CIVE 3331 Environmental Engineering
Spring 2005 Exam #1

Name: solution

Problem 1 – (Concentration)

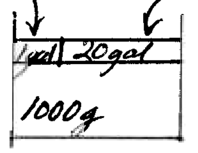
(20 points) One individual pours one gallon containing 10,000 mg/L of a hazardous chemical into 1,000 gallons of water. A second person pours 20 gallons containing 2,500 mg/L of the same chemical in the water. You learn that the chemical formula of this highly biodegradable chemical is $C_{10}H_{20}$. You collect a 5-mL sample for your laboratory to analyze. What laboratory results do you expect for:

a. Concentration of the chemical after the second individual has added their 20 gallons (express results in ppm)?
b. The COD in the 5-mL sample in mg/L?

The oxidation equation for the COD is (naturally, you have to balance the equation!)

$\underline{1}\ C_{10}H_{20} + \underline{15}\ O_2 \Leftrightarrow \underline{10}\ CO_2 + \underline{10}\ H_2O$

1 gal @ 10,000 mg/L — 20 gal @ 2500 mg/L



$\underbrace{\qquad\qquad}_{V_t = 1021\ gal}$

a) $\dfrac{(1\ gal)(10{,}000\ mg/L) + (20\ gal)(2500\ mg/L)}{1021\ gal}$

$= 58.76\ mg/L$ $\qquad \underline{\underline{\sim 58\ mg/L}}$

b) $C_{10}H_{20} + 15\,O_2 \rightleftharpoons 10\,CO_2 + 10\,H_2O$

$58.8\ mg/L\ C_{10}H_{20} \cdot \dfrac{1\ mol\ C_{10}H_{20}}{140\ g\ C_{10}H_{20}} \cdot \dfrac{15\ mol\ O_2}{1\ mol\ C_{10}H_{20}} \cdot \dfrac{32\ g\ O_2}{1\ mol\ O_2} = 202.28\ mg/L - O_2$

$\underline{\underline{\sim 200\ mg/L\ O_2}}$

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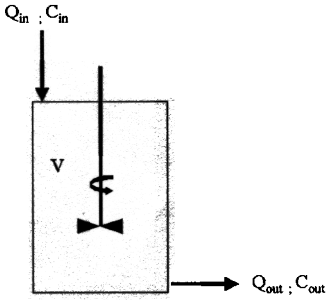
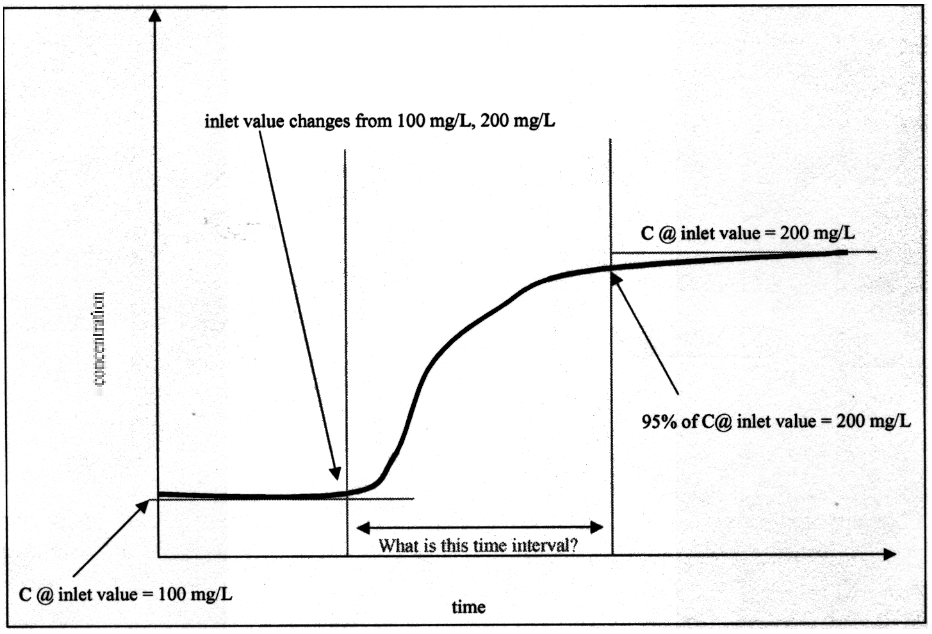
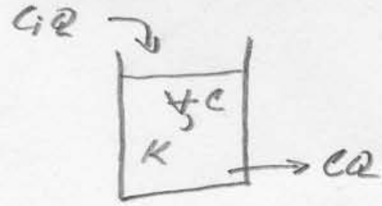
Problem 2 – (Mass Balance)

(40 points) The reactor in the sketch below is used to treat an industrial waste product, using a reaction that destroys the pollutant according to first-order kinetics with k = 0.25/day. The reactor volume is 500 m^3, the volumetric flow rate of inlet and outlet is 50 m^3/day, and the inlet constituent concentration is 100 mg/L.



(1) Write the **transient** (non-equilibrium) mass balance model (equations) for the reactor (leave in algebraic form).
(2) Determine the **equilibrium** concentration of the constituent in the reactor using the numerical values provided.
(3) Determine the **equilibrium** concentration of the constituent in the reactor if the inlet concentration is doubled (200 mg/L).
(4) Use the **transient** model solution to determine how long until the constituent concentration is 95% of the new equilibrium value (Part 4) after the change in inlet concentration occurs. (Hint: Look at the diagram below)





① $\frac{d}{dt}(CV) = C_iQ - CQ - KCV$

② Equilibrium

$\frac{dCV}{dt} = 0$

$C_iQ = CQ + KCV$

$C = \frac{C_iQ}{Q+KV}$ $\quad C_i = 100\,mg/L$

$C_i = 100\,mg/L$
$V = 500\,m^3$
$Q = 50\,m^3/d$

$$C = \frac{(100\,mg/L)(50\,m^3/d)}{(50\,\frac{m^3}{d} + (\frac{0.25}{day})(500\,m^3)} = \frac{5{,}000\ \frac{mg\,m^3}{d\cdot L}}{(50 + 125\,\frac{m^3}{d})} = \frac{5{,}000}{175} = 28.57\,mg/L$$

③ Double $C_i = 200\,mg/L$

$$C = \frac{(200\,mg/L)(50\,m^3/d)}{(50\,\frac{m^3}{d} + (0.25/d)(500\,m^3)} = \frac{10{,}000}{175} = 57.14\,mg/L$$

④ Time to equilibrium

$$c(t) = \frac{C_2Q}{Q+KV} + \left(\frac{C_1Q}{Q+KV} - \frac{C_2Q}{Q+KV}\right)\exp\left(-\left(\frac{Q+KV}{V}\right)t\right)$$

$C_1 = 100$
$C_2 = 200$

$\frac{Q+KV}{V} = \frac{50\,m^3/d + 0.25(500)}{500}$
$= \frac{175}{500} = 0.35$

$\frac{C_2Q}{Q+KV} = 57.14$, $\frac{C_1Q}{Q+KV} = 28.57$

$$c(t) = 57.14 + (28.57 - 57.14)\exp(-0.35t)$$
$$= 57.14 - 28.57\exp(-0.35t)$$

$C_{95} = 0.95(57.14) = 54.283$

$54.283 - 57.14 = -28.57e^{-0.35t}$ solve for t

$$-2.857 = -28.57\,e^{-0.35t}$$

$$0.1 = e^{-0.35t}$$

$$\ln(0.1) = -0.35\,t$$

$$\frac{\ln(0.1)}{-0.35} = t$$

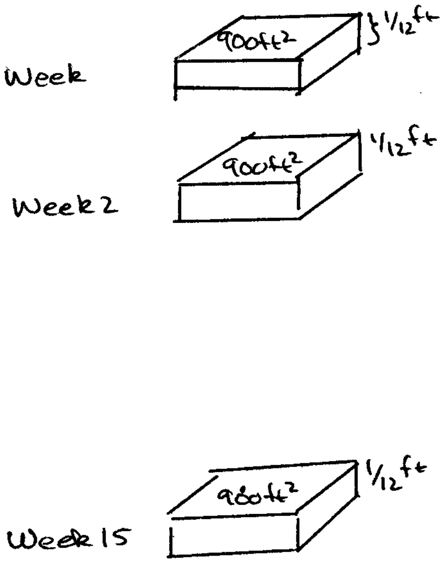
$$\frac{-2.302}{-0.35} = 6.57$$

$\therefore$ 6.57 days to new equilibrium

Name: Solution

Problem 3 – (Energy Balance)

(15 Points) An uncovered swimming pool loses 1.0 inches off its 900 ft^2 surface each week by evaporation. The enthalpy of vaporization for the water at pool temperature is 1000 Btu/lb. The cost of energy to heat the pool is \$10.00 per million Btu. A highly trained sales associate claims that a \$800 pool cover that reduces evaporation by 70% will pay for itself in 15 weeks. Is this claim correct?



Per week

$V_{evap} = (900\,ft^2)(1/12\,ft) = 75\,ft^3$

$M_{evap} = \rho_w V_{evap} = (62.4\,lbs/ft^3)(75\,ft^3) = 4680\,lbs$

$E_{evap} = M_{evap}(BTU/M) = (4680\,lbs)(1000\,Btu/lb) = 4.68 \cdot 10^6\,Btu$

$\$_{evap} = E_{evap}(\$/E) = (4.68 \cdot 10^6\,Btu)(\$10.00/1 \cdot 10^6\,Btu) = \$46.80$

If Evap is reduced 70% then 30% still evaporates

$\$_{evap-with\ cover} = 0.30 \times \$46.80 = \$14.04$

Per 15 weeks

No cover

$\$46.80 \times 15 = 702^{00}$

Cover + Cost of Cover

$\$14.04 \times 15 = \$210^{68} + 800^{00} = \$1010^{60}$

Over only 15 weeks Cover does not pay for itself; sales person is incorrect.

However at 25 weeks, break-even occurs

$(46.80)(25) = \$1170$

$(14.04)(25) + 800 = \$1151$

For long-term cover makes economic sense

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Problem 4- (Chemical Equation Balances; Oxygen Demand)

(25 Points) Suppose a solution of 100.0 mg/L of glycine [$CH_2(NH_2)COOH$] is oxidized biologically. The two reactions are written below. The first reaction represents the conversion of carbon in the glycine to CO2 with a by-product of ammonia. The second reaction represents the conversion of ammonia into nitrate.

(1) Balance the two reactions.

$$\underline{2}\ CH_2(NH_2)COOH + \underline{3}\ O_2 \Rightarrow \underline{4}\ CO_2 + \underline{2}\ H_2O + \underline{2}\ NH_3$$

$$\underline{1}\ NH_3 + \underline{2}\ O_2 \Rightarrow \underline{1}\ NO_3^- + \underline{1}\ H^+ + \underline{1}\ H_2O$$

(2) Determine the theoretical carbonaceous oxygen demand (ThOD for reaction 1).

(3) Determine the theoretical nitrogenous oxygen demand (ThOD for reaction 2).

(4) Determine the total theoretical oxygen demand (Hint: 100mg/L glycine uses how many mg/L oxygen to convert the glycine into CO_2 and NO_3^-)

balance
C – CO_2
NH_2 – NH_3
NH_3 – NO_3
O – H_2O
H – H_2O

MW-Gly $\quad 2(12) + 5(1) + 1(14) + 2(16) = 75 g/mol$
$\quad\quad\quad\quad$ C $\quad$ H $\quad$ N $\quad$ O

(2)

$$CBOD = \frac{3 \cancel{mol\ O_2}}{2 \cancel{mol\ GLY}} \; \frac{32 g\ O_2}{1 \cancel{mol\ O_2}} \; \frac{1 \cancel{mol\ GLY}}{75 \cancel{g\ GLY}} \; \frac{100 mg\ \cancel{GLY}}{L} = \frac{64 mg}{L} - O_2$$

(3)

$$NBOD = \frac{2 \cancel{mol\ O_2}}{1 \cancel{mol\ NH_3}} \; \frac{2 \cancel{mol\ NH_3}}{2 \cancel{mol\ GLY}} \; \frac{32 \cancel{g\ O_2}}{1 \cancel{mol\ O_2}} \; \frac{1 \cancel{mol\ GLY}}{75 \cancel{g\ GLY}} \; \frac{100 mg\ \cancel{GLY}}{L} = 85 mg/L - O_2$$

(4)

Total: $\quad CBOD + NBOD = \frac{64 mg}{L} + \frac{85 mg}{L} = 149 mg/L$