UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 7 Examination in Engineering: August 2015

Module Number: CE7325 **Module Name: Environmental Engineering Design**

[Three Hours]

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

Q1. a) A partially treated industrial wastewater effluent 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.

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

(i) The annual hydraulic-loading rate (L_w),

(ii) The infiltration area requirement, and

(iii) The average application rate (R_a).

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

Parameter	Unit	Value
Average industrial effluent flow	m^3/d	5,500
Biochemical Oxygen Demand (BOD_5) of the industrial effluent	g/m^3	40
Application(flooding) period of effluent per operating cycle	*d*	3
Drying period per operating cycle	*d*	12
Organic loading rate as BOD_5	$g/m^2.week$	125
Annual evapotranspiration rate	*mm*	140
Annual percolation rate	*mm*	375
Annual precipitation	*mm*	50
RI system operating period per year	*d*	365

If R_a is modified to 0.75 *cm/d*,

(iv) What would be the required change in the application period per operating cycle (application and drying) of 12 *d* to achieve the same hydraulic loading rate?

[4.0 Marks]

b) i) Compare and contrast the following processes: Single-stage suspended growth carbon oxidation and nitrification system; Separate stage suspended growth nitrification process; Combined nitrification/denitrification system and Separate stage denitrification system.

[2.0 Marks]

ii) An activated-sludge process is to be designed to achieve a single-stage carbon oxidation and complete nitrification for a selected industrial wastewater. Determine the volume of the aerated reactor and the total oxygen requirement for the conditions given in Table Q1 (b).

The following equations are applicable:

$(1/SRT) = YU - k_d; U(nitrification) = k'N/(K_N + N)$; $k = \mu_m/Y$;
$P_x = QY(S_0 - S)/(1+SRT.k_d)$;
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*, $[M][T]^{-1}$
N = Effluent NH_4^+- N concentration, $[M]\ [L]^{-3}$
U = Specific substrate utilization rate, $[T]^{-1}$
k =Maximum rate of substrate utilization (k') for nitrification, $[T]^{-1}$
P_x = Net mass of volatile solids (biological solids) produced, $[M]\ [T]^{-1}$

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

Description	Unit	Value
Influent flow rate	m^3/d	5,000
Design solids retention time (SRT)	d	10
Influent soluble BOD_5(5-day Biochemical Oxygen Demand) (S_0)	g/m^3	350
Influent TKN (only ammonium-nitrogen exists) concentration (N_0)	g/m^3	65
Required effluent soluble $BOD_5(S)$	g/m^3	20
Concentration of nitrifiers (X_N) as volatile suspended solids (VSS)	g/m^3	175
Concentration of microorganisms for carbon oxidation (X) as VSS	g/m^3	2,500
Endogenous decay coefficient (k_d) for carbon oxidation	d^{-1}	0.08
Endogenous decay coefficient (k_d) for nitrification	d^{-1}	0.05
Half velocity constant (K_N) for Nitrogen	g/m^3	0.8
Maximum growth rate considering pH,dissolved oxygen (DO) and temperature	d^{-1}	0.4
Yield coefficient for microorganisms with respect to carbon oxidation(Y_C)	-	0.45
Yield coefficient for nitrifiers (Y_N)	-	0.21
f {Conversion factor from BOD_L (Ultimate BOD) to BOD_5}	-	0.7

[6.0 Marks]

Q2. a) i) Explain briefly the required pretreatment level of influent, target wastewater parameters and treatment mechanisms in a constructed wetland system.

[2.0 Marks]

ii) An industrial effluent is to be treated by a wastewater treatment plant consisting of a preliminary treatment followed by a facultative stabilization pond, an aerobic stabilization pond and two sub-surface flow constructed wetland systems (in parallel). Table Q2 (a) gives the design information. Figure Q2 (a) shows the *kt* value vs percent BOD_5 remaining for various dispersion factors.

1. Determine the hydraulic loading rate and the organic (BOD_5) surface loading rate of each stabilization pond.

2. Assuming that the total oxygen requirement is equal to the BOD_5utilized, obtain the daily oxygen requirement for the aerobic stabilization pond.

3. Verify whether the given design values of the sub-surface flow constructed wetland system agree with the allowable loading rates.

Table Q2 (a): Design information.

Description	Unit	Value
Average wastewater flow rate *(Q)*	m^3/d	10,000
Influent total BOD_5(5*d* Biochemical Oxygen Demand)	g/m^3	3,000
Minimum water temperature in all systems *(T)*	^oC	30
Design data of the facultative stabilization pond		
Hydraulic retention time *(HRT)*	*d*	15
Overall first-order BOD_5 removal–rate constant at $30^0C(k_{30})$	d^{-1}	0.35
Dispersion factor	-	0.5
Pond depth	*m*	1.9
Design data of the aerobic stabilization pond		
Hydraulic retention time *(HRT)*	*d*	12.5
Overall first-order BOD_5 removal–rate constant at $30^0C(k_{30})$	d^{-1}	0.4
Dispersion factor	-	1.0
Pond depth	*m*	0.95
Design data of the sub-surface flow constructed wetland system		
Required effluent BOD_5 (C_e)	g/m^3	10
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)*	-	0.02
Hydraulic conductivity (k_s)	$m^3/m^2.d$	425.5
Porosity of basin medium (α)	-	0.32
Allowable hydraulic loading rates	$m^3/ha.d$	27.4 - 821.9
Allowable BOD_5loading rates	$g/m^2.d$	7.1-11.4

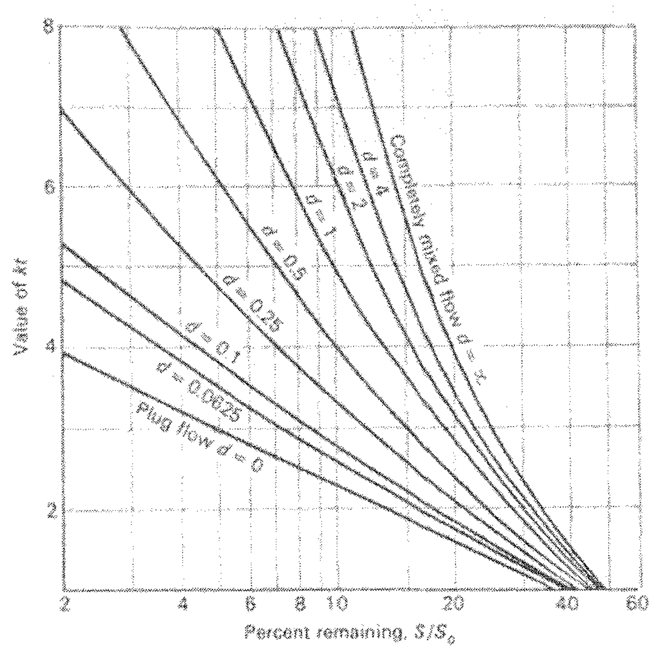

Figure Q2 (a):*kt* value with percent BOD_5 remaining at various dispersion factors

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

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

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, $[T]$; t = Actual detention time, $[T]$.

[7.0 Marks]

b) A secondary-treated wastewater is to be polished with Granular Activated Carbon (GAC) to remove the Total Organic Carbon (TOC). Table Q2 (b) shows the available wastewater and filter column data. Determine the amount of activated carbon that would be required for the polishing process. The GAC column 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^3'; 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 Q2 (b): Wastewater and filter column data.

Description	Unit	Value
TOC concentration after secondary treatment	g/m^3	3.37
Final *TOC* concentration	g/m^3	0.5
Ratio of theoretical adsorption capacity to breakthrough adsorption capacity	-	1: 0.2
Time to breakthrough (t_b)	d	60
Wastewater flow rate (Q)	m^3/d	600

[3.0 Marks]

Q3. a) Name three types of on-site domestic wastewater treatment systems which can be applied at difficult site conditions. Discuss their features/components which have made them suitable to be applied at such sites.

[2.0 Marks]

b) Design an on-site wastewater management system consisting of a septic tank, intermittent sand filter 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 (b) shows the design information.

The design should include;

(i) The volume of the septic tank,

(ii) The operating time of the sand filter (dosing time) at average and peak flow conditions,

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

(iv) The influent suspended solids (SS) concentration of the WWTP after the disposal of septage.

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 equation is applicable: $q_n = C(D^2)\sqrt{2gh_n}$;Q = Pipe discharge, $[L]^3[T]^{-1}$; q_n= Discharge from orifice $n, [L]^3[T]^{-1}$

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

Description	Unit	Value
Average flow rate	m^3/d	2.5
Peak factor	-	2.5
Detention time in the septic tank at the peak daily flow rate	d	0.55
Volume of water lost in the septic tank as a result of sludge and scum accumulation	*% on septic tank volume*	35
Sand filter dose rate per day	*times/d*	4
Gravitational acceleration (g)	ms^{-2}	9.81
No. of laterals	-	30
Diameter of an orifice (D)	mm	10
No. of orifices in one lateral	-	10
Head on last orifice (h_n)	m	3.0
Orifice discharge coefficient (C)	-	0.61
Maximum depth of the trench below the distribution pipe	m	1.6
Allowable hydraulic loading rate for the disposal field	$L/m^2.d$	16
Average flow rate to the small WWTP	m^3/d	7,000
SS concentration in influent to small WWTP	g/m^3	300
SS concentration in septage	g/m^3	8,500

[7.0 Marks]

c) Compare and contrast the following systems in design point of view: Flow-through aerated lagoon, rotating biological contactors and stabilization ponds.

[3.0 Marks]

Q4. a) Explain briefly three process design criteria used for establishing an anaerobic sludge digester.

[3.0 Marks]

b) The sludge from a primary sedimentation tank is to be digested anaerobically in a single-stage, high-rate digester. Table Q4 gives the design information.
Estimate following for the digester:
(i) Influent sludge flow rate;
(ii) Volumetric organic loading rate;
(iii) The percent waste stabilization; and
(iv) The amount of methane gas produced.
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 = InfluentBOD_5(5d Biochemical Oxygen Demand), $[M]/[L]^3$

S = EffluentBOD_5, $[M]/[L]^3$

Table Q4: Design information.

Description	Unit	Value
Sludge Moisture content at the primary sedimentation tank	%	94
Influent dry volatile solids load to the digester	*kg/d*	6,000
InfluentBOD_5 load to the digester	*kg/d*	5,300
Solids Retention Time(*SRT*) *at* the anaerobic digester at 35 ^0C	*d*	12
Waste stabilization efficiency at the anaerobic digester	%	65
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
Density of primary sludge	kg/m^3	1,050

[5.0 Marks]

c) A gravity thickener receives a waste-activated sludge that contains 0.3 % solids at a flow rate of 3,000 m^3/d. The solids loading rate on the thickener is 100 $kg/m^2.d$. The thickened sludge has a solid content of 5.5 %. This thickener is to be replaced by a vacuum filter-press to increase the thickening efficiency. The vacuum filter-press is expected to yield a solid content of 28%. The relative density of the sludge is 1.065.

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

[1.5 Marks]

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

[2.5 Marks]

Q5. a) Explain briefly the major steps, considerations and investigations to be done in designing a sanitary landfill.

[3.0 Marks]

b) Leachate exfiltrating from a naturally attenuating landfill is subjected to combine with ground water underneath and form a horizontal plume of water. Table Q5 (b) gives the related information. What is the peak concentration of the total nitrogen (*TN*) in the leachate? Assume that the dilution is the only attenuation mechanism.

Table Q5 (b): Landfill information.

Description	Unit	Value
Average concentration of *TN* in ground water	g/m^3	4
Average groundwater velocity	*m/d*	0.5
Average volume of leachate exfiltration per unit time	m^3/d	25
TN concentration in the down-gradient of the water plume at a horizontal distance of 200 *m*	g/m^3	20
Area intercepted by the plume at a horizontal distance of 200 *m*	m^2	15,000

[2.0 Marks]

c) Table Q5 (c) (i) shows the typical properties of un-compacted municipal solid waste (MSW) which is to be disposed on a proposed containment type landfill. Table Q5 (c) (ii) gives the design information of the landfill. The landfill will consist of stacks, and a stack will be composed of several cells placed on top of each other. The horizontal surface of a cell is square in shape. The MSW deposited on the landfill will be compacted to a weighted compaction ratio based on the fractional mass of each component in the MSW.
Determine;
   (i) The daily horizontal area covered by the solid waste,
   (ii) Annual volume of the landfill to handle the solid waste collected.

The following equations are applicable:

$$Volume\ of\ landfill = \frac{Annual\ average\ solid\ waste\ generation\ rate \times E}{Density\ of\ compacted\ fill(solid\ waste)};$$

$E = (V_{sw} + V_s)/V_{sw}$; where V_{sw}= Volume of solid waste in a stack, $[L]^3$;
V_s= Volume of soil in a stack, $[L]^3$

Table Q5 (c) (i): Typical Composition of un-compacted MSW.

Component	Mass (kg)	Volume (m^3)	Normal compaction ratio
Food wastes	4.5	0.02	2.9
Paper	20.0	0.2	5.5
Cardboard	3.0	0.03	4.2
Plastics	0.75	0.04	6.8
Garden trimmings	7.0	0.07	4.3
Wood	1.5	0.008	2.4
Tin cans	3.0	0.025	5.4

Table Q5 (c) (ii): Design information of the landfill.

Description	Unit	Value
Annual average solid waste generation rate	*Mg/year*	3,000
Thickness of an un-compacted layer of solid waste fill	*m*	1.44
Cell height	*m*	3.0
Thickness of the daily soil cover	*m*	0.2
Thickness of the soil cover at the completion of a cell	*m*	0.6
No. of cells per stack	-	6
Thickness of the soil cover at the completion of a stack	*m*	0.8
No. of operating days per a week	*d*	5

[7.0 Marks]