GEORGIA INSTITUTE OF TECHNOLOGY
School of Civil & Environmental Engineering
CEE 2300 – Environmental Engineering Principles

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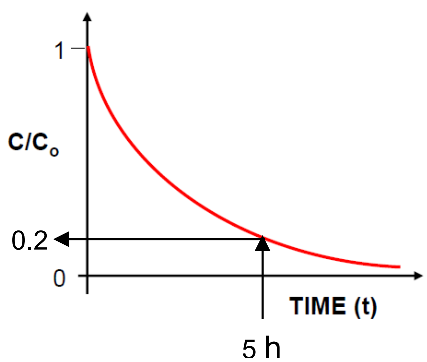
EXAM 2 – SOLUTIONS

1. (25 points) Briefly define/explain/answer the following:

1-a (5 pts) Priority Pollutants

The federal Clean Water Act (CWA), Section 307 defines a list of 129 priority pollutants for which the U.S. EPA must establish ambient water- quality criteria (the basis of state water-quality standards) and effluent limitations (rules controlling environmental releases from specific industrial categories based on the "best available technology economically achievable"). The initial list of priority pollutants was based on a 1977 consent decree that settled a legal challenge to the U.S. EPA's program for controlling hazardous pollutants (Natural Resources Defense Council; June 9, 1976).

1-b (5 pts) Plot the normalized concentration of a pollutant (C/C_o on the y-axis) versus time (t on the x-axis) for a batch reactor achieving 80% pollutant destruction in 5 hours assuming that pollutant destruction follows first-order kinetics.



1-c (5 pts) First Law of Thermodynamics.

Energy cannot be created or destroyed, excluding nuclear reactions (but energy can be converted)(conservation of energy).

1-d (5 pts) Second Law of Thermodynamics.

Energy conversion is not 100% efficient; thus, loss of useful energy occurs, typically through waste heat. In other words, there will always be some waste heat released during energy conversions.

1-e (5 pts) Convective Heat Transfer (give an example)

Heat transfer in which a fluid (gas or liquid) at one temperature comes in contact with a substance at another temperature. Example: heating a room with hot water radiator or a stove.

2. **(25 points)** For a continuous-flow, completely mixed reactor (i.e., CSTR), do the following:
2-a. Set up a mass balance equation for a zero-order contaminant removal rate and then solve it for the steady-state detention time (θ).

2-b. For a CSTR system with a flow rate (Q) equal to 1,000 m^3/day, an influent contaminant concentration(C_o) equal to 200 mg/L, and a zero-order reaction rate constant (k) equal to 20 mg/L · day, calculate the steady-state detention time (θ, days) and the reactor volume (V, m^3) necessary to achieve a contaminant removal efficiency equal to 90%.

<u>Solution:</u>

2-a: Zero-order rate: $dC/dt = - k$

Write a mass balance for steady-state: $V\, dC/dt = 0 = Q\, C_o - Q\, C_t - k\, V$

Divide by Q and set $V/Q = \theta$ = hydraulic retention time (T)

$0 = C_o - C_t - k\, \theta$

Solve for θ: $\boxed{\theta = (C_o - C_t)/k}$

2-b: For an influent contaminant concentration of 200 mg/L and a reactor removal efficiency of 90%,

$C_t = (1 - 0.9)\, 200 = 20$ mg/L

$\theta = (200 - 20)$ mg/L x (1/20) L · day/mg $\boxed{= 9 \text{ days}}$

But, $\theta = V/Q \implies V = \theta\, Q = (9\text{ d})\, 1000\ m^3/d$ $\boxed{= 9{,}000\ m^3}$

3. **(25 points)** A homeowner is considering buying a new natural gas furnace. Assume natural gas is 100% methane delivered at 25^{o}C and 1 atm pressure. The methane lower heating value (LHV or net heat of combustion) at 25^{o}C is -802.2 kJ/mol of methane, whereas its higher heating value (HHV or gross heat of combustion) at 25^{o}C is -890.2 kJ/mol of methane. For a typical home in Georgia with an annual gas consumption equivalent to 20,000 kWh and the price of 1 m^3 of natural gas at \$0.26, calculate the annual savings in dollars related to natural gas consumption if the homeowner buys a condensing as opposed to a non-condensing furnace.
Note: 1 kWh = 3,600 kJ

Solution:

Gas volume/mol at 25^{o}C and 1 atm:

V = n R T/P = 1 mol x 0.082 L atm/mol K x 298 K x 1/1 atm = 24.4 L/mol = 0.0244 m^3/mol

A) Annual gas cost for a non-condensing furnace:

Energy/m^3 gas = (802.2 kJ/mol gas) x (1/3,600 kWh/kJ) x (1 mol gas/0.0244 m^3 gas) =
= 9.13 kWh/m^3 gas

Gas cost = (20,000 kWh/yr) x (1/9.13 kWh/m^3 gas) x (\$0.26/m^3 gas) = \$569.6/year

B) Annual gas cost for a condensing furnace:

Energy/m^3 gas = (890.2 kJ/mol gas) x (1/3,600 kWh/kJ) x (1 mol gas/0.0244 m^3 gas) =
= 10.13 kWh/m^3 gas

Gas cost = (20,000 kWh/yr) x (1/10.13 kWh/m^3 gas) x (\$0.26/m^3 gas) = \$513.3/year

Savings = \$569.6 - \$513.3 $\boxed{= \$56.3/\text{year}}$ Or ($56.3/$569.6) x 100 $\boxed{= 9.9\% \text{ savings}}$

Alternative, shorter solution:

Yearly gas consumption: 20,000 kWh x 3,600 kJ/kWh = 7.2 x 10^7 kJ/year

Difference condensing vs. non-condensing furnace: 890.2 - 802.2 = 88 kJ/mol methane

Savings: 88/890.2 = 0.0989 per mol methane

(7.2 x 10^7 kJ/year) x (1/802.2 kJ/mol) x 0.0989 = 8,872 mol methane/year

(8,872 mol methane/year) x (0.0244 m^3/mol) x \$0.26/m^3 $\boxed{= \$56.3/\text{year}}$

4. (25 points) An uncovered swimming pool loses 1 inch of water off of its 1,000 ft^2 surface per week due to evaporation. The heat of vaporization for water at the pool temperature is 1,050 BTU/lb. The cost of energy to heat the pool is $10 per million BTU. A salesman claims that a $500 pool cover that reduces evaporative water losses by two-thirds will pay for itself in one 15-week swimming season. Can it be true?
Note: 1 ft = 12 in; water specific weight = 62.4 lb/ft^3

Solution:

Energy lost due to water evaporation:

$$1 \text{ in/week} \times 15 \text{ wks} \times 1 \text{ ft}/12 \text{ in} \times 1{,}000 \text{ ft}^2 \times 62.4 \text{ lb/ft}^3 \times 1{,}050 \text{ BTU/lb} = 81.9 \times 10^6 \text{ BTU/season}$$

Cover saves:

$$2/3 \times 81.9 \times 10^6 \text{ BTU/season} \times \$10/10^6 \text{ BTU} \boxed{= \$546/\text{year}}$$

ANSWER: Yes, a $500 cover does pay for itself in less than one season.