UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 6 Examination in Engineering: January 2022

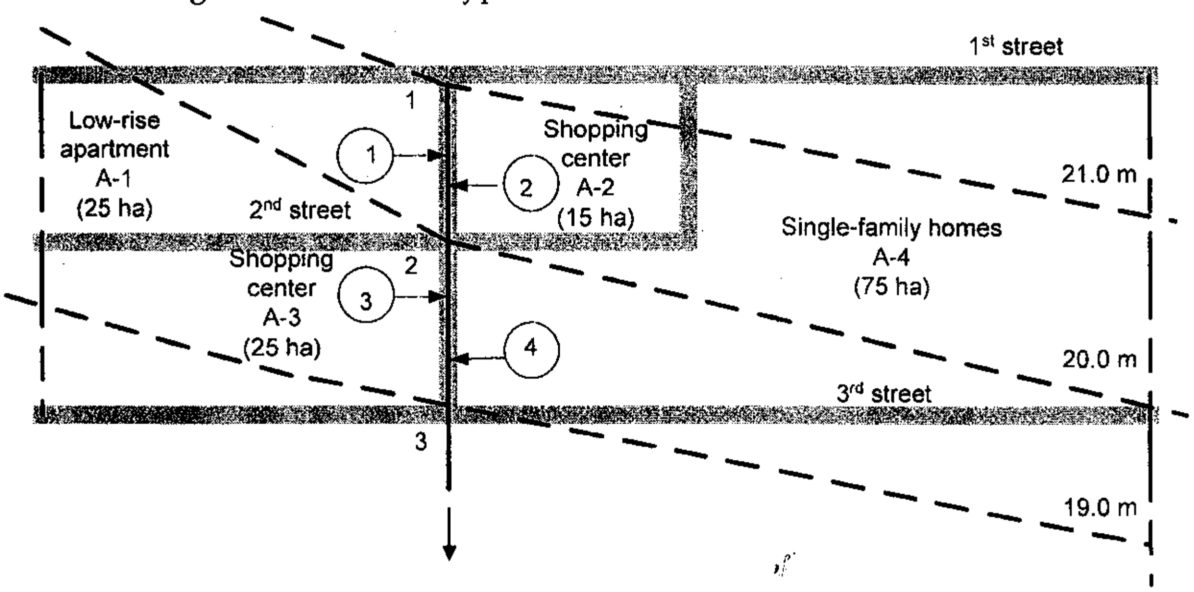
Module Number: CE6303 **Module Name: Environmental Engineering Design**

[Three Hours]

[Answer **all questions**, questions carry **unequal** marks, the distribution of marks within a question is indicated at the end of each part]

Q1. For a municipal council, a wastewater collection, treatment, and disposal/reuse system has been proposed. The design of this system consists of a wastewater collection network and a wastewater treatment plant (WWTP). The WWTP will consist of preliminary treatment, primary sedimentation, a flow-through aerated lagoon system (an aerated lagoon and an earthen sedimentation basin without solid recycle), a complete nitrification process in an Activated Sludge Process *(ASP)* and a wastewater reclamation system. Following questions (1 to 5) are based on this proposed wastewater collection, treatment and disposal/reuse system.

1. The proposed WWTP will receive wastewater from respective areas through a gravity-flow trunk sanitary sewer laid via junctions 1, 2 and 3 (Figure 1). Circled numbers indicate the wastewater entry location from respective areas. Calculate the **design average** and **design peak flow rates** of the WWTP. The following design criteria are applicable:
    1. Design population density for all the types of dwellings = 500 *persons/ha*
    2. Design residential wastewater flow = 380 *L/capita. d*
    3. Commercial flow = 150 *m^3/ha.d*
    4. The infiltration rate is negligible
    5. Peaking factor for all the types of areas = 2.0



Used to indicate the location or line to which wastewater from the contributing area is discharged; —— Trunk sewer

Figure 1

[8.0 Marks]

2. a) (i) Using the substrate mass balance equation, prove that the equilibrium state effluent soluble BOD_5 (5-day Biochemical Oxygen Demand) concentration (S) in a flow-through aerated lagoon (without recycle) is given by the following equation: $S/S_0 = 1/\{1 + k(V/Q)\}$; where S_0=influent soluble BOD_5 concentration; V = volume of reactor; Q = flow rate and k = first-order observed soluble BOD_5 removal -rate constant.

[2.0 Marks]

(ii) In the proposed WWTP, primary treated effluent will enter the flow-through aerated lagoon system. If the wastewater contains adequate nitrogen, phosphorus and other trace nutrients for biological growth, and the hydraulic regime of the reactor is complete mix, determine;

I. The surface area of the flow-through aerated lagoon,

[1.0 Marks]

II. The effluent soluble BOD_5 (S),

[2.0 Marks]

III. The effluent TSS (Total Suspended Solids) concentration,

[2.0 Marks]

IV. The oxygen requirement.

[2.0 Marks]

Table 2(a) gives the design information. The following equations are applicable: $k_T = k_{20}\theta^{(T-20)}$; where T = temperature; k_T= 'k' at 'T' = temperature; $P_x = QY_{obs}(S_0 - S)$; where P_x = biological solids wasted per day ($kg\ VSS/d$); Oxygen requirement $(kg\ of\ O_2/d) = \{Q(S_0 - S)/x\} - 1.42P_x$.

Table 2(a): Design information for the flow-through aerated lagoon.

Description	Unit	Value
Removal efficiency of the primary clarifier for; *TSS* *sBOD₅*	%	 50 35
Influent characteristics to the primary clarifier in terms of; Total suspended solids *(TSS)* concentration Soluble 5-*d* Biochemical Oxygen Demand ($sBOD_5$) Influent *SS* are not biologically degradable	g/m^3	 500 307.7
Water temperature in the lagoon	^0C	30
Temperature coefficient (θ) at 20 ^0C	-	1.05
Conversion factor *(x)* for BOD_5 to BOD_L (Ultimate Biochemical Oxygen Demand)	-	0.60
Observed yield coefficient (Y_{obs})	-	0.35
VSS (Volatile Suspended Solids)/ *TSS* ratio	-	0.80
First-order observed soluble BOD_5 removal -rate constant *(k)* at 20 ^0C	d^{-1}	2.6
Design solids retention time *(SRT)*	*d*	10
Depth of the lagoon	*m*	2.0

b) Table 2(b) gives design conditions and requirements for the earthen sedimentation basin, which follows the above aerated lagoon. Determine the **total depth** of the sedimentation basin excluding the free board. The accumulated sludge will be compacted to an average final value of 12 % of the initial solids volume. Assume that the maximum amount of volatile suspended solids (*VSS*) accumulated at the end of t^{th} year is given by the following equation:

$(VSS)_t = [0.7+0.4(t-1)]$ X *mass of VSS added per year (kg/yr)*

Table 2(b): Design information for the earthen sedimentation basin.

Description	Unit	Value
Hydraulic detention time	*d*	3.0
Liquid level above the sludge layer at its maximum level of accumulation	*m*	1.6
TSS concentration of the effluent from the sedimentation basin	g/m^3	30
Volatile suspended solids (*VSS*) content of TSS discharged to the sedimentation basin	%	75
Period between two consecutive removals of sludge from the sedimentation basin	*years*	6
Relative density of the accumulated sludge	-	1.04

[5.0 Marks]

3. a) The effluent from the earthen sedimentation basin will be directed to an Activated Sludge Process (ASP), in which a complete nitrification will take place. Figure 3 depicts a schematic diagram of the complete nitrification process. Table 3 (a) gives the design information of the complete nitrification process. Determine;

(i) The volume of the aerated reactor,

[1.5 Marks]

(ii) The total oxygen requirement for the complete nitrification,

[1.5 Marks]

(iii) The net mass of volatile solids (biological solids) produced (P_X),

[1.0 Marks]

(iv) The effluent flow rate (Q_e),

[1.0 Marks]

(v) The power requirement for mixing and supplying oxygen.

[3.0 Marks]

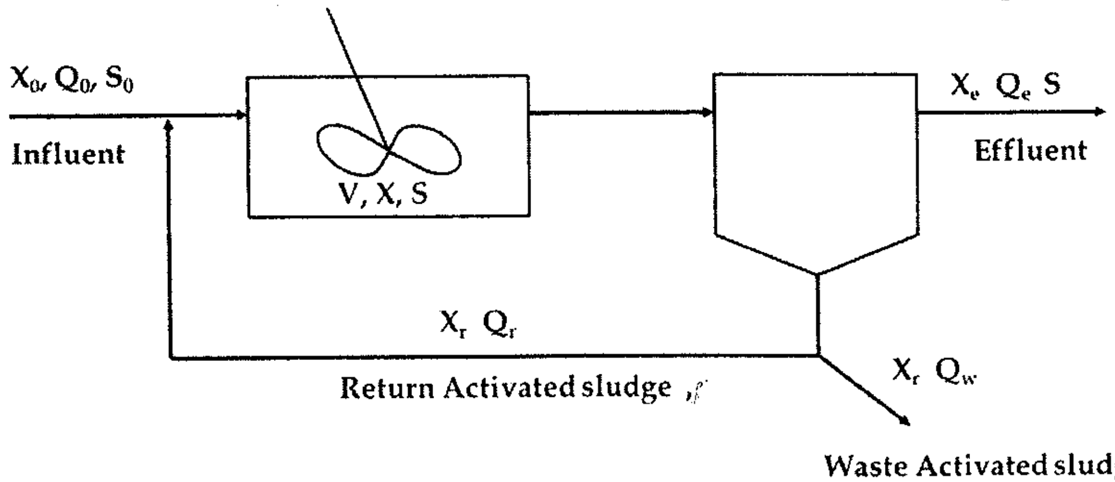


Figure 3: Schematic diagram of the complete nitrification process.

Following equations may be applicable for the complete nitrification process:

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

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

The oxygen required for nitrification is 4.3 *mgO₂/mg ammonium nitrogen, [M][T]* $^{-1}$

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

Table 3(a): Design information for the complete nitrification process.

Description	Unit	Value
Influent characteristics to the primary clarifier in terms of NH_4^+-N	g/m^3	65
Removal efficiency of the primary clarifier for NH_4^+-N	%	5
Concentration of microorganisms (X) as volatile suspended solids (*VSS*)	g/m^3	175
Endogenous decay coefficient (k_d)	d^{-1}	0.05
Yield coefficient (Y) for microorganisms	-	0.22
Maximum specific growth rate (μ_m)	d^{-1}	0.45
Dissolved oxygen to be maintained in the reactor	g/m^3	2.0
Minimum *pH* of the wastewater	-	7.1
Minimum sustained temperature	^0C	16
SF (Safety Factor) for *SRT* for nitrification	-	3.23
Half velocity constant (K_{O2}) for oxygen	g/m^3	1.3
Half velocity constant (K_N) for NH_4^+-N	g/m^3	0.8
Flow rate of the waste sludge disposal line (Q_w)	m^3/d	500
Elevation of the reactor	m	500
Aerator Oxygen transfer rate	$kg\ O_2/kWh$	1.8
Power required for mixing	$kW/10^3\ m^3$ of Reactor	8
Aeration constant, α	-	0.85
Aeration constant, β	-	1.0

$$N = N_0 \left(\frac{\beta C_{s(alt)} - C_L}{9.17}\right) 1.024^{(T-20)} \alpha;\ C_{s,alt} = C_{s(at\ sea\ level)} \times F_a$$

C_L = Operating oxygen concentration, $[M]\ [L]^{-3}$
$C_{s(alt)}$ = Oxygen saturation concentration for tap water at given temperature and altitude, $[M]\ [L]^{-3}$
F_a = Oxygen solubility correlation factor
N = $kg\ O_2/kW.h$ transferred under field conditions.

No = $kg\ O_2/kW.h$ transferred in water at 20 ^0C, and zero DO
T = Temperature, ^0C
α = Oxygen transfer correction factor for waste
β = Salinity-surface tension correction factor, usually 1

b) 2.13 percent (2.13 %) of the effluent flow from the above complete nitrification process will be given further treatment in a water reclamation system to make it suitable for reuse. The nitrified effluent from the *ASP* will enter an anaerobic filter for denitrification. Denitrified wastewater will be fed to a fixed bed adsorber filled with Granular Activated Carbon (*GAC*) via a granular gravity filter. Finally, the effluent of the adsorber will undergo ultra-violet *(UV)* disinfection to be suitable for reuse. The target parameter of the fixed bed adsorber will be the remaining dissolved organic matter *(DOM)*. *sCOD* is considered as a measure of *DOM*.
Assume that the influent flow rate to the anaerobic filter, granular gravity filter and the *GAC* adsorbers are the same. **Determine the amount of activated carbon that would be required for the adsorption process.**
Table 3 (b) gives the design information.
The *GAC* adsorber is described by the Freundlich isotherm, $\frac{x}{m} = 0.0015C_e^{3.56}$;
Where,
C_e = Equilibrium concentration of the adsorbate in the solution after adsorption, $[M][L^{-3}]$
x/m = Amount adsorbate adsorbed per unit weight of adsorbent, $[M]/[M]$
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 3(b): Design information of the Granular Activated Carbon Adsorbers.

Description	Unit	Value
Soluble Chemical Oxygen Demand (*sCOD*) in the effluent of the granular gravity filter	g/m^3	12
Final *sCOD* concentration	g/m^3	3
Ratio of theoretical adsorption capacity to breakthrough adsorption capacity	-	1: 0.3
Time to breakthrough (t_b)	d	50

[5.0 Marks]

4. In the WWTP, the primary sludge and activated excess sludge (biological solids) are mixed together, thickened in a gravity thickener, and digested anaerobically in a batch digester. Assume that three fourth (3/4) of the biological solids produced by the nitrification process in the *ASP* is wasted every day and directed to the sludge treatment train. Figure 4 illustrates a schematic diagram of the sludge treatment train.

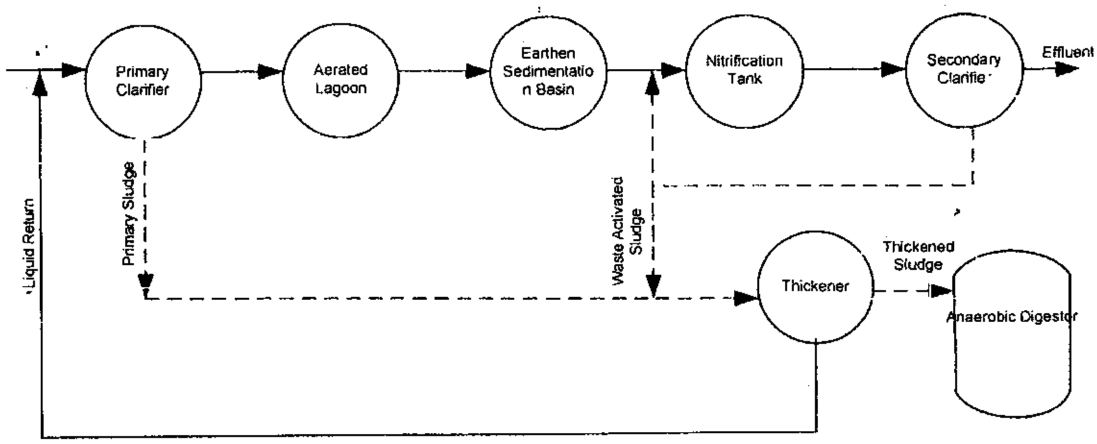


Figure 4: Schematic diagram of the sludge treatment train.

The following equation is applicable:

$V = t_1(V_1 + V_2)/2 + V_2 t_2$; 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 4 gives the additional design information.

Table 4: Additional design information for the sludge treatment train.

Description	Unit	Value
Removal efficiency of the primary clarifier for *TSS*	%	50
Influent characteristics to the primary clarifier in terms of *TSS*	g/m^3	500
Density of any type of sludge	kg/m^3	1000
Primary sludge		
Content of solids in the primary sludge	%	4.0
Activated sludge		
Content of solids in the activated sludge (biological solids)	%	0.9
Thickened sludge		
Content of solids in the thickened sludge	%	5.0
Batch anaerobic digester		
Non-biodegradable organic matter fraction in the influent	%	40
Inert matter content of the influent	%	40
Digestion period(t_1)	*d*	35
Digested sludge storage period(t_2)	*d*	90
Solid content in the digested sludge	%	6.0

a) Determine the solids load onto the thickener.

[3.0 Marks]

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

[2.0 Marks]

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

[3.0 Marks]

5. Preparing a hydraulic profile for average flow conditions, find the following control elevations for the nitrification process (ASP) of the above WWTP:

a) Water surface elevation in the secondary clarifier,

[3.0 Marks]

b) Water surface elevation in the aeration tank effluent channel,

[3.0 Marks]

c) Elevation of the effluent weir in the aeration tank.

[1.0 Mark]

Figure 6 illustrates the design information. The following data and assumptions are applicable:

Secondary sedimentation tank
Weir crest elevation - 100 *m*
Diameter at weir circle - 17 *m*
Wier spacing -0.3 *m*
Weir type- 90 ^{0} V notch
Underflow- 0.4 *Q*
Length of the pipe between the sedimentation tank and the effluent channel of the aeration tank = 50 m

Head loss computations
<u>Head loss coefficients</u>
Pipe entrance-0.5
Pipe bends- 0.4
Pipe exit-1.0
Pipe friction in Darcy-Weibach equation - 0.02
The free fall between the weir crest and the water surface in the downstream channel- 0.01 m
The following equations may be applicable:
Head on vee notch weir =$q = 0.55h^{5/2}$
Frictional head loss (h_f)= $f \frac{LV^2}{D\,2g}$ (Darcy-Weibach equation)
Minor head losses (h_m)=$K\frac{V^2}{2g}$

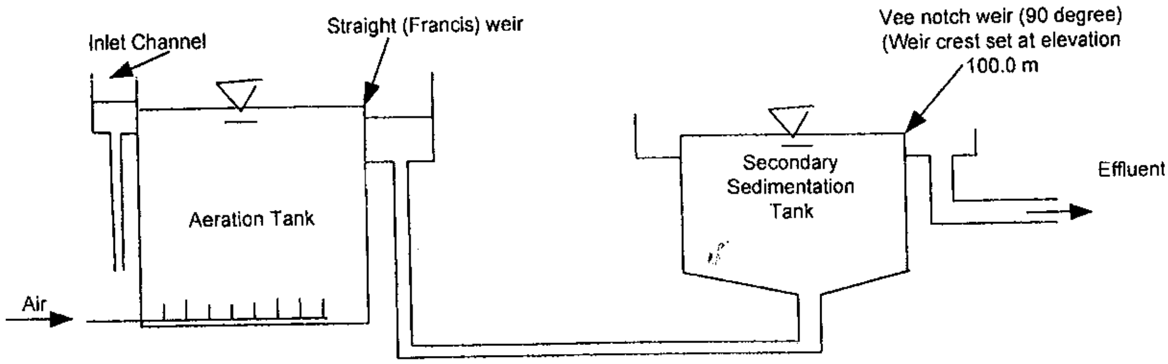
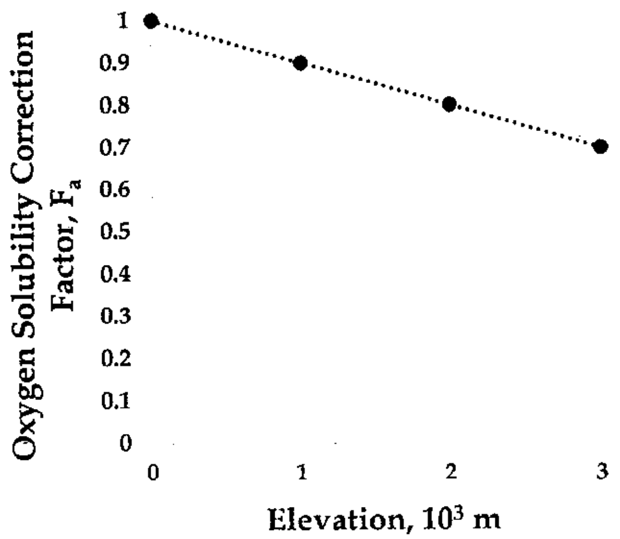


Figure 5: Schematic diagram of the Activated Sludge Process (ASP).

Additional Tables and Figures

Oxygen Solubility Correction Factor Versus Elevation



Dissolved Oxygen Saturation at Sea Level

Dissolved Oxygen (mg/L) at Saturation in freshwater		
Temperature (C⁰)	(F⁰)	Dissolved Oxygen at saturation (mg/L)
0^0	32^0	14.6
5^0	41^0	12.8
10^0	50^0	11.3
15^0	59^0	10.1
20^0	68^0	9.1
25^0	77^0	8.3
30^0	86^0	7.6