Thermodynamic Properties of Steam :-

Various properties → Various condition of steam (Wet, dry & superheated)

i) Enthalpy of steam (h) :-

It is the amount of heat added to the water from freezing point to till the water.

Wet steam, $h_w = h_f + x h_{fg}$.

Dry steam. $h_d = h_f + h_{fg} = h_g$.

Superheated steam. $h_{sup} = h_g + C_{ps}(T_{sup} - T_{sat})$

where,

h = Enthalpy of steam KJ/kg.

$T_{sup} - T_{sat}$ = degree of superheat.

C_{ps} = Specific heat of superheated steam ($2 - 2.3$ KJ/kg.K)

ii) Specific Volume of Steam (V).

It is defined as the volume occupied by the unit mass of steam at the given pressure and temperature.

Wet steam $V_w = x V_g$.

Dry steam $V_d = V_g$.

Superheated steam $V_{sup} = \frac{V_g T_{sup}}{T_{sat}}$

V = specific volume (m^3/kg)
W = wet d - dry.
sup - superheated.
h - enthalpy.
S - entropy.

iii) Work done during expansions (W).

During the evapouration process, there is a considerable increases in its volume when the pressure remains constant.

Energy required for absorption of latent heat for increasing volume of the steam.

Wet steam, $W_{wet} = 100 p x V_g$.

Dry steam $W_d = 100 p V_g$ kJ

Superheated steam. $W_{sup} = 100 p V_{sup}$.

where,

W = work done in KJ.

P = pressure at which evaporation (bar)

iv) Internal Energy of Steam (U) :

Internal energy of steam is defined as the actual heat energy stored in the steam above the freezing point of water at the given conditions.

$$h = W + \Delta u.$$

$$\Delta u = h - W$$

Wet steam $U_w = [h_f + x h_{fg}] - [100\, p x v_g]$.

Dry steam $U_d = [h_f + h_g] - [100 \cdot p v_g]$

Superheated steam $U_{sup} = h_{sup} - 100\, p v_s$

v) Entropy of steam (S).

It is the property of the stream which increases with increase in temperature and decrease with decrease in temperature.

Wet steam $S_{wet} = S_f + x S_g$.

Dry steam $S_{dry} = S_f + S_g$.

Superheated steam $S_{sup} = S_g + C_{ps} \left(\frac{T_{sup}}{T_{sat}} \right)$.

Determination of Dryness fraction :-

It is defined as the ratio of the mass of actual dry steam to the mass of same quanity of wet steam.

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

where

m_g = Mass of actual dry steam.

m_f = Mass of water is suspension

m = mass of wet steam. $= m_g + m_f$.

latent heat of evaporization:-

The amount of heat added during heating of water from boiling point to dry saturated state is called latent heat of evaporization (or) enthalpy of vaporization.

(9) A rigid tank 1 m^3 contain liquid vapour mixture of water at 1.5 MPa and dryness fraction of 0.9. The mixture of is allowed to cool until the pressure is reduced to 300 kPa. Determine the final mass of liquid, mass of vapour and heat transfer during the process. (12)

Given :-

$V = 1 m^3$

$P = 1.5$ MPa $= 15$ bar.

$x = 0.90$.

To find :-

m_f, m_g & Q

$\because m = m_f + m_g$.

$m = x m_g$.

Solution :-

Initially the steam is wet condition.

$v_f = 0.001154$ m^3/kg

$v_g = 0.13167$ m^3/kg.

$h_f = 844.6$ kJ/kg

$h_{fg} = 1945.3$ kJ/kg.

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

$$= 844.6 + 0.90 (1945.3)$$

$$= 2595.37 \text{ kJ/kg}.$$

$$v_{wet} = x v_g.$$

$$= 0.9 (0.13167)$$

$$= 0.1185 \text{ m}^3/\text{kg}.$$

At 300 kPa (3 bar)

$v_f = 0.001074$ m^3/kg.

$v_g = 0.60553$ m^3/kg.

$h_f = 561.5$ kJ/kg

$h_{fg} = 2163.2$ kJ/kg.

It is rigid tank, its volume does not change.

$$v_1 = v_2 = v_g \cdot x.$$

$$0.1185 = 0.60553 \times x.$$

$$x = 0.1957.$$

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

$$= 561.5 + 0.1957 (2163.2)$$

$$h_2 = 984.83 \text{ kJ/kg}.$$

$$m = \frac{V}{v_{wet}} = \frac{1}{0.1187} = 8.4245 \text{ kg}.$$

Mass of Vapour

$m_g = x \cdot m$ = formula check. ?

$= 0.1957 + 8.4245$

$$\boxed{m_g = 1.648 \text{ kg}}.$$

mass of liquid.

$m = m_f + m_g$.

$m_f = m - m_g$.

$= 8.4245 - 1.648$.

$$\boxed{m_f = 6.775 \text{ kg}}.$$

Total Heat transfer.

$Q = m(h_2 - h_1)$

$= 1(984.83 - 2595.37)$

$$\boxed{Q = -1610.54 \text{ kJ/kg}}.$$

this negative sign indicate that heat is transferred from the tank to surrounding.

(10). Steam intially at 0.3 MPa, 250°c is cooled at constant volume.

a) At what temperature will the steam become saturated vapour.

b) What is the quality of steam at 80°c?

c) What is the heat transferred per kg of steam in cooling from 250°c to 80°c?

Given :-

$P_1 = 0.3$ MPa $= 3$ bar

$T = 250°c$

$T_2 = 80°c$

Solution :-

a) At 3 bar, from steam table.

$T_{sat} = 133.5°c$

$T = 250°c$.

$T > T_{sat}$

The condition of the steam is superheated.

At 3 bar, 25°c in enthalpy superheated steam.

$h_1 = 2967.6$ KJ/kg.

$V_1 = 0.7964$ m^3/kg.

At constant Volume,

$V_1 = V_2 = 0.7964$ m^3/kg.

When $V_g = 0.7964$, $t_{sat} = 123.9°c$.

Steam became saturated vapour at $t = 123.9°c$.

b) At 80°c, quality of steam.

$V_f = 0.001029$ m^3/kg. $h_f = 334.91$ KJ/kg. $P_2 = 0.47360$.

$V_g = 3.4091$ m^3/kg $h_{fg} = 2308.8$ KJ/kg.

$V_1 = V_2 = x V_g$.

$0.7964 = x \cdot 3.4091$

$x = 0.2336$.

$V_1 = V_2 = V_f + x \cdot V_g$.

$= 0.001029 + x(3.407 - 0.001029)$

$x \doteq 0.234$.

$h_2 = h_f + x_2 h_{fg}$.

$= 334.91 + (0.234)(2308.8)$

$h_2 = 874.28$ KJ/kg.

Heat Transfer,

$Q = U_2 - U_1$ $\Rightarrow$ $h = U + PV$

$U = h - PV$.

$Q = (h_2 - P_2V_2) - (h_1 - P_1V_1)$

$= h_2 - P_2V_2 - h_1 + P_1V_1$.

$Q =$ ~~[illegible]~~

$Q = (h_2 - h_1) + V(P_1 - P_2)$

$Q = (874.28 - 2967.6) + 0.7964(3 - 0.4739)$

$Q = -2091.7 + 2.0115$

$Q =$ ~~-2089.682~~ KJ/kg.

$Q = -2089.6$ KJ/kg.

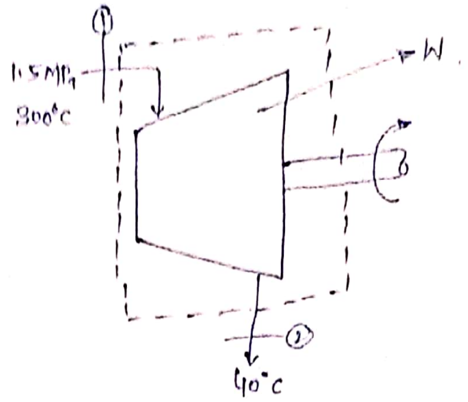
(11). Steam initially at 1.5 MPa, 300°c expands reversibly and adiabatically in a steam turbine to 40°c. Determine the ideal work output of the turbine per kg of steam.

Given:

$P = 1.5$ MPa $= 15$ bar

$T_1 = 300°c$

$T_2 = 40°c$



To find:

Work output of the turbine.

Solution:

Formula, @ turbine in SFFE.

$$\boxed{W = h_1 - h_2}.$$

$T = 300°C$, $T_{sat} = 198.3$.

$T > T_{sat}$.

Steam condition is Superheated

At 40°c, $P_{sat} = 7.375$ kPa $= 0.07375$ bar, $S_f = 0.572$ kJ/kgK.

$h_f = 167.5$ KJ/kg.

$V_g = 19.546\ m^3/kg$. $h_{fg} = 2406.9$ KJ/kg.

$S_{fg} = 7.686$ KJ/kg.K.

At $t = 300°c$

$S_1 = 6.921$ KJ/kg.k, $h_1 = 3038.9$ KJ/kg.

$S_1 = S_2$

$S_1 = S_f + x_2 S_{fg}$.

$6.921 = 0.572 + x_2 (7.686)$

$$\boxed{x_2 = 0.826}.$$

$h_2 = h_f + x_2 h_{fg}$

$= 167.5 + 0.826 (2406.9)$

$h_2 = 2155.5$ KJ/kg.

$W = h_1 - h_2 = 3038.9 - 2155.5$

$$\boxed{W = 883.4 \text{ KJ/kg}}.$$