CHAPTER SEVEN

7.1
$$\frac{0.80\ \text{L}}{\text{h}}\left|\frac{3.5\times10^4\ \text{kJ}}{\text{L}}\right|\frac{0.30\ \text{kJ work}}{1\ \text{kJ heat}}\left|\frac{1\ \text{h}}{3600\ \text{s}}\right|\frac{1\ \text{kW}}{1\ \text{kJ/s}}=2.33\ \text{kW}\Rightarrow \underline{\underline{2.3\ \text{kW}}}$$

$$\frac{2.33\ \text{kW}}{}\left|\frac{10^3\ \text{W}}{1\ \text{kW}}\right|\frac{1.341\times10^{-3}\ \text{hp}}{1\ \text{W}}=3.12\ \text{hp}\Rightarrow \underline{\underline{3.1\ \text{hp}}}$$

7.2 All kinetic energy dissipated by friction

(a) $E_k=\dfrac{mu^2}{2}$

$$=\frac{5500\ \text{lb}_\text{m}}{2}\left|\frac{55^2\ \text{miles}^2}{\text{h}^2}\right|\frac{5280^2\ \text{ft}^2}{1^2\ \text{mile}^2}\left|\frac{1^2\ \ \text{h}^2}{3600^2\ \text{s}^2}\right|\frac{1\ \text{lb}_\text{f}}{32.174\ \text{lb}_\text{m}\cdot\text{ft}/\text{s}^2}\left|\frac{9.486\times10^{-4}\ \text{Btu}}{0.7376\ \text{ft}\cdot\text{lb}_\text{f}}\right.$$

$$=\underline{\underline{715\ \text{Btu}}}$$

(b)
$$\frac{3\times10^8\ \text{brakings}}{\text{day}}\left|\frac{715\ \text{Btu}}{\text{braking}}\right|\frac{1\ \text{day}}{24\ \text{h}}\left|\frac{1\ \text{h}}{3600\ \text{s}}\right|\frac{1\ \text{W}}{9.486\times10^{-4}\ \text{Btu/s}}\left|\frac{1\ \text{MW}}{10^6\ \text{W}}\right.=2617\ \text{MW}$$

$$\Rightarrow \underline{\underline{3000\ \text{MW}}}$$

7.3 **(a)** Emissions:

$$\text{Paper}\Rightarrow\frac{1000\ \text{sacks}}{}\left|\frac{(0.0510+0.0516)\ \text{oz}}{\text{sack}}\right|\frac{1\ \text{lb}_\text{m}}{16\ \text{oz}}=\underline{\underline{6.41\ \text{lb}_\text{m}}}$$

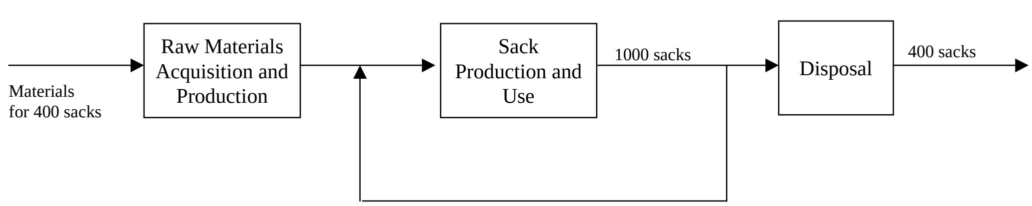
$$\text{Plastic}\Rightarrow\frac{2000\ \text{sacks}}{}\left|\frac{(0.0045+0.0146)\ \text{oz}}{\text{sack}}\right|\frac{1\ \text{lb}_\text{m}}{16\ \text{oz}}=\underline{\underline{2.39\ \text{lb}_\text{m}}}$$

Energy:

$$\text{Paper}\Rightarrow\frac{1000\ \text{sacks}}{}\left|\frac{(724+905)\ \text{Btu}}{\text{sack}}\right.=\underline{\underline{1.63\times10^6\ \text{Btu}}}$$

$$\text{Plastic}\Rightarrow\frac{2000\ \text{sacks}}{}\left|\frac{(185+464)\ \text{Btu}}{\text{sack}}\right.=\underline{\underline{1.30\times10^6\ \text{Btu}}}$$

(b) For paper (double for plastic)



7.3 (cont'd)

Emissions:

$$\text{Paper} \Rightarrow \frac{400 \text{ sacks}}{} \left| \frac{0.0510 \text{ oz}}{\text{sack}} \right| \frac{1 \text{ lb}_m}{16 \text{ oz}} + \frac{1000 \text{ sacks}}{} \left| \frac{0.0516 \text{ oz}}{\text{sack}} \right| \frac{1 \text{ lb}_m}{16 \text{ oz}} = \underline{\underline{4.5 \text{ lb}_m}}$$

$$\Rightarrow \underline{\underline{30\% \text{ reduction}}}$$

$$\text{Plastic} \Rightarrow \frac{800 \text{ sacks}}{} \left| \frac{0.0045 \text{ oz}}{\text{sack}} \right| \frac{1 \text{ lb}_m}{16 \text{ oz}} + \frac{2000 \text{ sacks}}{} \left| \frac{0.0146 \text{ oz}}{\text{sack}} \right| \frac{1 \text{ lb}_m}{16 \text{ oz}} = \underline{\underline{2.05 \text{ lb}_m}}$$

$$\Rightarrow \underline{\underline{14\% \text{ reduction}}}$$

Energy:

$$\text{Paper} \Rightarrow \frac{400 \text{ sacks}}{} \left| \frac{724 \text{ Btu}}{\text{sack}} \right. + \frac{1000 \text{ sacks}}{} \left| \frac{905 \text{ Btu}}{\text{sack}} \right. = \underline{\underline{1.19 \times 10^6 \text{ Btu; } 27\% \text{ reduction}}}$$

$$\text{Plastic} \Rightarrow \frac{800 \text{ sacks}}{} \left| \frac{185 \text{ Btu}}{\text{sack}} \right. + \frac{2000 \text{ sacks}}{} \left| \frac{464 \text{ Btu}}{\text{sack}} \right. = \underline{\underline{1.08 \times 10^6 \text{ Btu; } 17\% \text{ reduction}}}$$

(c) $$.\frac{3 \times 10^8 \text{ persons}}{} \left| \frac{1 \text{ sack}}{\text{person - day}} \right| \frac{1 \text{ day}}{24 \text{ h}} \left| \frac{1 \text{ h}}{3600 \text{ s}} \right| \frac{649 \text{ Btu}}{1 \text{ sack}} \left| \frac{1 \text{ J}}{9.486 \times 10^{-4} \text{ Btu}} \right| \frac{1 \text{ MW}}{10^6 \text{ J/s}}$$

$$= \underline{\underline{2{,}375 \text{ MW}}}$$

Savings for recycling: $0.17(2{,}375 \text{ MW}) = \underline{\underline{404 \text{ MW}}}$

(d) Cost, toxicity, biodegradability, depletion of nonrenewable resources.

7.4 **(a)** Mass flow rate: $$\dot{m} = \frac{3.00 \text{ gal}}{\text{min}} \left| \frac{1 \text{ ft}^3}{7.4805 \text{ gal}} \right| \frac{(0.792)(62.43) \text{ lb}_m}{1 \text{ ft}^3} \left| \frac{1 \text{ min}}{60 \text{ s}} \right. = 0.330 \text{ lb}_m/\text{s}$$

Stream velocity: $$u = \frac{3.00 \text{ gal}}{\text{min}} \left| \frac{1728 \text{ in}^3}{7.4805 \text{ gal}} \right| \frac{1}{\Pi(0.5)^2 \text{ in}^2} \left| \frac{1 \text{ ft}}{12 \text{ in}} \right| \frac{1 \text{ min}}{60 \text{ s}} = 1.225 \text{ ft/s}$$

Kinetic energy: $$E_k = \frac{mu^2}{2} = \frac{0.330 \text{ lb}_m}{\text{s}} \left| \frac{(1.225)^2 \text{ ft}^2}{\text{s}^2} \right| \frac{1}{2} \left| \frac{1 \text{ lb}_f}{32.174 \text{ lb}_m \cdot \text{ft/s}^2} \right. = \underline{\underline{7.70 \times 10^{-3} \frac{\text{ft} \cdot \text{lb}_f}{\text{s}}}}$$

$$= (7.70 \times 10^{-3} \text{ ft} \cdot \text{lb}_f \text{ / s}) \left(\frac{1.341 \times 10^{-3} \text{ hp}}{0.7376 \text{ ft} \cdot \text{lb}_f \text{ / s}} \right) = \underline{\underline{1.40 \times 10^{-5} \text{ hp}}}$$

(b) Heat losses in electrical circuits, friction in pump bearings.

7.5 **(a)** Mass flow rate:

$$\dot{m} = \frac{42.0\text{ m}}{\text{s}}\left|\frac{\pi(0.07\text{ m})^2}{4}\right|\frac{10^3\text{ L}}{1\text{ m}^3}\left|\frac{273\text{ K}}{573\text{ K}}\right|\frac{130\text{ kPa}}{101.3\text{ kPa}}\left|\frac{1\text{ mol}}{22.4\text{ L (STP)}}\right|\frac{29\text{ g}}{\text{mol}} = 127.9\text{ g/s}$$

$$\dot{E}_k = \frac{\dot{m}u^2}{2} = \frac{127.9\text{ g}}{2\quad\text{s}}\left|\frac{1\text{ kg}}{1000\text{ g}}\right|\frac{42.0^2\text{ m}^2}{\text{s}^2}\left|\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right|\frac{1\text{ J}}{\text{N}\cdot\text{m}} = \underline{\underline{113\text{ J/s}}}$$

(b)

$$\frac{127.9\text{ g}}{\text{s}}\left|\frac{1\text{ mol}}{29\text{ g}}\right|\frac{673\text{ K}}{273\text{ K}}\left|\frac{101.3\text{ kPa}}{130\text{ kPa}}\right|\frac{22.4\text{ L (STP)}}{1\text{ mol}}\left|\frac{1\text{ m}^3}{10^3\text{ L}}\right|\frac{4}{\pi(0.07)^2\text{ m}^2} = 49.32\text{ m/s}$$

$$\dot{E}_k = \frac{\dot{m}u^2}{2} = \frac{127.9\text{ g}}{2\quad\text{s}}\left|\frac{1\text{ kg}}{1000\text{ g}}\right|\frac{49.32^2\text{ m}^2}{\text{s}^2}\left|\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right|\frac{1\text{ J}}{\text{N}\cdot\text{m}} = 155.8\text{ J/s}$$

$$\Delta\dot{E}_k = \dot{E}_k(400^\circ\text{C}) - \dot{E}_k(300^\circ\text{C}) = (155.8 - 113)\text{ J/s} = 42.8\text{ J/s} \Rightarrow \underline{\underline{43\text{ J/s}}}$$

(c) Some of the heat added goes to raise *T* (and hence *U*) of the air

7.6 **(a)**

$$\Delta E_p = mg\Delta z = \frac{1\text{ gal}}{}\left|\frac{1\text{ ft}^3}{7.4805\text{ gal}}\right|\frac{62.43\text{ lb}_m}{1\text{ ft}^3}\left|\frac{32.174\text{ ft}}{\text{s}^2}\right|\frac{-10\text{ ft}}{}\left|\frac{1\text{ lb}_f}{32.174\text{ lb}_m\cdot\text{ft/s}^2}\right| = \underline{\underline{-83.4\text{ ft}\cdot\text{lb}_f}}$$

(b) $E_k = -\Delta E_p \Rightarrow \dfrac{mu^2}{2} = mg(-\Delta z) \Rightarrow u = [2g(-\Delta z)]^{1/2} = \left[2\left(32.174\dfrac{\text{ft}}{\text{s}^2}\right)(10\text{ ft})\right]^{1/2} = \underline{\underline{25.4\dfrac{\text{ft}}{\text{s}}}}$

(c) $\underline{\underline{\text{False}}}$

7.7 **(a)** $\underline{\underline{\Delta\dot{E}_k \Rightarrow \textit{positive}}}$ When the pressure decreases, the volumetric flow rate increases, and hence the velocity increases.

$\underline{\underline{\Delta\dot{E}_p \Rightarrow \textit{negative}}}$ The gas exits at a level below the entrance level.

(b) $$\dot{m} = \frac{5\text{ m}}{\text{s}}\left|\frac{\pi(1.5)^2\text{ cm}^2}{}\right|\frac{1\text{ m}^3}{10^4\text{ cm}^2}\left|\frac{273\text{ K}}{303\text{ K}}\right|\frac{10\text{ bars}}{1.01325\text{ bars}}\left|\frac{1\text{ kmol}}{22.4\text{ m}^3\text{ (STP)}}\right|\frac{16.0\text{ kg CH}_4}{1\text{ kmol}}$$

$$= 0.0225\text{ kg/s}$$

$$\frac{P_{out}\dot{V}_{out}}{P_{in}\dot{V}_{in}} = \frac{\dot{n}RT}{\dot{n}RT} \Rightarrow \frac{\dot{V}_{out}}{\dot{V}_{in}} = \frac{P_{in}}{P_{out}} \Rightarrow \frac{u_{out}(\text{m/s})\cdot A(\text{m}^2)}{u_{in}(\text{m/s})\cdot A(\text{m}^2)} = \frac{P_{in}}{P_{out}}$$

$$\Rightarrow u_{out} = u_{in}\frac{P_{in}}{P_{out}} = 5(\text{m/s})\frac{10\text{ bar}}{9\text{ bar}} = 5.555\text{ m/s}$$

$$\Delta\dot{E}_k = \frac{1}{2}\dot{m}(u_{out}^2 - u_{in}^2) = \frac{0.5(0.0225)\text{ kg}}{\text{s}}\left|\frac{(5.555^2 - 5.000^2)\text{m}^2}{\text{s}^2}\right|\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\left|\frac{1\text{ W}}{1\text{ N}\cdot\text{m/s}}\right.$$

$$= \underline{\underline{0.0659\text{ W}}}$$

$$\Delta\dot{E}_p = \dot{m}g(z_{out} - z_{in}) = \frac{0.0225\text{ kg}}{\text{s}}\left|\frac{9.8066\text{ m}}{\text{s}}\right|\frac{-200\text{ m}}{}\left|\frac{1\text{ N}}{\text{kg}\cdot\text{m/s}^2}\right|\frac{1\text{ W}}{1\text{ N}\cdot\text{m/s}}$$

$$= \underline{\underline{-44.1\text{ W}}}$$

7.8

$$\Delta\dot{E}_p = \dot{m}g\Delta z = \frac{10^5\ \text{m}^3}{\text{h}}\left|\frac{10^3\ \text{L}}{1\ \text{m}^3}\right|\frac{1\ \text{kg H}_2\text{O}}{1\ \text{L}}\left|\frac{9.81\ \text{m}}{\text{s}^2}\right|-75\ \text{m}\left|\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right|\frac{1\ \text{J}}{1\ \text{N}\cdot\text{m}}\left|\frac{2.778\times10^{-7}\ \text{kW}\cdot\text{h}}{1\ \text{J}}\right.$$
$$= -2.04\times10^4\ \text{kW}\cdot\text{h/h}$$

The maximum energy to be gained equals the potential energy lost by the water, or

$$\frac{2.04\times10^4\ \text{kW}\cdot\text{h}}{\text{h}}\left|\frac{24\ \text{h}}{1\ \text{day}}\right|\frac{7\ \text{days}}{1\ \text{week}} = \underline{\underline{3.43\times10^6\ \text{kW}\cdot\text{h/week}}}\ \text{(more than sufficient)}$$

7.9 **(b)** $Q - W = \Delta U + \Delta E_k + \Delta E_p$

$$\Big\Downarrow \begin{array}{l} \Delta E_k = 0\ \text{(system is stationary)} \\ \Delta E_p = 0\ \text{(no height change)} \end{array}$$

$\underline{\underline{Q - W = \Delta U,\ Q < 0, W > 0}}$

(c) $Q - W = \Delta U + \Delta E_k + \Delta E_p$

$$\Big\Downarrow \begin{array}{l} Q = 0\ \text{(adiabatic)},\ W = 0\text{(no moving parts or generated currents)} \\ \Delta E_k = 0\ \text{(system is stationary)} \\ \Delta E_p = 0\ \text{(no height change)} \end{array}$$

$\underline{\underline{\Delta U = 0}}$

(d). $Q - W = \Delta U + \Delta E_k + \Delta E_p$

$$\Big\Downarrow \begin{array}{l} W = 0\ \text{(no moving parts or generated currents)} \\ \Delta E_k = 0\ \text{(system is stationary)} \\ \Delta E_p = 0\ \text{(no height change)} \end{array}$$

$\underline{\underline{Q = \Delta U, Q < 0}}$ Even though the system is isothermal, the occurrence of a chemical reaction assures that $\Delta U \neq 0$ in a non-adiabatic reactor. If the temperature went up in the adiabatic reactor, heat must be transferred from the system to keep T constant, hence $Q < 0$.

7.10 4.00 L, 30 °C, 5.00 bar $\Rightarrow$ V (L), T (°C), 8.00 bar

(a). Closed system: $\Delta U + \Delta E_k + \Delta E_p = Q - W$

$$\Big\Downarrow \begin{cases} \Delta E_k = 0\ \text{(initial / final states stationary)} \\ \Delta E_p = 0\ \text{(by assumption)} \end{cases}$$

$\underline{\underline{\Delta U = Q - W}}$

(b) Constant $T \Rightarrow \Delta U = 0 \Rightarrow Q = W = \dfrac{-7.65\ \text{L}\cdot\text{bar}}{}\left|\dfrac{8.314\ \text{J}}{0.08314\ \text{L}\cdot\text{bar}}\right. = \underline{\underline{-765\ \text{J}}}$ transferred from gas to surroundings

(c) Adiabatic $\Rightarrow Q = 0 \Rightarrow \Delta U = -W = 7.65\ \text{L}\cdot\text{bar} > 0$, $\underline{\underline{T_{\text{final}} > 30°\text{C}}}$

7.11 $A = \dfrac{\pi(3)^2 \ \text{cm}^2}{} \left| \dfrac{1 \text{ m}^2}{10^4 \ \text{cm}^2} \right. = 2.83 \times 10^{-3} \ \text{m}^2$

(a) Downward force on piston:

$$F_d = P_{\text{atm}} A + m_{\text{piston+weight}}\, g$$

$$= \frac{1 \text{ atm}}{} \left| \frac{1.01325 \times 10^5 \ \text{N/m}^2}{\text{atm}} \right| \frac{2.83 \times 10^{-3} \ \text{m}^2}{} + \frac{24.50 \text{ kg}}{} \left| \frac{9.81 \text{ m}}{\text{s}^2} \right| \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} = 527 \text{ N}$$

Upward force on piston: $F_u = AP_{\text{gas}} = \left(2.83 \times 10^{-3} \ \text{m}^2\right)\left[P_g\left(\text{N/m}^2\right)\right]$

Equilibrium condition:

$$F_u = F_d \Rightarrow 2.83 \times 10^{-3} \text{m}^2 \cdot P_0 = 527 \Rightarrow \underline{\underline{P_0 = 1.86 \times 10^5 \ \ \text{N/m}^2 = 1.86 \times 10^5 \ \text{Pa}}}$$

$$V_0 = \frac{nRT}{P_0} = \frac{1.40 \text{ g N}_2}{} \left| \frac{1 \text{ mol N}_2}{28.02 \text{ g}} \right| \frac{303 \text{ K}}{1.86 \times 10^5 \ \text{Pa}} \left| \frac{1.01325 \times 10^5 \ \text{Pa}}{1 \text{ atm}} \right| \frac{0.08206 \text{ L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} = \underline{\underline{0.677 \text{ L}}}$$

(b) For any step, $\Delta U + \Delta E_k + \Delta E_p = Q - W \underset{\substack{\Delta E_k = 0 \\ \Delta E_p = 0}}{\Rightarrow} \Delta U = Q - W$

Step 1: $Q \approx 0 \Rightarrow \underline{\underline{\Delta U = -W}}$

Step 2: $\underline{\underline{\Delta U = Q - W}}$ As the gas temperature changes, the pressure remains constant, so that $V = nRT/P_g$ must vary. This implies that the piston moves, so that W is not zero.

Overall: $T_{\text{initial}} = T_{\text{final}} \Rightarrow \Delta U = 0 \Rightarrow \underline{\underline{Q - W = 0}}$

In step 1, the gas expands $\Rightarrow W > 0 \Rightarrow \Delta U < 0 \Rightarrow \underline{\underline{T \text{ decreases}}}$

(c) Downward force $F_d = (1.00)\left(1.01325 \times 10^5\right)\left(2.83 \times 10^{-3}\right) + (4.50)(9.81)(1) = 331 \text{ N}$ (units as in Part (a))

Final gas pressure $P_f = \dfrac{F}{A} = \dfrac{331 \text{ N}}{2.83 \times 10^{-3} \ \text{m}^2} = 1.16 \times 10^5 \ \ \text{N/m}^2$

Since $T_0 = T_f = 30°\text{C}$, $P_f V_f = P_0 V_0 \Rightarrow V_f = V_0 \dfrac{P_0}{P_f} = (0.677 \text{ L}) \dfrac{1.86 \times 10^5 \ \text{Pa}}{1.16 \times 10^5 \ \text{Pa}} = 1.08 \text{ L}$

Distance traversed by piston $= \dfrac{\Delta V}{A} = \dfrac{(1.08 - 0.677) \text{ L}}{} \left| \dfrac{1 \ \text{m}^3}{10^3 \ \text{L}} \right| \dfrac{}{2.83 \times 10^{-3} \ \text{m}^2} = 0.142 \text{ m}$

$$\Rightarrow W = Fd = (331 \text{ N})(0.142 \text{ m}) = 47 \text{ N} \cdot \text{m} = 47 \text{ J}$$

Since work is done by the gas on its surroundings, $W = +47 \text{ J} \underset{Q - W = 0}{\Rightarrow} \underline{\underline{Q = +47 \text{ J}}}$

(heat transferred to gas)

7.12 $\hat{V} = \dfrac{32.00 \text{ g}}{\text{mol}} \left| \dfrac{4.684 \text{ cm}^3}{\text{g}} \right| \dfrac{10^3 \text{ L}}{10^6 \text{ cm}^3} = 0.1499 \ \ \text{L/mol}$

$$\hat{H} = \hat{U} + P\hat{V} = 1706 \ \ \text{J/mol} + \frac{41.64 \text{ atm}}{} \left| \frac{0.1499 \text{ L}}{\text{mol}} \right| \frac{8.314 \quad \text{J/(mol} \cdot \text{K)}}{0.08206 \text{ L} \cdot \text{atm/(mol} \cdot \text{K)}} = \underline{\underline{2338 \ \ \text{J/mol}}}$$

7.13 **(a)** Ref state $(\hat{U}=0) \Rightarrow \underline{\underline{\text{liquid Bromine @ 300 K, 0.310 bar}}}$

(b) $\Delta\hat{U} = \hat{U}_{\text{final}} - \hat{U}_{\text{initial}} = 0.000 - 28.24 = \underline{\underline{-28.24 \text{ kJ/mol}}}$

$\Delta\hat{H} = \Delta\hat{U} + \Delta(P\hat{V}) = \Delta\hat{U} + P\Delta\hat{V}$ (Pressure Constant)

$$\Delta\hat{H} = -28.24 \text{ kJ/mol} + \frac{0.310 \text{ bar} \,\Big|\, (0.0516 - 79.94) \text{ L} \,\Big|\, 8.314 \text{ J} \,\Big|\, 1 \text{ kJ}}{\Big|\, \text{mol} \,\Big|\, 0.08314 \text{ L}\cdot\text{bar} \,\Big|\, 10^3 \text{ J}} = \underline{\underline{-30.7 \text{ kJ/mol}}}$$

$\Delta H = n\Delta\hat{H} = (5.00 \text{ mol})(-30.7 \text{ kJ / mol}) = -153.58 \text{ kJ} \Rightarrow \underline{\underline{-154 \text{ kJ}}}$

(c) $\hat{U}$ independent of $P \Rightarrow \hat{U}(300 \text{ K}, 0.205 \text{ bar}) = \hat{U}(300 \text{ K}, 0.310 \text{ bar}) = 28.24 \text{ kJ/mol}$

$\hat{U}(340 \text{ K}, P_f) = \hat{U}(340 \text{ K}, 1.33 \text{ bar}) = 29.62 \text{ kJ/mol}$

$\Delta\hat{U} \underset{\Downarrow}{=} \hat{U}_{\text{final}} - \hat{U}_{\text{initial}}$

$\Delta\hat{U} = 29.62 - 28.24 = \underline{\underline{1.380 \text{ kJ/mol}}}$

$\hat{V}$ changes with pressure. At constant temperature $\Rightarrow P\hat{V} = P'\hat{V}' \Rightarrow \hat{V}' = P\hat{V} / P'$

$$\hat{V}'(T = 300\text{K}, P = 0.205 \text{ bar}) = \frac{(0.310 \text{ bar})(79.94 \text{ L / mol})}{0.205 \text{ bar}} = 120.88 \text{ L / mol}$$

$$n = \frac{5.00 \text{ L} \,\Big|\, 1 \text{ mol}}{\Big|\, 120.88 \text{ L}} = 0.0414 \text{ mol}$$

$\Delta U = n\Delta\hat{U} = (0.0414 \text{ mol})(1.38 \text{ kJ / mol}) = \underline{\underline{0.0571 \text{ kJ}}}$

$\Delta U + \underbrace{\cancel{\Delta E_k}}_{0} + \underbrace{\cancel{\Delta E_p}}_{0} = Q - \underbrace{\cancel{W}}_{0} \Rightarrow \underline{\underline{Q = 0.0571 \text{ kJ}}}$

(d) Some heat is lost to the surroundings; the energy needed to heat the wall of the container is being neglected; internal energy is not completely independent of pressure.

7.14 **(a)** By definition $\hat{H} = \hat{U} + P\hat{V}$; ideal gas $P\hat{V} = RT \Rightarrow \hat{H} = \hat{U} + RT$

$\hat{U}(T,P) = \hat{U}(T) \Rightarrow \hat{H}(T,P) = \hat{U}(T) + RT = \hat{H}(T)$ independent of P

(b) $$\Delta\hat{H} = \Delta\hat{U} + R\Delta T = 3500 \frac{\text{cal}}{\text{mol}} + \frac{1.987 \text{ cal} \,\Big|\, 50 \text{ K}}{\text{mol}\cdot\text{K} \,\Big|} = 3599 \text{ cal/mol}$$

$\Delta H = n\Delta\hat{H} = (2.5 \text{ mol})(3599 \text{ cal / mol}) = 8998 \text{ cal} \Rightarrow \underline{\underline{9.0 \times 10^3 \text{ cal}}}$

7.15 $\Delta U + \Delta E_k + \Delta E_p = Q - Ws$

$\Downarrow$

$\Delta E_k = 0$ (no change in m and u)

$\Delta E_p = 0$ (no elevation change)

$W_s = P\Delta V$ (since energy is transferred from the system to the surroundings)

$\Delta U = Q - W \Rightarrow \Delta U = Q - P\Delta V \Rightarrow Q = \Delta U + P\Delta V = \Delta(U + PV) = \Delta H$

7.16. **(a)** $\Delta E_k = 0 \ (u_1 = u_2 = 0)$

$\Delta E_p = 0$ (no elevation change)

$\Delta P = 0$ (the pressure is constant since restraining force is constant, and area is constrant)

$W_s = P\Delta V$ (the only work done is expansion work)

$\hat{H} = 34980 + 35.5T$ (J / mol), $V_1 = 785\ \text{cm}^3$, $T_1 = 400$ K, $P = 125$ kPa, $Q = 83.8$ J

$$n = \frac{PV}{RT} = \frac{125\times10^3\ \text{Pa}}{8.314\ \text{m}^3\cdot\text{Pa/mol}\cdot\text{K}}\left|\frac{785\ \text{cm}^3}{400\ \text{K}}\right|\frac{1\ \text{m}^3}{10^6\ \text{cm}^3} = 0.0295\ \text{mol}$$

$$Q = \Delta H = n(\hat{H}_2 - \hat{H}_1) = 0.0295\ \text{mol}\left[34980 + 35.5T_2 - 34980 - 35.5(400\text{K})\right]\ (\text{J/mol})$$

$$83.8\ \text{J} = 0.0295\left[35.5T_2 - 35.5(400)\right] \Rightarrow \underline{\underline{T_2 = 480\ \text{K}}}$$

$$i)\ V = \frac{nRT}{P} = \frac{0.0295\ \text{mol}}{125\times10^5\ \text{Pa}}\left|\frac{8.314\ \text{m}^3\cdot\text{Pa}}{\text{mol}\cdot\text{K}}\right|\frac{10^6\ \text{cm}^3}{1\quad \text{m}^3}\left|\ 480\ \text{K}\right. = \underline{\underline{941\ \text{cm}^3}}$$

$$ii)\ W = P\Delta V = \frac{125\times10^5\ \text{N}}{\text{m}^2}\left|\ (941-785)\text{cm}^3\right|\frac{1\quad \text{m}^3}{10^6\ \text{cm}^3} = \underline{\underline{19.5\ \text{J}}}$$

$$iii)\ Q = \Delta U + P\Delta V \Rightarrow \Delta U = Q - \Delta PV = 83.8\ \text{J} - 19.5\ \text{J} = \underline{\underline{64.3\ \text{J}}}$$

(b) $\underline{\underline{\Delta E_p = 0}}$

7.17 **(a)** "The gas temperature remains constant while the circuit is open." (If heat losses could occur, the temperature would drop during these periods.)

(b) $\Delta U + \Delta E_p + \Delta E_R = \dot{Q}\Delta t - \dot{W}\Delta t$

$$\Big\Downarrow \ \Delta E_p = 0,\ \Delta E_k = 0,\ \dot{W} = 0,\ \hat{U}(t=0) = 0;\quad \dot{Q} = \frac{0.90\times1.4\ \text{W}}{}\left|\frac{1\ \text{J/s}}{1\ \text{W}}\right. = 1.26\ \text{J/s}$$

$$U(\text{J}) = 1.26\ t$$

Moles in tank: $n = PV/RT = \dfrac{1\ \text{atm}}{}\left|\dfrac{2.10\ \text{L}}{(25+273)\text{K}}\right|\dfrac{1\quad \text{mol}\cdot\text{K}}{0.08206\ \text{L}\cdot\text{atm}} = 0.0859\ \text{mol}$

$$\hat{U} = \frac{U}{n} = \frac{1.26t\ (\text{J})}{0.0859\ \text{mol}} = 14.67t$$

Thermocouple calibration: $T = aE + b \xrightarrow[T=100,\ E=5.27]{T=0,\ E=-0.249} T(^\circ\text{C}) = 18.1E(\text{mV}) + 4.51$

$\hat{U} = 14.67t$	0	440	880	1320
$T = 18.1E + 4.51$	25	45	65	85

(c) To keep the temperature uniform throughout the chamber.

(d) Power losses in electrical lines, heat absorbed by chamber walls.

(e) In a closed container, the pressure will increase with increasing temperature. However, at the low pressures of the experiment, the gas is probably close to ideal $\Rightarrow \hat{U} = f(T)$ only. Ideality could be tested by repeating experiment at several initial pressures $\Rightarrow$ same results.

7.18 **(b)** $\Delta\dot{H} + \Delta\dot{E}_k + \Delta\dot{E}_p = \dot{Q} - \dot{W}_s$ (The system is the liquid stream.)

$$\Bigg\Downarrow \begin{array}{l} \Delta\dot{E}_k = 0 \text{ (no change in } m \text{ and } u) \\ \Delta\dot{E}_p = 0 \text{ (no elevation change)} \\ \dot{W}_s = 0 \text{ (no moving parts or generated currents)} \end{array}$$

$$\underline{\underline{\Delta\dot{H} = \dot{Q},\ \dot{Q} > 0}}$$

(c) $\Delta\dot{H} + \Delta\dot{E}_k + \Delta\dot{E}_p = \dot{Q} - \dot{W}_s$ (The system is the water)

$$\Bigg\Downarrow \begin{array}{l} \Delta\dot{H} = 0 \text{ (} T \text{ and } P \text{~constant)} \\ \Delta\dot{E}_k = 0 \text{ (no change in } m \text{ and } u) \\ \dot{Q} = 0 \text{ (no } \Delta T \text{ between system and surroundings)} \end{array}$$

$$\underline{\underline{\Delta\dot{E}_p = -\dot{W}_s,\ \dot{W}_s > 0 \text{ (for water system)}}}$$

(d) $\Delta\dot{H} + \Delta\dot{E}_k + \Delta\dot{E}_p = \dot{Q} - \dot{W}_s$ (The system is the oil)

$$\Downarrow \Delta\dot{E}_k = 0 \text{ (no velocity change)}$$

$\underline{\underline{\Delta\dot{H} + \Delta\dot{E}_p = \dot{Q} - \dot{W}_s}}$ $\dot{Q} < 0$ (friction loss); $\dot{W}_s < 0$ (pump work).

(e) $\Delta\dot{H} + \Delta\dot{E}_k + \Delta\dot{E}_p = \dot{Q} - \dot{W}_s$ (The system is the reaction mixture)

$$\Bigg\Downarrow \begin{array}{l} \Delta\dot{E}_k = \Delta\dot{E}_p = 0 \text{ (given)} \\ \Delta\dot{W}_s = 0 \text{ (no moving parts or generated current)} \end{array}$$

$$\underline{\underline{\Delta\dot{H} = \dot{Q},\ \dot{Q} \text{ pos. or neg. depends on reaction}}}$$

7.19 **(a)** <u>molar flow:</u> $\dfrac{1.25 \text{ m}^3}{\text{min}} \bigg| \dfrac{273 \text{ K}}{423 \text{ K}} \bigg| \dfrac{122 \text{ kPa}}{101.3 \text{ kPa}} \bigg| \dfrac{1 \text{ mol}}{22.4 \text{ L(STP)}} \bigg| \dfrac{10^3 \text{ L}}{1 \text{ m}^3} = 43.4 \text{ mol/min}$

$\Delta\dot{H} + \Delta\dot{E}_k + \Delta\dot{E}_p = \dot{Q} - \dot{W}_s$

$$\Bigg\Downarrow \begin{array}{l} \Delta\dot{E}_k = \Delta\dot{E}_p = 0 \text{ (given)} \\ \dot{W}_s = 0 \text{ (no moving parts)} \end{array}$$

$$\dot{Q} = \Delta\dot{H} = \dot{n}\Delta\hat{H} = \frac{43.37 \text{ mol}}{\text{min}} \bigg| \frac{1 \text{ min}}{60\text{s}} \bigg| \frac{3640 \text{ J}}{\text{mol}} \bigg| \frac{\text{kW}}{10^3 \text{ J/s}} = \underline{\underline{2.63 \text{ kW}}}$$

(b) More information would be needed. The change in kinetic energy would depend on the cross-sectional area of the inlet and outlet pipes, hence the internal diameter of the inlet and outlet pipes would be needed to answer this question.

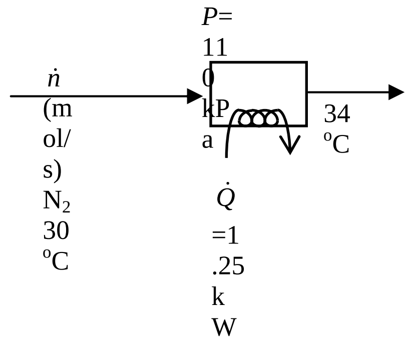
7.20 **(a)** $\hat{H} = 1.04[T(^\circ\text{C}) - 25] \quad \hat{H} \text{ in kJ/kg}$

$\hat{H}_{\text{out}} = 1.04[34.0 - 25] = 9.36 \text{ kJ/kg}$

$\hat{H}_{\text{in}} = 1.04[30.0 - 25] = 5.20 \text{ kJ/kg}$

$\Delta\hat{H} = 9.36 - 5.20 = 4.16 \text{ kJ/kg}$

$\Delta\dot{H} + \Delta\dot{E}_k + \Delta\dot{E}_p = \dot{Q} - \dot{W}_s$



$$\Bigg\Downarrow \begin{array}{l}\Delta\dot{E}_k = \Delta\dot{E}_p = 0 \text{ (assumed)} \\ \dot{W}_s = 0 \text{ (no moving parts)}\end{array}$$

$\dot{Q} = \Delta\dot{H} = \dot{n}\Delta\hat{H}$

$$\Rightarrow \dot{n} = \frac{\dot{Q}}{\Delta\hat{H}} = \frac{1.25 \text{ kW}}{} \left| \frac{\text{kg}}{4.16 \text{ kJ}} \right| \frac{1 \text{ kJ/s}}{\text{kW}} \left| \frac{10^3 \text{ g}}{1 \text{ kg}} \right| \frac{1 \text{ mol}}{28.02 \text{ g}} = 10.7 \text{ mol/s}$$

$$\Rightarrow \dot{V} = \frac{10.7 \text{ mol}}{\text{s}} \left| \frac{22.4 \text{ L(STP)}}{\text{mol}} \right| \frac{303 \text{ K}}{273 \text{ K}} \left| \frac{101.3 \text{ kPa}}{110 \text{ kPa}} \right. = 245.5 \text{ L/s} \Rightarrow \underline{\underline{246 \text{ L/s}}}$$

(b) Some heat is lost to the surroundings, some heat is needed to heat the coil, enthalpy is assumed to depend linearly on temperature and to be independent of pressure, errors in measured temperature and in wattmeter reading.

7.21 **(a)**
$$\left.\begin{array}{l} \hat{H} = aT + b \quad a = \dfrac{\hat{H}_2 - \hat{H}_1}{T_2 - T_1} = \dfrac{129.8 - 25.8}{50 - 30} = 5.2 \\ b = \hat{H}_1 - aT_1 = 25.8 - (5.2)(30) = -130.2 \end{array}\right\} \Rightarrow \underline{\underline{\hat{H}(\text{kJ/kg}) = 5.2T(^\circ\text{C}) - 130.2}}$$

$$\hat{H} = 0 \Rightarrow T_{\text{ref}} = \frac{130.2}{5.2} = \underline{\underline{25^\circ \text{C}}}$$

$$\text{Table B.1} \Rightarrow (S.G.)_{C_6H_{14}(l)} = 0.659 \Rightarrow \hat{V} = \frac{1 \text{ m}^3}{659 \text{ kg}} = 1.52 \times 10^{-3} \text{ m}^3/\text{kg}$$

$$\hat{U}(\text{kJ/kg}) = \hat{H} - P\hat{V} = (5.2T - 130.2) \text{kJ/kg}$$

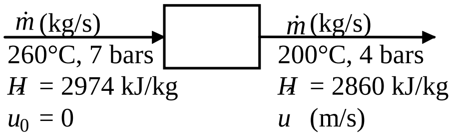
$$- \frac{1 \text{ atm}}{} \left| \frac{1.0132 \times 10^5 \text{ N/m}^2}{1 \quad \text{atm}} \right| \frac{1.52 \times 10^{-3} \text{ m}^3}{1 \quad \text{kg}} \left| \frac{1 \text{ J}}{1 \text{ N} \cdot \text{m}} \right| \frac{1 \text{ kJ}}{10^3 \text{ J}}$$

$$\Rightarrow \underline{\underline{\hat{U}(\text{kJ/kg}) = 5.2T - 130.4}}$$

(b) $\underline{\text{Energy balance:}}$ $\Delta E_k, \Delta E_p, W=0$
$$Q = \Delta U = \frac{20 \text{ kg}}{} \left| \frac{[(5.2 \times 20 - 130.4) - (5.2 \times 80 - 130.4)] \text{ kJ}}{1 \qquad\qquad \text{kg}} \right. = -6240 \text{ kJ}$$

$$\underline{\text{Average rate of heat removal}} = \frac{6240 \text{ kJ}}{5 \text{ min}} \left| \frac{1 \text{ min}}{60 \text{ s}} \right. = \underline{\underline{20.8 \text{ kW}}}$$

7.22



$$\Delta \dot{H} + \Delta \dot{E}_k + \Delta \dot{E}_p = \dot{Q} - \dot{W}_s$$

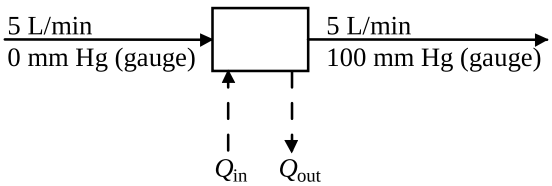
$$\Big\Downarrow \; \Delta \dot{E}_p = \dot{Q} = \dot{W}_s = 0$$

$$\Delta \dot{E}_k = -\Delta \dot{H} \Rightarrow \frac{\dot{m}u^2}{2} = -\dot{m}\left(\hat{H}_{\text{out}} - \hat{H}_{\text{in}}\right)$$

$$\Big\Downarrow$$

$$u^2 = 2\left(\hat{H}_{\text{in}} - \hat{H}_{\text{out}}\right) = \frac{(2)(2974-2860)\text{kJ}}{\text{kg}}\left|\frac{10^3 \text{N}\cdot\text{m}}{1 \text{ kJ}}\right|\frac{1 \text{ kg}\cdot\text{m/s}^2}{1 \text{ N}} = 2.28\times 10^5 \frac{\text{m}^2}{\text{s}^2} \Rightarrow \underline{\underline{u = 477 \text{ m/s}}}$$

7.23 **(a)**



Since there is only one inlet stream and one outlet stream, and $\dot{m}_{\text{in}} = \dot{m}_{\text{out}} \equiv \dot{m}$, Eq. (7.4-12) may be written

$$\dot{m}\Delta\hat{U} + \dot{m}\Delta\left(P\hat{V}\right) + \frac{\dot{m}}{2}\Delta\left(u^2\right) + \dot{m}g\Delta z = \dot{Q} - \dot{W}_s$$

$$\Delta\hat{U} = 0 \text{ (given)}$$

$$\dot{m}\Delta P\hat{V} = \dot{m}\hat{V}\left(P_{\text{out}} - P_{\text{in}}\right) = \dot{V}\Delta P$$

$$\Delta u^2 = 0 \text{ (assume for incompressible fluid)}$$

$$\Delta z = 0$$

$$\dot{W}_s = 0 \text{ (all energy other than flow work included in heat terms)}$$

$$\dot{Q} = \dot{Q}_{\text{in}} - \dot{Q}_{\text{out}}$$

$$\Big\Downarrow$$

$$\underline{\underline{\dot{V}\Delta P = \dot{Q}_{\text{in}} - \dot{Q}_{\text{out}}}}$$

(b) Flow work: $\dot{V}\Delta P = \dfrac{5 \text{ L}}{\text{min}}\left|\dfrac{(100-0)\text{mm Hg}}{}\right|\dfrac{1 \text{ atm}}{760 \text{ mm Hg}}\left|\dfrac{8.314 \text{ J}}{0.08206 \text{ liter}\cdot\text{atm}}\right. = 66.7 \text{ J/min}$

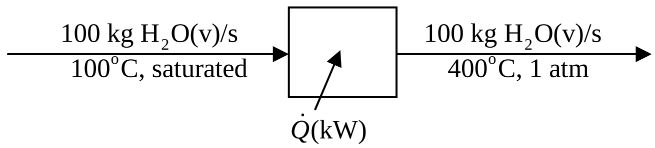
Heat input: $\dot{Q}_{\text{in}} = \dfrac{5 \text{ ml } O_2}{\text{min}}\left|\dfrac{20.2 \text{ J}}{1 \text{ ml } O_2}\right. = 101 \text{ J/min}$

Efficiency: $\dfrac{\dot{V}\Delta P}{\dot{Q}_{\text{in}}} = \dfrac{66.7 \text{ J/min}}{101 \text{ J/min}} \times 100\% = \underline{\underline{66\%}}$

7.24 **(a)** $\Delta\dot{H} + \Delta\dot{E}_k + \Delta\dot{E}_p = \dot{Q} - \dot{W}_s;\ \Delta\dot{E}_k,\ \Delta\dot{E}_p,\ \dot{W}_s = 0 \Rightarrow \Delta\dot{H} = \dot{Q}$

$\hat{H}(400^\circ\text{C},\ 1\text{ atm}) = 3278\ \text{kJ/kg}$ (Table B.7)

$\hat{H}(100^\circ\text{C},\ \text{sat'd} \Rightarrow 1\text{ atm}) = 2676\ \text{kJ/kg}$ (Table B.5)



$$\dot{Q} = \frac{100\text{ kg}}{\text{s}}\left|\frac{(3278-2676.0)\text{kJ}}{\text{kg}}\right|\frac{10^3\text{ J}}{1\text{ kJ}} = \underline{\underline{6.02\times10^7\ \text{J/s}}}$$

(b) $\Delta U + \Delta E_k + \Delta E_p = Q - W;\ \Delta E_k,\ \Delta E_p,\ W = 0 \Rightarrow \Delta U = Q$

Table B.5 $\Rightarrow$ $\hat{U}(100°\text{C, 1 atm}) = 2507\dfrac{\text{kJ}}{\text{kg}}$, $\hat{V}(100°\text{C, 1 atm}) = 1.673\ \dfrac{\text{m}^3}{\text{kg}} = \hat{V}(400°\text{C}, P_{\text{final}})$

Interpolate in Table B.7 to find P at which $\hat{V}$ =1.673 at 400°C, and then interpolate again to find $\hat{U}$ at 400°C and that pressure:

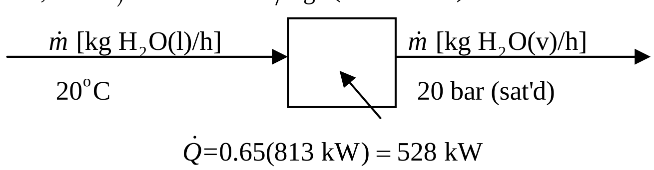
$$\hat{V} = 1.673\ \text{m}^3/\text{g} \Rightarrow P_{\text{final}} = 1.0 + 4.0\left(\frac{3.11-1.673}{3.11-0.617}\right) = 3.3\text{ bar},\ \hat{U}(400°\text{C, 3.3 bar}) = 2966\text{ kJ/kg}$$

$$\Rightarrow Q = \Delta U = m\Delta\hat{U} = 100\text{ kg}\left[(2966-2507)\text{kJ/kg}\right]\left(10^3\ \text{J/kJ}\right) = \underline{\underline{4.59\times10^7\ \text{J}}}$$

The difference is the net energy needed to move the fluid through the system (flow work). (The energy change associated with the pressure change in Part (b) is insignificant.)

7.25 $\hat{H}(H_2O(l),\ 20^\circ\text{C}) = 83.9\ \text{kJ/kg}$ (Table B.5)

$\hat{H}(\text{steam, 20 bars, sat'd}) = 2797.2\ \text{kJ/kg}$ (Table B.6)



(a) $\Delta\dot{H} + \Delta\dot{E}_k + \Delta\dot{E}_p = \dot{Q} - \dot{W}_s;\ \Delta\dot{E}_k,\ \Delta\dot{E}_p,\ \dot{W}_s = 0 \Rightarrow \Delta\dot{H} = \dot{Q}$

$\Downarrow\ \Delta\dot{H} = \dot{m}\Delta\hat{H}$

$$\dot{m} = \frac{\dot{Q}}{\Delta\hat{H}} = \frac{528\text{ kW}}{}\left|\frac{\text{kg}}{(2797.2-83.9)\text{kJ}}\right|\frac{1\text{ kJ/s}}{1\text{ kW}}\left|\frac{3600\text{ s}}{1\quad\text{h}}\right. = \underline{\underline{701\ \text{kg/h}}}$$

(b) $\dot{V} = (701\ \text{kg/h})(\underset{\uparrow\ \text{Table B.6}}{0.0995}\ \text{m}^3/\text{kg}) = \underline{\underline{69.7\ \text{m}^3/\text{h sat'd steam @ 20 bar}}}$

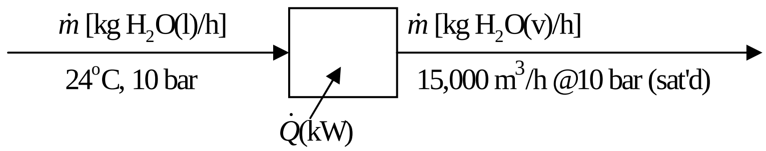
(c) $$\dot{V} = \frac{\dot{n}RT}{P} = \frac{701\text{ kg/h}}{18.02\text{ g/mol}}\left|\frac{10^3\text{ g/kg}}{20\text{ bar}}\right|\frac{485.4\text{ K}}{}\left|\frac{0.08314\text{ L}\cdot\text{bar}}{\text{mol}\cdot\text{K}}\right|\frac{1\text{ m}^3}{10^3\text{ L}} = \underline{\underline{78.5\ \text{m}^3/\text{h}}}$$

The calculation in (b) is more accurate because the steam tables account for the effect of pressure on specific enthalpy (nonideal gas behavior).

(d) Most energy released goes to raise the temperature of the combustion products, some is transferred to the boiler tubes and walls, and some is lost to the surroundings.

7.26 $\hat{H}(H_2O(l),\ 24^\circ C,\ 10\text{ bar}) = 100.6\ \text{kJ/kg}$ (Table B.5 for saturated liquid at 24°C; assume $\hat{H}$ independent of P).

$\hat{H}(10\text{ bar, sat'd steam}) = 2776.2\ \text{kJ/kg}$ (Table B.6) $\Rightarrow \Delta\hat{H} = 2776.2 - 100.6 = \underline{\underline{2675.6\ \text{kJ/kg}}}$



$$\dot{m} = \frac{15000\ \text{m}^3}{\text{h}} \left| \frac{\text{kg}}{\underset{\uparrow \text{(Table 8.6)}}{0.1943\ \text{m}^3}} \right. = 7.72\times 10^4\ \text{kg/h}$$

$\underline{\text{Energy balance}}\ (\Delta\dot{E}_p,\ \dot{W}_s = 0)$: $\Delta\dot{H} + \Delta\dot{E}_k = \dot{Q}$

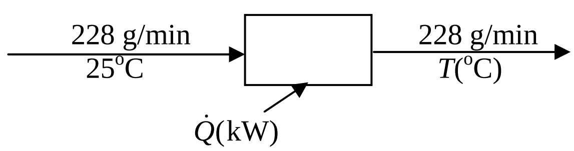
$$\Delta\dot{E}_k = \dot{E}_{k_{final}} - \dot{E}_{k_{initial}} \xRightarrow{\dot{E}_{k_{initial}}\approx 0} \Delta\dot{E}_k = \dot{E}_{k_{final}}$$

$$\Delta\dot{E}_k = \frac{\dot{m}u_f^{\ 2}}{2} = \frac{7.72\times10^4\ \text{kg}}{\text{h}} \left| \frac{(15{,}000\ \text{m}^3/\text{h})^2}{\underset{\uparrow\ A=\pi D^2/4}{[0.15^2\ \pi/4]^2\ \text{m}^2}} \right| \frac{1}{2} \left| \frac{1\quad \text{h}^3}{3600^3\ \text{s}^3} \right| \frac{1\ \text{J}}{1\ \text{kg}\cdot\text{m}^2/\text{s}^2} = 5.96\text{x}10^5\ \text{J/s}$$

$$\dot{Q} = \dot{m}\Delta\hat{H} + \Delta\dot{E}_k = \frac{7.72\times10^4\ \text{kg}}{\text{h}} \left| \frac{2675.6\ \text{kJ}}{\text{kg}} \right| \frac{1\ \text{h}}{3600\ \text{s}} + \frac{5.96\times10^5\ \text{J}}{\text{s}} \left| \frac{1\ \text{kJ}}{10^3\ \text{J}} \right.$$

$$= 57973\ \text{kJ/s} = \underline{\underline{5.80\times10^4\ \text{kW}}}$$

7.27 (a)



$\underset{\Delta\dot{E}_x,\ \Delta\dot{E}_p,\ \dot{W}_s=0}{\underline{\text{Energy balance:}}}$ $\dot{Q} = \Delta\dot{H} \Rightarrow \dot{Q}(\text{W}) = \frac{228\ \text{g}}{\text{min}} \left| \frac{1\ \text{min}}{60\ \text{s}} \right| \frac{(\hat{H}_{out} - \overset{=0}{\cancel{\hat{H}_{in}}})\ \text{J}}{\text{g}}$

$$\Rightarrow \hat{H}_{\text{out}}(\text{J/g}) = 0.263\dot{Q}(W)$$

$T(^\circ C)$	25	26.4	27.8	29.0	32.4
$\hat{H}(\text{J/g}) = 0.263\dot{Q}(W)$	0	4.47	9.28	13.4	24.8

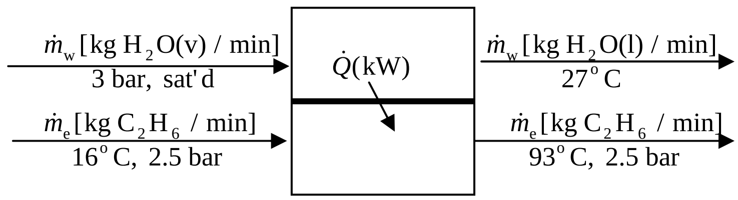
(b) $\hat{H} = b(T-25) \xrightarrow{\text{Fit to data by least squares (App. A.1)}} b = \sum_i \hat{H}_i\,(T_i - 25) \big/ \sum_i (T_i - 25)^2 = 3.34$

$$\Rightarrow \underline{\underline{\hat{H}(\text{J/g}) = 3.34[T(^\circ C) - 25]}}$$

(c) $\dot{Q} = \Delta\dot{H} = \frac{350\ \text{kg}}{\text{min}} \left| \frac{10^3\text{g}}{\text{kg}} \right| \frac{1\ \text{min}}{60\ \text{s}} \left| \frac{3.34(40-20)\text{J}}{\text{g}} \right| \frac{\text{kW}\cdot\text{s}}{10^3\ \text{J}} = \underline{\underline{390\ \text{kW}}}$ heat input to liquid

(d) Heat is absorbed by the pipe, lost through the insulation, lost in the electrical leads.

7.28



(a) $\underline{C_2H_6 \text{ mass flow:}}$ $\dot{m}_e = \dfrac{795\ \text{m}^3}{\text{min}}\left|\dfrac{10^3\ \text{L}}{\text{m}^3}\right|\dfrac{2.50\ \text{bar}}{289\ \text{K}}\left|\dfrac{1\quad \text{K-mol}}{0.08314\ \text{L-bar}}\right|\dfrac{30.01\ \text{g}}{\text{mol}}\left|\dfrac{1\ \text{kg}}{1000\ \text{g}}\right.$

$= 2.487 \times 10^3\ \text{kg/min}$

$\hat{H}_{ei} = 941\ \text{kJ/kg}, \hat{H}_{ef} = 1073\ \text{kJ/kg}$

$\underline{\text{Energy Balance on } C_2H_6:}\ \Delta\dot{E}_p,\ \dot{W}_s = 0,\ \Delta\dot{E}_k \cong 0 \Rightarrow \dot{Q} = \Delta\dot{H}$

$$\dot{Q} = 2.487 \times 10^3 \frac{\text{kg}}{\text{min}}\left[(1073 - 941)\frac{\text{kJ}}{\text{kg}}\right] = \frac{2.487 \times 10^3\ \text{kJ}}{\text{min}}\left|\frac{1\ \text{min}}{60\ \text{s}}\right. = \underline{\underline{5.47 \times 10^3\ \text{kW}}}$$

(b) $\hat{H}_{s_1}(3.00\ \text{bar, sat'd vapor}) = 2724.7\ \text{kJ/kg}$ (Table B.6)

$\hat{H}_{s_2}(\text{liquid, } 27°\text{C}) = 113.1\ \text{kJ/kg}$ (Table B.5)

Assume that heat losses to the surroundings are negligible, so that the heat given up by the condensing steam equals the heat transferred to the ethane $(5.47 \times 10^3\ \text{kW})$

$\underline{\text{Energy balance on } H_2O:}\ \dot{Q} = \Delta\dot{H} = \dot{m}(\hat{H}_{s_2} - \hat{H}_{s_1})$

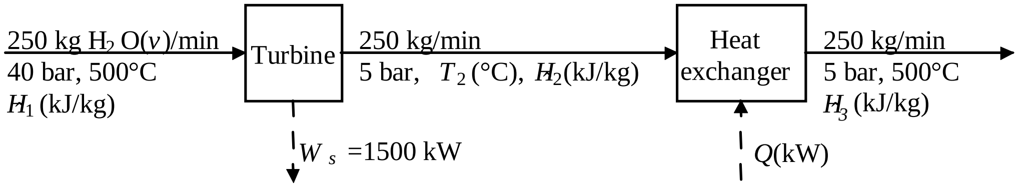
$$\Rightarrow \dot{m} = \frac{\dot{Q}}{\hat{H}_{s_2} - \hat{H}_{s_1}} = \frac{-5.47 \times 10^3\ \text{kJ}}{\text{s}}\left|\frac{\text{kg}}{(113.1 - 2724.7)\text{kJ}}\right| = 2.09\ \text{kg/s steam}$$

$$\Rightarrow \dot{V}_s = (2.09\ \text{kg/s})(\underset{\substack{\uparrow \\ \text{Table B.6}}}{0.606\ \text{m}^3/\text{kg}}) = \underline{\underline{1.27\ \text{m}^3/\text{s}}}$$

Too low. Extra flow would make up for the heat losses to surroundings.

(c) $\underline{\underline{\text{Countercurrent flow}}}$ Cocurrent (as depicted on the flowchart) would not work, since it would require heat flow from the ethane to the steam over some portion of the exchanger. (Observe the two outlet temperatures)

7.29



$H_2O(v,\ 40\text{ bar},\ 500°\text{C})$: $\hat{H}_1 = 3445\ \text{kJ/kg}$ (Table B.7)

$H_2O(v,\ 5\text{ bar},\ 500°\text{C})$: $\hat{H}_3 = 3484\ \text{kJ/kg}$ (Table B.7)

(a) Energy balance on turbine: $\Delta\dot{E}_p = 0,\ \dot{Q} = 0,\ \Delta\dot{E}_k \cong 0$

$$\Delta\dot{H} = -\dot{W}_s \Rightarrow \dot{m}\left(\hat{H}_2 - \hat{H}_1\right) = -\dot{W}_s \Rightarrow \hat{H}_2 = \hat{H}_1 - \dot{W}_s/\dot{m}$$

$$= \frac{3445\text{ kJ}}{\text{kg}} - \frac{1500\text{ kJ}}{\text{s}}\left|\frac{\text{min}}{250\text{ kg}}\right|\frac{60\text{ s}}{1\text{ min}} = 3085\ \text{kJ/kg}$$

$\hat{H} = 3085\ \text{kJ/kg}$ and $P = 5$ bars $\Rightarrow \underline{\underline{T = 310°\text{C}}}$ (Table B.7)

(b) Energy balance on heat exchanger: $\Delta\dot{E}_p = 0,\ \dot{W}_s = 0,\ \Delta\dot{E}_k \cong 0$

$$\dot{Q} = \Delta\dot{H} = \dot{m}\left(\hat{H}_3 - \hat{H}_2\right) = \frac{250\text{ kg}}{\text{min}}\left|\frac{(3484-3085)\text{kJ}}{\text{kg}}\right|\frac{1\text{ min}}{60\text{ s}}\left|\frac{1\text{ kW}}{1\text{ kJ/s}}\right. = \underline{\underline{1663\text{ kW}}}$$

(c) Overall energy balance: $\Delta\dot{E}_p = 0, \Delta\dot{E}_k \cong 0$

$$\Delta\dot{H} = \dot{Q} - \dot{W}_s \Rightarrow \dot{m}_s\left(\hat{H}_3 - \hat{H}_1\right) = \dot{Q} - \dot{W}_s$$

$$\dot{Q} = \Delta\dot{H} + \Delta\dot{W}_s = \frac{250\text{ kg}}{\text{min}}\left|\frac{(3484-3445)\text{kJ}}{\text{kg}}\right|\frac{1\text{ min}}{60\text{ s}}\left|\frac{1\text{ kW}}{1\text{ kJ/s}}\right. + \frac{1500\text{ kJ}}{\text{s}}\left|\frac{1\text{ kW}}{1\text{ kJ/s}}\right.$$

$$= \underline{\underline{1663\text{ kW}}}\ \surd$$

(d) $H_2O(v,\ 40\text{ bar},\ 500°\text{C})$: $\hat{V}_1 = 0.0864\ \text{m}^3/\text{kg}$ (Table B.7)

$H_2O(v,\ 5\text{ bar},\ 310°\text{C})$: $\hat{V}_2 = 0.5318\ \text{m}^3/\text{kg}$ (Table B.7)

$$u_1 = \frac{250\text{ kg}}{\text{min}}\left|\frac{1\text{ min}}{60\text{ s}}\right|\frac{0.0864\text{ m}^3}{\text{kg}}\left|\frac{1}{0.5^2\ \pi/4\ \text{m}^2}\right. = 1.83\ \text{m/s}$$

$$u_2 = \frac{250\text{ kg}}{\text{min}}\left|\frac{\text{min}}{60\text{ s}}\right|\frac{0.5318\text{ m}^3}{\text{kg}}\left|\frac{1}{0.5^2\ \pi/4\ \text{m}^2}\right. = 11.3\ \text{m/s}$$

$$\Delta\dot{E}_k = \frac{\dot{m}}{2}\left[u_2^2 - u_1^2\right] = \frac{250\text{ kg}}{\text{min}}\left|\frac{1}{2}\right|\frac{1\text{ min}}{60\text{ s}}\left|\frac{\left[(11.3)^2 - (1.83)^2\right]\text{m}^2}{\text{s}^2}\right|\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\left|\frac{1\text{ kW}\cdot\text{s}}{10^3\text{ N}\cdot\text{m}}\right.$$

$$= 0.26\text{ kW} << 1500\text{ kW}$$

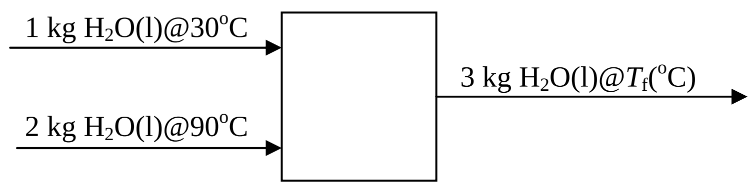
7.30 **(a)** $\Delta\dot{E}_p,\ \Delta\dot{E}_k,\ \dot{W}_s = 0 \Rightarrow \dot{Q} = \Delta\dot{H} \Rightarrow -hA(T_s - T_o) = -300\ \text{kJ/h} \Rightarrow \underline{\underline{1.8h\ (T_s - T_o) = 300\ \dfrac{\text{kJ}}{\text{h}}}}$

(b) Clothed: $\underset{T_s = 34.2}{h = 8} \Rightarrow \underline{\underline{T_o = 13.4°\text{C}}}$

Nude, immersed: $\underset{T_s = 34.2}{h = 64} \Rightarrow \underline{\underline{T_o = 31.6°\text{C}}}$ (Assuming T_s remains 34.2°C)

(c) *The wind raises the effective heat transfer coefficient*. (Stagnant air acts as a thermal insulator —i.e., in the absence of wind, h is low.) For a given T_o, the skin temperature must drop to satisfy the energy balance equation: when T_s drops, you feel cold.

7.31 Basis: 1 kg of 30°C stream



(a) $T_f = \dfrac{1}{3}(30°\text{C}) + \dfrac{2}{3}(90°\text{C}) = \underline{\underline{70°\text{C}}}$

(b) Internal Energy of feeds: $\left.\begin{array}{l}\hat{U}(30°\text{C, liq.}) = 125.7\ \text{kJ/kg}\\ \hat{U}(90°\text{C, liq.}) = 376.9\ \text{kJ/kg}\end{array}\right\}$

(Table B.5 - neglecting effect of P on $\hat{H}$)

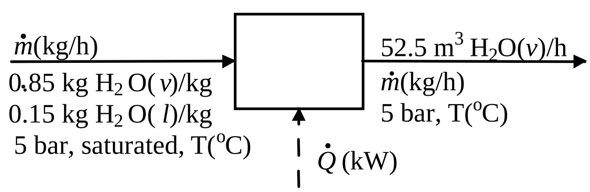
Energy Balance: $Q - W = \Delta U + \Delta E_p + \Delta E_k \xrightarrow{Q=W=\Delta E_p=\Delta E_k=0} \Delta U = 0$

$\Rightarrow 3\hat{U}_f - (1\ \text{kg})(125.7\ \text{kJ/kg}) - (2\ \text{kg})(376.9\ \text{kJ/kg}) = 0$

$\Rightarrow \underline{\underline{\hat{U}_f = 293.2\ \text{kJ/kg}}} \Rightarrow \underline{\underline{T_f = 70.05°\text{C}}}$ (Table B.5)

$\text{Diff.} = \dfrac{70.05 - 70.00}{70.05} \times 100\% = \underline{\underline{0.07\%}}$ (Any answer of this magnitude is acceptable).

7.32



(a) Table B.6 $\xRightarrow{P=5\text{ bars}}$ $\underline{\underline{T = 151.8°\text{C}}}$, $\underline{\underline{\hat{H}_L = 640.1\ \text{kJ/kg},\ \hat{H}_V = 2747.5\ \text{kJ/kg}}}$

$\hat{V}(5\ \text{bar, sat'd}) = 0.375\ \text{m}^3/\text{kg} \Rightarrow \dot{m} = \dfrac{52.5\ \text{m}^3}{\text{h}}\left|\dfrac{1\ \text{kg}}{0.375\ \text{m}^3}\right. = \underline{\underline{140\ \text{kg/h}}}$

(b) $\underline{H_2O\text{ evaporated}} = (0.15)(140\ \text{kg/h}) = 21\ \text{kg/h}$

Energy balance: $\dot{Q} = \Delta\dot{H} = \dfrac{21\ \text{kg}}{\text{h}}\left|\dfrac{(2747.5 - 640.1)\text{kJ}}{\text{kg}}\right|\dfrac{1\ \text{h}}{3600\ \text{s}}\left|\dfrac{1\ \text{kW}}{1\ \text{kJ/s}}\right. = \underline{\underline{12\ \text{kW}}}$

7.33 **(a)** $P = 5\text{ bar} \xrightarrow{\text{Table B.6}} \underline{\underline{T_{\text{saturation}} = 151.8^o\text{C}}}$. At 75°C the discharge is all liquid

(b) Inlet: T=350°C, P=40 bar $\xrightarrow{\text{Table B.7}} \hat{H}_{\text{in}} = 3095\text{ kJ / kg}$, $\hat{V}_{\text{in}} = 0.0665\text{ m}^3\text{ / kg}$

Outlet: T=75°C, P=5 bar $\xrightarrow{\text{Table B.7}} \hat{H}_{\text{out}} = 314.3\text{ kJ / kg}$, $\hat{V}_{\text{out}} = 1.03 \times 10^{-3}\text{ m}^3\text{ / kg}$

$$u_{\text{in}} = \frac{\dot{V}_{\text{in}}}{A_{\text{in}}} = \frac{200\text{ kg}}{\text{min}}\left|\frac{1\text{ min}}{60\text{ s}}\right|\frac{0.0665\text{ m}^3\text{ / kg}}{\left[\pi(0.075)^2\text{ / }4\right]\text{m}^2} = 50.18\text{ m / s}$$

$$u_{\text{out}} = \frac{\dot{V}_{\text{out}}}{A_{\text{out}}} = \frac{200\text{ kg}}{\text{min}}\left|\frac{1\text{ min}}{60\text{ s}}\right|\frac{0.00103\text{ m}^3\text{ / kg}}{\left[\pi(0.05)^2\text{ / }4\right]\text{m}^2} = 1.75\text{ m / s}$$

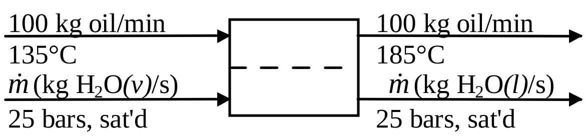
Energy balance: $\dot{Q} - \dot{W}_s \approx \Delta\dot{H} + \Delta\dot{E}_k = \dot{m}(\hat{H}_2 - \hat{H}_1) + \frac{\dot{m}}{2}(u_2^2 - u_1^2)$

$$\dot{Q} - \dot{W}_s = \frac{200\text{ kg}}{\text{min}}\left|\frac{1\text{ min}}{60\text{ s}}\right|\frac{(314\text{-}3095)\text{ kJ}}{\text{kg}} + \frac{200\text{ kg}}{2\text{ min}}\left|\frac{1\text{ min}}{60\text{ s}}\right|\frac{(1.75^2\text{-}50.18^2)\text{ m}^2}{\text{s}^2}$$

$= \underline{\underline{-13,460\text{ kW}}}$ ($\Rightarrow$ 13,460 kW transferred from the turbine)

7.34 **(a)** Assume all heat from stream transferred to oil

$$\dot{Q} = \frac{1.00 \times 10^4\text{ kJ}}{\text{min}}\left|\frac{1\text{ min}}{60\text{ s}}\right. = 167\text{ kJ/s}$$



Energy balance on H_2O: $\dot{Q} = \Delta\dot{H} = \dot{m}\left(\hat{H}_{\text{out}} - \hat{H}_{\text{in}}\right)$

$\Delta\dot{E}_p,\ \Delta\dot{E}_k,\ \dot{W}_s = 0$

$\hat{H}(l,\ 25\text{ bar, sat'd}) = 962.0\text{ kJ/kg}$, $\hat{H}(v,\ 25\text{ bar, sat'd}) = 2800.9\text{ kJ/kg}$ (Table B.6)

$$\dot{m} = \frac{\dot{Q}}{\hat{H}_{\text{out}} - \hat{H}_{\text{in}}} = \frac{-167\text{ kJ}}{\text{s}}\left|\frac{\text{kg}}{(962.0 - 2800.9)\text{kJ}}\right. = 0.091\text{ kg/s}$$

Time between discharges: $\frac{1200\text{ g}}{\text{discharge}}\left|\frac{1\text{ s}}{0.091\text{ kg}}\right|\frac{1\text{ kg}}{10^3\text{ g}} = \underline{\underline{13\text{ s/discharge}}}$

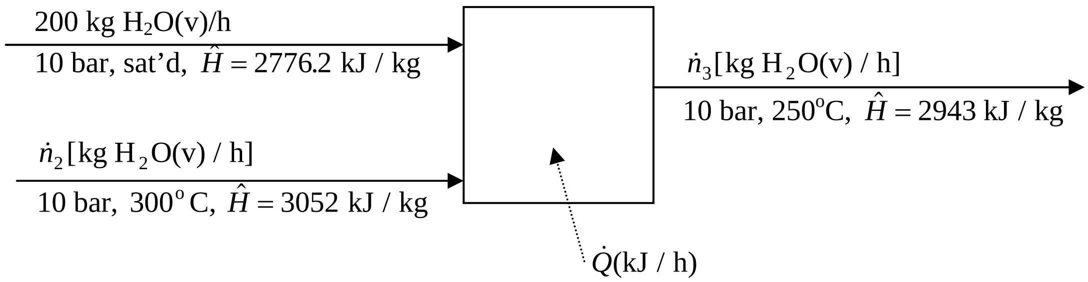
(b) Unit Cost of Steam: $\frac{\$1}{10^6\text{ Btu}}\left|\frac{(2800.9 - 83.9)\text{ kJ}}{\text{kg}}\right|\frac{0.9486\text{ Btu}}{\text{kJ}} = \$2.6 \times 10^{-3}\text{ / kg}$

Yearly cost:

$$\frac{1000\text{ traps}}{}\left|\frac{0.091\text{ kg stream}}{\text{trap}\cdot\text{s}}\right|\frac{0.10\text{ kg last}}{\text{kg stream}}\left|\frac{2.6 \times 10^{-3}\$}{\text{kg lost}}\right|\frac{3600\text{ s}}{\text{h}}\left|\frac{24\text{ h}}{\text{day}}\right|\frac{360\text{ day}}{\text{year}}$$

$= \underline{\underline{\$7.4 \times 10^5\text{ / year}}}$

7.35 Basis: Given feed rate



$\hat{H}$ from Table B.6 (saturated steam) or Table B.7 (superheated steam)

Mass balance: $200 + \dot{n}_2 = \dot{n}_3$ (1)

$\underset{\Delta\dot{E}_K,\ \Delta\dot{E}_p,\ \dot{W}=0}{\text{Energy balance:}}$ $\dot{Q} = \Delta\dot{H} = \dot{n}_3\,(2943) - 200(2776.2) - \dot{n}_2\,(3052),\ \dot{Q}$ in kJ/h (2)

(a) $\dot{n}_3 = 300$ kg/h $\xrightarrow{(1)}$ $\dot{n}_2 = 100$ kg/h $\xrightarrow{(2)}$ $\dot{Q} = \underline{\underline{2.25\times10^4\ \text{kJ/h}}}$

(b) $\dot{Q} = 0$ $\xrightarrow{(1),(2)}$ $\dot{n}_2 = \underline{\underline{306\ \text{kg/h}}}$, $\dot{n}_3 = \underline{\underline{506\ \text{kg/h}}}$

7.36 **(a)** $T_{saturation}$ @ 1.0 bar = 99.6 °C $\Rightarrow T_f = \underline{\underline{99.6^\circ\text{C}}}$

H_2O (1.0 bar, sat'd) $\Rightarrow \hat{H}_l = 417.5$ kJ / kg, $\hat{H}_v = 2675.4$ kJ / kg

H_2O (60 bar, 250°C) = 1085.8 kJ / kg

Mass balance: $m_v + m_l = 100$ kg (1)

$\underset{\Delta\dot{E}_K,\ \dot{Q},\ \Delta\dot{E}_p,\ \dot{W}=0}{\text{Energy balance:}}$ $\Delta\dot{H} = 0$

$$\Rightarrow m_v\hat{H}_v + m_l\hat{H}_l - m_1\hat{H}_1 = m_v\hat{H}_v + m_l\hat{H}_l - (100\text{ kg})(1085.8\text{ kJ / kg}) = 0 \quad (2)$$

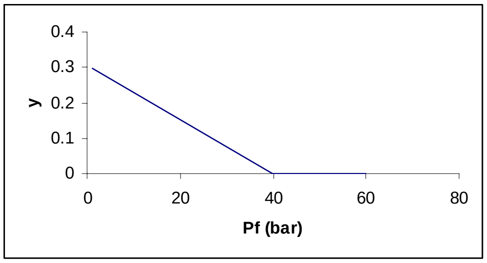
$$\xrightarrow{(1,2)} m_l = 70.4\text{ kg},\ m_v = 29.6\text{ kg} \Rightarrow y_v = \frac{29.6\text{ kg vapor}}{100\text{ kg}} = \underline{\underline{0.296\frac{\text{kg vapor}}{\text{kg}}}}$$

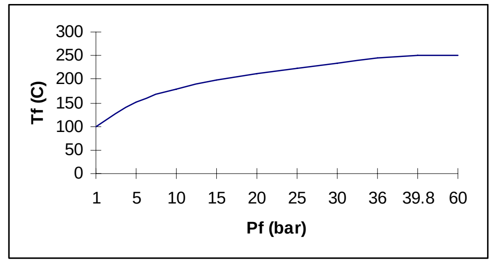
(b) $\underline{\underline{T \text{ is unchanged.}}}$ The temperature will still be the saturation temperature at the given final pressure. The system undergoes expansion, so assuming the same pipe diameter, $\Delta\dot{E}_k > 0$. $\underline{\underline{y_v \text{ would be less (less water evaporates)}}}$ because some of the energy that would have vaporized water instead is converted to kinetic energy.

(c) $P_f = \underline{\underline{39.8\text{ bar}}}$ (pressure at which the water is still liquid, but has the same enthalpy as the feed)

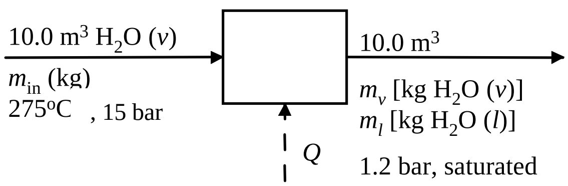
(d) Since enthalpy does not change, then when $P_f \geq 39.8$ bar the temperature cannot increase, because a higher temperature would increase the enthalpy. Also, when $P_f \geq 39.8$ bar, the product is only liquid $\Rightarrow$ no evaporation occurs.

7.36 (cont'd)





7.37 $\boxed{10\ \text{m}^3\text{, n moles of steam}(v)\text{, }275°\text{C, 15 bar} \Rightarrow 10\ \text{m}^3\text{, n moles of water }(v+l)\text{, 1.2 bar}}$



(a) P=1.2 bar, saturated, $\xrightarrow{\text{Table B.6}}$ $T_2 = \underline{\underline{104.8^\circ\text{C}}}$

(b) Total mass of water: $m_{\text{in}} = \dfrac{10\ \text{m}^3}{} \left| \dfrac{1\ \text{kg}}{0.1818\ \text{m}^3} \right. = 55\ \text{kg}$

Mass Balance: $m_v + m_l = 55.0$

Volume additivity: $V_v + V_l = 10.0\ \text{m}^3 = m_v(1.428\ \text{m}^3/\text{kg}) + m_l(0.001048\ \text{m}^3/\text{kg})$

$$\Rightarrow m_v = 7.0\ \text{kg},\ m_l = \underline{\underline{48.0\ \text{kg condensed}}}$$

(c) Table B.7 $\Rightarrow \hat{U}_{\text{in}} = 2739.2\ \text{kJ/kg};\quad \hat{V}_{\text{in}} = 0.1818\ \text{m}^3/\text{kg}$

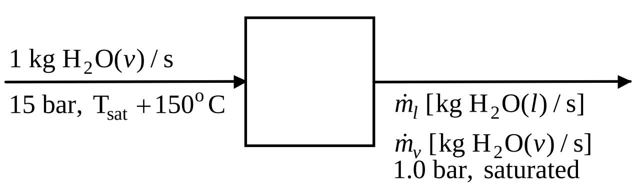
$$\text{Table B.6} \Rightarrow \begin{cases} \hat{U}_l = 439.2\ \text{kJ/kg}; & \hat{V}_l = 0.001048\ \text{m}^3/\text{kg} \\ \hat{U}_v = 2512.1\ \text{kJ/kg}; & \hat{V}_v = 1.428\ \text{m}^3/\text{kg} \end{cases}$$

$\underset{\Delta E_p, \Delta E_k\ ,\ W=0}{\underline{\text{Energy balance:}}}$ $Q = \Delta U = m_v\hat{U}_v + m_l\hat{U}_l - m_{\text{in}}\hat{U}_{\text{in}}$

$$= [(7.0)(2512.1\ \text{kJ/kg}) + (48.0)(439.2) - 55\ \text{kg}\ (2739.2)]\ \text{kJ}$$

$$= \underline{\underline{-1.12 \times 10^5\ \text{kJ}}}$$

7.38 **(a)** Assume both liquid and vapor are present in the valve effluent.



(b) Table B.6 $\Rightarrow \text{T}_{\text{sat'n}}(15\ \text{bar}) = 198.3^\circ\text{C} \Rightarrow \text{T}_{\text{in}} = 348.3^\circ\text{C}$

Table B.7 $\Rightarrow \hat{H}_{\text{in}} = \hat{H}(348.3^\circ\text{C, 15 bar}) \approx 3149\ \text{kJ/kg}$

Table B.6 $\Rightarrow \hat{H}_l(1.0\ \text{bar, sat'd}) = 417.5\ \text{kJ/kg};\quad \hat{H}_v(1.0\ \text{bar, sat'd}) = 2675.4\ \text{kJ/kg}$

7.38 (cont'd)

$$\underset{\Delta\dot{E}_p,\Delta\dot{E}_k,\dot{Q},\dot{W}_s=0}{\underline{\text{Energy balance:}}}\quad \Delta\dot{H}=0 \Rightarrow \dot{m}_l\hat{H}_l+\dot{m}_v\hat{H}_v-\dot{m}_{\text{in}}\hat{H}_{\text{in}}=0$$

$$\Rightarrow \dot{m}_{\text{in}}\hat{H}_{\text{in}}=\dot{m}_l\hat{H}_l+\dot{m}_v\hat{H}_v \xrightarrow{\dot{m}_v+\dot{m}_l} \underline{\underline{3149\text{ kJ / kg}}}=\dot{m}_l(417.5)+(1-\dot{m}_l)(2675.4)$$

There is no value of $\dot{m}_l$ between 0 and 1 that would satisfy this equation. (For any value in this range, the right-hand side would be between 417.5 and 2675.4). The two-phase assumption is therefore incorrect; the effluent must be pure vapor.

(c) Energy balance $\Rightarrow \dot{m}_{\text{out}}\hat{H}_{\text{out}}=\dot{m}_{\text{in}}\hat{H}_{\text{in}} \xrightarrow{\dot{m}_{\text{in}}=\dot{m}_{\text{out}}=1} 3149\text{ kJ / kg}=\hat{H}(1\text{ bar, }T_{\text{out}})$

$$\xrightarrow{\text{Table B.7}} T_{\text{out}}\approx \underline{\underline{337^\circ\text{C}}}$$

(This answer is only approximate, since $\Delta\dot{E}_k$ is not zero in this process).

7.39 Basis: $\underline{40\text{ lb}_\text{m}/\text{min circulation}}$

(a) Expansion valve

R = Refrigerant 12

Inlet: 40 lb$_\text{m}$ R(l)/min, 93.3 psig, 86°F, $\hat{H}$ = 27.8 Btu/lb$_\text{m}$

Outlet: 40 lb$_\text{m}$ / min, x_v lb$_\text{m}$ R (v) / lb$_\text{m}$, (1 − x_v) lb$_\text{m}$ R(l) / lb$_\text{m}$

$\hat{H}_v$ = 77.8 Btu / lb$_\text{m}$, $\hat{H}_l$ = 9.6 Btu / lb$_\text{m}$

$\underline{\text{Energy balance:}}$ $\Delta\dot{E}_p,\ \dot{W}_s,\ \dot{Q}=0,$ neglect $\Delta\dot{E}_k \Rightarrow \Delta\dot{H}=\sum_{\text{out}}\dot{n}_i\hat{H}_i-\sum_{\text{in}}\dot{n}_i\hat{H}_i=0$

$$\frac{40X_v\text{ lb}_\text{m}R(v)}{\text{min}}\left|\frac{77.8\text{ Btu}}{\text{lb}_\text{m}}\right.+\frac{40(1-X_v)\text{lb}_\text{m}R(l)}{\text{min}}\left|\frac{9.6\text{ Btu}}{\text{lb}_\text{m}}\right.-\frac{40\text{ lb}_\text{m}}{\text{min}}\left|\frac{27.8\text{ Btu}}{\text{lb}_\text{m}}\right.=0$$

$$\Downarrow$$

$$X_v=\underline{\underline{0.267}}\ (26.7\%\text{ evaporates})$$

(b) $\underline{\text{Evaporator coil}}$

Inlet: 40 lb$_\text{m}$ /min, 0.267 R(v), 0.733 R(l), 11.8 psig, 5°F

$\hat{H}_v$ = 77.8 Btu/lb$_\text{m}$, $\hat{H}_l$ = 9.6 Btu/lb$_\text{m}$

Outlet: 40 lb$_\text{m}$ R(v)/min, 11.8 psig, 5°F, $\hat{H}$ = 77.8 Btu/lb$_\text{m}$

$\underline{\text{Energy balance:}}$ $\Delta\dot{E}_p,\ \dot{W}_s=0,$ neglect $\Delta\dot{E}_k \Rightarrow \dot{Q}=\Delta\dot{H}$

$$\dot{Q}=\frac{40\text{ lb}_\text{m}}{\text{min}}\left|\frac{77.8\text{ Btu}}{\text{lb}_\text{m}}\right.-\frac{(40)(0.267)\text{lb}_\text{m}R(v)}{\text{min}}\left|\frac{77.8\text{ Btu}}{\text{lb}_\text{m}}\right.-\frac{(40)(0.733)\text{lb}_\text{m}R(l)}{\text{min}}\left|\frac{9.6\text{ Btu}}{\text{lb}_\text{m}}\right.$$

$$=\underline{\underline{2000\text{ Btu/min}}}$$

7.39 (cont'd)

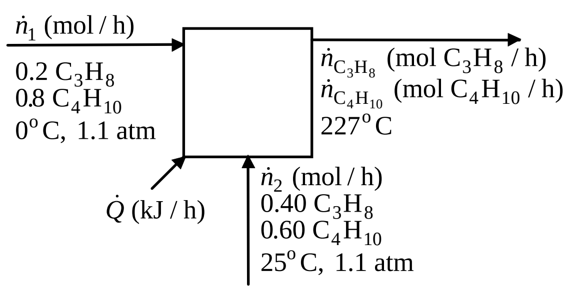
(c) We may analyze the overall process in several ways, each of which leads to the same result. Let us first note that the net rate of heat input to the system is

$$\dot{Q} = \dot{Q}_{\text{evaporator}} - \dot{Q}_{\text{condenser}} = 2000 - 2500 = -500 \text{ Btu/min}$$

and the compressor work W_c represents the total work done on the system. The system is closed (no mass flow in or out). Consider a time interval $\Delta t(\text{min})$. Since the system is at steady state, the changes ΔU, ΔE_k and ΔE_p over this time interval all equal zero. The total heat input is $\dot{Q}\Delta t$, the work input is $\dot{W}_c\Delta t$, and (Eq. 8.3-4) yields

$$\dot{Q}\Delta t - \dot{W}_c\Delta t = 0 \Rightarrow \dot{W}_c = \dot{Q} = \frac{-500 \text{ Btu}}{\text{min}}\left|\frac{1 \text{ min}}{60 \text{ s}}\right|\frac{1.341\times10^{-3}\text{ hp}}{9.486\times10^{-4} \text{ Btu/s}} = \underline{\underline{11.8 \text{ hp}}}$$

7.40 Basis: Given feed rates



Molar flow rates of feed streams:

$$\dot{n}_1 = \frac{300 \text{ L}}{\text{hr}}\left|\frac{1.1 \text{ atm}}{1 \text{ atm}}\right|\frac{1 \text{ mol}}{22.4 \text{ L(STP)}} = 14.7 \text{ mol/h}$$

$$\dot{n}_2 = \frac{200 \text{ L}}{\text{hr}}\left|\frac{273 \text{ K}}{298 \text{ K}}\right|\frac{1.1 \text{ atm}}{1 \text{ atm}}\left|\frac{1 \text{ mol}}{22.4 \text{ L(STP)}}\right. = 9.00 \text{ mol/h}$$

Propane balance $\Rightarrow$ $\dot{n}_{C_3H_8} = \frac{14.7 \text{ mol}}{\text{h}}\left|\frac{0.20 \text{ mol } C_3H_8}{\text{mol}}\right. + \frac{9.00 \text{ mol}}{\text{h}}\left|\frac{0.40 \text{ mol } C_3H_8}{\text{mol}}\right.$

$= 6.54 \text{ mol } C_3H_8/\text{h}$

Total mole balance: $\dot{n}_{C_4H_{10}} = (14.7 + 9.00 - 6.54) \text{ mol } C_4H_{20}/\text{h} = 17.16 \text{ mol } C_4H_{20}/\text{h}$

Energy balance: $\Delta\dot{E}_p,\ \dot{W}_s = 0,$ neglect $\Delta\dot{E}_k \Rightarrow \dot{Q} = \Delta\dot{H}$

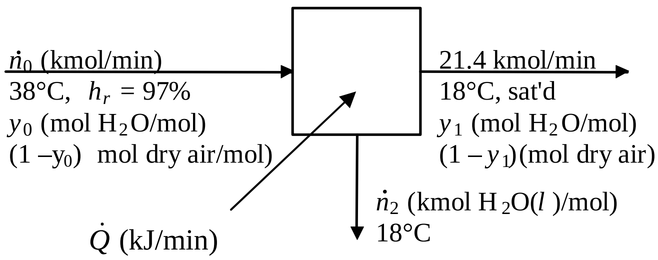
$$\dot{Q} = \Delta\dot{H} = \sum_{\text{out}} \dot{N}_i\hat{H}_i - \sum_{\text{in}} \dot{N}_i\hat{H}_i = \frac{6.54 \text{ mol } C_3H_8}{\text{h}}\left|\frac{20.685 \text{ kJ}}{\text{mol}}\right. + \frac{17.16 \text{ mol } C_4H_{10}}{\text{h}}\left|\frac{27.442 \text{ kJ}}{\text{mol}}\right.$$

$$-\frac{(0.40\times9.00) \text{ mol } C_3H_8}{\text{h}}\left|\frac{1.772 \text{ kJ}}{\text{mol}}\right. - \frac{(0.60\times9.00) \text{ mol } C_4H_{10}}{\text{h}}\left|\frac{2.394 \text{ kJ}}{\text{mol}}\right. = \underline{\underline{587 \text{ kJ/h}}}$$

($\hat{H}_i = 0$ for components of 1st feed stream)

7.41 Basis: $\dfrac{510 \text{ m}^3}{\text{min}} \left| \dfrac{273 \text{ K}}{291 \text{ K}} \right| \dfrac{10^3 \text{ L}}{\text{m}^3} \left| \dfrac{1 \text{ mol}}{22.4 \text{ L(STP)}} \right| \dfrac{1 \text{ kmol}}{10^3 \text{ mol}} = 21.4 \text{ kmol/min}$

(a)



Inlet condition: $y_o = \dfrac{h_r P^*_{H_2O}(38°\text{C})}{P} = \dfrac{0.97(49.692 \text{ mm Hg})}{760 \text{ mm Hg}} = 0.0634 \text{ mol } H_2O/\text{mol}$

Outlet condition: $y_1 = \dfrac{P^*_{H_2O}(18°\text{C})}{P} = \dfrac{15.477 \text{ mm Hg}}{760 \text{ mm Hg}} = 0.0204 \text{ mol } H_2O/\text{mol}$

Dry air balance: $(1-0.0634)\dot{n}_o = (1-0.0204)21.4 \Rightarrow \dot{n}_o = 22.4 \text{ kmol/min}$

Water balance: $(0.0634)22.4 = \dot{n}_2 + (0.0204)21.4 \Rightarrow \dot{n}_2 = 0.98 \text{ kmol/min}$

$$\frac{0.98 \text{ kmol}}{\text{min}} \left| \frac{18.02 \text{ kg}}{\text{kmol}} \right. = \underline{\underline{18 \text{ kg / min } H_2O \text{ condenses}}}$$

(b). Enthaphies: $\hat{H}_{\text{air}}(38°\text{C}) = 0.0291(38-25) = 0.3783 \text{ kJ/mol}$

$\hat{H}_{\text{air}}(18°\text{C}) = 0.0291(18-25) = -0.204 \text{ kJ/mol}$

$$\left.\begin{aligned}
\hat{H}_{H_2O}(v,\ 38°\text{C}) &= \frac{2570.8 \text{ kJ}}{\text{kg}} \left| \frac{1 \text{ kg}}{10^3 \text{ g}} \right| \frac{18.02 \text{ g}}{\text{mol}} = 46.33 \text{ kJ/mol} \\
\hat{H}_{H_2O}(v,\ 18°\text{C}) &= \frac{2534.5 \text{ kJ}}{\text{kg}} \left| \frac{1 \text{ kg}}{10^3 \text{ g}} \right| \frac{18.02 \text{ g}}{\text{mol}} = 45.67 \text{ kJ/mol} \\
\hat{H}_{H_2O}(l,\ 18°\text{C}) &= \frac{75.5 \text{ kJ}}{\text{kg}} \left| \frac{1 \text{ kg}}{10^3 \text{ g}} \right| \frac{18.02 \text{ g}}{\text{mol}} = 1.36 \text{ kJ/mol}
\end{aligned}\right\} \text{Table B.5}$$

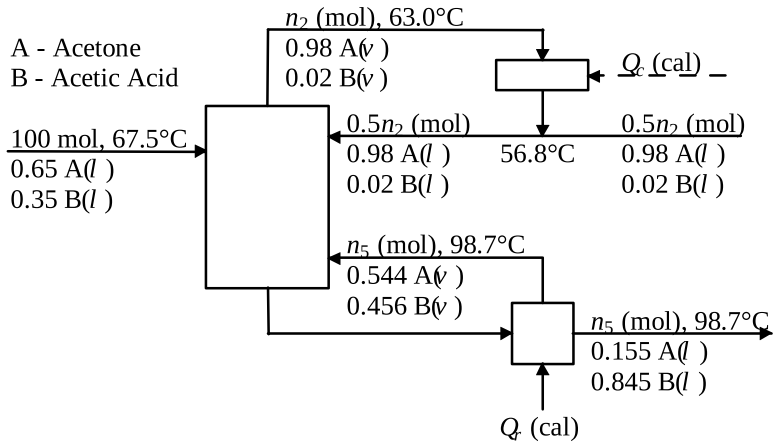
Energy balance:

$\Delta\dot{E}_p, \dot{W}_s = 0, \Delta\dot{E}_k \cong 0$

$$\dot{Q} = \Delta\dot{H} = \sum_{\text{out}} \dot{n}_i \hat{H}_i - \sum_{\text{in}} \dot{n}_i \hat{H}_i \Rightarrow \dot{Q} = (1-0.0204)(21.4\times10^3)(-0.204)$$
$$+(0.0204)(21.4\times10^3)(45.67) + (0.98\times10^3)(1.36) - (1-0.0634)(22.4\times10^3)(0.3783)$$
$$-(0.0634)(22.4\times10^3)(46.33) = -5.67\times10^4 \text{ kJ/min}$$

$$\Rightarrow \frac{5.67\times10^4 \text{ kJ}}{\text{min}} \left| \frac{60 \text{ min}}{\text{h}} \right| \frac{0.9486 \text{ Btu}}{\text{kJ}} \left| \frac{1 \text{ ton cooling}}{12000 \text{ Btu}} \right. = \underline{\underline{270 \text{ tons of cooling}}}$$

7.42 Basis: 100 mol feed



(a) Overall balances:

$$\left.\begin{array}{l}\text{Total moles: } 100 = 0.5n_2 + n_5 \\ A\text{: } 0.65(100) = 0.98(0.5n_2) + 0.155n_5\end{array}\right\} \begin{array}{l} n_2 = 120 \text{ mol} \\ n_5 = 40 \text{ mol}\end{array}$$

Product flow rates: Overhead $0.5(120)0.98 = 58.8 \text{ mol } A$

$0.5(120)0.02 = 1.2 \text{ mol } B$

Bottoms $0.155(40) = 6.2 \text{ mol } A$

$0.845(40) = 33.8 \text{ mol } B$

$$\underbrace{\text{Overall energy balance:}}_{\Delta E_p,\, W_s = 0,\, \Delta E_k \cong 0} \quad Q = \Delta H = \sum_{\text{out}} n_i \hat{H}_i - \sum_{\text{in}} n_i \hat{H}_i$$

$$\Rightarrow Q = 58.8(0) + 1.2(0) + 6.2(1385) + 33.8(1312) - 65\underset{\text{interpolate in table}}{\underbrace{(354)}} - 35\underset{\text{interpolate in table}}{\underbrace{(335)}} = \underline{\underline{1.82 \times 10^4 \text{ cal}}}$$

(b) Flow through condenser: $2(58.8) = 117.6 \text{ mols } A$

$2(1.2) = 2.4 \text{ mols } B$

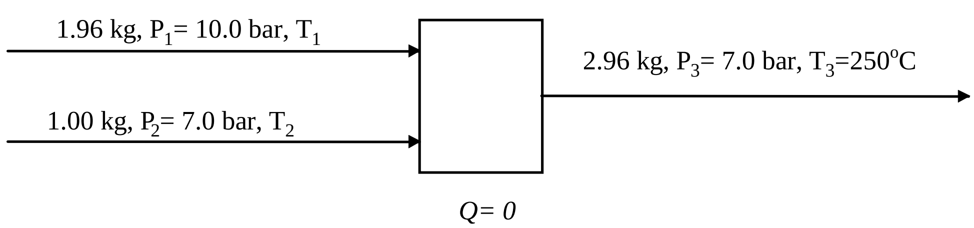
$$\underbrace{\text{Energy balance on condenser:}}_{\Delta E_p,\, W_s = 0,\, \Delta E_k \cong 0} \quad Q_c = \Delta H$$

$Q_c = 117.6(0 - 7322) + 2.4(0 - 6807) = \underline{\underline{-8.77 \times 10^5 \text{ cal}}}$ heat removed from condenser

Assume negligible heat transfer between system & surroundings other than Q_c & Q_r

$Q_r = Q - Q_c = 1.82 \times 10^4 - \left(-8.77 \times 10^5\right) = \underline{\underline{8.95 \times 10^5 \text{ cal}}}$ heat added to reboiler

7.43



7.43 (cont'd)

(a) $T_2 = T(P = 7.0 \text{ bar, sat'd steam}) = \underline{\underline{165.0\ ^\circ\text{C}}}$

$\hat{H}_3(\text{H}_2\text{O}(v),\ \text{P} = 7.0 \text{ bar},\ \text{T} = 250\ ^\circ\text{C}) = 2954 \text{ kJ/kg}$ (Table B.7)

$\hat{H}_2(\text{H}_2\text{O}(v),\ \text{P} = 7.0 \text{ bar, sat'd}) = 2760 \text{ kJ/kg}$ (Table B.6)

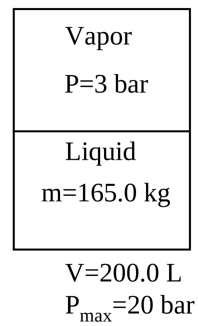
$\underset{\Delta E_p,\ Q,\ W_s,\ \Delta E_k \cong 0}{\underline{\text{Energy balance}}}$

$\Delta H = 0 = 2.96\hat{H}_3 - 1.96\hat{H}_1 - 1.0\hat{H}_2 \Rightarrow 1.96\hat{H}_1 = 2.96 \text{ kg}(2954 \text{ kJ / kg}) - 1.0 \text{ kg}(2760 \text{ kJ / kg})$

$\Rightarrow \hat{H}_1(10.0 \text{ bar},\ \text{T}_1) = 3053 \text{ kJ / kg} \Rightarrow \underline{\underline{\text{T}_1 \cong 300^\circ \text{C}}}$

(b) The estimate is <u>too low</u>. If heat is being lost the entering steam temperature would have to be higher for the exiting steam to be at the given temperature.

7.44 (a) $T_1 = T(P = 3.0 \text{ bar, sat'd.}) = \underline{\underline{133.5^\circ \text{C}}}$



$\hat{V}_l(P = 3.0 \text{ bar, sat'd.}) = 0.001074 \text{ m}^3 \text{ / kg}$

$\hat{V}_v(P = 3.0 \text{ bar, sat'd.}) = 0.606 \text{ m}^3 \text{ / kg}$

$$V_l = \frac{0.001074 \text{ m}^3}{\text{kg}} \left| \frac{1000 \text{ L}}{\text{m}^3} \right| \frac{165 \text{ kg}}{} = \underline{\underline{177.2 \text{ L}}}$$

$V_{space} = 200.0 \text{ L} - 177.2 \text{ L} = \underline{\underline{22.8 \text{ L}}}$

$$m_v = \frac{22.8 \text{ L}}{} \left| \frac{1 \text{ m}^3}{1000 \text{ L}} \right| \frac{1 \text{ kg}}{0.606 \text{ m}^3} = \underline{\underline{0.0376 \text{ kg}}}$$

(b) $P = P_{\max} = 20.0 \text{ bar}; \qquad m_{total} = 165.0 + 0.0376 = 165.04 \text{ kg}$

$T_1 = T(P = 20.0 \text{ bar, sat'd.}) = \underline{\underline{212.4^\circ \text{C}}}$

$\hat{V}_l(P = 20.0 \text{ bar, sat'd.}) = 0.001177 \text{ m}^3 \text{ / kg};\quad \hat{V}_v(P = 20.0 \text{ bar, sat'd.}) = 0.0995 \text{ m}^3 \text{ / kg}$

$V_{total} = m_l\hat{V}_l + m_v\hat{V}_v \Rightarrow m_l\hat{V}_l + (m_{total} - m_l)\hat{V}_v$

$$\Rightarrow \frac{200.0 \text{ L}}{} \left| \frac{1 \text{ m}^3}{1000 \text{ L}} \right. = m_l \text{ kg}(0.001177 \text{ m}^3 \text{ / kg}) + (165.04 - m_l)\text{kg}(0.0995 \text{ m}^3 \text{ / kg})$$

$\Rightarrow m_l = 164.98 \text{ kg};\quad m_v = 0.06 \text{ kg}$

$$V_l = \frac{0.001177 \text{ m}^3}{\text{kg}} \left| \frac{1000 \text{ L}}{\text{m}^3} \right| \frac{164.98 \text{ kg}}{} = \underline{\underline{194.2 \text{ L}}};\quad V_{space} = 200.0 \text{ L} - 194.2 \text{ L} = \underline{\underline{5.8 \text{ L}}}$$

$$m_{evaporated} = \frac{(0.06 - 0.04) \text{ kg}}{} \left| \frac{1000 \text{ g}}{\text{kg}} \right. = \underline{\underline{20 \text{ g}}}$$

(c) $\underset{\Delta E_p,\ W_s,\ \Delta E_k \cong 0}{\underline{\text{Energy balance}}}$ $\quad \text{Q} = \Delta U = U(P = 20.0 \text{ bar, sat'd}) - U(P = 3.0 \text{ bar, sat'd})$

$\hat{U}_l(P = 20.0 \text{ bar, sat'd.}) = 906.2 \text{ kJ / kg};\quad \hat{U}_v(P = 20.0 \text{ bar, sat'd.}) = 2598.2 \text{ kJ / kg}$

$\hat{U}_l(P = 3.0 \text{ bar, sat'd.}) = 561.1 \text{ kJ / kg};\quad \hat{U}_v(P = 3.0 \text{ bar, sat'd.}) = 2543 \text{ kJ / kg}$

$Q = 0.06 \text{ kg}(2598.2 \text{ kJ / kg}) + 164.98 \text{ kg}(906.2 \text{ kJ / kg}) - 0.04 \text{ kg}(2543 \text{ kJ / kg})$

$\qquad - 165.0 \text{ kg } (561.1 \text{ kJ / kg}) = \underline{\underline{5.70 \times 10^4 \text{ kJ}}}$

Heat lost to the surroundings, energy needed to heat the walls of the tank

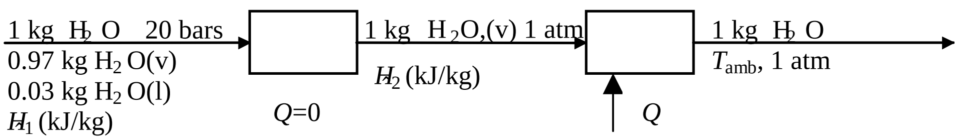
7.44 (cont'd)

(d) (i) The specific volume of liquid increases with the temperature, hence the same mass of liquid water will occupy more space; (ii) some liquid water vaporizes, and the lower density of vapor leads to a pressure increase; (iii) the head space is smaller as a result of the changes mentioned above.

(e) – Using an automatic control system that interrupts the heating at a set value of pressure
– A safety valve for pressure overload.
– Never leaving a tank under pressure unattended during operations that involve temperature and pressure changes.

7.45 Basis: 1 kg wet steam

(a)



Enthalpies: $\left.\begin{aligned}\hat{H}(v,\ 20\text{ bars, sat'd}) &= 2797.2\ \text{kJ/kg}\\ \hat{H}(l,\ 20\text{ bars, sat'd}) &= 908.6\ \text{kJ/kg}\end{aligned}\right\}(\text{Table B.7})$

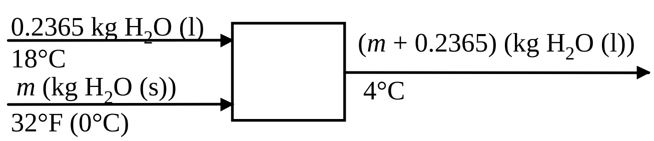
Energy balance on condenser: $\Delta H = 0 \Rightarrow \hat{H}_2 = \hat{H}_1 = 0.97(2797.2) + 0.03(908.6)$
$\Delta E_p, \Delta E_k, Q, W_s = 0$

$\Rightarrow \hat{H}_2 = 2740\ \text{kJ / kg} \xrightarrow{\text{Table B.7}} \underline{\underline{T \approx 132^\circ\text{C}}}$

(b) As the steam (which is transparent) moves away from the trap, it cools. When it reaches its saturation temperature at 1 atm, it begins to condense, so that $\underline{\underline{T = 100^\circ\text{C}}}$. The white plume is a mist formed by liquid droplets.

7.46 Basis: $\dfrac{8\text{ oz H}_2\text{O}(l)}{} \left| \dfrac{1\text{ quart}}{32\text{ oz}} \right| \dfrac{1\text{ m}^3}{1057\text{ quarts}} \left| \dfrac{1000\text{ kg}}{\text{m}^3} \right. = 0.2365\text{ kg H}_2\text{O}(l)$

(For simplicity, we assume the beverage is water)



Assume $P = 1$ atm

Enthalpies (from Table B.5):
$\hat{H}\left(\text{H}_2\text{O}(l),\ 18^\circ\text{C}\right) = 75.5$ kJ/kg; $\hat{H}\left(\text{H}_2\text{O}(l),\ 4^\circ\text{C}\right) = 16.8$ kJ/kg; $\hat{H}\left(\text{H}_2\text{O}(s),\ 0^\circ\text{C}\right) = -348$ kJ/kg

Energy balance (closed isobaric system): $\Rightarrow \Delta H = \sum_{\text{out}} n_i \hat{H}_i - \sum_{\text{in}} n_i \hat{H}_i = 0$
$\Delta E_p,\ \Delta E_k,\ Q,\ W = 0$

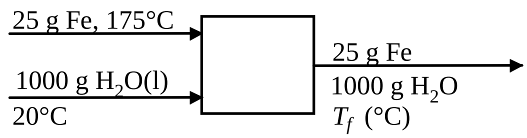
$\Rightarrow (m + 0.2365)\text{kg}(16.8\ \text{kJ / kg}) = 0.2365\ \text{kg}(75.5\ \text{kJ / kg}) + m\ \text{kg}\ (-348\ \text{kJ / kg})$

$\Rightarrow m = 0.038\ \text{kg} = \underline{\underline{38\text{ g ice}}}$

7.47 **(a)** When $T = 0^\circ \mathrm{C},\ \hat{H} = 0,\ \Rightarrow \underline{\underline{\mathrm{T_{ref}} = 0^\circ \mathrm{C}}}$

(b) Energy Balance-Closed System: $\Delta U = 0$

$\Delta E_k, \Delta E_p, Q, W = 0$



$$U_{\mathrm{Fe}}\left(T_f\right) + U_{\mathrm{H_2O}}\left(T_f\right) - U_{\mathrm{Fe}}\left(175^\circ \mathrm{C}\right) - U_{\mathrm{H_2O}}\left(20^\circ\ \mathrm{C},\ 1\ \mathrm{atm}\right) = 0\ \text{ or }\ \Delta U_{\mathrm{Fe}} + \Delta U_{\mathrm{H_2O}} = 0$$

$$\Delta U_{\mathrm{Fe}} = \frac{25.0\ \mathrm{g}}{} \left| \frac{4.13\left(T_f - 175\right)\mathrm{cal}}{\mathrm{g}} \right| \frac{4.184\ \ \mathrm{J}}{\mathrm{cal}} = 432\left[T_f - 175\right]\mathrm{J}$$

$$\text{Table B.5} \Rightarrow \Delta U_{\mathrm{H_2O}} = \frac{1.0\ \ \mathrm{L}}{} \left| \frac{10^3\ \ \mathrm{g}}{1\ \ \mathrm{L}} \right| \frac{\left(\hat{U}_{\mathrm{H_2O}}\left(T_f\right) - 83.9\right)\ \mathrm{J}}{\mathrm{g}} = 1000\left(\hat{U}_{\mathrm{H_2O}}\left(T_f\right) - 83.9\right)\mathrm{J}$$

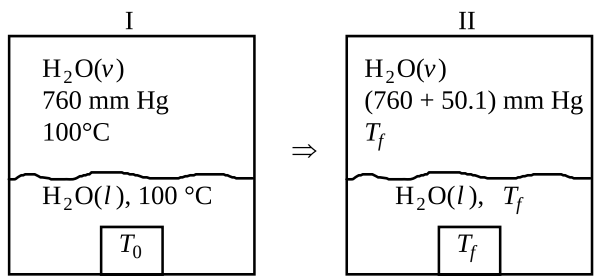
$$\Rightarrow 432T_f + 1000\hat{U}_{\mathrm{H_2O}}\left(T_f\right) - 1.60 \times 10^5 = f\left(T_f\right) = 0$$

$\Rightarrow$

T_f °C	30	40	35	34
$f\left(T_f\right)$	-2.1×10^4	$+2.5 \times 10^4$	1670	-2612

$\xrightarrow{\text{Interpolate}}$ $\underline{\underline{T_f = 34.6^\circ \mathrm{C}}}$

7.48



⇒ 1.08 bar sat'd
⇒ T_f = 101.8°C (Table 8.5)

Energy balance - closed system:
$\Delta E_p,\ \Delta E_K,\ W,\ Q = 0$

$$\Delta U = 0 = m_v^{\mathrm{II}}\hat{U}_v^{\mathrm{II}} + m_l^{\mathrm{II}}\hat{U}_l^{\mathrm{II}} + m_b^{\mathrm{II}}\hat{U}_b^{\mathrm{II}} - m_v^{\mathrm{I}}\hat{U}_v^{\mathrm{I}} - m_l^{\mathrm{I}}\hat{U}_l^{\mathrm{I}} - m_b^{\mathrm{I}}\hat{U}_b^{\mathrm{I}}$$

v-vapor
l-liquid
b-block

	$I(1.01\text{ bar},\ 100°\text{C})$	$II(1.08\text{ bar},\ 101.8°\text{C})$
$\hat{V}_l(\text{L/kg})$	1.044	1.046
$\hat{V}_v(\text{L/kg})$	1673	1576
$\hat{U}_l(\text{L/kg})$	419.0	426.6
$\hat{U}_v(\text{L/kg})$	2506.5	2508.6

Initial vapor volume: $V_v^{\mathrm{I}} = 20.0\text{ L} - 5.0\text{ L} - \dfrac{50\text{ kg}}{} \Big| \dfrac{1\text{ L}}{8.92\text{ kg}} = 14.4\text{ L } H_2O(v)$

Initial vapor mass: $m_v^{\mathrm{I}} = 14.4\text{ L}/(1673\text{ L/kg}) = 8.61\times10^{-3}\text{ kg } H_2O(v)$

Initial liquid mass: $m_l^{\mathrm{I}} = 5.0\text{ L}/(1.044\text{ L/kg}) = 4.79\text{ kg } H_2O(l)$

Final energy of bar: $\hat{U}_b^{\mathrm{II}} = 0.36(101.8) = 36.6\text{ kJ/kg}$

Assume negligible change in volume & liquid $\Rightarrow V_v^{\mathrm{II}} = 14.4\text{ L}$

Final vapor mass: $m_v^{\mathrm{II}} = 14.4\text{ L}/(1576\text{ L/kg}) = 9.14\times10^{-3}\text{ kg } H_2O(v)$

Initial energy of the bar:

$$\hat{U}_b^{\mathrm{I}} = \frac{1}{5.0\text{ kg}}\left(9.14\times10^{-3}(2508.6) + 4.79(426.6) + 5.0(36.6) - 8.61\times10^{-3}(2506.5) - 4.79(419.0)\right)$$
$$= 44.1\text{ kJ/kg}$$

(a) Oven Temperature: $T_o = \dfrac{44.1\text{ kJ / kg}}{0.36\text{ kJ / kg}\cdot{}^{o}\text{ C}} = \underline{\underline{122.5°\text{C}}}$

$H_2O_{\text{evaporated}} = m_v^{\mathrm{II}} - m_v^{\mathrm{I}} = 9.14\times10^{-3}\text{ kg} - 8.61\times10^{-3}\text{ kg} = 5.30\times10^{-4}\text{ kg} = \underline{\underline{0.53\text{ g}}}$

(b) $\hat{U}_b^{\mathrm{I}} = 44.1 + 8.3/5.0 = 45.8\text{ kJ/kg}$
$T_o = 45.8/0.36 = \underline{\underline{127.2°\text{C}}}$

(c) Meshuggeneh forgot to turn the oven on ($T_o < 100°\text{C}$)

7.49 **(a)** Pressure in cylinder $= \dfrac{\text{weight of piston}}{\text{area of piston}} + \text{atmospheric pressure}$

$$P = \frac{30.0\text{ kg}}{400.0\text{ cm}^2}\left|\frac{9.807\text{ N}}{\text{kg}}\right|\frac{(100\text{ cm})^2}{1^2(\text{m})^2}\left|\frac{1.0\text{ bar}}{10^5\text{ N/m}^2}\right. + \frac{1\text{ atm}}{}\left|\frac{1.013\text{ bar}}{\text{atm}}\right. = \underline{\underline{1.08\text{ bar}}}$$

$$\Rightarrow T_{sat} = 101.8°\text{C}$$

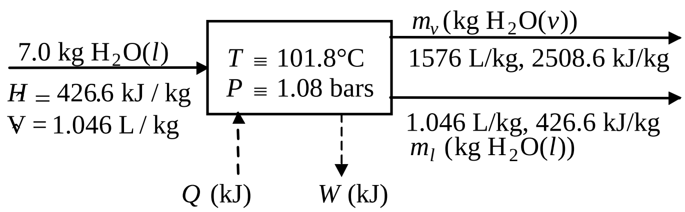
Heat required to bring the water and block to the boiling point

$$Q = \Delta U = m_w\left(\hat{U}_{wl}(1.08\text{ bar, sat'd}) - \hat{U}_{wl}(\text{l, }20°\text{C})\right) + m_{Al}\left(\hat{U}_{Al}(T_{sat}) - \hat{U}_{Al}(20°\text{C})\right)$$

$$= \frac{7.0\text{ kg}}{}\left|\frac{(426.6-83.9)\text{kJ}}{\text{kg}}\right. + \frac{3.0\text{ kg}}{}\left|\frac{[0.94(101.8-20)]\text{kJ}}{\text{kg}}\right. = 2630\text{ kJ}$$

2630 kJ < 3310 kJ $\Rightarrow$ Sufficient heat for vaporization

(b) $\underline{\underline{T_f = T_{sat} = 101.8°\text{C}}}$. Table B.5 $\Rightarrow \begin{array}{l}\hat{V}_l = 1.046\text{ L/kg},\ \hat{U}_l = 426.6\text{ kJ/kg}\\ \hat{V}_v = 1576\text{ L/kg},\ \hat{U}_v = 2508.6\text{ kJ/kg}\end{array}$



(Since the Al block stays at the same temperature in this stage of the process, we can ignore it -i.e., $\hat{U}_{\text{in}} = \hat{U}_{\text{out}}$)

Water balance: $7.0 = m_l + m_v$ **(1)**

Work done by the piston: $W = F\Delta z = \left[w_{\text{piston}} + P_{\text{atm}}A\right]\Delta z$

$$= \left[\frac{w}{A} + P_{\text{atm}}\right](A\Delta z) = P\Delta V \Rightarrow W = (1.08\text{ bar})\left[1576m_v + 1.046m_l - (1.046)(7.0)\right]\text{ L}$$

$$\times \frac{8.314\text{ J / mol}\cdot\text{K}}{0.08314\text{ liter - bar / mol}\cdot\text{K}}\left|\frac{1\text{ kJ}}{10^3\text{ J}}\right. = (170.2m_v + 0.113m_l - 0.7908)\text{kJ}$$

Energy balance: $\Delta U = Q - W$

$$\Rightarrow \overbrace{2508.6m_v + 426.6m_L - 426.6(7)}^{\Delta U} = \overbrace{(3310-2630)}^{Q} - \overbrace{(170.2m_v + 0.113m_L - 0.7908)}^{W}$$

$$\Rightarrow 2679m_v + 426.7m_L - 3667 = 0 \quad \textbf{(2)}$$

Solving (1) and (2) simultaneously yields $m_v = 0.302$ kg, $m_l = 6.698$ kg

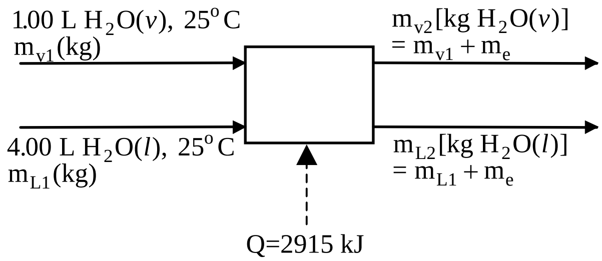
Liquid volume $= (6.698\text{ kg})(1.046\text{ L/kg}) = \underline{\underline{7.01\text{ L liquid}}}$

Vapor volume $= (0.302\text{ kg})(1576\text{ L/kg}) = \underline{\underline{476\text{ L vapor}}}$

Piston displacement: $\Delta z = \dfrac{\Delta V}{A} = \dfrac{[7.01 + 476 - (7.0)(1.046)]\text{L}}{}\left|\dfrac{10^3\text{ cm}^3}{1\text{ L}}\right|\dfrac{1}{400\text{ cm}^2} = \underline{\underline{1190\text{ cm}}}$

(c) $T_{\text{upper}} \Rightarrow$ All 3310 kJ go into the block before a measurable amount is transferred to the water. Then $\Delta U_{AL} = Q \Rightarrow (3.0\text{ kg})\left[0.94(T_u - 20)\text{ kJ/kg}\right] = 3310 \Rightarrow T_u = 1194°\text{C}$ *if melting is neglected.* In fact, the bar would melt at $\underline{660^{\circ}\text{C}}$.

7.50



Assume not all the liquid is vaporized. Eq. at T_f, P_f. m_e = kg H_2O vaporized.

Initial conditions: Table B.5 $\Rightarrow \hat{U}_{L1} = 104.8$ kJ/kg, $\hat{V}_{L1} = 1.003$ L/kg $\quad P = 0.0317$ bar

$T = 25°\text{C}$, sat'd $\Rightarrow \hat{U}_{v1} = 2409.9$ kJ/kg, $\hat{V}_{L1} = 43{,}400$ L/kg

$m_{v1} = (1.00\text{ l})/(43400\text{ l/kg}) = 2.304\times10^{-5}$ kg, $m_{LI} = (4.00\text{ l})/(1.003\text{ l/kg}) = 3.988$ kg

Energy balance:

$$\Delta U = Q \Rightarrow \left(2.304\times10^{-5} + m_e\right)\hat{U}_v\left(T_f\right) + \left(3.988 - m_e\right)\hat{U}_L\left(T_f\right) - \left(2.304\times10^{-5}\right)(2409.9)$$
$$-(3.988)(104.8) = 2915 \text{ kJ}$$

$$\Rightarrow \left(2.304\times10^{-5} + m_e\right)\hat{U}_v\left(T_f\right) + \left(3.988 - m_e\right)\hat{U}_v\left(T_f\right) = 3333$$
$$\Downarrow$$
$$\Rightarrow m_e = \frac{3333 - \left(2.304\times10^{-5}\right)\hat{U}_v - 3.988\hat{U}_L}{\hat{U}_v - \hat{U}_L} \qquad \textbf{(1)}$$

$$\underline{V_L + V_v = V_{\text{tank}}} \Rightarrow \left(2.304\times10^{-5} + \underset{\text{kg}}{\underset{\uparrow}{m_e}}\right)\underset{\text{liters/kg}}{\underset{\uparrow}{\hat{V}_L}}\left(T_f\right) + \left(3.988 - m_e\right)\hat{V}_L\left(T_f\right) = 5.00 \text{ L}$$

$$\Rightarrow m_e = \frac{5.00 - \left(2.304\times10^{-5}\right)\hat{V}_v - 3.988\hat{V}_L}{\hat{V}_v - \hat{V}_L} \qquad (2)$$

$$(1)-(2) \Rightarrow f\left(T_f\right) = \frac{3333 - \left(2.304\times10^{-5}\right)\hat{U}_v\left(T_f\right) - 3.988\hat{U}_L\left(T_f\right)}{\hat{U}_v - \hat{U}_L}$$
$$-\frac{5.00 - \left(2.304\times10^{-5}\right)\hat{V}_v - 3.988\hat{V}_L}{\hat{V}_v - \hat{V}_L} = 0$$

Procedure: Assume $T_f \overset{\text{Table 8.5}}{\Rightarrow} \hat{U}_v,\ \hat{U}_L,\ \hat{V}_v,\ \hat{V}_L \Rightarrow f\left(T_f\right)$ Find T_f such that $f\left(T_f\right) = 0$

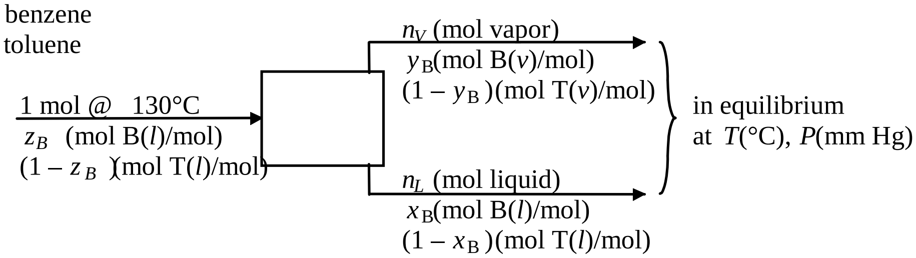
T_f	$\hat{U}_v$	$\hat{U}_L$	$\hat{V}_v$	$\hat{V}_L$	f
201.4	2593.8	856.7	123.7	1.159	-5.12×10^{-2}
198.3	2592.4	842.9	131.7	1.154	-1.93×10^{-2}
195.0	2590.8	828.5	140.7	1.149	1.34×10^{-2}
196.4	2591.5	834.6	136.9	1.151	-4.03×10^{-4}

$\Rightarrow \underline{\underline{T_f \cong 196.4°\text{C},\ P_f = 14.4 \text{ bars}}}$

$$\xrightarrow[\text{or Eq(2)}]{\text{Eq(1)}} m_e = 2.6\times10^{-3} \text{ kg} \Rightarrow \underline{\underline{2.6 \text{ g evaporated}}}$$

7.51. Basis: 1 mol feed

B = benzene
T = toluene



(a) 7 variables: $(n_V,\ y_B,\ n_L,\ x_B,\ Q,\ T,\ P)$
–2 equilibrium equations
–2 material balances
–1 energy balance
2 degrees of freedom. If T and P are fixed, we can calculate $n_V,\ y_B,\ n_L,\ x_B$, and Q.

(b) Mass balance: $n_V + n_L = 1 \Rightarrow n_V = 1 - n_2$ **(1)**

Benzene balance: $z_B = n_V y_B + n_L x_B$ **(2)**

$C_6H_6(l)$: $(T=0,\ \hat{H}=0),\ (T=80,\ \hat{H}=10.85) \Rightarrow \hat{H}_{BL} = 0.1356T$ **(3)**

$C_6H_6(v)$: $(T=80,\ \hat{H}=41.61),(T=120,\ \hat{H}=45.79) \Rightarrow \hat{H}_{BV} = 0.1045T + 33.25$ **(4)**

$C_7H_8(l)$: $(T=0,\ \hat{H}=0),\ (T=111,\ \hat{H}=18.58) \Rightarrow \hat{H}_{TL} = 0.1674T$ **(5)**

$C_7H_8(v)$: $(T=89,\ \hat{H}=49.18),\ (T=111,\ \hat{H}=52.05) \Rightarrow \hat{H}_{TV} = 0.1304T + 37.57$ **(6)**

Energy balance: $\Delta E_p,\ W_s = 0$, neglect ΔE_k

$$Q = \Delta H = n_V y_B \hat{H}_{BV} + n_V(1-y_B)\hat{H}_{TV} + n_L x_B \hat{H}_{BL} + n_L(1-x_B)\hat{H}_{TL} - (1)z_B\hat{H}_{BL}(T_F) - (1)(1-z_B)\hat{H}_{TL}(T_F) \quad \textbf{(7)}$$

Raoult's Law: $y_B P = x_B p_B^*$ **(8)**

$(1-y_B)P = (1-x_B)p_T^*$ **(9)**

Antoine Equation. For T= 90°C and P=652 mmHg:

$$p_B^*(90^o\text{C}) = 10^{[6.89272-1203.531/(90+219.888)]} = 1021\ \text{mmHg}$$
$$p_T^*(90^o\text{C}) = 10^{[6.95805-1346.773/(90+219.693)]} = 406.7\ \text{mmHg}$$

Adding equations (8) and (9) $\Rightarrow$

$$P = x_B p_B^* + (1-x_B)p_T^* \Rightarrow x_B = \frac{P-p_T^*}{p_B^*-p_T^*} = \frac{P-p_T^*}{p_B^*-p_T^*} = \frac{652-406.7}{1021-406.7} = \underline{\underline{0.399\ \text{mol B}(l)\,/\,\text{mol}}}$$

$$y_B = \frac{x_B p_B^*}{P} = \frac{0.399(1021\ \text{mmHg})}{652\ \text{mmHg}} = \underline{\underline{0.625\ \text{mol B}(v)\,/\,\text{mol}}}$$

Solving (1) and (2) $\Rightarrow$ $n_V = \dfrac{z_B - x_B}{y_B - x_B} = \dfrac{0.5-0.399}{0.625-0.399} = \underline{\underline{0.446\ \text{mol vapor}}}$

$$n_L = 1 - n_V = 1 - 0.446 = \underline{\underline{0.554\ \text{mol liquid}}}$$

7.51 (cont'd)

Substituting (3), (4), (5), and (6) in (7) ⇒

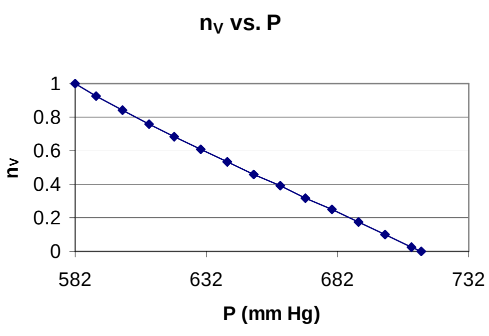
$$Q = 0.446(0.625)[0.1045(90) + 33.25] + 0.446(1 - 0.625)[0.1304(90) + 37.57]$$
$$+ 0.554(0.399)[0.1356(90)] + 0.554(1 - 0.399)[0.1674(90)] - 0.5[0.1356(130)]$$
$$- 0.5[0.1674(130)] \Rightarrow Q = \underline{\underline{8.14 \text{ kJ / mol}}}$$

(c). If P<P_{min}, all the output is vapor. If P>P_{max}, all the output is liquid.

(d) At P=652 mmHg it is necessary to add heat to achieve the equilibrium and at P=714 mmHg, it is necessary to release heat to achieve the equilibrium. The higher the pressure, there is more liquid than vapor, and the liquid has a lower enthalpy than the equilibrium vapor: enthalpy out < enthalpy in.

z_B	T	P	p_B	p_T	x_B	y_B	n_V	n_L	Q
0.5	90	652	1021	406.7	0.399	0.625	0.446	0.554	8.14
0.5	90	714	1021	406.7	0.500	0.715	-0.001	1.001	-6.09
0.5	90	582	1021	406.7	0.285	0.500	0.998	0.002	26.20
0.5	90	590	1021	406.7	0.298	0.516	0.925	0.075	23.8
0.5	90	600	1021	406.7	0.315	0.535	0.840	0.160	21.0
0.5	90	610	1021	406.7	0.331	0.554	0.758	0.242	18.3
0.5	90	620	1021	406.7	0.347	0.572	0.680	0.320	15.8
0.5	90	630	1021	406.7	0.364	0.589	0.605	0.395	13.3
0.5	90	640	1021	406.7	0.380	0.606	0.532	0.468	10.9
0.5	90	650	1021	406.7	0.396	0.622	0.460	0.540	8.60
0.5	90	660	1021	406.7	0.412	0.638	0.389	0.611	6.31
0.5	90	670	1021	406.7	0.429	0.653	0.318	0.682	4.04
0.5	90	680	1021	406.7	0.445	0.668	0.247	0.753	1.78
0.5	90	690	1021	406.7	0.461	0.682	0.176	0.824	-0.50
0.5	90	700	1021	406.7	0.477	0.696	0.103	0.897	-2.80
0.5	90	710	1021	406.7	0.494	0.710	0.029	0.971	-5.14

(e). $P_{max} = 714$ mmHg, $P_{min} = 582$ mmHg



$\underline{\underline{n_V = 0.5 \ @ \ P \cong 640 \text{ mmHg}}}$

7.52 **(a).** Bernoulli equation: $\frac{\Delta P}{\rho}+\frac{\Delta u^2}{2}+g\Delta z=0$

$$\frac{\Delta P}{\rho}=\frac{\left(0.977\times10^{-5}-1.5\times10^{5}\right)\text{Pa}}{}\left|\frac{1\text{ N / m}^2}{\text{Pa}}\right|\frac{\text{m}^3}{1.12\times10^3\text{ kg}}=-46.7\frac{\text{m}^2}{\text{s}^2}$$

$$g\Delta z=(9.8066\text{ m / s}^2)(6)\text{m}=58.8\text{ m}^2\text{ / s}^2$$

$$\underline{\text{Bernoulli}}\Rightarrow\frac{\Delta u^2}{2}=(46.7-58.8)\text{ m}^2\text{ / s}^2\Rightarrow u_2^2=u_1^2+2\left(-12.1\text{ m}^2\text{ / s}^2\right)$$

$$=(5.00)^2\text{ m}^2\text{ / s}^2-(2)(12.1)\text{ m}^2\text{ / s}^2=0.800\text{ m}^2\text{ / s}^2\Rightarrow u_2=\underline{\underline{0.894\text{ m / s}}}$$

(b). Since the fluid is incompressible, $\dot{V}\left(m^3/s\right)=\pi d_1^2\,u_1/4=\pi d_2^2\,u_2/4$

$$\Rightarrow d_1=d_2\sqrt{\frac{u_2}{u_1}}=(6\text{ cm})\sqrt{\frac{0.894\text{ m/s}}{5.00\text{ m/s}}}=\underline{\underline{2.54\text{ cm}}}$$

7.53 **(a).** $\dot{V}\left(\text{m}^3/\text{s}\right)=A_1\left(\text{m}^2\right)u_1(\text{m/s})=A_2\left(\text{m}^2\right)u_2(\text{m/s})\Rightarrow u_2=u_1\frac{A_1}{A_2}\xRightarrow{A_1=4A_2}\underline{\underline{u_2=4u_1}}$

(b). Bernoulli equation ($\Delta z=0$)

$$\frac{\Delta P}{\rho}+\frac{\Delta u^2}{2}=0\Rightarrow\Delta P=P_2-P_1=-\frac{\rho\left(u_2^2-u_1^2\right)}{2}$$

Multiply both sides by -1

Substitute $u_2^2=16u_1^2$

Multiply top and bottom of right - hand side by A_1^2

note $\dot{V}^2=A_1^2u_1^2$

$$\underline{\underline{P_1-P_2=\frac{15\rho\dot{V}^2}{2A_1^2}}}$$

(c) $P_1-P_2=\left(\rho_{\text{Hg}}-\rho_{\text{H}_2\text{O}}\right)gh=\frac{15\rho_{\text{H}_2\text{O}}\dot{V}^2}{2A_1^2}\Rightarrow\dot{V}^2=\frac{2A_1^2gh}{15}\left(\frac{\rho_{\text{Hg}}}{\rho_{\text{H}_2\text{O}}}-1\right)$

$$\dot{V}^2=\frac{2\left[\pi(7.5)^2\right]^2\text{cm}^4}{15}\left|\frac{1\quad\text{m}^4}{10^8\text{ cm}^4}\right|\frac{9.8066\text{ m}}{\text{s}^2}\left|38\text{ cm}\right|\frac{1\text{ m}}{10^2\text{ cm}}\left|(13.6-1)\right.=1.955\times10^{-3}\ \frac{\text{m}^6}{\text{s}^2}$$

$$\Rightarrow\dot{V}=0.044\ \text{m}^3/\text{s}=\underline{\underline{44\ \text{L/s}}}$$

7.54 **(a).** Point 1 - surface of fluid. $P_1 = 3.1$ bar, $z_1 = +7$m, $u_1 = 0(\text{m/s})$

Point 2 - discharge pipe outlet. $\underset{(=1.013 \text{ bar})}{P_2 = 1 \text{ atm}}$, $z_2 = 0(\text{m})$, $u_2 = ?$

$$\frac{\Delta\rho}{\rho} = \frac{(1.013 - 3.1)\text{bar}}{} \left| \frac{10^5 \text{N}}{\text{m}^2 \cdot \text{bar}} \right| \frac{1 \qquad \text{m}^3}{0.792 \times 10^3 \text{ kg}} = -263.5 \text{ m}^2/\text{s}^2$$

$$g\Delta z = \frac{9.8066 \text{ m}}{\text{s}^2} \left| \frac{-7\text{m}}{} \right. = -68.6 \text{ m}^2/\text{s}^2$$

Bernoulli equation $\Rightarrow \dfrac{\Delta u^2}{2} = -\dfrac{\Delta P}{\rho} - g\Delta z = (263.5 + 68.6) \text{ m}^2/\text{s}^2 = 332.1 \text{ m}^2/\text{s}^2$

$$\Big\Downarrow \Delta u^2 = u_2^2 - 0^2$$

$$u_2^2 = 2(332.1 \text{ m}^2/\text{s}^2) = 664.2 \text{ m}^2/\text{s}^2 \Rightarrow u_2 = \underline{\underline{25.8 \text{ m/s}}}$$

$$\dot{V} = \frac{\pi(1.00^2) \text{ cm}^2}{4} \left| \frac{2580 \text{ cm}}{1 \qquad \text{s}} \right| \frac{1 \quad \text{L}}{10^3 \text{ cm}^3} \left| \frac{60 \text{ s}}{1 \text{ min}} \right. = \underline{\underline{122 \text{ L/min}}}$$

(b) The friction loss term of Eq. (7.7-2), which was dropped to derive the Bernoulli equation, becomes increasingly significant as the valve is closed.

7.55 Point 1 - surface of lake. $P_1 = 1$ atm, $z_1 = 0$, $u_1 = 0$

Point 2 - pipe outlet. $P_2 = 1$ atm, $z_2 = z(\text{ft})$

$$u_2 = \frac{\dot{V}}{A} = \frac{95 \text{ gal}}{\text{min}} \left| \frac{1 \qquad \text{ft}^3}{7.4805 \text{ gal}} \right| \frac{1}{\pi(0.5 \times 1.049)^2 \text{in}^2} \left| \frac{144 \text{ in}^2}{1 \text{ ft}^2} \right| \frac{1 \text{ min}}{60 \text{ s}} = 35.3 \text{ ft/s}$$

Pressure drop: $\Delta P/\rho = 0 \quad (P_1 = P_2)$

Friction loss: $F = 0.041(2z) \text{ ft} \cdot \text{lb}_f/\text{lb}_m = 0.0822\, z \text{ (ft} \cdot \text{lb}_f/\text{lb}_m)$

$\left(L = \dfrac{Z}{\sin 30°} = 2z\right)$

Shaft work: $$\frac{\dot{W}_s}{\dot{m}} = \frac{\text{-8 hp}}{} \left| \frac{0.7376 \text{ ft} \cdot \text{lb}_f \text{ / s}}{1.341 \times 10^{-3} \text{ hp}} \right| \frac{1 \text{ min}}{95 \text{ gal}} \left| \frac{7.4805 \text{ gal}}{1 \text{ ft}^3} \right| \frac{1 \quad \text{ft}^3}{62.4 \text{ lb}_m} \left| \frac{60 \text{ s}}{1 \text{ min}} \right.$$

$$= -333 \text{ ft} \cdot \text{lb}_f/\text{lb}_m$$

Kinetic energy: $$\Delta u^2/2 = \frac{\left[(35.3)^2 - 0^2\right]\text{ft}^2}{2 \qquad \text{s}^2} \left| \frac{1 \qquad \text{lb}_f}{32.174 \text{ lb}_m \cdot \text{ft/s}^2} \right. = 19.4 \text{ ft} \cdot \text{lb}_f/\text{lb}_m$$

Potential energy: $$g\Delta z = \frac{32.174 \text{ ft}}{\text{s}^2} \left| \frac{z(\text{ft})}{} \right| \frac{1 \text{ lb}_f}{32.174 \text{ lb}_m \cdot \text{ft/s}^2} = z(\text{ft} \cdot \text{lb}_f/\text{lb}_m)$$

Eq. (7.7 - 2) $\Rightarrow \dfrac{\Delta P}{\rho} + \dfrac{\Delta u^2}{2} + g\Delta z + F = \dfrac{-\dot{W}_s}{\dot{m}} \Rightarrow 19.4 + z + 0.082z = 333 \Rightarrow z = \underline{\underline{290 \text{ ft}}}$

7.56 Point 1 - surface of reservoir. $P_1 = 1$ atm (assume), $u_1 = 0$, $z_1 = 60$ m

Point 2 - discharge pipe outlet. $P_2 = 1$ atm (assume), $u_2 = ?$, $z_2 = 0$

$$\Delta P/\rho = 0$$

$$\frac{\Delta u^2}{2} = \frac{u_2^2}{2} = \frac{(\dot{V}/A)^2}{2} = \frac{\dot{V}^2(\mathrm{m^6/s^2})}{(2)} \left| \frac{1}{[\pi(35)^2]^2\ \mathrm{cm^4}} \right| \frac{10^8\ \mathrm{cm^4}}{1\ \mathrm{m^4}} \left| \frac{1\ \mathrm{N}}{1\ \mathrm{kg\cdot m/s^2}} \right.$$

$$= 3.376\dot{V}^2\,(\mathrm{N\cdot m/kg})$$

$$g\Delta z = \frac{9.8066\ \mathrm{m}}{\mathrm{s^2}} \left| \frac{-65\ \mathrm{m}}{} \right| \frac{1\ \mathrm{N}}{1\ \mathrm{kg\cdot m/s^2}} = -637\ \mathrm{N\cdot m/kg}$$

$$\frac{\dot{W}_s}{\dot{m}} = \frac{0.80\times10^6\ \mathrm{W}}{} \left| \frac{1\ \mathrm{N\cdot m/s}}{\mathrm{W}} \right| \frac{\mathrm{s}}{\dot{V}(\mathrm{m^3})} \left| \frac{1\ \mathrm{m^3}}{1000\ \mathrm{kg}} \right. = 800/\dot{V}\,(\mathrm{N\cdot m/kg})$$

Mechanical energy balance: neglect F (Eq. 7.7-2)

$$\frac{\Delta P}{\rho} + \frac{\Delta u^2}{2} + g\Delta z = \frac{-\dot{W}_s}{\dot{m}} \Rightarrow 3.376\dot{V}^2 - 637 = -\frac{800}{\dot{V}} \stackrel{T+E}{\Longrightarrow} \dot{V} = \frac{1.27\ \mathrm{m^3}}{\mathrm{s}} \left| \frac{60\ \mathrm{s}}{1\ \mathrm{min}} \right. = \underline{\underline{76.2\ \mathrm{m^3/min}}}$$

Include friction (add $F > 0$ to left side of equation) $\Rightarrow \dot{V}$ increases.

7.57 **(a)**. Point 1: Surface at fluid in storage tank, $P_1 = 1$ atm, $u_1 = 0$, $z_1 = H(\mathrm{m})$

Point 2 (just within pipe): Entrance to washing machine. $P_2 = 1$ atm, $z_2 = 0$

$$u_2 = \frac{600\ \mathrm{L}}{\mathrm{min}} \left| \frac{}{\pi(4.0\ \mathrm{cm})^2/4} \right| \frac{10^3\ \mathrm{cm^3}}{1\ \ \mathrm{L}} \left| \frac{1\ \mathrm{min}}{60\ \mathrm{s}} \right| \frac{1\ \mathrm{m}}{100\ \mathrm{cm}} = 7.96\ \mathrm{m/s}$$

$$\frac{\Delta P}{\rho} = 0;\ \frac{\Delta u^2}{2} = \frac{u_2^2}{2} = \frac{(7.96\ \mathrm{m/s})^2}{2} \left| \frac{1\ \ \mathrm{J}}{1\ \mathrm{kg\cdot m^2/s^2}} \right. = 31.7\ \mathrm{J/kg}$$

$$g\Delta z = \frac{9.807\ \mathrm{m}}{\mathrm{s^2}} \left| \frac{(0 - H(\mathrm{m}))}{} \right| \frac{1\ \ \mathrm{J}}{1\ \mathrm{kg\cdot m^2/s^2}} = -9.807H\ (\mathrm{J/kg})$$

Bernoulli Equation: $\dfrac{\Delta P}{\rho} + \dfrac{\Delta u^2}{2} + g\Delta z = 0 \Rightarrow \underline{\underline{H = 3.23\ \mathrm{m}}}$

(b). Point 1: Fluid in washing machine. $P_1 = 1$ atm, $u_1 \approx 0$, $z_1 = 0$

Point 2: Entrance to storage tank (within pipe). $P_2 = 1$ atm, $u_2 = 7.96$ m/s, $z_2 = 3.23$ m

$$\frac{\Delta P}{\rho} = 0;\ \frac{\Delta u^2}{2} = 31.7\ \frac{\mathrm{J}}{\mathrm{kg}};\ g\Delta z = 9.807(3.23 - 0) = 31.7\ \frac{\mathrm{J}}{\mathrm{kg}};\ F = 72\ \frac{\mathrm{J}}{\mathrm{kg}}$$

Mechanical energy balance: $\dot{W}_s = -\dot{m}\left[\dfrac{\Delta P}{\rho} + \dfrac{\Delta u^2}{2} + g\Delta z + F\right]$

$$\Rightarrow \dot{W}_s = -\frac{600\ \mathrm{L}}{\mathrm{min}} \left| \frac{0.96\ \mathrm{kg}}{\mathrm{L}} \right| \frac{1\ \mathrm{min}}{60\ \mathrm{s}} \left| \frac{(31.7 + 31.7 + 72)\ \ \mathrm{J}}{\mathrm{kg}} \right| \frac{1\ \ \mathrm{kW}}{10^3\ \ \mathrm{J/s}} = -1.30\ \mathrm{kW}$$

(work applied to the system)

Rated Power $= 1.30\ \mathrm{kW}/0.75 = \underline{\underline{1.7\ \mathrm{kW}}}$

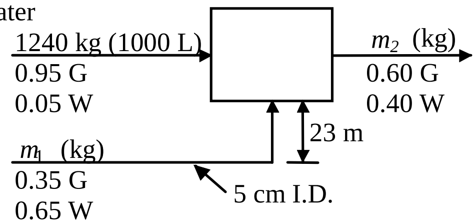
7.58 Basis: 1000 liters of 95% solution. Assume volume additivity.

Density of 95% solution (Eq. 6.1-1): $\dfrac{1}{\rho}=\sum \dfrac{x_i}{\rho_i}=\dfrac{0.95}{1.26}+\dfrac{0.05}{1.00}=0.804\dfrac{\text{l}}{\text{kg}}\Rightarrow \rho = 1.24 \text{ kg/liter}$

Density of 35% solution: $\dfrac{1}{\rho}=\dfrac{0.35}{1.26}+\dfrac{0.65}{1.00}=0.9278\dfrac{\text{l}}{\text{kg}}\Rightarrow \rho = 1.08 \text{ kg/liter}$

Mass of 95% solution: $\begin{array}{c|c} 1000 \text{ liters} & 1.24 \text{ kg} \\ \hline & \text{liter} \end{array} = 1240 \text{ kg}$

G = glycerol
W = water



$$\left.\begin{array}{l}\underline{\text{Mass balance:}}\ 1240 + m_1 = m_2 \\ \underline{\text{Glycerol balance:}}\ (0.95)(1240)+(0.35)(m_1)=(0.60)(m_2)\end{array}\right\}\Rightarrow \begin{array}{l} m_1 = 1740 \text{ kg 35\% solution} \\ m_2 = 2980 \text{ kg 60\% solution}\end{array}$$

Volume of 35% solution added $= \begin{array}{c|c} 1740 \text{ kg} & 1 \text{ L} \\ \hline & 1.08 \text{ kg} \end{array} = 1610 \text{ L}$

$\Rightarrow$ Final solution volume $=(1000+1610)\text{ L} = \underline{\underline{2610 \text{ L}}}$

Point 1. Surface of fluid in 35% solution storage tank. $P_1 = 1$ atm, $u_1 = 0$, $z_1 = 0$

Point 2. Exit from discharge pipe. $P_2 = 1$ atm, $z_2 = 23$ m

$$u_2 = \begin{array}{c|c|c|c|c} 1610 \text{ L} & 1 \quad \text{m}^3 & 1 \text{ min} & 1 & 10^4 \ \text{cm}^2 \\ \hline 13 \text{ min} & 10^3 \ \text{L} & 60 \text{ s} & \pi(2.5)^2 \ \text{cm}^2 & 1 \quad \text{m}^2 \end{array} = 1.051 \text{ m/s}$$

$$\Delta P/\rho = 0,\ \frac{\Delta u^2}{2}=\frac{\Delta u_2^2}{2}=\begin{array}{c|c} (1.051)^2 \ \text{m}^2/\text{s}^2 & 1 \quad \text{N} \\ \hline (2) & 1 \text{ kg}\cdot\text{m/s}^2 \end{array} = 0.552 \text{ N}\cdot\text{m/kg}$$

$$g\Delta z = \begin{array}{c|c|c} 9.8066 \text{ m} & 23 \text{ m} & 1 \text{ N} \\ \hline \text{s}^2 & & 1 \text{ kg}\cdot\text{m/s}^2 \end{array} = 225.6 \text{ N}\cdot\text{m/kg},\ F = 50 \text{ J/kg} = 50 \text{ N}\cdot\text{m/kg}$$

Mass flow rate: $\dot{m} = \begin{array}{c|c} 1740 \text{ kg} & 1 \text{ min} \\ \hline 13 \text{ min} & 60 \text{ s} \end{array} = 2.23 \text{ kg/s}$

Mechanical energy balance (Eq. 7.7-2)

$$\dot{W}_s = -\dot{m}\left[\frac{\Delta P}{\rho}+\frac{\Delta u^2}{2}+g\Delta z + F\right] = -\begin{array}{c|c|c|c} 2.23 \text{ kg} & (0.552+225.6+50)\text{N}\cdot\text{m} & 1 \text{ J} & 1 \text{ kW} \\ \hline \text{s} & \text{kg} & 1 \text{ N}\cdot\text{m} & 10^3 \ \text{J/s} \end{array}$$

$= -0.62 \text{ kW} \Rightarrow \underline{\underline{0.62 \text{ kW}}}$ delivered to fluid by pump.