Tutorial-5 (Q-6-10), 19114018, Ayushman Tripathy

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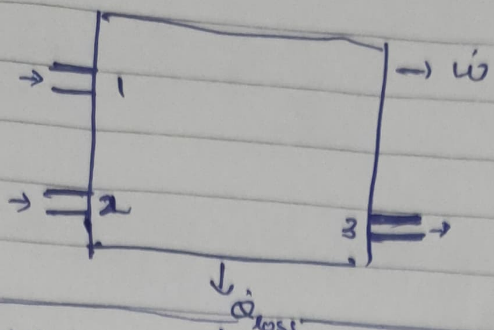

Inlet 1	Inlet 2	Outlet 3
$\dot{m}_1 = 2\ kg/s$	$\dot{m}_2 = 0.5\ kg/s$	$\dot{m}_3 = ?$
$P_1 = 2MPa$	$P_2 = 120\ kPa$	$A_3 = \frac{\pi d_3^2}{4}$
$T_1 = 500°C$	$T_2 = 30°C$	$d_3 = 0.15m$
		$P_3 = 150\ kPa$
		$x = 80\%$
		⇒ Sat. liq - vap.

By consv. of mass of sys.

$\Sigma \dot{m}_{in} = \Sigma \dot{m}_{out}$

$\dot{m}_1 + \dot{m}_2 = \dot{m}_3$

⇒ $2\ kg/s + 0.5\ kg/s = \boxed{2.5\ kg/s = \dot{m}_3}$

As sat. - liq. vap. mix

⇒ $T_3 = 111.38°C$

{T_{sat} at 1.5 bar}

But $\dot{m}_3 = \rho A v_3 = \frac{1}{v} \cdot A \cdot v_3$ {as $\rho = \frac{1}{v}$}

⇒ $v_3 = \frac{v\ \dot{m}_3}{A} = \frac{(v_f + x\ v_{fg})\ \dot{m}_3}{A}$

$v_f = 0.001053\ m^3/kg$

$v_{fg} = 1.15695\ m^3/kg$

$x = 0.8$

⇒ $v = v_f + x\ v_{fg}$

$\boxed{v = 0.926613\ m^3/kg}$

$\boxed{A = \frac{\pi d^2}{4} = 0.01767 m^2}$

⇒ $v_3 = \frac{v\ \dot{m}_3}{A} = 131.08892\ m/s$

∴ $\boxed{v_3 = 131.08892\ m/s}$

$\approx 131.1\ m/s$

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we have

$$\Sigma \dot{m}_{in}\left(h_{in} + \frac{v_{in}^2}{2} + gz_{in}\right) + \dot{Q}_{in} = \Sigma \dot{m}_{out}\left(h_{out} + \frac{v_{out}^2}{2} + gz_{out}\right) + \dot{W} + \dot{Q}_{loss}$$

$$\Rightarrow \dot{m}_1\left(h_1 + \frac{v_1^2}{2}\right) + \dot{m}_2\left(h_2 + \frac{v_2^2}{2}\right) + 0 = \dot{m}_3\left(h_3 + \frac{v_3^2}{2}\right) + \dot{W} + \dot{Q}_{loss}$$

$\{\dot{Q}_{in} = 0\}$

$$\rightarrow \dot{W} = -\dot{Q}_{loss} + \dot{m}_1\left(h_1 + \frac{v_1^2}{2}\right) + \dot{m}_2\left(h_2 + \frac{v_2^2}{2}\right) - \dot{m}_3\left(h_3 + \frac{v_3^2}{2}\right)$$

① 20 bar, 500°C, steam

$h_1 = 3467.55$ kJ/kg

$\dot{m}_1 = 2$ kg/s

$v_1 \approx 0$ {low flow}

② 1.2 bar, 30°C, cooled water

$h_2 = h_f$ at 30°C $= 125.66$ kJ/kg

$\dot{m}_2 = 0.5$ kg/s

$v_2 \approx 0$

③ 1.5 bar, sat. liq-vap ; $x = 0.8$

$h_3 = h_f + x h_{fg} = 467.2 + 0.8 \times 2226.3$

$= 2248.24$ kJ/kg

$\dot{m}_3 = 2.5$ kg/s

$v_3 = 131.1$ m/s

$$\Rightarrow \dot{W} = -\dot{Q}_{loss} + \dot{m}_1 h_1 + \dot{m}_2 h_2 - \dot{m}_3\left(h_3 + \frac{v_3^2}{2}\right)$$

$$= -300\text{ kW} + \underbrace{2 \times 3467.55}_{\text{kW}} + \underbrace{0.5 \times 125.66}_{\text{kW}} - 2.5\,\text{kg/s}\left(2248.24 + \frac{(131.1)^2 \times 10^{-3}}{2}\,\text{kJ/kg}\right)$$

$= -300 + 6935.1 + 62.83 - 5642.084013$

$= 1055.8459$ kW

$\therefore$ $\boxed{\dot{W} = \text{Power Output} = 1055.8459\text{ kW}}$

≈ 1056 kW

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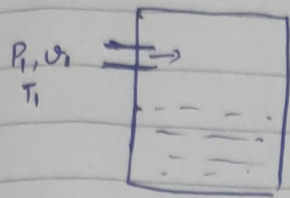

Input water does some Pv work {flow}
As bottle outlet ~~isn't~~ isn't there
⇒ No flow work in outgoing

$$m_1(P_1 v_1) + m_1\left(u_1 + \frac{v_1^2}{2} + gz_1\right) + Q = \underbrace{m_2\left(u_2 + \frac{v_2^2}{2} + gz_2\right)}_{\text{water inside bottle}} + W_s$$

$m_1 = m_2 = m$ {Mass consv.} , $v_2 = 0$, $Q = W_s = 0$ & assuming same level

$v_2 = 0$ velocity

$$\Rightarrow h_1 + \frac{v_1^2}{2} + gz = u_2 + 0 + gz$$

⇒ As no data about velocity is give we assume it to be very small

$$\Rightarrow \boxed{h_1 = u_2}$$

$h_1 = h$ at 0.8MPa, 350°C of water

↓

8 bar, 350°C

↳ $T_{sat} = 170.43 < T$ {350°C} ⇒ Superheated vapour

$h \rightarrow$ 8 bar : 350°C ⇒ 3161.68 kJ/kg

$\therefore \boxed{h_1 = u_2 = 3161.68 \text{ kJ/kg}}$

Given P_{final} = 8 bar.

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At 8 bar , $u_g = 2575.73$ kJ/kg

But $u = 3161.68$ kJ/kg $> u_g$

$\therefore$ final state = superheated vap.

At, 8bar, 500°C → $u_1 = 3125.95$ kJ/kg
8bar, 600°C ⇒ $u_2 = 3297.91$ kJ/kg

Interpolation⇒ $\frac{u - u_1}{u_2 - u_1} = \frac{T - T_1}{T_2 - T_1}$

$\Rightarrow \frac{3161.68 - 3125.95}{3297.91 - 3125.95} = \frac{T - 500}{600 - 500}$

$\Rightarrow \boxed{T = 520.778\,°C}$

At 8bar
$T_1 = 500°C \Rightarrow v_1 = 0.44331$ m³/kg
$T_2 = 600°C, \Rightarrow v_2 = 0.50184$ m³/kg

$\frac{v - v_1}{v_2 - v_1} = \frac{T - T_1}{T_2 - T_1}$

$\Rightarrow \frac{v - 0.44331}{0.50184 - 0.44331} = \frac{520.778 - 500}{600 - 500}$

$\Rightarrow \boxed{v = 0.45547 \text{ m}^3/\text{kg}}$

$\Rightarrow m = \frac{V}{v} \Rightarrow V = mv = 0.75 \times 0.45547$

$\boxed{V = 0.3416 \text{m}^3}$

$\therefore \boxed{T = 520.778\,°C, \; V = 0.3416 \text{ m}^3}$

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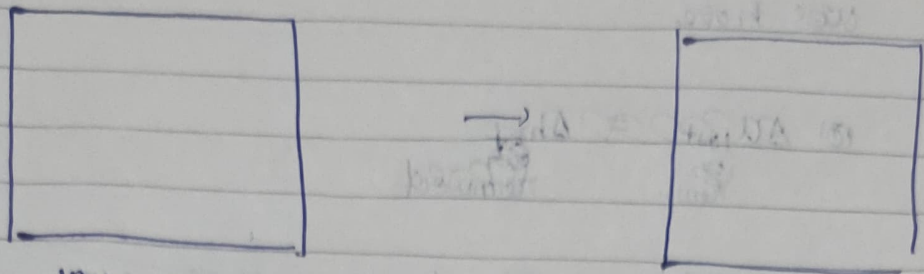

100L, 1MPa,
200°C, air
R = 0.287 kJ/kgK

100L, 100kPa
50°C, air
R = 0.287 kJ/kgK

$Pv = RT$

$\frac{PV}{m} = RT \Rightarrow m = \frac{PV}{RT}$

$\Rightarrow m_i = \frac{10^3\,\text{kPa} \times (100 \times 10^{-3})\,m^3}{0.287 \times (473)}$

$= 0.7366\ \text{kg}$

$m_f = \frac{100\,\text{kPa} \times (100 \times 10^{-3})\,m^3}{0.287 \times 323} = 0.10787\,\text{kg}$

$\therefore m_i = 0.7366\ \text{kg}$, $m_f = 0.10787\ \text{kg}$

$T_i = 200°C$ $\qquad T_f = 50°C$

From ideal-gas properties of air table,

$u_{470K} = 337.32\ \text{kJ/kg}$

$u_{480K} = 344.70\ \text{kJ/kg}$

$\Rightarrow \frac{u - 337.32}{344.70 - 337.32} = \frac{473 - 470}{480 - 470}$

$\Rightarrow \boxed{u = 339.534\ \text{kJ/kg}}$

$\therefore \boxed{u_{i\,473} = 339.534\ \text{kJ/kg}}$

$u_{320} = 228.42\ \text{kJ/kg}$

$u_{325} = 232.02\ \text{kJ/kg}$

$\Rightarrow \frac{u_{323} - 228.42}{232.02 - 228.42} = \frac{323 - 320}{325 - 320}$

$\therefore \boxed{u_{f\,323K} = 230.58\ \text{kJ/kg}}$

PTO

$$h_{av} = \frac{h_1 + h_2}{2}$$

$$h_1 = h_{470} + \frac{3}{10}\left(h_{480} - h_{470}\right) = 475.315 \text{ kJ/kg}$$

$$h_2 = h_{320} + \frac{3}{5}\left(h_{325} - h_{320}\right) = 323.302 \text{ kJ/kg}$$

$$h = \frac{h_1 + h_2}{2} = 399.3085 \text{ kJ/kg}$$

Energy balance

$$\underbrace{m_2 u_2 - m_1 u_1 + \Delta m_{\text{lost}}\left(h_{avg}\right)}_{\text{Tot energy lost by sys}} = Q$$

$$Q = 0.10787 \times 230.58 - 0.7366 \times 339.534 + (0.7366 - 0.10787) \times 399.3085$$

$$\boxed{Q = 25.829 \text{ kJ}}$$

$$\therefore \boxed{Q = 25.83 \text{ kJ}}$$

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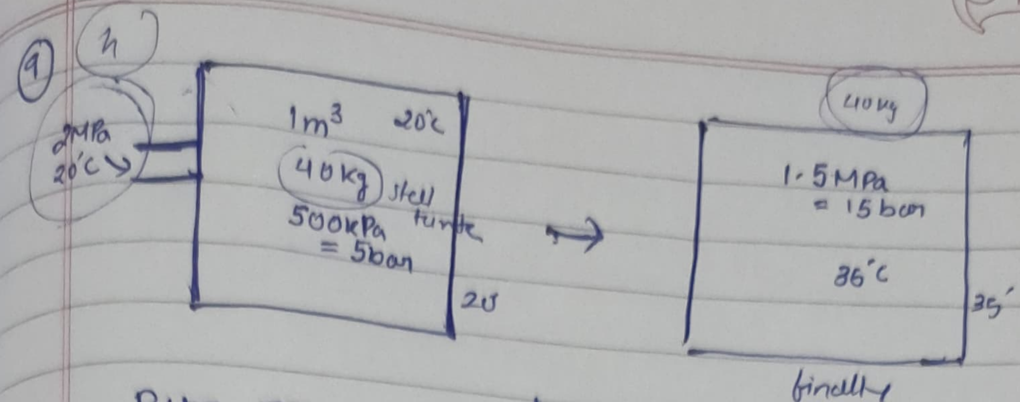

$Pv = RT$

$\Rightarrow \frac{PV}{m} = RT$

$\Rightarrow m = \frac{PV}{RT}$

$m_1 = \frac{P_1 V}{RT_1} = \frac{500 \times 1}{0.287 \times (273+20)} = 5.9459$ kg

$m_2 = \frac{1500 \times 1}{0.287 \times (273+35)} = 16.96909$ kg

$\Delta m = m_2 - m_1 = 11.0231$ kg.

$Q = m_2 U_2 - m_1 u_1 + m_s \cdot \Delta U_s + w_s + (\Delta m) h_{in}$

s = steel

$\Rightarrow Q = m_2 u_2 - m_1 u_1 + m_s (c_s (T_2 - T_1)) - \Delta m\, h_{in}$

$= (m_1 + \Delta m) u_2 - m_1 u_1 + m_s c_s (T_2 - T_1) - \Delta m (u_1 + Pv)$

$= m_1 (u_2 - u_1) + \Delta m (u_2 - u_1 - Pv_{in}) + m_s c_s (T_2 - T_1)$

$\because$ Here $\Delta T = 15°C$ is very small

$\therefore$ c_v can be assumed constant

$c_{p, air} = 1.005$ kJ/kgK , $c_{v, air} = c_p - R \approx 0.717$ kJ/kgK

$\Rightarrow Q = m_1 c_v \Delta T + \Delta m c_v \Delta T - \Delta m R T_{in} + m_s c_s \Delta T$

(as $Pv_{in} = RT_{in}$)

$= 5.9459 \times 0.717 \times 15 + 11.0231 \times 0.717 \times 15 - 11.023 \times 0.287 \times 293.15 + 40 \times 0.460 \times 15$

$\boxed{Q = -468.908 \text{ kJ}}$ $\boxed{Q = -468.908 \text{ kJ}}$

$\{ T_{in} = T_1 = 20°C = 293.15 K,\ c_s = 0.5000$ kJ/kg $\Delta T = 35 - 20 = 15°C \}$

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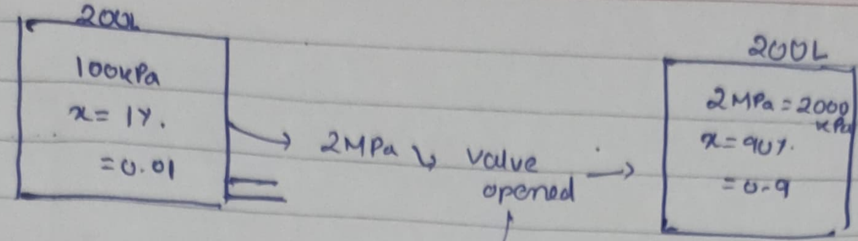

⇒ flow occurs at 2MPa {Sat. vap. given?}.

Finally

Initially + Finally: Sat. liq-vap as 'x' is given

$\Rightarrow \quad v_1 = v_f + x\, v_{fg}$ {at 100kPa}

$= 0.001043 + 0.001 \times 1.69296$ {Borgnakke values of steam table}

$= 0.0179726 \ m^3/kg$

$\Rightarrow m_1 = \frac{V}{v_1} = \frac{200 \times 10^{-3}}{0.0179726} = 11.128 \ kg$

$v_2 = v_f + x\, v_{fg}$ } at 2000 kPa

$= 0.001177 + 0.9 \times 0.09845$

$= 0.089782 \ m^3/kg$

$\Rightarrow m_2 = \frac{V}{v_2} = \frac{200 \times 10^{-3}}{0.089782} = 2.227 \ kg$

$\therefore \Delta m_{\text{flowed out}} = m_1 - m_2 = 11.128 - 2.227$

$\boxed{\Delta m = 8.9003 \ kg}$

$Q + \underbrace{(\Delta m)\left(P\,v_{in}\right)}_{\text{Flow energy in}} = \Delta U_{sys} = m_2 u_2 - m_1 u_1$

$\Rightarrow \boxed{Q + \Delta m\, h_{in} = m_2 u_2 - m_1 u_1}$

u_1: $P = 100 \ kPa$ & SLVMIX $\quad u_f + x\, u_{fg} =$

$= 417.33 + 0.01 \times 2088.72$

$\boxed{u_1 = 438.2172 \ kJ/kg}$

PTO

$$u_2 = u_f + x\,u_{fg}$$
$$= 906.42 + 0.9 \times 1693.84$$
$$= 2430.876 \text{ kJ/kg}$$

$$h_{in} = h_g \text{ at } 2\text{MPa}$$
$$= 2799.51 \text{ kJ}$$

$$Q + \Delta m\, h_{in} = m_2 u_2 - m_1 u_1$$
$$\Rightarrow Q = m_2 u_2 - m_1 u_1 - \Delta m\, h_{in}$$
$$= 2.227 \times 2430.876 - 11.128 \times 438.2172 - 8.9003 \times 2799.51$$
$$= 25453.5587 \text{ kJ}$$

$$\therefore Q = 25.45356 \text{ MJ}$$
$$\boxed{Q \approx 25.4534 \text{ MJ}}$$