Midterm Exam #2
CEE 11 – Engineered Systems and Sustainability
University of California at Berkeley
Fall Semester 2022

NAME: Solutions

Instructions: answer the questions that follow directly on these pages in the spaces provided. Use the back of the page if you need more room for your answer. If you believe there is insufficient information provided to answer a question completely, state reasonable additional assumptions and proceed from there.

This quiz is closed-book/closed-notes, but see last page for aid sheet. You may use a calculator.

Please write your name in the space provided above!

Time: 50 minutes

Question	SCORE:	OUT OF:
1	_____	5
2	_____	5
3	_____	5
4	_____	5
Total	_____	20

1. DRINKING WATER DISINFECTION

(a) Suppose chlorine is using to disinfect water. When chlorine dissolves in water it forms both hypochlorous acid (HOCl) and hypochlorite ion (OCl^-). At pH = 7.75, what fraction of dissolved chlorine will be present as HOCl?

The equilibrium constant $K_A = [H^+][OCl^-]/[HOCl] = 3 \times 10^{-8}$ mol/L.

Given pH = 7.75, $[H+] = 10^{-pH} = 1.8 \times 10^{-8}$ mol/L.

$$\alpha_{HOCl} = \frac{[HOCl]}{[HOCl] + [OCl^-]} = \frac{1}{1 + \frac{[OCl^-]}{[HOCl]}} = \frac{1}{1 + \frac{K_A}{[H^+]}}$$

$$= \frac{1}{1 + \frac{3 \times 10^{-8}\ mol/L}{1.8 \times 10^{-8}\ mol/L}}$$

$$= \frac{1}{1 + 1.67}$$

= 37.5% of chlorine will be in HOCl form.

(b) identify three other methods that can be used to disinfect drinking water.

boiling

ozonation

filtration

germicidal UV radiation

2. COAL COMBUSTION

The complete stoichiometric combustion of graphite can be written

$$C(s) + O_2 + 3.8\ N_2 \rightarrow CO_2 + 3.8\ N_2$$

(a) What fraction of the carbon in graphite is not fully oxidized to CO_2 under fuel-rich combustion conditions with $\lambda = 0.9$?

At $\lambda = 0.9$, combustion stoichiometry is

$$C(s) + 0.9[O_2 + 3.8N_2] \longrightarrow a\,CO + b\,CO_2 + 3.4N_2$$

carbon balance: $a + b = 1$

oxygen balance: $a + 2b = 1.8$

} so $b = 0.8$, $a = 0.2$

Answer: 20% of carbon in the fuel is emitted in the form of CO, a product of incomplete combustion. The remaining 80% is emitted as CO_2.

(b) What fraction of the fuel energy input in part (a) is wasted due to incomplete combustion? The heating values of CO and graphite are 10.1 and 32.8 kJ/g, respectively.

CO

$$\text{wasted energy} = \frac{0.2 \text{ mol}}{\text{mol C}} \times 10.1 \frac{\text{kJ}}{\text{g CO}} \times \frac{28 \text{ g}}{\text{mol}} = 56.6 \text{ kJ}$$

$$\text{complete combustion} = \frac{1 \text{ mol}}{\text{mol C}} \times 32.8 \frac{\text{kJ}}{\text{g C}} \times \frac{12 \text{ g}}{\text{mol}} = 393.6 \text{ kJ}$$

$$\frac{\text{wasted}}{\text{ideal}} = \frac{56.6}{393.6} = 14.4\%$$

alternative calculation

$$\% \text{ waste} = \frac{0.2 \text{ mol} \times 28 \text{ g/mol} \times 10.1 \text{ kJ/g}}{1 \text{ mol} \times 12 \text{ g/mol} \times 32.8 \text{ kJ/g}} = 14.4\%$$

(c) Name three air pollutants other than CO and CO_2 that are typically emitted when real coal is burned in place of graphite.

S in coal → sulfur dioxide (SO_2)

N in coal → nitric oxide (NO)

mineral matter → ash (particulate matter or PM) in coal

3. WIND AND SOLAR POWER

(a) Annual electricity consumption averages 14 MWh for each household in Texas. How many wind turbines with rated power output of 5 MW would be needed to supply enough electricity to power all 11 million households in Texas? Assume a capacity factor of 30% for the wind turbines.

$$\#\text{ of turbines needed} = \frac{14\ \frac{\text{MWh}}{\text{yr}} \times 11\ \text{million homes}}{5\ \frac{\text{MW}}{\text{turbine}} \times \frac{365 \times 24\ \text{hrs}}{\text{yr}} \times 0.3}$$

$$= 11{,}720\ \text{turbines}$$

+ a lot of new transmission lines!

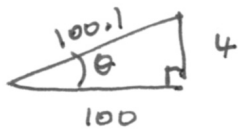
(b) Explain why single-junction solar panels made of crystalline silicon cannot convert more than 32% of incident sunlight energy into electricity. The band gap energy for silicon is 1.1 eV.

① photons with energies below the required band gap give no power output ($\lambda > 1100$ nm IR)

② photons with higher than the band gap energy — the excess photon energy above the band gap energy is not used → more energy loss. This loss gets bigger as we progress from red to violet wavelengths.

③ other practical issues including reflection of some incoming sunlight and blocking of solar beam by electrical contacts on panel surface.

4. RUNAWAY CAR ON A DOWNHILL GRADE



Suppose a car is coasting in neutral and without braking on a long downhill section of highway with a grade of 4%. What is the terminal velocity (answer in km/h) that the car would reach?

→ $\tan\theta = \frac{\sin\theta}{\cos\theta} \simeq 0.04$, with $\cos\theta \simeq 1$

Vehicle properties: m = 1500 kg, $C_D = 0.3$, $A_F = 2.5\ m^2$, $C_R = 0.015$.

$$C_R mg + C_D A_F \frac{\rho_a v^2}{2} = mg \sin\theta$$

$$v = \left[\frac{2(\sin\theta - C_R)mg}{C_D A_F \rho_a}\right]^{1/2}$$

$$= \left(\frac{2(0.04 - 0.015) \times 1500\ kg \times 9.8\ \frac{m}{s^2}}{0.3 \times 2.5\ m^2 \times 1.2\ kg/m^3}\right)^{1/2}$$

$$= 28.6\ m/s$$

Converting to km/h units

$$v = 28.6\ \frac{m}{s} \times \frac{1\ km}{1000\ m} \times \frac{3600\ s}{1\ hr}$$

$$= 103\ km/h$$