CBE 20255

HW 8

1. ☆

1. $T_1 = 30^\circ C = (273.15+30) K = 303.15 K$

$T_2 = 50^\circ C = (273.15+50) K = 323.15 K$

$\hat{H}(T_1) = 25.8 kJ\ kg^{-1}$

$\hat{H}(T_2) = 129.8 kJ\ kg^{-1}$

Assuming linear relationship between enthalpy and temperature,

$$\hat{H}(T) = \hat{H}(T_1) + \frac{\hat{H}(T_2) - \hat{H}(T_1)}{T_2 - T_1}(T - T_1)$$

$$= 25.8 + 5.2(T - 303.15)$$

$$= (5.2T - 1550.58)\ kJ \cdot kg^{-1}$$

2. $\hat{H}(T_0) = 5.2T - 1550.58 = 0$

$\longrightarrow T_0 = 298.18 K \simeq 25^\circ C$

The reference state is room temperature

3. $\hat{H} = \hat{U} + P_0 \hat{V}$

At 1atm,

$\hat{H}(T) = \hat{U}(T) + P_0 \hat{V}(T) \qquad P_0 = 1atm$

$\hat{U}(T) = \hat{H}(T) - P_0 \hat{V}(T)$

$$\hat{V}(T_1) = \frac{1}{650.16\,kg/m^3} = 1.538 \times 10^{-3}\ m^3/kg \quad \text{from Nist Webbook}$$

$$\hat{V}(T_2) = \frac{1}{631.33\,kg/m^3} = 1.5840 \times 10^{-3}\ m^3/kg \quad \text{from Nist Webbook}$$

$$\hat{U}(T_1) = \hat{H}(T_1) - P_0 \hat{V}(T_1)$$

$$= 25.8\ kJ\ kg^{-1} - 1.01\times 10^5\ Pa \cdot 1.538 \times 10^{-3}\ m^3\ kg^{-1} \cdot \frac{0.001\,kJ}{J}$$

$$= 25.8\ kJ\ kg^{-1} - 0.16\ kJ\ kg^{-1}$$

$$= \cancel{25.96\ kJ\ kg^{-1}}\ 25.6\ kJ\ kg^{-1}$$

$$\hat{U}(T_2) = \hat{H}(T_2) - P_0 \hat{V}(T_2)$$

$$= 129.8\,kJ/kg - 1.01\times 10^5\ Pa \cdot 1.5840 \times 10^{-3}\ m^3/kg \cdot \frac{0.001\,kJ}{J}$$

$$= 129.8\,kJ/kg - 0.16\ kJ\ kg^{-1}$$

$$= 129.2\ kJ/kg$$

Assuming $\hat{U}(T)$ is linear to T,

$$\hat{U}(T) = \hat{U}(T_1) + \frac{\hat{U}(T_2) - \hat{U}(T_1)}{T_2 - T_1}(T - T_1)$$

$$= 25.6 + 5.2(T - 303.15)$$

$$= (5.2T - 1550.58)\ kJ \cdot kg^{-1}$$

4. $\dot{q} = \Delta\hat{H} \cdot \dot{m} = -[\hat{H}(T_4) - \hat{H}(T_3)] \cdot \dot{m}$

$$= -5.2(T_4 - T_3) \cdot 20\,kg \cdot min^{-1}$$

$$= -3640\ kJ \cdot min^{-1}$$

2、☆

All thermophysical parameters are from steam tables in the back of textbook.

1、 $P_1 = 3.0\ \text{bar} \longrightarrow T_1 = 406.67\,K$

2、 At T_1 and P_1,

$$\rho_{steam} = 1.651\ kg/m^3 \qquad \rho_{water} = 932.17\ kg/m^3$$

$$m_{water} = 165.0\,kg = \rho_{water} V_{water}$$

$$\longrightarrow V_{water} = 177\ L$$

$$V_{steam} = V_{tank} - V_{water} = 23\ L$$

$$m_{steam} = V_{steam} \cdot \rho_{steam} = 23\,L \cdot \frac{1\,m^3}{1000\,L} \cdot 1.651\,kg/m^3$$

$$= 0.038\ kg$$

So $m_{total} = m_{water} + m_{steam} = 165.038\,kg$

3. $P_2 = 20.0\ \text{bar} \longrightarrow T_2 = 485.52\,K$

4、 At T_2 and P_2,

$$\rho_{steam} = 10.047\,kg/m^3 \qquad \rho_{water} = 849.156\,kg/m^3$$

$$\begin{cases} \rho_{steam} V_{steam} + \rho_{water} V_{water} = m_{total} = 165.038\,kg \\ V_{steam} + V_{water} = V_{tank} = 200\,L \end{cases}$$

$$\longrightarrow \begin{cases} V_{steam} = 0.0057\ m^3 = 5.7\ L \\ V_{water} = 0.1943\ m^3 = 194.3\ L \end{cases}$$

$$m_{steam} = V_{steam}\,\rho_{steam} = 0.057\ kg$$

5. $$q = \Delta H = m_2^{steam}\hat{H}_2^{steam} + m_2^{water}\hat{H}^{water} - m_1^{steam}\hat{H}_1^{steam} - m_1^{water}\hat{H}_1^{water}$$

$m_1^{steam} = 0.038\ kg$ $\qquad$ $m_2^{steam} = 0.057\ kg$

$m_1^{water} = 165.0\ kg$ $\qquad$ $m_2^{water} = 164.981\ kg$

$\hat{H}_1^{steam} = 2724.66\ kJ/kg$ $\qquad$ $\hat{H}_2^{steam} = 2797.21\ kJ/kg$

$\hat{H}_1^{water} = 561.451\ kJ/kg$ $\qquad$ $\hat{H}_2^{water} = 913.703\ kJ/kg$

$$q = \Delta H = 58160\ kJ$$

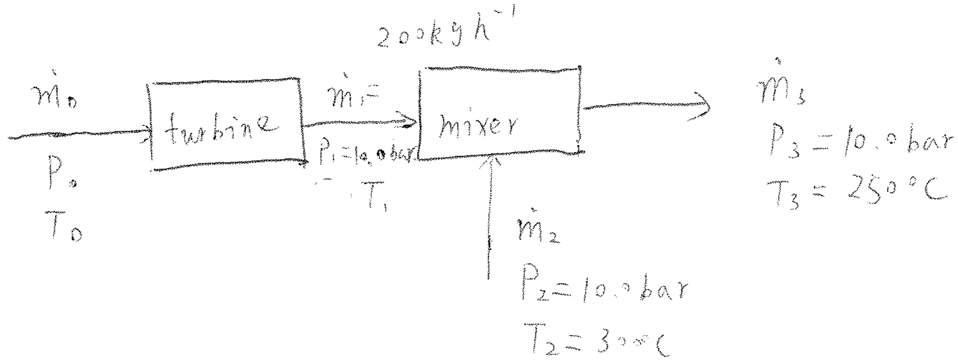
6. $P_3 = 10\ bar \longrightarrow T_3 = 453.03\ K$

7. Rate of steam releasing should be inverse of latent heat of vaporization at 10 bar

$$\longrightarrow \frac{1}{2023.56\ kJ/kg} = 4.94 \times 10^{-4}\ kg/kJ$$

3. ☆ All thermophysical parameters are from steam tables in the back of textbook.

1.



2.

$P_1 = 10.0\ \text{bar}$

$T_1 = 179.88\ °C$

3.

$$q = \dot{m}_3 \hat{H}_3 - \dot{m}_2 \hat{H}_2 - \dot{m}_1 \hat{H}_1$$

$$\dot{m}_2 = \dot{m}_3 - \dot{m}_1 = 300 - 200 = 100\ \text{kg h}^{-1}$$

$\hat{H}_1 = 2776.16\ \text{kJ/kg}$

$\hat{H}_2 = 3051.7\ \text{kJ/kg}$

$\hat{H}_3 = 2943.22\ \text{kJ/kg}$

$$q = (300 \cdot 2943.22 - 100 \cdot 3051.7 - 200 \cdot 2776.16)\ \text{kJ}$$

$$= 22564\ \text{kJ}$$

4. Enthalpy balance,

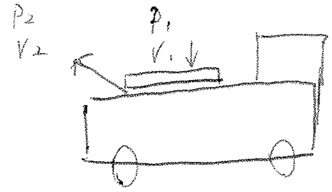
$$\begin{cases} \dot{m}_1 \hat{H}_1 + \dot{m}_2 \hat{H}_2 = \dot{m}_3 \hat{H}_3 \\ \dot{m}_3 = \dot{m}_1 + \dot{m}_2 \end{cases}$$

$$\rightarrow \begin{cases} \dot{m}_2 = 308 \text{ kg h}^{-1} \\ \dot{m}_3 = 508 \text{ kg h}^{-1} \end{cases}$$

508 kg h^{-1} of 250°C, 10.0 bar steam can be produced.

4. ☆

1.



$m = 75\,lb = 34\,kg \qquad \rho_{air} = 0.075\,lbm/ft^3 = 1.2\,kg/m^3$

When energy is balanced, Bernoulli equation tells us

$$P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2$$

$$P_2 - P_1 = \frac{1}{2}\rho\,(V_1^2 - \underbrace{\cancel{V_2^2}}_{=0}) + \underbrace{\cancel{\rho g (h_1 - h_2)}}_{\text{negligible}}$$

$$P_2 - P_1 = \frac{mg}{A} = \frac{34\,kg \cdot 9.804\,m/s^2}{60 \times 78\,in^2 \cdot \frac{0.00064516\,m^2}{in^2}} = 110\ \text{Pa}$$

$$110\ \text{Pa} = \frac{1}{2}\rho V_1^2$$

$$\longrightarrow V_1 = 13.6\ \text{m/s} = 30.4\ \text{mph}$$

2、Above this speed, pressure difference ~~created~~ caused by the weight of mattress is smaller than kinetic energy difference. So air will tend to flow to the bottom of mattress with non-zero velocity in order to rebalance energy. Consequently, the mattress will start to lift.

3. To safely drive at 60 mph, more weight should be added to mattress to increase pressure difference.

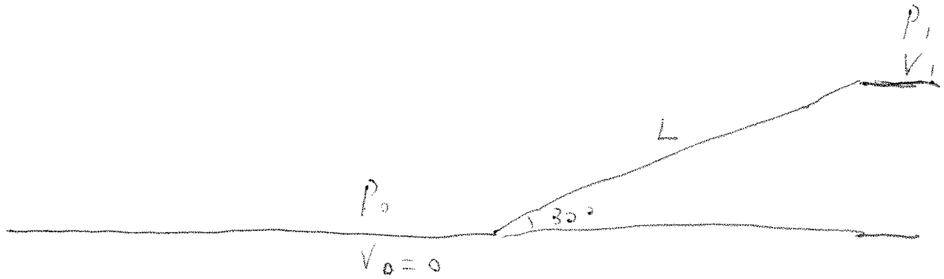
$$\frac{(m + m_{book})g}{A} = \frac{1}{2}\rho V^2 = \frac{1}{2} \cdot 1.2 \cdot (26.82)^2 \text{ Pa}$$

$$\rightarrow m_{book} = 98.9 \text{ kg}$$

Around 30~40 very thick text books.

5. ☆

1.



$d = 1.049\ in = 0.027m$ $\quad$ $8hp = 5965.6W$

$\dot{Q} = 95\ gal/min = 0.006\ m^3/s$ $\quad$ $\rho = 1000 kg/m^3$

$V_1 = \frac{\dot{Q}}{\pi(\frac{d}{2})^2} = 10.48 m/s$

Modified Bernoulli equation with frictional loss and external power:

$$\cancel{\dot{Q}P_0} + \tfrac{1}{2}\dot{Q}\rho \underbrace{V_0^2}_{=0} + \dot{Q}\rho g h_0 - \dot{Q}\rho g(0.041L) + 5965.6W$$

$$= \cancel{\dot{Q}P_1} + \tfrac{1}{2}\dot{Q}\rho V_1^2 + \dot{Q}\rho g h_1$$

$$\dot{Q}\rho g(h_1 - h_0) = -\tfrac{1}{2}\dot{Q}\rho V_1^2 - \dot{Q}\rho g(0.041L) + 5965.6W$$

$$h_1 - h_0 = L\sin(30°) = \tfrac{1}{2}L$$

$$\rightarrow \tfrac{1}{2}\dot{Q}\rho g L = -\tfrac{1}{2}\dot{Q}\rho V_1^2 - \dot{Q}\rho g(0.041L) + 5965.6W$$

$$\rightarrow L = 177.1m$$

$$\Delta h = \tfrac{1}{2}L = 88.6M$$

2. It's incorrect. Deeper the initial ~~posit~~ position results in larger the elevation. The pressure gain will finally balance the elevation penealty.