Catalog

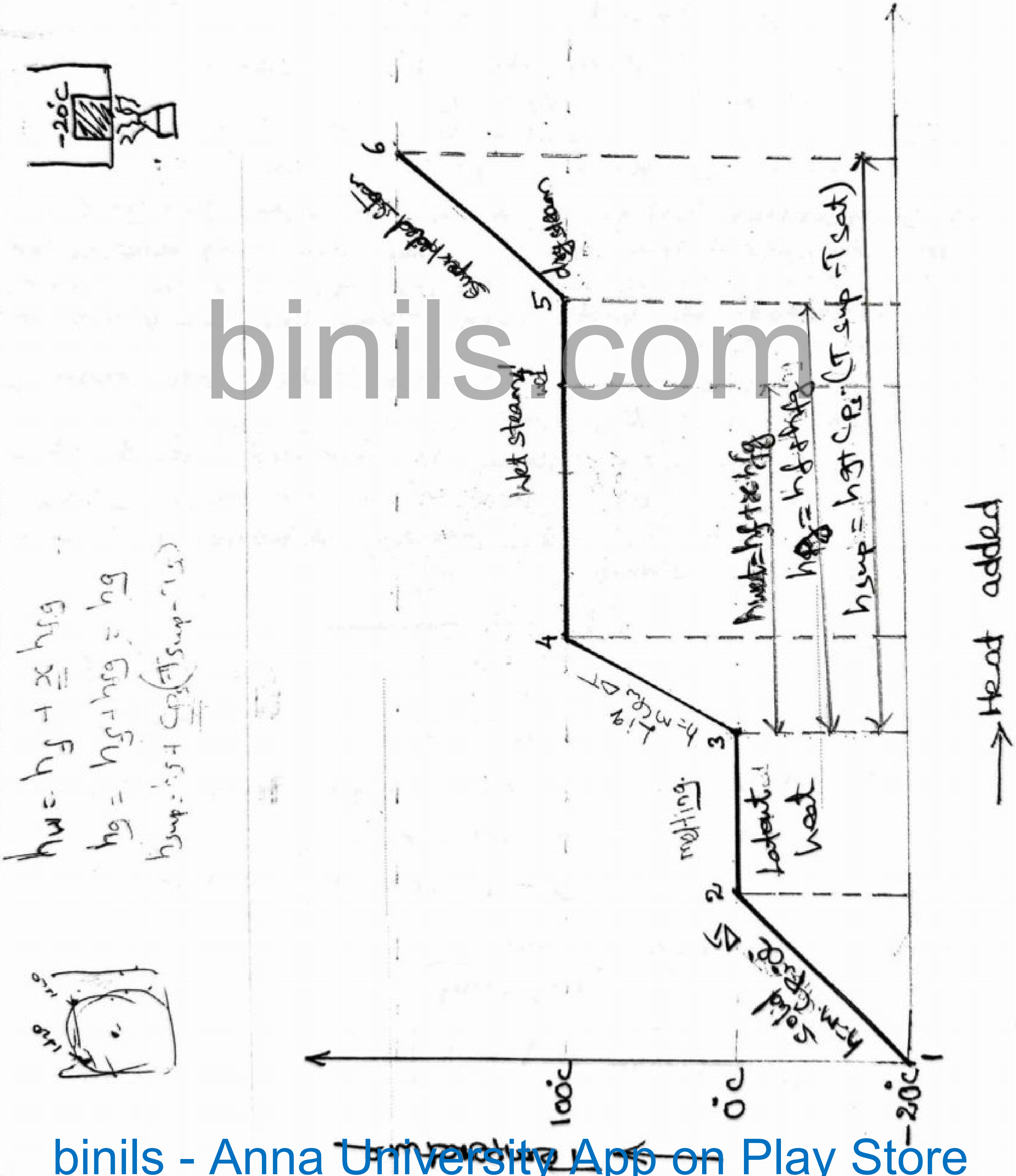
UNIT-II

Properties of pure substance and steam power cycles

Properties of pure substance (water, air) and steam power cycles.

Pure substance is a substance which has a fixed chemical composition throughout its mass.

Formation of steam: (or) Phase change process of pure substances:



Consider one kg of ice in a closed vessel under a pressure of p and at a temp. of −20°C. If the ice is gradually heated when the pressure remains constant, the following changes will occur.

(a) The temperature of the ice will increases till it reaches the freezing temperature of water at 0°C. It is shown by the line 1-2.

(b) On further heating beyond point 2, there is no rise in temp. till the whole of the ice has been melted and converted into water. This process is represented by the line 2-3. The heat added during the period is called Latent heat of Ice.

(c) On further heating, the water reaches its boiling point or saturation point 4. The amount of heat added during heating of water from 0°C to saturation temp. of 100°C is known as sensible heat.

(d) On further heating beyond 4, the water will gradually be converted into steam when the temp remains constant. The same process continues till all water particles converted into wet steam. The line 4-4' represents this process.

(e) If the wet steam is further heated, wet steam is converted into dry steam.

(f) When the dry steam is further heated, the temperature rises again. This process is called super heating and the steam obtained is known as superheated steam.

Dryness fraction: (x)

$$x = \frac{m_g}{m_f + m_g}$$

m_g – mass of dry steam in kg

m_f – mass of water vapour.

This term (x) applicable only for wet steam.

for dry steam $m_f = 0$

so $x = 1$ for dry steam.

Wetness fraction: $= \frac{m_f}{m_f + m_g}$

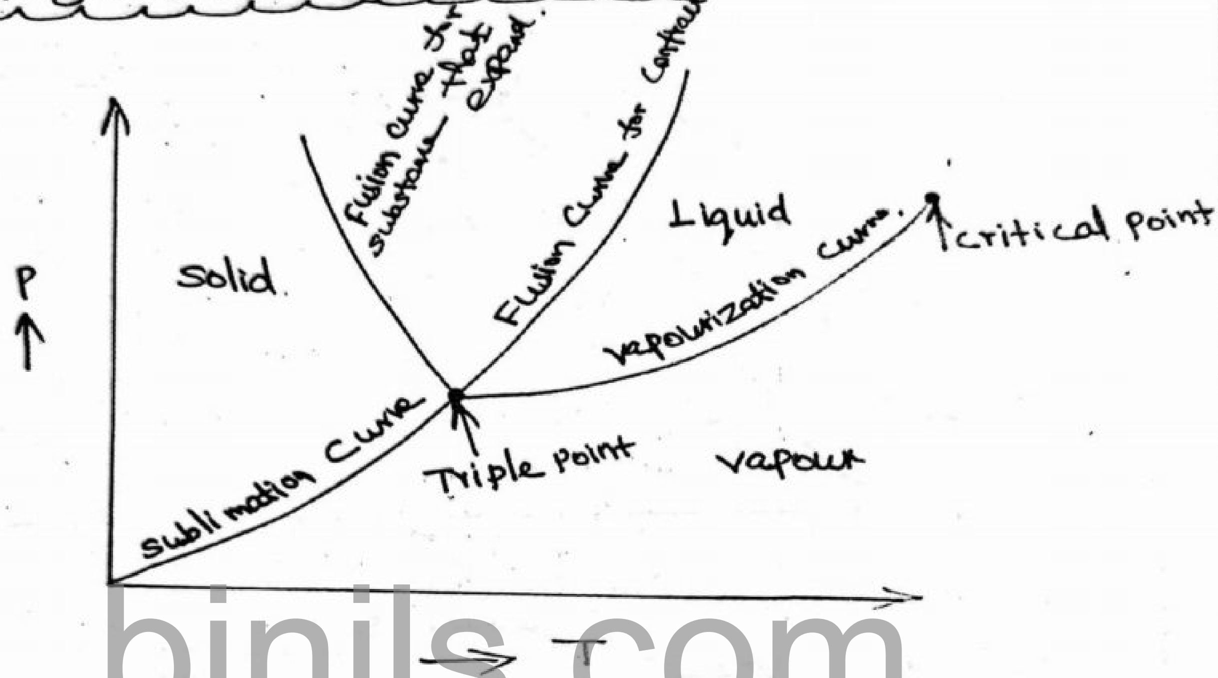
Wetness fraction $= 1 - x$

Phase Rule (or) Gibbs Phase Rule

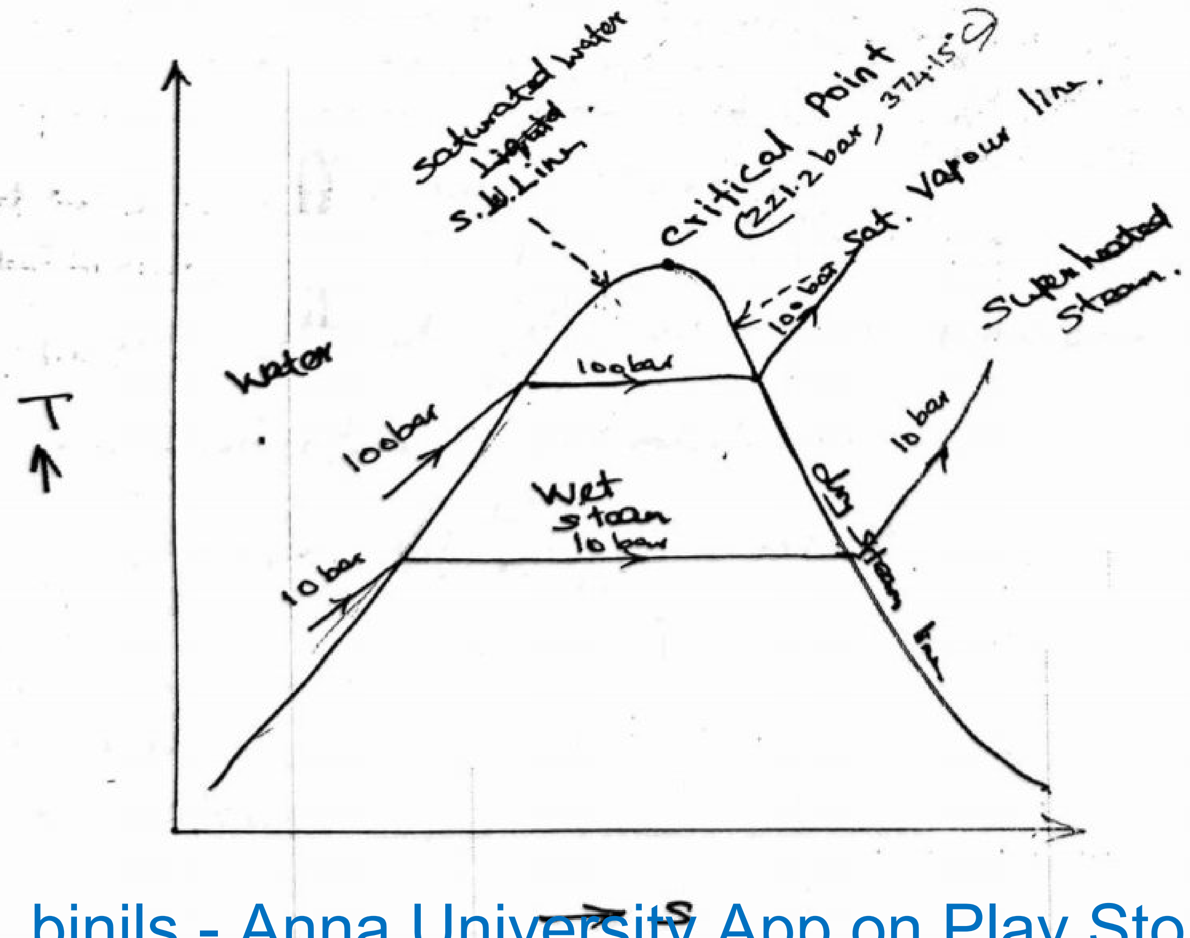
$$n = C - \phi + 2$$

n – The no. of independent variables.
C – The no. of components
ϕ – The no. of phases.

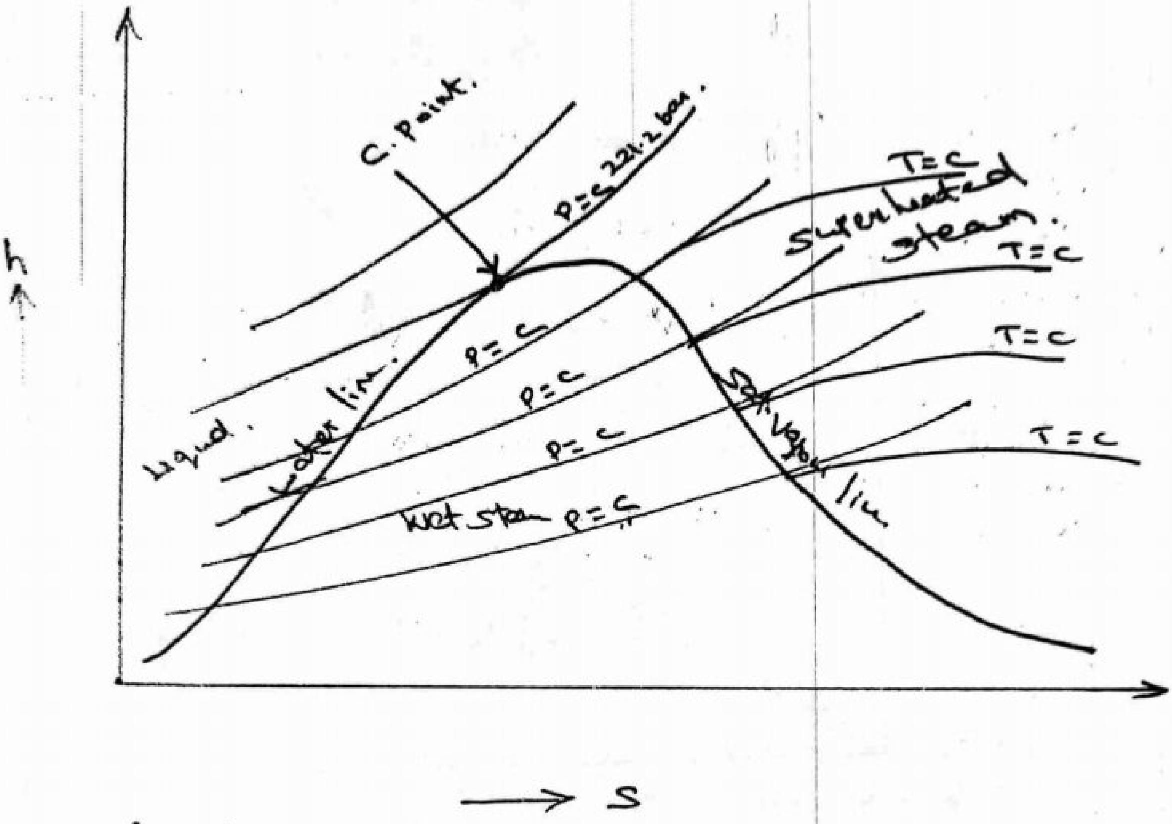
P–T diagram of pure substance:



T–s diagram of pure substance.



h–s diagram (or) Mollier chart



Types of steam:

1. Wet steam
2. dry steam
3. super heated steam.

x = dryness fraction

x = (0 to 1) varies from

"x" values	Substance Condition	Enthalpy (h)	Entropy (s)
If $x = 0$	Water	$h = h_f$	$s = s_f$
If $x = 0.1 - 0.99$	Wet steam	$h_{wet} = h_f + x h_{fg}$	$s_{wet} = s_f + x s_{fg}$
If $x = 1$	dry steam	$h_{dry} = h_f + h_{fg} = h_g$	$s_{dry} = s_f + s_{fg} = s_g$
—	Super heated steam	$h_{sup} = h_g + C_{ps}(T_{sup} - T_s)$	$s_{sup} = s_g + C_{ps} \log_e\left(\frac{T_{sup}}{T_s}\right)$

T_{sup} – Super heated Temp.

T_s – Saturated Temp.

C_{ps} – specific heat of steam

Important formulae

Properties	Wet steam	dry steam	superheated steam
Enthalpy (h) kJ/kg	$h_{wet} = h_f + x h_{fg}$	$h_{dry} = h_g = h_f + h_{fg}$	$h_{sup} = h_g + C_{p_s}(T_{sup} - T_s)$
Entropy (s) kJ/kg K	$s_{wet} = s_f + x s_{fg}$	$s_{dry} = s_g = s_f + s_{fg}$	$s_{sup} = s_g + C_{p_s} \ln\left(\frac{T_{sup}}{T_s}\right)$
Sp. Volume (v) m^3/kg	$v_{wet} = x v_g$	$v_{dry} = v_g$	$v_{sup} = v_g\left(\frac{T_{sup}}{T_s}\right)$
Density (ρ) kg/m^3	$\rho_{wet} = \frac{1}{v_{wet}}$	$\rho_{dry} = \frac{1}{v_g}$	$\rho_{sup} = \frac{1}{v_{sup}}$
Work done (W) kJ/kg	$W_{wet} = 100\,P\,x\,v_g$	$W_{dry} = 100\,P\,v_g$	$W_{sup} = 100 \times P\,v_{sup}$
Internal energy (u) kJ/kg	$u_{wet} = h_{wet} - W_{wet}$	$u_{dry} = h_{dry} - W_{dry}$	$u_{sup} = h_{sup} - W_{sup}$

$h = u + pV$

$u = h - pV$

$= h - W$

Systems	Work done	Heat transfer
Boiler	$W = 0$ ✓	$Q = h_2 - h_1$
Turbine	$W = h_2 - h_1$	$Q = 0$
Condenser	$W = 0$ ✓	$Q = h_1 - h_2$
Nozzle	$W = 0$ ✓	$Q = 0$

Steam Table:

Table 1 - Temp. Table.

Table 2 - Pressure Table.

Table 3 - Sp. vol. of superheated steam

Table 4 - Sp. enth "

Table 5 - Sp. entropy "

Table 1
Temperature Tables

Temp	Pr	Sp. vol v_f	Sp. vol v_g	Sp. enth h_f	Sp. enth h_{fg}	Sp. enth h_g	s_f	[illegible]
0	–	–	–	–				
1								
2								
3								
4								

Table 3
Sp. volume m^3/kg

Pr in bar	T_s °C	100	150	200	250
0.02	17.5				
0.04	29.0				
0.06	36.2				
0.08	–				

1. Determine the condition of steam at a temp. of 220°C and enthalpy of 2750 kJ/kg.

Wet → dry steam → Super heated

wet < h_g < super

G.D

$T = 220°C$

$h = 2750$ kJ/kg

To find: condition of steam.

wet (or) dry (or) superheated

Solution:

From steam table at 220°C

$h_g = 2799$ kJ/kg

g – dry steam

$h < h_g \Rightarrow$ Wet steam.

$h = h_g \Rightarrow$ dry steam.

$h > h_g \Rightarrow$ superheated steam.

$h < h_g$ so the steam condition is Wet

Table 1

Temp Tab

°C	Bar	v_f	v_g	h_f	h_{fg}	h_g
220°C	23.18	[illegible]	[illegible]	943.7	185[illegible]	2799.9

$h_{wet} = 2750$ kJ/kg.

$x = ?$

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

From steam table at 220°C

$h_f = 943.7$ kJ/kg.

$h_{fg} = 1856.2$ kJ/kg.

$2750 = 943.7 + x(1856.2)$

$$x = 0.973$$

2. Find the specific volume and enthalpy of steam at 9 bar when the steam condition is (a) wet with dryness fraction 0.95 (b) dry saturated (c) superheated and the temp. of steam is 240°C.

G.D:

$P = 9$ bar

(a) wet steam with $x = 0.95$

(b) dry steam.

(c) superheated steam $T_{sup} = 240°C$.

To find: v, h

From steam table at 9 bar.

Table 2. Pressure Tables

P bar	T_s °C	v_f	v_g	h_f	h_{fg}	h_g
9	175.4	0.00121	0.21482	742.6	2029.5	2772.1

$T_s = 175.4°C$

$v_f = 0.00121\ m^3/kg$

$v_g = 0.21482\ m^3/kg$.

$h_f = 742.6\ KJ/kg$

$h_{fg} = 2029.5\ KJ/kg$.

$h_g = 2772.1\ KJ/kg$.

(a) Wet steam: $x = 0.95$.

sp. volume $v_{wet} = x v_g = 0.95 \times 0.21482 = 0.204\ m^3/kg$

Enthalpy $h_{wet} = h_f + x h_{fg} = 742.6 + 0.95(2029.5) = 2670.625\ KJ/kg$

(b) dry steam:

$v_{dry} = v_g = 0.21482\ m^3/kg$.

$h_{dry} = h_g = 2772.1\ KJ/kg$.

(c) super heated steam: $T_{sup} = 240°C$

$v_{sup} = v_g \left(\frac{T_{sup}}{T_s}\right) = 0.21482 \left(\frac{240+273}{175.4+273}\right) = 0.2457\ m^3/kg$

$h_{sup} = h_g + C_{ps}(T_{sup} - T_s)$

$h_{sup} = ?$ From super heated steam Table ④ at 9 bar and 240°C

sp. enthalpy of superheated steam

P_r	T_s	100°C	150°C	200°C	250°C
5	175.4				
6					
7					
8					
9	175.4			2832.7	2946.8

(Table 4)

200°C — 2832.7 KJ/kg

250°C — 2946.8 KJ/kg

Interpolation method

$$= 2832.7 + \frac{(2946.8 - 2832.7)}{250 - 200}(240 - 200)$$

$$h_{sup} = 2923.98\ KJ/kg$$

3. 2 kg of steam initially at 5 bar and 0.6 dry is heated at constant Pressure until the temperature becomes 350°C. Find the change in entropy and change internal energy.

G.D:

$m = 2\ kg$

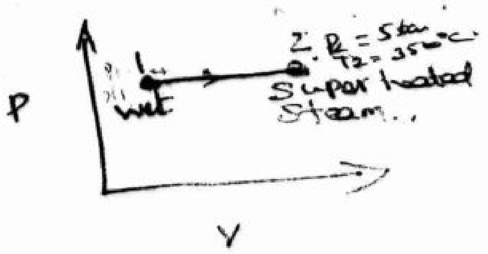
$P_1 = 5\ bar$

$x_1 = 0.6$

② $T_2 = 350°C$

Constant pressure process

$P_1 = P_2 = 5\ bar$.



To find: $\Delta U = m(U_2 - U_1)$

$\Delta S = m(S_2 - S_1)$

Solution:

From steam Table at 5 bar

$T_s = 151.8°C$

$T_2 > T_s$ so the Final conditions Superheated steam.

- $T_2 > T_s \Rightarrow$ super
- $T_2 = T_s =$ dry
- $T_2 < T_s =$ wet

T_s – sat. Temp (or) dry steam Temp.

(i) Change in entropy:

$\Delta S = m(S_2 - S_1)$

$\Delta S = m(S_{sup} - S_{wet})$

$S_{wet} = S_f + x\, S_{fg}$

From steam table at 5 bar.

$S_f = 1.86\, KJ/KgK$

$S_{fg} = 4.959\, KJ/KgK$.

$S_{wet} = 1.86 + 0.6(4.959) = 4.835\, KJ/KgK$.

$S_{sup} = ?$

From superheated steam (table-(5)) at 5 bar and 350°C

$S_{sup} = 7.634\, KJ/KgK$.

$\Delta S = m(S_{sup} - S_{wet})$

$= 2(7.634 - 4.835)$

$\boxed{\Delta S = 5.598\, KJ/KgK}$

(ii) Change in Internal energy:

$\Delta U = m(U_2 - U_1)$

$\Delta U = m(U_{sup} - U_{wet})$

$U_{wet} = h_{wet} - W_{wet}$

$= h_f + x\, h_{fg} - 100\, P\, v_{wet}$

$= h_f + x\, h_{fg} - 100 \times P \times x\, v_g$.

From steam table at 5 bar

$h_f = 640.1\, KJ/Kg$

$h_{fg} = 2107.4\, KJ/Kg$

$v_g = 0.37466\, m^3/Kg$

$U_{wet} = 640.1 + 0.6(2107.4) - 100 \times 5 \times 0.6 \times 0.37466$

$= 1904.54 - 112.398$

$\boxed{U_{wet} = 1792.142\, KJ/Kg}$

$U_{sup} = h_{sup} - W_{sup}$

$U_{sup} = h_{sup} - 100\, P\, v_{sup}$

$h_{sup} = ?$

From superheated steam (table-4) at 5 bar and 350°C

$h_{sup} = 3168.1\ KJ/Kg$

$v_{sup} = ?$

From superheated steam (table-3) at 5 bar and 350°C

$v_{sup} = 0.5701\ m^3/kg$

$U_{sup} = 3168.1 - 100 \times 5 \times 0.5701$

$U_{sup} = 2883.05\ KJ/kg.$

$\Delta U = m(U_{sup} - U_{wet})$

$= 2(2883.05 - 1792.142)$

$\Delta U =$ [illegible] KJ

$\boxed{\Delta U = 2181.816\ KJ}$

4. Steam at 0.8 MPa, 250°C and flowing at the rate of 1 kg/s passes into a pipe carrying wet steam at 0.8 MPa, 0.95 dry. After Adiabatic mixing the flow rate is 2.3 kg/s. Determine the properties of the steam after mixing. (Nov-04, Nov 12).

G.D:

$P_1 = 0.8\,MPa = 8\,bar$ $T_s = 170.4°C$

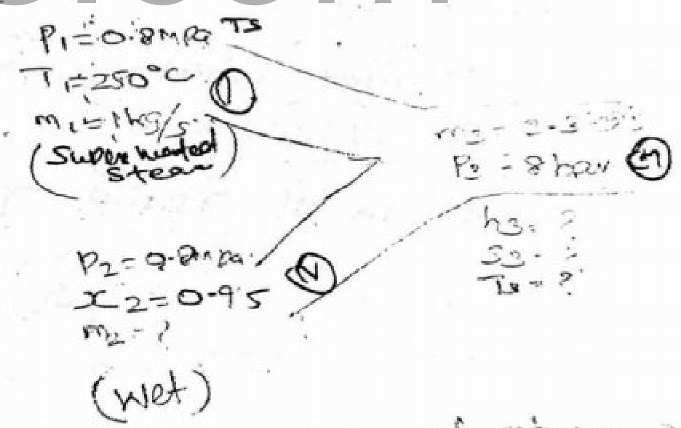
$T_1 = 250°C$

$m_1 = 1\,kg/s$

$P_2 = 0.8\,MPa = 8\,bar$

$x_2 = 0.95$

$m_3 = 2.3\,kg/s$



To find:

$h_3, S_3 = ?$

Solution:

mass of steam before mixing = mass of steam after mixing.

$m_1 + m_2 = m_3$

$1 + m_2 = 2.3$

$m_2 = 1.3\ kg/s$

Energy Balance eqn:

$m_1 h_1 + m_2 h_2 = m_3 h_3$

From steam table at 8 bar

$T_s = 170.4°C$

$T_1 > T_s$ So the steam condition at point 1 is superheated steam.

$m_1 h_{sup} + m_2 h_{wet} = m_3 h_3$

$h_{sup} = ?$

From superheated steam table-4 at 8 bar and 250°C

$h_{sup} = 2950.4$ KJ/kg.

$h_{wet} = ?$

$h_{wet} = h_f + x h_{fg}$

From steam table at 8 bar

$h_f = 720.9$ KJ/kg

$h_{fg} = 2046.5$ KJ/kg

$h_{wet} = 720.9 + 0.95(2046.5)$

$h_{wet} = 2664.27$ KJ/kg.

$1 \times (2950) + 1.3 \times (2664.27) = 2.3 \times (h_3)$

$h_3 = 2788.67$ KJ/kg

wet - dry - super
wet < h_g < sup

From steam table at 8 bar

$h_g = 2767.4$ KJ/kg

$h_3 > h_g$ so the steam condition at point (3) is superheated steam.

2nd option

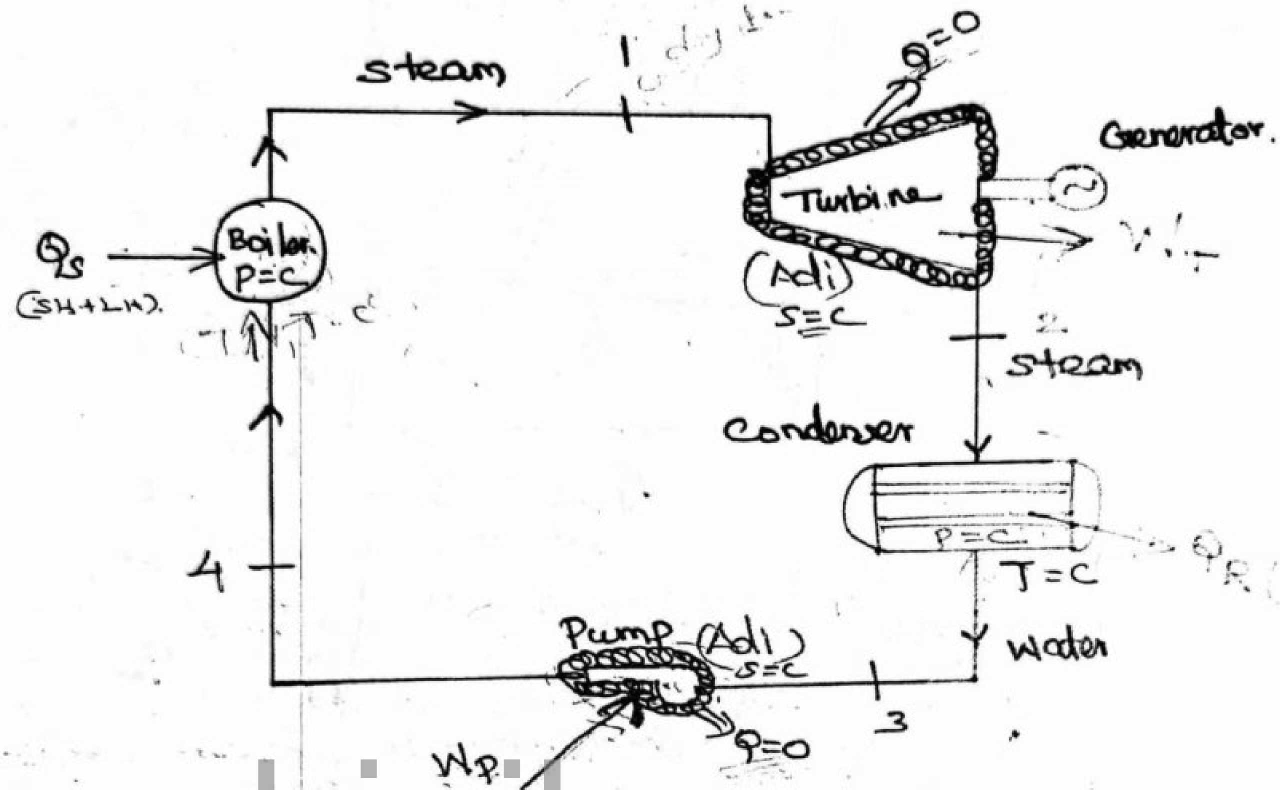
From Mollier chart corresponding to 8 bar and

$h_3 = 2788.67$ KJ/kg.

Superheated Temp. $T_3 = 180°C$

Entropy $S_3 = 6.65$ KJ/kgK.

Steam power cycles
(or)
Rankine cycle



1-2 → Adiabatic Expansion Process.

Turbine workdone

$$W_T = h_1 - h_2$$

2-3 → Const. Pr. heat Rejection process.

Heat Rejection $Q_R = h_2 - h_3$

3-4 → Adiabatic Compression process $\boxed{w = pv}$

$$W_P = h_4 - h_3 \Rightarrow \text{(or)} \quad W_P = v_{f_3}(P_4 - P_3)$$

$$W_P = v_{f_3}(P_1 - P_2)$$

$P_1 = P_4$, $P_2 = P_3$

4-1 → Const. Pr heat supplied process.

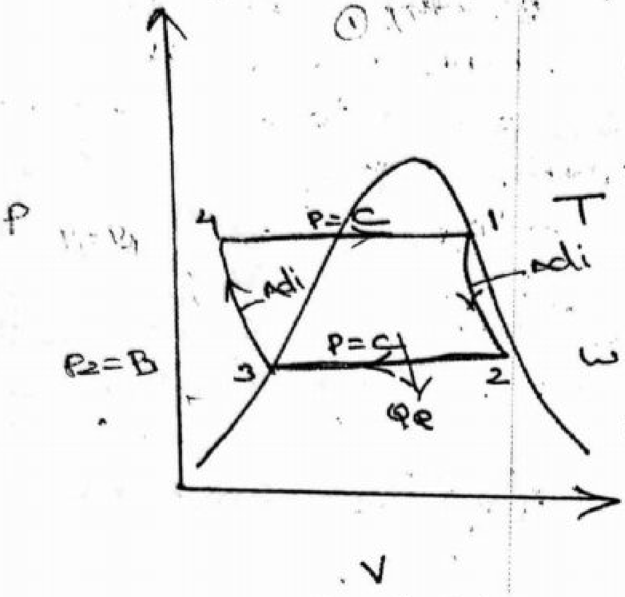
$$Q_s = h_1 - h_4$$

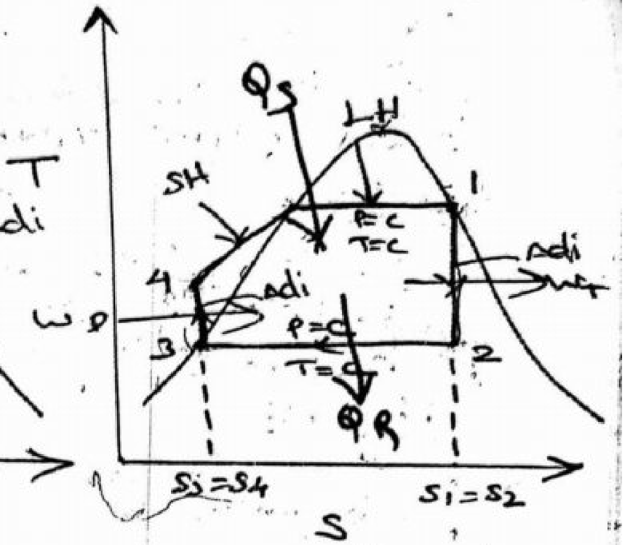
Workdone $W = W_T - W_P$ (or) $Q_s - Q_R$

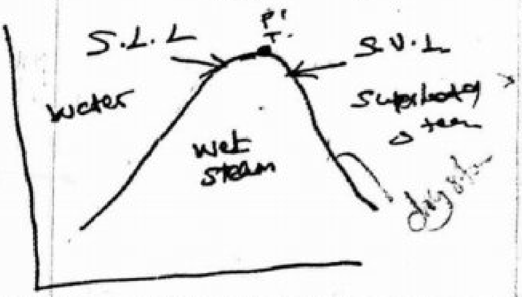
$$\eta = \frac{W}{Q_s} = \frac{W_T - W_P}{Q_s} = \frac{(h_1 - h_2) - (h_4 - h_3)}{h_1 - h_4}$$

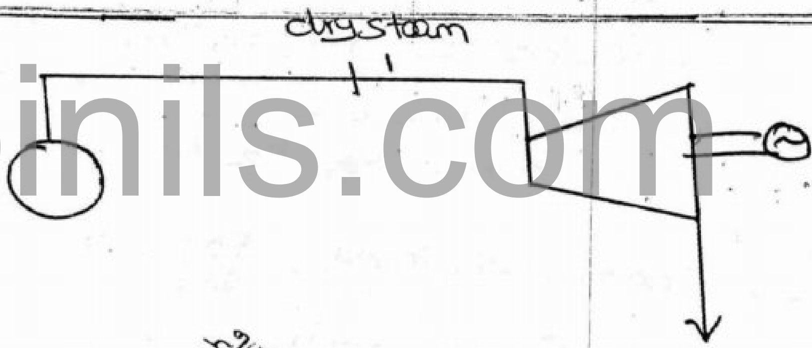
(or)

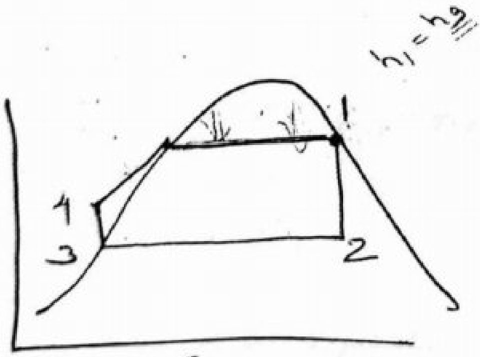
$$\eta = \frac{W}{Q_s} = \frac{Q_s - Q_R}{Q_s} = \frac{(h_1 - h_4) - (h_2 - h_3)}{(h_1 - h_4)}$$



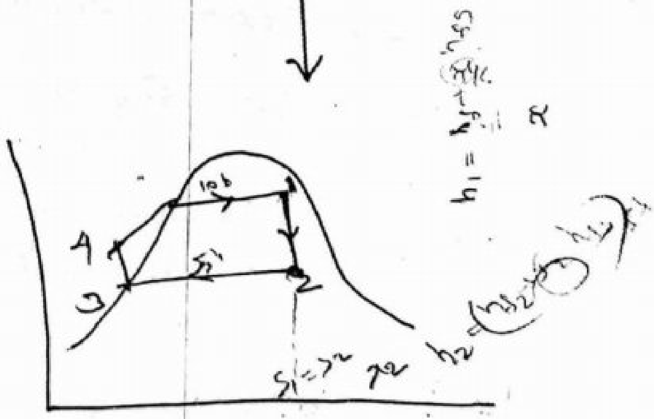




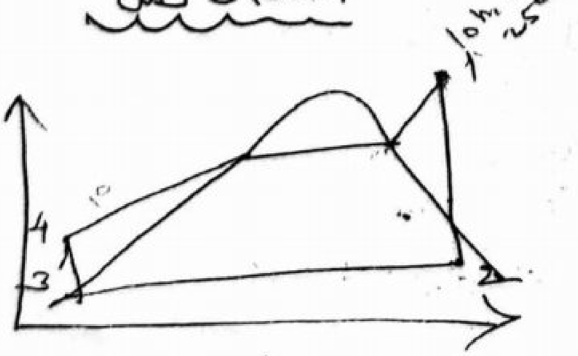




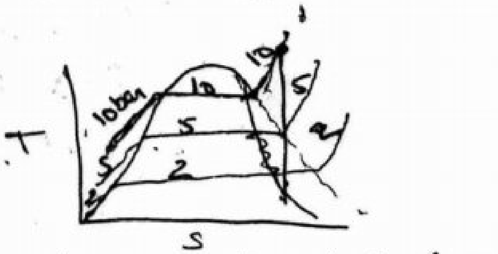
dry steam



wet steam.

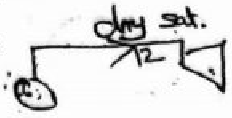


Super heated steam



behaviour of Temp. Lines

1. Dry saturated steam is supplied to a steam turbine at 12 bar and after the expansion its condenser pressure is 1 bar. Find the Rankine cycle efficiency, specific steam consumption. Neglect feed pump work.

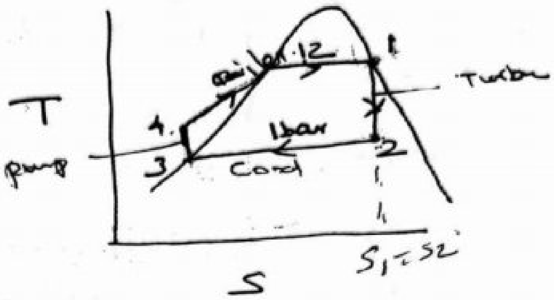


G.D:

Dry saturated steam

$P_1 = 12$ bar (Turbine pr) (Boiler)

$P_2 = 1$ bar (cond. pr).



To find:

$$\eta_{Rankine} = \frac{W}{Q_s} = \frac{W_T - W_P}{Q_s}$$

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

$W_P = h_4 - h_3$

$$= \frac{(h_1 - h_2) - W_P}{h_1 - (h_3 + W_P)}$$

$h_4 = h_3 + W_P$

Neglect the pump work

$$\eta_{Rankine} = \frac{h_1 - h_2}{h_1 - h_3}$$

$h_1, h_2, h_3 = ?$

$h_1 = ?$ At point 1 steam condition is dry

$h_1 = h_g$

From steam Table at 12 bar

$h_g = 2782.7$ kJ/kg $\quad s_1 = s_g = 6.519$ kJ/kgK.

$$\boxed{h_1 = h_g = 2782.7 \text{ kJ/kg}}$$

$h_2 = ?$ At point 2 steam condition is wet (x_2)

$h_2 = (h_{f_2} + x_2 h_{fg_2})_{1bar}$

$x_2 = ?$, $(s_1)_{dry} = (s_2)_{wet}$

$(s_g)_{12bar} = (s_{f_2} + x_2 s_{fg_2})_{1bar}$.

$6.519 = (s_{f_2} + x_2 s_{fg_2})_{1bar}$

From steam Table at 1 bar

$s_f = 1.3026$ kJ/kgK $\quad h_f = 417.5$ kJ/kg

$s_{fg} = 6.0568$ " $\quad h_{fg} = 2258.9$ "

$6.519 = 1.3026 + x_2 (6.0568)$

$$\boxed{x_2 = 0.86}$$

$h_2 = h_{f_2} + x_2 h_{fg_2} = 417.5 + 0.81 \times 2258)$

$h_2 = 2357.66 \text{ kJ/kg}$

$h_3 = ?$

At Point 3 steam condition is fluid (f)

$h_3 = (h_{f_3})_{1 bar} = h_{f_2}$ at steam table at 1 bar h_f

$h_{f_3} = \; h_3 = 417.5 \text{ kJ/kg}$

$$\eta_{Rankine} = \frac{h_1 - h_2}{h_1 - h_3} = \frac{2782.7 - 2357.66}{2782.7 - 417.5} \times 100$$

$\eta = 0.1797 = \underline{17.97\%}$ ✓

S.S. Consumption:

$$SSC = \frac{3600}{W} = \frac{3600}{h_1 - h_2} = \frac{3600}{2782.7 - 2357.66}$$

$SSC = 8.46 \text{ kJ/kw-hr}$

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2. A steam boiler generates steam at 30 bar, 300°C at the rate of 2 kg/s. This steam is expanded isentropically in a turbine to a condenser pressure of 0.05 bar, condensed at constant pressure and pumped back to boiler.
   (a) Draw the T-s diagram of Rankine cycle.
   (b) Find Heat supplied in the boiler per hr.
   (c) Determine the quality of steam after expansion.
   (d) Wt is the power generated by the turbine.
   (e) Find Rankine cycle efficiency.

To find: G.D: $P_1 = 30$ bar (Boiler), $T_1 = 300°C$, $m = 2$ kg/s, $P_2 = 0.05$ bar (condenser), $T_s = 233.8°$

Q_s, x_2, W_T, η

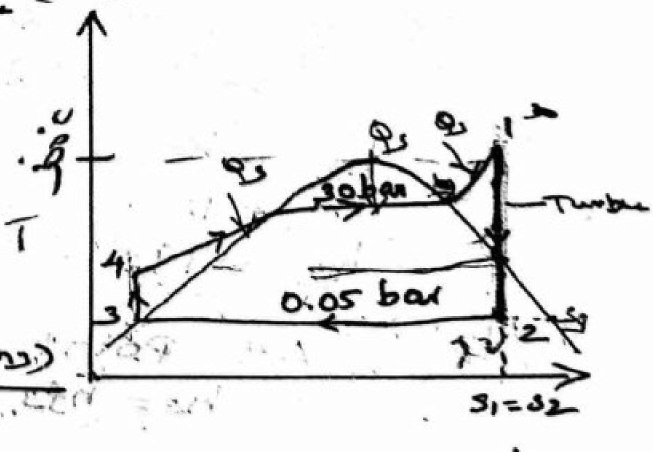
Heat Supplied $Q_s = h_1 - h_4$

$P_1 = 30$ bar
$T_1 = 300°C$

$W_T = h_1 - h_2$

$$\eta_{Rankine} = \frac{W}{Q_s} = \frac{W_T - W_p}{Q_s}$$

$$\eta = \frac{(h_1 - h_2) - (h_4 - h_3)}{h_1 - h_4}$$



$s_2 = s_g$ — line

$s_2 < s_g$ = wet

Solution:

$h_1, h_2, h_3, h_4 = ?$

$h_1 = ?$ At point 1 steam condition is superheated.

From steam table at 30 bar

$T_s = 233.8°C$ (saturated Temp (or) dry steam Temp).

$T_1 > T_s$ so the steam condition is

Superheated steam.

From superheated steam Table at 30 bar & 300°C

$h_1 = 2995 \text{ kJ/kg}$ $\quad s_1 = 6.542 \text{ kJ/kgK}$

$h_2 = ?$ At point 2 steam condition is Wet steam

$s_1 = s_2 = 6.542 \text{ kJ/kgK}$.

From steam Table at 0.05 bar

$s_g = 8.396 \text{ kJ/kgK}$.

$s_2 < s_g$ so the steam condition is Wet.

$h_2 = h_{f_2} + x_2 h_{fg_2}$

$x_2 = ?$

$s_1 = s_2$

$(s_1)_{\text{sup } 30 \text{ bar}} = (s_2)_{\text{wet } 0.05 \text{ bar}}$

$6.542 = (s_{f_2} + x_2 s_{fg_2})_{0.05}$

From steam Table at 0.05 bar.

$s_f = 0.476 \text{ kJ/kgK}$ $\quad h_f = 137.8 \text{ kJ/kg}$.

$s_{fg} = 7.920$ $\quad h_{fg} = 2423.8 \text{ kJ/kg}$.

$v_f = 0.001005 \text{ m}^3/\text{kg}$

$6.542 = 0.476 + x_2(7.920)$

$x_2 = 0.766$

$h_2 = h_{f_2} + x_2 h_{fg_2}$

$= 137.8 + 0.766(2423.8)$

$h_2 = 1994.3 \text{ kJ/kg}$

$h_3 = ?$ At point 3 steam condition is fluid.

$h_3 = (h_{f3})_{0.05 \text{ bar}} = 137.8 \text{ kJ/kg}$

$h_4 = ?$ $\quad W_P = h_4 - h_3 = v_3(P_4 - P_3)$ $\quad PV$

$h_4 - h_3 = v_{f_3}(P_1 - P_2)$

$h_4 = h_3 + v_{f_3}(P_1 - P_2)$

$= 137.8 + 0.001005\,(30 - 0.05) \times 100$

$\boxed{h_4 = 140.81\ kJ/kg}$

(b) Heat supplied $Q_s = m(h_1 - h_4)$

$= 2(2995.1 - 140.81)$

$= 5708.58\ kJ/sec.$

$= 5708.58 \times 3600 =$

$Q_s = 20.55 \times 10^6\ kJ/hr$

(c) $x_2 = 0.766.$

(d) $W_T = m(h_1 - h_2) = 2(2995.1 - 1994.4)$

$W_T = 2001.34\ kJ/sec$

(e) $\eta_{Rankine} = \frac{W_T - W_P}{Q_s} = \frac{m(h_1 - h_2) - m(h_4 - h_3)}{m(h_1 - h_4)}$

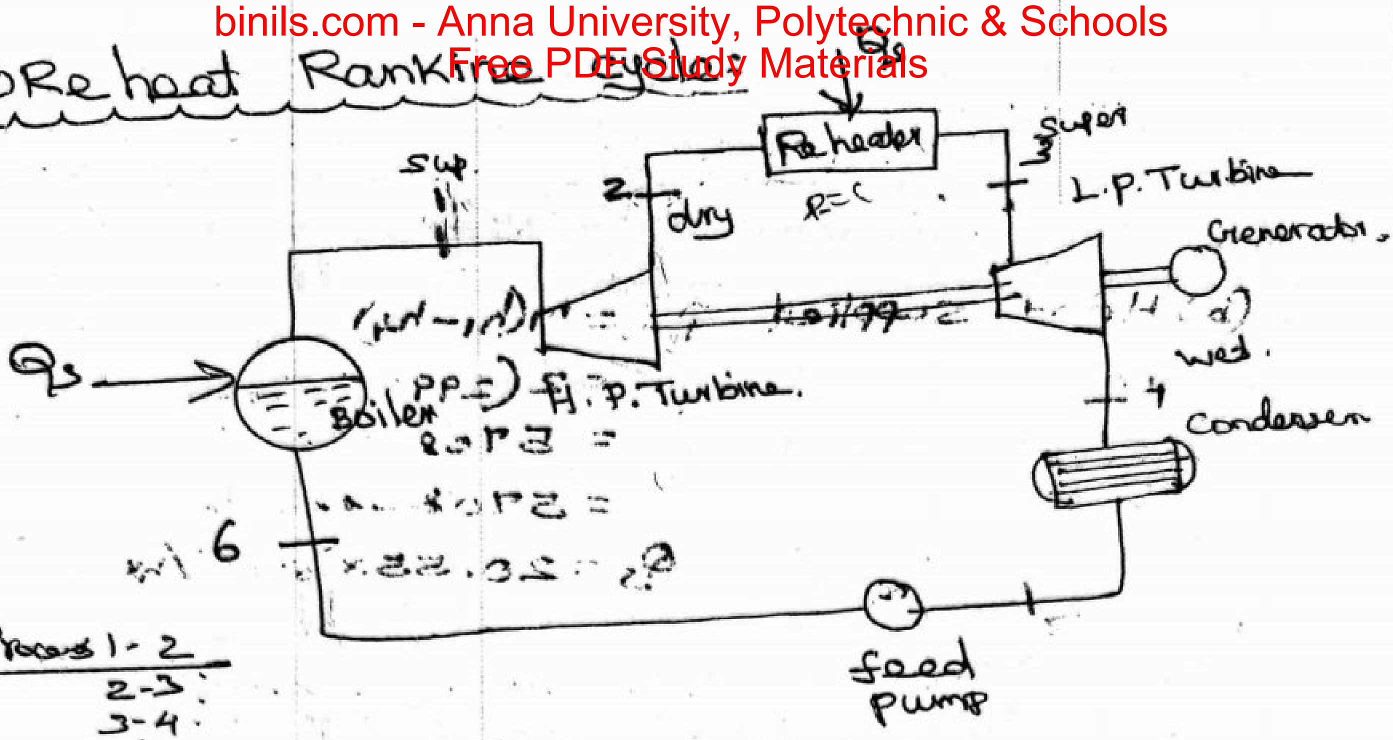
$= \frac{(2995.1 - 1994.43) - (140.81 - 137.8)}{2995.1 - 140.81} \times 100$

$\eta_{Rankine} = 35\%$

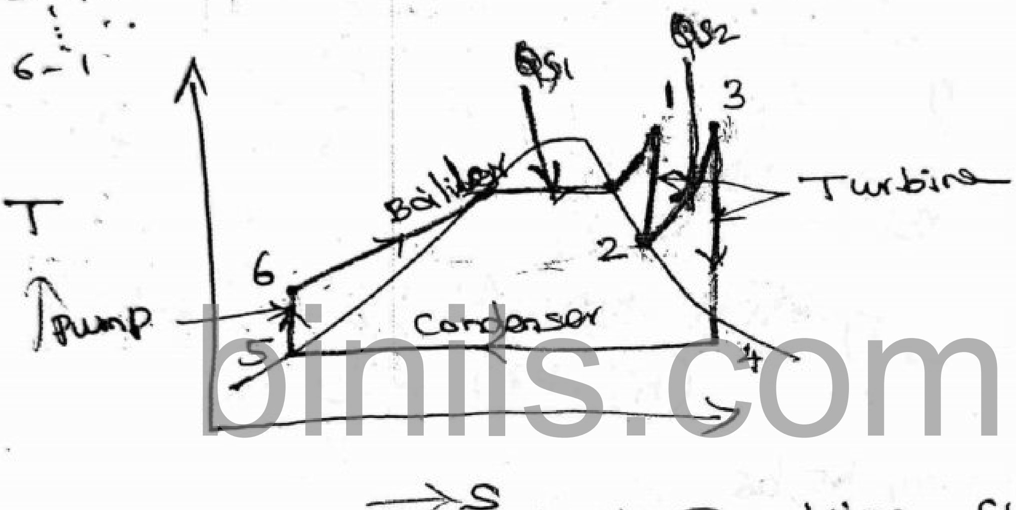
Types of Rankine cycle

① Reheat Rankine Cycle.
② Regenerative Rankine cycle.

① Reheat Rankine cycle



Process 1-2
2-3
3-4
...
6-1



T-s diagram of Reheat Rankine cycle

$$\eta = \frac{W}{Q_s} = \frac{(W_{T_{1-2}} + W_{T_{3-4}}) - W_p}{(h_1-h_6)+(h_3-h_2)}$$

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

1. Consider a steam power plant operating on an reheat Rankine cycle. The steam enters the H.P. turbine at 30 bar and 350°C. After expansion to 5 bar, the steam is reheated to 350°C and then expanded the L.P. turbine to the condenser pressure of 0.07 bar. Determine the thermal efficiency of the cycle and the quality of the steam at the outlet of the L.P. turbine.

G.D:

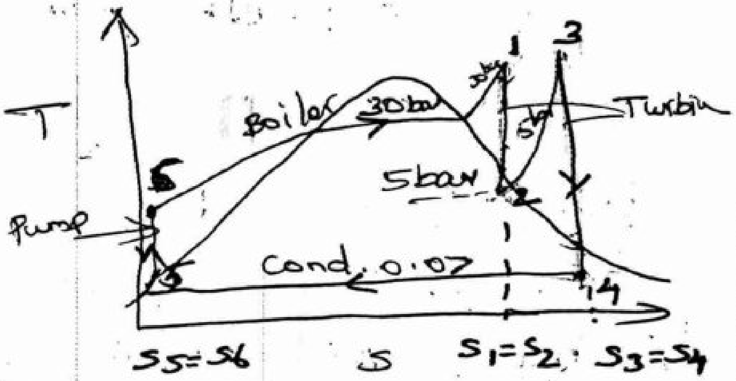
$P_1 = 30$ bar } $T_s = 233.8°C$ superheated, $T_1 > T_s$

$T_1 = 350°C$

$P_2 = 5$ bar

$T_3 = 350°C$

$P_4 = 0.07$ bar.



To find η, x_4.

$$\eta = \frac{W_{net}}{Q_s} = \frac{W_T - W_P}{Q_s}$$

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

$h_1, h_2, h_3, h_4, h_5, h_6 = ?$

$h_1 = ?$ At Point 1 steam condition is Superheated.

From superheated steam table at 30 bar and 350°C

$h_1 = 3117.5$ kJ/kg $\qquad s_1 = 6.742$ kJ/kgK.

$h_2 = ?$ At Point 2 steam condition is ______.

$\{s_1\}_{sup} = \{s_2\}_? = 6.742$ kJ/kgK.

From steam table at 5 bar

$s_g = 6.819$ kJ/kgK.

$s_2 < s_g$ so the steam condition is wet

$h_2 = h_{f_2} + x_2 h_{fg_2}$

$(s_1)_{sup\ 30bar} = (s_2)_{wet\ 5bar}$

$6.742 = (s_{f_2} + x_2 s_{fg_2})_{5\ bar}$

From steam table at 5 bar

$s_f = 1.860 \qquad h_f = 640.1$

$s_{fg} = 4.959 \qquad h_{fg} = 2107.4$

$6.742 = 1.860 + x_2(4.939)$

$x_2 = 0.98$

$h_2 = h_{f_2} + x_2 h_{fg_2}$

$= 640.1 + 0.98(2107.5)$

$h_2 = 2706.56\ kJ/kg$

$h_3 = ?$ At point 3 steam condition is Superheated.

$P_2 = P_3$ [redacted] $= 5\ bar \Rightarrow T_s = 151.8°C$

$T_3 = 350°C$

$T_3 > T_s$ so the steam condition is superheated.

From Superheated steam Table at 5 bar and 350°C

$h_3 = 3168.1\ kJ/kg$ $\quad S_3 = 7.634\ kJ/kgK$.

$h_4 = ?$ At point 4 steam condition is Wet.

$S_3 = S_4 = 7.634\ kJ/kgK$.

From steam Table at 0.07 bar

$S_g = 8.277\ kJ/kgK$.

$S_4 < S_g$ so the steam condition is Wet

$h_4 = h_{f_4} + x_4 h_{fg_4}$

$x_4 = ?$

$(S_3)_{sup\ 5bar} = (S_4)_{wet\ 0.07bar}$.

$7.634 = (S_{f_4} + x_4 S_{fg_4})_{0.07}$

From steam Table at 0.07 bar.

$S_f = 0.559$ $\quad h_f = 163.4$

$S_{fg} = 7.718$ $\quad h_{fg} = 2409.2$

$v_f = 0.001007$

$7.634 = 0.559 + x_4(7.718)$

$x_4 = 0.91$

$h_4 = h_{f_4} + x_4 h_{fg_4}$

$= 163.4 + 0.91(2409.2)$

$h_4 = 2355.772\ kJ/kg$

$h_5 = ?$ AT Point 5 steam condition is <u>fluid</u>

$h_5 = (h_{f5})_{0.07 bar}$

From steam table at 0.07 bar.

$h_5 = h_f = 163.4\ kJ/kg$

$h_6 = ?$ AT point 6 steam condition is <u>fluid</u>.

$W_p = h_6 - h_5 = v_5 (P_6 - P_5) =$

$= v_{f5} (P_1 - P_4)$

$= 0.001007 (30 - 0.07) \times 100$

$h_6 - h_5 = 3.013951$

$h_6 = 3.013951 + h_5$

$= 3.013951 + 163.4$

$h_6 = 166.41\ kJ/kg$

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

$$= \frac{(3115.3 - 2706.56) + (3168.1 - 2355.772) - (166.41 - 163.4)}{(3115.3 - 166.41) + (3168.1 - 2706.56)}$$

$\eta = 35.71\ \%$

2) A Reheat Cycle operating between 30 and 0.04 bar has a superheat and Reheat Temp. of 450°C. The first expansion takes place till the steam is dry saturated and then reheat is given. Neglecting feed pump work. Determine the ideal cycle efficiency.

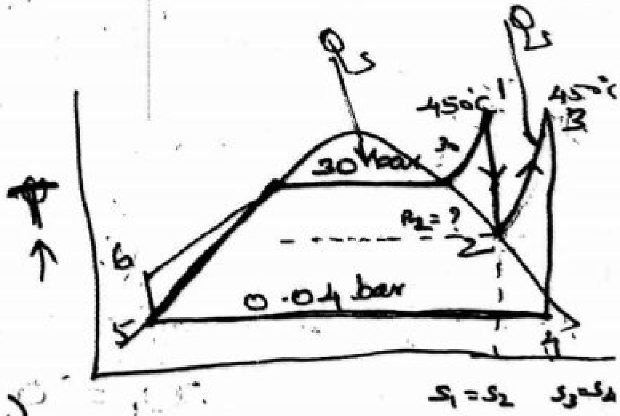
Gi.D

$P_1 = 30 bar$

$T_1 = 450°C$

$P_4 = 0.04 bar$

$T_3 = 450°C$



To find:- $\eta = \frac{W}{Q_s} = \frac{W_T - W_p}{Q_s}$

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

$h_1, h_2, h_3, h_4, h_5 = ?$

$h_1 = ?$ At Point 1 steam condition is superheated

From superheated steam Table at 30 bar & 450°C.

$h_1 = 3344$ kJ/kg . $S_1 = 7.08$ kJ/kg K

$h_2 = ?$ At Point 2 steam condition is dry

$h_2 = h_g$ at $P_x = ?$

$(S_1)_{sup\ 30bar} = (S_2)_{dry\ ?}$ = ~~7.08 = Sg (dry)~~

$7.08 = S_g$

From steam Table at $S_g = 7.08$ kJ/kg k.

Corresponding Pressure $P_2 = 2.3$ bar.

P	Sg
2.1	7.11
2.2	7.095
2.3	7.08

From steam table at 2.3 bar.

$h_2 = h_g = 2712.6$ kJ/kg $= h_2$.

$h_3 = ?$ At Point 3 steam condition is superheated

From superheated steam Table at 2.3 bar & 450°C.

$h_3 = 3381.46$ kJ/kg $S_3 = 8.3061$ kJ/kg k

$h_4 = ?$ At Point 4 steam condition is wet

$S_3 = S_4 = 8.3061$ kJ/kg k

at point 4 → $P_x = 0.04$ bar.

From steam table at 0.04 bar.

$S_g = 8.476$

$S_4 < S_g$ so the steam condition is wet

$h_4 = h_{f_4} + x_4 h_{fg_4}$

$(S_3)_{sup\ 2.3bar} = (S_4)_{wet\ 0.04 bar}$

$8.3061 = S_{f_4} + x_4 S_{fg_4}$

From steam Table at 0.04 bar.

$S_f = 0.423$ $h_f = 121.4$

$S_{fg} = 8.053$ $h_{fg} = 2433.1$

$8.3061 = 0.423 + x_4 (8.053)$

$x_4 = 0.98$

$h_4 = h_{f_4} + x_4 h_{fg_4}$

$= 121.4 + 0.98 (2433.1)$

$h_4 = 2505.84$ kJ/kg

$h_5 = ?$ At point 5 steam condition is fluid

$h_5 = (h_{f5})_{0.04\,bar} = 121.4$ KJ/kg

$$\eta = \frac{(3344.35 - 2712.6) + (3381.46 - 2505.84)}{(3344.35 - 121.4) + (3381.46 - 2712.6)} \times 100$$

$$\boxed{\eta = 38.73\%}$$

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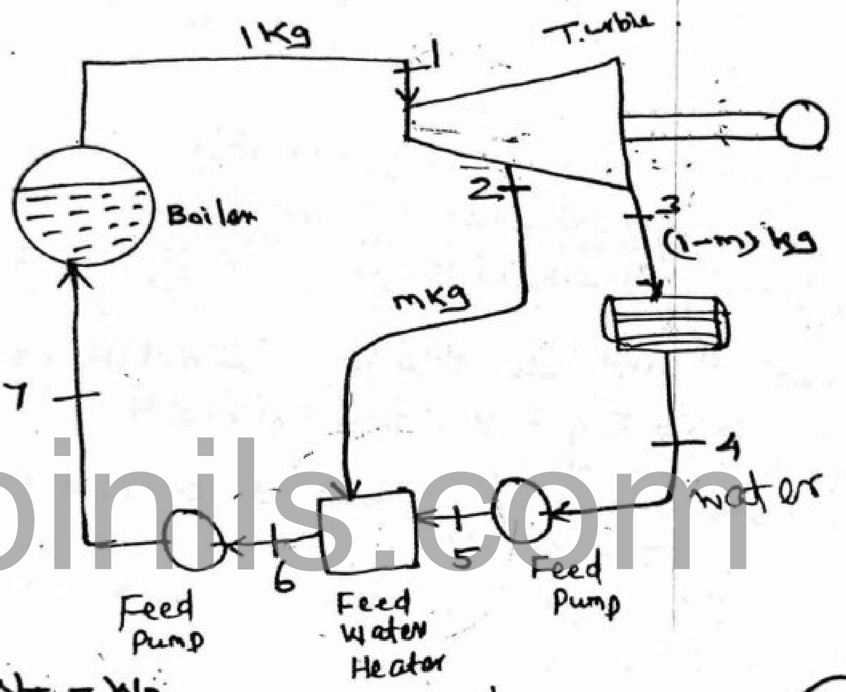
2. Regenerative Rankine cycle

(i) Single stage Regenerative cycle
(ii) Multi " " "

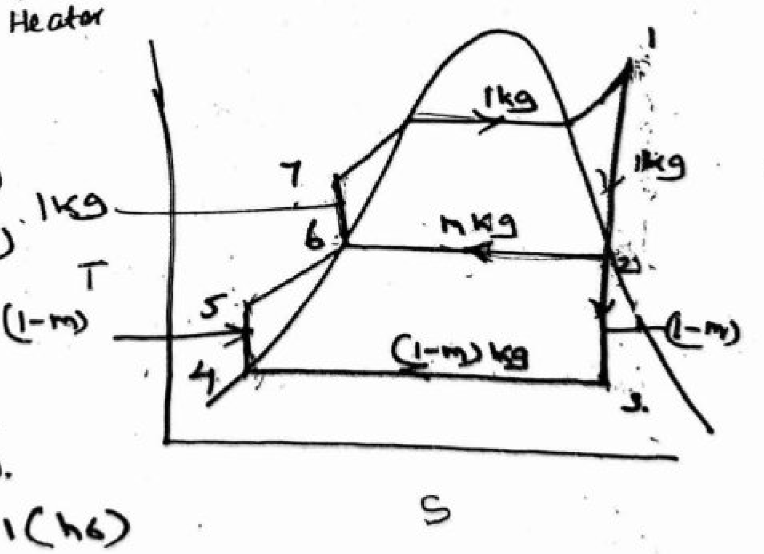


$$\eta = \frac{W}{Q_s} = \frac{W_T - W_P}{Q_s}$$

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

$W_P = (1-m)(h_5 - h_4) + 1(h_7 - h_6)$

$Q_s = 1(h_1 - h_7)$



$m = ?$

Energy Balance eqn.

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

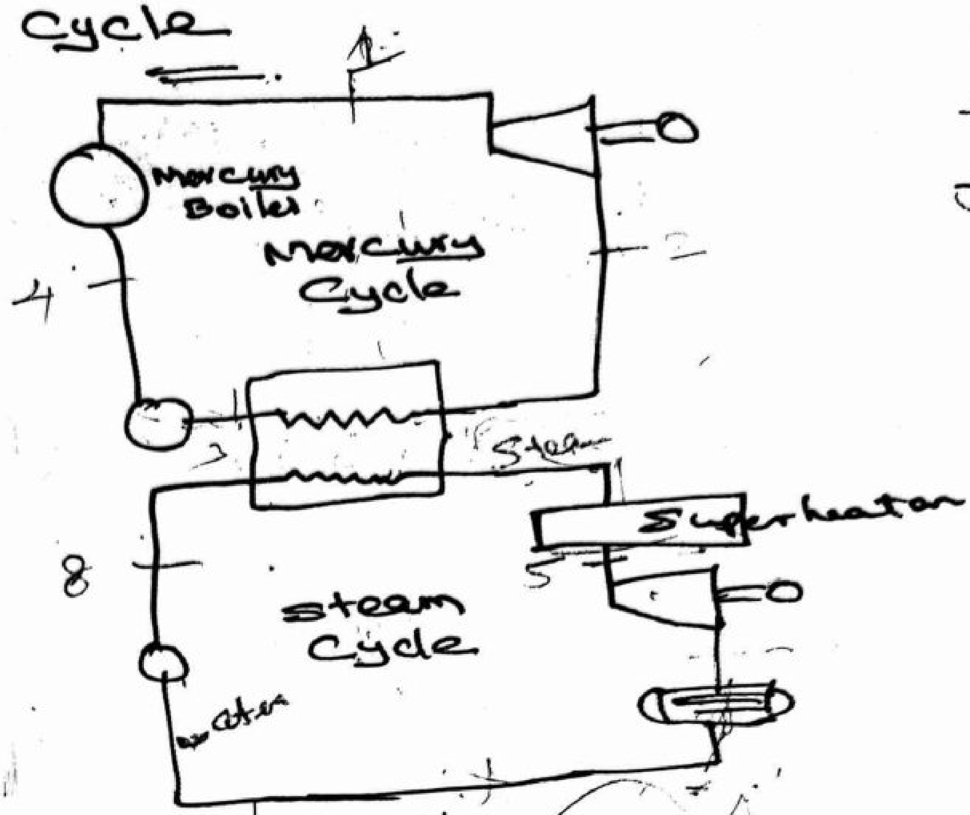
$m h_2 + h_5 - m h_5 = h_6$

$m h_2 - m h_5 = h_6 - h_5$

$m(h_2 - h_5) = h_6 - h_5$

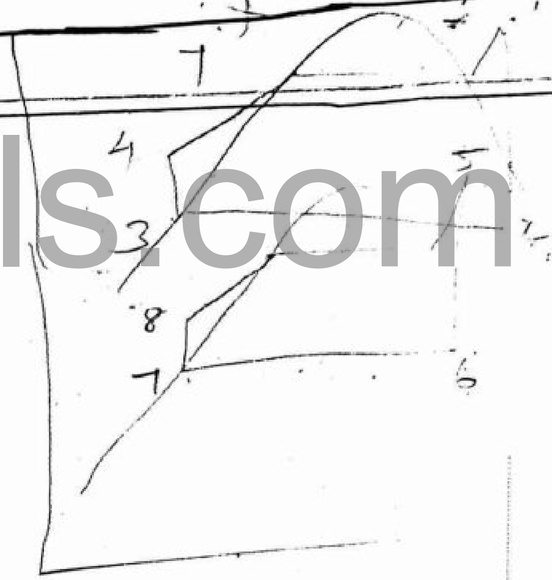
$$\boxed{m = \frac{h_6 - h_5}{h_2 - h_5}}$$

Binary Cycle
Combined Cycle



$W_T = (h_1 - h_2)$

Combined Cycle



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Gas turbine & Steam turbine plant : working