SOLVED PROBLEMS ON STEAM PROPERTIES

1. A vessel of volume 0.04 m^3 contains a mixture of saturated water and steam at a temperature of 250°C. The mass of the liquid present is 9 kg. Find the pressure, mass, specific volume, enthalpy, entropy and internal energy. [April/May 2012,2015]

Given Data:

Volume, V = 0.04 m^3

Temperature, T = 250°C

Mass, m = 9 kg

To find:

1) p, 2) m, 3) v, 4) h, 5) S,6) ΔU

Solution:

From the Steam tables corresponding to 250°C, $v_f = v_1$ = 0.001251 m^3/kg

$v_g = v_s$ = 0.050037 m^3/kg p = 39.776 bar

Total volume occupied by the liquid,

$V_1 = m_1 \times v_1$

$= 9 \times 0.001251$

$= 0.0113\ m^3$.

Total volume of the vessel,

V = Volume of liquid + Volume of steam

$= V_1 + V_S$

$0.4 = 0.0113 + V_S$

$V_S = 0.0287\ m^3$.

Mass of steam, $m_s = V_S / v_s$

$= 0.0287 / 0.050037$

$= 0.574$ kg.

Mass of mixture of liquid and steam, $m = m_1 + m_s$

$= 9 + 0.574$

$= 9.574$ kg.

Total specific volume of the mixture,

$v = 0.04 / 9.574$

$=0.00418\ m^3 / kg.$

We know that,

$v = v_f + x\ v_{fg}$

$0.00418 = 0.001251 + x\ (0.050037 – 0.001251)$

$x = 0.06$

From Steam table corresponding to 250 °C,

$h_f = 1085.8$ KJ / kg

$h_{fg} = 1714.6$ KJ / kg

$s_f = 2.794$ KJ / kg K

$s_{fg} = 3.277$ KJ / kg K.

Enthalpy of mixture,

$h = h_f + x\ h_{fg}$

$= 1085.8 + 0.06 \times 1714.6$

= 1188.67 KJ / kg Entropy of mixture,

$s = s_f + x\, s_{fg}$

$= 2.794 + 0.06 \times 3.277$

= 2.99 kJ / kg K. Internal energy, $u = h - p\, v$

$= 1188.67 - 39.776 \times 10^2 \times 0.00418$

= 1172 KJ / kg.

Result:

p = 39.776 bar

m = 9.574 kg

v = 0.00418 m^3 / kg
h = 1188.67 KJ / kg

S = 2.99 KJ /kg K

ΔU= 1172 KJ / kg.

2). A steam power plant uses steam at boiler pressure of 150 bar and temperature of 550°C with reheat at 40 bar and 550 °C at condenser pressure of 0.1 bar. Find the quality of steam at turbine exhaust, cycle efficiency and the steam rate. [May/June 2014]

Given Data:

p_1 = 150 bar

T_1 = 550°C

p_2 = 40 bar

T_3 = 550 °C

p_3 = 0.1 bar

To find:

4. The quality of steam at turbine exhaust, (x_4)
5. cycle efficiency and
6. The steam rate.

Solution:

1. The quality of steam at turbine exhaust, (x_4):

Properties of steam from steam tables at 150 bar & 550°C h_1 = 3445.2 KJ/kg.

S_1= 6.5125 KJ/kg K

At 40 bar & 550°C

h_3 = 3558.9 KJ/kg.

S_3= 7.2295 KJ/kg K

At 40 bar

Tsat = 250.3°C = 523.3 K

hf =1087.4 KJ/kg. hfg = 1712.9 KJ/kg.
Sf= 2.797 KJ/kg K Sfg= 3.272 KJ/kg K

At 0.1 bar

hf =191.8 KJ/kg. hfg = 2392.9 KJ/kg.
S_f= 0.649 KJ/kg K S_{fg}= 7.502 KJ/kg K

1-2 = isentropic

S_1 = S = 6.5125 KJ/kg K

S_2 = S_g at 40 bar

Therefore,

Exit of HP turbine is superheat

$T_{sup} = 332°C$

$h_2 = 3047.18$ KJ/kg

$S_3 = S_g$ at 0.1 bar

Steam is at wet condition.

$S_4 = S_3 = 7.2295$ KJ/kg K

$S4 = Sf4 + x4\ \ Sfg4$

$7.2295 = 0.649 + x_4 \times 7.502$

$x_4 = 0.877$

$h4 = hf4 + x4\ \ hfg4$

$= 191.8 + 0.877 \times 2392.9$

$h_4 = 2290.37$ KJ/kg K

2) Cycle efficiency:

$D = (h_1 - h_2) + (h_3 - h_4) / (h_1 - h_{f4}) + (h_3 - h_2)$

$= (3445.2 - 3047.15) + (3558.9 - 2290.37) / (3445.2 - 191.8) + (3558.9 - 3047.18)$

$= 0.4426 \times 100$

$= 44.26\%$

3) Steam rate:

$= 3600 / (h_1 - h_2) + (h_3 - h_4)$

$= 3600 / (3445.2 - 3047.15) + (3558.9 - 2290.37)$

$= 2.16$ kg/Kw–hr.

Result:

The quality of steam at turbine exhaust, $(x_4) = 0.877$

cycle efficiency = 44.26%

The steam rate = 2.16 kg/Kw–hr.

3). Ten kg of water 45 °C is heated at a constant pressure of 10 bar until it becomes superheated vapour at 300°C. Find the change in volume, enthalpy, internal energy and entropy.

Given Data:

m= 10 kg t=45°C

$p_1 = p_2 = 10$ bar

$T_2 = 300°C$

To find:

Change in volume,

Change in Enthalpy,

Change in Internal energy,

Change in Entropy.

From steam tables, corresponding to 45°C,

$v_1 = v_{f1} = 0.001010\ m^3/kg$; $h_1 = h_{f1} = 188.4$ KJ/kg;

$s_1 = s_{f1} = 0.638$ KJ/kg K

From steam tables, corresponding to 10 bar and 300°C,

$h_2 = 3052.1$ KJ/kg; $s_2 = 7.125$ KJ/kg K;

$v_2 = 0.258\ m^3/kg$;

Change in Volume, $\Delta V = m (v_2 - v_1)$

$= 10 (0.258 - 0.001010)$

$= 2.5699\ m^3$.

Change in Enthalpy, $\Delta h = m (h_2 - h_1)$

$= 10 (3052.1 - 188.4)$

$= 28637$ KJ.

Change in Entropy, $\Delta S = m (s_2 - s_1)$

$= 10 (7.125 - 0.638)$

$= 64.87$ KJ/K.

Result:

Change in volume, ΔV= 2.5699 m3.
Change in Enthalpy,=h2 8637 KJ.
Change in Internal energy, ΔU = 26067.1 KJ.
Change in Entropy, ΔS = 64.87 KJ/K.

4) 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.

e) Find the heat supplied in the boiler per hour.

f) Determine the quality of steam after expansion.

g) What is the power generated by the turbine?

h) Estimate the Ranking efficiency considering pump work.

Given Data:

p_1 = 30 bar

p_2 = 0.05 bar

T_1 = 300°C

m = 2 kg / s

To find:

Find the heat supplied in the boiler per hour (Q_S)
Determine the quality of steam after expansion (x_2)
What is the power generated by the turbine (W_T)

Estimate the Ranking efficiency considering pump work (Ɗ)

Solution:

2. Heat supplied in the boiler per hour (Q_S):

Properties of steam from the steam table

At 30 bar & 300°C

h_1 = 2995.1 KJ/kg; S_1 = 6.542 KJ/kg K;

At 0.05 bar

h_{f2} = 137.8 KJ/kg; h_{fg2} = 2423.8 KJ/kg;

S_{f2} = 0.476 KJ/kg K; S_{fg2} = 7.920 KJ/kg K;

V_{f2} = 0.001005 m^3/kg.

1-2 = Isentropic expansion in the turbine

$S_1 = S_2$ = 6.542 KJ/ kg K

$S_2 = S_{f2} + x_2 \times S_{fg2}$

$6.542 = 0.476 + x_2 \times 7.92$

$= 0.766$

Therefore, Quality of steam after expansion = 0.766 dry.

$h_2 = h_{f2} + x_2 \times h_{fg\,2}$

$= 137.81 + 0.766 \times 2423.8$

= 1994.43 KJ/kg.

$h_3 = h_{fg2}$ = 137.8 KJ/kg.

Considering the pump work, $h_4 - h_3 = v_{f2}\,(p_1 - p_2)$

$h_4 = h_3 + v_{f2}\,(p_1 - p_2)$

$= 137.8 + 0.001005 \times (30 - 0.05) \times 10^2$

= 140.81 KJ/kg.

Heat supplied in the boiler:

$$Q_S = m \times (h_1 - h_4)$$

$$= 2 \times (2995.1 - 140.81)$$

$$= 5708.58 \text{ KJ/s}$$

$$= 20.55 \times 10^6 \text{ KJ /hr.}$$

Power generated by the turbine:

$$W_T = m \times (h_1 - h_2)$$

$$= 2 \times (2995.1 - 1994.43)$$

$$= 2001.34 \text{ KW.}$$

Rankine efficiency by the plant:

$$(\eta) = (h_1 - h_2) - (h_4 - h_3) / (h_1 - h_4)$$
$$= (2995.1 - 1994.43) - (140.81 - 137.8) / (2995.1 - 140.81)$$
$$= 35\ \%$$

Result:

Find the heat supplied in the boiler per hour (Q_S) = 20.55×10^6 KJ /hr

Determine the quality of steam after expansion (x_2) = 0.766 dry
What is the power generated by the turbine (W_T) = 2001.34 KW.

Estimate the Ranking efficiency considering pump work (η) = 35%

5)*Determine the state of steam at a pressure of 12 bar with its specific volume of 0.175 m^3/kg.*

Given data:

p = 12 bar

v = 0.175 m^3/kg

To find:

State of steam (whether dry, wet or superheated)

Solution:

From saturated water table of pressure scale at 12 *bar*,

Specific volume of dry steam, $v_g = 0.16321\ m^3/kg$, T, $=188°C = 188 + 273 = 461\ K$

Since $v > v_g$, the steam is in superheated condition.

Note:

$v > v_g \Rightarrow$ Superheated steam

$v = v_g \Rightarrow$ Dry steam

$v < v_g \Rightarrow$ Wet steam

We know that $v_{sup} = v_g \left(\frac{T_{sup}}{T_s} \right)$

$$T_{sup} = \frac{v_{sup}}{v_g} \times T_s = \left(\frac{0.175}{0.16321} \right) \times 461 = 494.3\ K = 221.3°C$$

The steam is **superheated to 221.3°C** **Ans.**

6)Determine the condition of steam at a temperature of 220°C and enthalpy of 2750 kJ/kg.

Given data:

$T = 220°C$

$h = 2750\ kJ/kg$

To find:

State of steam

Solution:

From saturated water table of temperature scale at 220°*C*,

$h_f = 943.7\ kJ/kg$

h_{fg} = 1856.2 *kJ/kg*

h_g = 2799.9 *kJ/kg*

Since $h < h_g$, the steam is in wet condition.

Note:

$h > h_g \Rightarrow$ Superheated steam

$h = h_g \Rightarrow$ Dry steam

$h < h_g \Rightarrow$ Wet steam

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

$$x = \frac{h_{wet} - h_f}{h_{fg}} = \frac{2750 - 943.7}{1856.2} = \mathbf{0.973} \qquad \textbf{Ans.}$$

7)*Find the specific volume and enthalpy of steam at 9 bar when the condition of steam is (a) wet with dryness fraction 0.98 (b) dry saturated and (c) superheated and the temperature of steam 240°C.*

Given data:

p = 9 *bar*

(i) x = 0.95, (ii) x = 1, (iii) Superheated with T_{sup} = 240°*C* = 240 + 273 = 513 *K*

Solution:

From saturated water table of pressure scale at 9 *bar*,

T_s = 175.4°*C* = 175.4 + 273 = 448.4 *K*

v_f = 0.001121 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:

$$v_{wet} = v_f + x\,(v_g - v_f)$$

$$= 0.001121 + 0.95 \times (0.21482 - 0.001121) = \mathbf{0.204\ m^3/kg}$$ **Ans.**

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

$$= 742.6 + 0.95 \times 2029.5 = \mathbf{2670.63\ kJ/kg}$$ **Ans.**

(b) Dry steam:

$$v_g = \mathbf{0.21482\ m^3/kg}$$ **Ans.**

$$h_g = \mathbf{2772.1\ kJ/kg}$$ **Ans.**

(c) Superheated steam, $T_{sup} = 240^oC$:

$$v_{sup} = v_g \left(\frac{T_{sup}}{T_s}\right) = 0.21482 \times \left(\frac{513}{448.4}\right) = \mathbf{0.246\ m^3/kg}$$ **Ans.**

Corresponding to $p = 9\ bar$ and $T = 240^oC$ from the superheated enthalpy table,

$$h_{sup} = \mathbf{2923.29\ kJ/kg}$$ **Ans.**

8)*Find the internal energy of unit mass of steam at a pressure of 7 bar (i) when its quality is 0.8 (ii) when it is dry and saturated and (iii) superheated, the degree of superheat being 65°C. The specific heat of superheated steam at constant pressure is 2.277 kJ/kg K.*

Given data

p = 7 *bar* = 700 *kPa*

(i) x = 0.80

(ii) dry saturated and

(iii) Superheated, (T_{sup} - T_s) = 65°*C*

To find

Internal energy

Solution

From saturated water table of pressure scale at 7 *bar*,

T_1 = 165°*C*,v_f = 0.001108 m^3/kg,v_g = 0.27268 m^3/kg

h_{fg} = 2064.9 *kJ/kg*h_f = 697.1 *kJ/kg*,h_g = 2762 *kJ/kg*,

S_f = 1.992 *kJ/kg K*S_{fg} = 4.713 *kJ/kg K*S_g = 6.705 *kJ/kg K*

(i) When x = 0.8:

$$h_{wet} = h_f + x\, h_{fg} = 697.1 + 0.8 \times 2064.9 = 2349.02\ kJ/kg$$

$$v_{wet} = v_f + x\,(v_g - v_f)$$

$$= 0.001108 + 0.8 \times (0.27268 - 0.001108) = 0.218\ m^3/kg$$

Work done, $W = p\, v_{wet} = 700 \times 0.218 = 152.6\ kJ/kg$

Internal energy, $u = h - W = 2349.02 - 152.6 =$ **2196.42 *kJ/kg*** **Ans.**

(ii) When it is dry and saturated:

$$h_g = 2762\ kJ/kg$$

$$W_{dry} = p\, v_g = 700 \times 0.27268 = 190.88\ kJ/kg$$

$$u_g = h_g - W = 2762 - 190.88 =$$ **2571.12 *kJ/kg*** **Ans.**

(iii) When superheated:

$$h_{sup} = h_g + C_p\,(T_{sup} - T_{sat}) = 2762 + 2.277 \times 65 = 2910\ kJ/kg$$

$$W_{sup} = p\ v_{sup}$$

$$= p \times v_g \times \left(\frac{T_{sup}}{T_s}\right)$$

$$= 700 \times 0.27268 \times \left(\frac{230 + 273}{165 + 273}\right)$$

$$= 219.2\ kJ/kg$$

$$u_{sup} = h - W = 2910 - 219.2 =$$ **2690.8 *kJ/kg*** **Ans.**

$\because T_{sup} - T_s = 65$

$T_{sup} = T_s + 65$

$= 165 + 65 = 230°C$

9)Determine the condition of steam whether it is wet, dry or superheated for the following cases by using Steam tables only.

(i) Steam has a pressure of 10 bar and specific volume 0.22 m^3/kg.
(ii) Steam has a pressure 15 bar and temperature 225°C.
(iii) Steam has a temperature 200°C and enthalpy 2790.9 kJ/kg.
(iv) Steam has a temperature of 120°C and entropy 7 kJ/kgK.

Given data:

(i) p = 10 *bar* and v = 0.22 m^3/kg

(ii) p = 15 *bar* and T = 225°*C*

(iii) T = 200°*C* and h = 2790.9 *kJ/kg*

(iv) T = 120°*C* and s = 7 *kJ/kg K*

To find:

Condition of steam

Solution:

(i) $p = 10\ bar$ and $v = 0.22\ m^3/kg$

From saturated water table of pressure scale at 10 *bar*, $v_g = 0.1943\ m^3/kg$

Since $v > v_g$, the **steam is superheated.**

(ii) $p = 15\ bar$ and $T = 225°C$

From saturated water table of pressure scale at 15 *bar*, $T_s = 198.3°C$

Since $T > T_s$, the **steam is superheated.**

(iii) $T = 200°C$ and $h = 2790.9\ kJ/kg$

From saturated water table of temperature scale at $200°C$, $h_g = 2790.9\ kJ/kg$

Since $h = h_g$, the **steam is dry saturated.**

(iv) $T = 120°C$ and $s = 7\ kJ/kgK$

From saturated water table of temperature scale at $120°C$, $s_g = 7.129\ kJ/kg\ K$

Since $s < s_g$, the **steam is in wet condition.**

10)*One kg of steam contains 1/3 liquid and 2/3 vapour by volume. The temperature of the steam is 150°C. Find the quality, specific volume and specific enthalpy of mixture.*

Given data:

$m = 1\ kg$, $V_f = 1/3$,$V_g = 2/3$,$T_3 = 150°C$

To find:

Quality x, specific volume, v and specific enthalpy, h

Solution:

$p = 4.76\ bar, \quad v_f = 0.001091\ m^3/kg, \quad v_g = 0.39245\ m^3/kg,$

$h_f = 632.2\ kJ/kg, \quad h_{fg} = 2113.2\ kJ/kg$

$$\frac{v_f}{v_g} = \frac{\frac{1}{3}}{\frac{2}{3}} = \frac{1}{2}$$

$$\frac{v_f}{v_g} = \frac{m_w v_f}{m_s v_g} = \frac{1}{2}$$

$$\frac{m_w}{m_s} \times \frac{0.001091}{0.39245} = \frac{1}{2}$$

$$\frac{m_w}{m_s} = 179.86$$

Dryness fraction, $$x = \frac{m_s}{m_w + m_s}$$

$$= \frac{1}{\left(\frac{m_w}{m_s}\right) + 1} = \frac{1}{179.86 + 1} = \mathbf{0.0055} \qquad \textbf{Ans.}$$

Volume of mixture, $$v = v_f + x\,(v_g - v_f)$$

$$= 0.001091 + 0.0055 \times (0.39245 - 0.001091)$$

$$= \mathbf{0.00324\ m^3/kg} \qquad \textbf{Ans.}$$

Enthalpy of mixture, $$h = h_f + x\,h_{fg}$$

$$= 632.2 + 0.0055 \times 2113.2$$

$$= \mathbf{643.82\ kJ/kg} \qquad \textbf{Ans.}$$