## UNIT - I

## Rankine Cycle

(i) Simple rankine cycle.

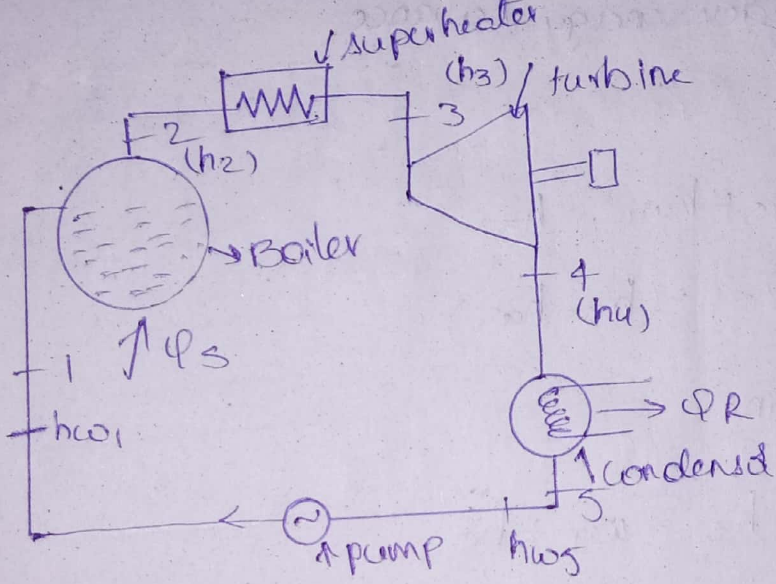
(ii) Reheat Rankine cycle

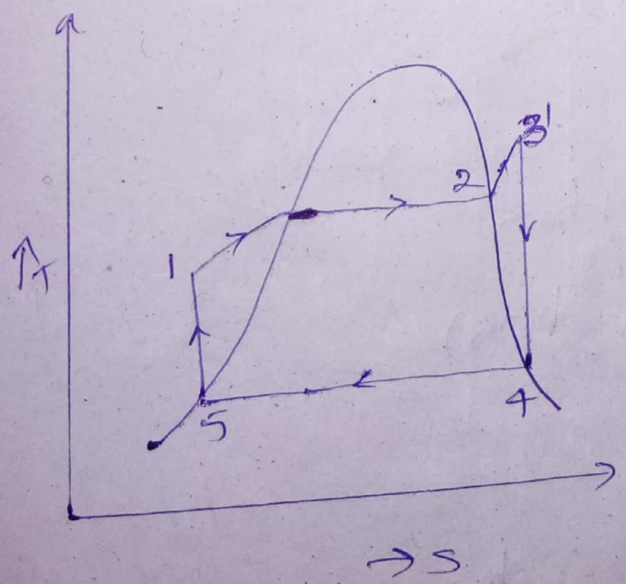
(iii) Regenerative Rankine cycle

(iv) combined Reheat & regenerative Rankine cycle

(v) modified Rankine cycle

1. Simple Rankine cycle :-



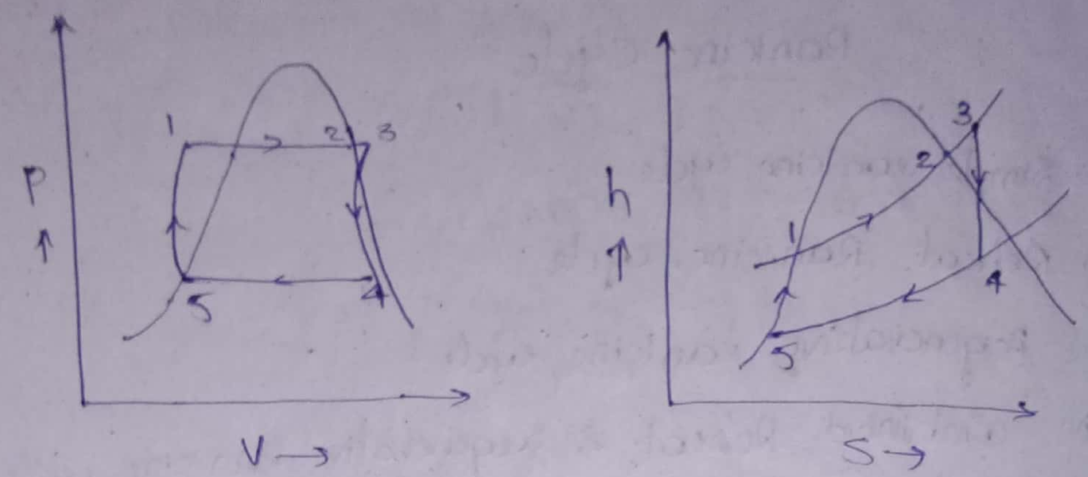

1-2 : heat addition to boiler

2-3 : superheating

3-4 : turbine expansion

4-5 : const press. heat rejection

5-1 : Isentropic compr.




## * Thermal $\eta$ of rankine cycle :-

consider energy balance

(i) boiler

$$Q_S + h_{w_1} = h_3$$

$$Q_S = (h_3 - h_{w_1})$$

(ii) Turbine

$$h_3 = W_T + h_4$$

$$W_T = (h_3 - h_4)$$

(iii) condensa

$$h_4 = Q_R + h_{w_5}$$

$$Q_R = (h_4 - h_{w_5})$$

(iv) pump

$$h_{w_5} + W_P = h_{w_1}$$

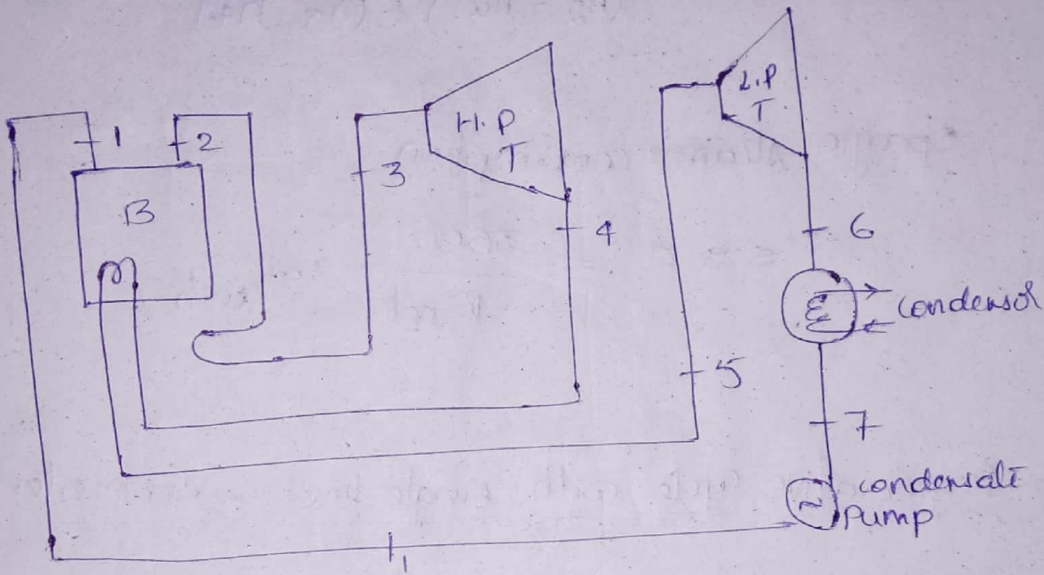
$$W_P = (h_{w_1} - h_{w_5})$$

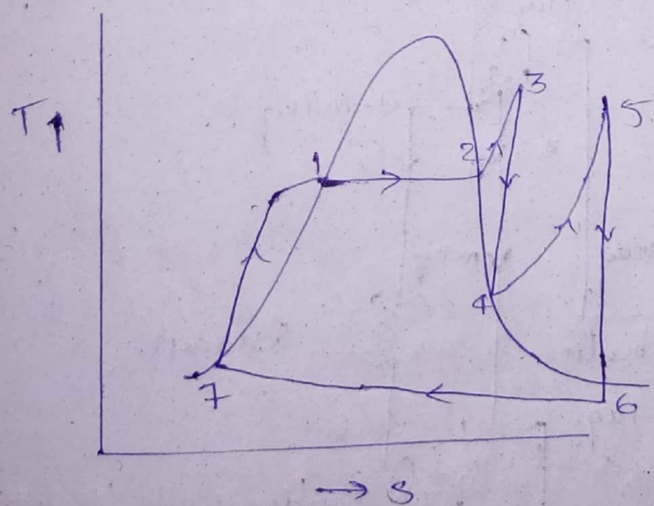
$$\eta_{th} = \frac{W_{net}}{Q_s}$$

$$\eta_{th} = \frac{W_T - W_P}{Q_s} \quad (\because W_P = 0)$$

$$\boxed{\eta_{th} = \frac{h_3 - h_4}{h_3 - h_{w_1}}}$$

2. Reheat Rankine cycle :-




$$\eta_{th} = \frac{W_{net}}{Q_s} \times 100$$

$$= \frac{(W_{H.P.T} + W_{L.P.T}) - W_P}{Q_B + Q_R} \times 100$$

$$W_{H.P.T} = (h_3 - h_4)$$

$$W_{L.P.T} = (h_5 - h_6)$$

$$W_P = (h_1 - h_7) = v_7 (P_1 - P_7)$$

$$Q_B = (h_2 - h_{w1})$$

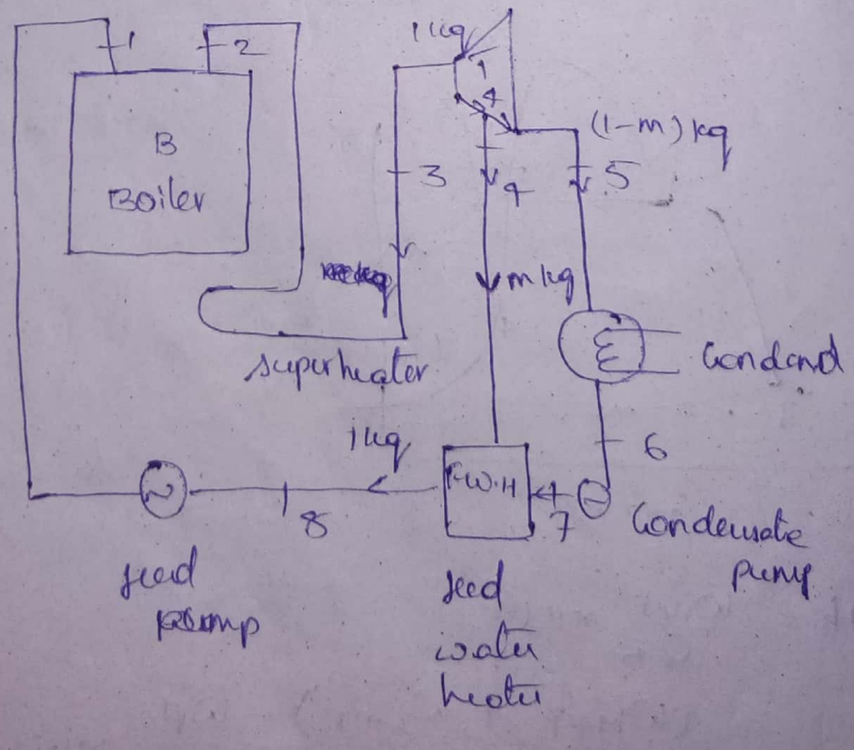
$$Q_R = (h_5 - h_4)$$

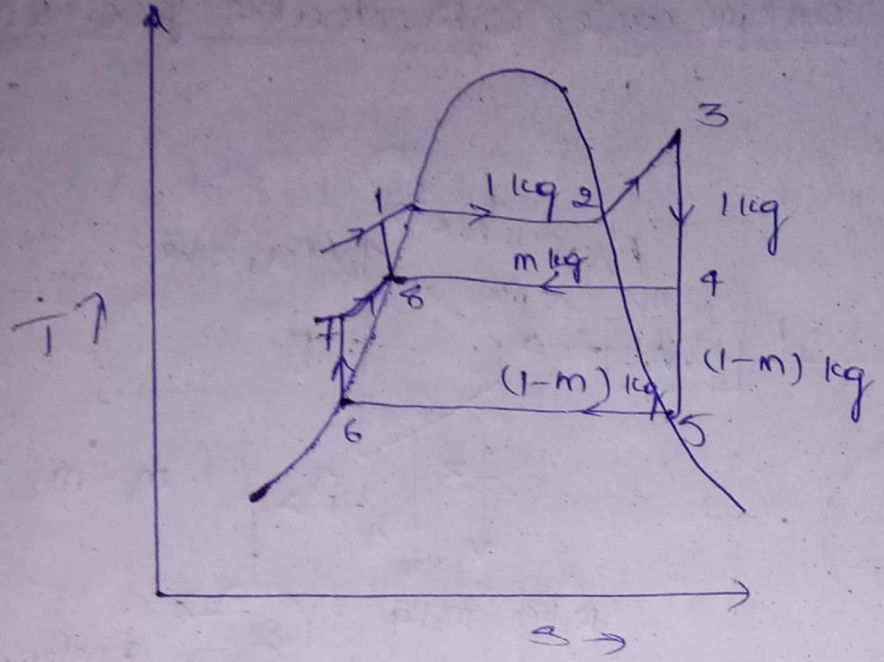
$$\eta_{th} = \frac{[(h_3 - h_4) + (h_5 - h_6)] - (h_1 - h_7)}{(h_2 - h_{w1}) + (h_5 - h_4)}$$

Specific steam consumption

$$S.S.C = \frac{3600}{W_{net}} \text{ kg/kW.h}$$

3. Regenerative cycle with single feed water heater :-






$$\eta_{th} = \frac{W_{net}}{Q_s} \times 100$$

$$= \frac{W_T - (W_{CPT} + W_{FP})}{(h_3 - h_{w1})} \times 100$$

$$W_T = 1(h_3 - h_4) + (1-m)(h_4 - h_5)$$

$$W_{cp} = (h_7 - h_6) = v_6 (P_7 - P_6)$$

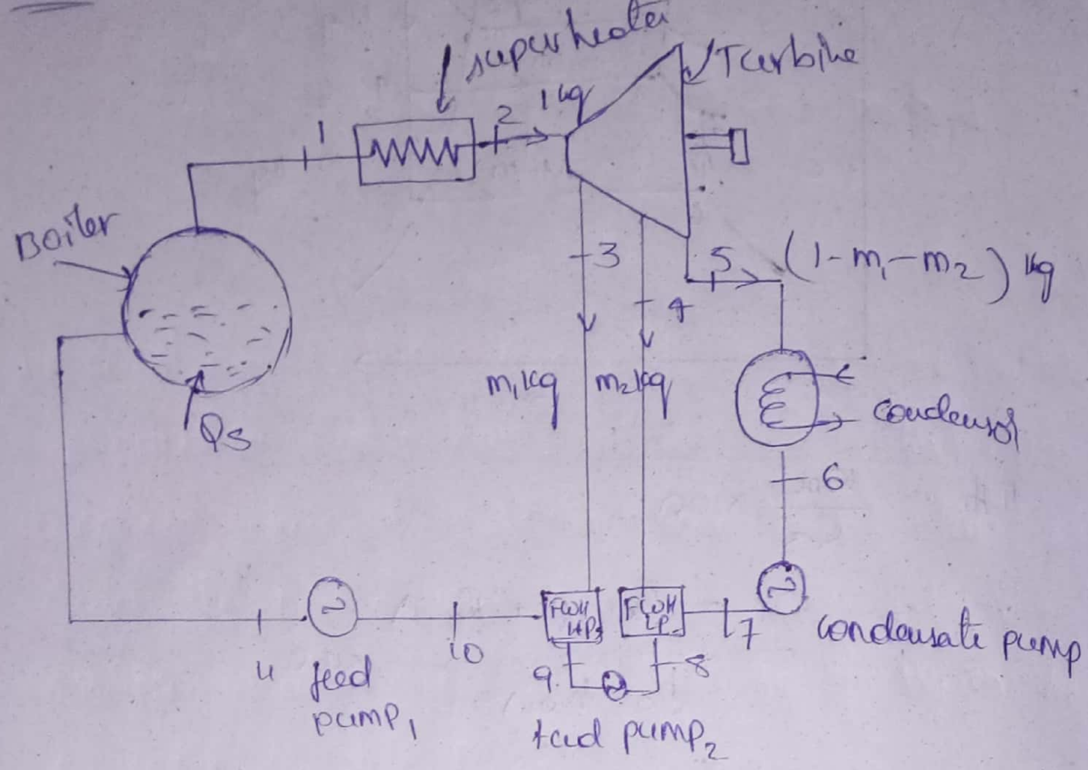
$$W_{F.P} = (h_1 - h_8) = v_8 (p_1 - p_8)$$

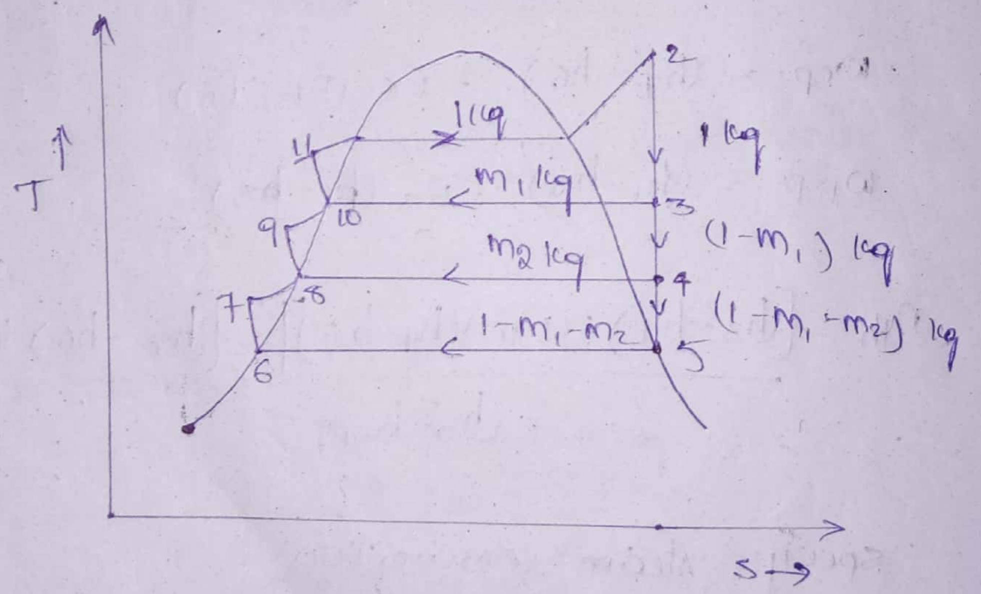
$$\eta_{th} = \frac{\left[(h_3 - h_4) + (1-m)(h_4 - h_5)\right] - \left[(h_7 - h_6) + (h_1 - h_8)\right]}{(h_3 - h_{w1})}$$

specific steam consumption

$$S.S.C = \frac{3600}{W_{net}} \quad kg/kWh$$

Regenerative rankine cycle with double feed water heater :-




$$\eta_{th} = \frac{W_{net}}{Q_s} \times 100 = \frac{W_T - W_P}{Q_S} \times 100$$

$$W_T = 1(h_2 - h_3) + (1-m_1)(h_3 - h_4) + (1-m_1-m_2)(h_4 - h_5)$$

$$W_P = W_{CP} + W_{FP_1} + W_{FP_2}$$

$$= (h_7 - h_6) + (h_9 - h_8) + (h_{11} - h_{10})$$

heat supplied $Q_s = (h_2 - h_{11})$

$$\eta_{th} = \frac{[1(h_2-h_3) + (1-m_1)(h_3-h_4) + (1-m_1-m_2)(h_4-h_5)] - ((h_7-h_6)+(h_9-h_8)+(h_{11}-h_{10}))}{h_2-h_{11}}$$

specific steam consumption

$$S.S.C = \frac{3600}{W_{net}} \; kg/kW.h$$

→ mass of the steam exerted for H.P feed water heater ($m_1$) :-

consider energy balance of HP FWH

$$m_1 h_3 + (1-m_1) h_{w9} = 1 \times h_{w10}$$

$$m_1 h_3 + h_{w9} - m_1 h_{w9} = h_{w10}$$

$$m_1 (h_3 - h_{w9}) = h_{w10} - h_{w9}$$

$$\boxed{m_1 = \frac{h_{w10} - h_{w9}}{h_3 - h_{w9}}}$$

→ mass of the steam extracted for LP feed water ($m_2$).

consider energy balanced for LP FWH.

$$m_2 h_4 + (1-m_1-m_2) h_{w7} = (1-m_1) h_{w8}$$

$$m_2 h_4 + h_{w7} - m_1 h_{w7} - m_2 h_{w7} = (1-m_1) h_{w8}$$

$m_2 h_4 + h_{w7} - m_1 h_{w7} - m_2 h_{w7} = h_{w8} - m_1 h_{w8}$

$m_2 (h_4 - h_{w7}) + h_{w7} - m_1 h_{w7} = h_{w8} - m_1 h_{w8}$

$$m_2 = \frac{h_{w8} - m_1 h_{w8} - h_{w7} + m_1 h_{w7}}{h_4 - h_{w7}}$$

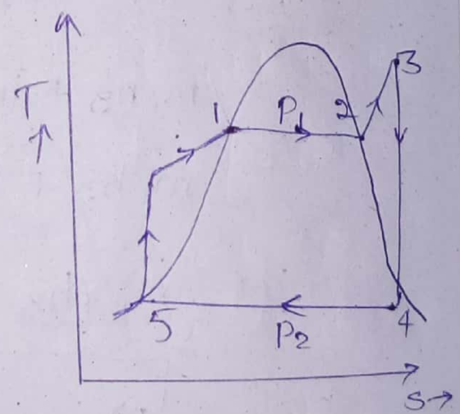
1. In a steam turbine steam at 20 bar, 360°C is expanded to 0.08 bar. It is then enters into condenser where it is condensate to saturated liquid water the pump feed back to water into the boiler. Assume ideal process. find per kg of steam the net work & cycle η.

sol Given data

$P_1 = 20$ bar

$P_2 = 0.08$ bar

$T_1 = 360°C$




$t_s \rightarrow 212.4°C$

find $W_{net} = ?$

$\eta_{cycle} = ?$

$P_1 = P_2 = P_3 = 20$ bar

$P_4 = P_5 = 0.08$ bar.

enthalpy of super heated steam

$h_3 = h_{sup_3} = h_{s_3} + c_p (t_{sup} - t_s)$

$= 2792.2 + 2.1 (360 - 212.4)$

$= 3107.1$ kJ/kg

$\phi_3 = \phi_4$

$\phi_{sup_3} = \phi_{wet\,4}$

$$\phi_{s3} + c_p \ln\left[\frac{T_{sup_3}}{T_{s3}}\right] = \phi_{w4} + x_4\,\phi_{e4}$$

$$6.337 + 2.1 \ln\left[\frac{360+273}{212.4+273}\right] = 0.593 + x_4 \times 7.637$$

$x_4 = 0.82.$

enthalpy of wet exhaust steam

$h_4 = h_{wet_4} = h_{w4} + x_4 L_4$

$= 173.9 + 0.82 \times 2403.2$

$= 2144.52$ kJ/kg

$W_{net} = W_T - W_P$

$W_T = (h_3 - h_4)$

$= 3107.1 - 2144.52$

$= 962.5$ kJ/kg

$W_P = (h_{w1} - h_{w5}) = v_5 (P_1 - P_5)$

$= 0.001008 (20 - 0.08) \times 100$

$= 2$ kJ/kg

$W_{net} = W_T - W_P$

$= 962.5 - 2.00$

$= 960.5$ kJ/kg

$w_p = h_{w01} - h_{w05} = 2$

$h_{w01} = 2 + 173.9$

$h_{w01} = 175.9$ kJ/kg

$Q_s = (h_3 - h_{w1})$

$= 3107.1 - 175.9$

$= 2931.2$ kJ/kg

$\eta_{cycle} = \frac{w_{net}}{Q_s} \times 100$

$= \frac{960.5}{2931.2} \times 100$

$= 32.76\%$

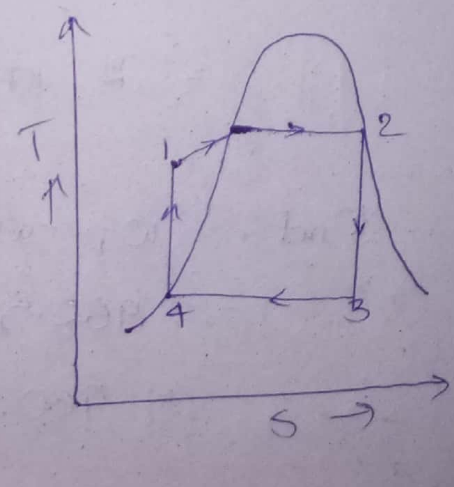
2. In a rankine cycle, the steam at inlet to the turbine is saturated at a pressure of 35 bar at exhaust pressure is 0.2 bar. Determine pump work, turbine work, $\eta$ rankine, condensor heat flow, dryness of the end of the expansion. Assume flow rate is 9.5 kg/sec

Sol: $P_1 = P_2 = 35$ bar

$P_3 = P_4 = 0.2$ bar

$x_2 = 1$

$x_3 = ?$



$h_2 = h_{g2} = 2802 \text{ kJ/kg}$

$\phi_2 = \phi_3$

$\phi_{g2} = \phi_{wet\,3}$

$6.123 = \phi_{w3} + x_3 \phi_{e3}$

$6.123 = 0.832 + x_3(7.077)$

$x_3 = 0.74 < 1.$

enthalpy of exhaust steam

$h_3 = h_{wet\,3} = h_{w3} + x_3 l_3$

$= 251.5 + 0.74 \times 2358.4$

$= 1996.71 \text{ kJ/kg}$

$h_4 = h_{w4} = 251.5 \text{ kJ/kg}$

→ Pump work $w_p = v_4 (P_1 - P_4) \times 100$

$= 0.001017 (35 - 0.2) \times 100$

$= 3.5 \text{ kJ/kg}$

$w_p = (h_{w1} - h_{w4}) = 3.5$

$h_{w1} = 3.5 + 251.5$

$= 255 \text{ kJ/kg}$

→ turbine work $w_T = (h_2 - h_3)$

$= \dot{m} (h_2 - h_3)$

$= 9.5 (2802 - 1996.71)$

$= 7652 \text{ kW}$