ENV 4001: Environmental Systems Engineering

Fall 2021
Test #1
Wednesday, Sept. 29

University of South Florida
Civil & Environmental Eng.
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Instructions:

1. You may read these instructions, but do not turn the page or begin working until instructed.
2. This quiz contains four questions. Answer question 1. Then choose ***any two of the last three problems***.
3. If you attempt *all* the problems (not recommended), make sure you clearly indicate which ones you want me to grade. If it is not clear, I will grade whichever ones I think I can grade the fastest. That might not work in your favor.
4. Some questions might have multiple parts. In those cases, the point value of each part is indicated. The total number of points possible is 60.
5. Unit conversion factors and other potentially useful information is provided on the back of this page.
6. Answer each question in the space provided. If you need more space, you can attach additional pages as needed, but make sure to put your name on them.
7. Show your work and state any important assumptions you make. I cannot award partial credit if I can't follow what you did.
8. Report a reasonable number of significant digits in your answers.
9. Include units in your answers as appropriate. An answer without proper units is not correct!
10. You are allowed to use your text book, your course notes, or other printed materials. You may not receive help from another person.
11. A hand-held calculator is recommended. Other electronic devices are not permitted.
12. Time limit: 60 minutes. Stop working when asked. If you continue working after time has been called, you will be penalized at a rate of 1 point per minute.
13. **Don't cheat**. Cheating will result in appropriate disciplinary action according to university policy. More importantly, cheating indicates a lack of personal integrity.
14. Please print your name legibly in the space indicated below, and turn in this test at the end of the period.
15. Hints:
    - Read each question carefully and answer the question that is asked.
    - Watch your units. If you take good care of your units, they will take good care of you.
    - Work carefully and don't rush.

Name: ANSWER KEY … test version 2

Potentially useful constants:

Ideal gas constant, R:	8.314 Pa•m^3•mol^{-1}•K^{-1} = 82.06×10^{-6} atm•m^3•mol^{-1}•K^{-1}
Gravitational acceleration, g:	9.81 m/s^2
Molar mass of water, H_2O:	18.01 g/mole
Density of water at 25 °C:	0.9970 g/mL = 997 kg/m^3
Viscosity of water at 25 °C:	0.890×10^{-3} Pa•sec
Density of air at 25 °C:	1.18 kg/m^3
Viscosity of air at 25 °C:	1.85×10^{-5} Pa•sec

Potentially useful conversion factors:

Pressure:	1 atm = 760 mm Hg = 760 torr = 101325 Pa
	1 Pa = 1 N/m^2 = 1 kg/(m•sec^2)
Mass:	1 kg = 1000 g = 10^6 mg = 10^9 μg
	1 kg = 2.207 lb_{mass}
	1 t (metric tonne) = 1000 kg = 2207 lb_{mass}
	1 ton (English ton) = 2000 lb_{mass}
Length:	1 km = 1000 m = 10^5 cm = 10^6 mm = 10^9 μm
	1 ft = 12 in = 30.48 cm = 0.3048 m
Temperature:	25 °C = 298.15 K
Volume:	1 m^3 = 1000 L = 10^6 mL = 10^6 cm^3
	1 gal = 3.785 L
Work/Energy:	1 BTU = 1.055 kJ
Power:	1 MW = 10^6 W = 10^6 J/s = 10^6 N•m/s
Area :	1 ha = 10^4 m^2

Atomic Masses:

H = 1.008 g/mole	C = 12.011 g/mole	N = 14.007 g/mole	O = 15.999 g/mole
P = 30.974 g/mole	S = 32.06 g/mole	Cl = 35.453 g/mole	Br = 79.904 g/mole
Na = 22.99 g/mole	Mg = 24.31 g/mole	Al = 26.98 g/mole	K = 39.10 g/mole
Ca = 40.08 g/mole	Fe = 55.85 g/mole	Cu = 63.55 g/mole	

1. (10 pts) The United Nations has developed 17 *Sustainable Development Goals* (SDGs). Below, I have listed the numbers of six of the SDGs. In the spaces next to the numbers, you are required to indicate the *name of the goal* and a *brief description of the goal*. To help you, I have provided lists of the names and descriptions – but in the wrong order, of course. All you have to do is fill in the blanks with the proper letters. I have already done one of them for you, so you see how it works. Your job is to fill in the remaining 10 blanks. Please write clearly so I can tell what letter you have put in each blank. (No credit if I can't read it!)

SDG number	SDG name	Description
1	B	K
3	A	J
6	D	G
9	E	L
13	C	H
14	F	I

List of SDG names (put these in the middle column in the table above):

A. Good health and well-being

~~B. No poverty~~

C. Climate action

D. Clean water and sanitation

E. Industry, innovation, and infrastructure

F. Life below water

List of SDG descriptions (put these in the last column in the table above):

G. Ensure access to water and sanitation for all

H. Take urgent action to combat climate change and its impacts

I. Conserve and sustainably use the oceans, seas, and marine resources

J. Ensure healthy lives and promote well-being for all at all ages

~~K. End poverty in all its forms everywhere~~

L. Build resilient infrastructure, promote sustainable industrialization, and foster innovation

2. (25 pts) A student working in the laboratory needs to use an aqueous solution that contains cyanide, CN^- (*aq*), and has a pH of 6.0. This is dangerous, because the cyanide ion is in equilibrium with hydrogen cyanide, HCN (*aq*), which is also called hydrocyanic acid. The HCN can volatilize into the air, and the student might breathe it. Breathing HCN is very dangerous – in fact it is lethal at concentrations above 200 ppm or so. We want to make sure that the concentration in the air does not exceed 100 ppm. I looked up Henry's constant for HCN and I found a value of 9.3 mol/(L•atm).

The temperature in the lab is 22 °C and the pressure is atmospheric.

a. (4 pts) If the allowable concentration of HCN in the air is 100 ppm, what is the allowable *partial pressure* of HCN in the air? Report your answer in units of atm.

$$\frac{P_{HCN}}{P_{total}} = \frac{100}{1{,}000{,}000} \Rightarrow P_{HCN} = \left(\frac{100}{1{,}000{,}000}\right)(1 \text{ atm})$$

$$\boxed{P_{HCN} = 1.0 \times 10^{-4} \text{ atm}}$$ allowable partial pressure

b. (7 pts) If the allowable concentration of HCN in the air is 100 ppm, what is the allowable concentration in units of mg/m³?

$$\frac{n}{V} = \frac{P}{RT} = \frac{(1.0 \times 10^{-4} \text{ atm})}{\left(82.06 \times 10^{-6} \frac{\text{atm} \cdot \text{m}^3}{\text{mol} \cdot \text{K}}\right)(295.\text{ K})} = 4.131 \times 10^{-3} \frac{\text{mol}}{\text{m}^3}$$

molar mass of HCN = 27.03 g/mol

$$\left(4.131 \times 10^{-3} \frac{\text{mol}}{\text{m}^3}\right)\left(27.03 \frac{\text{g}}{\text{mol}}\right)\left(\frac{1000 \text{ mg}}{1 \text{ g}}\right) = \boxed{112 \text{ mg/m}^3}$$ allowable conc. in mg/m³

problem 2 continues →

2. continued

c. (4 pts) If the allowable concentration of HCN in the air is 100 ppm, and we assume that the air is in equilibrium with the student's aqueous solution, what is the allowable concentration of HCN in the aqueous solution? Report your answer in units of mol/L.

$HCN (g) \rightleftharpoons HCN (aq)$ ... air-water equilibrium ... Henry's Law!

Given $K_H = 9.3 \frac{mol/L}{atm}$

$[HCN (aq)] = (1.0 \times 10^{-4} \ atm)(9.3 \frac{mol/L}{atm}) = \boxed{9.3 \times 10^{-4} \frac{mol}{L}}$ allowable aqueous conc.

d. (10 pts) Under the conditions described above, what is the allowable concentration of CN^- in the aqueous solution, in units of mg/L? The student must make sure that the CN^- concentration in solution does not exceed this value, or it could be dangerous! Hint: the CN- (*aq*) ion is in equilibrium with the HCN (*aq*).

$HCN (aq) \rightleftharpoons H^+ + CN^-$ $pK_A = 9.2$ from table in text

$$\frac{\{H^+\}\{CN^-\}}{\{HCN\}} = 10^{-9.2} \Rightarrow \frac{[H^+][CN^-]}{[HCN]} = 10^{-9.2}$$

Know $pH = 6.0 \Rightarrow [H^+] = 10^{-6.0}$ ... also $[HCN] = 9.3 \times 10^{-4} \frac{mol}{L}$ from above

$$[CN^-] = (10^{-9.2})(9.3 \times 10^{-4}) / (10^{-6.0}) = 5.868 \times 10^{-7} \frac{mol}{L}$$

$$(5.868 \times 10^{-7} \frac{mol}{L})(\frac{26.02 \ g}{1 \ mol})(\frac{1000 \ mg}{1 \ g}) = \boxed{0.015 \ mg/L}$$

That's quite low! To be safe, we must keep the conc. of CN^- very low, to avoid formation of toxic HCN.

NOTE: If you were really working with these chemicals in the lab, you would take a lot of extra safety precautions. For the purposes of this test, we are assuming that the student is (foolishly) not using these extra precautions.

3. (25 pts) *based on a problem from your text book ... but don't bother looking for the solution, it's not there.*
If you attend an ice-hockey game, you will see the ice rink use a re-surfacing machine to treat the ice between periods. The most popular brand of ice re-surfacing machine is Zamboni; often the re-surfacing machine is just called "the Zamboni". As far as I know, the Zamboni runs on a standard gasoline-powered internal combustion engine. This means that it emits carbon monoxide (CO) into the air as it operates. If the fuel injector has the right air-to-fuel ratio, the CO emission rate will be low, and it isn't a problem. But if the CO emission rate is too high, we could have a problem, because CO is being emitted into a closed space (i.e., the ice rink), and it is bad for your health at high concentrations.

Suppose we have the following information about our favorite ice rink.

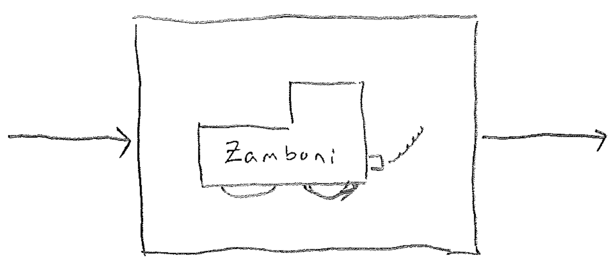
- The volume of air inside the arena is $V = 5.0\times10^4$ m^3, and it is well mixed.
- The arena is ventilated at a rate $Q = 4.0$ m^3/s.
- The concentration of CO in the ventilation air pumped *in* to the arena is $C_I = 2.5$ mg/m^3.
- Our poorly tuned Zamboni emits CO at a rate $E = 62$ mg/s as it operates.
- CO is non-reactive.
- When the Zamboni first starts operating, the concentration of CO in the air inside the arena is $C_0 = 2.5$ mg/m^3. However, that concentration might change over time because the Zamboni is emitting CO into the air.

a. (12 pts) *Write a mass balance* for the mass of CO in the air inside the arena. Then, use your mass balance to *derive a differential equation* that describes the rate of change of the *concentration* of CO in the air. Your differential equation should be in the form $dC/dt = \ldots$, where C represents the concentration of CO in the air inside the rink.

Control volume = ice rink / arena.

Balance : mass of CO

1 stream in, 1 stream out



Accumulation = Flow in − Flow out + Sources − Sinks

$$\frac{d}{dt}\begin{bmatrix}\text{mass of CO} \\ \text{in arena air}\end{bmatrix} = QC_I - QC_E + E - 0$$

$$\frac{d}{dt}[V\cdot C] = QC_I - QC_E + E.$$ Notice $C_E = C$ because well mixed.

$$V\frac{dC}{dt} = QC_I - QC + E$$

$$\boxed{\frac{dC}{dt} = \frac{Q}{V}C_I - \frac{Q}{V}C + \frac{E}{V}}$$

problem 3 continues →

3. continued

b. (7 pts) If the Zamboni ran forever, eventually the concentration of CO in the air would reach a steady-state value. What would be the steady-state concentration of CO in the air inside the arena? You must show your work to get full credit. Hint: you do not need to solve the differential equation from part (a) in order to answer this. Instead, how would your mass balance change for these conditions?

At steady state, accumulation = 0, but everything else is the same.

$0 = QC_I - QC_E + E - 0$ ... and $C_E = C$ because well-mixed.

$QC = QC_I + E \Rightarrow C = C_I + \frac{E}{Q}$ at steady-state

$C = 2.5\ \frac{mg}{m^3} + \frac{62\ mg/s}{4.0\ m^3/s} \Rightarrow \boxed{C = 18\ \frac{mg}{m^3}}$ at steady state

c. (6 pts) I thought about asking you to solve the differential equation, but probably that is too much to ask in a timed exam. I will give you the solution instead. The following expression gives the concentration of CO in the air inside the arena.

$$C(t) = \left(C_I + \frac{E}{Q}\right) - \left(C_I + \frac{E}{Q} - C_0\right) e^{-\frac{Q}{V}t}$$

We want to be sure that the concentration of CO in the arena stays below 10 mg/m^3. How long (in minutes) would the Zamboni have to operate in order for the air concentration to exceed this level? Based on this, are you worried about attending an indoor ice-hockey game?

$10\ \frac{mg}{m^3} = 18\ \frac{mg}{m^3} - \left(18\ \frac{mg}{m^3} - 2.5\ \frac{mg}{m^3}\right) e^{-\frac{Q}{V}t}$

$-8\ \frac{mg}{m^3} = -\left(15.5\ \frac{mg}{m^3}\right) e^{-\frac{Q}{V}t} \Rightarrow \frac{8.0}{15.5} = e^{-\frac{Q}{V}t} \Rightarrow \ln\left(\frac{8.0}{15.5}\right) = -\frac{Q}{V}t$

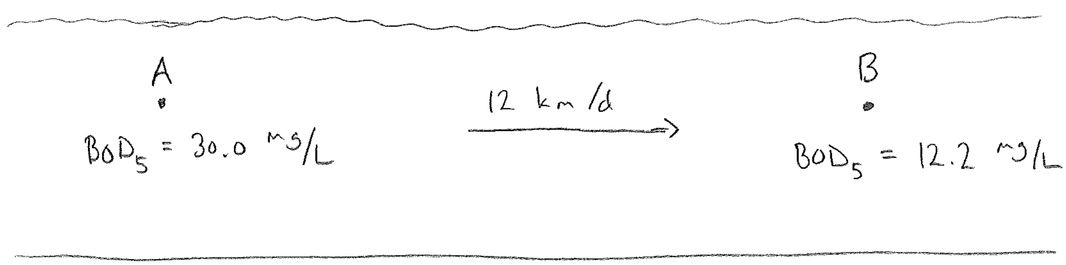
$-0.6614 = -\frac{Q}{V}t \Rightarrow t = (0.6614)\frac{V}{Q} \Rightarrow t = 0.6614\ \theta$

$t = 0.6614\left(\frac{5 \times 10^4\ m^3}{4.0\ m^3/s}\right) = 8267\ s * \frac{1\ min}{60\ s} = \boxed{138\ min}$

We should be fine. The Zamboni would have to run for over 2 hr before the CO concentration would reach a dangerous level.

4. (25 pts) I am concerned about the levels of dissolved oxygen in a nearby river. I took water samples from the river from two locations, point A and point B. Point B is 36 km downstream of point A. I brought the water samples back to the lab, and I ran 5-day BOD tests for each of the water samples. Here is some more information.
   - Average velocity of the river = 12 km/d
   - Measured BOD_5 in sample from point A = 30.0 mg/L
   - Measured BOD_5 in sample from point B = 12.2 mg/L
   - Degradation of pollutants in the river follows first-order kinetics

   a. (8 pts) Estimate/calculate the first-order rate coefficient, k_1, for degradation of pollutants in the river. Hint #1: use the measured BOD_5 values from point A and point B. Hint #2: a river can be modeled as what type of a reactor? Hint #3: You can assume steady-state conditions. Hint #4: BOD is a measure of the level of pollution in the river.



- Rivers behave like plug-flow reactors
- So we have PFR, steady state, first-order kinetics
- Thus: $C_E = C_I e^{-k_1 \theta}$
- But what are C_E C_I and θ ?
- River flows from point A to point B so $C_I = 30.0$ mg/L $C_E = 12.2$ mg/L

  Travel time is 3 d from point A to point B

$$(12.2 \text{ mg/L}) = (30.0 \text{ mg/L}) \exp[-k_1 (3.0 \text{ d})] \Rightarrow \ln\left(\frac{12.2}{30}\right) = -k_1 (3.0 \text{ d})$$

$$\boxed{k_1 = 0.30 \text{ d}^{-1}}$$

problem 4 continues →

4. continued

b. (9 pts) Suppose I had run my BOD tests for a really long time (much longer than 5 days). If I had done that, what BOD would I have measured in sample A and in sample B?

Problem is asking for BOD_{ult}! ... we know BOD_5 and k_1.

Point A: $BOD_5 = BOD_{ult}\{1 - \exp[-k_1(5\,d)]\}$

$30.0\ mg/L = BOD_{ult}\{1 - \exp[-(0.30\ d^{-1})(5.0\ d)]\}$

$\boxed{BOD_{ult} = 38.6\ mg/L}$ at Point A

Point B: $BOD_5 = BOD_{ult}\{1 - \exp[-k_1(5\,d)]\}$

$12.2\ mg/L = BOD_{ult}\{1 - \exp[-(0.30\ d^{-1})(5\,d)]\}$

$\boxed{BOD_{ult} = 15.7\ mg/L}$

c. (8 pts) How much oxygen was consumed by bacteria in the river between point A and point B? Hint: how much pollutant went away between point A and point B? – how much O_2 would be consumed if that much pollutant went away?

At point A, $L_0 = BOD_{ult} = 38.6\ mg/L$. There's enough contaminant to consume $38.6\ mg/L\ O_2$.

At point B, $L_0 = BOD_{ult} = 15.7\ mg/L$, There's enough contaminant to consume $15.7\ mg/L\ O_2$.

How much contaminant went away? ... enough to consume $22.9\ mg/L\ O_2$.

How much O_2 would be consumed by that? $\boxed{22.9\ mg/L\ O_2 \text{ consumed}}$

5. (2 pts) EXTRA CREDIT
Name the band that first recorded the song "[I wanna drive the] Zamboni".

The Gear Daddies.
You can find it on Spotify!

END OF TEST