UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 6 Examination in Engineering: February 2020

Module Number: CE6304 **Module Name: Environmental Engineering Design**

[Three Hours]

[Answer **all questions**, questions carry **unequal** marks, the distribution of marks within a question is indicated at the end of each part]

Q1. (a) In a municipal council, a proposed municipal wastewater treatment plant will receive influent via a gravity-flow inception sanitary sewer going through a street as given in Table Q1 (a) from the junction 1 to the junction 4 via the junction 2 and 3. Design this inception sewer. The inception sewer will receive wastewater from trunk sewers. The design should include the design flow rates, pipe diameters, pipe slopes and the pipe invert elevations.

Table Q1(a)

Line	From junction	To junction	Length of sewer (m)	Average residential flow (m^3/d)	Average commercial flow (m^3/d)	Average institutional flow (m^3/d)	Ground surface elevation (m)	
							At upper man hole	At lower man hole
1	1	2	500	3000	-	-	22.0	21.0
2	2	3	500	2000	1000	1000	21.0	20.0
3	3	4	400	3000	1500	1000	19.0	18.0

Assume that the following design criteria apply:

1. The infiltration rate is negligible.
2. Peaking factors:
   Residential areas = 2.5; Commercial areas= 1.8; Institutions = 4.0
3. Major manholes are located at the junctions 1, 2, 3 and 4.
4. The local building code specifies 200 *mm* as the smallest pipe diameter permissible for this situation.
5. The minimum practical slope of a sewer for construction is about 0.0008 *m/m*.
6. The allowable minimum velocity is 0.75 ms^{-1}.
7. According to the local building code, the minimum depth of the cover over the top of the sewer is 2.0 *m*.
8. The pipe wall thickness is 0.05 *m*.
9. For the hydraulic design calculations, use the Manning's equation, $V = (1/n)R^{2/3}S^{1/2}$, where V = velocity (ms^{-1}); n = friction factor (0.013); R = hydraulic radius=cross-sectional area of flow(m^2)/wetted perimeter (m); S = slope of energy grade line (m/m).

(10.0 Marks)

b) What is the primary design parameter, based on which a carbon oxidation combined complete nitrification process is designed?

[1.0 Mark]

c) In the design of the above process, this primary design parameter is estimated based only on the process of converting ammonia into nitrate by *Nitrosomonas* bacteria. Explain why.

[2.0 Marks]

d) If the Solids Retention Time *(SRT)* is equal to the mass of solids retained in the system divided by the mass of solids going out of the entire system every day, obtain the following expression for the *SRT* of the *ASP* (Activated Sludge Process) in Figure Q1(f), $SRT = \frac{V_r X}{(Q_w X_r + Q_e X_e)}$.

[2.0 Marks]

e) Applying flow balance to the secondary sedimentation tank of the *ASP* depicted by Figure Q1(f), estimate an expression for the effluent flow rate *(Q_e)* of the process.

[2.0 Marks]

f) The municipal wastewater treatment plant mentioned in the part (a) will consist of preliminary treatment, primary sedimentation, carbon oxidation combined complete nitrification process, in which an *ASP* {Figure Q1(f)} is to be designed to achieve both carbon oxidation and complete nitrification in one reactor.

Five percentage (5 %) of the effluent flow from the above system will be given further treatment in a water reclamation system to make it suitable for reuse. Therefore, the above amount of flow is directed to a water reclamation system consisting of an anaerobic filter, granular gravity filter, granular activated carbon *(GAC)* adsorption process and ultra violet *(UV)* disinfection in order to be suitable for reuse.

The nitrified effluent from the *ASP* will enter the anaerobic filter for denitrification. Denitrified wastewater will be fed to the *GAC* adsorption process via a granular gravity filter. A fixed-bed adsorber filled with *GAC* will be used for the adsorption process, which is to remove the remaining dissolved organic matter *(DOM)*.

Table Q1(f) gives the design data of the *ASP* and fixed-bed *GAC* adsorbers. Assume that the influent flow rate to the anaerobic filter, granular gravity filter and the *GAC* adsorbers are the same.

Assume that the wastewater contains adequate nitrogen, phosphorus and other trace nutrients for biological growth, and the hydraulic regime of the reactor is complete mix.

Following equations may be applicable for both carbon oxidation and nitrification processes:

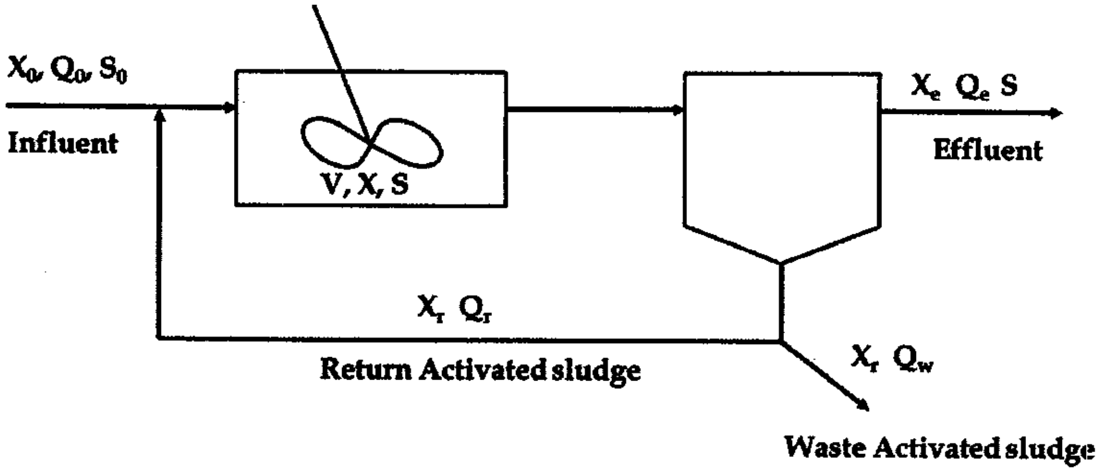


Figure Q1 (f): Schematic diagram of the carbon oxidation combined complete nitrification.

$$\mu_m' = \mu_m e^{0.098(T-15)} \times \frac{DO}{(K_{O2} + DO)} \times [1 - 0.833(7.2 - pH)]$$

$$(1/SRT) = YU - k_d;\ U = kS/(K + S);\ k = \mu_m/Y;\ 1/SRT^M \sim Yk - k_d;$$
$$SRT = SF(SRT^M);\ P_x = QY(S_0 - S)/(1 + k_d . SRT)$$

Oxygen requirement for carbon oxidation, $[M][T]^{-1} = Q(S_0\text{-}S)/f - 1.42P_x$
The oxygen required for nitrification is 4.3 mgO_2/mg *ammonium nitrogen*, $[M][T]^{-1}$

μ_m = Maximum specific growth rate $[T]^{-1}$
μ_m' = Maximum specific growth rate (μ_m) considering *pH*, dissolved oxygen *(DO)* and temperature for nitrification $[T]^{-1}$
k = Maximum rate of substrate utilization, $[T]^{-1}$
N = Effluent NH_4^+- N concentration, $[M]\ [L]^{-3}$
P_x = Net mass of volatile solids (biological solids) produced, $[M]\ [T]^{-1}$
SRT = Solids Retention Time, $[T]$
SRT^M = Minimum Solids Retention Time, $[T]$
U = Specific substrate utilization rate, $[T]^{-1}$

$$N = N_0 \left(\frac{\beta C_{s(alt)} - C_L}{9.17}\right) 1.024^{(T-20)} \alpha;\ C_{s,alt} = C_{s(at\ sea\ level)} \times F_a$$

C_L = Operating oxygen concentration, $[M]\ [L]^{-3}$
$C_{s(alt)}$ = Oxygen saturation concentration for tap water at given temperature and altitude, $[M]\ [L]^{-3}$
F_a = Oxygen solubility correlation factor
N = $kg\ O_2/kW.h$ transferred under field conditions.
N_0 = $kg\ O_2/kW.h$ transferred in water at 20 ^{0}C, and zero DO
T = Temperature, ^0C
a = Oxygen transfer correction factor for waste
β = Salinity-surface tension correction factor, usually 1

Table Q1(f) Design information.

Description	Unit	Value
Primary Clarifier and *ASP*		
Removal efficiency of the primary clarifier for;		
TSS	%	55
$sBOD_5$		35
NH_4^+-N		5
Influent characteristics to the primary clarifier in terms of;	g/m^3	
Total suspended solids (*TSS*) concentration		500
Soluble 5-*d* Biochemical Oxygen Demand ($sBOD_5$)		380
Ammonium Nitrogen (NH_4^+-N) concentration		65
Required effluent $sBOD_5$ of *ASP* for carbon oxidation	g/m^3	20
Concentration of microorganisms (*X*) as volatile suspended solids (*VSS*)	g/m^3	
with respect to carbon oxidation		3,500
with respect to nitrification		175
Endogenous decay coefficient (k_d)	d^{-1}	
with respect to carbon oxidation		0.06
with respect to nitrification		0.05
Yield coefficient (*Y*) for microorganisms	-	
with respect to carbon oxidation		0.65
with respect to nitrification		0.22
f {Conversion factor from BOD_L (Ultimate *BOD*) to BOD_5}	-	0.68
Maximum specific growth rate (μ_m)	d^{-1}	0.45
Dissolved oxygen to be maintained in the reactor	g/m^3	2.0
Minimum *pH* of the wastewater	-	7.1
Minimum sustained temperature	^0C	16
SF (Safety Factor) for *SRT* for nitrification	-	3.23
Half velocity constant (K_{O2}) for oxygen	g/m^3	1.3
Half velocity constant (K_N) for NH_4^+-N	g/m^3	0.8
Flow rate of the waste sludge disposal line (Q_w)	m^3/d	500
Elevation of the reactor	*m*	500
Aerator Oxygen transfer rate	$kg\ O_2/kWh$	1.8
Power required for mixing	$kW/10^3\ m^3$ *of Reactor*	8
Aeration constant, α	-	0.85
Aeration constant, β	-	1.0
Granular Activated Carbon Adsorbers		
Final soluble Chemical Oxygen Demand (*sCOD*) concentration	g/m^3	2.5
No. of *GAC* adsorbers in parallel	-	10
Ratio of theoretical to breakthrough adsorption capacity	-	1: 0.5
Time to breakthrough (t_b)	*d*	50

(i) Draw the schematic flow diagram of the above wastewater treatment plant including the water reclamation system, and give a qualitative explanation for this treatment system (i.e., target wastewater parameters and treatment mechanism of each unit process/operation)

[2.0 Marks]

(ii) Determine the volume of the aerated reactor and the total oxygen requirement for both carbon oxidation and nitrification, and the effluent flow rate *(Q_e)*.

[7.0 Marks]

(iii) Determine the power requirement for mixing and supplying oxygen to obtain the required number of aerators.

[3.0 Marks]

(iv) Describe briefly how the multiple columns operated in series improve the effectiveness of the treatment mechanism of *GAC* adsorption process.

[2.0 Marks]

(v) If the soluble Chemical Oxygen Demand *(sCOD)* in the effluent of the granular gravity filter is 60 *g/m³*, determine the amount of activated carbon that would be required for the adsorption process. *sCOD* is considered as a measure of *DOM*.

The *GAC* adsorber is described by the Freundlich isotherm, $\frac{x}{m} = 0.0015C_e^{3.56}$;
Where,

C_e = Equilibrium concentration of the adsorbate in the solution after adsorption, *[M][L⁻³]*

x/m = Amount adsorbate adsorbed per unit weight of adsorbent, *[M]/[M]*

Note: When the unit of 'C_e' is '*g/m*'; the unit of *(x/m)* is '*mg/mg*'

The following equation may also be used:

$$\left(\frac{x}{m}\right)_b = \frac{X_b}{M_c} = Q\left(C_i - \frac{C_b}{2}\right)\frac{t_b}{M_c}$$

$(x/m)_b$ = Field breakthrough adsorption capacity,*[M]/[M]*

C_b = Breakthrough adsorbate concentration in the effluent, *[M][L⁻³]*

C_i = Influent adsorbate concentration, *[M][L⁻³]*

M_c = Mass of *GAC* in the column, *[M]*

X_b = Mass of adsorbate adsorbed onto the *GAC* column at breakthrough,*[M]*

[4.0 Marks]

g) At sludge treatment of the treatment train described in Q1(f), the primary and activated excess sludge (biological solids) are mixed together, thickened in a gravity thickener, and digested anaerobically in a batch digester. Assume that three fourth (3/4) of the biological solids produced by each of carbon oxidation and nitrification processes in the *ASP* is wasted every day, and directed to the sludge treatment train.

Following equation is applicable:

$V = t_1(V_1 + V_2)/2 + V_2t_2$; where

t_1 = Digestion period, *[T]*

t_2 = Digested sludge storage period, *[T]*

V = Standard-rate digester volume, *[L]³*

V_1 = Raw sludge loading rate, $[L]^3[T]^{-1}$
V_2 = Digested sludge accumulation rate, $[L]^3[T]^{-1}$

Assume that the supernatant in the thickener is free of suspended solids. Table Q1(g) gives the additional design information.

Table Q1(g) Additional design information for the sludge treatment train.

Description	Unit	Value
Density of sludge	kg/m^3	1000
Primary sludge		
Content of solids in the primary sludge	%	4.0
Activated sludge		
Content of solids in the activated sludge (biological solids)	%	0.9
Thickened sludge		
Content of solids in the thickened sludge	%	5.0
Batch anaerobic digester		
Non-biodegradable organic matter fraction in the influent	%	40
Inert matter content of the influent	%	40
Digestion period(t_1)	*d*	35
Digested sludge storage period(t_2)	*d*	90
Solid content in the digested sludge	%	6.0

(i) Dewatering, thickening and stabilization are three processes of sludge treatment. If all three processes are applied in a sludge treatment train, arrange these processes in the proper order of operation. Explain the purpose of each process.

[3.0 Marks]

(ii) Determine the solids load onto the thickener.

[3.0 Marks]

(iii) Determine the percent sludge volume reduction by the thickener.

[1.0Mark]

(iv) Determine the sludge flow rate and sludge mass load rate on the digester.

[1.0Mark]

(v) If the total biodegradable portion of the organic matter is subjected to anaerobic digestion, determine the digester volume.

[2.0Marks]

(vi) The above thickener is to be replaced by a belt filter-press to increase the thickening efficiency. The belt filter-press is expected to yield a solid content of 30 %. The relative density of the sludge is 1.06. What percentage of annual sludge volume saving will arise due to this substitution?

[2.0 Marks]

Q2. (a) In a treatment train, name at which levels that each type of stabilization pond (anaerobic, maturation and facultative ponds) can be placed.

[2.0 Marks]

(b) A wastewater treatment train consists of a waste stabilization ponds (*WSPs*) system with an anaerobic pond, facultative pond and a maturation pond connected in series. Table Q2 (b) shows the design information.

Table Q2 (b) Design information.

Description	Unit	Value
WSPs		
Net evaporation rate *(e)*	*mm/d*	6
Anaerobic pond		
Influent wastewater flow rate	m^3/d	3,000
Soluble Influent 5 *d* biochemical oxygen demand ($sBOD_5$)	g/m^3	350
Design volumetric loading rate for $sBOD_5$	$g/m^3.d$	300
Minimum allowable hydraulic retention time (*HRT*)	*d*	1
Depth	*m*	4.0
$sBOD_5$ removal efficiency	%	75
Facultative pond		
Design surface loading rate for $sBOD_5$	*kg/ha.d*	350
Minimum allowable *HRT*	*d*	4.0
Depth	*m*	1.75
$sBOD_5$ removal efficiency	%	60
Maturation pond		
Design *HRT*	*d*	4.0
Depth	*m*	1.2
$sBOD_5$ removal efficiency	%	70.0

Following equation is applicable for the anaerobic pond:
$HRT = L_i/\lambda_v$; where
L_i= Influent BOD_5, $[M]/[L]^3$;
λ_v= Volumetric BOD_5 loading rate, $[M]/[L]^3.[T]$

Following equations are applicable for facultative and maturation ponds:
$HRT = 2Ad/(2Q_i - Ae)$; $Q_e = Q_i - Ae$
Where,
A = Surface area of the pond, $[L]^2$
d= Depth of the pond, $[L]$
e = Net evaporation rate, $[L]/[T]$
Q_e = Effluent flow rate, $[L]^3/[T]$;
Q_i =Influent flow rate, $[L]^3/[T]$;
Compute the following:

(i) The volume and area requirements for the anaerobic pond, [2.0 Marks]

(ii) The area requirement and the effluent flow rate of the facultative pond, [2.0 Marks]

(iii) The area requirement and the effluent flow rate of the maturation pond, [2.0 Marks]

(iv) Effluent soluble BOD_5 from maturation pond. [2.0 Marks]

(c) Table Q2(c) gives the conditions and requirements for the design of an earthen sedimentation basin, which follows an aerated lagoon. Determine the total depth of the sedimentation basin excluding the free board. The accumulated sludge will be compacted to an average final value of 12 % of the initial solids volume. Assume that the maximum amount of volatile suspended solids (VSS) accumulated at the end of t^{th} year is given by the following equation:

$$W_t = W_0 e^{-k_d t}$$

W_t = Mass of VSS remaining that have not degraded after time t, *[M]*
W_0 = Mass of VSS deposited initially, *[M]*
k_d = Decay coefficient, $[T]^{-1}$
t = Time, *[T]*

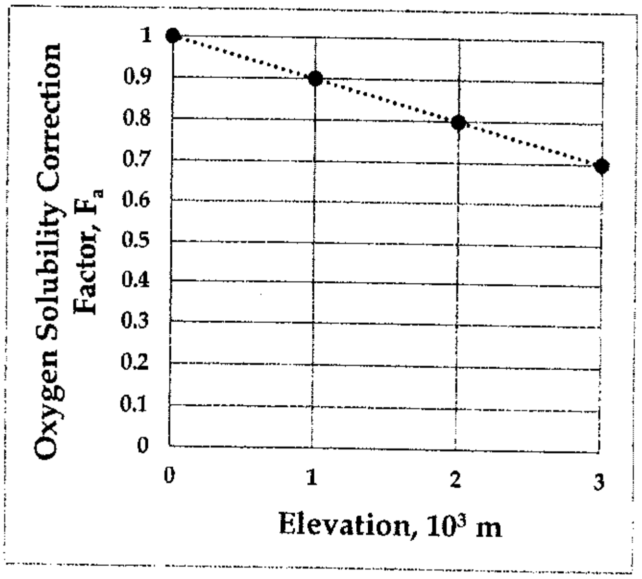
Table Q2 (c): Design criteria of the earthen sedimentation basin.

Description	Unit	Value
Wastewater flow	m^3/d	22 000
Hydraulic detention time	*d*	3.0
Liquid level above the sludge layer at its maximum level of accumulation	*m*	1.6
Total suspended solids (TSS) concentration of the effluent from the aerated lagoon	g/m^3	400
TSS concentration of the effluent from the sedimentation basin	g/m^3	30
Volatile suspended solids (VSS) content of TSS discharged to the sedimentation basin	%	75
Period between two consecutive removals of sludge from the sedimentation basin	*years*	6
Relative density of the accumulated sludge	-	1.04
Decay coefficient (k_d)	$year^{-1}$	0.4

[3.0 Marks]

Additional Tables and Figures

Oxygen Solubility Correction Factor Versus Elevation



Dissolved Oxygen Saturation at Sea Level

Dissolved Oxygen (mg/L) at Saturation in freshwater		
Temperature (C^0)	(F^0)	Dissolved Oxygen at saturation (mg/L)
0^0	32^0	14.6
5^0	41^0	12.8
10^0	50^0	11.3
15^0	59^0	10.1
20^0	68^0	9.1
25^0	77^0	8.3
30^0	86^0	7.6

Nomograph for solution of Manning's equation for roughness coefficient (n) = 0.013