UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 6 Examination in Engineering: December 2015

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

[Three Hours]

[Answer all questions, each question carries twelve marks]

Q1. a) A partially treated municipal wastewater is to be further treated at a rapid infiltration *(RI)* system. The effluent will be applied as a cycle of flooding followed by drying to maximize the nitrification.

Table Q1 (a) Design information of the RI system.

Parameter	Unit	Value
Annual average hydraulic loading rate	*m/yr.*	20
Biochemical Oxygen Demand *(BOD_5)* of the partially treated municipal wastewater	g/m^3	50
Application(flooding) period of effluent per operating cycle	*d*	2
Drying period per operating cycle	*d*	6
RI system operating period per year	*d*	365

Using the information given in Table Q1 (a), determine;

(i) The annual average BOD_5 loading rate,

(ii) The average application rate (Ra),

(iii) The average BOD_5 loading rate over the 8 d cycle, and

(iv) The BOD_5 loading rate for the first day of application.

[4.0 Marks]

b) (i) Using flow diagrams, explain the nitrogen removal process in the Oxidation ditch and the Bardenpho process highlighting the reason for the lower nitrogen removal efficiencies in the former than in the latter.

[2.0 Marks]

(ii) A selected primary clarified effluent is to be treated in 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. Determine the volume of each aerated reactor and the total oxygen requirement for both carbon oxidation and nitrification for the conditions given in Table Q1 (b).Assume that ammonia (NH_3) does not undergo any reaction in the ASP for carbon oxidation.

The following equations are applicable:

$(1/\theta_c) = YU - k_d$; $U = k'N/(K + N)$; $k' = \mu_m'/Y$; $1/\theta_c^M \sim Yk' - k_d$;

$\theta_c = SF(\theta_c^M)$; $P_x = QY(S_0 - S)/(1 + k_d \cdot \theta_c)$

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

N = Effluent NH_4^+- N concentration, $[M]\ [L]^{-3}$
U = Specific substrate utilization rate, $[T]^{-1}$
k' = Maximum rate of substrate utilization for nitrification, $[T]^{-1}$
P_x = Net mass of volatile solids (biological solids) produced, $[M]\ [T]^{-1}$
θ_c = Mean cell residence time {Solids Retention Time (SRT)}, $[T]^{-1}$
θ_C^M = Minimum mean cell residence time, $[T]^{-1}$

Table Q1(b) Design information of the activated-sludge process.

Description	Unit	Value
Flow rate of the primary clarified effluent (Q)	m^3/d	6,000
Soluble BOD_5 (5-day Biochemical Oxygen Demand) in primary clarified effluent (S_0)	g/m^3	300
Ammonium Nitrogen $(NH_4^+\text{-}N)$ concentration in primary clarified effluent (N_0)	g/m^3	60
Required effluent soluble $BOD_5(S)$ of ASP for carbon oxidation	g/m^3	15
Design mean cell residence time of ASP for carbon oxidation	d	5
Concentration of microorganisms (X) as VSS		
with respect to carbon oxidation	g/m^3	2,000
with respect to nitrification	g/m^3	185
Endogenous decay coefficient (k_d)		
with respect to carbon oxidation	d^{-1}	0.085
with respect to nitrification	d^{-1}	0.055
Yield coefficient (Y) for microorganisms		
with respect to carbon oxidation	-	0.4
with respect to nitrification	-	0.205
f {Conversion factor from BOD_L (Ultimate BOD) to BOD_5}	-	0.75
Maximum growth rate considering pH, dissolved oxygen (DO) and temperature (μ_m')	d^{-1}	0.4
SF (Safety Factor) for the mean cell residence time	-	3.0
Half velocity constant (K) for Nitrogen	g/m^3	0.84

[6.0 Marks]

Q2. a) Explain briefly the treatment mechanism of an RBC (Rotating Biological Contactors) process.

[2.0 Marks]

b) An industrial effluent is to be treated by a wastewater treatment plant consisting of a preliminary treatment followed by a flow-through aerated lagoon (without recycle) system (aerated lagoon and sedimentation basin). This secondary-treated wastewater is to be polished with Granular Activated Carbon (GAC) adsorbers to remove the total COD. Table Q2 gives the design information.

(i) Determine the following for the flow-through aerated lagoon:
Surface area (A); Water temperature (T_w); Effluent soluble bCOD (Biodegradable Chemical Oxygen Demand) value; Effluent TSS (Total Suspended Solids) concentration; and Total oxygen requirement.

The following conditions and requirements are applicable:
$T_w = (AfT_a + QT_i)/(Af + Q)$; $k_T = k_{20}\theta^{(T-20)}$; $S/S_0 = 1/\{1 + k(V/Q)\}$;
$P_x = QY_{obs}(S_0 - S)$

Oxygen requirement for carbon oxidation, $[M][T]^{-1} = Q(S_0-S)/x - 1.42P_x$
P_x = Net mass of volatile solids (biological solids) produced, $[M]\ [T]^{-1}$
T = Temperature, ^0C
S_0 = Influent soluble biodegradable organic matter concentration, $[M][L]^{-3}$
S = Effluent soluble biodegradable organic matter concentration, $[M][L]^{-3}$
V = Volume of the reactor, $[L]^3$

[6.0 Marks]

(ii) Determine the amount of activated carbon that would be required for the polishing process. Assume that the removal efficiency of suspended COD in the flow-through aerated lagoon system is 90 %.

The GAC adsorber 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, $[M]$

[4.0 Marks]

Table Q2 Design information.

Description	Unit	Value
Flow-through aerated lagoon		
Average wastewater flow rate (Q)	m^3/d	9,000
Influent total COD (Chemical Oxygen Demand)	g/m^3	225
Influent soluble $bCOD$ (Biodegradable COD)	g/m^3	175
Influent SS (Suspended Solids) concentration; Influent SS are not biologically degradable	g/m^3	100
Influent wastewater temperature (T_i)	^0C	25
Average atmospheric temperature (T_a)	^0C	28
Temperature coefficient (θ)	-	1.07
Temperature proportionality factor (f)	-	0.55
Conversion factor (x) for BOD_5 to BOD_L (Ultimate Biochemical Oxygen Demand)	-	0.65
Observed yield coefficient (Y_{obs})	-	0.55
VSS (Volatile Suspended Solids)/TSS	-	0.9
First-order observed soluble biodegradable organic matter removal -rate constant (k_{20})	d^{-1} at 20 ^0C	2.1
Design hydraulic retention time	d	11
Lagoon depth	m	2

GAC adsorber	Unit	Value
Final COD concentration	g/m^3	2.5
No. of GAC adsorbers in parallel	-	10
Ratio of theoretical to breakthrough adsorption capacity	-	1: 0.25
Time to breakthrough (t_b)	d	50

Q3. a) Name three principal considerations in selection and design of onsite systems. Discuss briefly how each of above considerations affects the design.

[2.0 Marks]

b) Design an on-site wastewater management system consisting of a septic tank, constructed wetland system 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.

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

Description	Unit	Value
Septic tank		
Average flow rate	m^3/d	3.0
Peak factor	-	2.75
Detention time at the peak daily flow rate	d	0.5
Volume of water lost in the septic tank as a result of sludge and scum accumulation as a percentage of the septic tank volume	%	30
Effluent Biochemical Oxygen Demand (BOD_5) value	g/m^3	300
Sub-surface flow constructed wetland system		
Required effluent BOD_5 (C_e)	g/m^3	35
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
Trench-type soil absorption field		
Maximum depth of the trench below the distribution pipe	m	1.5
Allowable hydraulic loading rate for the disposal field	$L/m^2.d$	18
Disposal of septage		
Average flow rate to the small WWTP	m^3/d	7,500
BOD_5 value in influent to small WWTP	g/m^3	350
BOD_5 value in the septage	g/m^3	8,000

Assume the following:
The wastewater infiltrates into the vadoze zone of soil only through side walls of the trench; Average daily septage volume that requires delivery at a wastewater treatment facility is equal to the volume of the septic tank; The delivery of septage in the small WWTP will be completed within one day.

The 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 detention time,$[T]$

The design should include;

(i) The volume of the septic tank,

[2.0 Marks]

(ii) Verification whether the given design values of the sub-surface flow constructed wetland system agree with the allowable loading rates,

[4.0 Marks]

(iii) The required length of the disposal trench, and

[2.0 Marks]

(iv) The influent BOD_5 value of the WWTP after the disposal of septage.

[2.0 Marks]

Q4. a) 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.

[2.0 Marks]

b) A gravity thickener receives a waste-activated sludge that contains 0.25 % solids at a flow rate of 3,500 m^3/d. The solids loading rate on the thickener is 150 $kg/m^2.d$. The thickened sludge has a solid content of 6.0 %. This 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.

(i) Compute the hydraulic loading rate of the thickener.

[2.0 Marks]

(ii) What percentage of annual sludge volume saving will arise due to this substitution?

[2.0 Marks]

c) The thickened sludge from the gravity thickener mentioned in part (b) above, is to be 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 (5d Biochemical Oxygen Demand), $[M]/[L]^3$

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

Table Q4 Design information.

Description	Unit	Value
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	$m^3/kg\ BOD_5$ stabilized	0.35

Estimate the following for the digester:

(i) Volumetric organic loading rate;

[2.0 Marks]

(ii) The percent waste stabilization; and

[2.0 Marks]

(iii) The amount of methane gas produced.

[2.0 Marks]

Q5. a) Describe briefly how the multiple columns operated in series improve the effectiveness of the treatment mechanism of GAC (Granular Activated Carbon) adsorption process.

[1.0 Mark]

b) What is the advantage of using;

(i) A down-flow GAC contactor over an up-flow contactor?

[1.5 Marks]

(ii) A moving-bed or an expanded- bed contactor over a fixed-bed contactor?

[1.5 Marks]

c) Draw a schematic flow diagram of an RBC (Rotating Biological Contactor) application for the secondary treatment of wastewater. Consider that the treatment train consists of a primary clarifier, an 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 perpendicular to the flow and the two reactors are operated in parallel.

[3.0 Marks]

d) (i) A cyclone separator (Figure Q5) is operating in conditions where D_{cut} is 10 μm. There is another cyclone that is of the same design, with all the dimensions are one-half as big as the present one. If the same air stream (i.e. The total volumetric flow rate, particle loading and the particle size distribution do not change) is fed to this new cyclone, what will the value of D_{cut} be?

[2.0 Marks]

(ii) The cut diameter of a cyclone is D1. The cut diameter of a combination of three such individual cyclones in series with complete remixing of the gas stream between them, is D3. What is the value of (D_3/D_1)?

State whether the same answer would be obtained for (D_3/D_1) if there is only one cyclone with N=15, instead of having three cyclones in series with remixing.

[3.0 Marks]

Following equations may be applicable:

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

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

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.

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

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

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*

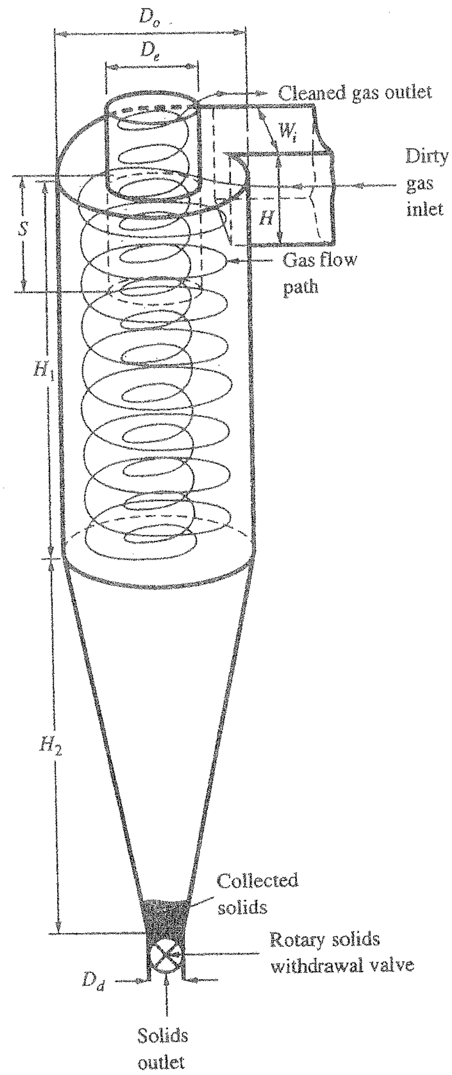

Figure Q5 Schematic diagram of a cyclone separator