UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 6 Examination in Engineering: January 2019

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 process, the Solids Retention Time *(SRT)* is estimated based only on the process of converting ammonia into nitrate by *Nitrosomonas* bacteria." Rationalize this statement.

[2.0 Marks]

b) A primary-treated effluent is to undergo treatment by a carbon oxidation combined complete nitrification process, in which an Activated Sludge Process *(ASP)* (Figure Q1) is to be designed to achieve both carbon oxidation and complete nitrification in one reactor. This system is followed by an anaerobic filter, granular gravity filter, granular activated carbon *(GAC)* adsorption process and ultra violet *(UV)* disinfection 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. Table Q1(b) 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.

Following equations may be applicable for both carbon oxidation and nitrification processes:

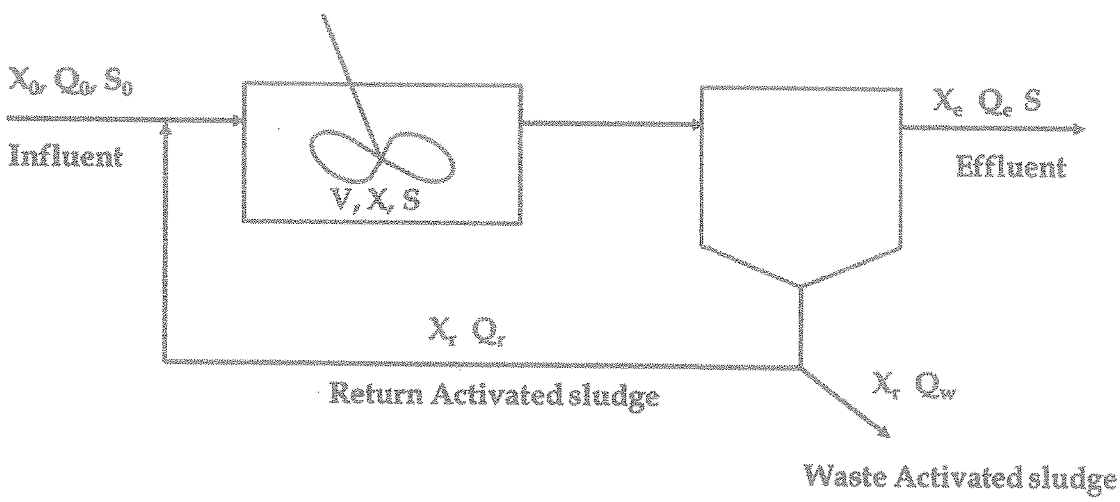


Figure Q1 Schematic diagram of the carbon oxidation combined complete nitrification.

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

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

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*, $[M][T]^{-1}$
Effluent flow rate $(Q_e) = Q\text{-}Q_w$

μ'_m = Maximum specific growth rate (μ_m) considering *pH*, dissolved oxygen (*DO*) and temperature for nitrification $[T]^{-1}$
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, $[T]$
SRT^M = Minimum Solids Retention Time, $[T]$

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	500
TSS removal efficiency of the primary clarifier	%	55
Soluble 5-*d* Biochemical Oxygen Demand ($sBOD_5$) in primary clarified effluent	g/m^3	400
Ammonium Nitrogen (NH_4^+-N) concentration in primary clarified effluent	g/m^3	65
Required effluent $sBOD_5$ of *ASP* for carbon oxidation	g/m^3	20
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 specific growth rate (μ_m)	d^{-1}	0.45
Dissolved oxygen to be maintained in the reactor	g/m^3	2.5
Minimum pH of the wastewater	-	7.2
Minimum sustained temperature	^0C	15
SF (Safety Factor) for *SRT* for nitrification	-	3.25

Description	Unit	Value
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	250

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

[5.0 Marks]

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

[7.0 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 three fourth of the biological solids produced by each of carbon oxidation and nitrification processes in the *ASP* is wasted every day, and directed to the sludge treatment train.

Following equation is applicable: $V_s = \left\{V_i - \frac{2}{3}(V_i - V_f)\right\}t$ where V_i= Initial sludge loading rate, $[L]^3[T]^{-1}$; V_f=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	1100
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)	d	35
Solid content in the digested sludge	%	6.0

(i) Using a sketch, explain briefly the reactor configurations of a two-stage high-rate anerobic digester.

[3.0 Marks]

(ii) Determine the solids load onto the digester.

[2.0 Marks]

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

[5.0Marks]

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

[4.0 Marks]

Q2. A wastewater treatment train consists of a waste stabilization pond (*WSPs*) system with an anaerobic pond, facultative pond and a maturation pond connected in series. Five percentage of the effluent flow from the *WSPs* system is given further treatment in a water reclamation system to make it suitable for reuse. Therefore, the above amount of flow is directed to a water reclamation system consisting of 3 sub-surface flow constructed wetlands connected in parallel, followed by a granular activated carbon (*GAC*) adsorption process. A fixed-bed contactor filled with *GAC* is used for the adsorption process, which is to remove the remaining dissolved organic matter (*DOM*). Table Q2 shows the design information.

Table Q2 Design information.

Description	Unit	Value
WSPs		
Net evaporation rate (*e*)	*mm/d*	4
Anaerobic pond		
Influent wastewater flow rate	m^3/d	4,000
Influent 5-day 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*	4.0
SolubleBOD_5 removal efficiency	%	75
Facultative pond		
Design surface loading rate for BOD_5	*kg/ha.d*	350
Minimum allowable *HRT*	*d*	4.0
Depth	*m*	1.6
Soluble BOD_5 removal efficiency	%	60
Maturation pond		
Design *HRT*	*d*	4.0
Depth	*m*	1.25
BOD_5 removal efficiency	%	70.0
Sub-surface flow constructed wetland system		
Required effluent BOD_5 (C_e)	g/m^3	6
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*)	-	0.01
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 - 821.9
Allowable BOD_5 loading rates	$g/ m^2.d$	7.1- 11.4

Fixed-bed GAC contactor		
Initial concentration of adsorbate *(DOM)* (C_0)	g/m^3	2.0
Final equilibrium concentration of adsorbate (C_e)	g/m^3	0.01
Density of *GAC*	*g/L*	500
Freundlich capacity factor (K_f)	$(mg/g)(L/mg)^{1/n}$	30
Freundlich intensity parameter $(1/n)$	-	0.6
EBCT	*minutes*	15

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:
$(C_e/C_0) = exp(-K_T t')$; $t' = (LW\alpha d)/Q$; $A_c = Q/k_s S$
WhereC_0 = Influent BOD_5, $[M]/[L]^3$; L = Length of the basin, $[L]$; W = Width of the basin, $[L]$;
t' =Pore-space retention time, $[T]$

The adsorption in the GAC contactor is given by Freundlich isotherm equation,

$$q_e = K_f C_e^{(1/n)}$$

$GAC\ usage\ rate\ (m_{GAC}/Qt) = (C_0 - C_e)/q_e$; and
$Specific\ throughput(Qt/m_{GAC}) = t/(EBCT \times \rho_{GAC})$

Where, Q = Volumetric flow rate, $[L]^3[T]^{-1}$
C_0=Initial concentration of adsorbate, $[M]\ [L]^{-3}$
t = Time, $[T]$
C_e=Final equilibrium concentration of adsorbate, $[M]\ [L]^{-3}$
m_{GAC}= Mass of adsorbent, $[M]$
q_e=Adsorbate concentration on the adsorbent phase after equilibrium, $[M]/[M]$
$EBCT$= Empty - Bed Contact Time, $[T] = V_b/Q$
V_b = Volume of *GAC* in contactor, $[L]^3$; Volume of wastewater treated=Mass of *GAC* for given *EBCT/GAC* usage rate

a) The volume and area requirements for the anaerobic pond,
[2.0 Marks]

b) The area requirement and the effluent flow rate of the facultative pond,
[2.0 Marks]

c) The area requirement and the effluent flow rate of the maturation pond, and
[2.0 Marks]

d) Effluent soluble BOD_5 of maturation pond.
[2.0 Marks]

e) Verify whether the design values of the sub-surface flow constructed wetland system agree with the allowable loading rates.
[4.0 Marks]

f) Determine the amount of activated carbon that would be required for the polishing process of removing the remaining *DOM*, and the volume of wastewater treated in the proposed *GAC* contactor.

[5.0 Marks]

Q3. Design an on-site wastewater management system consisting of a septic tank and a trench-type soil absorption field for a housing scheme. Table Q3 shows the design information.

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	3.75
Effluent 5-*d* Biochemical Oxygen Demand (BOD_5) value	g/m^3	350
Liquid depth of the septic tank	m	1.25
Width of the septic tank	m	0.75
Height of the free board	m	0.55
Ratio of the lengths of 1st compartment and the second compartment	-	2:1
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

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 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 $30^0\ C$)
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 = $0.5\ V_{st}$

a) Calculate the total capacity of the septic tank with two compartments and the free board.

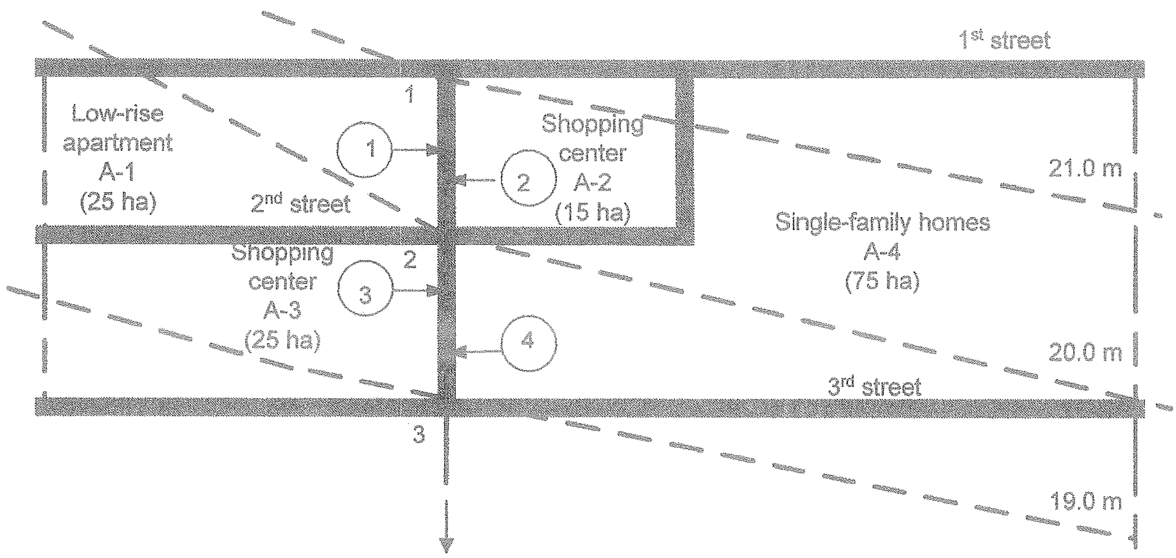
[3.0 Marks]

c) Calculate the required length of the disposal trench.

[2.0 Marks]

Q4. Design a gravity-flow trunk sanitary sewer from the 1st street at the junction 1 to the 3rd street at the junction 3 via the junction 2 {Figure Q4 (a)}. Major manholes are located at the junctions 1, 2 and 3. The design should include the design flow rates, pipe diameters, pipe slopes and the pipe invert elevations. Use Figure Q4 (b) for the hydraulic design calculations. Assume that the following design criteria apply:

1. Design population density for all types of dwellings = 200 *persons/ha;*
2. Design wastewater flow = 375 *L/capita. d.*
3. Commercial flow = 40 $m^3/ha.d.$
4. The infiltration rate is negligible.
5. Peaking factor for all types of areas = 2.0.
6. Lengths between the junctions 1 and 2, and 2 and 3 = 500 *m*.
7. Allowable minimum pipe diameter = 200 *mm;* minimum slope of a sewer =0.0008 m/m; minimum velocity = 0.75 ms^{-1}.
8. Minimum depth of the cover over the top of the sewer = 2.0 *m*.
9. Pipe wall thickness= 0.05 *m*



Used to indicate the location or line to which wastewater from the contributing area is discharged.

Trunk sewer

Figure Q4 (a) Sketch of the plot to be sewered

[10.0 Marks]

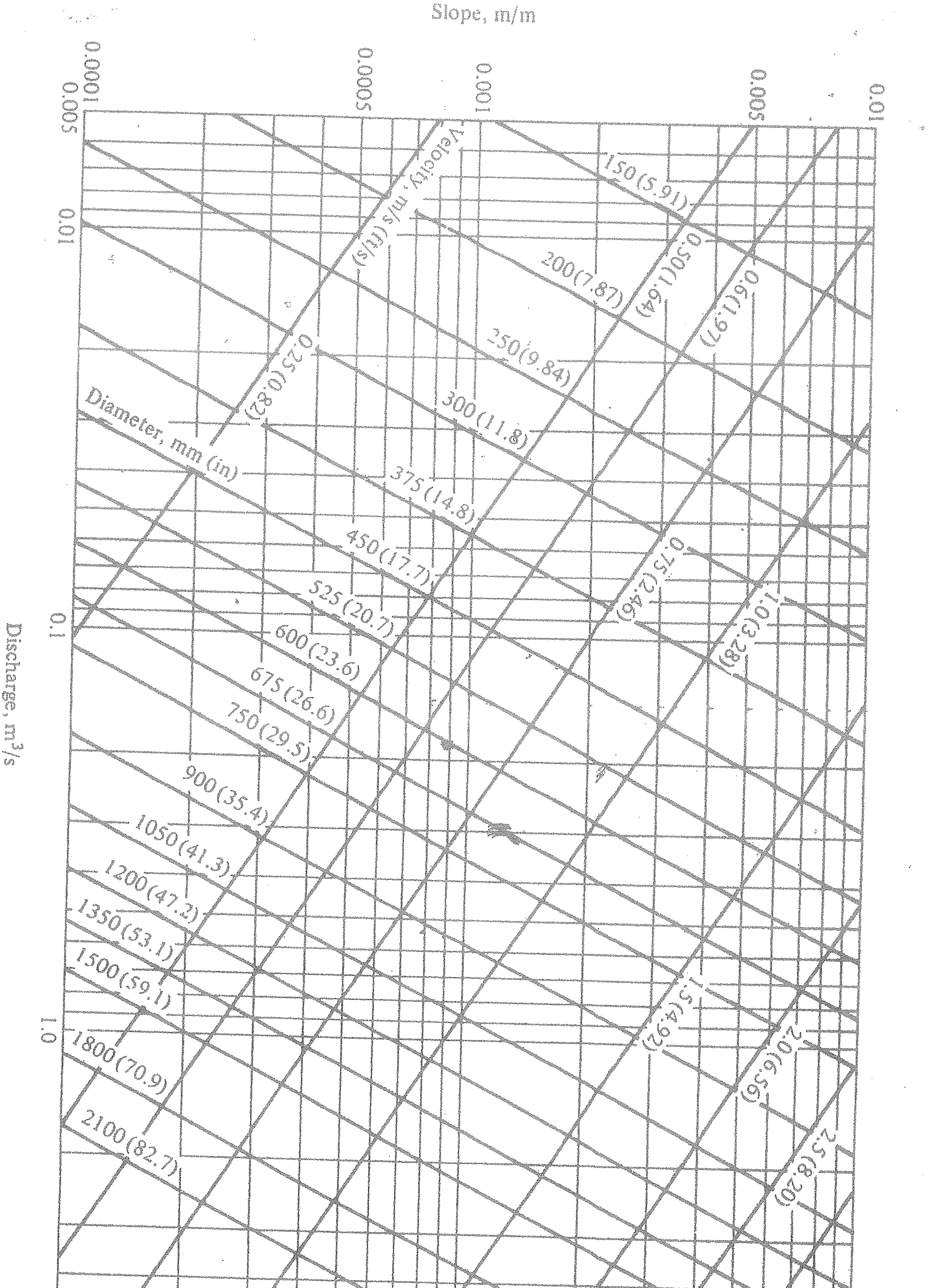


Figure Q4 (b) Nomograph for solution of Manning's equation for n=0.013