# Civ-B5, WATER SUPPLY AND WASTEWATER TREATMENT

**Duration - 3 Hours**

**NOTES:**

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. This is closed book exam; a formula sheet and necessary aids are provided.

3. Candidates may use one of two calculators, the Casio or Sharp approved models.

4. There are three sections to this exam (Parts A, B and C). Answer all questions in Part A, 2 questions in Part B and 1 question in Part C.

**PART A:**

(5) 1. What are the advantages of dual media filtration with anthracite-sand to a mono-medium sand filter? For a dual media filter, explain why anthracite is often placed on top of sand. Provide a sketch of particle size versus depth for the mono-medium filter.

(4) 2. How does the objective of a primary clarifier differ from the objective a secondary clarifier? Which clarifier would likely remove a higher concentration of $BOD_5$? (4 marks)

(8) 3. On the basis of disinfection capacity and disinfectant by-product formation, compare ozone, free chlorine and chlorine dioxide as possible disinfecting agents for water treatment. What are two important distinctions between disinfection with UV and disinfection with free chlorine? What is the difference between total and free chlorine.

(8) 4. A town in Northern Ontario has two possible water sources for water treatment: a groundwater aquifer and a small lake. The groundwater aquifer has a pH of 8, a turbidity of 0.8 NTU, an average TOC of 1.5 mg/L, manganese of 0.4 mg/L[1] and an alkalinity of 100 mg/L as $CaCO_3$. The reservoir has a pH of 5.6, a turbidity of 10 NTU, an average TOC of 8.0 mg/L, manganese of 0.03 mg/L and an alkalinity of 50 mg/L as $CaCO_3$. Provide a preliminary process sketch of the treatment train for both water sources that indicates the important unit operations and ***briefly*** explain your rationale for selecting that process. In both designs describe what major driving forces are impacting your design decisions.

(5) 5. Two activated sludge systems to have identical hydraulic retention times and MLVSS. One system has a sludge age that is exactly two times greater than the other system. All other things being equal determine which system will remove the most $BOD_5$.

[1] Drinking water guideline for manganese is 0.05 mg/L.

**PART B:**

Answer 2 questions from this section.

(25) 6. Shallow automatic backwash filters are to be used as the final process in a municipal wastewater treatment plant treating an average flow of 0.55 $m^3/s$. The average temperature of the wastewater is 15°C. For the filter properties given below, calculate the total filter surface area required if the maximum allowable head loss is 0.2 m. Assume a maximum friction factor of 250 and check that this assumption is not violated. Use the $d_{60}$ particle size in the head loss calculations.

<u>Filter Properties</u>

- Filter depth = 0.3 m
- Uniformity coefficient = 1.4
- Effective size = 0.5 mm
- Sphericity = 0.82
- Porosity = 0.42
- Relative density = 2.65

(25) 7. Design a horizontal clarifier to have a flow rate of 20,000 $m^3/d$ and an average retention time of 0.5 h. The tank should have a maximum effective depth of 4.5 m and a length to width ratio of 4:1. The average water temperature is 10°C.

A particle size analysis has been performed on the influent suspended solids (Table 1). For particles with a specific gravity of 2.5, determine the effluent TSS concentration from the clarifier and the overall removal efficiency.

**Table 1:** Influent Particle Size Analysis

| Mean Particle Diameter, μm | Mass Concentration, mg/L |
|---|---|
| 10 | 75 |
| 50 | 150 |
| 100 | 165 |
| 150 | 130 |

(25) 8. A flocculation basin consists of two compartments with four parallel streams. The plant flow rate is 20000 $m^3/d$ and the average water temperature is 15 °C. Each horizontal paddle set in the floc basin has eight blades and two paddle arms (Figure 2). The blade width is 10 cm and its length is 3.0 m. The total paddle arm length is 3.0 m. At the ends of each paddle arm are two blades, which are spaced 90 cm apart. The paddles in the first compartment are rotating at a speed of 5 rpm. The rotational speed of the paddles in the second compartment is 2.5 rpm. Each compartment cell (i.e. compartment for each parallel stream) has a width and length of 4 m. The depth in the influent to the first compartment is 4.0 m and increases to 4.5 m at the effluent. The depth at the effluent of the second compartment is 5.0 m.

a) How much power is dissipated into the water for each compartment?

b) Determine the G·t value for each compartment.

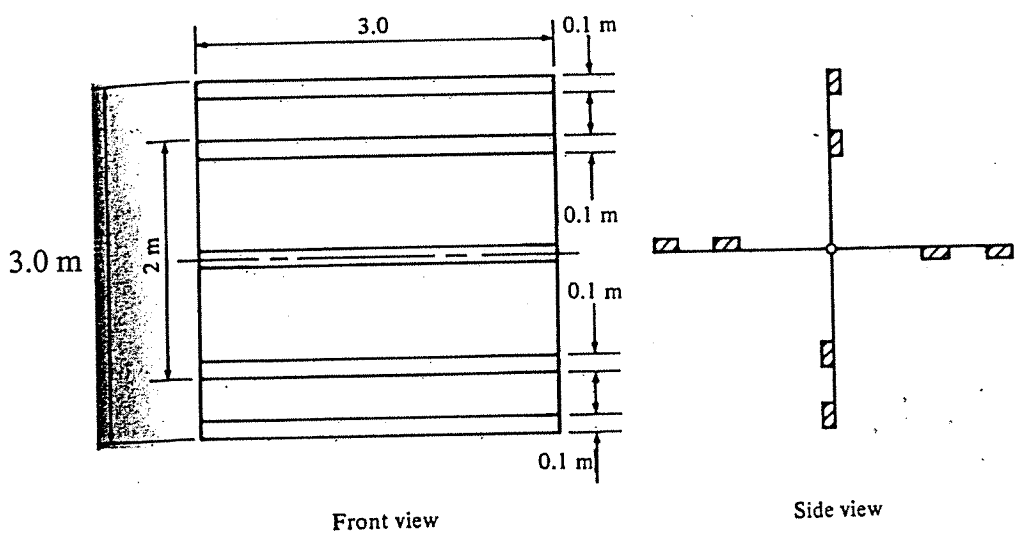


**Figure 2:** Flocculator design.

## PART C

Answer 1 question from this section

(25) 9. An activated sludge system consists of 2 CSTRs in parallel for aeration and one secondary clarifier. Each aeration reactor has a surface area of 196 $m^2$ and a depth of 6 m. The system must produce a soluble effluent $BOD_5$ of 15 mg/L from a wastewater with a total volumetric flow rate of 9400 $m^3$/d and influent soluble $BOD_5$ of 270 mg/L. The biomass recycle ratio is kept constant at 0.4 and the settling data for the total suspended solids are shown in Figure 1. The bio-kinetic properties are provided below. The effluent concentration of biomass from the secondary clarifier is 0 mg/L. The temperature of the wastewater is 10°C. For the conditions of this activated sludge system determine the solids retention time MLVSS and waste TSS concentration from the secondary clarifier.

<u>Microbiological Characteristics</u> (Temperature at 20°C)

| | |
|---|---|
| $Y = 0.46$ | $k = 3.7\ d^{-1}$ |
| $K_S = 80$ mg/L | $k_d = 0.05\ d^{-1}$ |
| $f = VSS/TSS = 0.9$ | $X_{influent} = 0$ mg/L |

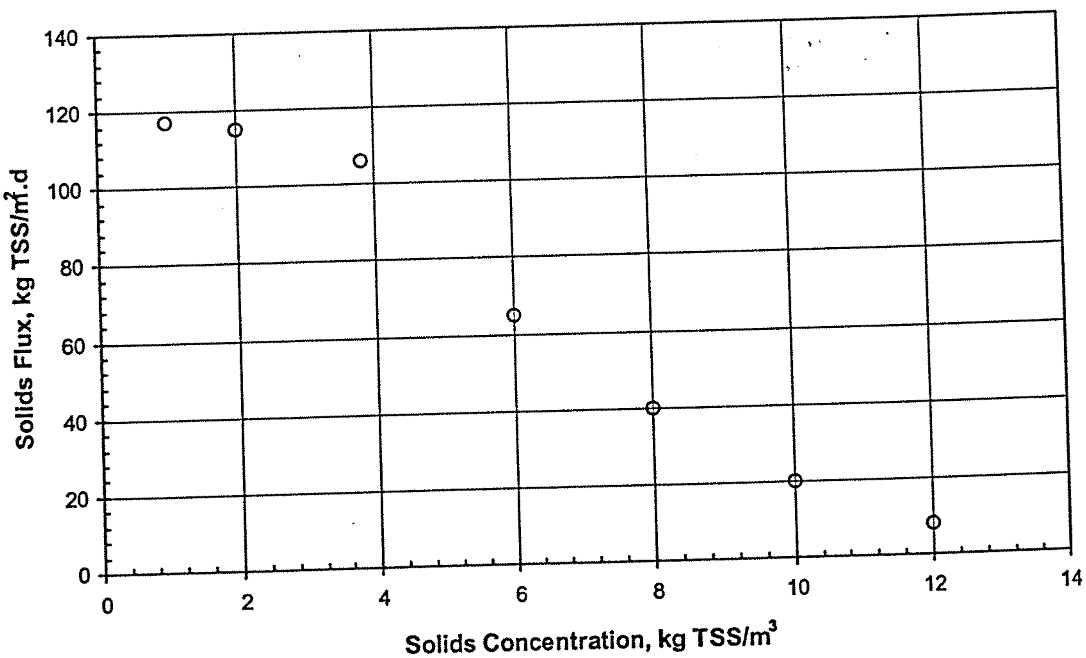


**Figure 1:** Settling data for secondary clarifier.

(25) 10. An industrial wastewater treatment facility has a daily flow of 310 $m^3/d$ and a $BOD_5$ of 600 mg/L. Because influent concentration of solids is very low, an extended aeration system is used to treat the waste. The average temperature of the waste is 16°C. City by-laws require that the effluent $BOD_5$ must be less than 50 mg/L prior to discharging the waste into the municipal sewer system.

a) Calculate the volume of the aeration reactor and the MLVSS.

b) Given that the 10 kW mechanical aerators have standard oxygen transfer rate of 0.75 kg $O_2$/kW.h, determine the effluent DO concentration.

**Microbiological Properties (at 20°C)**

$Y = 0.5$ $k = 4.5\ d^{-1}$

$K_S = 120$ mg/L $k_d = 0.04\ d^{-1}$

Conversion factor (*f*) for relating $BOD_5$ to COD is 0.68.

**Aeration Properties (at 20°C)**

$\beta = 0.95$ $\alpha = 0.8$

$K_La = 0.90\ h^{-1}$

**Formula Sheet**

$$r = \frac{dC}{dt}$$

$$-r_A = \frac{Q}{A}\left(C_{O,A} - C_A\right)$$

$$\theta = V / Q$$

$$C_n = \frac{C_O}{(1+\tau k)^n}$$

$$\frac{A_C L}{Q} = \int_{C_O}^{C} \frac{dC}{r}$$

$$v^2 = \frac{4}{3} \cdot \frac{g d}{C_D} \cdot \left(\frac{\rho_P - \rho}{\rho}\right)$$

$$\mathrm{Re} < 1,\ C_D = \frac{24}{\mathrm{Re}}$$

$$\mathrm{Re} > 1,\ C_D = \frac{24}{\mathrm{Re}} + \frac{3}{\sqrt{\mathrm{Re}}} + 0.34$$

$$G = \sqrt{\frac{P}{\mu V}}$$

$$P = 1.44 \times 10^{-4}\, C_D \rho b \left[N(1-k)\right]^3 (r_o^4 - r_i^4)$$

$$v_C = \frac{Q}{A_S}$$

$k = 0.25$ with stators

$k = 0.0$ without stators

$C_D = 1.4$

$$\% R_T = \frac{\Delta h_1}{h_T}\left(\frac{R_1 + R_2}{2}\right) + \frac{\Delta h_2}{h_T}\left(\frac{R_2 + R_3}{2}\right) + \ldots$$

$$v'_C = \frac{Q}{n A_P \cos\theta}$$

$$X_r = (1 - X_C) + \int_0^{X_C} \frac{v}{v_C}\, dx$$

$$R_H = \frac{A_X}{w_P}$$

$$SF_T = SF_g + SF_u = C_i v_h + C_i U$$

$$\mathrm{Re} = \frac{v d \rho}{\mu}$$

$$A_S\, SF_L \geq Q\, C_O$$

$$\mathrm{Re} = \frac{v d \psi \rho}{\mu}$$

$$h_L = f_f \frac{(1-e)}{e^3 \psi} \cdot \frac{v_S^2}{g} \cdot \frac{L}{d}$$

$$f_f = 150 \frac{1-e}{\mathrm{Re}} + 1.75$$

# Formula Sheet

$$h_{L,i}=\frac{(1-e)}{e^3\psi}\cdot\frac{v_S^2}{g}\cdot L\Sigma\left(f_{fi}\frac{x_i}{d_i}\right)$$

$$d_{60}=U\,d_{10} \qquad d_{90}=d_{10}\,U^{1.67}$$

$$\mathrm{Re}_{mf}=\frac{v_{mf}\,d_{90}\,\rho}{\mu}$$

$$\mathrm{Ga}=\frac{d_{90}^3\rho(\rho_s-\rho)g}{\mu^2}$$


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$$\mathrm{Re}_{mf}=\left[33.7^2+0.0408\,\mathrm{Ga}\right]^{0.5}-33.7$$

$$\ln\frac{N}{N_O}==-\alpha C^n t$$

$$r_S=\frac{-k\,X\,S}{K_S+S}$$

$$r'_g=-Y\,r_s-k_d\,X$$

$$\theta_X=\frac{X_V\,V}{(Q-Q_W)\,X_{Ve}+Q_W X_{Vr}}$$

$$k_T=k_{20}\,1.04^{T-20}$$

$$\frac{1}{\theta_X}=\frac{Y(S_O-S)}{X_V\,\theta}-k_d$$

$$\frac{1}{\theta^m}=\frac{Y\,k\,S_O}{K_S+S_O}-k_d$$

$$P_X=Y_{obs}\,Q(S_O-S)$$

$$Y_{obs}=\frac{Y}{1+k_d\,\theta_X}$$

$$F/M=\frac{S_O}{\theta X_V}$$

$$r=\frac{1-\dfrac{\theta}{\theta_X}}{\dfrac{X_{Vr}}{X_V}-1}$$

$$r_{gas}=K_L a(C_S-C)$$

$$C=C_S-(C_S-C)\cdot\exp(-K_L a\,t)$$

$$N=N_O\left(\frac{\beta C_S-C}{9.09}\right)\alpha\,1.024^{T-20}$$

$$P_R=\frac{O_{2R}}{N\cdot 24}$$

$$H = \frac{p_g}{C_l} \qquad H' = \frac{C_g}{C_l} \qquad H' = \frac{H}{RT}$$

$$(K_L a)_{VOC} = \psi (K_L a)_{O_2} \qquad O_{2R} = \frac{Q(S_O - S)}{f} - 1.42\, P_x$$

**Formula Sheet**

$$E = Q_g H' C_l (1 - e^{-\phi})$$

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$$\phi = \frac{(K_L a)_{VOC} V}{H' Q_g}$$

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$$(K_L a)_T = (K_L a)_{20}\, 1.024^{(T-20)}$$

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$$R = 0.0821 \frac{L \cdot atm}{mol \cdot K}$$

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$$Q_{O_2} = \frac{O_{2R}}{E} \cdot 0.7$$

$$Q_a = \frac{Q_{O_2}}{0.21} \times \frac{273 + T}{273}$$

**Table C.1 Physical properties of water in SI units**

| Temp, °C | Specific weight $\gamma$, $N/m^3$ | Density $\rho$, $kg/m^3$ | Viscosity $\mu \times 10^3$, $N \cdot s/m^2$ | Kinematic viscosity $\nu \times 10^6$, $m^2/s$ | Surface tension $\sigma \times 10^2$, N/m | Vapor-pressure head $p_v/\gamma$,† m | Bulk modulus of elasticity $K \times 10^{-7}$, $N/m^2$ |
|---|---|---|---|---|---|---|---|
| 0 | 9806 | 999.9 | 1.792 | 1.792 | 7.62 | 0.06 | 204 |
| 5 | 9807 | 1000.0 | 1.519 | 1.519 | 7.54 | 0.09 | 206 |
| 10 | 9804 | 999.7 | 1.308 | 1.308 | 7.48 | 0.12 | 211 |
| 15 | 9798 | 999.1 | 1.140 | 1.141 | 7.41 | 0.17 | 214 |
| 20 | 9789 | 998.2 | 1.005 | 1.007 | 7.36 | 0.25 | 220 |
| 25 | 9778 | 997.1 | 0.894 | 0.897 | 7.26 | 0.33 | 222 |
| 30 | 9764 | 995.7 | 0.801 | 0.804 | 7.18 | 0.44 | 223 |
| 35 | 9749 | 994.1 | 0.723 | 0.727 | 7.10 | 0.58 | 224 |
| 40 | 9730 | 992.2 | 0.656 | 0.661 | 7.01 | 0.76 | 227 |
| 45 | 9711 | 990.2 | 0.599 | 0.605 | 6.92 | 0.98 | 229 |
| 50 | 9690 | 988.1 | 0.549 | 0.556 | 6.82 | 1.26 | 230 |
| 55 | 9666 | 985.7 | 0.506 | 0.513 | 6.74 | 1.61 | 231 |
| 60 | 9642 | 983.2 | 0.469 | 0.477 | 6.68 | 2.03 | 228 |
| 65 | 9616 | 980.6 | 0.436 | 0.444 | 6.58 | 2.56 | 226 |
| 70 | 9589 | 977.8 | 0.406 | 0.415 | 6.50 | 3.20 | 225 |
| 75 | 9560 | 974.9 | 0.380 | 0.390 | 6.40 | 3.96 | 223 |
| 80 | 9530 | 971.8 | 0.357 | 0.367 | 6.30 | 4.86 | 221 |
| 85 | 9499 | 968.6 | 0.336 | 0.347 | 6.20 | 5.93 | 217 |
| 90 | 9466 | 965.3 | 0.317 | 0.328 | 6.12 | 7.18 | 216 |
| 95 | 9433 | 961.9 | 0.299 | 0.311 | 6.02 | 8.62 | 211 |
| 100 | 9399 | 958.4 | 0.284 | 0.296 | 5.94 | 10.33 | 207 |

† $\gamma = 9806\ N/m^3$.