



Civil Engineering Department

CVG2132 – FUNDAMENTALS OF ENVIRONMENTAL ENGINEERING

Homework 2:

Professor: Rob Delatolla

Due Date: Oct. 12, 2011 (4:00pm) – Cubby « CVG 2132 », Mezzanine A (0.5) CBY

Question 1: An aerated lagoon with a liquid volume of 2700 m^3 is designed to accommodate an inlet flow rate of 105 L/min . BOD (biological oxygen demand) is a non-conservative pollutant that is of key importance at the lagoon and its average inlet concentration is 278 mg/L . Assume a reaction rate of 0.30 d^{-1} for BOD removal in the lagoon and the aeration rate significantly mixing mixes the lagoon.

Answer the following questions: **(a)** What is the concentration of BOD at the exit of the lagoon? **(b)** If the provincial limit for release into waterways is 25 mg/L , what would you suggest to change and/or implement?

ANS:

Given:

$$Q_{in} = 105 \text{ L/min}$$

$$V = 2700 \text{ m}^3$$

$$C_{in} = 278 \text{ mg BOD /L}$$

$$k = 0.30 \text{ 1/d}$$

$$\text{regulation: } C_{eff} = 25 \text{ mg/L}$$

Unknowns:

$$C_{eff} = ?$$

Assumptions:

1. $\rho_{in} = \rho_{eff} = \rho_w = 1000 \text{ kg/m}^3$
2. Steady state processes
3. Reaction order = 1 (from the units of k)
4. Lagoon is perfectly mixed due to aerators, lagoon = CSTR.

(a)

Constituent BOD Mass Balance on lagoon:

$$QC_{in} = QC_{eff} + kCV$$

$$\text{CSTR: } C_{eff} = C$$

$$0 = QC_{in} - QC - kCV$$

Divide by Q to simplify (remember: $\theta = V/Q$):

$$0 = C_e - C - kC\theta$$

Isolate for C :

$$C = C_e / (1 + k\theta)$$

Calculate θ :

$$\tau = V/Q = (2700 \text{ m}^3) * (1000 \text{ L/m}^3) / (105 \text{ L/min})$$

$$\tau = 25714 \text{ min} = (25714 \text{ min}) / (60 \text{ min/h}) = 429 \text{ h} = 17.8 \text{ d}$$

Solve for C_{eff} :

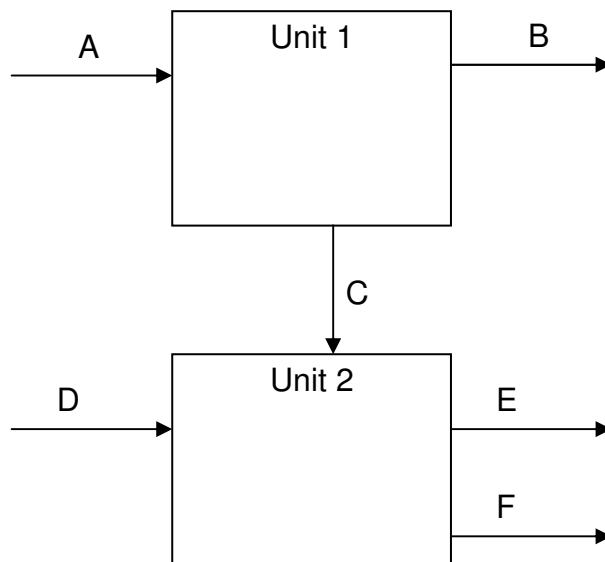
$$C_{eff} = C = (278 \text{ mg/L}) / [1 + (0.3 \text{ d}^{-1}) * (17.8)] \text{ and thus, } C_{eff} = 43.8 \text{ mg/L}$$

(b)

(i) Increase the volume of the lagoon and thus τ will increase and the effluent concentration will decrease. Requires land.

(ii) Add an upgrade unit to the unit at the end of the lagoon to “polish” the effluent and reduce the concentration of BOD further.

Question 2: Two conservative species, x and y flow through a treatment process that is represented by the flow diagram below. Find the **flow rate (Q)** and **concentrations (x and y)** of each constituent that is missing in the table below. Assume that the constituents are conservative and that the system is dilute.



Stream	Q	x	y
Units	m ³ /d	mg x/ m ³	mg y/ m ³
A	10	0.3	0.5
B	6	0.4	0.3
C	?	?	?
D	3	?	0.16
E	3	0.1	0.2
F	?	0.2	?

ANS:

Given:

Values shown in table above.

Unknowns:

$$Q_C = ?$$

$$Q_F = ?$$

$$x_C = ?$$

$$x_D = ?$$

$$y_C = ?$$

$$y_F = ?$$

Assumptions:

1. dilute system: $\rho_A = \rho_B = \rho_C = \rho_D = \rho_E = \rho_F$
2. steady state processes
3. x and y are inert

Total Mass Balance on Unit 1:

$$Q_A \rho_A = Q_B \rho_B + Q_C \rho_C$$

$$\text{since } \rho_A = \rho_B = \rho_C$$

$$Q_A = Q_B + Q_C$$

$$Q_C = Q_A - Q_B = 10 \text{ m}^3/\text{d} - 6 \text{ m}^3/\text{d}$$

$$Q_C = 4 \text{ m}^3/\text{d}$$

Total Mass Balance on Unit 2:

$$Q_C \rho_C + Q_D \rho_D = Q_E \rho_E + Q_F \rho_F$$

$$Q_F = Q_C + Q_D - Q_E = 4 \text{ m}^3/\text{d} + 3 \text{ m}^3/\text{d} - 6 \text{ m}^3/\text{d}$$

$$Q_F = 1 \text{ m}^3/\text{d}$$

Constituent x Mass Balance on 1:

$$Q_A * x_A = Q_B * x_B + Q_C * x_C$$

$$x_C = [Q_A * x_A - Q_B * x_B] / Q_C$$

$$x_C = [10 \text{ m}^3/\text{d} * 0.2 \text{ mg}/\text{m}^3 - 6 \text{ m}^3/\text{d} * 0.4 \text{ mg}/\text{m}^3] / (4 \text{ m}^3/\text{d})$$

$$x_C = 0.15 \text{ mg}/\text{m}^3$$

Constituent x Mass Balance on 2:

$$Q_C * x_C + Q_D * x_D = Q_E * x_E + Q_F * x_F$$

$$4 * 0.15 + 3 * x_D = 3 * 0.1 + 1 * 0.2$$

$$3 * x_D = 5.9$$

$$x_D = 0.33 \text{ mg}/\text{m}^3$$

Constituent y Mass Balance on 1:

$$Q_A * y_A = Q_B * y_B + Q_C * y_C$$

$$10 * 0.5 = 6 * 0.3 + 4 * y_C$$

$$4 * y_C = 3.2$$

$$y_C = 0.8 \text{ mg}/\text{m}^3$$

Constituent y Mass Balance on 2:

$$Q_C * y_C + Q_D * y_D = Q_E * y_E + Q_F * y_F$$

$$4 * 0.8 + 3 * 0.16 = 3 * 0.2 + 1 * y_F$$

$$3 * y_F = 3.08$$

$$y_F = 1.03 \text{ mg}/\text{m}^3$$

Question 3: The concentration of species C was measured as a function of time during a chemical reaction. The observed concentration of species C at various time intervals is presented below.

Answer the following questions: **(a)** Determine the reaction order and rate constant of substance C, k_C (show all work and the evaluations of every kinetic order) **(b)** Is species C being removed or produced? **(c)** If the half-life of a chemical compound A is 30 days under these same conditions, determine the first-order removal rate constant of species A, k_A .

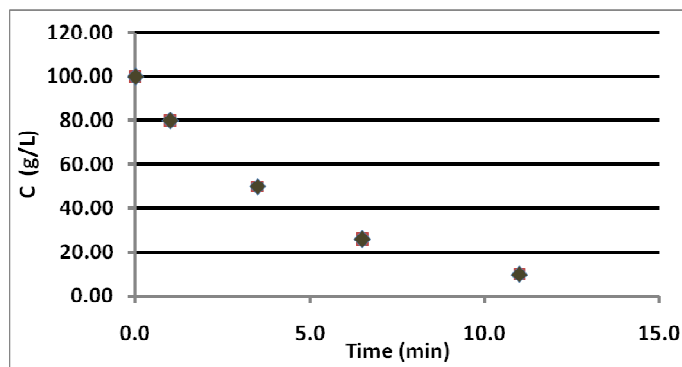
Time (minutes)	Concentration C (mg/L)
0.0	100.00
1.0	80.00
3.5	50.00
6.5	26.00
11.0	10.00

ANS:

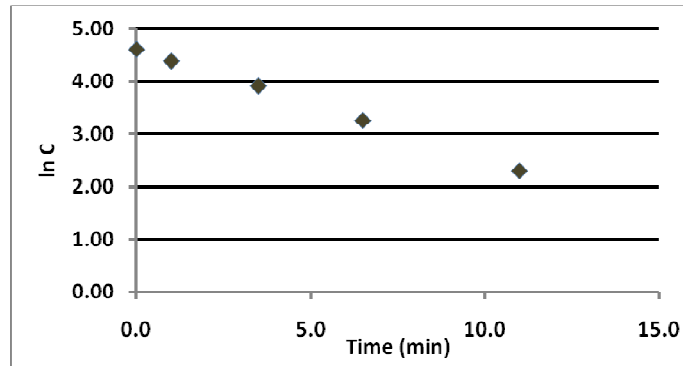
Calculate the $\ln C$ and $1/C$ values to prepare for plotting:

Time (minutes)	Concentration C (mg/L)	$\ln C$	$1/C$ (L/g)
0.0	100.00	4.61	0.01
1.0	80.00	4.38	0.01
3.5	50.00	3.91	0.02
6.5	26.00	3.26	0.04
11.0	10.00	2.30	0.10

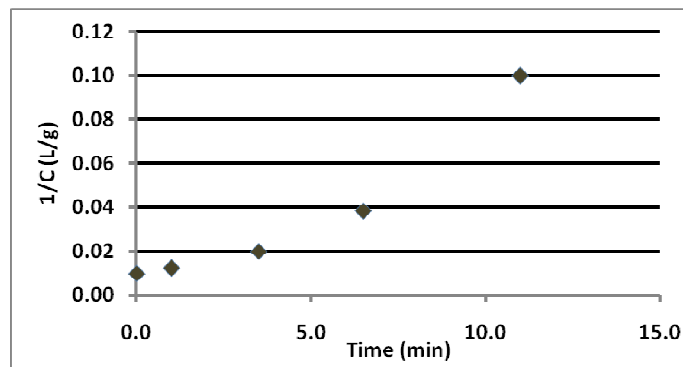
Plot the C vs. Time graph to investigate zero order kinetics:



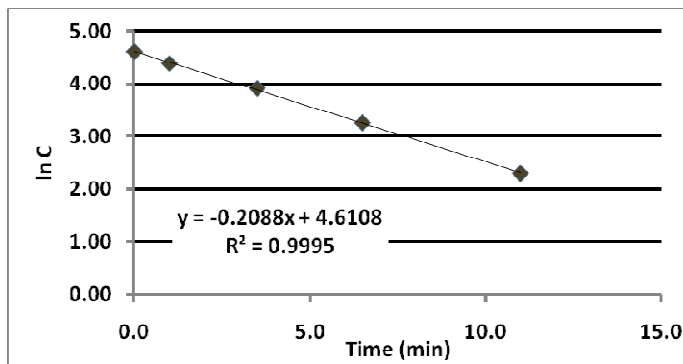
Plot the $\ln C$ vs. Time graph to investigate first order kinetics:



Plot the C vs. Time graph to investigate second order kinetics:



The $\ln C$ vs. Time graph shows a linear trend and thus first order kinetics is a good model to describe the reaction rate of C in the system:



The reaction order of C in the system is **FIRST ORDER KINETICS**.

(a) The rate constant of substance C, k_C , is the slope of the graph: $\ln \frac{C}{C_0} = -kt$; $\ln C = \ln C_0 - kt$

$k_C = 0.21 \text{ 1/min.}$

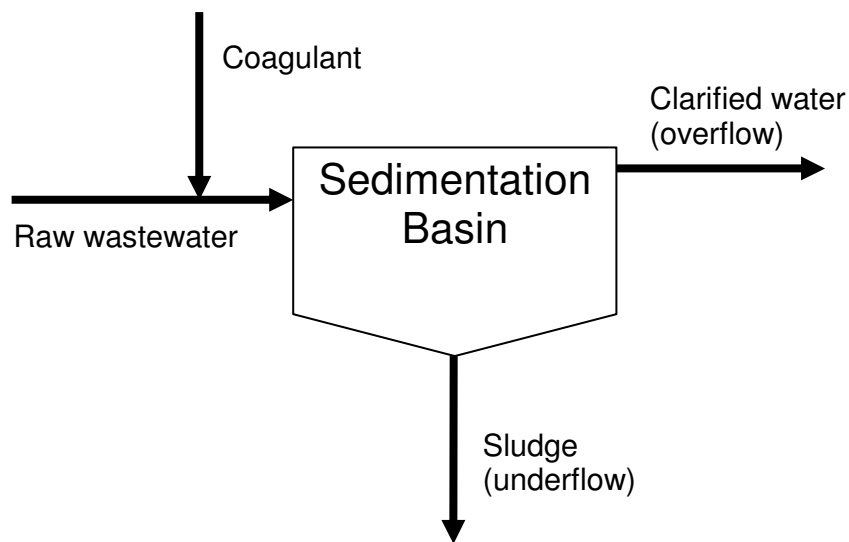
(b) C is being **removed**.

(c) $\ln 0.5 = -k_A t_{1/2}$
 $k_A = 0.693/t_{1/2} = 0.023 \text{ 1/d}$

Question 4: A primary sedimentation basin has an influent flow of $8400 \text{ m}^3/\text{d}$, which has an influent suspended solids concentration of 185 mg TSS/L . To improve this process, 5 mg/L of coagulant (a chemical used to bind particles, allowing them to grow and improve settling) is added to the influent. Assume all the coagulant ends up in the sludge. The chemical addition results in a removal of 87% of the influent solids. The resulting underflow sludge stream has a 7% solids concentration and a density of $1,028 \text{ kg/m}^3$.

Calculate (a) the mass flux of sludge (kg sludge/d = kg of TSS & coagulant/d) produced in the underflow from this tank, (b) the volumetric flow rate of sludge (m^3/d) produced in the underflow from this tank, and (c) the concentration of suspended solids in the overflow effluent (mg TSS/L)? Hint: the water added with the coagulant is negligible compared to the influent flow rate.

ANS:



Given:

$Q_{in} = 8400 \text{ m}^3/\text{d}$

$C_{in,TSS} = 185 \text{ mg TSS/L}$

$C_{in,coagulant} = 5 \text{ mg Coag /L}$

$C_{sludge} = 7\%$

$\rho_{sludge} = 1,028 \text{ kg/m}^3$

87% removal of TSS

Unknowns:

$$Q_{\text{sludge}} = ?$$

$$F_{\text{sludge}} = ?$$

$$C_{\text{eff, TSS}} = ?$$

Assumptions:

1. $\rho_{\text{in}} = \rho_{\text{eff}} = \rho_{\text{w}} = 1000 \text{ kg/m}^3$
2. Steady state processes
3. TSS and Coagulant are inert

Total Mass Balance:

$$Q_{\text{in}} \rho_{\text{in}} = Q_{\text{eff}} \rho_{\text{eff}} + Q_{\text{sludge}} \rho_{\text{sludge}}$$

$$(8400 \text{ m}^3/\text{d})(1000 \text{ kg/m}^3) = (Q_{\text{eff}} \text{ m}^3/\text{d})(1000 \text{ kg/m}^3) + (Q_{\text{sludge}} \text{ m}^3/\text{d})(1028 \text{ kg/m}^3) \quad (1)$$

Coagulant Mass Balance:

$$Q_{\text{in}} C_{\text{in,coag}} = Q_{\text{eff}} C_{\text{eff, coag}} + Q_{\text{sludge}} C_{\text{sludge, coag}}$$

$$(8400 \text{ m}^3/\text{d})(5 \text{ mg/L}) = (Q_{\text{eff}} \text{ m}^3/\text{d})(\text{zero}) + (Q_{\text{sludge}})(C_{\text{sludge, coag}}) = F_{\text{sludge, coag}}$$

$$F_{\text{sludge, coag}} = 42 \text{ kg/d}$$

TSS Mass Balance:

$$Q_{\text{in}} C_{\text{in,TSS}} = Q_{\text{eff}} C_{\text{eff, TSS}} + Q_{\text{sludge}} C_{\text{sludge, TSS}}$$

$$(8400 \text{ m}^3/\text{d})(185 \text{ mg TSS/L}) = (Q_{\text{eff}} \text{ m}^3/\text{d})(C_{\text{eff, TSS}}) + (Q_{\text{sludge}} \text{ m}^3/\text{d})(C_{\text{sludge, TSS}}) \quad (2)$$

Additional given info:**84% removal:**

$$0.84 \times Q_{\text{in}} C_{\text{in,TSS}} = Q_{\text{sludge}} C_{\text{sludge, TSS}}$$

$$0.84 \times (8400 \text{ m}^3/\text{d})(185 \text{ mg TSS/L}) = F_{\text{sludge, TSS}} = 1305 \text{ kg TSS/d}$$

Sludge is 7% solids concentration:

$$C_{\text{sludge}} = 0.07 [\text{kg sludge solids/ kg total}] \times \rho_{\text{sludge}} [\text{kg total/ m}^3]$$

$$C_{\text{sludge}} = 0.07 \times (1028 \text{ kg/m}^3) = 71.96 \text{ kg/m}^3$$

Solve for the mass flux of sludge (F_{sludge}) & sludge flow rate (Q_{sludge}):

$$F_{\text{sludge}} = F_{\text{sludge, TSS}} + F_{\text{sludge, coag}} = 1305 + 42 = 1347 \text{ kg/d}$$

$$Q_{\text{sludge}} = F_{\text{sludge}} / C_{\text{sludge}} = 1347 \text{ [kg/d]} / 71.96 \text{ kg/m}^3 = \mathbf{18.72 \text{ m}^3/\text{d}}$$

Solve for the TSS concentration in the effluent ($C_{\text{eff, TSS}}$):

- Solve for Q_{eff} in equation 1 and then solve for $C_{\text{eff, TSS}}$ in equation 2.
- $Q_{\text{eff}} = \mathbf{8380.3 \text{ m}^3/\text{d}}$
- $C_{\text{eff, TSS}} = \mathbf{24.7 \text{ mg TSS/L}}$