CVG 2132 Fundamentals of Environmental Engineering
MIDTERM 2015 – V1

PART A. Short Questions (35 points)

1. (5 points)

a) What changes occurred as a result of the Love Canal incident?

- The Love Canal incident led to creation of hazardous waste legislation that was intended to prevent further contamination of land and water with hazardous chemicals. The name of this legislation was RCRA (Resource Conservation and Recovery Act). It created a system for the inventory and management of hazardous chemical and greatly tightened the control of the disposal of hazardous and non-hazardous waste on land.

- Also, this incident led to the creation of the Comprehensive Environmental Response Compensation and Liability Act (CERCLA). Funds from the act help clean toxic existing sites contaminated sites that were contaminated by companies that no longer exist so they could not be made responsible for the damage they caused. CERCLA addresses the sins of the past

OR

b) What were the repercussions of the Cuyahoga River fire?

- The 1969 fire received a lot of publicity and this led to the National Environment Protection Act (NEPA), which lead to the formation of the Environmental Protection Agency (USEPA).
- Then, the EPA established the 1972 Clean Water Act that aims to make all rivers in the US swimmable, fishable and navigable. As the result of this act many wastewater treatment plants were built or upgraded and the quality of river waters has improved over time.

2. (5 points) Based on size what are the three types of solids? What type of solids does the TDS test measure?

The three types of solids based on size are: suspended solids
Colloidal solids
Dissolved solids (1 point each)

The TDS measurement actually measures the dissolved plus colloidal solids (2 points)

3. **(9 points) Calculate the concentrations of the substances shown in the table below in mg/L-as $CaCO_3$. Show your work with all the relevant units.**

Substance	**Conc. (g/m^3)**	**MW (g/mol)**	**CONC. (mg/L as $CaCO_3$)**
Ca^{2+}	40	40.0	100
HCO_3^-	98	61.0	80.3
CO_3^{-2}	6	60.0	10

$$MW_{CaCO_3} = \left(40\frac{g\ Ca}{mole\ Ca}\right) + \left(12\frac{g\ C}{mole\ C}\right) + 3moles \times \left(16\frac{g\ O}{mole\ O}\right) = 100\frac{g\ CaCO_3}{mole\ CaCO_3}$$

$$EW_{CaCO_3} = \frac{MW_{CaCO_3}}{z_{CaCO_3}} = \frac{\frac{100\ g\ CaCO_3}{mole\ CaCO_3}}{2\ \frac{eq\ CaCO_3}{mole\ CaCO_3}} = 50\frac{g\ CaCO_3}{eq}$$

$$EW_{Ca^{+2}} = \frac{MW_{Ca^{+2}}}{z_{Ca^{+2}}} = \frac{\frac{40\ g\ Ca^{+2}}{mole\ Ca^{+2}}}{2\ \frac{eq\ Ca^{+2}}{mole\ Ca^{+2}}} = 20\frac{g\ Ca^{+2}}{eq}$$

$$EW_{HCO_3^-} = \frac{MW_{HCO_3^-}}{z_{HCO_3^-}} = \frac{\frac{61\ g\ HCO_3^-}{mole\ HCO_3^-}}{1\ \frac{eq\ HCO_3^-}{mole\ HCO_3^-}} = 61\frac{gHCO_3^-}{eq}$$

$$EW_{CO_3^{-2}} = \frac{MW_{CO_3^{-2}}}{z_{CO_3^{-2}}} = \frac{\frac{60\ g\ CO_3^{-2}}{mole\ CO_3^{-2}}}{2\ \frac{eq\ CO_3^{-2}}{mole\ CO_3^{-2}}} = 30\frac{gHCO_3^-}{eq}$$

$$Ca^{+2}\text{conc.} = 40\frac{g\ Ca^{2+}}{m^3} \times \frac{eq\ Ca^{2+}}{20\ g\ Ca^{2+}} \times \frac{50\ g\ CaCO_3}{eq} \times \frac{1000mg}{g} \times \frac{m^3}{1000\ L} = 100\frac{mg}{L}\ as\ CaCO_3$$

$$HCO_3^-\text{conc.} = 98\frac{g\ HCO_3^-}{m^3} \times \frac{eq\ HCO_3^-}{61\ g\ HCO_3^-} \times \frac{50\ g\ CaCO_3}{eq} \times \frac{1000mg}{g} \times \frac{m^3}{1000\ L} = 80.3\frac{mg}{L}\ as\ CaCO_3$$

$$CO_3^{-2}\text{conc.} = 6\frac{g\ CO_3^{-2}}{m^3} \times \frac{eq\ CO_3^{-2}}{30\ g\ CO_3^{-2}} \times \frac{50\ g\ CaCO_3}{eq} \times \frac{1000mg}{g} \times \frac{m^3}{1000\ L} = 10\frac{mg}{L}\ as\ CaCO_3$$

If moles are used instead of equivalents one must incorporate the number of moles of Ca^{+2}, HCO_3^- and CO_3^{-2} that per mole of $CaCO_3$ in terms of the charge exchange.

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4. (5 points) Determine the pH of the above solution.

$$K_a = \frac{[H^+] \times [\mathrm{CO}_3^{-2}]}{[\mathrm{HCO}_3^{-1}]} = 4.68 \times 10^{-11}$$

$$[HCO_3^-\,] = \ 98\frac{g\ HCO_3^-}{m^3} \times \frac{mole\ HCO_3^-}{61\ g\ HCO_3^-} \times \frac{m^3}{1000L} = 1.61 \times 10^{-3}\frac{mole\ HCO_3^-}{L}$$

$$[CO_3^{-2}]\ =\ 6\frac{g\ CO_3^{-2}}{m^3} \times \frac{mole\ CO_3^{-2}}{60\ g\ CO_3^{-2}} \times \frac{m^3}{1000L} = 0.1 \times 10^{-3}\frac{mole\ CO_3^{-2}}{L}$$

$$so\ \ [H^+] = \frac{K_a \times [\mathrm{HCO}_3^{-1}\,]}{[\mathrm{CO}_3^{-2}\,]} = \frac{(4.68 \times 10^{-11}) \times [1.61 \times 10^{-3}\frac{mole\ H\mathrm{CO}_3^-}{L}]}{[0.1 \times 10^{-3}\frac{mole\ Ca}{L}]}$$

$$= 7.53 \times 10^{-10}\frac{mole\ H^+}{L}$$

- $and\ \ pH = -log_{10}[H^+] = -log_{10}\left[7.53 \times 10^{-10}\frac{moleH^+}{L}\right] = 9.12$

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5. (5 points) Leachate is produced when precipitation infiltrates a sanitary landfill, contacts the waste materials in the landfill, percolates through this material and appears at the bottom of the landfill. Assume 6 kg of benzene (C_6H_6) were placed within the landfill. Assume half the benzene volatilizes into the landfill gas and half the benzene dissolves in the 4000 m^3 of leachate produced within one year. Determine the benzene concentration of the leachate in (i) mg/L; and (ii) moles/L.

$$MW_{C_6H_6} = \left(6 \times 12\frac{g\ C}{mole\ C}\right) + \left(6 \times 1\frac{g\ H}{mole\ H}\right) = 78\frac{g\ C_6H_6}{mole\ C_6H_6}$$

$$CONC_{C_6H_6} = \frac{0.5 \times 6\ kg\ C_6H_6}{4000\ m^3} \times \frac{10^6 mg}{kg} \times \frac{m^3}{1000\ L} = 0.75\frac{mg\ C_6H_6}{L}$$

$$[C_6H_6] = \frac{0.5 \times 6\ kg\ C_6H_6}{4000\ m^3} \times \frac{10^3 g}{kg} \times \frac{mole\ C_6H_6}{78\ g\ C_6H_6} \times \frac{m^3}{1000\ L} = 9.615 \times 10^{-6}\frac{mole\ C_6H_6}{L}$$

6. (3 points) The reaction rate constant for a reaction is given as 2 $\frac{L^3}{mg \cdot d}$. The reaction order is

a) a zero order reaction
b) a first order reaction
c) a second order reaction
d) a third order reaction
e) none of the above

Correct answer is e)

7. (3 points) <u>Select all the correct answers.</u> A reactor that has continuous feed flow and periodic effluent flow can be classified as

a) Batch reactor
b) Semi-batch reactor
c) Continuous flow reactor
d) Steady-state reactor
e) Unsteady-state reactor
f) A plug flow reactor
g) Completely mixed reactor

Correct answers are b) and e)

PART B. Long Questions (65 points)

Analyze the secondary clarifier shown below. The ML stream is considered dilute. The clarifier is a gravity-driven solids (TSS) separation process, in which most of the TSS settles to the bottom of the clarifier forming a sludge that pumped out by stream S. There are no reactions taking place in this unit.

The recycled sludge stream (RS) has a TSS concentration of 1% solids (i.e., 0.01 kg TSS/ kg total) and a density of 1005 kg/m^3.The ML stream has TSS concentration of 1200 g/m^3. The secondary clarifier separates 99% of the mass of TSS in the feed stream (ML) and sends it to the sludge stream (S).

Clearly state all the assumptions.

Clearly explain in words every step.

FIND:

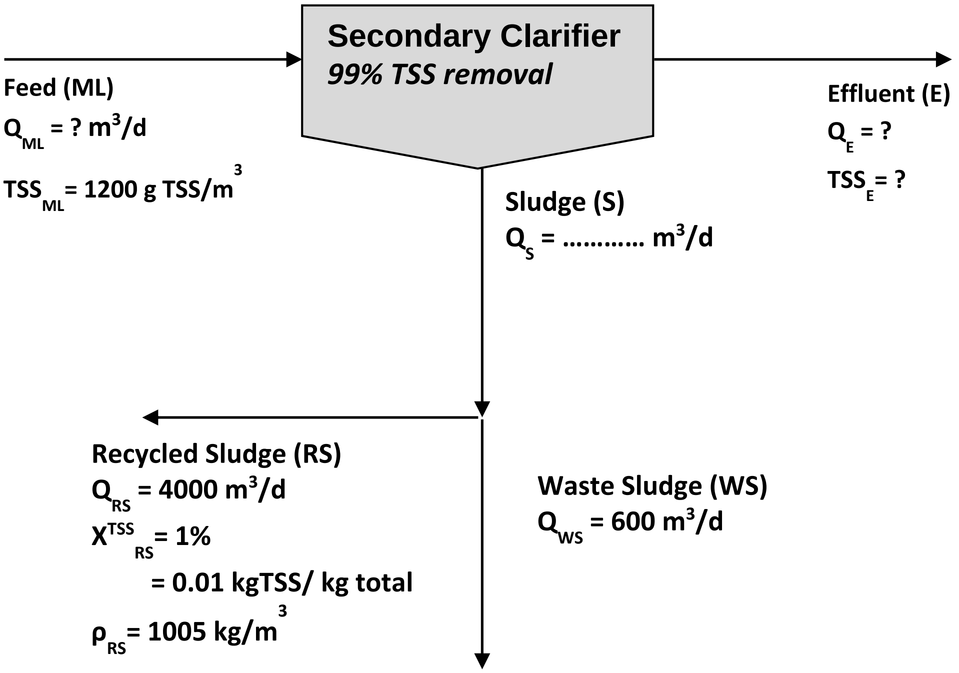
a) X^{TSS}_{S}, the TSS concentration in sludge stream (S) in kg TSS/kg total

If you cannot determine X^{TSS}_{S}, then assume it equals 0.008 kg TSS/kg total

b) The volumetric feed flowrate, Q_{ML} (in m^3/d)

c) The effluent flowrate, Q_E (m^3/d)

d) The effluent TSS concentration (mg/L)



TARGET	
Justified steady state assumption	2
Justified dilute stream assumption	2
Recognize split, $\mathbf{X^{TSS}_{S} = X^{TSS}_{WS} = X^{TSS}_{RS} = 1\%}$ $\boldsymbol{\rho_S = \rho_{WS} = \rho_{RS} = 1005\ kg/m^3}$	14
Total MB around joint S – WS – RS, get Q_S	12
Removal equation, solve for Q_{ML}	10
Total MB around separator, solve for Q_E	12
TSS MB around separator, solve for RE	12
	64

SOLUTION

a) X^{TSS}_S, the TSS concentration in sludge stream (S) in kg TSS/kg total

Assumptions

- As there are no apparent changes with time, assume steady state conditions prevail.
- As stream ML is dilute and its separation produces a sludge stream, thus stream E must be dilute. Accordingly, assume $\rho_{ML} = \rho_E = \rho_{water} = 1000$ kg/m^3
- Since we are told this is a separation process, there should be no reactions and Consumption = 0 and Generation = 0 in the TSS mass balances.

Since S – SW- WS is a split, the characteristics of these streams are the same.

  - $\mathbf{X^{TSS}_{S} = X^{TSS}_{WS} = X^{TSS}_{RS} = 1\%}$
  - $\boldsymbol{\rho_S = \rho_{WS} = \rho_{RS} = 1005\ kg/m^3}$

Answer to part a) $\mathbf{X^{TSS}_{S} = 0.01}$ **kg TSS/kg total = 1%**

b) The volumetric feed flowrate, Q_{ML} (in m^3/d)

Conduct a Total mass balance around the split S – RS - WS

- Accumulation = $\Sigma M_{IN} - \Sigma M_{OUT} = \Sigma (Q\cdot\rho)_{IN} - \Sigma (Q\cdot\rho)_{OUT}$
- Accumulation = 0 because of steady state conditions

$0 = (Q_S \rho_S) - (Q_{RS} \cdot \rho_{RS}) - (Q_{WS} \cdot \rho_{WS})$

Sincethe densities of the three streams are the same, divide out the densities

$0 = (Q_S) - (Q_{RS}) - (Q_{WS})$

$0 = Q_S - 4000\ m^3/d - 600\ m^3/d$ Eq.1

$Q_S = 4600\ m^3/d$

Based on the 99 % TSS removal information provided in the problem statement

$$0.99 \times Q_{ML} \times TSS_{ML} = M_S^{TSS} = Q_S \times \rho_S \times X_S^{TSS} \quad \text{Eq. 2}$$

Mass of $TSS_S = Q_S \cdot \rho_S \cdot X_{TSS} = 4600\ \frac{m^3}{d} \times 1005\ \frac{kg}{m^3} \cdot\times 0.01\ \frac{kgTSS}{kg\ Total} = 46230 \frac{\text{kg TSS}}{d}$ Eq. 3

$$Q_{ML} = \frac{Q_S \times \rho_S \times X_S^{TSS}}{0.99 \times TSS_{ML}} = \frac{46230 \frac{\text{kg TSS}}{d} \times \frac{1000g}{kg}}{0.99 \times 1200 \frac{g\ TSS}{m^3}} = 38914 \frac{m^3}{d} \quad \text{Eq. 4}$$

Answer to part b) **Q_{ML} = 38914 m^3d**

c) The effluent flowrate, Q_E (m^3/d)

Conduct a Total mass balance around the system

- Accumulation = $\Sigma M_{IN} - \Sigma M_{ouT} = \Sigma (Q \cdot \rho)_{IN} - \Sigma (Q \cdot \rho)_{OUT}$
- Accumulation = 0 because of steady state conditions

$$\mathbf{0} = Q_{ML} \times \rho_{ML} - Q_S \times \rho_S - Q_E \times \rho_E \quad \text{Eq.5}$$

$$\mathbf{0} = \left(38914 \frac{m^3}{d} \times 1000 \frac{kg\ total}{m^3}\right) - \left(4600 \frac{m^3}{d} \times 1005 \frac{kg\ total}{m^3}\right) - \left(Q_E \times 1000 \frac{kg\ total}{m^3}\right) \quad \text{Eq.6}$$

Answer to part c) Q_E = **34291 m^3/d**

d) The effluent TSS concentration (mg/L)

Conduct a TSS mass balance around the secondary clarifier

- Accumulation = $\Sigma M_{IN} - \Sigma M_{OUT} = \Sigma (Q \cdot TSS)_{IN} - \Sigma (Q \cdot TSS)_{OUT}$
- Accumulation = 0 because of steady state conditions

  0 = (Mass of TSS_{ML}) – (Mass of TSS_S) – (Mass of TSS_E)

$$\mathbf{0} = (Q_{ML} \times TSS_{ML}) - (Q_S \times \rho_S \times X_S^{TSS}) - (Q_E \times TSS\rho_E) \qquad \text{Eq.7}$$

$$\begin{aligned}\mathbf{0} = &\left(38914\frac{m^3}{d} \times 1200\frac{g\ TSS}{m^3}\right) \\ &- \left(4600\frac{m^3}{d} \times 1005\frac{kg\ total}{m^3} \times 0.01\frac{kg\ TSS}{kg\ total} \times 1000\frac{g}{kg}\right) \\ &- \left(34291\frac{m^3}{d} \times TSS_E\right)\end{aligned} \qquad \text{Eq.8}$$

TSS_E = 13.6 g TSS / m^3

Answer part d) TSS_E = 13.6 g TSS /m^3