Assignment – 2

Topic: Properties Of Steam

(**Disclaimer:** The purpose of these AI-generated responses is just education and reference. Utilise them to grasp topics and structure, but always rewrite in your own words and double-check the content before submitting.)

Q-1: 1 Evaluate the condition of the steam (i.e., wet, dry saturated or superheated) for the following cases:

Answer:

(a) Steam at 15 bar pressure and specific volume is 0.12 m³/kg.

- From steam tables, at $p = 15$ bar:
  - v_g (specific volume of dry saturated vapor) = **0.1317 m³/kg**
- Given specific volume, $v = 0.12$ m³/kg.
- Since $v < v_g$, the steam is **wet**.

∴ Condition: Wet Steam

(b) Steam at 10 bar pressure and 200°C temperature.

- From steam tables, at $p = 10$ bar:
  - Saturation temperature, $T_{sat} = 179.9°C$
- Given temperature, $T = 200°C$.
- Since $T > T_{sat}$, the steam is **superheated**.

∴ Condition: Superheated Steam

(c) Steam at 20 bar and having specific enthalpy 2650 kJ/kg.

- From steam tables, at $p = 20$ bar:
  - h_f = 908.79 kJ/kg
  - h_g = 2799.1 kJ/kg
- Given specific enthalpy, $h = 2650$ kJ/kg.
- Since $h_f < h < h_g$, the steam is **wet**.

∴ Condition: Wet Steam

(d) Steam at temperature of 150°C and specific volume 0.3928 m³/kg.

- From steam tables, at $T = 150°C$:
  - v_g (specific volume of dry saturated vapor) = **0.3928 m³/kg**
- Given specific volume, $v = 0.3928$ m³/kg.
- Since $v = v_g$, the steam is **dry saturated**.

∴ Condition: Dry Saturated Steam

Final Answers for Q-1:
(a) Wet Steam
(b) Superheated Steam
(c) Wet Steam
(d) Dry Saturated Steam

Q-2: Calculate the external work done during evaporation, internal energy of steam, and internal latent heat of evaporation for steam at 10 bar pressure and dryness = 0.8.

Answer:

Given:

- $p = 10$ bar
- Dryness fraction, $x = 0.8$
- From steam tables, at 10 bar:
  - $h_f = 762.81$ kJ/kg
  - $h_{fg} = 2015.3$ kJ/kg
  - $v_g = 0.19444$ m³/kg

Step 1: External Work Done during Evaporation (W)

External work done is the work done during constant pressure vaporization.
$W = p \cdot (v_g - v_f) \approx p \cdot v_g$ (since v_f is very small)
$W = 1000$ kPa × 0.19444 m³/kg (Note: 1 bar = 100 kPa)

$$W = 194.44 \text{ kJ/kg}$$

This is the work done for dry saturated steam. For wet steam, we multiply by the dryness fraction.

$$W_{wet} = x \cdot W = 0.8 \times 194.44 = 155.55 \text{ kJ/kg}$$

∴ External Work Done = 155.55 kJ/kg

Step 2: Internal Latent Heat of Evaporation (Internal Energy of Evaporation)

The total latent heat (h_{fg}) goes into increasing internal energy and doing external work.

$$h_{fg} = \text{Internal Energy of Evaporation} + \text{External Work Done}$$

Rearranging:

$$\text{Internal Energy of Evaporation} = h_{fg} - W$$
$$= 2015.3 - 194.44 = 1820.86 \text{ kJ/kg}$$

For wet steam:

$$= x \times 1820.86 = 0.8 \times 1820.86 = 1456.69 \text{ kJ/kg}$$

∴ Internal Latent Heat = 1456.69 kJ/kg

Step 3: Internal Energy of Steam (u)

The internal energy of wet steam is given by:

$$u = h - pv$$

Where h is the specific enthalpy of wet steam.

First, find enthalpy of wet steam, h:

$$h = h_f + xh_{fg}$$
$$h = 762.81 + (0.8 \times 2015.3)$$
$$h = 762.81 + 1612.24 = 2375.05 \text{ kJ/kg}$$

Now, find specific volume of wet steam, v:

$$v = x \cdot v_g = 0.8 \times 0.19444 = 0.15555 \text{ m}^3\text{/kg}$$

Now, calculate internal energy:

$$u = h - pv$$
$$u = 2375.05 \text{ kJ/kg} - (1000 \text{ kPa} \times 0.15555 \text{ m}^3\text{/kg})$$
$$u = 2375.05 - 155.55 = 2219.50 \text{ kJ/kg}$$

∴ Internal Energy of Steam = 2219.50 kJ/kg

Final Answers for Q-2:

1. External Work Done during Evaporation = **155.55 kJ/kg**
2. Internal Energy of Steam = **2219.50 kJ/kg**
3. Internal Latent Heat of Evaporation = **1456.69 kJ/kg**

Q-3: 1.5 kg of steam at a pressure of 10 bar and temperature of 250°C is expanded until the pressure becomes 2.8 bar. The dryness fraction of steam is then 0.9. Calculate change in internal energy.

Answer:

Given:

- Mass of steam, $m = 1.5$ kg
- Initial State: $p_1 = 10$ bar, $T_1 = 250°\text{C}$
- Final State: $p_2 = 2.8$ bar, $x_2 = 0.9$

We need to find the internal energy at the initial and final states.

Step 1: Determine Initial State (State 1) and find u_1

At $p_1 = 10$ bar, the saturation temperature $T_{sat} \approx 179.9°\text{C}$.
Since $T_1(250°\text{C}) > T_{sat}(179.9°\text{C})$, the initial steam is **superheated**.

From superheated steam tables at $p = 10$ bar and $T = 250°\text{C}$:

- Specific enthalpy, $h_1 = 2943$ kJ/kg (approx.)
- Specific volume, $v_1 = 0.2328$ m³/kg (approx.)

Internal energy is given by $u = h - pv$.
Ensure consistent units: $p_1 = 10 \text{ bar} = 1000 \text{ kPa}$

$$u_1 = h_1 - p_1 v_1$$
$$u_1 = 2943 - (1000 \times 0.2328)$$
$$u_1 = 2943 - 232.8 = 2710.2 \text{ kJ/kg}$$

Step 2: Determine Final State (State 2) and find u_2

At $p_2 = 2.8$ bar, the steam is wet with $x_2 = 0.9$.
From saturated steam tables at $p = 2.8$ bar:

- $h_f = 551.4$ kJ/kg

- $h_{fg} = 2171.0$ kJ/kg
- $v_g = 0.6463$ m³/kg

First, find enthalpy at state 2:

$$h_2 = h_f + x_2 h_{fg}$$
$$h_2 = 551.4 + (0.9 \times 2171.0)$$
$$h_2 = 551.4 + 1953.9 = 2505.3 \text{ kJ/kg}$$

Find specific volume at state 2:

$$v_2 = x_2 \cdot v_g = 0.9 \times 0.6463 = 0.58167 \text{ m}^3\text{/kg}$$

Now, calculate internal energy at state 2:

$$p_2 = 2.8 \text{ bar} = 280 \text{ kPa}$$
$$u_2 = h_2 - p_2 v_2$$
$$u_2 = 2505.3 - (280 \times 0.58167)$$
$$u_2 = 2505.3 - 162.8676 = 2342.4324 \text{ kJ/kg}$$

Step 3: Calculate Change in Internal Energy (ΔU)

Change in internal energy per kg is:

$$\Delta u = u_2 - u_1$$
$$\Delta u = 2342.4324 - 2710.2 = -367.7676 \text{ kJ/kg}$$

Total change in internal energy for 1.5 kg of steam is:

$$\Delta U = m \cdot \Delta u = 1.5 \times (-367.7676) = -551.6514 \text{ kJ}$$

The negative sign indicates a decrease in internal energy.

Final Answer for Q-3:
Change in Internal Energy, $\Delta U = -551.65$ kJ

Q-4: Combined separating and throttling calorimeter is used to find the dryness fraction of steam. Following readings were taken:
Main pressure = 12 bar
Mass of water collected in separating calorimeter = 2 kg
Mass of steam condensed in throttling calorimeter = 20 kg
Temperature of steam after throttling = 110°C
Pressure of steam after throttling = 1 bar
Assume c_p of steam = 2.1 kJ/kg K
Calculate dryness fraction of steam.

Answer:

Given:

- $p_1 = 12$ bar
- Mass from separator (water), $m_w = 2$ kg
- Mass from throttling (steam), $m_s = 20$ kg
- After throttling: $p_3 = 1$ bar, $T_3 = 110$°C
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Step 1: Find Dryness fraction from Separating Calorimeter (x_1)

The separating calorimeter collects suspended water particles. The mass of water collected is m_w. The mass of steam that passed through is m_s.

$$x_1 = \frac{\text{Mass of dry steam}}{\text{Total mass}} = \frac{m_s}{m_s + m_w}$$
$$x_1 = \frac{20}{20 + 2} = \frac{20}{22} = 0.9091$$

$\therefore x_1 = 0.9091$

Step 2: Find Dryness fraction from Throttling Calorimeter (x_2)

After throttling, the pressure is 1 bar. At 1 bar, the saturation temperature is 99.63°C.
Since $T_3(110°\text{C}) > T_{sat}(99.63°\text{C})$, the steam is superheated after throttling.

From superheated steam tables at $p_3 = 1$ bar and $T_3 = 110$°C:

- Enthalpy, $h_3 \approx 2696.5$ kJ/kg (Alternatively, we can calculate it).

The process in the throttling calorimeter is throttling, so enthalpy remains constant.

$$h_2 = h_3$$

State 2 is at the main pressure $p_1 = 12$ bar and is wet steam.
$h_2 = h_f + x_2 h_{fg}$ at 12 bar.

From saturated steam tables at $p = 12$ bar:

- $h_f = 798.65$ kJ/kg
- $h_{fg} = 1986.2$ kJ/kg

Now, we need h_3. Since precise tables are not provided, we can calculate h_3 using the saturation enthalpy at 1 bar and the superheat.
At $p = 1$ bar:

- $h_g = 2675.5$ kJ/kg
- $h_3 = h_g + c_p(T_3 - T_{sat})$
- $h_3 = 2675.5 + 2.1 \times (110 - 99.63)$
- $h_3 = 2675.5 + 2.1 \times 10.37$
- $h_3 = 2675.5 + 21.777 = 2697.277$ kJ/kg

Now, using $h_2 = h_3$:

$$h_f + x_2 h_{fg} = 2697.277$$
$$798.65 + x_2(1986.2) = 2697.277$$
$$x_2(1986.2) = 2697.277 - 798.65 = 1898.627$$
$$x_2 = \frac{1898.627}{1986.2} = 0.9559$$

$\therefore x_2 = 0.9559$

Step 3: Find Overall Dryness Fraction (x)

$$x = x_1 \times x_2$$
$$x = 0.9091 \times 0.9559 = 0.8689$$

Final Answer for Q-4:
Overall Dryness Fraction of steam, $x = 0.869$

Q-5: Determine the mass of 0.15 m³ of wet steam at a pressure of 4 bar and dryness fraction 0.8. Also calculate the heat of 1 m³ of steam.

Answer:

Given:

- Volume of wet steam, $V = 0.15$ m^3
- Pressure, $p = 4$ bar
- Dryness fraction, $x = 0.8$

Step 1: Find Specific Volume (v) of the wet steam

From saturated steam tables at $p = 4$ bar:

- $v_g = 0.4625 \text{ m}^3/\text{kg}$ (Specific volume of dry saturated vapor)

For wet steam, the specific volume is given by:

$$v = x \cdot v_g$$
$$v = 0.8 \times 0.4625 = 0.37 \text{ m}^3/\text{kg}$$

Step 2: Find Mass (m) of 0.15 m³ of wet steam

$$m = \frac{V}{v} = \frac{0.15}{0.37} = 0.4054 \text{ kg}$$

∴ **Mass = 0.4054 kg**

Step 3: Calculate the "Heat of 1 m³ of steam"

The phrase "heat of steam" typically refers to the **total heat** or **enthalpy** contained in the steam.

First, find the mass of 1 m³ of this wet steam.

$$m_{1m^3} = \frac{1}{v} = \frac{1}{0.37} = 2.7027 \text{ kg}$$

Now, find the specific enthalpy (h) of the wet steam.
From saturated steam tables at $p = 4$ bar:

- $h_f = 604.74$ kJ/kg
- $h_{fg} = 2133.8$ kJ/kg

$$h = h_f + x h_{fg}$$
$$h = 604.74 + (0.8 \times 2133.8)$$
$$h = 604.74 + 1707.04 = 2311.78 \text{ kJ/kg}$$

Now, calculate the total enthalpy for 1 m³ of steam:

$$\text{Heat} = m_{1m^3} \times h = 2.7027 \times 2311.78 = 6247.6 \text{ kJ}$$

∴ **Heat of 1 m³ of steam = 6247.6 kJ**

Final Answers for Q-5:

1. Mass of 0.15 m³ of wet steam = **0.405 kg**
2. Heat of 1 m³ of steam = **6247.6 kJ**

Q-6: Determine the enthalpy and internal energy of 1 kg of steam at a pressure 10 bar(abs.):
(i) when the dryness fraction of the steam is 0.85
(ii) when the steam is dry and saturated
(iii) when the steam is superheated to 300°C.
Neglect the volume of water and take C_{ps} as 2.1 kJ/kgK.

Answer:

Given:

- $p = 10$ bar
- For (i) $x = 0.85$
- For (iii) $T_{sup} = 300°\text{C}$
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From saturated steam tables at $p = 10$ bar:

- $T_{sat} = 179.9°\text{C}$
- $h_f = 762.81$ kJ/kg
- $h_{fg} = 2015.3$ kJ/kg
- $h_g = 2778.1$ kJ/kg
- $v_g = 0.19444\ \text{m}^3/\text{kg}$

The internal energy is calculated as $u = h - pv$. We neglect v_f, so for wet and dry saturated steam, $v \approx xv_g$ and for superheated steam, we will need v_{sup}.

Part (i): Wet Steam, x = 0.85

Enthalpy (h):

$$h = h_f + xh_{fg}$$
$$h = 762.81 + (0.85 \times 2015.3)$$
$$h = 762.81 + 1713.005 = 2475.815\ \text{kJ/kg}$$

Internal Energy (u):

$$v = xv_g = 0.85 \times 0.19444 = 0.165274 \text{ m}^3/\text{kg}$$
$$u = h - pv$$
$$u = 2475.815 - (1000 \times 0.165274) \text{ (since 10 bar = 1000 kPa)}$$
$$u = 2475.815 - 165.274 = 2310.541 \text{ kJ/kg}$$

∴ **For (i):** $h = 2475.82$ kJ/kg, $u = 2310.54$ kJ/kg

Part (ii): Dry Saturated Steam, x = 1

Enthalpy (h):

$$h = h_g = 2778.1 \text{ kJ/kg}$$

Internal Energy (u):

$$v = v_g = 0.19444 \text{ m}^3/\text{kg}$$
$$u = h - pv$$
$$u = 2778.1 - (1000 \times 0.19444)$$
$$u = 2778.1 - 194.44 = 2583.66 \text{ kJ/kg}$$

∴ **For (ii):** $h = 2778.1$ kJ/kg, $u = 2583.66$ kJ/kg

Part (iii): Superheated Steam, T = 300°C

For superheated steam, we need the specific volume and enthalpy. We can calculate them.

Degree of superheat = $T - T_{sat} = 300 - 179.9 = 120.1°\text{C}$

Enthalpy (h):

$$h_{sup} = h_g + c_{ps}(T_{sup} - T_{sat})$$
$$h_{sup} = 2778.1 + 2.1 \times 120.1$$
$$h_{sup} = 2778.1 + 252.21 = 3030.31 \text{ kJ/kg}$$

Specific Volume (v):

For an ideal gas approximation for superheated steam, $v_{sup} = v_g \times \frac{T_{sup}}{T_{sat}}$ (T in Kelvin)

$$T_{sat(K)} = 179.9 + 273 = 452.9 \text{ K}$$
$$T_{sup(K)} = 300 + 273 = 573 \text{ K}$$
$$v_{sup} = 0.19444 \times \frac{573}{452.9}$$
$$v_{sup} = 0.19444 \times 1.265 = 0.24597 \text{ m}^3/\text{kg}$$

Internal Energy (u):

$$u = h - pv$$

$$u = 3030.31 - (1000 \times 0.24597)$$
$$u = 3030.31 - 245.97 = 2784.34 \text{ kJ/kg}$$

∴ **For (iii):** $h = 3030.31$ kJ/kg, $u = 2784.34$ kJ/kg

Final Answers for Q-6:
(i) Wet Steam (x=0.85): $h = 2475.82$ kJ/kg, $u = 2310.54$ kJ/kg
(ii) Dry Saturated Steam: $h = 2778.1$ kJ/kg, $u = 2583.66$ kJ/kg
(iii) Superheated Steam (300°C): $h = 3030.31$ kJ/kg, $u = 2784.34$ kJ/kg

Q-7: Determine the enthalpy and internal energy of 1 kg of steam at a pressure 10 bar(abs.), (i) when the dryness fraction of the steam is 0.85 (ii) when the steam is dry and saturated (iii) when the steam is superheated to 300°C. Neglect the volume of water and take p as 2.1 kJ/kgK.

Answer:

This question is a duplicate of Q-6.