CHE 203

HW # 1

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

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

7.2 All kinetic energy dissipated by friction

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

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

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

(b)

$\frac{3\times10^8\text{ brakings}}{\text{day}}\left|\frac{715\text{ Btu}}{\text{braking}}\right|\frac{1\text{ day}}{24\text{ h}}\left|\frac{1\text{ h}}{3600\text{ s}}\right|\frac{1\text{ W}}{9.486\times10^{-4}\text{ Btu}/\text{s}^2}\left|\frac{1\text{ MW}}{10^6\text{ W}}\right. = 2617\text{ MW}$

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: $E_k = \frac{mu^2}{2} = \frac{0.330\text{ lb}_m}{\text{s}}\left|\frac{(1.225)^2\text{ ft}^2}{\text{s}^2}\right|\frac{1}{2}\left|\frac{1\qquad\text{lb}_f}{32.174\text{ lb}_m\cdot\text{ft}/\text{s}^2}\right. = \underline{7.70\times10^{-3}\ \frac{\text{ft}\cdot\text{lb}_f}{\text{s}}}$

$= (7.70\times10^{-3}\text{ ft}\cdot\text{lb}_f/\text{s})\left(\frac{1.341\times10^{-3}\text{ hp}}{0.7376\text{ ft}\cdot\text{lb}_f/\text{s}}\right) = \underline{1.40\times10^{-5}\text{ hp}}$

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

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

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

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

(b)

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

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

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

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

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

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

(b) $$\dot{m} = \frac{5\ \text{m}}{\text{s}} \left| \pi(1.5)^2\ \text{cm}^2 \right| \frac{1\ \text{m}^3}{10^4\ \text{cm}^2} \left| \frac{273\ \text{K}}{303\ \text{K}} \right| \frac{10\ \text{bars}}{1.01325\ \text{bars}} \left| \frac{1\ \text{kmol}}{22.4\ \text{m}^3\ \text{(STP)}} \right| \frac{16.0\ \text{kg CH}_4}{1\ \text{kmol}}$$
$$= 0.0225\ \text{kg/s}$$

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

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

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

(a) Downward force on piston:

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

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

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

Equilibrium condition:

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

$V_0 = \frac{nRT}{P_0} = \frac{1.40 \text{ g } N_2}{} \left| \frac{1 \text{ mol } N_2}{28.02 \text{ g}} \right| \frac{303 \text{ K}}{1.86 \times 10^5 \text{ Pa}} \left| \frac{1.01325 \times 10^5 \text{ Pa}}{1 \text{ atm}} \right| \frac{0.08206 \text{ L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} = \underline{0.677 \text{ L}}$

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

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

Step 2: $\underline{\Delta U = Q - W}$ 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: $T_{initial} = T_{final} \Rightarrow \Delta U = 0 \Rightarrow \underline{Q - W = 0}$

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

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

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

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

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

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

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

(heat transferred to gas)