UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 6 Examination in Engineering: November 2016

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

[Three Hours]

[Answer **all questions**, each question carries **unequal** marks]

Q1. a) "In designing a single-stage carbon oxidation combined complete nitrification process, the main design parameter applied is the 'solids retention time *(SRT)*', while the 'hydraulic retention time *(HRT)*' too is used as a design parameter. The *SRT* is typically selected based only on the nitrification process, while the *HRT* is selected considering both the carbon oxidation and nitrification processes." Rationalize this statement.

[2.0 Marks]

b) A primary-treated effluent is to undergo treatment by a suspended growth single-stage carbon oxidation combined complete nitrification in an activated sludge process *(ASP)* (Figure Q1). The *ASP* 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. Three fixed-bed contactors filled with *GAC* and connected in parallel are used for the adsorption process. Table Q1 gives the design data of the *ASP* 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.

The following equations are applicable for the *ASP*:

$(1/SRT) = YU - k_d; U = k'N/(K+N) (for\ nitrification)$;

$k' = \mu_m'/Y\ (for\ nitrification)$; $P_x = QY(S_0 - S)/(1+SRT.k_d); U = (S_0 - S)/\theta X$

All equations above are applicable for both carbon oxidation and nitrification processes unless it is specifically mentioned.

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*, $[M][T]^{-1}$

k' = Maximum rate of substrate utilization for nitrification, $[T]^{-1}$

P_x = Net mass of volatile solids (biological solids) produced, $[M]\ [T]^{-1}$

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

U = Specific substrate utilization rate, $[T]^{-1}$

Following equations are applicable for the fixed-bed *GAC* contactors:

Freundlich isotherm equation is given by, $q_e = K_f C_e^{(1/n)}$

$GAC\ usage\ rate\ (m_{GAC}/Qt) = (C_0 - C_e)/q_e$

Volume of wastewater treated=Mass of GAC for given EBCT/GAC usage rate

EBCT= Empty - Bed Contact Time, $[T] = V_b/Q$, where, V_b = Volume of *GAC* in contactor, $[L]^3$; t = Time, $[T]$;

m_{GAC} = Mass of adsorbent in the contactor, $[M]$

Table Q1 Design information.

Description	Unit	Value
ASP		
Flow rate of the primary clarified effluent (Q)	m^3/d	5,000
Solids retention time (SRT) for nitrification	d	10
Soluble BOD_5(5-day Biochemical Oxygen Demand) in primary clarified effluent(S_0)	g/m^3	350
Ammonium Nitrogen $(NH_4^+\text{-}N)$ concentration in primary clarified effluent (N_0)	g/m^3	65
Required effluent soluble $BOD_5(S)$ of ASP for carbon oxidation	g/m^3	20
Concentration of microorganisms (X) as 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	-	0.45
with respect to nitrification	-	0.21
f {Conversion factor from BOD_L (Ultimate BOD) to BOD_5}	-	0.7
Maximum growth rate considering pH, dissolved oxygen (DO) and temperature (μ_m') with respect to nitrification	d^{-1}	0.4
Half velocity constant (K) for Nitrogen with respect to nitrification	g/m^3	0.8
Sludge wasting rate (Q_w)	m^3/d	50
Fixed-bed GAC contactor		
No of GAC contactors in parallel	-	3
Initial concentration of adsorbate (C_0)	g/m^3	2.75
Final equilibrium concentration of adsorbate (C_e)	g/m^3	0.1
Density of GAC	g/L	600
EBCT	*minutes*	20
Freundlich capacity factor, (K_f)	$(mg/mg)(L/mg)^{1/n}$	0.036
Freundlich intensity parameter$(1/n)$	-	3.56

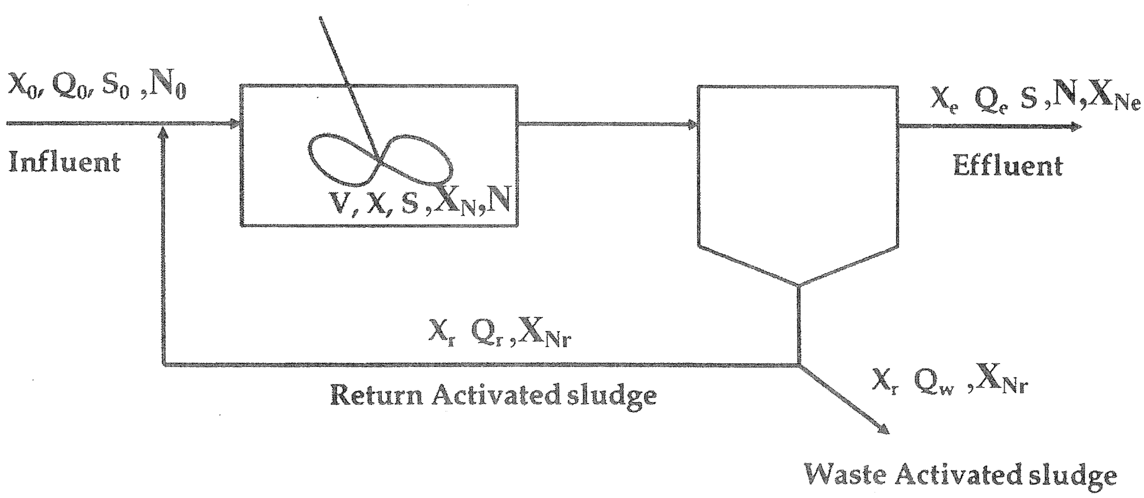

Figure Q1 Schematic diagram of the *ASP*

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

[2.0 Marks]

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

[6.0 Marks]

(iii) Determine the *GAC* requirement and the volume of wastewater treated in the *GAC* contactor.

[4.0 Marks]

Q2. a) Draw a schematic flow diagram of an *RBC* application for secondary treatment of wastewater. Assume that the treatment train includes a primary clarifier, a *RBC* system, a secondary clarifier and the treated effluent. The *RBC* system consists of two reactors each with 3 *RBC* units. The shaft of the 3 *RBC* units in a reactor is parallel to the flow, and the two reactors are operated in parallel.

[2.0 Marks]

b) A primary treated municipal wastewater is to be treated using a staged *RBC* (Rotating Biological Contactors) system followed by an overland flow *(OF)* system. The *RBC* is designed having a tapered feed flow for each stage.
The effluent will be applied in a cycle of flooding followed by drying to maximize the nitrification in the *OF* 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 OF systems.

Description	Unit	Value
RBC system		
Flow rate (Q)	m^3/d	1,500
Soluble BOD_5in the primary effluent	g/m^3	500
No. of stages of the *RBC* system	-	2
Standard disk density	$m^2/shaft$	9,300
Maximum organic loading ($sBOD_5$) on 1st stage for secondary treatment	$g/m^2.d$	18
OF system		
Annual average hydraulic loading rate	m/yr	20
Application(flooding) period of effluent per operating cycle	d	2
Drying period per operating cycle	d	6
OF system operating period per year	d	365

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

[1.5 Marks]

(ii) If the number of shafts at each subsequent stage decreases by one unit, draw a schematic flow diagram of the *RBC* system. Assume the flow is perpendicular to the shaft.

[1.5 Marks]

(iii) How much is the soluble BOD_5 in the RBC effluent?

[2.0 Marks]

(iv) Determine following for the OF system:

The annual average BOD_5 loading rate,

The average application rate (R_a),

The average BOD_5 loading rate over a 8 d cycle, and

The BOD_5 loading rate for the first day of application.

[0.75+0.75+0.75+0.75 Marks]

Q3. a) A series of waste stabilization ponds (*WSPs*) will be used to treat the wastewater discharged by a tannery industry. In addition to the *WSPs* system, the treatment train will consist of preliminary treatments such as coarse and fine screening, and post chlorination. Draw the schematic flow diagram of this treatment train. Give a brief explanation on the purpose of each treatment unit process and give reasons for the order of placement of each unit process in the treatment train.

[2.0 Marks]

b) A wastewater treatment train employing a *WSPs* system with an anaerobic pond, facultative pond and a maturation pond connected in series, followed by a 3 sub-surface flow constructed wetlands connected in parallel, is to be designed. 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	5,000
Influent 5-day biochemical oxygen demand (BOD_5)	g/m^3	300
Design volumetric loading rate for BOD_5	$g/m^3.d$	300
Minimum allowable hydraulic retention time (HRT)	d	1
Depth	m	4
SolubleBOD_5removal efficiency	%	70
Facultative pond		
Design surface loading rate for BOD_5	$g/ha.d$	350
Minimum allowable HRT	d	4
Depth	m	1.5
SolubleBOD_5removal efficiency	%	58
Maturation pond		
Design HRT	d	3.6
Depth	m	1.5
BOD_5 removal efficiency	%	75.2
Sub-surface flow constructed wetland system		
Required effluent BOD_5 (C_e)	g/m^3	5
1st order reaction rate constant (K_T) at 30°C for the constructed wetland system	d^{-1}	1.35
Design basin depth (d)	m	0.35
Basin slope (S)	-	0.02
Hydraulic conductivity (k_s)	$m^3/m^2.d$	420.0
Porosity of basin medium (α)	-	0.30
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

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, $[L]^2$; 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, $[L]/[T]$

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, $[T]$

Calculate 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, and

[2.0 Marks]

(iv) Effluent soluble BOD_5 of maturation pond.

[2.0 Marks]

Verify;

(v) Whether the design values of the sub-surface flow constructed wetland system agree with the allowable loading rates.

[4.0 Marks]

Q4. a) Explain briefly three design criteria used for establishing a high-rate mesophilic anaerobic sludge digester.

[3.0 Marks]

b) A sludge treatment train is to be designed for a wastewater treatment plant consisting of a primary sedimentation tank followed by an activated sludge process (*ASP*). At sludge treatment, the primary and activated excess sludge are mixed together, thickened in a gravity thickener, and digested anaerobically in a single-stage high-rate digester. Table Q4 gives the design information.

The hydraulic regime of the digester is completely-mixed, and the sludge contains adequate nitrogen and phosphorus for the biological activity.
Mass of waste stabilized = Mass of BOD_5 utilized - 1.42 P_x;
Where, $P_x = QY(S_0 - S)/(1 + SRT.k_d)$; P_x =Net mass of volatile solids (biological solids) produced after anaerobic digestion, $[M]\,[T]^{-1}$
Q = Flow rate, $[L]^3/[T]^{-1}$
S_0 = Influent BOD_5, $[M]/[L]^3$

S = Effluent BOD_5, $[M]/[L]^3$

Table Q4 Design information of the sludge treatment train.

Description	Unit	Value
Density of sludge	kg/m^3	1000
Primary sludge		
Influent suspended solids *(SS)* load to the primary clarifier	*kg/d*	1,728
Removal efficiency of *SS* by the primary clarifier	%	55
Content of solids in the primary sludge	%	4.5
Activated sludge		
Amount of biological solids wasted from the *ASP*	*kg/d*	500
Content of solids in the activated sludge	%	0.8
Thickened sludge		
Content of solids in the thickened sludge	%	5.5
Single-stage and high-rate anaerobic digester		
BOD_5 of the influent to the digester	g/m^3	1,500
Solids Retention Time*(SRT)* at the anaerobic digester at 35 ^0C	*d*	13
Waste stabilization efficiency at the anaerobic digester	%	75
Yield coefficient *(Y)* for anaerobic microorganisms at 35 ^0C	-	0.08
Endogenous decay coefficient for anaerobic microorganisms(k_d)	d^{-1}	0.03
Volume of methane produced per 1 $kgBOD_5$ stabilized	m^3	0.35

(i) Determine the solids load onto the digester.

[2.0 Marks]

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

[3.0Marks]

(iii) Estimate the following for the digester: volumetric organic loading rate; the percent waste stabilization; and the volume of methane gas produced.

[4.0 Marks]

Q5. a) Describe briefly how the structural arrangement of an intermittent sand filter helps treat septic tank effluent.

[2.0 Marks]

b) Determine 5-day biochemical oxygen demand (BOD_5) and the suspended solids *(SS)* concentration in the influent of a small wastewater treatment plant *(WWTP)* after the disposal of septage from a rural area with 2100 homes. Table Q5 depicts the design information.

Table Q5 Design information.

Description	Unit	Value
BOD_5 in the septage	g/m^3	6,000
SS in the septage	g/m^3	15,000
Frequency of pumping out septage	*yr*	3
Operation period	*d/yr*	175
Volume of septage pumped out	$m^3/tank$	3.8
Average flow rate of the *WWTP*	m^3/d	2460
Influent BOD_5 load on to small *WWTP* before septage disposal	*kg/d*	615
Influent *SS* load on to small *WWTP* before septage disposal	*kg/d*	565.8

[4.0 Marks]

c) "A centrifugal separator is more efficient than a gravity settler in removing particulate matters in air. "Rationalize this statement in terms of the principal design criteria of the devices.

[1.0 Mark]

d) A cyclone separator (Figure Q5) is operating in conditions where D_{cut} is $5\mu m$. Following equations are applicable to the above device:

Fraction captured $(\varepsilon) = \frac{N\pi D^2 V_c \rho_{part}}{9W_i\,\mu}$ for a block flow model;

$D_{cut} = \left(\frac{4.5W_i\,\mu}{N\pi V_c \rho_{part}}\right)^{(1/2)}$ for a block flow model.

ρ_{part} = Density of a particle, $[M][L]^{-3}$

D = Diameter of a particle, $[L]$

N = No. of turns that the gas makes traversing the outer helix of a cyclone in a cyclone separator; Consider N=5 as and when appropriate.

V_c = Velocity along a curved path of a particle, $[L][T]^{-1}$

W_i = Height of the inlet gas flow to a cyclone separator in the radial direction so that the maximum distance any particle must move to reach the wall is W_i, $[L]$

μ = Viscosity of gas stream = 1.8×10^{-5} *kg/m.s*

(i) If it is necessary to increase the flow rate to the cyclone by 25 %, what will the new value of D_{cut} be? Assume that nothing else will change.

[1.0 Mark]

(ii) The block flow-model efficiency of the cyclone separator is ε_1. The block flow-model efficiency of a combination of 5such individual cyclones in series with complete remixing of the gas stream between them is ε_5. What is the value of $\varepsilon_5/\varepsilon_1$? State whether the same ratio would be obtained for $\varepsilon_5/\varepsilon_1$ if there is only one cyclone with N=25, instead of having 5 cyclones in series with remixing.

[2.0 Marks]

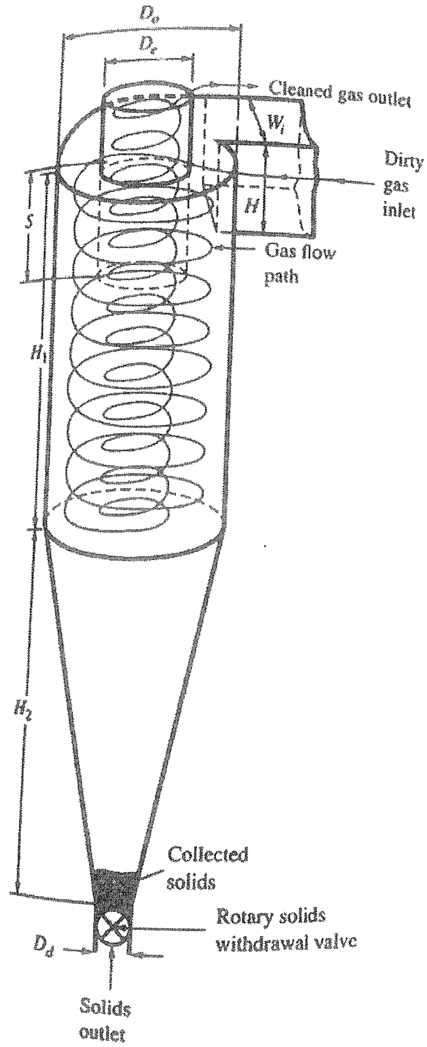

Figure Q5 Schematic diagram of a cyclone separator