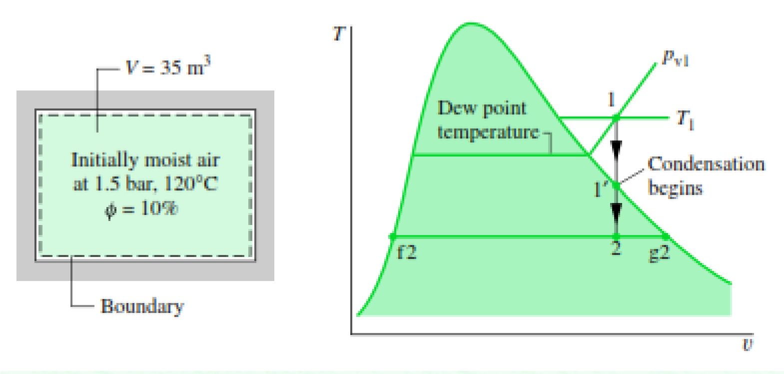
Applied thermodynamics

Section 2-2

الأسبوع الأول من توقف الدراسة

2.15 An air–water vapor mixture is contained in a rigid, closed vessel with a volume of 35 m^3 at 1.5 bar, 120˚C, and $\varnothing = 10\%$. The mixture is cooled at constant volume until its temperature is reduced to 22˚C. Determine the heat transfer during the process, in kJ.



$$Q = \underline{m_a(u_{a2} - u_{a1})} + \underline{m_{v2}u_{g2} + m_{w2}u_{f2} - m_{v1}u_{g1}}$$

$$\Delta U = Q - \cancel{W}^{\,0}$$

$$Q = U_2 - U_1$$

$$U_1 = m_a u_{a1} + m_{v1}u_{v1} = m_a u_{a1} + m_{v1}u_{g1}$$

$$U_2 = m_a u_{a2} + m_{v2}u_{v2} + m_{w2}u_{w2} = m_a u_{a2} + m_{v2}u_{g2} + m_{w2}u_{f2}$$

$$m_a = \frac{p_{a1}V}{(\overline{R}/M_a)T_1} = \frac{[(1.5 - 0.1985) \times 10^5 \text{ N/m}^2](35 \text{ m}^3)}{(8314/28.97 \text{ N} \cdot \text{m/kg} \cdot \text{K})(393 \text{ K})}$$
$$= 40.389 \text{ kg}$$

$$v_{v1} = \frac{(\overline{R}/M_v)T_1}{p_{v1}} = \left(\frac{8314}{18}\frac{\text{N}\cdot\text{m}}{\text{kg}\cdot\text{K}}\right)\left(\frac{393\ \text{K}}{0.1985 \times 10^5\ \text{N/m}^2}\right)$$
$$= 9.145\ \frac{\text{m}^3}{\text{kg}}$$

$$m_{v1} = \frac{V}{v_{v1}} = \frac{35\ \text{m}^3}{9.145\ \text{m}^3/\text{kg}} = 3.827\ \text{kg}$$

$$x_2 = \frac{v_{v2} - v_{f2}}{v_{g2} - v_{f2}} = \frac{9.145 - 1.0022 \times 10^{-3}}{51.447 - 1.0022 \times 10^{-3}} = 0.178$$

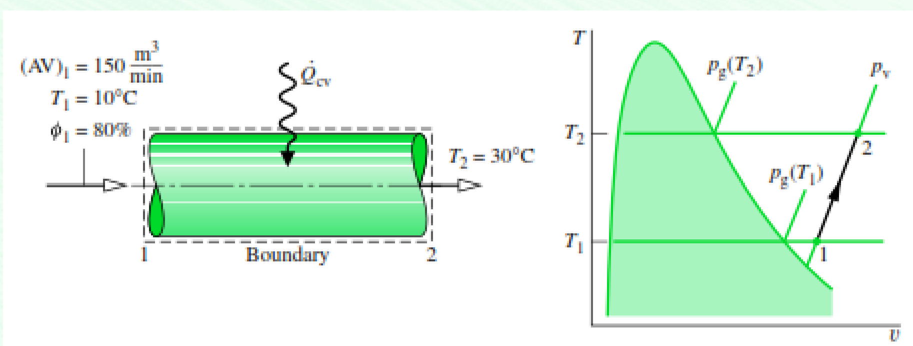
$$m_{w2} = m_{v1} - m_{v2} = 3.827 - 0.681 = 3.146\ \text{kg}$$

$$m_{v2} = (0.178)(3.827) = 0.681\ \text{kg}$$

$$Q = 40.389(210.49 - 281.1) + 0.681(2405.7) + 3.146(92.32) - 3.827(2529.3)$$
$$= -2851.87 + 1638.28 + 290.44 - 9679.63 = -10{,}603\ \text{kJ}$$

prob 2.16

Moist air enters a duct at 10°C, 80% relative humidity, and a volumetric flow rate of 150 m³/min. The mixture is heated as it flows through the duct and exits at 30°C. No moisture is added or removed, and the mixture pressure remains approximately constant at 1 bar. For steady-state operation, determine (a) the rate of heat transfer, in kJ/min, and (b) the relative humidity at the exit. Changes in kinetic and potential energy can be ignored.



$$\dot{m}_{a1} = \dot{m}_{a2} \quad \text{(dry air)}$$
$$\dot{m}_{v1} = \dot{m}_{v2} \quad \text{(water)}$$

$$0 = \dot{Q}_{cv} - \dot{W}_{cv}^{\,0} + (\dot{m}_a h_{a1} + \dot{m}_v h_{v1}) - (\dot{m}_a h_{a2} + \dot{m}_v h_{v2})$$

$$\dot{Q}_{cv} = \dot{m}_a(h_{a2} - h_{a1}) + \dot{m}_v(h_{v2} - h_{v1})$$

$$\dot{Q}_{cv} = \dot{m}_a\left[\left(h_{a2} - h_{a1}\right) + \omega\left(h_{v2} - h_{v1}\right)\right]$$

To evaluate $\dot{Q}_{cv}$ from this expression requires the specific enthalpies of the dry air and water vapor at the inlet and exit, the mass flow rate of the dry air, and the humidity ratio.

The specific enthalpies of the dry air are obtained from Table A-22 at the inlet and exit temperatures T_1 and T_2, respectively: $h_{a1} = 283.1$ kJ/kg, $h_{a2} = 303.2$ kJ/kg. The specific enthalpies of the water vapor are found using $h_v \approx h_g$ and data from Table A-2 at T_1 and T_2, respectively: $h_{g1} = 2519.8$ kJ/kg, $h_{g2} = 2556.3$ kJ/kg.

The mass flow rate of the dry air can be determined from the volumetric flow rate at the inlet $(AV)_1$

$$\dot{m}_a = \frac{(AV)_1}{v_{a1}}$$

$$v_{a1} = \frac{(\bar{R}/M)T_1}{p_{a1}} \qquad p_{v1} = \phi_1 p_{g1} = (0.8)(0.01228 \text{ bar}) = 0.0098 \text{ bar}$$

$$v_{a1} = \frac{\left(\dfrac{8314}{28.97}\dfrac{\text{N}\cdot\text{m}}{\text{kg}\cdot\text{K}}\right)(283 \text{ K})}{(0.9902 \times 10^5 \text{ N/m}^2)} = 0.82 \text{ m}^3/\text{kg} \qquad \dot{m}_a = \frac{150 \text{ m}^3/\text{min}}{0.82 \text{ m}^3/\text{kg}} = 182.9 \text{ kg/min}$$

$$\omega = 0.622\left(\frac{p_{v1}}{p - p_{v1}}\right) = 0.622\left(\frac{0.0098}{1 - 0.0098}\right) = 0.00616 \frac{\text{kg (vapor)}}{\text{kg (dry air)}}$$

$$\dot{Q}_{cv} = 182.9\left[(303.2 - 283.1) + (0.00616)(2556.3 - 2519.8)\right] = 3717 \text{ kJ/min}$$

$$\phi_2 = \frac{p_{v2}}{p_{g2}} = \frac{0.0098}{0.04246} = 0.231 (23.1\%)$$