UNIVERSITY OF JOHANNESBURG

PROGRAM	:	BACCALAUREUS TECHNOLOGIAE: *ENGINEERING : CIVIL*
SUBJECT	:	**WASTEWATER TREATMENT TECHNOLOGY IV**
CODE	:	**WWT411**
ASSESSMENT	:	WINTER EXAMINATION (MAIN PAPER)
DATE		2nd JUNE 2016
DURATION	:	(SESSION 1) 08:30 - 11:30
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TOTAL MARKS	:	100

ASSESSOR	:	G.K. NKHONJERA
MODERATOR	:	PROF. F.M. ILUNGA
NUMBER OF PAGES:		PAGES: 17 including the cover page and Annexures.

INSTRUCTIONS :

1. This paper contains 4 questions in Section A and 3 questions in Section B
2. Section A: ANSWER **ALL** QUESTIONS
3. Section B: ANSWER **TWO** QUESTIONS ONLY
4. Make sure that you understand what the question requires before attempting it.
5. Any additional material is to be placed in the answer book and must indicate clearly the question number, your name, and Student number.
5. Where necessary, answers without calculations will not be considered.

SECTION A
ANSWER ALL QUESTIONS

QUESTION 1 [10]

1.1 Sludge is basically the residual or semi-solid material that is produced as a by-product during wastewater treatment. Describe any major difference between primary and secondary sludges. (2)

1.2 With respect to simple wastewater treatment technologies, briefly explain how treatment of wastewater is achieved in constructed wetland technologies. (2)

1.3 From your own understanding of sludge treatment, discuss the purposes of the following basic processes for sludge treatment:

a) Thickening. (2)
b) Conditioning. (2)
c) Reduction. (2)

QUESTION 2 [15]

2.1 In the primary wastewater treatment processes, there is an optimum detention time beyond which the efficiency of the tank may not improve. Discuss any TWO reasons why this is like that. (4)

2.2 A rectangular sedimentation basin, designed to treat wastewater ($\rho = 1000$ kg/m^3), has an overflow rate of 30 m^3/d.m^2. The dimensions of the basin are 15 m long, 6 m wide and 2.75 m deep (this being the side water depth). With the Darcy-friction factor taken as $f = 0.03$ and sticky-factor, $\beta = 0.005$, determine the following:

a) Whether the basin will be effective in removing particles with a diameter of 0.1 mm and a specific gravity of 2.5. (5)

b) The strength of the raw wastewater being received at the primary treatment process, given that the local authority limits the effluent BOD and TSS not to exceed 161 mg/L and 85 mg/L respectively. (6)

QUESTION 3 [15]

3.1 With respect to the principles of operations of the grit removal chambers and primary wastewater treatment clarifiers, discuss any TWO major differences between the two processes at a wastewater treatment plant. (4)

3.2 The bar racks (coarse screens) are installed in a dual rectangular channel as shown in **Fig 3.1** so that at any other time only one channel is in operation. The channels, which are made of concrete, are isolated by the use of slide gates to allow water to pass through the screens in one channel only. The flow required to be treated at this wastewater treatment plant is 69.44 m^3/min. Each channel dimensions are 1.6 m wide and 1.8 m deep. If the freeboard in the channel is 0.6 m, estimate the headlosses incurred in the bar rack when the screen is:

a) Not clogged. (5)
b) 15% clogged. (3)
c) 75% unclogged. (3)

You may be free to use the following assumptions:
- Bar width = 10 mm.
- Bar spacing (CD) = 25 mm.
- Discharge coefficient, C = 0.6
- Bar rack is mechanically cleaned.

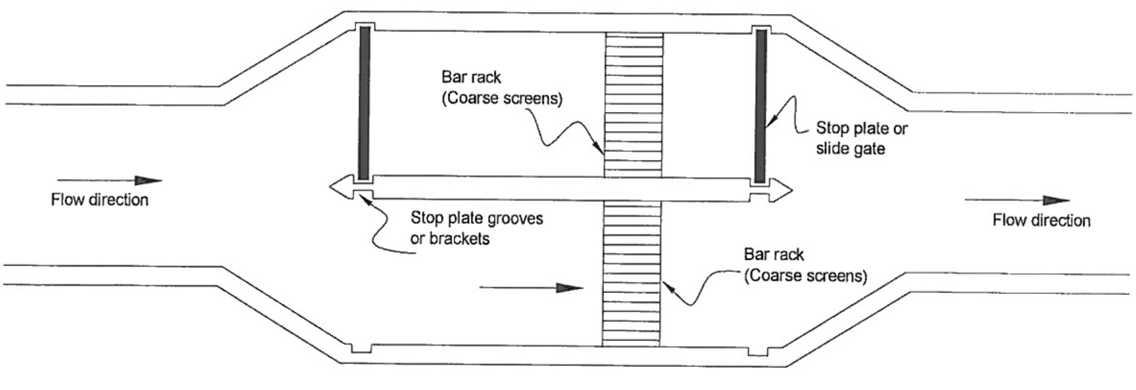

Fig. 3.1: *Dual channel with bar rack screens*

QUESTION 4 [20]

4.1 With a well labelled sketch of a flow diagram, discuss how biological oxidation is achieved in a conventional PLUG-FLOW ACTIVATED SLUDGE PROCESS. (7)

4.2 In reference to wastewater treatment processes, discuss the major differences between the following terms:

a) Biomass and Substrate. (2)
b) Hydraulic detention time and Mean Cell Residence Time. (2)
c) Primary Settling Tank (PST) and Secondary Settling Tank (SST). (2)

4.3 Consider a small town that needs a cheap technology to treat its wastewater. From local materials available so far, a single-stage rock media trickling filter (**Fig. 4.2**) is the only option. However, the local municipality requires that the BOD effluent standards of 30 mg/L must be met regardless of whichever technology is used. It is established that the total wastewater flow of 10 ML/d to the filter contains BOD of 150 mg/L. In order to increase efficiency, 87% of the flow will have to be recycled back to the filter. If the depth of this filter is taken as 1.8 m, determine the:

a) Diameter of the trickling filter. (5)
b) Hydraulic loading to the filter (including recycle flow). (2)
Assume that the NRC Equation applies and that the wastewater is at room temperature.

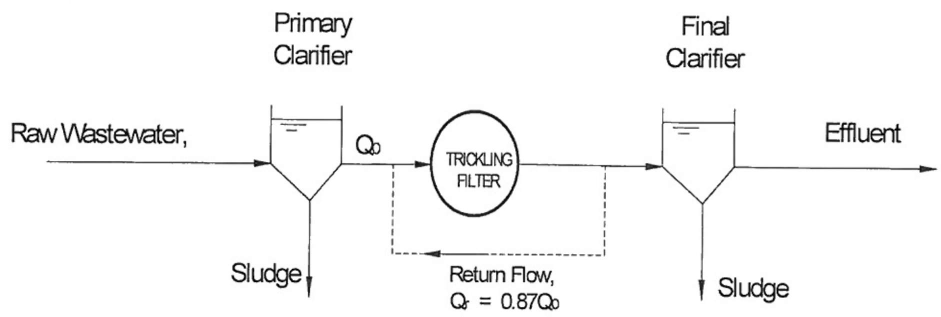

Fig. 4.2: *Single-stage rock media trickling filter*

SECTION B
ANSWER TWO QUESTIONS ONLY

QUESTION 5 [20]

5.1 The decomposition of wastes is generally governed by the mixed culture of microorganisms present in wastewater. From your understanding so far, discuss any THREE types of decomposition that happen in wastewater. (9)

5.2 A small to medium wastewater treatment plant has a reactor in form of a Complete-mix Activated Sludge Process. The reactor treats a wastewater flow of 21600 m^3/d to yield an effluent BOD of 30 mg/L and suspended solids of 25 mg/L. The BOD level of the effluent from primary clarifiers is 200 mg/L. The BOD of suspended solids in the effluent is assumed to be 63% of the TSS concentration. If the MLSS = 2500 mg/L and that MLVSS is 80% of MLSS, determine the following:

a) Hydraulic retention time (HRT). (3)
b) Size of the rectangular aeration tank, given that the liquid effective depth is 1.75 m and that L:W = 8:1. (4)
c) Volume of wastewater wasted daily. (2)
d) Recirculation ration, R. (2)

Assume the following: $Y = 0.65$ *mg VSS/mg BOD;* $k_d = 0.1\ d^{-1}$*;* $\theta_c = 10$ *days;* $\mu_m = 3.0\ d^{-1}$*; underflow concentration = 11000 mg/L.*

QUESTION 6 [20]

Fig. 6.3 below, represents a two-stage rock media trickling filter that is planned for a small rural town to treat wastewater to meet the municipal BOD effluent standards of 30 mg/L. The total flow to be treated is 541.67 m^3/hr. Given the design criteria and other design data as presented below, design this two-stage trickling filter.

- *BOD concentration of raw wastewater = 403 mg/L.*
- *BOD removal efficiency of primary clarifier = 43%.*
- *Filter depth for both filters = 1.5 m.*
- *Adopt a design philosophy of equal efficiency.*
- *Wastewater is at room temperature.*
- *The NRC Equation applies.*

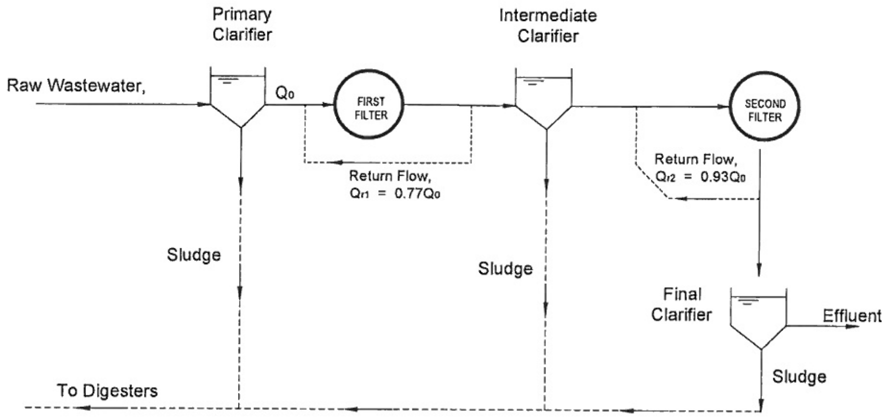

Fig. 6.3: *Two-Stage rock media trickling filter*

QUESTION 7 [20]

Design a circular primary clarifier to handle a wastewater flow from a small town with a total population of 170 000, given the following design information:

2 Centre-feed type of clarifiers with one out of service, (1 clarifier in operation).
Average rate of water supply = 250 l/p/d.
Wastewater generation rate = 80% of water supply
Inflow and infiltration accounted for is 30%.
Overflow rate = 35 $m^3/d.m^2$.
Side water depth = 4.3 m.
Feedwell detention time = 20 minutes.
Depth of Feedwell = 75% of SWD.
EDI detention time = 10 seconds.
Depth of EDI = 27% of Depth of Feedwell.
Suspended solids in wastewater = 300 mg/L.
BOD_5 of wastewater = 200 mg/L.
Municipal standards for the following are:
a) BOD_5 = 120 mg/L.
b) TSS = 100 mg/L.

Summarize your design output by providing the following information:
Diameter of clarifier.
Diameter and depth of Feedwell.
Diameter and depth of EDI.
Check flow velocity and provide necessary comments.
Weir loading rates.
Check whether the effluent BOD_5 and TSS meet the required standards.

GOOD LUCK TO YOU ALL !!!!!

APPENDIX A

FORMULAS

Newton's Law formula $$V_s = \sqrt{\frac{4g(\rho_s - \rho)d}{3C_D\rho}}$$ Where: $$C_D = \frac{24}{N_R} + \frac{3}{\sqrt{N_R}} + 0.34$$	Headlosses in the screen, h_L, $$h_L = \frac{1}{C}\left(\frac{V_{thru}^2 - V_{ap}^2}{2g}\right)$$
Scour Velocity, V_{sc}, $$V_{sc} = \sqrt{\frac{8\beta(\rho_s - \rho)gd}{1000f}}$$	Weir loading, WL $$WL = \frac{Q}{Length}$$
Detention time, t_d, $$t_d = \frac{\forall}{Q}$$	Number of bars, N_b, $$N = \frac{Width\_of\_channel - bar\_space}{bar\_width + bar\_space}$$
Stoke's Law formula $$V_s = \frac{g(\rho_s - \rho)d^2}{18\mu}$$	Number of spacing, N_{sp}, $$N_{sp} = N_b + 1$$
Mass Balance Equation for Biomass $$QX_o + (\forall)\left(\frac{\mu_m SX}{K_s + S} - k_d X\right) = (Q - Q_w)X_e + Q_w X_r$$	Mass Balance Equation for Substrate $$QS_o - (\forall)\left(\frac{\mu_m SX}{Y(K_s + S)}\right) = (Q - Q_w)S + Q_w S$$

Mass balance for biomass around the secondary clarifier, $$(Q+Q_r)X=(Q-Q_w)X_e+Q_rX_r+Q_wX_r$$	Quadratic equation, $$ax^2+bx+c=0$$ $$x=\frac{-b\pm\sqrt{b^2-4ac}}{2a}$$
Hydraulic retention time, θ, $$\theta=\frac{\forall}{Q}$$	Mean cell residence time, θ_c, $$\theta_c=\frac{\forall X}{Q_wX_r}$$
Concentration of rbsCOD in the effluent, S, $$S=\frac{K_s(1+k_d\theta_c)}{\theta_c(\mu_m-k_d)-1}$$	Concentration of biomass in the reactor, X, $$X=\frac{\theta_c(Y)(S_o-S)}{\theta(1+k_d\theta_c)}$$
Specific substrate utilization rate, U, $$U=\frac{S_o-S}{\theta X}$$ Also, $$\frac{1}{\theta_c}=YU-k_d$$	Food to Microorganism (F/M) $$F/M=\frac{QS_o}{\forall X}$$ Also, $$Q_wX'_r=\frac{\forall X'}{\theta_c}$$
Recirculation ratio, R, for trickling filters $$R=\frac{Q_r}{Q}$$	Recirculation factor, F_1, for 1st trickling filter, $$F_1=\frac{1+R_1}{(1+0.1R_1)^2}$$
Efficiency for the first trickling filter: $$E_1=\frac{1}{1+4.12\left(\frac{QC_{in}}{\forall_1F_1}\right)^{0.5}}$$	Efficiency for the second trickling filter: $$E_2=\frac{1}{1+\frac{4.12}{1-E_1}\left(\frac{QC_e}{\forall_2F_2}\right)^{0.5}}$$

Hydraulic loading to the Trickling filter, with recycled flow $HL = \frac{Q(1+R)}{A_s}$	

Percentage removal, R, of BOD and TSS,

$$R_{BOD/TSS} = \frac{t}{a+bt}$$

Where:

R = Expected removal efficiency, (%).

t = Nominal detention time, (hours).

a,b = Empirical constants as shown below.

Typical values of the empirical constants at 20°C

Items	***a***	***b***
BOD	0.018	0.020
TSS	0.0075	0.014

Where:

- N_R = Reynolds number, dimensionless
- C_D, = Drag coefficient, dimensionless
- V_h = Average horizontal fluid velocity in tank, m/s
- β = Sticky material coefficient, dimensionless
- f = Darcy-Weisbach, friction factor
- ν = Kinematic viscosity, m^2/s ; $\nu = \mu/\rho$
- μ = Dynamic viscosity, Pa · s
- ρ = Density of fluid, kg/m^3
- ρ_s = Density of the particle, kg/m^3

- d = Size of the particle (m)
- V_s = Settling velocity (m/s)
- V_o = Overflow rate (m/s or $m^3/s.m^2$)
- V_{thru} = Velocity through the bar screen (m/s)
- h_L = headloss (m)
- C = Empirical discharge coefficient
- $\forall$ = Volume of the tank (m^3)
- WL = Weir loading ($m^3/d.m$)
- N_b = Number of bars in the bar screen
- N_{sp} = Number of spacing in the screen

For Suspended growth (Completely mixed reactor) ,

- Q = wastewater flow rate into the aeration tank, m^3/d
- X_o = microorganism concentration (volatile suspended solids or VSS) entering aeration tank, mg/L.
- $\forall$ = volume of aeration tank, m^3
- μ_m = maximum growth rate constant, d^{-1}
- S = readily biodegradable soluble COD (rbsCOD) in aeration tank and effluent, mg/L.
- X = microorganism concentration (mixed-liquor volatile suspended solids or MLVSS) in the aeration tank, mg/L.
- K_s = half velocity constant.
- Also, K_s = soluble BOD_5 concentration at one-half the maximum growth rate, mg/L.
- k_d = decay rate of microorganisms, d^{-1}
- Q_w = flow rate of liquid containing microorganisms to be wasted, m^3/d.
- X_e = microorganism concentration (VSS) in effluent from secondary settling tank, mg/L.
- X_r = microorganism concentration (VSS) in sludge being wasted, mg/L.
- Y = yield coefficient.
- U = specific substrate utilization rate.
- S_o = influent readily biodegradable soluble COD (rbsCOD), mg/L.

For Attach growth (trickling filter),

- E_1 = fraction of BOD_5 removal for first stage at 20°C, including recirculation and sedimentation
- Q = wastewater flow rate, m^3/s
- C_{in} = influent BOD_5, mg/L
- $\forall$ = volume of filter media, m^3
- F = recirculation factor
- R = recirculation ratio = Q_r / Q
- Q_r = recirculation flow rate, m^3/s
-

APPENDIX B

TYPICAL DESIGN CRITERIA FOR PRIMARY SEDIMENTATION BASINS

Typical design criteria for primary sedimentation basins		
Design Parameter	**Range of values**	**Typical design value/ Comments**
General		
Overflow rate (average flow)	30 to 50 $m^3/d.m^2$	40 $m^3/d.m^2$
Overflow rate (peak flow)	60 to 120 $m^3/d.m^2$	100 $m^3/d.m^2$
Detention time (average flow)	1.5 to 2.5 hours	2.0 hours
Horizontal flow velocity	0.020 to 0.025 m/s	
Weir loading rate	125 to 500 $m^3/d.m$	250 $m^3/d.m$
Sludge hoppers	1.7 vertical : 1 horizontal	Minimum: bottom width < 0.60 m
Geotechnical		Consider potential for floatation when tank is empty.

Design Parameter	**Range of values**	**Typical design value/ Comments**
Circular Tanks		
Dimensions		
Diameter	3 to 100 m	12 to 45 m
Side water depth (SWD)	3 to 5 m	4.3 m
Floor slope	1 vertical to 12 horizontal	
Splitter box		
Inlet velocity	< 0.3 m/s	At peak flow

Design Parameter	**Range of values**	**Typical design value/ Comments**
Circular Tanks		
Inlet configuration		
Detention time	20 minutes	Feedwell
Submergence	30 to 75% of depth	Size to prevent scour
EDI detention time	8 to 10 seconds	
Baffles		
Effluent		Below weir
Horizontal		Below feedwell

Typical design criteria for primary sedimentation basins		
Design Parameter	**Range of values**	**Typical design value/ Comments**
<u>**Rectangular tanks**</u>		
Dimensions		
Length	30 to 110 m	30 to 60 m
Width	3 to 24 m	6 m maximum per flight
Depth	2 to 5 m	4.3 m
Floor slope	1%	
Distribution channel		
Velocity	0.3 to 0.75 m/s	
Flow distribution		Prefer orifice or gates

Typical design criteria for primary sedimentation basins		
Design Parameter	Range of values	Typical design value/ Comments
Rectangular tanks		
Inlet configuration		
Ports	3 to 4 per tank at < 3 m	2 m
Energy dissipation		Target or finger baffle
Baffles		
Distance	0.6 to 0.9 m from inlet	
Submergence	0.5 to 0.6 m	
Porosity	Individual openings > 5 cm and < 10 cm	5% open area

APPENDIX C

PHYSICAL PROPERTIES OF WATER

Temperature (°C)	Density, ρ (kg/m^3)	Specific weight, γ (kN/m^3)	Dynamic viscosity, μ (mPa · s)*	Kinematic viscosity, ν ($\mu m^2/s$)*
0	999.842	9.805	1.787	1.787
3.98	1,000.000	9.807	1.567	1.567
5	999.967	9.807	1.519	1.519
10	999.703	9.804	1.307	1.307
12	999.5	9.802	1.235	1.236
15	999.103	9.798	1.139	1.14
17	998.778	9.795	1.081	1.082
18	998.599	9.793	1.053	1.054
19	998.408	9.791	1.027	1.029
20	998.207	9.789	1.002	1.004
21	997.996	9.787	0.998	1
22	997.774	9.785	0.955	0.957
23	997.542	9.783	0.932	0.934
24	997.3	9.781	0.911	0.913
25	997.048	9.778	0.89	0.893
26	996.787	9.775	0.87	0.873
27	996.516	9.773	0.851	0.854
28	996.236	9.77	0.833	0.836
29	995.948	9.767	0.815	0.818
30	995.65	9.764	0.798	0.801
35	994.035	9.749	0.719	0.723
40	992.219	9.731	0.653	0.658
45	990.216	9.711	0.596	0.602
50	988.039	9.69	0.547	0.554
60	983.202	9.642	0.466	0.474
70	977.773	9.589	0.404	0.413
80	971.801	9.53	0.355	0.365
90	965.323	9.467	0.315	0.326
100	958.366	9.399	0.282	0.294

***Pa · s = (mPa · s) × 10^{-3}**

***$m^2/s = (\mu m^2/s) \times 10^{-6}$**