

CV3015 – ENVIRONMENTAL ENGINEERING AY21/22 SOLUTION

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Q1.

$$(a)(i) \frac{C_i - C_e}{C_i} = \% \text{ removal} \rightarrow \frac{C_e}{C_i} = 1 - \% \text{ removal} \rightarrow \frac{C_i}{C_e} = \frac{1}{1 - \% \text{ removal}}$$

$$\log\left(\frac{C_i}{C_e}\right) = \log\left(\frac{1}{1 - \% \text{ removal}}\right) = k * Ct \rightarrow k = \frac{\log\left(\frac{1}{1 - \% \text{ removal}}\right)}{Ct}$$

$$\text{For Disinfectant A: } k = \frac{\log\left(\frac{1}{1 - 0.9999}\right)}{1 * 5} = 0.8$$

$$\text{For Disinfectant B: } k = \frac{\log\left(\frac{1}{1 - 0.9999}\right)}{2 * 2.5} = 0.8$$

$$\text{For Disinfectant C: } k = \frac{\log\left(\frac{1}{1 - 0.99}\right)}{0.5 * 5} = 0.8$$

Since all k values are equal, all disinfectants are equally as effective for primary disinfection of water. By process of elimination, Disinfectant C would not be chosen due to lowest % removal of bacteria. Between Disinfectant A and Disinfectant B, Disinfectant B would be chosen as its required contact time is the fastest.

(ii) Breakpoint chlorination is important in disinfection process as it allows us to know the amount of chlorine dosage needed to achieve a desired amount of HOCl as free chlorine. Chlorine added beyond the breakpoint reacts with water and forms HOCl in direct proportion with the chlorine added and the HOCl formed as free chlorine is more effective than chloramines formed in initial stages.

$$\text{breakpoint chlorine dosage} = 2.0 - 1(0.5) = 1.5 \text{ mg/L}$$

(b) For $C_5H_7NO_2 + 5O_2 \rightarrow 5CO_2 + NH_3 + 2H_2O$:

$$TON = 12 \text{ mg/L} = \frac{14}{113} [C_5H_7NO_2] \rightarrow [C_5H_7NO_2] = 96.857 \text{ mg/L}$$

$$TOC = \frac{5 * 12}{113} [C_5H_7NO_2] = 51.429 \text{ mg/L}$$

$$ThOD = \frac{5 * 32}{113} [C_5H_7NO_2] = 137.143 \text{ mg/L}$$

For $C_{18}H_{36}O_2 + 26O_2 \rightarrow 18CO_2 + 18H_2O$:

$$TOC = \frac{18 * 12}{284} [C_{18}H_{36}O_2] = \frac{54}{71} [C_{18}H_{36}O_2]$$

$$ThOD = \frac{26 * 32}{284} [C_{18}H_{36}O_2] = \frac{208}{71} [C_{18}H_{36}O_2]$$

For $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$:

$$TOC = \frac{6 * 12}{180} [C_6H_{12}O_6] = \frac{2}{5} [C_6H_{12}O_6]$$

$$ThOD = \frac{6 * 32}{180} [C_6H_{12}O_6] = \frac{16}{15} [C_6H_{12}O_6]$$

Concentration Calculations:

$$TOC = 51.429 + \frac{54}{71} [C_{18}H_{36}O_2] + \frac{2}{5} [C_6H_{12}O_6] = 145$$

$$\frac{54}{71} [C_{18}H_{36}O_2] + \frac{2}{5} [C_6H_{12}O_6] = 93.571 \rightarrow (1)$$

$$ThOD = 137.143 + \frac{208}{71} [C_{18}H_{36}O_2] + \frac{16}{15} [C_6H_{12}O_6] = 435$$

$$\frac{208}{71} [C_{18}H_{36}O_2] + \frac{16}{15} [C_6H_{12}O_6] = 297.587 \rightarrow (2)$$

Solving (1) and (2) gives:

$$[C_5H_7NO_2] = 96.857mg/L, [C_{18}H_{36}O_2] = 53.621mg/L, [C_6H_{12}O_6] = 131.972mg/L.$$

$$(c)(i) R = 1 - \frac{C_p}{C_f} \rightarrow C_p = (1 - R)C_f$$

$$C_f = (1 - 0.7)(1 - R_B)(500) = 15 \rightarrow R_B = 0.9$$

∴ The minimum Ca^{2+} rejection of membrane B is 90%.

(ii) 1. Reduce turbidity of RO feed water to < 0.5 NTU using coagulation-flocculation, granular filtration, or membrane filtration.

2. Reduce scaling due to hardness of water by lowering pH or adding anti-scalants.

Q2.

$$(a) v_b = v_s(f_e)^{4.5} \rightarrow 0.1v_s = v_s(f_e)^{4.5} \rightarrow f_e = 0.1^{1/4.5} = 0.59948 \approx 0.6$$

$$f = 0.5 \left(\frac{L_A}{L} \right) + 0.4 \left(\frac{L_B}{L} \right)$$

$$\text{bed expansion} = 35\%$$

$$\frac{L_e}{L} = \frac{1-f}{1-f_e} = 1.35 \rightarrow \frac{1 - [0.5 \left(\frac{L_A}{L} \right) + 0.4 \left(\frac{L_B}{L} \right)]}{1-0.6} = 1.35$$

$$0.46 = 0.5 \left(\frac{L_A}{L} \right) + 0.4 \left(\frac{L_B}{L} \right) \rightarrow 0.46L = 0.5L_A + 0.4L_B$$

$$0.46L = 0.5L_A + 0.4(L - L_A) \rightarrow 0.06L = 0.1L_A \rightarrow L_A = 0.6L, L_B = 0.4L$$

$$\text{For Material A: } Re = \frac{\psi \rho d v}{\mu} = \frac{0.8 \times 1000 \times 0.002 \times 0.0005}{0.89 \times 10^{-3}} = 0.89888 < 1$$

$$C_D = \frac{24}{Re} = \frac{24}{0.89888} = 26.7$$

$$\frac{h_A}{L_A} = \frac{1.067 C_D v^2}{\psi g d f^4} = \frac{1.067 \times 26.7 \times 0.0005^2}{0.8 \times 9.81 \times 0.002 \times 0.5^4} = 0.0072602 \rightarrow h_A = 0.0072602 L_A$$

$$\text{For Material B: } Re = \frac{\psi \rho d v}{\mu} = \frac{0.8 \times 1000 \times 0.001 \times 0.0005}{0.89 \times 10^{-3}} = 0.44944 < 1$$

$$C_D = \frac{24}{Re} = \frac{24}{0.44944} = 53.4$$

$$\frac{h_B}{L_B} = \frac{1.067 C_D v^2}{\psi g d f^4} = \frac{1.067 \times 53.4 \times 0.0005^2}{0.8 \times 9.81 \times 0.001 \times 0.4^4} = 0.070900 \rightarrow h_B = 0.070900 L_B$$

$$h_A + h_B = 0.2 \rightarrow 0.0072602 L_A + 0.070900 L_B = 0.2$$

Sub in L_A and L_B values:

$$0.0072602(0.6L) + 0.070900(0.4L) = 0.2 \rightarrow 6.032716L = 0.2 \rightarrow L = 6.1132m$$

$$\therefore L_A = 3.6679m, L_B = 2.4453m$$

$$(b) v_0 = \frac{Q}{10 \times 5} = \frac{1000/3600}{10 \times 5} = 5.5556 \times 10^{-3} m/s$$

$$v_s = \frac{g(\rho_p - \rho)d^2}{18\mu} \text{ given that } \rho_p \text{ is constant} \rightarrow v_s \propto d^2 \rightarrow v_{s,a} = 4v_{s,b}$$

$$h_{s,a} = 1 \times 2 = 2m$$

$$X_{r,a} = \frac{h_{s,a}}{h_0} = \frac{2}{5} = 0.4 = 40\%$$

$$X_{r,a} = \frac{v_{s,a}}{v_0} \rightarrow 0.4 = \frac{v_{s,a}}{5.5556 \times 10^{-3}} \rightarrow v_{s,a} = 2.2222 \times 10^{-3} m/s$$

$$v_{s,a} = 4v_{s,b} \rightarrow v_{s,b} = 0.25v_{s,a} = 0.25(2.2222 \times 10^{-3}) = 5.5556 \times 10^{-4} m/s$$

$$X_{r,b} = \frac{v_{s,b}}{v_0} = \frac{5.5556 \times 10^{-4}}{5.5556 \times 10^{-3}} = 0.1 = 10\%$$

Q3.

$$(a) Q_{upstream} = Q_{downstream} \rightarrow \frac{V_{upstream}}{A_{upstream}} = \frac{V_{downstream}}{A_{downstream}}$$

$$\frac{1}{20+25} = \frac{V_{downstream}}{25} \rightarrow V_{downstream} = \frac{5}{9} m/s$$

$$H_L = \frac{1}{c} \left[\frac{V_s^2 - V_c^2}{2g} \right] = \frac{1}{0.7} \left[\frac{1^2 - \left(\frac{5}{9}\right)^2}{2(9.81)} \right] = 0.10068m$$

(b) Water or wastewater is first pressurized which helps to dissolve air or gas into the water. After the water is pressurized, it is released into the flotation tank or basin. As the water is allowed to decompress, the pressure is released, and tiny bubbles of air come out of water in the form of microscopic bubbles.

The bubbles would then adhere to the suspended matter, causing the suspended matter to float to the surface of the water. The floats are then removed with a skimming device.

(c) The EQ tank in the wastewater treatment process serves various purposes. It helps to:

1. Overcome the operational problems caused by flowrate variation
2. Improve the performance and reliability of the downstream processes
3. Improve effluent quality and settling due to improved consistency in constituents

(d)

	Advantages	Disadvantages
Rectangular Settling Tank	<ol style="list-style-type: none"> 1. Lesser land required for a similar surface area 2. Low capital cost 	<ol style="list-style-type: none"> 1. Higher hydraulic head loss 2. High maintenance cost
Circular Settling Tank	<ol style="list-style-type: none"> 1. No dead spaces 2. Low maintenance cost 	<ol style="list-style-type: none"> 1. More land required for a similar surface area 2. High capital cost

(e) For organic carbon compounds removal, the primary biological process used is aerobic digestion. In aerobic digestion, aerobic microorganisms, mainly bacteria, break down organic matter into carbon dioxide and water through the process of aerobic respiration. A supply of oxygen is required to support the growth of aerobic bacteria.

To remove nitrogen compounds, nitrification and denitrification processes are used. Initially, nitrification helps to convert NH_4^+ to NO_3^- in the presence of high oxygen supply. Subsequently, denitrification helps to convert NO_3^- to N_2 in the presence of high carbon and low oxygen supply.

For phosphorous compounds removal, biological phosphorous removal is used through a specific bacteria known as phosphorus-accumulating organisms (PAOs). In anaerobic conditions, acetic acid is introduced and PHA forms. Simultaneously, Poly-P degradation produces energy for PHA production. Cells would then release phosphate in liquid state. Subsequently, in aerobic conditions, phosphate is absorbed back into PAO, thus Poly-P forms again. Oxygen would then oxidise PHA to provide energy for Poly-P formation and removal.

Q4.

(a) Coagulation involves the addition of chemicals to destabilize particles so they can aggregate or form a precipitate that will sweep the particles from solution or adsorb dissolved constituents.

Flocculation is the aggregation of destabilized particles into larger flocs that are easier to remove from water than original particles.

Besides solids, the two processes can remove certain heavy metals, organic compounds, some pathogens, and help reduce the color and turbidity of water.

(b) $BOD\ removed = 200 - 2.5 = 197.5$

$$\frac{\text{biodegradable COD}}{\text{biodegradable BOD}} = \frac{\text{biodegradable COD}}{197.5} = 1.6 \rightarrow \text{biodegradable COD} = 316\text{mg/L}$$

$$\text{biomass} = 100 \times 1.42 = 142\text{mg/L}$$

$$COD\ removed = 316 - 142 = 174$$

$$\text{growth yield} = \frac{100}{197.5} \text{ or } \frac{100}{174} = 0.5063\text{gVSS/gBOD or } 0.5747\text{gVSS/gCOD}$$

(c) Methanogens and acid fermenters have a syntrophic relationship, where acid fermenters produce volatile fatty acids (VFAs), and methanogens convert VFAs into methane and carbon dioxide. An upset which creates an imbalance between the fermenters and methanogens would affect the biogas production rates, VFA concentration, and pH.

Biogas production rate would likely decrease. An upset that disturbs this balance could lead to an accumulation of VFAs, which can inhibit methanogens and reduce methane production, ultimately resulting in a lower biogas production rate.

VFA concentration would increase. The rate of VFAs production might surpass the rate of consumption by methanogens. This can lead to higher VFAs concentration in the system.

The pH should decrease. VFAs are acidic meaning their accumulation can lead to a decrease in the pH. As pH drops, it can further inhibit the activity of methanogens, and further diminish the biogas production rates.

$$(d) MLSS = 3500mg/L = 3500 \times \frac{g}{1000mg} /L = 3.5g/L$$

$$SVI = \frac{840mL/2L}{3.5g/L} = 120mL/g$$

(e) Primary air pollutants are emitted directly from air pollution sources; an example is Nitrous Oxides (NO_x). They are emitted directly from motor vehicles, combustion processes, and industrial processes. The impact on the environment is global warming due to increased greenhouse gas emissions, and the impact on human health is respiratory and cardiovascular problems.

Secondary air pollutants are formed in the atmosphere via chemical reactions; an example is Ozone (O₃). Harmful ground level ozone is formed by a chemical reaction between Nitrous Oxides (NO_x) and Volatile Organic Compounds (VOC) in the presence of heat and sunlight. The impact on the environment is smog formation, and the impact on human health is respiratory and cardiovascular problems.

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NOTE:

Do reach out to me at KEAL0001@e.ntu.edu.sg if you have any queries regarding any of my submitted workings. Feel free to leave an email to ask any questions covered in the curriculum, will be glad to help!

DISCLAIMER:

You are advised to take my solutions as a **guide**, rather than an absolute answer to the questions.