GEORGIA INSTITUTE OF TECHNOLOGY

School of Civil & Environmental Engineering

CEE 2300 – Environmental Engineering Principles

Instructor: S. G. Pavlostathis **Spring 2013**

EXAM 2 – Closed Book & Notes

DATE: Wednesday, March 13, 2013

TIME: 1:35 to 2:55 PM

NAME: ___________________________

Student ID #: _____________________

1. ________/25
2. ________/25
3. ________/25
4. ________/25

TOTAL: ________/100

NAME: ______________________________

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

1-a (5 pts) Priority Pollutants

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.

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

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

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%.

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

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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?
<u>Note</u>: 1 ft = 12 in; water specific weight = 62.4 lb/ft^3

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APPENDIX – USEFULL EQUATIONS & DATA

Atomic weights: H =1, O = 16, C = 12, N = 14, S = 32, P = 31, Ca = 40, F = 19, Al = 27, Na = 23
Mg = 24.3

Ideal gas law: $P V = n R T$ $R = 0.082$ L atm/(mol K)

Absolute temperature: $K = {}^{o}C + 273.15$
${}^{o}R = {}^{o}F + 459.67$

Henry's law: $P_{A,g} = k_H [A]$
$P_{A,g}$ = partial pressure of A gas, atm
k_H = Henry's law constant, L · atm/mol
$[A]$ = aqueous-phase concentration of A, mol/L

Water: $[H^+] [OH^-] = K_w = 10^{-14}$ $(mol/L)^2$ @ 298 K

pH: $pH = -\log [H^+]$ $[H^+]$ in units of mol/L

Acetic acid: $AcH \Leftrightarrow Ac^- + H^+$ $pK_a = 4.7$

Carbonate system (@ 298 K):
$[CO_2]_{aq} = K_H P_{CO2} P_{total}$ $K_H = 0.0334$ mol/L · atm
$CO_{2,\,aq} + H_2O \Leftrightarrow H^+ + HCO_3^-$ $K_1 = 4.47 \times 10^{-7}$ mol/L
$HCO_3^- \Leftrightarrow H^+ + CO_3^{2-}$ $K_2 = 4.68 \times 10^{-11}$ mol/L

Gibbsite (@ 298 K): $Al(OH)_{3\,(s)} \Leftrightarrow Al^{3+} + 3\,OH^-$ $K_{sp} = 1 \times 10^{-32}$ mol^4/L^4

Kinetics (Removal or destruction)

Rate Order	Rate Expression	Batch Reactor Time (t)	CSTR Detention time (θ)	PFR Detention time (θ)
Zero	$dC/dt = -k$	$t = (C_o - C_t)/k$	$\theta = (C_o - C_t)/k$	$\theta = (C_o - C_t)/k$
First	$dC/dt = -k\,C$	$t = (\ln C_o - \ln C_t)/k$	$\theta = [(C_o/C_t) - 1]/k$	$\theta = (\ln C_o - \ln C_t)/k$
Second	$dC/dt = -k\,C^2$	$t = [(1/C_t) - (1/C_o)]/k$	$\theta = [1/(k\,C_t)]\,[(C_o/C_t) - 1]$	$\theta = [(1/C_t) - (1/C_o)]/k$

CSTR–Step Function Response: $C_t = C_\infty + (C_o - C_\infty) \exp[-(k + \theta^{-1})t]$
k = first-order rate constant (d^{-1})
θ = hydraulic retention time (d)

ΔH^o = heat of reaction = $\Sigma_{products} H^o - \Sigma_{reactants} H^o$ where H^o = standard enthalpy at 298 K

Rate of change in stored energy (Heat): $\Delta H = \dot{m}\, c\, \Delta T$
$\dot{m}$ = mass flow rate
c = specific heat capacity
ΔT = temperature change

Heat transfer rate: $q = A (T_2 - T_1)/R$
q = heat transfer rate through a surface (W or BTU/h)
A = surface area (m^2 or ft^2)
T_2, T_1 = high, low temper. on each side of the surface (°C or °F)
R = overall thermal resistance (m^2 °C/W or ft^2 °F h/BTU)