

HW 1

Title: Energy Balance I

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$$7.1 \quad \frac{0.80 \text{ L}}{\text{h}} \left| \frac{3.5 \times 10^4 \text{ kJ}}{\text{L}} \right| \frac{0.30 \text{ kJ work}}{1 \text{ kJ heat}} \left| \frac{1 \text{ h}}{3600 \text{ s}} \right| \frac{1 \text{ kW}}{1 \text{ kJ/s}} = 2.33 \text{ kW} \Rightarrow \underline{2.3 \text{ kW}}$$

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

7.2 All kinetic energy dissipated by friction

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

$$= \frac{5500 \text{ lb}_m}{2} \left| \frac{55^2 \text{ miles}^2}{\text{h}^2} \right| \frac{5280^2 \text{ ft}^2}{1^2 \text{ mile}^2} \left| \frac{1^2 \text{ h}^2}{3600^2 \text{ s}^2} \right| \frac{1 \text{ lb}_f}{32.174 \text{ lb}_m \cdot \text{ft} / \text{s}^2} \left| \frac{9.486 \times 10^{-4} \text{ B}}{0.7376 \text{ ft} \cdot \text{lb}} \right|$$

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

(b)

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

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

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

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

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

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

7.5 (a) Mass flow rate:

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

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

(b)

$$\frac{127.9 \text{ g}}{\text{s}} \left| \frac{1 \text{ mol}}{29 \text{ g}} \right| \left| \frac{673 \text{ K}}{573 \text{ K}} \right| \left| \frac{101.3 \text{ kPa}}{130 \text{ kPa}} \right| \left| \frac{22.4 \text{ L (STP)}}{1 \text{ mol}} \right| \left| \frac{1 \text{ m}^3}{10^3 \text{ L}} \right| \left| \frac{4}{\pi(0.07)^2 \text{ m}^2} \right| = 49.32 \text{ m/s}$$

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

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

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

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

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

$$(b) \dot{m} = \frac{5 \text{ m}}{\text{s}} \left| \frac{\pi(1.5)^2 \text{ cm}^2}{4} \right| \left| \frac{1 \text{ m}^3}{10^6 \text{ cm}^3} \right| \left| \frac{273 \text{ K}}{303 \text{ K}} \right| \left| \frac{10 \text{ bars}}{1.01325 \text{ bars}} \right| \left| \frac{1 \text{ kmol}}{22.4 \text{ m}^3 \text{ (STP)}} \right| \left| \frac{16.0 \text{ kg CH}_4}{1 \text{ kmol}} \right| = 0.0225 \text{ kg/s}$$

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

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

$$7.i1 \quad A = \frac{\pi(3)^2 \text{ cm}^2}{10^4 \text{ cm}^2} \left| \frac{1 \text{ m}^2}{10^4 \text{ cm}^2} \right| = 2.83 \times 10^{-3} \text{ m}^2$$

(a) Downward force on piston:

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

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

Equilibrium condition:

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

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

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

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

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

In step 1, the gas expands $\Rightarrow W > 0 \Rightarrow \Delta U < 0 \Rightarrow T$ 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 $T_0 = T_f = 30^\circ \text{C}$, $P_f V_f = P_0 V_0 \Rightarrow V_f = V_0 \frac{P_0}{P_f} = (0.677 \text{ L}) \frac{1.86 \times 10^5 \text{ Pa}}{1.16 \times 10^5 \text{ Pa}} = 1.08 \text{ L}$

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

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

Since work is done by the gas on its surroundings, $W = +47 \text{ J} \Rightarrow_{Q-W=0} Q = +47 \text{ J}$
 (heat transferred to gas)