UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 6 Examination in Engineering: December 2022

Module Number: CE6303 **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]

A wastewater collection, treatment, and disposal/reuse system has been proposed for a municipal council. The design of this system consists of a wastewater treatment plant *(WWTP)* and its hydraulic profile. The *WWTP* will consist of preliminary treatment, primary sedimentation, Activated Sludge Process *(ASP)* and disinfection. The following questions (Q1 to Q3) are based on this proposed wastewater collection, treatment and disposal/reuse system.

Q1. In the above *WWTP*, the primary-treated effluent is to undergo treatment by a carbon oxidation combined complete nitrification process. An Activated Sludge Process *(ASP)* (Figure Q1) is to be designed to achieve both carbon oxidation and complete nitrification in one reactor. This system is followed by an anaerobic filter, granular gravity filter, granular activated carbon *(GAC)* adsorption process and ultraviolet *(UV)* disinfection in order to be suitable for reuse. The nitrified effluent from the *ASP* enters the anaerobic filter for denitrification. Denitrified wastewater will be fed to the *GAC* adsorption process via a granular gravity filter. Table Q1 gives the design data of the *ASP*.

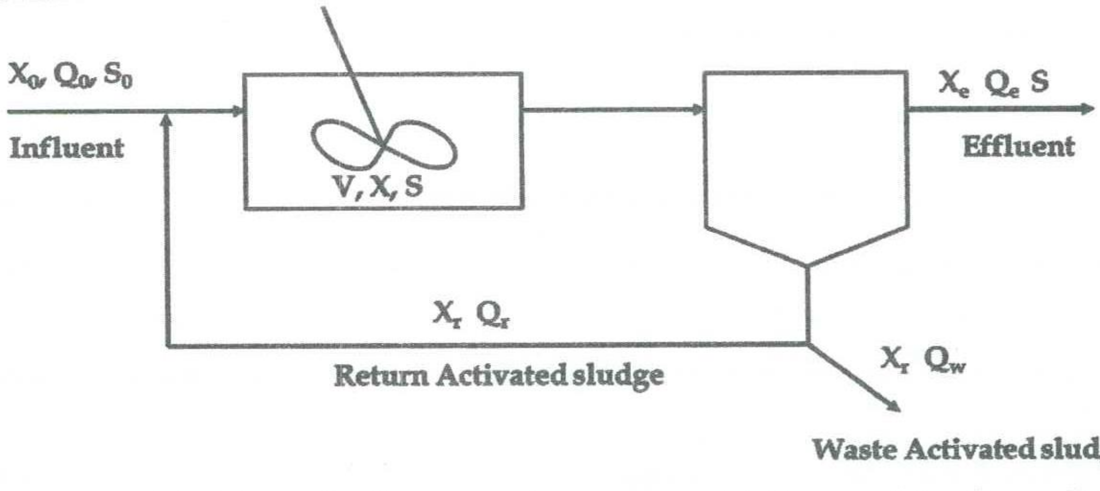

Figure Q1: Schematic diagram of the carbon oxidation combined complete nitrification

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

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

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

$SRT = SF(SRT^M)$; $P_x = QY(S_0 - S)/(1 + k_d.SRT)$

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

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

Table Q1: Design information

Description	Unit	Value
Primary Clarifier and *ASP*		
Flow rate of the primary clarified effluent (Q)	m^3/d	6,500
Total suspended solids *(TSS)* concentration in the influent of the primary clarifier	g/m^3	500
TSS removal efficiency of the primary clarifier	%	55
Soluble 5-*d* Biochemical Oxygen Demand $(sBOD_5)$ in primary clarified effluent	g/m^3	400
Ammonium Nitrogen $(NH_4^+\text{-}N)$ concentration in primary clarified effluent	g/m^3	65
Required effluent $sBOD_5$ of *ASP* for carbon oxidation	g/m^3	20
Concentration of microorganisms *(X)* as volatile suspended solids *(VSS)*		
with respect to carbon oxidation	g/m^3	2,500
with respect to nitrification	g/m^3	175
Endogenous decay coefficient (k_d)		
with respect to carbon oxidation	d^{-1}	0.08
with respect to nitrification	d^{-1}	0.05
Yield coefficient *(Y)* for microorganisms		
with respect to carbon oxidation	-	0.42
with respect to nitrification	-	0.22
f {Conversion factor from BOD_L (Ultimate *BOD*) to BOD_5}	-	0.7
Maximum specific growth rate (μ_m)	d^{-1}	0.45
Dissolved oxygen to be maintained in the reactor	g/m^3	2.5
Minimum pH of the wastewater	-	7.2
Minimum sustained temperature	^0C	15
SF (Safety Factor) for *SRT* for nitrification	-	3.25
Half velocity constant (K_{O2}) for oxygen	g/m^3	1.3
Half velocity constant (K_N) for $NH_4^+\text{-}N$	g/m^3	0.8
Flow rate of the waste sludge disposal line (Q_w)	m^3/d	250
Recirculation flow rate (Q_r)	m^3/d	0.4 *Q*

(a) Explain briefly the above treatment system qualitatively (i.e., target wastewater parameters and treatment mechanism of each unit process)

[3.0 Marks]

(b) Determine;

(i) The volume of the aerated reactor

[2.0 Marks]

(ii) The total biological solids produced from both carbon oxidation and nitrification processes

[2.0 Marks]

(iii) The total oxygen requirement for both carbon oxidation and nitrification processes

[2.0 Marks]

(iv) The effluent flow rate *(Q_e)*

[1.0 Mark]

Q2. In the above *WWTP*, the sludge produced in the primary and the secondary sedimentation tanks are mixed, thickened in a gravity thickener, and digested anaerobically in a two-stage digester. Assume that three fourths (3/4) of the biological solids produced in the *ASP* is wasted every day and directed to the sludge treatment train as shown in Figure Q2.

Following equations are applicable:
For the 1st stage digester; $V = V_1 t_1$
For the 2nd stage digester; $V = t_1(V_1 + V_2)/2 + V_2 t_2$; 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 Q2 gives the additional design information.

Table Q2: Additional design information for the sludge treatment train

Description	Unit	Value
Density of any type of sludge	*kg/m³*	1000
Primary sludge		
Content of solids in the primary sludge	%	4.0
Secondary sludge		
Content of solids in the secondary sludge	%	3.0
Thickened sludge		
Content of solids in the thickened sludge	%	6.0
Two stage anaerobic digester		
Non-biodegradable organic matter fraction in the influent	%	40
Inert matter content of the influent	%	40
Digestion period – first stage digester	*d*	10
Digestion period – second stage digester	*d*	3
Digested sludge storage period	*d*	90
Solid content in the digested sludge	%	8.0

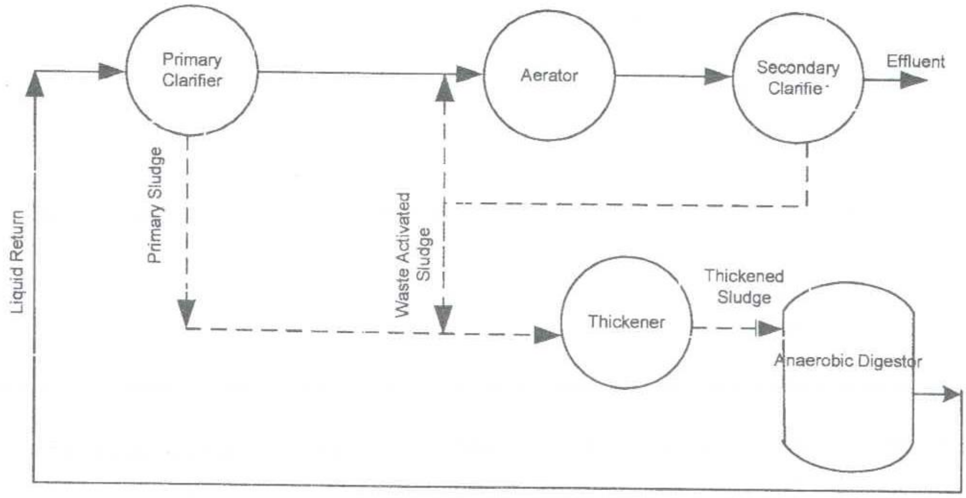

Figure Q2: Schematic diagram of the sludge treatment train

a) Determine the solids load onto the thickener.

[3.0 Marks]

b) Determine the percent sludge volume reduction by the thickener.

[1.0 Mark]

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

[5.0 Marks]

Q3. In order to prepare a hydraulic profile of the primary sedimentation tank and the *ASP* of the above *WWTP* at the average flow conditions, find the following control elevations:

a) The water surface elevation in the secondary clarifier,

[3.0 Marks]

b) The water surface elevation in the effluent channel of the aeration tank,

[3.0 Marks]

c) The elevation of the effluent weir in the aeration tank; the water surface elevation in the aeration tank near the effluent weir; and the water surface elevation near the influent channel of the aeration tank,

[4.0 Marks]

d) The water surface elevation in the effluent channel of the primary clarifier.

[2.0 Marks]

Figure Q3 illustrates the schematic diagram of the primary sedimentation tank and the *ASP*. The following data and assumptions are applicable:

Primary sedimentation tank (Circular)
Diameter at weir circle – 14 *m*
Wier spacing -0.3 *m*
Weir type- 90 ^{0} V notch
Return flows from the sludge processing facilities = 0.15 *Q*; where *Q* =Influent flow rate to the primary sedimentation tank

Secondary sedimentation tank (Circular)
Weir crest elevation - 100 m
Diameter at the weir circle - 18 m
Wier spacing -0.3 m
Weir type- 90 ^{0} V notch
Consider that the underflow rate is equal to the recirculation flow rate (Q_r)

Aeration tank (Rectangular)
Inlet type-slide gates (Assume that the head on the slide gates are negligible)
Length of aeration tank effluent weir - 15 m
Wier spacing -0.3 m
Weir type- 90 ^{0} V notch

Head loss computations
Head loss coefficients
- Pipe entrance-0.5
- Pipe bends- 0.4
- Pipe exit-1.0
- Pipe friction in Darcy-Weisbach equation - 0.02

The free fall between the weir crest and the water surface in the downstream channel- 0.01 m
Head loss across the aeration tank =0.02 m
Head on vee notch weir $=q = 0.55h^{5/2}$
Frictional head loss $(h_f)= f\frac{LV^2}{D\,2g}$ (Darcy-Weisbach equation)
Minor head losses $(h_m)=K\frac{V^2}{2g}$

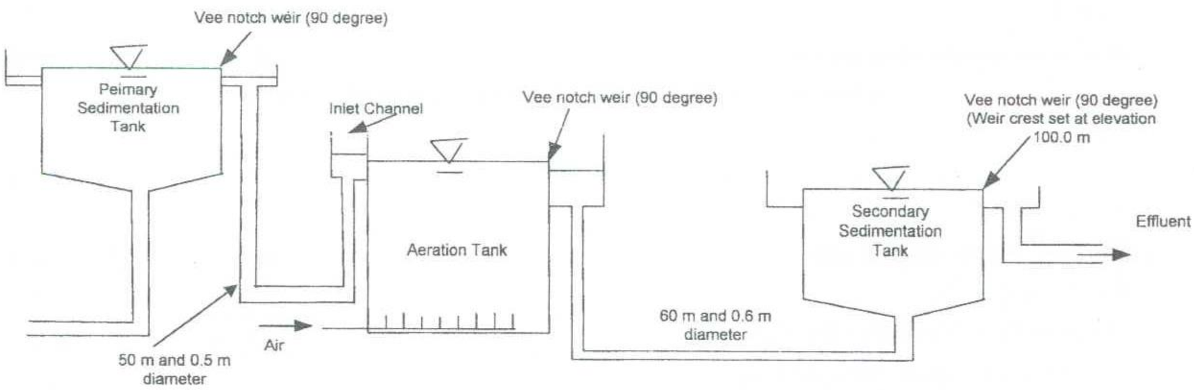

Figure Q3: Schematic diagram of the Activated Sludge Process (ASP)

Q4. (a) A waste stabilization ponds *(WSPs)* system is going to be used to treat the wastewater discharged by a tannery industry. In addition to the *WSPs*, the treatment train will consist of preliminary treatment such as coarse and fine screening, a sub-surface flow constructed wetland and post chlorination. Draw the schematic flow diagram of this treatment train. Give a brief explanation on the purpose of each treatment unit operation/process and give reasons for the order of placement of each unit operation/process in the treatment train.

[3.0 Marks]

(b) The *WSPs* consists of an anaerobic pond, a facultative pond and a maturation pond connected in series. 5 % of the effluent flow from the *WSPs* system is given further treatment in 3 no. sub-surface flow constructed wetlands connected in parallel to make it suitable for reuse. The rest of the treated effluent of *WSPs* will be land applied through a rapid infiltration *(RI)* system. Table Q4 shows the design information.

Table Q4: Design information

Description	Unit	Value
WSPs		
Net evaporation rate *(e)*	*mm/d*	4
Anaerobic pond		
Influent wastewater flow rate	m^3/d	4,000
Influent 5-day biochemical oxygen demand (BOD_5)	g/m^3	400
Design volumetric loading rate for BOD_5	$g/m^3.d$	300
Minimum allowable hydraulic retention time *(HRT)*	*d*	1
Depth	*m*	4.0
Soluble BOD_5 removal efficiency	%	75
Facultative pond		
Design surface loading rate for BOD_5	*kg/ha.d*	350
Minimum allowable *HRT*	*d*	4.0
Depth	*m*	1.5
Soluble BOD_5 removal efficiency	%	60
Maturation pond		
Design *HRT*	*d*	4.0
Depth	*m*	1.25
BOD_5 removal efficiency	%	70.0
Sub-surface flow constructed wetland system		
Required effluent BOD_5 (C_e)	g/m^3	6
1st order reaction rate constant (K_T) at 30°C for the constructed wetland system	d^{-1}	1.4
Design basin depth *(d)*	*m*	0.4
Basin slope *(S)*	-	0.01
Hydraulic conductivity (k_s)	$m^3/m^2.d$	420.0
Porosity of basin medium (α)	-	0.35
Allowable hydraulic loading rates	$m^3/ha.d$	27.4 - 821.9
Allowable BOD_5 loading rates	$g/m^2.d$	7.1-11.4
Rapid Infiltration *(RI)* System		
Application(flooding) period of effluent per operating cycle	*d*	2
Drying period per operating cycle	*d*	6
RI system operating period per year	*d*	325
Infiltration rate *(IR)*	*cm/h*	4.0
Application factor *(F)*	-	0.1
Allowable BOD_5 surface loading rate	$g/m^2.d$	50

Following equations are applicable for the facultative and maturation ponds:

$Q_e = Q_i - Ae; Q_{avg} = {(Q_i + Q_e)}/{2}; HRT = {V}/{Q_{avg}}$

Where, A = Surface area of the pond, *[L]*^{2}; Q_i =Influent flow rate, *[L]*^{3}*/[T]*; Q_e = Effluent flow rate, *[L]*^{3}*/[T]*; *e* = Net evaporation rate, *[L] /[T]*

Following equations are applicable for the sub-surface flow constructed wetland system:

$(C_e/C_0) = exp(-K_T t'); t' = (LW\alpha d)/Q; A_c = Q/k_s S$

Where C_0 = Influent BOD_5, *[M]/[L]*^{3}; *L* = Length of the basin, *[L]*; *W* = Width of the basin, *[L]*; *t'* =Pore-space retention time, *[T]*

Following equations are applicable for the rapid infiltration system;

$L_w = IRxODxF$

L_w -Annual average hydraulic loading rate based on the hydraulic conductivity of soil, [L]/[T]

IR -Infiltration rate, [L]/[T]

OD-number of operation days per year, [T]

F- An application factor

$R_a = \frac{L_w x Operating\ cycle\ time}{365\frac{d}{yr} x Application\ period}$; where,

R_a= Application rate, [L]/[T]

Determine;

(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 of maturation pond,

[2.0 Marks]

(v) Verify whether or not the design values of the sub-surface flow constructed wetland system agree with the allowable loading rates.

[4.0 Marks]

(vi) Determine;

a. The annual average hydraulic loading rate based on the hydraulic conductivity of soil *(L_w)*, and the area requirement based on L_w,

[1.5 Marks]

b. The annual average BOD_5 load, and the area requirement based on the BOD_5 loading rate,

[1.5 Marks]

c. The average application rate *(Ra)*.

[1.0 Mark]