

Civ-B5, WATER SUPPLY AND WASTEWATER TREATMENT

December 2003

Duration - 3 Hours

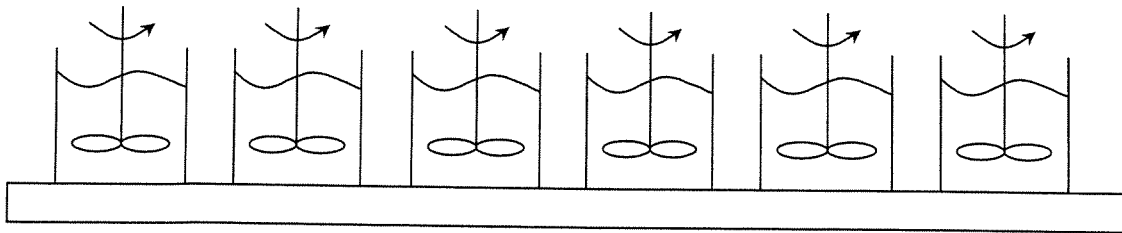
NOTES:

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 open 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:

- (10) 1. In the design of flocculation an interesting design parameter is the stator. Provide a sketch (side view) of a flocculator and indicate where the stator would be placed on the sketch. What is the purpose of a stator? All things being equal calculate the effect stators have on the volume of the flocculation chamber (i.e., compare the volume requirements of two flocculators that are identical with the exception that one flocculator has stators and the other does not).
- (10) 2. Provide a sketch of a wastewater treatment consisting of *only* primary treatment, a *conventional* water treatment plant, and a membrane plant that does not have any chemical addition. For each plant describe which process unit may contain Type I, II, and III settling.

- (10) 3. A local water treatment plant is interested in conducting a jar test investigation to optimize their coagulation/flocculation process step. The plant wants to maintain their use of alum, however, they are interested in optimizing the coagulant dose and determining whether or not they need a coagulant aid (the plant in the neighbouring town uses an anionic polymer). One of their variable-speed pumps has recently failed and they are also interested in optimizing rotational speeds during flocculation. Their current G-values during flocculation (three compartments) are 150, 75 and 10 s^{-1} . You have been hired to design one experiment (i.e., six jars) to test for turbidity removal. The town has a raw water turbidity of 1.5 NTU, and pH of 5.5. Your design should recommend specific coagulant dosages and G-values for the experiment and a rationale for the selection. Also explain whether you will incorporate chemical agents other than alum in the jar test and explain their role in the test. (10 marks)



Jar No.	1	2	3	4	5	6
Alum Dose						
Mixing Conditions						
Other						

- (5) 4. Two activated sludge systems to have identical hydraulic retention times and MLVSS. One system has a sludge age that is exactly four times greater than the other system. All other things being equal determine which system will remove the most BOD₅.

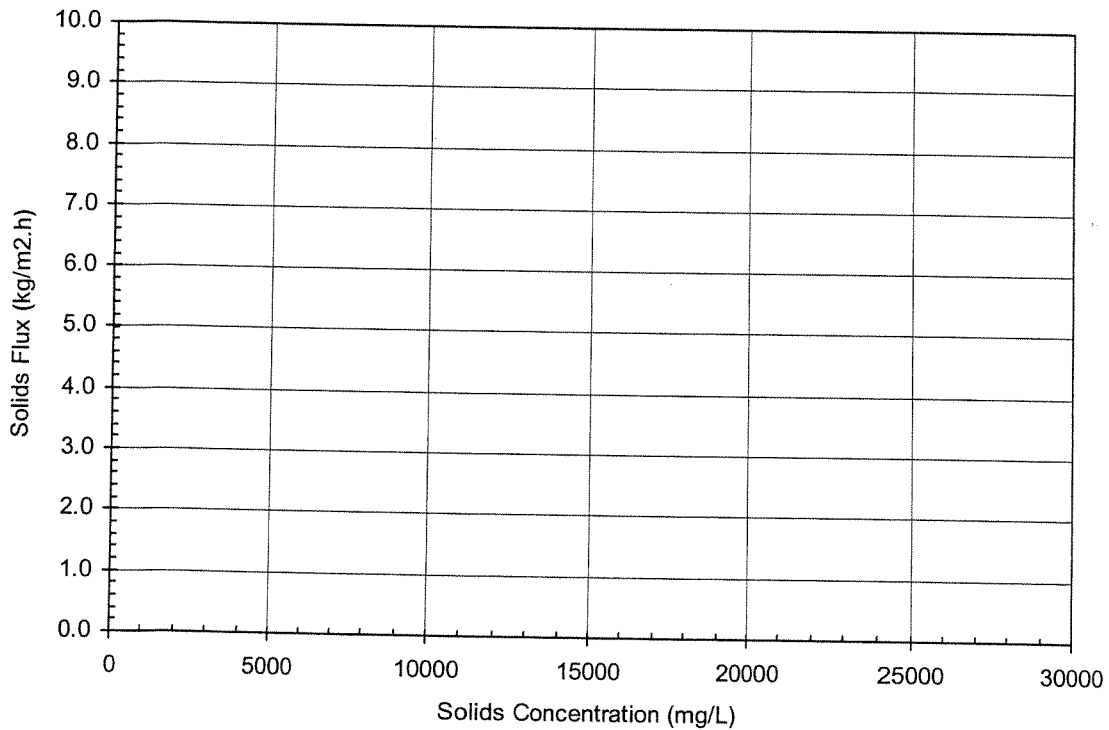
PART B:

Answer 2 questions from this section.

5. Wastewater at the Cobain Memorial Pollution Control Plant in Seattle, WA is treated with activate sludge treatment. The wastewater flows from the aeration basin to the secondary clarifier at a rate of 2,500 m³/d. The effluent solids concentration from the aeration basin is 4,500 mg/L. Because of space limitations the diameter of the secondary clarifier is 10 m. A settling analysis has been performed on the influent solids (Table 1), from which you have been hired to **determine underflow concentration and the recycle ratio for the described system.**

Table 1: Solids Analysis for Secondary Clarifier at the Cobain Memorial Pollution Control Plant

TSS, mg/L	850	1300	2500	4000	6,000	8,000	10,000	15,000	20,000	25,000
Velocity, m/h	7.5	5.8	3.2	2.0	1.1	0.6	0.3	0.15	0.1	0.07

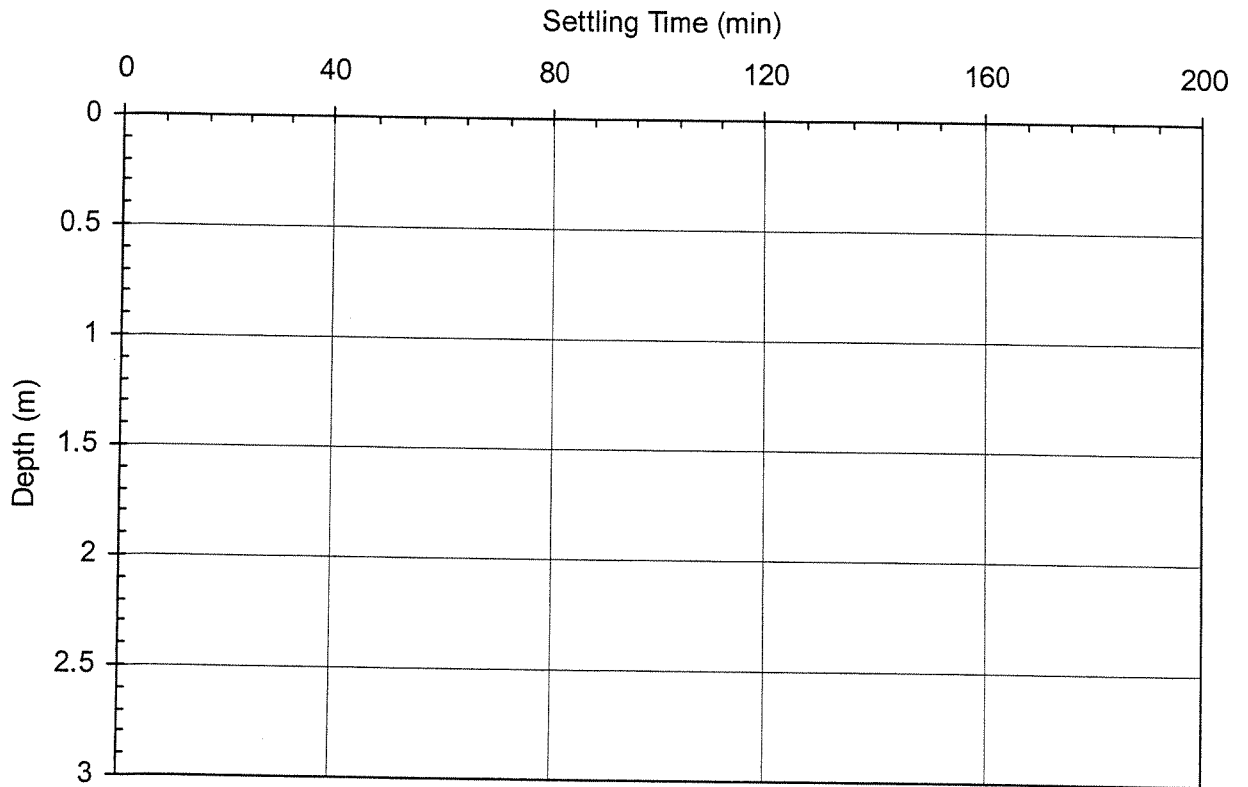


- (25)
6. The sand filters at the Springfield Water Treatment Plant (SWTP) have a depth of 0.8 m. The raw water has an average water temperature of the SWTP is 20°C. The sand has a porosity and sphericity of 0.42 and 0.9, respectively. A specific gravity of 2.65 can be assumed for the filter media. The effective size and uniformity coefficient of the sand is 0.6 mm and 1.4. The SWTP intends on backwashing at the minimum fluidization velocity (v_{mf}). Determine v_{mf} and estimate the per cent bed expansion assuming a expanded-bed porosity of 0.48..

- (25)
7. A settling column analysis is conducted on flocculated water and the percent removal from the test is provided in Table 2.
 - a) Determine the removal efficiency of the settling basin with a depth of 3.5 m, volume of 1400 m³, and flow rate of 11.2 MLD.
 - b) Over the life of the plant it is expected (based on current population growth) that the plant flow rate will increase by as much as 15%. Assuming that there is no change in tank depth, what would removal efficiency would be at the higher plant flow rate?
 - c) Provide a suggestion on how the plant could be modified/retrofitted, if the plant wanted to maintain the current dimensions and maintain current removal (i.e., original flow rate),

Table 2: Settling Column Test Results

Depth, m	Settling Time, min					
	0	40	80	120	160	200
0.5	0%	55%	71%	80%	87%	92%
1	0%	46%	55%	74%	74%	80%
1.5	0%	23%	42%	65%	65%	72%
2	0%	18%	32%	57%	57%	65%
2.5	0%	13%	28%	51%	51%	58%
3	0%	12%	25%	44%	44%	52%



PART C

- (25) 8. Wastewater from an automotive manufacturer has a daily flow of 8.5 ML/d and a BOD₅ of 350 mg/L. The influent concentration of active biomass is very low. The wastewater also contains benzene at a concentration of 15 mg/L. An activated sludge process, without biomass recycle, is planned for treating the high organic waste. City by-laws require that the effluent BOD₅ must be less than 25 mg/L prior to discharging the waste into the municipal sewer system. For an average wastewater temperature of 25°C, determine.
- The power consumption of a diffused aeration system that has a transfer efficiency of 15 % and standard oxygen transfer rate of 2.1 kg O₂/kW.h. The objective of the diffusers is to maintain a constant dissolved oxygen concentration of 2 mg/L in the aeration basin.
 - During the year, the temperature fluctuates between 8-22°C; the flow fluctuates between ±35 % of the average and the influent BOD₅ fluctuates between ±25 % of the average. Determine when the aeration pond is most vulnerable to experiencing wash out:

Microbiological Properties (at 20°C)

$$Y = 0.55$$

$$k = 1.5 \text{ d}^{-1}$$

$$K_S = 45 \text{ mg/L}$$

$$k_d = 0.02 \text{ d}^{-1}$$

$$X_{\text{influent}} = 0 \text{ mg/L}$$

Conversion factor (*f*) for relating BOD₅ to COD is 0.68.

Aeration Properties (at 20°C)

$$K_L a = 1.30 \text{ h}^{-1}$$

$$\alpha = 0.8$$

$$\beta = 0.85$$

$$C_S \text{ (at 25°C)} = 8.26 \text{ mg/L}$$

Physical Properties of Benzene

$$H = 0.2$$

$$\Psi = 0.6$$

Formula Sheet

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

$$\theta = V/Q$$

$$\frac{A_c L}{Q} = \int_{c_o}^c \frac{dC}{r}$$

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

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

$$k = 0.25 \text{ with stators}$$

$$k = 0.0 \text{ without stators}$$

$$C_D = 1.4$$

$$\% R_T = \frac{\Delta h_1}{h_T} \left(\frac{R_1 + R_2}{2} \right) + \frac{\Delta h_2}{h_T} \left(\frac{R_2 + R_3}{2} \right) + \dots \quad v'_c = \frac{Q}{nA_p \cos \theta}$$

$$X_r = (1 - X_c) + \int_0^{x_c} \frac{v}{v_c} dx$$

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

$$A_s SF_L \geq Q C_o$$

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

$$-r_A = \frac{Q}{A} (C_{o,A} - C_A)$$

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

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

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

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

$$v_c = \frac{Q}{A_s}$$

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

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

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

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

Formula Sheet

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

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$$d_{60} = U d_{10}$$

$$d_{90} = d_{10} U^{1.67}$$

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$$d_{90} = d_{10} U^{1.67}$$

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

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

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$$\text{Re}_{mf} = [33.7^2 + 0.0408 \text{Ga}]^{0.5} - 33.7$$

$$\ln \frac{N}{N_0} = -\alpha C^n t$$

$$r_s = \frac{-k X S}{K_s + S}$$

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

$$\theta_x = \frac{X_v V}{(Q - Q_w) X_{ve} + Q_w X_{vr}}$$

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

$$\frac{1}{\theta_x} = \frac{Y(S_0 - S)}{X_v \theta} - k_d$$

$$\frac{1}{\theta^m} = \frac{Y k S_0}{K_s + S_0} - k_d$$

$$P_X = Y_{obs} Q (S_0 - S)$$

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

$$F/M = \frac{S_0}{\theta X_v}$$

$$r = \frac{1 - \frac{\theta}{\theta_x}}{\frac{X_{vr}}{X_v} - 1}$$

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

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

$$N = N_0 \left(\frac{\beta C_s - C}{9.09} \right) \alpha 1.024^{T-20}$$

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

$$H = \frac{P_g}{C_l} \quad H' = \frac{C_g}{C_l}$$

$$H' = \frac{H}{RT}$$

$$(K_L a)_{VOC} = \psi (K_L a)_{O_2}$$

$$O_{2R} = \frac{Q(S_o - S)}{f} - 1.42 P_x$$

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 γ , N/m ³	Density ρ , kg/m ³	Viscosity $\mu \times 10^3$, N·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/γ ,† 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

† $\gamma = 9806 \text{ N/m}^3$.