

## CVG2132 – FUNDAMENTALS OF ENVIRONMENTAL ENGINEERING

### Homework 2:

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**Question 1:** In natural systems the water pH restoration generally occurs "quickly enough" via the interactions of air with the natural carbonate buffering system. But, in the water treatment plants and water worn carbon dioxide cannot be restored quickly enough.

(A) Name a method to reduce the pH in the processing plants.

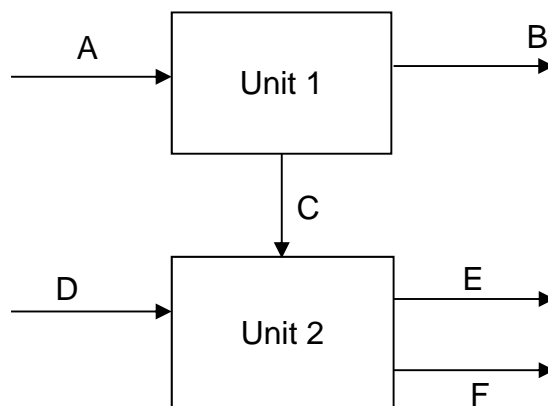
(B) Naming a method to increase the pH in the processing plants.

### **SOLUTION:**

a) pH is reduced by adding acids such sulfuric acid or hydrochloric acid or by bubbling  $\text{CO}_2$  through the solution (recarbonation systems after lime softening). Ottawa treatment plant add sulfuric acid to reach the optimum coagulation pH.

b) pH is increased by adding lime or adding strong base such as NaOH. Ottawa water treatment plants employed the former until about the year 2000 and then switched to the later.

**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. Do the calculations in detail and explain every step.



Stream	Q (m <sup>3</sup> /d)	x (mg x/ m <sup>3</sup> )	y (mg y/ m <sup>3</sup> )
A	?	0.5	0.5
B	3	?	0.3
C	2	0.2	?
D	7	0.84	0.16
E	?	0.8	?
F	3	?	0.5

**ANS:**

**Given:**

Values shown in table above.

**Components:** x, y and water

**Unknowns:**

$$Q_A = ?$$

$$Q_E = ?$$

$$X_B = ?$$

$$X_F = ?$$

$$y_C = ?$$

$$y_E = ?$$

**Assumptions:**

1. As there are no apparent changes with time, assume steady state conditions prevail
2. As the problem deals with dilute systems :  $\rho_A = \rho_B = \rho_C = \rho_D = \rho_E = \rho_F = \rho_{\text{water}} = 1000 \text{ kg/m}^3$
3. As x and y are conservative they are not involved in reactions.  
Thus, for both contaminants, Generation = 0 and Consumption = 0.  
And the processes are separation processes.

**Basis of Calculations:**  $Q_D = 7 \text{ m}^3/\text{d}$

**Total Mass Balance on Unit 1:**

$$\text{Accumulation} = \Sigma M_{\text{IN}} - \Sigma M_{\text{OUT}} = \Sigma (Q \cdot \rho)_{\text{IN}} - \Sigma (Q \cdot \rho)_{\text{OUT}}$$

Accumulation = 0 because of steady state conditions

$$0 = Q_A \cdot \rho_A - Q_B \cdot \rho_B - Q_C \cdot \rho_C$$

since  $\rho_A = \rho_B = \rho_C$  divide them out

$$Q_A = Q_B + Q_C$$

$$Q_A = Q_B + Q_C = 3 \text{ m}^3/\text{d} - 2 \text{ m}^3/\text{d}$$

$$\mathbf{Q_A = 5 \text{ m}^3/\text{d}}$$

**Total Mass Balance on Unit 2:**

$$\text{Accumulation} = \Sigma M_{\text{IN}} - \Sigma M_{\text{OUT}} = \Sigma (Q \cdot \rho)_{\text{IN}} - \Sigma (Q \cdot \rho)_{\text{OUT}}$$

Accumulation = 0 because of steady state conditions

$$0 = Q_C \cdot \rho_C + Q_D \cdot \rho_D - Q_E \cdot \rho_E - Q_F \cdot \rho_F$$

since the density of all the streams are the same, divide out the density

$$Q_E = Q_C + Q_D - Q_F = 2 \text{ m}^3/\text{d} + 7 \text{ m}^3/\text{d} - 3 \text{ m}^3/\text{d}$$

$$Q_F = 6 \text{ m}^3/\text{d}$$

#### Constituent x Mass Balance around Unit 1:

$$\text{ACCUMULATION} = \Sigma M_{x\text{-IN}} - \Sigma M_{x\text{-OUT}} = \Sigma (Q \cdot x)_{\text{IN}} - \Sigma (Q \cdot x)_{\text{OUT}}$$

Accumulation = 0 because of steady state conditions

$$0 = Q_A \cdot x_A - Q_B \cdot x_B - Q_C \cdot x_C$$

$$x_B = [(Q_A \cdot x_A) - (Q_C \cdot x_C)] / Q_B$$

$$x_B = [(5 \text{ m}^3/\text{d} \cdot 0.5 \text{ mg}/\text{m}^3) - (2 \text{ m}^3/\text{d} \cdot 0.2 \text{ mg}/\text{m}^3)] / (3 \text{ m}^3/\text{d})$$

$$x_B = 0.7 \text{ mg}/\text{m}^3$$

#### Constituent x Mass Balance around Unit 2:

$$\text{ACCUMULATION} = \Sigma M_{x\text{-IN}} - \Sigma M_{x\text{-OUT}} = \Sigma (Q \cdot x)_{\text{IN}} - \Sigma (Q \cdot x)_{\text{OUT}}$$

Accumulation = 0 because of steady state conditions

$$0 = (Q_C \cdot x_C) + (Q_D \cdot x_D) - (Q_E \cdot x_E) - (Q_F \cdot x_F)$$

$$x_F = [(Q_C \cdot x_C) + (Q_D \cdot x_D) - (Q_E \cdot x_E)] / Q_F$$

$$x_F = [(2 \text{ m}^3/\text{d} \cdot 0.2 \text{ mg}/\text{m}^3) + (7 \text{ m}^3/\text{d} \cdot 0.84 \text{ mg}/\text{m}^3) - (6 \text{ m}^3/\text{d} \cdot 0.8 \text{ mg}/\text{m}^3)] / (3 \text{ m}^3/\text{d})$$

$$x_F = 0.5 \text{ mg}/\text{m}^3$$

#### Constituent y Mass Balance around Unit 1:

$$\text{ACCUMULATION} = \Sigma M_{y\text{-IN}} - \Sigma M_{y\text{-OUT}} = \Sigma (Q \cdot y)_{\text{IN}} - \Sigma (Q \cdot y)_{\text{OUT}}$$

Accumulation = 0 because of steady state conditions

$$0 = Q_A \cdot y_A - Q_B \cdot y_B - Q_C \cdot y_C$$

$$y_C = [(Q_A \cdot y_A) - (Q_B \cdot y_B)] / Q_C$$

$$y_B = [(5 \text{ m}^3/\text{d} \cdot 0.5 \text{ mg}/\text{m}^3) - (3 \text{ m}^3/\text{d} \cdot 0.3 \text{ mg}/\text{m}^3)] / (2 \text{ m}^3/\text{d})$$

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

#### Constituent y Mass Balance around Unit 2:

$$\text{ACCUMULATION} = \Sigma M_{y\text{-IN}} - \Sigma M_{y\text{-OUT}} = \Sigma (Q \cdot y)_{\text{IN}} - \Sigma (Q \cdot y)_{\text{OUT}}$$

Accumulation = 0 because of steady state conditions

$$0 = (Q_C \cdot y_C) + (Q_D \cdot y_D) - (Q_E \cdot y_E) - (Q_F \cdot y_F)$$

$$y_E = [(Q_C * y_C) + (Q_D * y_D) - (Q_F * y_F)] / Q_E$$

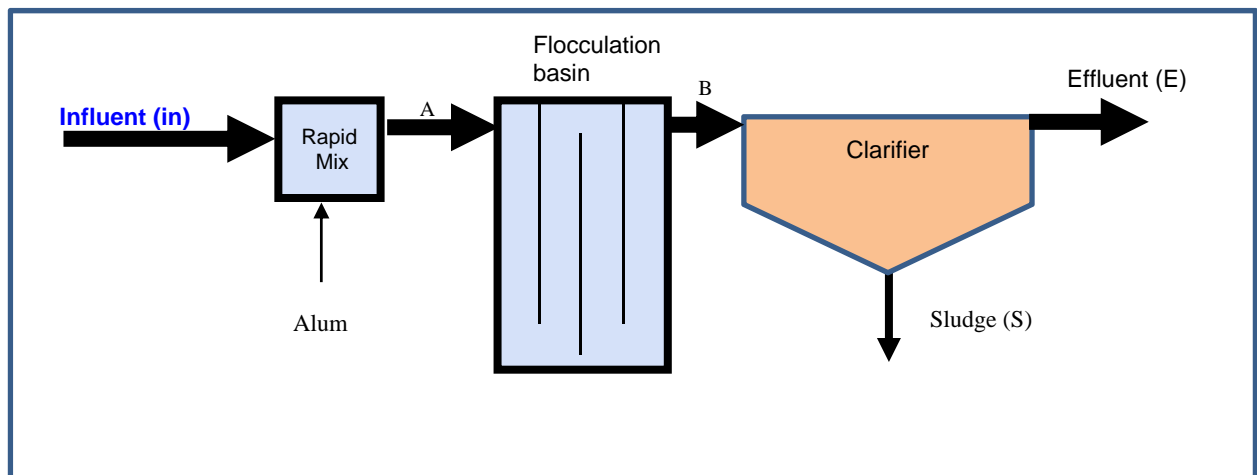
$$y_E = [(2 \text{ m}^3/\text{d} * 0.8 \text{ mg}/\text{m}^3) + (7 \text{ m}^3/\text{d} * 0.16 \text{ mg}/\text{m}^3) - (3 \text{ m}^3/\text{d} * 0.5 \text{ mg}/\text{m}^3)] / (6 \text{ m}^3/\text{d})$$

$$y_E = 0.2 \text{ mg}/\text{m}^3$$

**Question 3:** A drinking water treatment plant treats 100000 m<sup>3</sup>/d of murky river water which has an average turbidity of 40 NTU and a TSS concentration of 4 mg/L using a conventional treatment scheme (coagulation/flocculation/sedimentation/filtration/chlorination). The plant adds 25 g/m<sup>3</sup> of dissolved alum (i.e., Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>·18H<sub>2</sub>O, MW<sub>Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>·18H<sub>2</sub>O</sub> = 666.5 g) based on the feed flowrate. The alum stream contains no TSS. The alum helps remove turbidity and TSS by creating settleable particles that are removed in the clarifier. Because the coagulant stream is highly concentrated (45% alum) and its flow will be relatively small, so assume the mass of this stream is negligible. The mass of TSS formed equals 1.5 times the amount of Al added. The effluent of the clarifier has a turbidity of 1.0 NTU and 0.5 mg/L TSS. The sludge stream has a density of 1025 kg/m<sup>3</sup> and the TSS sludge concentration equals 3% solids (i.e., 0.03 kg TSS/kg total). The alum stream has a density of 1400 kg/m<sup>3</sup>.

Determine:

- the total mass flowrate of the alum stream in kg/d;
- the volumetric flowrate of the alum stream in m<sup>3</sup>/d;
- mass flowrate of the alum stream as a percentage of the feed (influent) mass flowrate;
- the volumetric flowrate of the sludge stream; and
- the volumetric flowrate of the clarifier effluent.



**SOLUTION:**

- As there are no apparent changes with time, assume steady state conditions prevail.
- Assume the influent and effluent stream are dilute so  $\rho_{in} = \rho_E = \rho_{water} = 1000 \text{ kg/m}^3$

**a) the Mass flowrate of the alum stream in kg/d;**

1. Alum added ( $M_{alum}$ )

$M_{alum} = Q_A \times Coag \ dose = \left[ 100000 \frac{m^3}{d} \right] \times \left[ 25 \frac{g \ alum}{m^3} \right]$ $= 2500000 \frac{g \ alum}{d}$	Eq. 1
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2. Mass flowrate of the alum chemical stream (as opposed to the mass of alum)

$M_{alum \ stream} = \frac{g \ alum \ stream}{0.45 \ g \ alum} \times 2500000 \frac{g \ alum}{d}$ $= 5555555.6 \frac{g \ alum \ stream}{d}$	Eq. 2
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Part a) answer  $M_{alum \ stream} = 5555555.6 \text{ g/d} = 5555.6 \text{ kg/d/d}$

**b) the mass flowrate of the alum stream in m<sup>3</sup>/d;**

1. Volumetric flowrate of the alum stream

$Q_{alum} = \frac{M_{alum \ stream}}{\rho_{alum \ stream}} = \frac{5555555.6 \frac{g \ alum \ chemical}{d} \times \frac{kg}{1000g}}{1400 \frac{kg}{m^3}} = 3.968 \frac{m^3}{d}$	Eq. 3
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Part b) answer  $Q_{alum} = 3.968 \text{ m}^3/\text{d}$

**c) Mass flowrate of the alum stream as a percentage of the feed mass flowrate (Per):**

$Per = 100 \times \frac{M_{alum\ stream}}{M_{in}} = 100 \times \frac{5555.6 \frac{kg\ alum\ stream}{d}}{Q_{in} \times \rho_{in}}$ $= 100 \times \frac{5555.6 \frac{kg\ alum\ stream}{d}}{100000 \frac{m^3}{d} \times 1000 \frac{kg}{m^3}} = 0.005556$	Eq. 4
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Part c) answer Per = 0.00556%, which is extremely small. So it confirms that the mass contribution of the coagulant stream to the total mass balance is negligible.

**d) the volumetric flowrate of the sludge stream**

Mass of Alum- related TSS formed:

$Mass\ TSS\ formed$ $= \left[ 2500000 \frac{g\ alum}{d} \right] \times \left[ \frac{1\ mol\ alum}{666.5\ g\ alum} \right] \times \left[ \frac{2\ mol\ Al}{1\ mol\ alum} \right]$ $\times \left[ \frac{26.98\ g\ Al}{1\ mole\ Al} \right] \times \left[ \frac{1.5\ g\ TSS}{g\ Al\ added} \right]$ $= 303601 \frac{g\ TSS\ formed}{d}$	Eq. 5
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- Now we have to resort to mass balances.
- Since turbidity is an optical measure, we cannot conduct turbidity mass balances.
- Because we have no information about streams A and B, avoid using them at least initially. So first try, mass balance of the overall system.

**Conduct a Total mass balance around the system (rapid mix + flocculation basin + clarifier)**

$$Accumulation = \Sigma M_{IN} - \Sigma M_{OUT} = \Sigma (Q \cdot \rho)_{IN} - \Sigma (Q \cdot \rho)_{OUT}$$

Accumulation = 0 because of steady state conditions

$$0 = (Q_{in} \rho_{in}) - (Q_{alum} \cdot \rho_{alum}) - (Q_S \cdot \rho_S) - (Q_E \cdot \rho_E)$$

$0 = \left( 100000 \frac{m^3}{d} \times 1000 \frac{kg}{m^3} \right) + \left( 0 \frac{kg}{d} \right) - \left( Q_S \frac{m^3}{d} \times 1025 \frac{kg}{m^3} \right)$ $+ \left( Q_E \frac{m^3}{d} \times 1000 \frac{kg}{m^3} \right)$	Eq. 6
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Or

$Q_E = (100000) - (1.025Q_S)$	Eq. 7
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**Conduct a TSS mass balance around the system (rapid mix + flocculation basin + clarifier)**

$$Accum = (Mass\ of\ TSS_{Influent}) - (Mass\ of\ TSS_{Sludge}) - (Mass\ of\ TSS_{Effluent}) + (Mass\ of\ TSS\ formed)$$

Because of steady-state conditions Accumulation = 0, so

$0 = [Q_{in} \times TSS_{in}] - [Q_E \times TSS_E] - [Q_S \times \rho_s \times x_s^{TSS}] + \left[ 303601 \frac{g\ FSS\ formed}{d} \times \frac{1\ kg}{1000g} \right]$	Eq. 8
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$0 = \left[ 100000 \frac{m^3}{d} \times 4 \frac{g}{m^3} \times \frac{1\ kg}{1000g} \right] - \left[ Q_E \times 0.5 \frac{g}{m^3} \times \frac{1\ kg}{1000g} \right] - \left[ Q_S \times 1025 \frac{kg\ tot}{m^3} \times \frac{0.03\ Kg\ TSS}{1\ Kg\ tot} \right] + \left[ 303.6 \frac{kg\ TSS\ formed}{d} \right]$	Eq. 9
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$0 = \left[ 400 \frac{kg\ TSS}{d} \right] - [0.0005 Q_E] - [30.75 \cdot Q_S] + \left[ 303.6 \frac{kg\ TSS\ formed}{d} \right]$	Eq. 10
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Substituting in equation 7

$0 = \left[ 400 \frac{kg\ TSS}{d} \right] - [0.0005 \cdot \{(100000) - (1.025 Q_S)\}] - [30.75 \cdot Q_S] + \left[ 303.6 \frac{kg\ TSS\ formed}{d} \right]$	Eq. 11
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So  $Q_S = 21.26\ m^3/d$

Part d) answer . The volumetric flowrate of stream S is  $21.26\ m^3/d$ .

Since it is less than 1% of  $Q_{in}$ , it seems like it is of the right order of magnitude

**e) the volumetric flowrate of the clarifier effluent.**

Substituting into eq. 7

$Q_E = (100000) - (1.025 Q_S) = (100000) - (1.025 \times 22.88) = 99978.2 \frac{m^3}{d}$	Eq. 12
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Part e) answer. The volumetric flowrate of stream E is  $99978.2\ m^3/d$ .