UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 6 Examination in Engineering: November 2017

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 designing a carbon oxidation combined complete nitrification followed by denitrification process, the addition of a carbon source externally is not necessary while it is a must in the separate-stage denitrification process." Rationalize this statement highlighting the need of carbon for the denitrification process.

[2.0 Marks]

b) A primary-treated effluent is to undergo treatment by a separate stage carbon oxidation and nitrification system, in which two activated-sludge processes *(ASPs)* are to be designed to achieve a carbon oxidation and a complete nitrification, respectively. This system is followed by an anaerobic filter, granular gravity filter and granular activated carbon *(GAC)* adsorption process 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 in order to remove the remaining dissolved organic matter. Fixed-bed contactors filled with *GAC* and connected in parallel are used for the adsorption process. Table Q1(b) gives the design data of the *ASPs* and fixed-bed *GAC* contactors. Assume that the influent flow rate to the denitrification process, granular gravity filter and the *GAC* adsorption process are the same.

Following equations are applicable for both carbon oxidation and nitrification processes:

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

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

Oxygen requirement for carbon oxidation, $[M][T]^{-1} = Q(S_0 - S)/f - 1.42P_x$

The oxygen required for nitrification is 4.3 mgO_2/mg *ammonium nitrogen,* $[M][T]^{-1}$

Effluent flow rate $(Q_e) = Q - Q_w$

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, $[T]^{-1}$

SRT^M = Minimum Solids Retention Time, $[T]^{-1}$

The GAC contactor is described by the Langmuir isotherm, $\frac{x}{m} = \frac{0.002C_e}{1-0.29C_e}$;

Where,

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

C_e = Equilibrium concentration of the adsorbate in the solution after adsorption, $[M][L^{-3}]$

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, $[M]$

Table Q1(b) 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	400
TSS removal efficiency of the primary clarifier	%	55
Soluble 5-d Biochemical Oxygen Demand $(sBOD_5)$ in primary clarified effluent	g/m^3	325
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
Design *SRT* of *ASP* for carbon oxidation	d	4.5
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 growth rate considering pH, dissolved oxygen (DO) and temperature $(\mu_m^{'})$ for nitrification	d^{-1}	0.45
SF (Safety Factor) for *SRT* for nitrification	-	3.25
Half velocity constant (K) for $NH_4^+\text{-}N$	g/m^3	0.8
Flow rate of the waste sludge disposal line (Q_w)		
For *ASP* for carbon oxidation	m^3/d	250
For *ASP* for nitrification	m^3/d	200
Fixed-bed GAC contactor		
Influent soluble chemical oxygen demand $(sCOD)$	g/m^3	9.6
Breakthrough $sCOD$	g/m^3	2.5
No. of *GAC* contactors in parallel	-	10
Ratio of theoretical to breakthrough adsorption capacity	-	1: 0.25
Time to breakthrough (t_b)	d	50

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

[3.0 Marks]

(ii) Determine the volume of each aerated reactor and the total oxygen requirement for both carbon oxidation and nitrification, and the effluent flow rates of each *ASP*. Assume that ammonia (NH_3) does not undergo any reaction in the *ASP* for carbon oxidation.

[6.0 Marks]

(iii) Determine the amount of activated carbon that would be required for the polishing process of the remaining dissolved organic matter in terms of *sCOD*.

[4.0 Marks]

c) At sludge treatment of the treatment train described in Q1(b), 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 two third of the biological solids produced by each *ASP* is wasted every day, and directed to the sludge treatment train.

Following equation is applicable: $V = \frac{(V_1+V_2)}{2}t_1 + V_2t_2$; where 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(c) gives the additional design information.

Table Q1(c) 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	%	4.5
Activated sludge		
Content of solids in the activated sludge (biological solids)	%	0.8
Thickened sludge		
Content of solids in the thickened sludge	%	5.5
Batch anaerobic digester		
Non-biodegradable organic matter fraction in the influent	%	35
Inert matter content of the influent	%	30
Digestion period(t_1)	*d*	30
Digested sludge storage period(t_2)	*d*	125
Solid content in the digested sludge	%	5.25

(i) Determine the solids load onto the digester.

[2.0 Marks]

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

[5.0Marks]

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

[4.0 Marks]

(Q2) A primary treated municipal wastewater is to be further processed using a staged *RBC* system followed by a rapid infiltration *(RI)* system. The *RBC* is designed having a tapered feed flow for each stage. The RBC effluent will be applied in a cycle of flooding followed by drying to maximize the nitrification in the *RI* system. Table Q2 gives the design information.

The soluble 5-day biochemical oxygen demand ($sBOD_5$) in each stage (S_n) of *RBC* is given by the following equation:

$$S_n = \frac{-1+\sqrt{1+(4)(0.00974)(A_s/Q)S_{(n-1)}}}{(2)(0.00974)(A_s/Q)};$$ where A_s=total disk surface area on stage '*n*'; Q=Flow rate on stage '*n*'; The units for 'S','A_s' and 'Q' are g/m^3, m^2 and m^3/d, respectively.

Table Q2 Design criteria of the staged *RBC* and *RI* systems.

Description	Unit	Value
RBC system		
Flow rate (Q)	m^3/d	2,250
Soluble 5-*d* Biochemical Oxygen Demand ($sBOD_5$) in the primary effluent	g/m^3	550
No. of stages of the *RBC* system	-	3
Standard disk density	$m^2/shaft$	9,300
Maximum organic loading ($sBOD_5$) on 1st stage for secondary treatment	$g/m^2.d$	20
RI system		
Total BOD_5 of the *RBC* effluent	g/m^3	50
Application factor *(F)* in calculating the annual hydraulic loading rate	-	0.1
Infiltration rate	cm/h	4.0
RI system operating period per year	*d*	250
Application(flooding) period of effluent per operating cycle	*d*	2
Drying period per operating cycle	*d*	6

a) Determine the number of *RBC* shafts for the stage 1.

[1.5 Marks]

b) If the number of shafts at 2nd and 3rd stages decrease by 3 and 2 units, respectively, draw a schematic flow diagram of the *RBC* system. Assume the flow is parallel to the shaft.

[1.5 Marks]

c) What is the $sBOD_5$ content in the *RBC* effluent?

[2.0 Marks]

d) Determine the following for the *RI* system:
   (i) The annual average hydraulic loading rate (L_w),
   (ii) The annual average BOD_5 loading rate,
   (iii) The average application rate of the influent (R_a),
   (iv) The infiltration area requirement, and
   (v) The average BOD_5 loading rate over an 8 *d* cycle.

[0.5+0.5+0.5+0.75+0.75 Marks]

Q3. A wastewater treatment train employing a waste stabilization pond (*WSP*) system consists of 2 anaerobic ponds, 2 facultative ponds and a maturation pond. Two anaerobic ponds are connected in parallel, and a facultative pond is connected to each anaerobic pond in series. The effluents from the 2 facultative ponds are connected to the maturation pond in series. Table Q3 shows the design information.

Table Q3 Design information.

Description	Unit	Value
Net evaporation rate (*e*)	*mm/d*	5
Anaerobic pond		
Influent wastewater flow rate	m^3/d	6,000
Influent 5-*d* 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
BOD_5 removal efficiency	%	75
Facultative pond		
Design surface loading rate for BOD_5	*kg/ha.d*	350
Minimum allowable *HRT*	*d*	4
Depth	*m*	1.5
BOD_5 removal efficiency	%	60
Maturation pond		
Design *HRT*	*d*	4.0
Depth	*m*	1.6
BOD_5 removal efficiency	%	70

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, $[L]^2$; Q_i =Influent flow rate, $[L]^3/[T]$; Q_e = Effluent flow rate, $[L]^3/[T]$; *d*= Depth of the pond, *[L]*, *e* = Net evaporation rate, *[L] /[T]*

Calculate the following:

a) The volume and area requirements for the anaerobic pond,

[3.0 Marks]

b) The area requirement and the effluent flow rate of the facultative pond,

[4.0 Marks]

c) The area requirement and the effluent flow rate of the maturation pond, and

[4.0 Marks]

d) Effluent BOD_5 of the maturation pond.

[1.0 Marks]

Q4. An on-site wastewater management system consists of a septic tank, sub-surface flow constructed wetland system (CWS) and trench-type soil absorption field for a housing scheme. The septage is to be delivered to a small wastewater treatment plant (WWTP). Table Q3 shows the design information.

Assume the following:

The wastewater infiltrates into the vadoze zone of soil only through side walls of the trench; The average septage volume delivered daily at the said WWTP is equal to the volume of the septic tank excluding the free board; The delivery of septage will be done daily.

Table Q3 Design information of the on-site wastewater management system.

Description	Unit	Value
Septic tank with two compartments		
Average flow rate	m^3/d	3.5
Effluent 5-*d* Biochemical Oxygen Demand (BOD_5) value	g/m^3	325
Liquid depth of the septic tank	m	1.0
Width of the septic tank	m	0.75
Height of the free board	m	0.5
Ratio of the lengths of 1st compartment and the second compartment	-	2:1
Sub-surface flow CWS		
Required effluent BOD_5 (C_e)	g/m^3	30
1st order reaction rate constant (K_T) at 30 °C	d^{-1}	1.4
Design basin depth (d)	m	0.4
Basin slope (S)	-	0.02
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 - 825.0
Allowable BOD_5 loading rates	$g/m^2.d$	7.1-11.4
Trench-type soil absorption field		
Maximum depth of the trench below the distribution pipe	m	1.25
Allowable hydraulic loading rate for the disposal field	$L/m^2.d$	20
Average wastewater flow rate to the small WWTP	m^3/d	7,500
BOD_5 value in influent to small WWTP	g/m^3	300
BOD_5 value in the septage	g/m^3	9,000

The following equations are applicable for the septic tank:

$V_s = t_s.Q$

Where, V_s= volume required for settling, $[L^3]$

Q= average daily flow of wastewater, $[L^3]/[T]$

t_s(*The time required for settling in days*)= $(1.5 - 0.3.\log Q)$,(> 0.2d), [T]

V_d (*The volume required for sludge digestion*) = $q_s\, t_d\, p$, $[L^3]$

q_s (*The volume of fresh sludge per person*) = 0.001 m^3/capita. d

t_d(*The time required for sludge digestion*)= 33 d (for an ambient temperature of 30° C)

p (*The population equivalent*) = Q /(0.2 m^3/capita. d)

V_{st} (*The volume required for sludge storage*) = $r\, p\, n$

n (*desludging interval*) = 2 *years*

r (*The volume of digested sludge per person per year*) = 0.04 m^3

The volume required for scum storage = 0.5 V_{st}

The following equations are applicable for the sub-surface flow *CWS*:

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

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

a) Calculate the working capacity of the septic tank with two compartments, and thereby the total volume of the septic tank including the free board.

[3.0 Marks]

b) Draw the plan and front elevational views of the septic tank.

[3.0 Marks]

c) Verify whether the given design values of the sub-surface flow *CWS* (with 1 basin) agree with the allowable loading rates. If not, state the next step of the design procedure.

[4.0 Marks]

d) Calculate the required length of the disposal trench.

[2.0 Marks]

e) What will be the daily average influent BOD_5 value at the small WWTP after mixing with the septage.

[2.0 Marks]