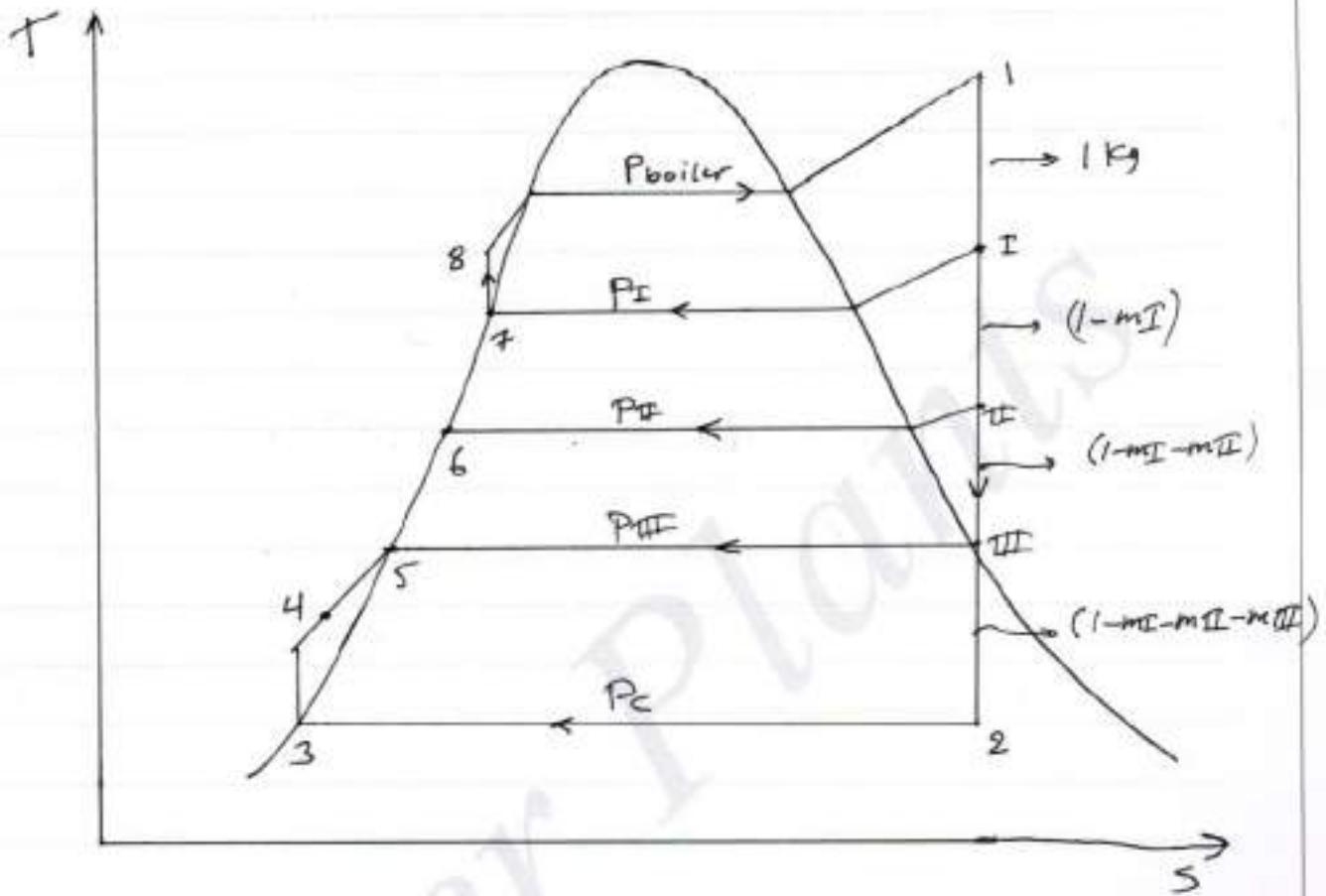
$$\eta_{cycle} = \frac{1416.7}{2861.4} = 49.5\%$$

Power Plants

- Backward flow heaters (Cascaded)



Power Plants



Power Plants

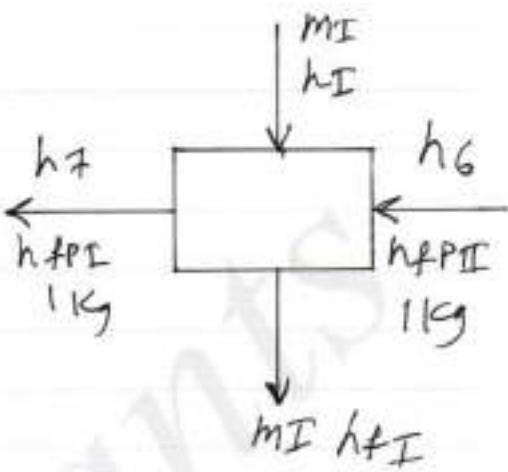
Heat balance for heaters

- 1st heater

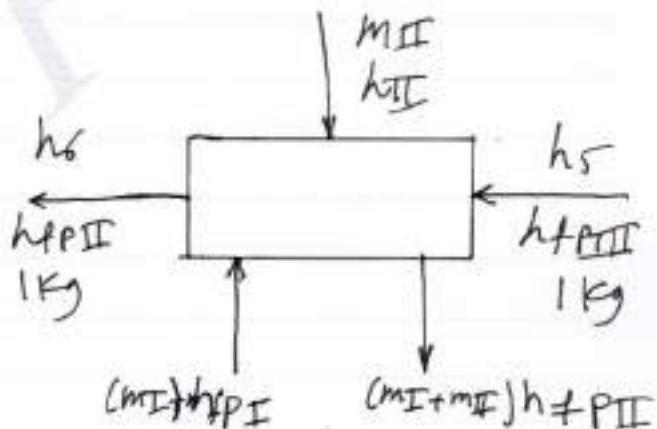
$$1\text{kg}(h_f - h_g) = m_I(h_I - h_{fI})$$

$$1\text{kg}(h_{fPI} - h_{fPII}) = m_I(h_I - h_{fI})$$

$$m_I = \frac{h_{fPI} - h_{fPII}}{h_I - h_{fI}}$$



- 2nd heater

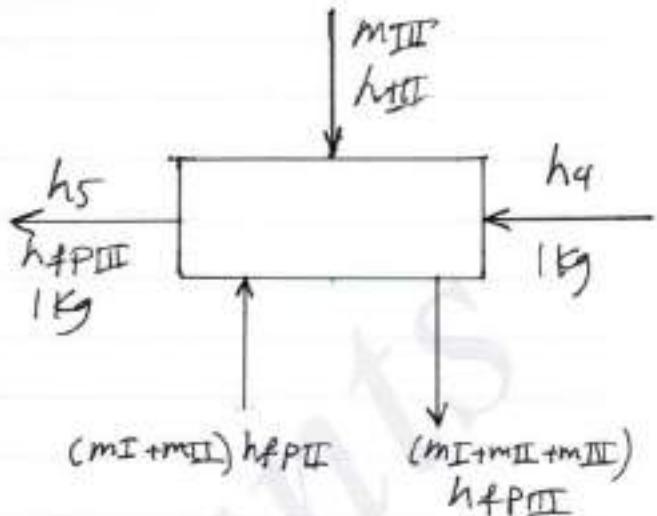


$$h_s + 1\text{kg} + m_{II}h_{fII} + m_I h_{fPI} = h_g + 1\text{kg} + (m_I + m_{II})h_{fPII}$$

We already evaluated m_I

So, m_{II} can be calculated.

Power Plants



$$h_4 \times 1\text{kg} + M_{III} h_{fPIII} + (m_I + m_{II}) h_{fPII} = h_5 \times 1\text{kg} + (m_I + m_{II} + m_{III}) h_{fPIII} \quad \textcircled{1}$$

m_I, m_{II} are evaluated previously

In order to calculate M_{III} , we need to estimate (h_4) , so we can make heat balance on the drain cooler

- Drain Cooler

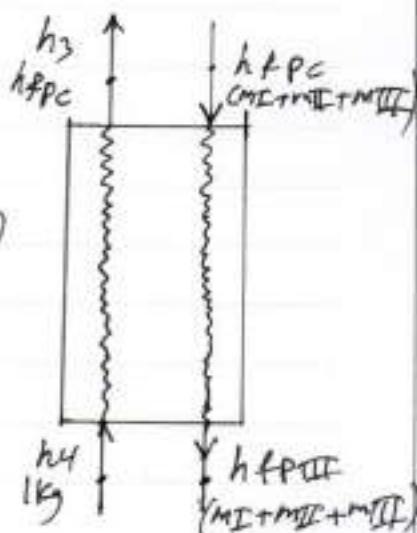
$$1\text{kg} (h_4 - h_3) = (m_I + m_{II} + m_{III}) (h_{fPIII} - h_{fPc})$$

$$1\text{kg} (h_4 - h_{fPc}) = (m_I + m_{II} + m_{III}) (h_{fPIII} - h_{fPc})$$

$$h_4 = (m_I + m_{II} + m_{III}) (h_{fPIII} - h_{fPc}) + h_{fPc} \quad \textcircled{2}$$

by substituting eqn \textcircled{2} in eqn \textcircled{1}

We can find M_{III} .

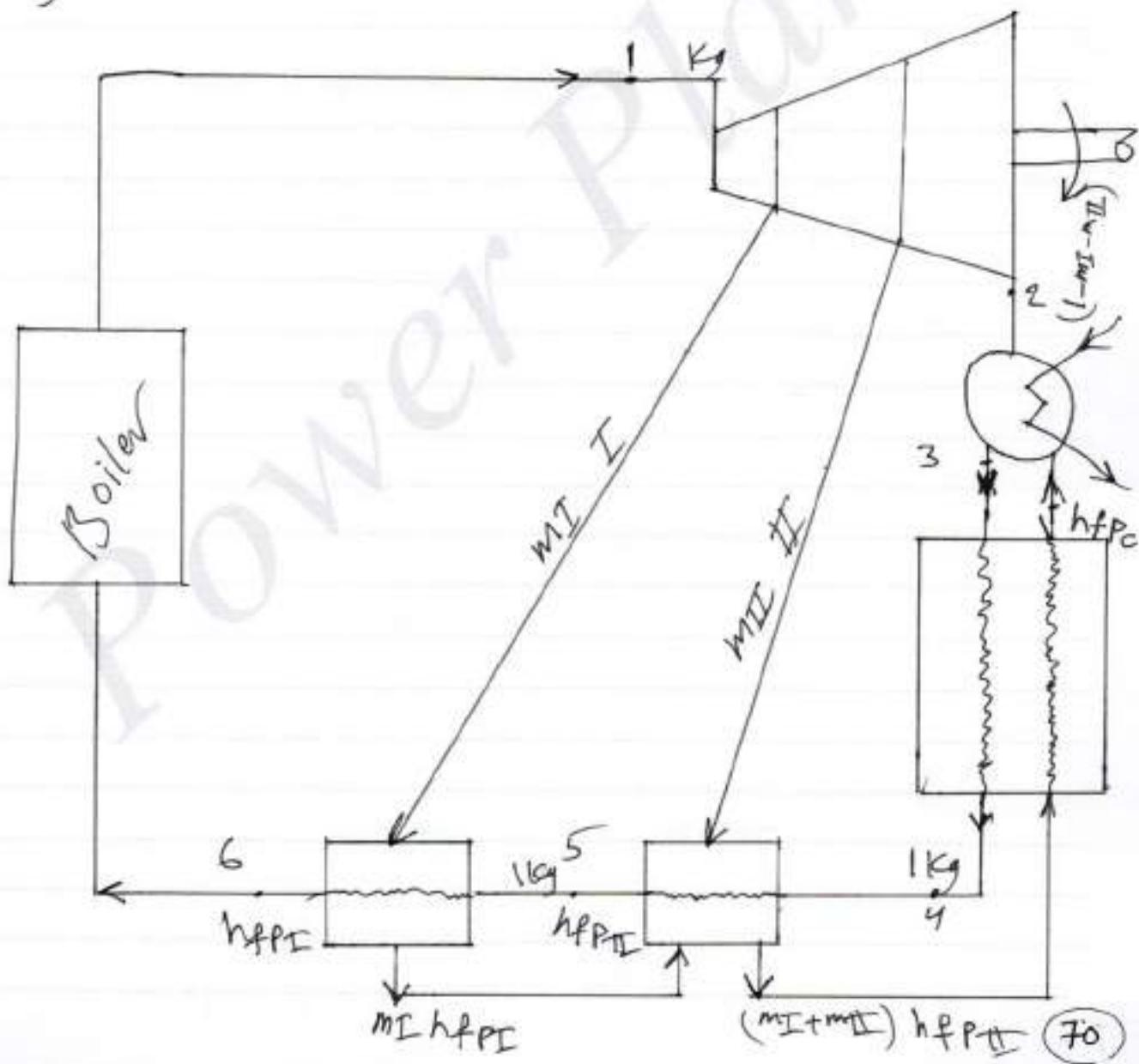


Power Plants

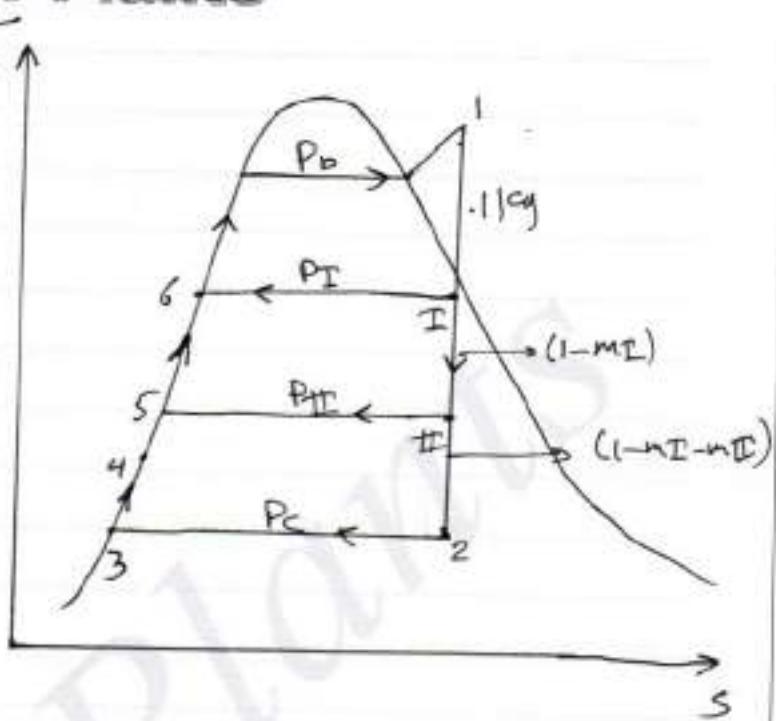
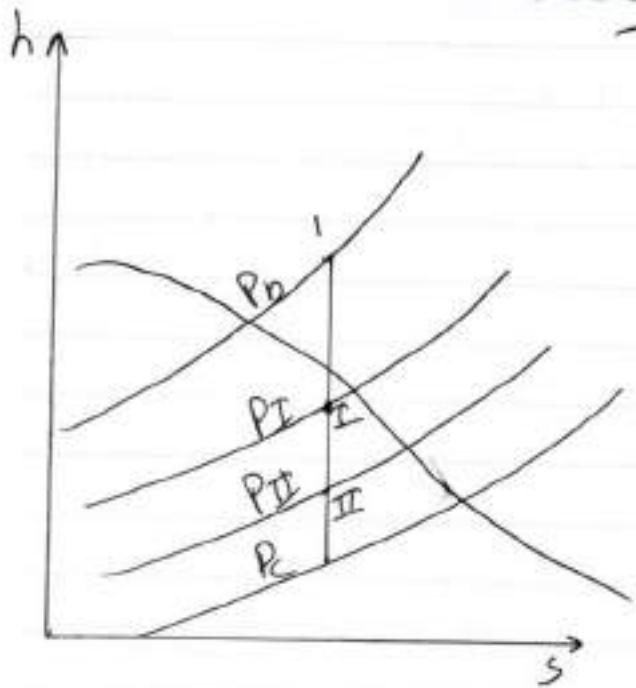
Ex/ Steam is supplied to a turbine at 30 bar and 350°C. The turbine exhaust pressure is 0.08 bar. The main condensate is heated in two stages of backward feedwater heaters. The steam bled from the turbine at 5 bar and 1 bar. Calculate:

- Masses of bled steam of each heater.
- Thermal efficiency of the cycle.

Neglect all pumps work.



Power Plants



From Mollier chart

At 30 bar, 350°C

$h_1 = 3115 \text{ kJ/kg}$
$h_I = 2720 \text{ kJ/kg}$
$h_{II} = 2450 \text{ kJ/kg}$
$h_2 = 2120 \text{ kJ/kg}$

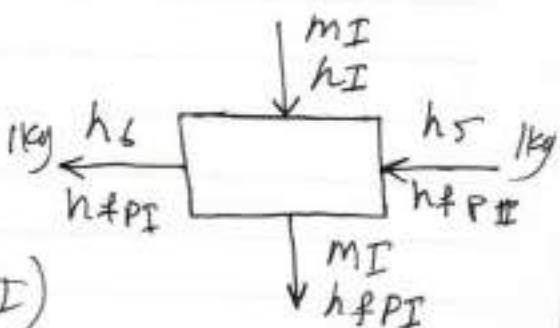
From steam table

$h_3 = h_{fpc} = 173.9 \text{ kJ/kg}$
$h_5 = h_{fPI} = 417.5 \text{ kJ/kg}$
$h_6 = h_{fPII} = 640.1 \text{ kJ/kg}$

Heat balance

1st heater

$$MI(h_I - h_{fPI}) = 1 \text{ kg} (h_{fPI} - h_{fPII})$$



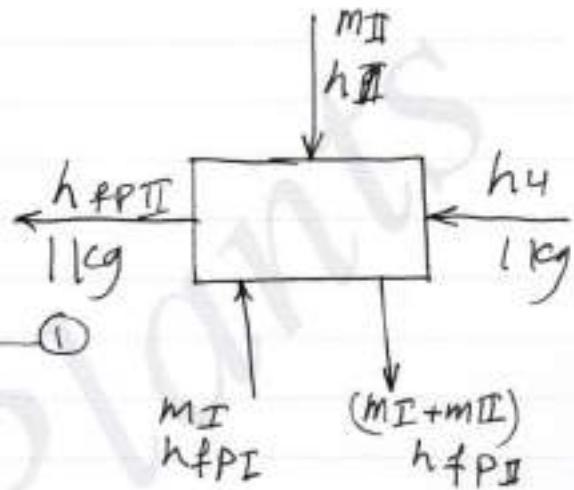
(7)

Power Plants

$$m_I = \frac{640.1 - 417.5}{2720 - 640.1} = 0.107 \text{ kg}$$

- 2nd heater

$$\begin{aligned} h_{II}m_{II} + m_I h_{fPI} + h_4 + 1 \text{ kg} \\ = h_{fPII} + 1 \text{ kg} + (m_I + m_{II}) h_{fPII} \quad \textcircled{1} \end{aligned}$$



- Drain cooler

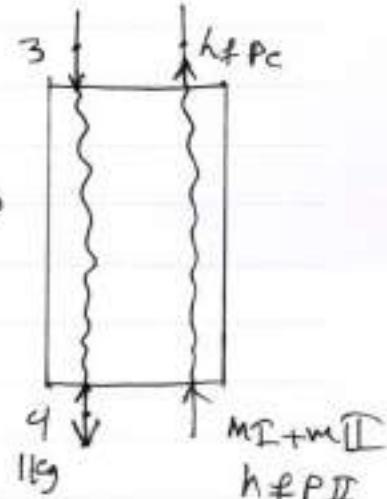
$$1 \text{ kg} (h_4 - h_3) = (m_I + m_{II})(h_{fPII} - h_{fPC})$$

$$h_4 = (m_I + m_{II})(h_{fPII} - h_{fPC}) + h_3 \quad \textcircled{2}$$

Inserting the value of h_4
in equⁿ ① :-

$$\begin{aligned} m_{II} h_{II} + m_I h_{fPI} + (m_I + m_{II})(h_{fPII} - h_{fPC}) + h_3 \\ = (m_I + m_{II}) h_{fPII} + h_{fPII} \end{aligned}$$

$$\begin{aligned} 2456 m_{II} + 0.107 * 640.1 + (0.107 + m_{II})(417.5 - 173.9) + 173.9 \\ = (0.107 + m_{II}) * 417.5 + 417.5 \end{aligned}$$



Power Plants

$$2450 \text{ mII} + 68.4967 + 243.6 \text{ mI} + 26.04 + 173.9 = \\ 417.5 \text{ mII} + 44.673 + 417.5$$

$$2276.1 \text{ mII} = 193.72$$

$$mI = 0.085 \text{ kg}$$

$$\text{W.D} = 1 \text{ kg} (h_1 - h_I) + (1 - mI)(h_I - h_{II}) + (1 - mI - mII)(h_{II} - h_2) \\ = (3115 - 2720) + (1 - 0.107)(2720 - 2450) + (1 - 0.107 - 0.085) \\ (2450 - 2120) \\ = 903 \text{ kJ/kg}$$

$$\text{Qadd} = (h_1 - h_C) \times 1 \text{ kg} \\ = (3115 - 640.1) = 2475.2 \text{ kJ/kg}$$

$$\eta_{\text{cycle}} = \frac{\text{W.D}}{\text{Qadd}} \\ = \frac{903}{2475.2} = 36.48 \%$$

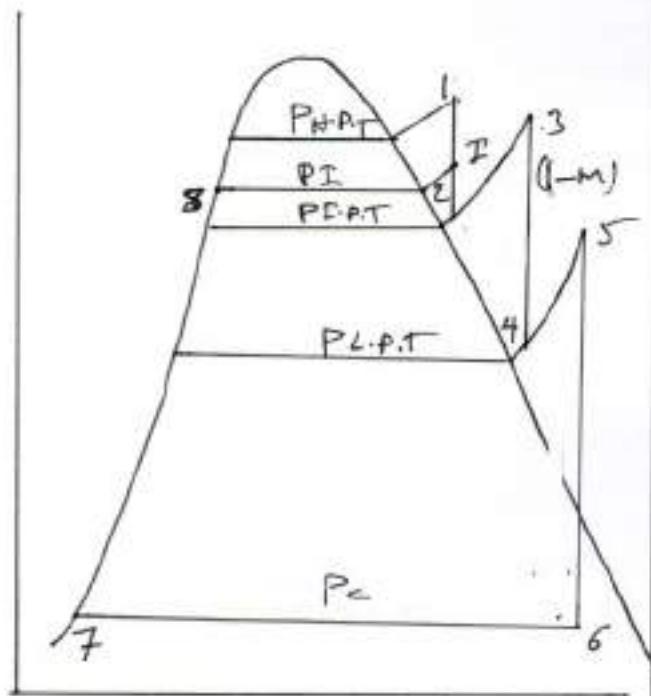
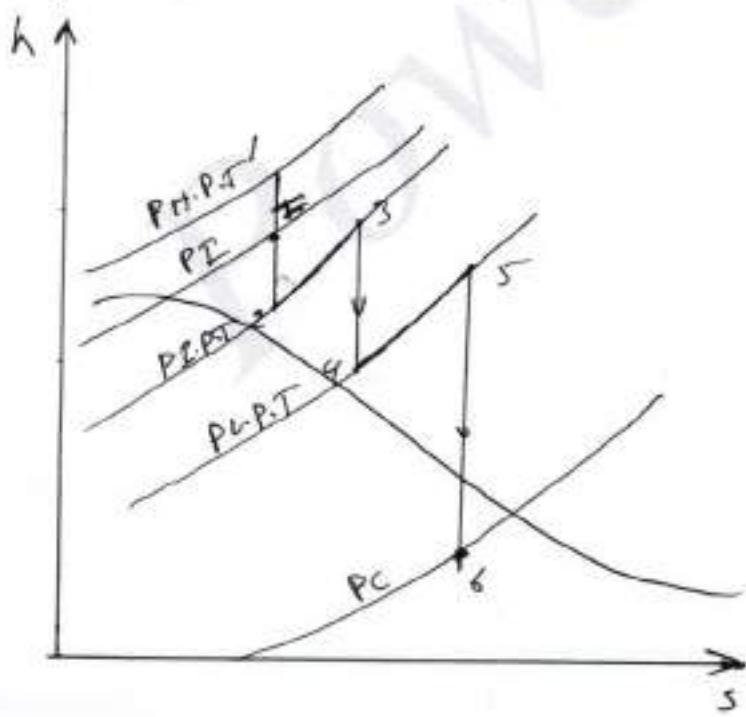
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Power Plants

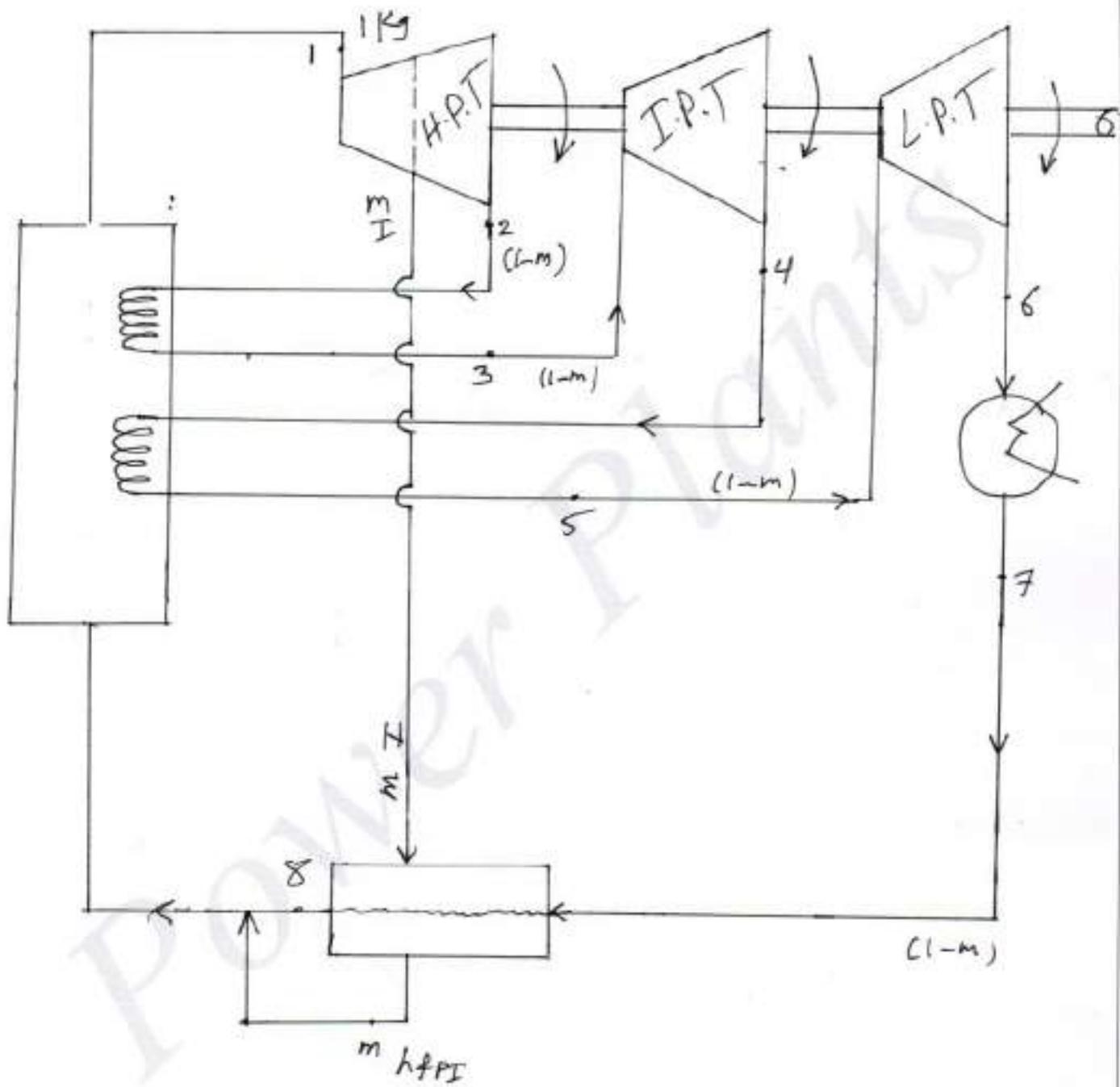
Ex/ In a steam power plant, Steam enters a H.P.T at 100 bar and 500°C and exits at 25 bar. Steam is re-heated to 490°C . Then, it enters intermediate pressure turbine and expands to 3 bar. Then, it is reheated again to 311°C , and it enters the L.P.T and expands to the condenser pressure of 0.05 bar. A closed feed water heater is located in the feed cycle and uses bleed steam from the H.P.T at 40 bar. The net output power is 100 MW.

Determine:-

- amount of steam used for bleeding.
- mass flow rate of the steam
- Work done
- Cycle efficiency.



Power Plants



Power Plants

From Mollier chart $h_1 = 3375 \text{ KJ/kg}$

$$h_2 = 2985 \text{ KJ/kg}$$

$$h_I = 3095 \text{ KJ/kg}$$

$$h_3 = 3440 \text{ KJ/kg}$$

$$h_4 = 2860 \text{ KJ/kg}$$

$$h_5 = 3090 \text{ KJ/kg}$$

$$h_6 = 2360 \text{ KJ/kg}$$

From Steam table $h_f = h_{fpc} = 137.82 \text{ KJ/kg}$

$$h_s = h_{fpI} = 1087.3 \text{ KJ/kg}$$

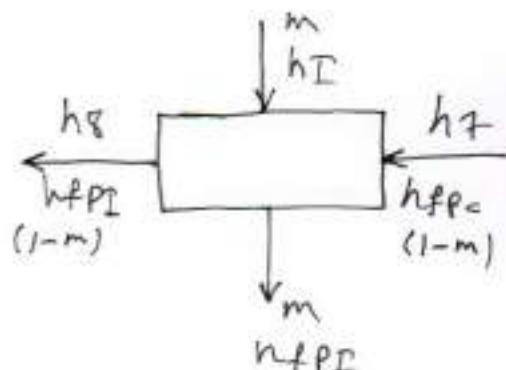
Heat balance for heater

$$m(h_I - h_{fpI}) = (1-m)(h_{fpI} - h_{fpc})$$

$$m(3095 - 1087.3) = (1-m)(1087.3 - 137.82)$$

$$2007.7m = 949.48 - 949.48 \quad m$$

$$m = 0.321 \text{ kg}$$



$$W.D. = (h_I - h_I) 169 + (1-m) [(h_I - h_2) + (h_3 - h_4) + (h_5 - h_6)]$$

$$= (3375 - 3095) + (1-0.321) [(3375 - 2985) + (3440 - 2860) + (3090 - 2360)]$$

$$= 1434.3 \text{ KJ/kg}$$

Power Plants

$$\begin{aligned} Q_{adef} &= (h_1 - h_8) \lg + (1-m) [(h_3 - h_2) + (h_5 - h_4)] \\ &= (3375 - 1087.3) + (1 - 0.321) [(3440 - 2985) + \\ &\quad (3090 - 2860)] \\ &= 2752.8 \text{ kJ/kg} \end{aligned}$$

$$P_{\text{output}} = m_s * W.D$$

$$m_s = \frac{100000}{1434.3} = 69.7 \text{ kg/s}$$

$$\eta_{\text{cycle}} = \frac{1434.3}{2752.8} = 52.1 \%$$

Power Plants

Sheet 1

Q1/ Steam is supplied to a two-stage at 40 bar and 350°C . It expands in the first turbine until it is just dry saturated, then it is reheated to 350°C and expanded through the second turbine. The condenser pressure is 0.035 bar. Calculate S.S.C and η_{cycle}

$$[2.79 \text{ kg/kW hr}, 38.4\%]$$

Q2/ A steam Power plant operates on ideal regenerative cycle with one open feed water heater. Steam enters the turbine at 15 MPa and 600°C . Some steam leaves the turbine at a pressure of 1.2 MPa and enters the open heater. Determine the fraction of steam extraction from the turbine and thermal efficiency of the cycle

$$[0.227 \text{ kg}, 46.3\%]$$

Q3/ In a regenerative steam cycle employing three closed feed water heaters, the steam is supplied to the turbine at 42 bar and 500°C and is exhausted to the condenser at 0.035 bar. The bleed steam for feed heating is taken at pressures of 15, 4 and 0.5 bar Neglect work of the pumps, calculate

- Masses of bleed steam
- Work done
- Cycle efficiency

$$[0.0952, 0.0969, 0.0902, 1133.6 \text{ kJ/kg}, 43.6\%]$$

Power Plants

Q4/ A steam power plant operates on an ideal reheat-regenerative cycle and has a net work power output of 120 MW. Steam enters the high-pressure turbine at 10 MPa and 550°C and leaves at 0.8 MPa. Some steam is extracted at this pressure to heat the feed water in an open feedwater heater. The rest is reheated to 500°C and expanded in the low pressure turbine to the condenser pressure of 10 kPa. Determine
a) mass of bleed steam
b) cycle efficiency

[$\approx 81.9 \text{ kg/s}, 44.4\%$]

Q5/ In a steam power plant, the steam mass flow rate is 80 ton/hr, the steam enter the turbine at 6 MPa and 480°C . Condenser pressure is 0.06 MPa. Mechanical and electrical efficiencies are 0.96 and 0.95 - Find

- a) S.S.C
- b) Output Power
- c) Cycle efficiency