CBE 20255

HW7 solution

1. I can't drive 55

1. $E_k = \frac{1}{2} m v^2$

$m = 5500\ lbm = 2495\ kg$

$v = 55\ mph = 24.6\ m/s$

$E_k = \frac{1}{2}\ 2495 \cdot 24.6^2 = 750\ kJ$

2. Internal energy of brake and subsequent dissipation as heat.

3. ① U.S. has 212 million licenced drivers

② 13.476 miles per year/driver ⟶ 37 miles /per day/driver

③ Assuming 3 miles / traffic light

* ① is from www.statista.com
② is from Federal Highway Administration www.fhwa.dot.gov

$$\text{Number of braking events} = \frac{37\ \text{miles/per day} \cdot \text{driver} \cdot 212 \times 10^6\ \text{drivers}}{3\ \text{miles/traffic light}}$$

$$= 2.6 \times 10^9$$

4. $$\text{Average rate of energy dissipation} = \frac{2.6 \times 10^9 \cdot 750\ kJ}{3600\ s/hr \quad 24\ hr/day} = 2.3 \times 10^4\ MW$$

5. Average household electric usage per day

$= 25.3\ kWh/day$ *

* From U.S. Energy Information Administration

$25.3\,kWh = 91080\,kJ$

From question (4), we know energy dissipation of braking events is $1.95 \times 10^{12}\ kJ/day$

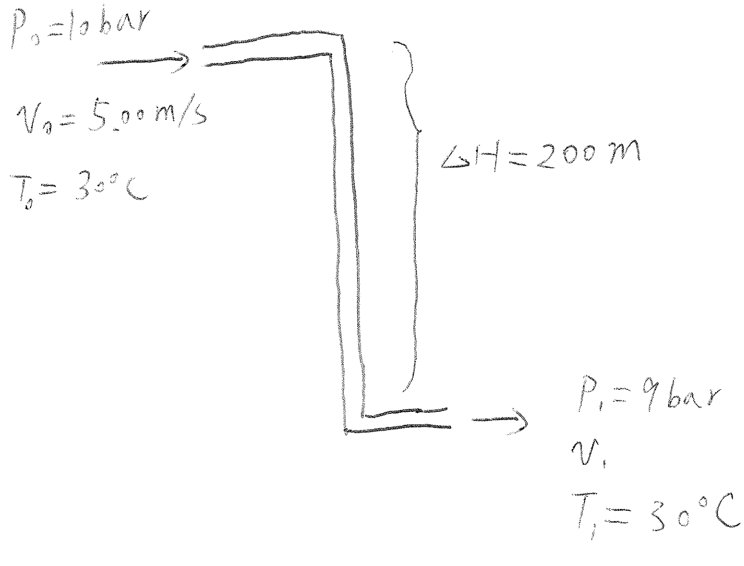
Number of ~~for~~ homes can be powered

$$= \frac{1.95 \times 10^{12}\ kJ/day}{91080\ kJ/day\text{-}home} = 2.1 \times 10^{6}\ homes$$

It can be roughly estimated that 2.1 million homes could be powered by energy dissipation caused by braking events.

6. "Regerative braking" is a method of braking in which energy is extracted from the parts braked, to be stored, primarily as electricity, and reused. It is definitely a good idea but its application is limited to electric or hybrid vehicles.

2. A Pipe Dream



1. $T_0 = 30°C = 303.15K$

$P_0 = 10$ bar

Assume methane as ideal gas

$$P_0 \dot{V}_0 = \dot{n}_0 RT \longrightarrow \frac{\dot{V}_0}{\dot{n}_0} = \frac{RT}{P_0} = \frac{8.314 \times 10^{-5} \cdot 303.15}{10}$$

$$= 2.52 \times 10^{-3} \ m^3/mol$$

$$\dot{V}_0 = A \cdot v_0$$

$$= \pi \left(\frac{D}{2}\right)^2 v_0$$

A is cross-sectional area, D is diameter of the pipe,

v_0 is linear velocity

$$\dot{V}_0 = \pi \left(\frac{3 \ cm}{2}\right)^2 \cdot 5.00 \ m \ s^{-1} = 3.53 \times 10^{-3} \ m^3/s$$

$$\dot{n}_0 = \frac{\dot{V}_0}{2.52 \times 10^{-3} \ m^3/mol} = \frac{3.53 \times 10^{-3} \ m^3/s}{2.52 \times 10^{-3} \ m^3/mol} = 1.40 \ mol/s$$

$$\dot{E}_k = \frac{1}{2} \dot{m} v_0^2 = \frac{1}{2} (MW_{CH_4} \cdot \dot{n}_0) v_0^2 = \frac{1}{2} \cdot (0.016 kg/mol \cdot 1.40 mol/s) \cdot (5.00 m/s)^2 = 0.28 \ W$$

2. According to material balance, if there is no reactions and accumulation within the pipe,

$$\dot{n}_0 = \dot{n}_1 \quad \text{at steady-state}$$

$$\text{So } \Delta \dot{E}_p = \dot{m}_1 g \Delta H$$

$$= (MW_{CH_4} \cdot \dot{n}_1) g \Delta H$$

$$= (MW_{CH_4} \cdot \dot{n}_0) g \Delta H$$

$$= (0.016 \text{kg/mol} \cdot 1.40 \text{mol/s}) \cdot 9.81 \text{ m/s}^2 \cdot (-200 \text{ m})$$

$$= -43.9 \text{ W}$$

3. $\dot{E}_K$

$$\frac{\dot{V}_1}{\dot{n}_1} = \frac{RT}{P_1} = \frac{8.314 \times 10^{-5} \cdot 303.15}{9} = 2.80 \times 10^{-3} \text{ m}^3/\text{mol}$$

$$\dot{n}_1 = \dot{n}_0$$

$$\dot{V}_1 = 3.92 \times 10^{-3} \text{ m}^3/\text{s}$$

$$V_1 = \frac{\dot{V}_1}{A} = \frac{3.92 \times 10^{-3} \text{ m}^3/\text{s}}{\pi \left(\frac{3 \text{cm}}{2}\right)^2} = 5.55 \text{ m}$$

$$\dot{E}_k = \frac{1}{2} \dot{m}_1 V_1^2 = \frac{1}{2} (0.016 \cdot 1.4 \text{mol/s}) \cdot (5.55 \text{ m})^2$$

$$= 0.34 \text{ W}$$

4. $\Delta \dot{E}_p + \Delta \dot{E}_k$

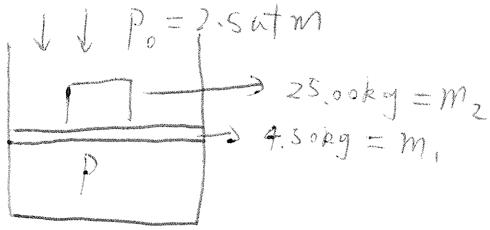
$= -43.9W + (0.34W - 0.28W)$

$= -43.3W < 0$

Potential and kinetic energy changes do not balance each other. The negative change suggests loss of sum of kinetic and potential energy. The loss may due to friction between gas and inner surface of the pipe as well as other minor losses.

3. Work = heat

1.



Pressures inside and outside balance each other,

$$P = P_0 + \frac{m_1 g}{A} + \frac{m_2 g}{A}$$

$$A = \text{area of piston} = \pi r^2 = \pi\left(\frac{d}{2}\right)^2 = 3.14 \cdot \left(\frac{0.06\,m}{2}\right)^2$$
$$= 2.83 \times 10^{-3}\,m^2$$

$$\text{so } P = 2.5\,atm + \frac{4.50\,kg \cdot 9.81\,m/s}{2.83 \times 10^{-3}\,m^2} + \frac{25.00\,kg \cdot 9.81\,m/s}{2.83 \times 10^{-3}\,m^2}$$

$$= 2.5\,atm + 1.56 \times 10^4\,Pa + \cancel{8.84 \times 10}\ 8.67 \times 10^4\,Pa$$

$$= 2.5\,atm + 1.56 \times 10^4\,Pa \cdot \frac{atm}{101000\,Pa} + 8.67 \times 10^4\,Pa \cdot \frac{atm}{101000\,Pa}$$

$$= 2.5\,atm + 1.01\,atm = 3.5\,atm$$

2. Assume ~~meth~~ N_2 inside cylinder as ideal gas

$$PV = nRT$$

$$n = \frac{m}{MW_{N_2}} = \frac{1.40}{28\,g/mol} = 0.05\,mol$$

$$V = \frac{nRT}{P} = \frac{0.05\,mol \cdot 8.206 \times 10^{-5}\,m^3\,atm\,K^{-1}\,mol^{-1} \cdot (273.15+30)\,K}{3.5\,atm}$$

$$= 3.55 \times 10^{-4}\,m^3$$

3. The work done in the expansion process

= Change of internal energy of N_2 $\neq 0$ = negative

4. Cooler

5. Heat flow

= Change of internal energy of N_2 $\neq 0$ = positive

6. Resisting force = $m \cdot g + P_0 A$

$= 4.50\,kg \cdot 9.81\,m/s^2 + 2.5\,atm \cdot 2.83 \times 10^{-3}\,m^2$

$= 759\,N$

~~Work = 759 N~~

At new equilibrium state,

$PV = nRT$

$P = 2.5\,atm + \frac{4.50\,kg \cdot 9.81\,m/s}{2.83 \times 10^{-3}} = 2.65\,atm$

$V = \frac{nRT}{P} = 4.69 \times 10^{-4}\,m^3$

$\Delta V = (4.69 \times 10^{-4}\,m^3 - 3.55 \times 10^{-4}\,m^3) = 1.14 \times 10^{-4}\,m^3$

$\Delta H = \frac{\Delta V}{A} = 0.040\,m$

$Work = -0.04\,m \cdot 759\,N = -30.5\,J$

Since at end state, temperature of N_2 returns to $30°C$,

no change in temperature between initial and final states,

there is no change in internal energy of N_2.

$$\Delta E_{internal} = Work + Heat$$

$$= 0$$

$$Heat = - Work$$

$$= 30.5 J$$

30.5 J heat flows in the system (N_2 gas in cylinder)

throughout the whole process.