The Siting and the Process Design of a Municipal Wastewater Facility

Fundamentals of Engineering Design Workbook

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1. Preface

The Siting and Process Design of a Municipal Wastewater Facility is a joint project by Faculty from the Departments of Chemical Engineering and Civil and Environmental Engineering to introduce freshmen to design concepts and problems. The Chemical Engineers focus on the process design concepts while the Civil Engineers focus on siting and related problems including:

- Potential Site Visits
- Environmental Restrictions
- Political Restrictions
- Economic Aspects Related to the Site
- Final Site Selection

The Chemical Engineers are concerned with

- The Process Concept
- Material Balances Around the Process and the Process Units
    - Stream Flow Rates
    - Stream Compositions
    - Stream Specifications
- Estimating the Size of Equipment
    - Size of Each Unit
    - Number of Units
- Cost Estimates for the Process
    - Overall Estimated Construction Cost
    - Annual Operating and Maintenance Costs

Material balances are introduced in the sophomore year in chemical engineering. It is, therefore, very understandable that these new concepts are not easy, especially for freshmen who have never been exposed to these concepts. However, experiences have shown, that with sufficient guidance, the freshman can solve the problem and have an understanding of the problem and its solution, and thus have a very meaningful experience.

This workbook follows the concept of Freshman Chemistry Laboratory Workbooks and is developed to guide the inexperienced students, step by step, through the process design of a wastewater facility. It is suggested that the students work through the workbook, in groups, and cooperate with each other for a meaningful learning experience. When difficulties are encountered, they should consult with their instructor to clarify the problem before proceeding.

In making the calculations and drawings, the student should apply the latest available computer technology such as EXCEL for the tabulation of the data and calculations and graphic programs for flow sheets. The report should be written with a word processor such as WORD. In this manner, at the conclusion of the course, the student has progressed very well for one semester of Freshman Engineering. The authors are thankful for the help given by Chin-Yu (Jenny) Lin in finalizing this workbook.

2. Process Design of a Wastewater Facility

In the process design of a wastewater facility, the important steps are:

1. Selection of the process for design
2. Development of the Material Balances for the Process
    a. Flow Rates
    b. Composition of Streams
3. Estimating the Size of Equipment Needed
    a. Size of each Unit
    b. Number of Units
4. Cost Estimates for the Process
    a. Overall Estimated Construction Cost
    b. Annual Operating and Maintenance Costs

2.1 Selection of the Process Design

Processes for wastewater treatment can be much too complex for students in the freshman year to comprehend. Hence, a simplified process is discussed which shows the essential aspects of the system, and which is more readily comprehended by the students. One such simplified process is shown in Figure 1. It entails

1. Screens
    - Remove large objects
2. Primary Sedimentation
    - Remove particulates by settling
3. Primary Vacuum Filter
    - For solids removal by filtration

4. Aeration System
    - Convert Biochemical Oxygen Demand (BOD), an indirect measure of organic material in the wastewater to sludge
5. Secondary Sedimentation
    - Remove sludge by settling
6. Secondary Vacuum Filter
    - Remove sludge by filtration

2.2 Development of Material Balances for the Process

Based upon design parameters which established:

1. Influent Flow Rate,
2. Influent Composition,
3. Maximum Tolerable Effluent Specification of the BOD_5 mg/L (the amount of oxygen consumed in by a sample incubated for 5 days at 20°C) and suspended solids (SS),

material balance calculations are made. Basic assumptions are made, where necessary, using literature recommendations. These material balance calculations are shown and are summarized in Table 1.

2.3 Estimation of the Size of Equipment Needed

Based upon the material balances, data and sizing recommendations in the literature, the number, size, and dimensions of each unit are determined. These data are shown and can be summarized. (See Section 3.4, Design of Process Units)

2.4 Cost Estimated for the Process

Literature correlations are used to estimate the process

1. Construction cost, and
2. Annual operation and maintenance cost.

Based upon the Engineering News Record Construction Cost Index, the effect of inflation is incorporated into the initial cost estimate using the data from the literature, and the current estimated cost is calculated.

2.5 The Problem

Design and Locate a Municipal Wastewater Facility that meets the following specifications:

Basis of Design:

Community	-	45000 households
Household	-	3 people each
Consumption	-	80 gallons/capita/day

Wastewater Treatment Facility Specifications (Composition)

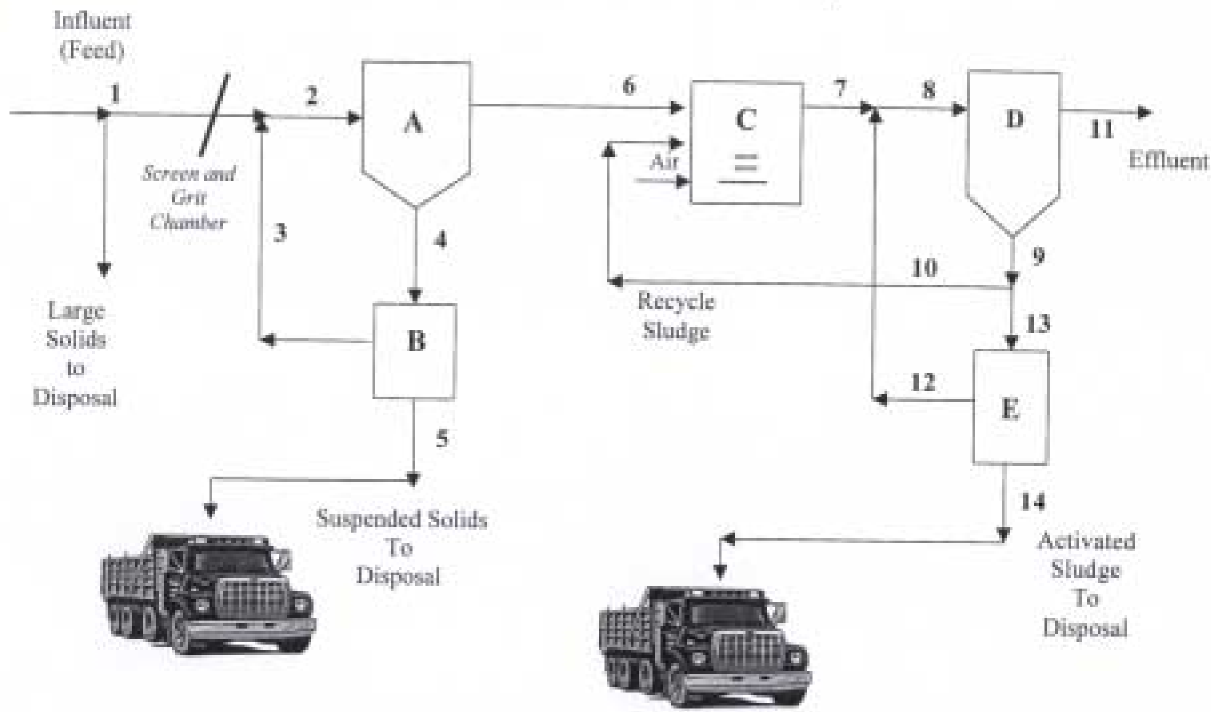
	Influent, mg/L	**Effluent, mg/L (MAX)**
BOD_5	250	30
Suspended Solids (SS)	250	30

2.6 The Simplified Process Flow Sheet

The simplified process flow sheet is shown in Figure 1. For the simple system neither the suspended solids or sludge separated in the vacuum filters is dried. Similarly the quantity of large objects is ignored and the analysis begins when these are removed.

Figure 1

Simplified Wastewate Treatment Facility



Unit A Primary Sedimentation
Unit B Vacuum Filter for Suspended Solids

Unit C Aerator
Unit D Secondary Sedimentation
Unit E Vacuum Filter for Sludge

2.7 The Solution of the Problem

The solution to the problem entails making material balances on the five units in the process. These are:

A. Primary Sedimentation Tank for Suspended Solids

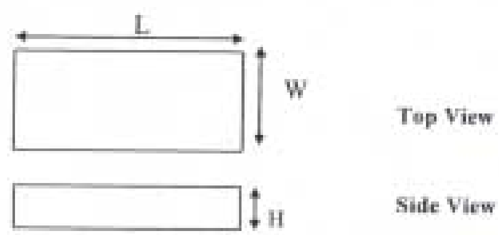
B. Vacuum Rotary Filter For Suspended Solids

C. Aerator (Activated Sludge Process)

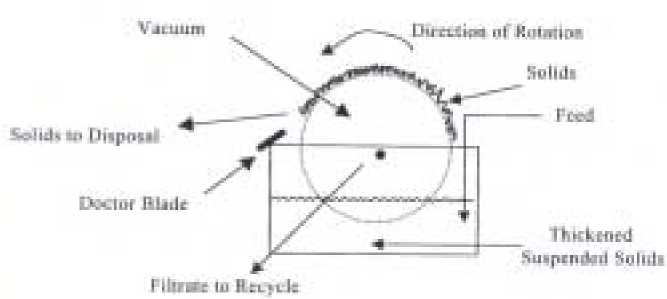
D. Secondary Sedimentation Tank For Sludge

E. Vacuum Rotary Filter For Sludge

Once the material balance and compositions are known, the units can be designed. The sedimentation tanks are rectangular with a large cross sectional area to reduce the flow rate and allow the solids to settle. In chemical engineering practice these units are called thickeners and can take other shapes (circular).



The Vacuum Rotary Filters remove the thickened solids from the system and recycle the filtrate. The principal of these units follows the simple filtration practice used in the chemistry laboratory.



Once the system has been designed costs estimates can be developed and costs can be made current to account for inflation using the Engineering News Record Construction Cost Index.

2.8 Material Balance

The material balance can simply be shown as in Figure 2 with the word equation. A material balance is the same as balancing your personal checking account. However, instead of counting money, we will count

- The Total Flow Rate in each stream per day, lb_m/d
- The BOD_5 Flow Rate in each stream per day, lb_m/d
- The Suspended Solids (SS) Flow Rate in each Stream per day, lb_m/d

We will work with compositions in mg/L and convert these for the equations into weight fraction. The weight fraction is simply the ratio of the flow rate of a component (BOD_5, SS, water) divided by the total stream flow rate. For example

$$\text{Weight Fraction of SS} = \frac{lb_m/d \;\; \text{SS in the Stream}}{lb_m/d \;\; \text{Total Flow of the Stream}}$$

Since there are only three components (BOD_5, SS, water), we can only have three independent equations. At steady state, these will generally be:

- Total Flow Rate in = Total Flow Rate Out
- Suspended Solids Flow Rate In = Suspended Solids Flow Rate Out
- BOD_5 Flow Rate In = BOD_5 Flow Rate Out

A water balance can also be made:

Water In = Water Out

However, this equation would not be independent. Once the total flow, BOD_5, and SS flow rates are known, water flow rates can be calculated as the difference since the

Total Flow Rate = Flow Rate of BOD_5

+ Flow Rate of SS

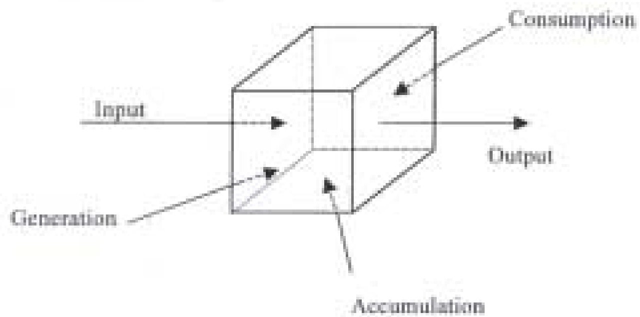
+ Flow Rate of Water

or Flow Rate of Water =

Total Flow Rate – Flow Rate of BOD_5 – Flow Rate of SS

Figure 2 shows the concept of the material balance.

Figure 2
The Concept of a Material Balance



INPUT + GENERATION – OUTPUT – CONSUMPTION = ACCUMULATION (+)
or
DEPLETION (-)

EXAMPLE:

Consider your checking account.

Deposit + Interest – Withdrawal – Bank fees = Accumulation (+)
or
Depletion (-)

Referring to Figure 2, for steady state operations, accumulation and depletion = 0, and when there is no chemical reaction (in the sedimentation and filtration units), generation and consumption = 0

Hence, for the sedimentation and filtration units (A, B, D, E)

Input = Output

For the Aeration Unit (C), reaction occurs, sludge is produced and hence

Input + Generation = Output

The analysis of the system is in two parts

- Primary Treatment (Units A and B)
- Secondary Treatment (Units C, D, and E)

These are shown on the attached flow sheets (Figures 3 and 4)

Figure 3

Material Balance Primary Treatment Process

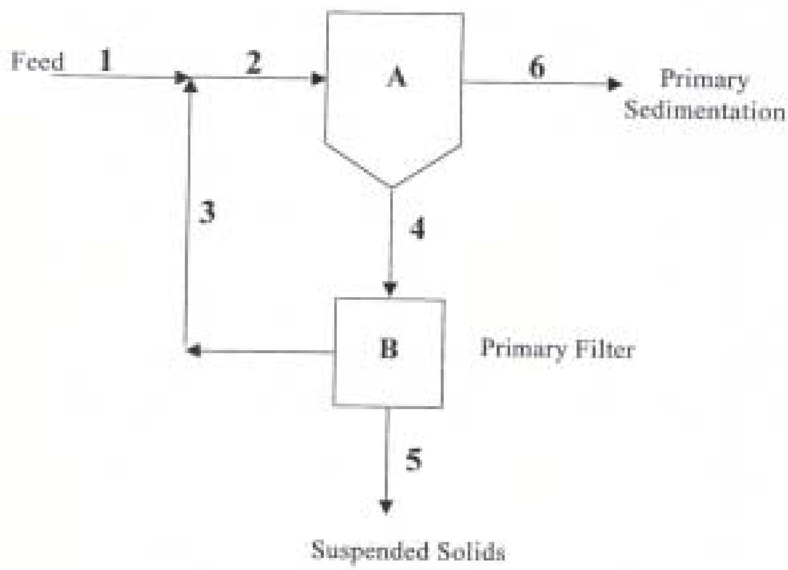
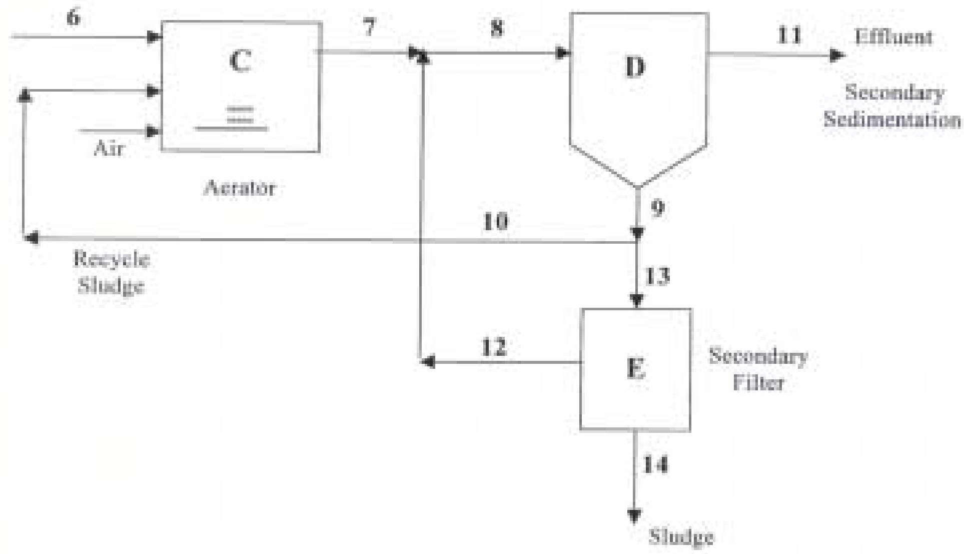


Figure 4

Material Balance
Secondary Treatment Process



2.9 Primary Treatment Analysis

In the primary treatment system material balances can be made as follows:

- Unit A
  Streams 2, 4, and 6
- Unit B
  Streams 3, 4, and 5
- The mixing Point (A Tee (a pipe fitting) in a pipeline)
  Streams 1, 2, and 3

In addition, an artificial boundary can be drawn around the entire primary treatment section and a material balance can be made involving streams 1, 5, and 6. (Figure 5)

Figure 5

Material Balance
Primary Treatment Process

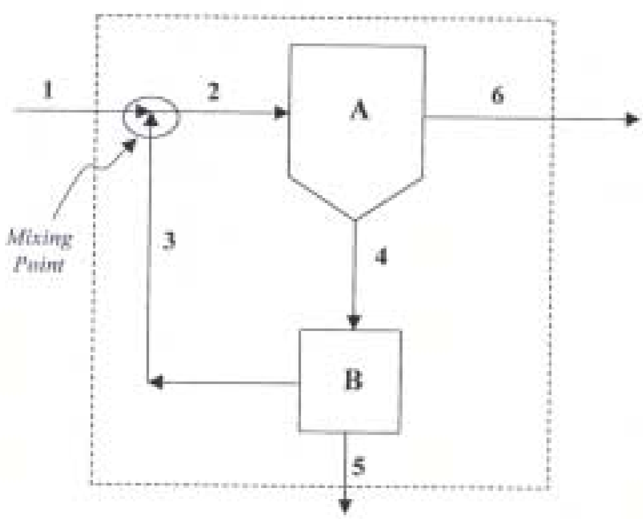


Table 1
Material Balance - Primary Treatment and Secondary Treatment

Worksheet

Stream	Total Flow Rate		COMPONENTS					
			BOD_5		SS		Water	
	GPD	lb/day	mg/L	lb/day	mg/L	lb/day	mg/L	lb/day
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								

3. Calculations

3.1 Primary Treatment Process Calculations

Stream 1

1. Calculate the total flow rate of Stream 1

			=	Gallons per day (GPM)

2. Convert this flow rate to pounds per day

		=	$\frac{lb_m}{d}$

3. Convert the concentration of BOD_5 and SS from mg/L to weight fraction

	1 L	1 g	=	$\frac{mg}{mg}$
	1000 g	1000 mg		

4. Calculate the flow rate of BOD_5 and SS in lb_m/d from the weight fractions

		=	$\frac{lb_m}{d}$

		=	$\frac{lb_m}{d}$

5. **Calculate the flow rate of the water in pounds per day**

Flow Rate of Water = Total Flow Rate – SS Flow Rate – BOD_5 Flow Rate

Flow Rate of Water = ___________ - ___________ - ___________

$$= \qquad \frac{lb_m}{d}$$

6. **Calculate the weight fraction of water**

$$\_\_\_\_\_\_\_\_\_\_ = \qquad \frac{\frac{lb_m}{d} \text{ of water stream 1}}{\frac{lb_m}{d} \text{ of total flow stream 1}} = \frac{lb_m}{lb_m} = \frac{mg}{mg}$$

7. **Convert the weight fraction of water to mg/L (Reverse step 3)**

$$\_\_\_\_\_\_\_\_ \Big| \_\_\_\_\_\_\_\_ \Big| \_\_\_\_\_\_\_\_ = \qquad \frac{mg}{L}$$

In order to proceed with the material balance, basic data are required on the Primary Filter (See Reference 1)

Basic Data:

__**Primary Sedimentation**__

See Sundstrom and Klei, Chapter 7, "Sedimentation Practice" p 209

- Removal Percentage of Suspended Solid _______ to _______

- Removal Percentage of BOD_5 _______ to _______
- Settled Solids Concentration, Per Cent _______ to _______

What is your decision?

- Removal Percentage of Suspended Solid _______
  Why did you make this decision?

- Removal Percentage of BOD_5 _______
  Why did you make this decision?

- Settled Solids Concentration, Percent _______
  Why did you make this decision?

Primary Filter

See Sundstrom and Klei, Chapter 8, "Vacuum Filtration Practice", p 233-234

Primary Sludge

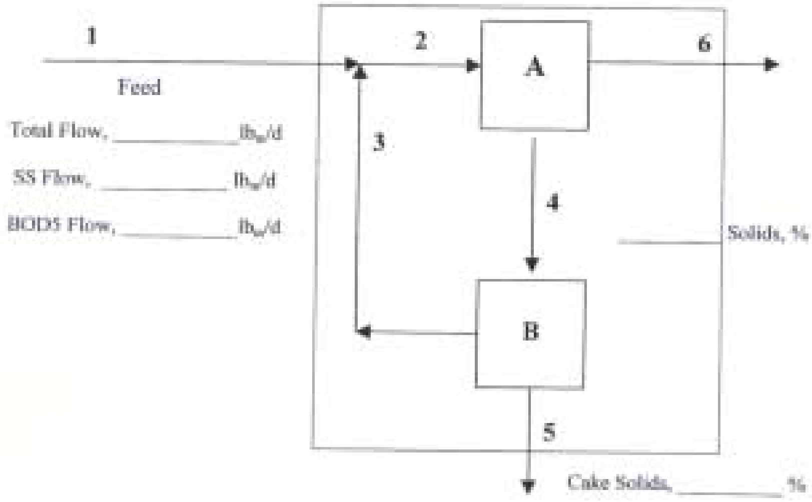
Percentage of Cake Solids _______ to _______

What is your decision? _________

Why did you make this decision?

You are now ready to perform the material balance on the primary treatment system.

Figure 6
Primary Treatment Process



What was your decision on Removal From the System?

SS = __________ %

BOD_5 = __________ %

Why did you make this decision?

3.1 Material Balance Calculations
Primary Treatment Process

1. Make a material balance around the artificial boundary in Figure 6.

This will include both units A and B. It will involve only streams 1, 5, and 6 which cross the artificial boundary. Streams 2, 3, and 4 are internal streams and do not cross this artificial boundary and hence do not have to be considered at this time.

Therefore,

a. Total Flow Rate Balance
Stream 1 = Stream 5 + Stream 6

b. Suspended Solids Flow Rate Balance
SS Stream 1 = SS Stream 5 + SS Stream 6

c. BOD_5 Flow Rate Balance
BOD_5 Stream 1 = BOD_5 Stream 5 + BOD_5 Stream 6

2. Basic Data

Suspended Solids Removal in Units A and B.

What was your decision on percentage removal? __________

3. Suspended solids are removed in Stream 5

Therefore

SS Stream 5 = SS Stream 1 | Fraction Removed

SS Stream 5 = ______ | ______ = lb_{ss}/d

What was your decision on percentage Cake Solids in Stream 5? ________

$$\text{Total Flow Stream 5} = \frac{\text{SS Stream 5}}{\text{Fraction of Cake}}$$

Total Flow Stream 5 = ____________ = lb_m/d

What was your decision on BOD_5 removal in this system? ____________ per cent

BOD_5 Stream 5 = BOD_5 Stream 1 | Fraction Removed

= ____________ | ____________ = lb_m/d

4. Stream 5 Water Balance

Total Stream 5 = BOD_5 Stream 5 + SS Stream 5 + Water Stream 5

Therefore,

Water Stream 5 = Total Stream 5 - BOD_5 Stream 5 - SS Stream 5

= ____________ - ____________ - ____________ = lb_m/d

5. Calculate the weight Fraction and hence, concentrations in Stream 5

Weight fraction BOD_5 = ____________ =

Concentration BOD_5, mg/L

____________ | ____________ | ____________ = $\frac{mg}{L}$

Hint: weight fraction has units of and is dimensionless

$$\frac{\frac{lb_m\ BOD_5\ \text{Flow Rate of}\ BOD_5}{d}}{\frac{lb_m\ \text{Total Flow Rate}}{d}} = \frac{lb_m\ BOD_5}{lb_m\ \text{total}} = \frac{mg}{mg}$$

Weight fraction SS = ______________ = $\frac{mg}{mg}$

Concentration SS, mg/L

= $\frac{mg}{L}$

Weight Fraction of Water = ______________ = $\frac{mg}{mg}$

Concentration of Water, mg/L

= $\frac{mg}{L}$

6. Knowing Stream 1 Flow Rate and Stream 5 Flow Rate Calculate Stream 6 Flow Rate

Total Stream 1 = Total Stream 5 + Total Stream 6

Total Stream 6 = Total Stream 1 - Total Stream 5

Total Stream 6 = __________ - __________ = $\frac{lb_m}{d}$

BOD_5 Stream 6 = BOD_5 Stream 1 – BOD_5 Stream 5

BOD_5 Stream 6 = __________ - __________ = $\frac{lb_m}{d}$

SS Stream 6 = SS Stream 1 – SS Stream 5

SS Stream 6 = ________ - ________ = $\frac{lb_m}{d}$

Water Steam 6 = Water Stream 1 – Water Stream 5

Water Stream 6 = ________ - ________ = $\frac{lb_m}{d}$

7. Calculate weight fractions and concentrations Stream 6

Weight Fraction BOD_5 = $\frac{\qquad}{\qquad}$ = $\frac{mg}{mg}$

Concentration BOD_5, mg/L

$\frac{\qquad}{\qquad}\Big|\frac{\qquad}{\qquad}\Big|\frac{\qquad}{\qquad}$ = $\frac{mg}{L}$

Weight Fraction SS = $\frac{\qquad}{\qquad}$ = $\frac{mg}{mg}$

Concentration SS, mg/L

$\frac{\qquad}{\qquad}\Big|\frac{\qquad}{\qquad}\Big|\frac{\qquad}{\qquad}$ = $\frac{mg}{L}$

Weight Fraction Water = $\frac{\qquad}{\qquad}$ = $\frac{mg}{mg}$

Concentration Water, mg/L

$\frac{\qquad}{\qquad}\Big|\frac{\qquad}{\qquad}\Big|\frac{\qquad}{\qquad}$ = $\frac{mg}{L}$

PRIMARY FILTER

Once Streams 1, 5, and 6 have been completely defined, we can make material balances around each unit.

Balance around Unit B, the Primary Filter

What was your decision about the settled solids in Unit A, the primary sedimentation tank? __________ %

What can you assume is the solids content of Stream 3, the filtrate from the filter? __________ %

(Hint: In Chemistry Laboratory when you performed filtration, what was the nature of the Filtrate?)

Why did you make this decision?

Therefore, SS Flow Rate Stream 3 = ____________ $\frac{lb_m}{d}$

1. SS Flow Rate Balance

SS Flow Rate Stream 4 = SS Flow Rate Stream 3 + SS Flow Rate Stream 5

SS Flow Rate Stream 4 = ____________ + ____________ = $\frac{lb_m}{d}$

$$\text{Total Flow Rate Stream 4} = \frac{\text{SS Flow Rate Stream 4}}{\text{Fraction Settled Solids}}$$

= ______________

= $\frac{lb_m}{d}$

2. Calculate the weight fraction of suspended solids in Stream 4

= ______________ = $\frac{mg}{mg}$

3. Calculate the concentration of suspended solids in Stream 4

= $\frac{mg}{L}$

4. Calculate the Total Flow Rate of Stream 3

Total Flow Rate Stream 4 = Total Flow Rate Stream 3
+ Total Flow Rate Stream 5

Total Flow Rate Stream 3 = Total Flow Rate Stream 4 – Total Flow Rate 5

Total Flow Rate Stream 3 = __________ - __________ = $\frac{lb_m}{d}$

What is the ratio of the Flow Rate Stream 3 to the Flow Rate Stream 1 ?

______________ =

5. Calculate the Total Flow Rate of Stream 2

Total Flow Rate Stream 1+ Total Flow Rate Stream 3 = Total Flow Rate Stream 2

Total Flow Rate Stream 2 = __________ + __________ = $\frac{lb_m}{d}$

6. Calculate Suspended Solids Flow Rate in Stream 2

SS Flow Rate Stream 2 = SS Flow Rate Stream 1 + SS Flow Rate Stream 3

= __________ + __________ = $\frac{lb_m}{d}$

7. Calculate the weight Fraction of Suspended Solids in Stream 2

= ____________

= $\frac{mg}{mg}$

8. Calculate the concentration of suspended solids in Stream 2

= $\frac{mg}{L}$

Since Stream 3 is much smaller than Stream 1, assume a minimal BOD_5 in Stream 3. What is a good estimate? ____________ $\frac{mg}{L}$

9. Calculate the weight fraction BOD_5 in Stream 3

= $\frac{mg}{mg}$

10. Calculate the BOD_5 Flow Rate in Stream 3

= $\frac{lb_m}{d}$

11. Calculate the BOD_5 Flow Rate in Stream 4

BOD_5 Flow Stream 4 = BOD_5 Stream 3 + BOD_5 Stream 5

= ____________ + ____________ = $\frac{lb_m}{d}$

12. Calculate the BOD_5 Flow Rate in Stream 2

BOD_5 Flow Stream 2 = BOD_5 Stream 1 + BOD_5 Stream 3

= ____________ + ____________ = $\frac{lb_m}{d}$

13. Calculate the weight fraction BOD_5 Stream 2 = __________ = $\frac{mg}{mg}$

14. Calculate the concentration of BOD_5 in Stream 2

____|____|____ = $\frac{mg}{L}$

15. Calculate the BOD_5 weight fraction in Stream 4 = ______________

= $\frac{mg}{mg}$

16. Calculate the BOD_5 concentration in Stream 4

____|____|____ = $\frac{mg}{L}$

17. Calculate the Water Flow Rate Stream 4

Water Stream 4 = Total Stream 4 − BOD_5 Stream 4 − SS Stream 4

= ____________ - ____________ - ____________

= $\frac{lb_m}{d}$

18.Calculate the weight fraction water Stream 4

= ____________ = $\frac{mg}{mg}$

19.Calculate the concentration water in Stream 4

= $\frac{mg}{L}$

20.Calculate the Water Flow Rate Stream 3

Water Flow Stream 3 = Total Flow Stream 3 – BOD_5 Flow Stream 3

– SS Flow Stream 3

= ________ - ________ - ________ = $\frac{lb_m}{d}$

21.Calculate the weight fraction water in Stream 3 = ____________ = $\frac{mg}{mg}$

22.Calculate the concentration of water in Stream 3

= $\frac{mg}{L}$

23.Calculate the Water Flow Rate in Stream 2

Water Flow Rate Stream 2 = Total Flow Rate Stream 2

- BOD_5 Flow Rate Stream 2

- SS Flow Rate Stream 2

= ________ - ________ - ________ = $\frac{lb_m}{d}$

24.Calculate the Weight Fraction of Water in Stream 2

$$= \frac{\qquad}{\qquad} = \qquad \frac{mg}{mg}$$

25.Calculate the concentration of water in Stream 2, mg/L.

$$\frac{\quad}{\quad}\Big|\frac{\quad}{\quad}\Big|\frac{\quad}{\quad} = \qquad \frac{mg}{L}$$

3.2 Secondary Treatment Process Aerator Analysis

The secondary treatment process takes the effluent from the primary treatment process and converts the complex molecules in the wastewater stream with the aid of microorganisms to biomass and gases. The secondary treatment process consists of two steps. These are:

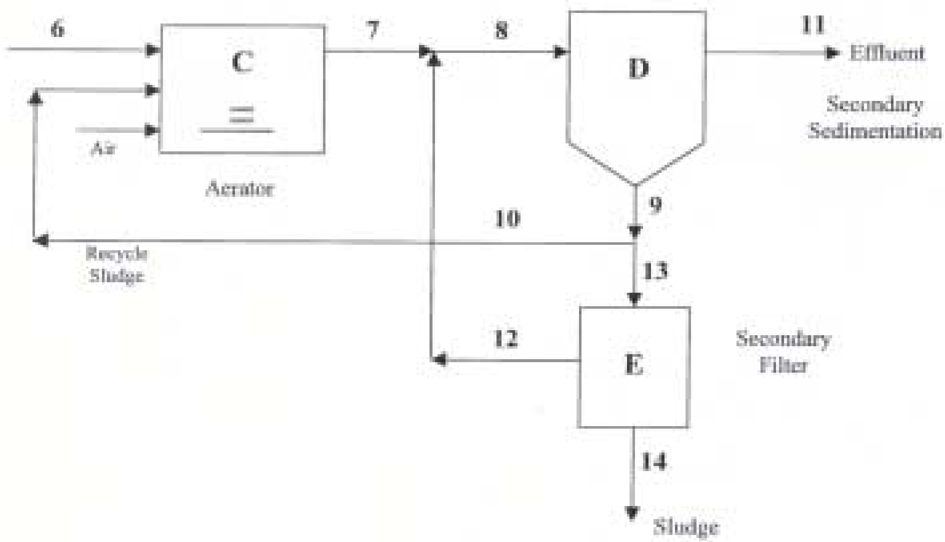
- The aerator
- Secondary sedimentation and Filtration

With the aid of microorganisms and air (O_2), the aerator is a biochemical reactor that converts the BOD_5 to biomass, thus reducing the BOD_5 concentration in the effluent in preparation for discharge back into nature's systems. The biomass is removed by secondary sedimentation and filtration and sold as a fertilizer. A part of the settled biomass from the secondary sedimentation tank is recycled to the aerator to provide the microorganisms to digest the BOD_5 in the wastewater.

In this analysis we will concentrate on one type of aerator only, called the conventional activated sludge process (Sundstrom and Klei, page 154. The design process is outlined on pages 164-165, and an example problem is shown on pages 166-168).

The secondary treatment process is shown in Figure 7.

Figure 7
Secondary Treatment Process



Aerator Analysis

The Conventional Activated Sludge Process Reactor with Recycle and Complete Mixing

Problem: Design the reactor, which will reduce the BOD_5 in Stream 6 to less than 30 mg/L.

1. Calculation of the outlet BOD_5 from the aerator (Stream 7)

For complete mixing with recycle, activated sludge process, Sundstrom and Klei give key equations in Table1, page 144.

Effluent waste concentration calculation:

$$S = \frac{K_m(1 + k_d\theta_c)}{\theta_c(k_o - k_d) - 1}$$

Where S = outlet BOD_5 concentration, mg/L (Stream 7)

θ_c = sludge age, hours. The sludge age is the sludge retention time in the reactor. How long does the sludge reside in the reactor? Sludge age should be between 3 and 14 days (Sundstrom and Klei, p 146)

K_m, k_d, k_o are kinetic coefficients. These are given in Sundstrom and Klei, Table 6-2, p 146 for Domestic wastewater composition based on BOD_5.

Calculation:

$$S = \frac{K_m(1 + k_d\theta_c)}{\theta_c(k_o - k_d) - 1}$$

Table 6-2, p 146, Sundstrom and Klei and Example Problem 6-1, p 166

K_m = __________ to __________ , mg/L

What is your decision? __________, mg/L

Why did you make this decision?

k_d = __________ to __________ , h^{-1}

What is your decision? __________, h^{-1}

Why did you make this decision?

k_e = __________ to __________ , h^{-1}

What is your decision? __________, h^{-1}

Why did you make this decision?

θ_c = __________ to __________ , days

What is your decision? __________, days

Why did you make this decision?

θ_c = ________ days | ________ = h

Therefore, $S = \dfrac{K_m \;\Big|\; (1 + k_d\,\theta_c) \;\Big|}{\;\Big|\; \;\Big|\; \theta_c\,(k_0 - k_d) - 1}$

$S = \dfrac{\text{mg}}{\text{L}} \;\Big|\; \dfrac{\quad}{\quad} \;\Big|\; \dfrac{\quad}{\quad}$

$S = \dfrac{\quad}{\quad} \;\Big|\; \dfrac{\quad}{\quad} \;\Big|\; \dfrac{\quad}{\quad}$

S = ________ mg/L BOD_5 in Stream 7.

Does this concentration meet the requirement of the specification of BOD_5 in the effluent?

2. Calculation of Reactor Volume Needed.

For the conventional process the hydraulic residence time is the number of hours the entire hydraulic stream (liquid and solids) resides in the reactor. With no recycle, it is defined as

$$\text{Hydraulic Residence Time} = \frac{\text{Volume of Reactor}}{\text{Total Flow Rate}}$$

$$\theta_h = \frac{V_r}{Q}$$

where θ_h = hydraulic residence time, h

V_r = reactor volume, m^3

Q = volumetric total flow rate, m^3/h

For recycle, however,

$$\theta = \theta_h = \frac{V_r}{\text{Volumetric Feed Rate (Stream 6)} + \text{Recycle (Stream 10)}}$$

However, it is desired to make θ_h as large as possible to provide for a bigger reactor to take care of unforeseen peak flow rates. Hence, conservatively,

$$\theta = \theta_h = \frac{V_r}{Q} \quad \text{can be used}$$

Key design data are provided by Sundstrom and Klei, Table 6-3, p 155 for the conventional/completely mixed system.

What is the range as residence time, θ in hours? ________ to ________ h

What is your decision? __________ h

Why did you make this decision?

Calculate the volume of the feed stream 6 (total flow) in m^3/h

$$Q = \frac{\quad\ \text{lb}}{\quad\ \text{d}} \Bigg| \quad \Bigg| \quad \Bigg| \quad \Bigg| \quad$$

$$Q = \qquad \frac{m^3}{h}$$

Calculate the volume of reactor needed

$$V_r = Q\theta$$

$$V_r = \frac{\quad}{\quad} \Bigg| \frac{\quad}{\quad} = \qquad m^3$$

3. Calculation of Solids Recycle Concentration. (Solids in Stream 10)

Sundstrom and Klei select Solids Recycle Concentration at 8,000 mg/L and then calculate the recycle ratio. Another approach is to calculate this number by first selecting a recycle ratio. Sundstrom and Klei, p 167, show

$$R = \frac{1-\left(\theta/\theta_c\right)}{\frac{X_r}{X}-1}$$

For this problem, both X and X_r can be approximated by the total solids concentration. Hence,

X = total solids concentration in reactor, mg/L

X_r = total solids concentration in the recycle stream (stream 10), mg/L

θ = residence time (hydraulic), h

θ_c = sludge age, h

If we choose to select the recycle ratio and calculate X_r, then

$$R = \frac{1-\theta/\theta_c}{\frac{X_r}{X}-1}$$

$$R\left(\frac{X_r}{X}-1\right) = 1-\frac{\theta}{\theta_c}$$

$$\frac{X_r}{X}-1 = \frac{1-\frac{\theta}{\theta_c}}{R}$$

$$\frac{X_r}{X} = 1 + \left[\frac{1 - \frac{\theta}{\theta_c}}{R}\right]$$

$$X_r = X\left[1 + \left(\frac{1 - \frac{\theta}{\theta_c}}{R}\right)\right]$$

In order to calculate X_r, we need to know

X = total concentration of solids in the reactor, mg/L

R = recycle ratio (Table 6-3, Sundstrom and Klei)

θ = hydraulic residence time, h

θ_c = sludge age, h

What is the range in recycle ratio for this process?

Sundstrom and Klei, Table 6-3, p 155

R = ________ to ________

What is your decision? ________

Why did you make this decision?

What was your decision for θ? ________ h

What was your decision for θ_c? ________ h

The concentration of solids in the reactor must first be calculated (See Table 6-1, p 144 Sundstrom and Klei):

$$X = \left[\frac{Y(S^0 - S)}{1 + k_d\theta_c}\right]\left[\frac{\theta_c}{\theta}\right]$$

where

X = total concentration of solids in the reactor, mg/L

S^0 = BOD_5 concentration in feed to reactor (Stream 6), mg/L

S = BOD_5 concentration in effluent stream from reactor (Stream 7), mg/L

Y = biomass synthesis constant and is the ratio of the units of microorganisms produced to the units of BOD_5 removed from the wastewater, mg/mg (Table 6-2, Sundstrom and Klei, p 146)

θ = hydraulic residence time, h

θ_c = sludge age

k_d = kinetic constant, h^{-1} (Tale 6-2, Sundstrom and Klei, p146)

What was your choice for θ? __________ h

What was your choice for θ_c? __________ h

What was your choice for k_d? __________ h^{-1}

What is the value of the BOD_5 in the reactor feed, S^0 (Stream 6)?

__________ mg/L

What did you calculate for the BOD_5 in the reactor effluent (Stream 7), S?

__________ mg/L

What is the range in values for Y (Sundstrom and Klei, Table 6-2, p146)?

__________ to __________ mg/mg

What is your decision? __________ mg/mg

Why did you make this decision?

Calculate:

$$X = \left[\frac{Y\left(S^{0} - S\right)}{1 + k_d\theta_c}\right]\left[\frac{\theta_c}{\theta}\right]$$

X = ______ | ______ | ______ | ______

X = mg/L

Now calculate X_r, the solids in the recycle stream (stream 10)

$$X_r = X\left[1 + \left(\frac{1 - \theta/\theta_c}{R}\right)\right]$$

$$X_r = \frac{\qquad \big| \qquad}{\qquad \big| \qquad}\left[1 + \left(\frac{1 - \frac{\quad}{\quad}}{\qquad}\right)\right] = \qquad \text{mg/L}$$

4. Calculate the total Flow Rate of Stream 10.

Stream 10 = Recycle Ratio times Stream 6

What was your choice of Recycle Ratio? __________

Stream 10 = ________ x Stream 6 = ______ | ______

Stream 10 = *lb/d*

5. Calculations for Stream 7.

Stream 7 = Stream 6 + Stream 10

= __________ + __________ = lb/d

If X = the solids concentration in the reactor, it is also the solid concentration in Stream 7 for a well mixed aerator.

Therefore, solids concentration in Stream 7 = $\frac{mg}{L}$

	mg	1 L	1 g
Weight Fraction X =	L	1,000 g	1,000 mg

= $\frac{mg}{mg}$

Flow of Solids in Stream 7

Solids Stream 7 = Weight Fraction x Total Flow Stream 7

= ___________ x ___________

= lb/d

BOD_5 in Stream 7 = $\frac{mg}{L}$. The value of S calculated previously.

	mg	1 L	1 g
Weight Fraction BOD_5 =	L	1,000 g	1,000 mg

= $\frac{mg}{mg}$

Flow Rate of BOD_5 in Stream 7 = Weight Fraction x Total Flow Stream 7

= _________ x ________ = lb/d

Total Flow Rate of Water in Stream 7 = Total Flow of Stream 7 – Total Flow of Solids in Stream 7 – Total Flow of BOD_5 in Stream 7

Total Flow Rate of Water in Stream 7 = ________ - ________ - _________

= __________ lb_w/d

$$\text{Weight Fraction Water of in Stream 7} = \frac{\text{Total Flow of Water in Stream 7}}{\text{Total Flow Rate in Stream 7}} = \_\_\_\_\_\_\_\_\_\_ =$$

Concentration of water in Stream 7

= Weight Fraction	1,000 mg	1,000 g
	1 g	1 L

=			=	$\frac{mg}{L}$

6. Calculations for Stream 10

$$X_r = \text{solids in Stream 10}, \frac{\text{mg}}{\text{L}} = \qquad \frac{\text{mg}}{\text{L}}$$

Weight Fraction of Solids in Stream 10 =

=	1 L	1 g	=	$\frac{mg}{mg}$
	1,000 g	1,000 mg		

Solids flow in Stream 10 = Weight Fraction x Total Flow Stream 10

= __________ x __________ = *lb/d*

7. **Calculation of Washout Residence Time.**

If the total volumetric flow rate, Q, (Stream 6) is high, there is the possibility that this high influent rate to the aerator will totally wash out the solids in the reactor, X, which provide the microorganisms in the system. Hence, the aerator cannot function. This condition must be avoided. Washout will not occur (desirable) if θ, the hydraulic residence time is greater than θ_w, the critical washout residence time. Hence,

$$\theta > \theta_w$$

The washout residence time, θ_w is calculated from the equation

$$\theta_w = \frac{(K_m + S^0)(1 + R - \beta R)}{(S^0(k_0 - k_d) - k_d K_m)}$$

K_m, k_0, k_d are the kinetic constants you chose from Table 6-2, p146 Sundstrom and Klei

R = recycle ratio you chose from Table 6-3, p155, Sundstrom and Klei

S^0 and S are the aerator influent (Stream 6) and effluent (Stream 7), BOD_5 concentrations, mg/L and $\beta = \dfrac{X_r}{X}$

Calculate θ_w

What was your decision for K_m? ___________ mg/L

What was your decision for k_0? ___________ h-1

What was your decision for k_d? ___________ h-1

What was S^0, the influent BOD_5 concentration for the reactor (Stream 6)? __________ mg/L

What was S, the effluent BOD_5 concentration for the reactor (Stream 7)? __________ mg/L

What was X, the solids concentration in the reactor? __________ mg/L

What was X_r, the solids concentration in the recycle Stream (Stream 10)? __________ mg/L

What is $\beta = \frac{X_r}{X}$? $\beta =$ ________ –

What was your choice of R? R = ____________

Calculate θ_w:

θ_w = ( ) | ____________________

θ_w = ________ | ________ | ________

θ_w = h

Is $\theta > \theta_w$? ___________

Will washout occur with your design? ___________

8. Calculation of the Solids Generation Rate

The solids produced by the microorganisms are required to complete the material balance for the secondary treatment process. The solids produced can be calculated from

$$P_t = \frac{V_r X}{\theta_c}$$

where P_t = solids produced in the aerator, kg/d

X = total solids concentration in the aerator, kg/m^3

θ_c = sludge age, days

V_r = volume of reactor, m^3

Calculation

What was your sludge age, θ_c ? __________ days

Convert X from $\frac{mg}{L}$ to $\frac{Kg}{m^3}$

$$X = \frac{\quad mg}{\quad L} \Big| \quad \Big| \quad \Big| \quad = \quad \frac{kg}{m^3}$$

What was the volume of the reactor, V_r, required? m^3

Calculate the Production Rate of Sludge

$$P_t = \frac{\quad m^3}{} \Big| \frac{kg}{m^3} \Big| \frac{}{d} = \quad \frac{kg}{d}$$

Convert to $\frac{lb_m}{d}$

$$P_t = \frac{\quad kg}{\quad d} \Big| \quad = \quad \frac{lb_m}{d}$$

9. **Calculation of Oxygen and Air Requirements for Microorganisms to Grow.**

Sundstrom and Klei (p 153, Equations 6-19) give the following equations

$$\frac{\text{Oxygen Demand}}{\text{Volume, Time}} = \frac{\text{mass } O_2}{\text{volume, time}} = \frac{S^0 - S}{\theta}(1 - aY) + 0.9ak_d X$$

$$\frac{\text{Oxygen Demand}}{\text{volume,time}} = \frac{\text{mass } O_2 \text{ required}}{\text{volume,time}} = \frac{\text{mg } O_2 \text{ required}}{\text{Liter,hr}}$$

S^0 = influent BOD_5 concentration (Stream 6), mg/L

S = effluent BOD_5 concentration (Stream 7), mg/L

θ = hydraulic residence time, h

Y = biomass synthesis constant and is the ratio of units of microorganisms produced to the units of BOD_5 removed from the wastewater. (Table 6-2, Sundstrom and Klei, p 146), mg/L

a = constant and can be taken at 1.44 $\frac{\text{mg } BOD_5}{\text{mgsolids}}$

k_d = kinetic constant, h^{-1}
(Sundstrom and Klei, Table 6-2, p146)

Hence,

$$\frac{\text{Oxygen Demand}}{\text{volume, time}} = \frac{S^0 - S}{\theta}(1 - aY) + 0.9ak_d X$$

$$\frac{\text{mg } O_2 \text{ required}}{\text{Liter,hr}} = \frac{S^0 - S}{\theta}(1 - aY) + 0.9ak_d X$$

What was the value of S^o, in the influent?

(BOD_5 to the aerator (Stream 6)) ________ $^{mg}/_{L}$

What was the value of S, in the effluent?

BOD_5 from the aerator (Stream 7) ________ $^{mg}/_{L}$

What is the value of Y? ________ $^{mg}/_{mg}$

What is the value of a ?

(Sundstrom and Klei, p 153) ________ $^{mgBOD}/_{mgSolid}$

What was your decision for k_d?
(Sundstrom and Klei, Table 6-2, p146) ________ h^{-1}

What was your calculated value of X, the solids
concentration in the reactor? ________ mg/L

What was your decision for the hydraulic residence time, θ ? ______h

Calculate the Oxygen Demand:

$$\frac{\text{Oxygen Demand}}{\text{Volume, Time}} = \frac{(\qquad)}{} \Big| \qquad \Big| \qquad$$

$$+ \qquad \Big| \qquad \Big| \qquad \Big| \qquad$$

$$= \underline{\qquad\qquad} + \underline{\qquad\qquad} = \qquad\qquad \frac{mg}{L, h}$$

What is your required reactor volume,

V_r, ____________ m^3 or ____________ L

$$\left(\frac{\text{Oxygen Demand}}{\text{Volume} \cdot \text{Time}}\right)(\text{Volume of Reactor}) \qquad = \qquad\qquad \frac{mg}{h}$$

$$\left(\frac{mg}{L\ ,\ h}\right)(L\ \ ) = \qquad\qquad \frac{mg}{h}$$

$$= \frac{\qquad \text{mg}}{\qquad \text{L} \cdot \text{h}} \Big| \qquad = \qquad\qquad \frac{mg}{h}$$

Convert $\frac{mg}{h}$ to $\frac{g \cdot mols}{d}$

$$\text{n} = \text{Oxygen Demand} \quad = \frac{\qquad \text{mg}}{\qquad \text{h}} \Big| \qquad \Big| \qquad \Big| \qquad$$

$$\text{n} = \underline{\qquad\qquad} \frac{g \cdot mols}{d}$$

Now use the ideal gas law to convert $\frac{g \cdot mols}{d}$ to $\frac{L}{d}$ at Standard Conditions of Temperature and Pressure

$$PV = nRT$$

Standard Conditions P = 1 atm

T = 0 ° C = 273.15 °K

R = 0.08206 $\frac{L \cdot atm}{gmol \cdot K}$

$$V = \frac{nRT}{P}$$

gmol	atm-L	K	
d	gmol-K		atm

V = ______________ Standard Liters per Day, L/d at standard conditions

Now convert to Standard Cubic Feet per Day (SCFD of O_2)

V = ______ L/d | ______ = ____________ SCFD of O_2

Now convert to SCFD of air since Air contains 21 mol per cent O_2 (For an ideal gas, mol per cent equals volume percent)

V = ______ | ______ = SCFD of Air

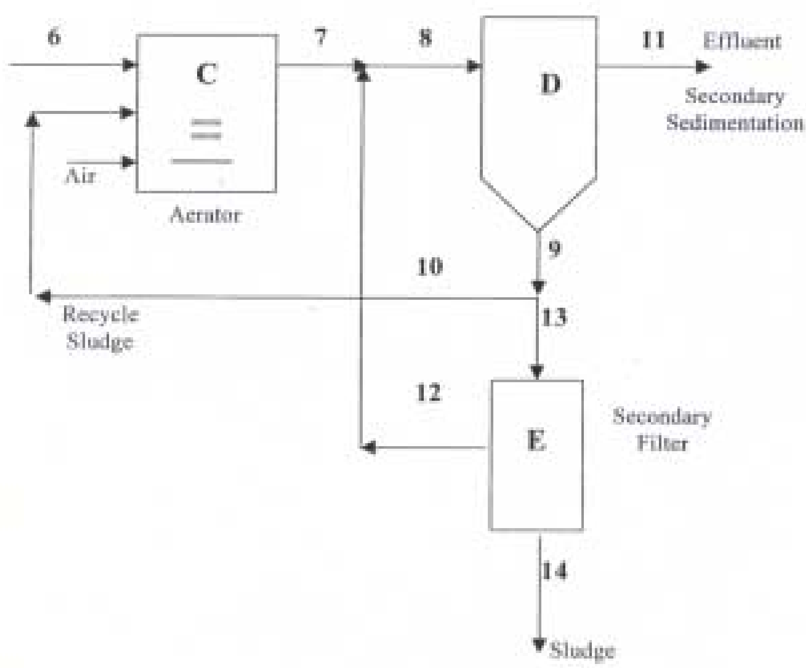
3.3 Secondary Treatment Process Calculations

The Secondary Treatment Process
Secondary Sedimentation and Filtration

This part of the process removes the sludge formed in the aerator from the BOD_5 in the wastewater, and recycles a portion of this sludge to the reactor to provide the microbes needed for reaction in the aerator. The water effluent reduced in BOD_5 is discharged back into nature, and the sludge is removed as cake from the secondary filter and sold as fertilizer.

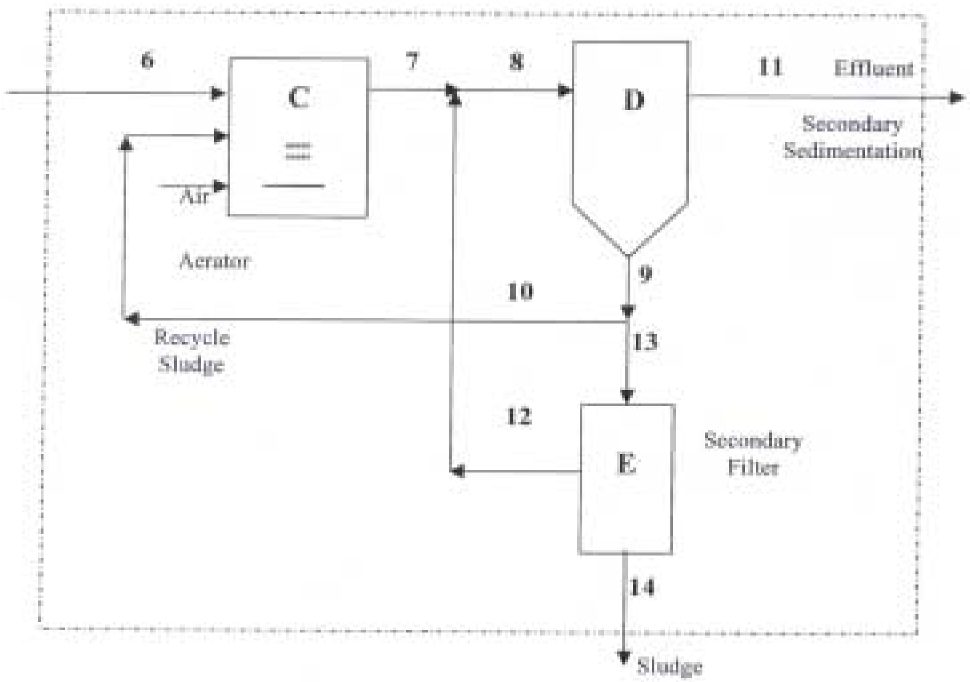
The Secondary Treatment Process is:

Figure 8
Secondary Treatment Process



The Secondary Treatment Process is:

Figure 9
Secondary Treatment Process



Material Balance Calculations
Secondary Treatment Process

1. Overall Units C, D, E (Figure 9)

Stream 6 = Stream 11+Stream 14

Overall Process Material Balance - Total Flow Rates

Let X = Total Flow Rate Stream 11, $^{lb}/_{d}$

Y = Total Flow rate Stream 14, $^{lb}/_{d}$

Therefore,

Total Flow Rate Stream 6 = X + Y

________________ = X + Y

2. Suspended Solids Balance

SS Stream 6 + Solids Produced in Aerator

= SS Stream 11 + SS Stream 14

How much solids were produced in the aerator? ____________ $^{lb}/_{d}$

Sundstrom and Klei, p 234 give the cake solids content from a filter for the activated sludge process

What is the cake solids content? _______ to _______ %

What is your decision? __________ %

Why did you make this decision?

What is the flow of suspended solids in Stream 14?

Total Flow Rate of Stream 14 x Fraction Cake Solids

Y x _______ = $^{lb}/_{d}$

What is the suspended solids in Stream 6? __________ $^{lb}/_{d}$

What is the suspended solids content of Stream 11?

What is the maximum suspended solids specification in Stream 11?

__________ $\frac{mg}{L}$

What would be the minimum? ___________ $\frac{mg}{L}$

What is your decision? ____________ $\frac{mg}{L}$

Why did you make this decision?

What is the weight fraction of suspended solids in Stream 11?

$$\frac{\quad\quad \text{mg}}{\text{L}} \left| \frac{\text{L}}{1000\text{ g}} \right| \frac{1\text{ g}}{1000\text{ mg}} = \qquad \text{Wt. Fraction, } \frac{mg}{mg}$$

What is the suspended solids flow in Stream 11?

Stream 11 x Weight Fraction

__X__ x ____________ =

Hence, the two equations are:

Total Flow Rate Stream 6 = X + Y = lb_m/d

SS Stream 6 + Suspended Solid Produced =

SS Stream 11 + SS Stream 14

________ + ________ = ________ + _________

Two equations, two unknowns

X = __________ $^{lb}/_{d}$ = Total Flow Rate of Stream 11

Y = __________ $^{lb}/_{d}$ = Total Flow Rate of Stream 14

SS Stream 11 = _________ x ____________ = $^{lb}/_{d}$

SS Stream 14 = _________ x ____________ = $^{lb}/_{d}$

Concentrations of SS Stream 11

$\frac{\text{SS Stream 11}}{\text{Total Flow Stream 11}}$ = weight fraction = _____________ = $\frac{mg}{mg}$

What is the concentration of suspended solids in Stream 11?

$$\frac{\_\_\_\_\_\_\ mg}{mg} \left| \frac{1000\ mg}{1\ g} \right| \frac{1000\ g}{1L} = \_\_\_\_\_\_\_\_\_\_\ \frac{mg}{L}$$

What is the Weight Fraction of SS Stream 14 =

$\frac{\text{SS Stream 14}}{\text{Total Flow Stream 14}}$ = weight fraction = _____________ = $\frac{mg}{mg}$

Concentration of SS in Stream 14 =

$$\frac{\_\_\_\_\_\_\ mg}{mg} \left| \frac{1000\ mg}{1\ g} \right| \frac{1000\ g}{1L} = \_\_\_\_\_\_\_\_\_\_\ \frac{mg}{L}$$

3. BOD_5 Balance

What is the BOD_5 flow Stream 7? __________ $^{lb}/_{d}$

Hence, what is an acceptable assumption for BOD_5 flow rate in Stream 11?

______________ $\frac{lb}{d}$

Therefore, what is a good assumption for BOD_5 flow rates, $\frac{lb}{d}$, and concentrations, $\frac{mg}{L}$

Stream 9 __________

Stream 10 __________

Stream 12 __________

Stream 13 __________

Stream 14 __________

What is the weight fraction of BOD_5 in Stream 11?

$$\frac{\text{Total Flow Rate of BOD}_5\text{ in Stream 11}}{\text{Total Flow Rate of Stream 11}} = \underline{\hspace{4cm}} = \qquad \frac{mg}{mg}$$

What is the concentration of BOD_5 in Stream 11?

Weight fraction	1000 mg	1000 g	=	$^{mg}/_{L}$
	1 g	1L		

What is the Total Water Flow Rate in Stream 11?

Total Water Flow Rate in Stream 11 = Total Flow Rate in Steam 11

– Total BOD_5 Flow Rate in Stream 11

– Total Suspended Solids Flow Rate in Stream 11

= __________ - __________ - __________ = $\frac{lb}{d}$

What is the weight Fraction of Water in Stream 11?

$$\frac{\text{Total Water Flow Rate in Stream 11}}{\text{Total Flow Rate of Stream 11}} = \_\_\_\_\_\_\_\_\_\_ = \qquad \frac{mg}{mg}$$

What is the concentration of water in Stream 11?

	mg	1000 mg	1000 g
	mg	1 g	1L

= $\frac{mg}{L}$

4. Balance around Unit E

Stream 13 = Stream 12 + Stream 14

SS Balance

SS Stream 13 = SS Stream 12 + SS Stream 14

What is a good assumption for SS in Stream 12? __________ $\frac{mg}{L}$

SS Stream 13 = ________ + ________ = $\frac{lb}{d}$

What is the concentration of solids in the recycle Stream 10 going to the aerator? (From aerator calculation) ________ $\frac{mg}{L}$

Therefore, what is the concentration of solids in

Stream 9 ________ mg/L

Stream 13 ________ mg/L

What is the solids weight fraction in Stream 13?

$$\frac{mg}{L}\left|\frac{L}{1000\ g}\right|\frac{1\ g}{1000\ mg} = \_\_\_\_\_\_\_\_ \text{ wt fraction, } \frac{mg}{mg}$$

What is the total Flow Stream 13

$$\frac{\text{SS Stream 13}}{\text{Wt Fraction}} = \_\_\_\_\_\_\_\_ = \_\_\_\_\_\_\_\_ \ lb/d$$

What is the water flow Stream 13?

Water Flow Rate Stream 13 = Total Flow Rate Stream 13

− Total Flow Rate BOD_5 in Stream 13

− Total Flow Rate Suspended Solids in Stream 13

Total Water Flow Rate Stream 13 = ________ - ________ - ________

= ________ lb/d

What is the weight Fraction Water Stream 13?

$$\frac{\text{Water Flow Rate Steam 13}}{\text{Total Flow Rate Steam 13}} = \_\_\_\_\_\_\_\_\_\_\_\_ = \qquad \frac{mg}{mg}$$

What is the concentration water stream 13?

$$\frac{\_\_\_\_\_\_\_\_\ mg}{mg} \cdot \frac{1000\ mg}{1\ g} \cdot \frac{1000\ g}{1L} = \qquad \frac{mg}{L}$$

What is the total flow rate Stream 12?

Total Flow Rate Steam 12 = Total Flow Rate Stream 13

-Total Flow Rate Stream 14

= ____________ - ____________ = $lb/_d$

What is the Total Water Flow Rate of Stream 12?

Total Water Flow Rate Stream 12 = Total Flow Rate Steam 12

- Total Suspended Solids Flow Rate Stream 12
- Total BOD_5 Flow Rate Steam 12

= ____________ - ____________ - ____________ = __________ $lb/_d$

What is the weight fraction water in Stream 12?

$$\frac{\text{Total Water Flow Rate of Stream 12}}{\text{Total Flow Rate of Stream 12}} = \_\_\_\_\_\_\_\_\_\_\_\_ = \qquad \frac{mg}{mg}$$

What is the concentration of water in Stream 12?

$$\frac{\quad}{\quad}\left|\frac{mg}{mg}\right|\frac{1000\ mg}{1\ g}\left|\frac{1000\ g}{1L}\right. = \qquad \frac{mg}{L}$$

What is the water flow in stream 14?

Total Water Flow Rate Stream 14 = Total Flow Rate of Stream 14 – Total BOD_5 Flow Rate of Stream 14 – Total Suspended Solids Flow Rate of Stream 14

= ____________ - ____________ - ____________ = $\frac{lb}{d}$

What is the weight fraction of water in Stream 14?

$$\frac{\text{Total Flow Rate of Water in Stream 14}}{\text{Total Flow Rate in Stream 14}} =$$

= ____________ = $\frac{mg}{mg}$

What is the concentration of water in Stream 14?

$$\frac{\quad}{\quad}\left|\frac{mg}{mg}\right|\frac{1000\ mg}{1\ g}\left|\frac{1000\ g}{1L}\right. = \qquad \frac{mg}{L}$$

5. Mixing Point Balance

Total Flow Rate of Stream 9 = Total Flow Rate of Stream 10 + Total Flow Rate of Stream 13

Total Flow Rate of Steam 9 = __________ + __________

= __________ $^{lb}/_{d}$

What is the Total Suspended Solids Flow Rate in Stream 9?

Total Suspended Solids Flow Rate in Stream 9 =
Total Suspended Solids Flow Rate in Stream 10 + Total Suspended Solids Flow Rate in Stream 13

= __________ + __________ = __________ $^{lb}/_{d}$

What is the Total Water Flow Rate in Stream 9?

Total Water Flow Rate in Stream 9 = Total Flow Rate in Stream 9 – Total BOD, Flow Rate in Steam 9 – Total Suspended Solids Flow Rate in Stream 9

Total Water Flow Rate in Stream 9

= __________ - __________ - __________ = $^{lb}/_{d}$

What is the weight faction of water in Stream 9?

$$\frac{\text{Water Flow Rate in Stream 9}}{\text{Total Flow Rate of Stream 9}} = \_\_\_\_\_\_\_\_\_\_ \text{ Weight Fraction, } \frac{mg}{mg}$$

$$= \qquad \frac{mg}{mg}$$

What is the concentration of water in Stream 9?

$$\frac{\quad}{\quad}\;\frac{mg}{mg}\left|\frac{1000\ mg}{1\ g}\right|\frac{1000\ g}{1L} = \qquad \frac{mg}{L}$$

What is the Total Water Flow Rate in Stream 10?

Total Water Flow Rate in Stream 10 = Total Flow Rate in Steam 10 – Total Flow Rate BOD_5 in Stream 10 – Total Flow Rate Suspended Solids in Stream 10

Total Water Flow Rate in Stream 10 =

__________ - __________ - __________ = $\quad {}^{lb}/_{d}$

What is the Weight Fraction of Water in Stream 10?

$$\frac{\text{Total Flow Rate of Water in Stream 10}}{\text{Total Flow Rate in Stream 10}} = \underline{\qquad\qquad} = \qquad \frac{mg}{mg}$$

What is the concentration of water in Stream 10?

$$\frac{\quad}{\quad}\;\frac{mg}{mg}\left|\frac{1000\ mg}{1\ g}\right|\frac{1000\ g}{1L} = \qquad \frac{mg}{L}$$

6. Balance Around Unit D

Stream 8 = Stream 9 + Stream 11

Total Flow Rate of Stream 8 = Total Flow Rate of Stream 9 + Total Flow Rate of Stream 11

Total Flow Rate of Stream 8 = ___________ + ___________ = $\frac{lb}{d}$

SS Flow Rate of Stream 8 = SS Flow Rate of Stream 9 + SS Flow Rate of Stream 11 = ___________ + ___________ = $\frac{lb}{d}$

BOD_5 Flow Rate Stream 8 = BOD_5 Flow Rate Stream 9 + BOD_5 Flow Rate Stream 11 = ___________ + ___________ = $\frac{lb}{d}$

Total Water Flow Rate Stream 8 = Total Flow Rate Stream 8 – Total BOD5 Flow Rate Stream 8 – Total SS Flow Rate Stream 8

= ___________ - ___________ - ___________ = $\frac{lb}{d}$

What is the SS Weight Fraction in Stream 8?

$\frac{SS\ \text{Stream 8}}{Total\ \text{Flow Rate Stream 8}}$ = ___________ = Wt. Fraction, $\frac{mg}{mg}$

What is the concentration of SS in Stream 8?

___________ mg	1000 mg	1000 g	= $\frac{mg}{L}$
mg	1 g	1L	

What is the BOD_5 Weight Fraction of Stream 8?

$$\frac{\text{Total Flow Rate of } BOD_5 \text{ in Stream 8}}{\text{Total Flow Rate of Stream 8}} = \underline{\hspace{3cm}}$$

$$= \qquad\qquad \text{Wt. Fraction, } \frac{mg}{mg}$$

What is the BOD_5 concentration in Stream 8?

	mg	1000 mg	1000 g		
	mg	1 g	1L	=	$\frac{mg}{L}$

What is the Water Weight Fraction of Stream 8?

$$\frac{\text{Total Flow Rate of Water in Stream 8}}{\text{Total Flow Rate in Stream 8}} = \underline{\hspace{3cm}}$$

$$= \qquad\qquad \text{Wt. Fraction, } \frac{mg}{mg}$$

What is the Water Concentration in Stream 8?

	mg	1000 mg	1000 g		
	mg	1 g	1L	=	$\frac{mg}{L}$

3.4 Design of Process Units

1. Primary Sedimentation Tank (Unit A)

Sundstrom and Klei, p 209

What is the overflow rate range? __________ to __________ $\frac{m^3}{m^2 \cdot d}$

What is your decision? __________ $\frac{m^3}{m^2 \cdot d}$

Why did you make this decision?

What is the detention time? __________ to __________ hours

What is your recommendation? __________ hours

Why did you make this decision?

What is the overflow rate from Unit A? Stream 6 = __________ $\frac{lb}{d}$

$$\frac{\quad\ lb}{d}\left|\frac{1\ ft^3}{62.3\ lb}\right|\frac{1\ m^3}{35.3145\ ft^3} = \qquad \frac{m^3}{d}$$

What is the required area?

$$\frac{\quad\ m^3}{d}\left|\frac{}{\frac{m^3}{m^2 \cdot d}}\right. = \qquad m^2$$

What is the total Volume needed?

$$\frac{\quad\ m^3}{d}\left|\frac{\quad h(Detention)}{}\right|\frac{1 d}{24\ hr} = \qquad m^3$$

What is the required depth?

$$\text{Depth} = \frac{\text{Volume}}{\text{Area}} = \frac{\qquad\qquad m^3}{\qquad\qquad m^2} = \qquad\qquad m$$

Sundstrom and Klei, p 207

Rectangular Tank

What is the maximum Length? __________ m

What is the length to width ratio? __________ to __________

What is your decision? __________ m

Why did you make this decision?

Therefore, what is the width? __________ m

What is the number of tanks?

Let N = number of tanks

V = Total Volume = N L W H

L = length, __________ m

W = width, __________ m

H = height, ____?____ m

V = total volume, __________ m^3

Therefore, $H = \frac{V}{NLW}$

Assume N = 1 H = __________ m

What is the acceptable depth? Sundstrom and Klei, p 207

__________ to __________ m

Is H = __________ m acceptable? __________

Therefore, for the Primary Sedimentation System

N = ___________

L = ___________ m

W = ___________ m

H = ___________ m

2. Aerator Design (Unit C)

Design Data

1. Depth is less than 5m (Sundstrom and Klei, p 42)

2. A completely mixed aerator (mechanically agitated) is known as the CMAS process. The CMAS basins can be designed as square, circular or rectangular. For good mixing, a
   Length to Width Ratio of 3/1 maximum is recommended.
   "Design of Municipal Wastewater Treatment Plants", p 616-617.

What is your choice of length to width ratio? X = _____________

Why did you make this decision?

For a rectangular reactor

$$V = N\,L\,W\,H$$

N = the number of units

L = length, m

W = width, m

H = depth, m

What is your decision on the depth? H = ____________ m

Why did you make this decision?

What was your calculated value for the aerator volume? V = ___________ m^3

Therefore,

$$V = N\,L\,W\,H$$

First Assume N = 1

$$\text{but } \frac{L}{W} = X = \underline{\hspace{3cm}}$$

Therefore, L = X W

or $V = L\,W\,H = (X\,W)\,W\,H$

$$W^2 = \frac{V}{XH} \qquad W = \left(\frac{V}{XH}\right)^{0.5}$$

$$W = \left[\ \_\_\_\_\ m^3 \ \Big|\ \_\_\_\_\ \Big|\ \frac{}{\_\_\_\_\ m}\ \right]^{1/2}$$

W = __________________ m

L = X W = ______________ m

H = ________________ m

N = 1

Therefore,

$$V = N\,L\,W\,H$$

$$V = \_\_\_\_ \Big|\ \_\_\_\_\ m\ \Big|\ \_\_\_\_\ m\ \Big|\ \_\_\_\_\ m = \qquad m^3$$

Is your assumption of N = 1 unit adequate? ___________

Therefore, N = __________

L = __________ m

W = __________ m

H = __________ m

3. Secondary Sedimentation (Unit D)

Secondary Clarifier Design is Rectangular

"The Design of Municipal Wastewater Treatment Plants" p 592, Table 11.15

Rectangular Shape Overflow Peak Flow Rates _________ to _________ $\frac{m^3}{m^2 \cdot h} = \frac{m}{h}$

Average Peak Overflow Rates _________ $\frac{m^3}{m^2 \cdot h} = \frac{m}{h}$

Overflow rate = Steam 11 = $\frac{lb}{d}$

$$Q = \text{Flow Rate} = \frac{\quad lb}{d} \cdot \frac{1\ ft^3}{62.3\ lb} \cdot \frac{1\ m^3}{35.3145\ ft^3} = \quad \frac{m^3}{d}$$

$$Q = \frac{\quad m^3}{d} \cdot \frac{1d}{24\ hr} = \quad \frac{m^3}{h}$$

Average Overflow = _________ $\frac{m^3}{m^2 \cdot h} = \frac{m}{h}$

$$\text{Area} = \frac{Q}{\text{Average Overflow}} = \frac{\quad m^3}{h} \cdot \frac{1}{\quad \frac{m^3}{m^2 \cdot h}} = \quad m^2$$

What is the required Sedimentation Tank Volume?

V = Feed Rate x Detention Time

Feed Rate = Stream 8 = ______________ $\frac{lb}{d}$

$$Q = \frac{\quad lb}{d} \left| \frac{1\ ft^3}{62.3\ lb} \right| \frac{1\ m^3}{35.3145\ ft^3} \left| \frac{1\ d}{24\ h} \right. = \qquad \frac{m^3}{h}$$

What is the detention time?

What detention time did you use for Primary Sedimentation? ___________ h

The Design of Wastewater Treatment Plant, p 594, Table 11.16,

What is the Range of detention times? ________ to ________ h

What is your decision? ___________ h

Why did you make this decision?

What is the Volume needed?

V = Q t where t = detention time in hours.

$$V = \frac{\quad m^3}{h} \left| \frac{\quad h}{} \right. = \qquad m^3$$

What is the required Height?

V = N A H

Assume N = 1

$$H = \frac{V}{A} = \frac{\qquad m^3}{\qquad m^2} = \qquad m$$

What is the range on the average depth? __________ to __________ m

"Design of Wastewater Treatment Plants" p 584

Are you in this range? ________

Do you need more than one tank to reduce the depth? _________

What is your decision? N = ______________

Why did you make this decision?

$V = NAH$

$H = \frac{V}{NA}$

V = _____________ m^3

A = _____________ m^2

N = _____________

H = _____________ m

Is this height in the range? ________

Do you need more than two tanks to reduce the depth? _________

What is your decision? N = ______

Therefore,

V = ____________ m^3

A = ____________ m^2

N = ____________

H = ____________ m

Is this height within range? ______

But $A = LW$

What is L? What is W? What is $\frac{L}{W}$?

What $\frac{L}{W}$ did you use for Primary Sedimentation? ____________

Is this a good assumption? __________

What is your decision? $\frac{L}{W}$ = ______X______ = ____________

L = X * W = ______ * W

A = L W

A = X W^2 or ________ m^2 = X W^2 = ____________ W^2

W^2 = ____________ m^2

W = ____________ m

L = ____________ m

V = N L W H

$$H = \frac{V}{N\,L\,W}$$

H = ______ | ______ | ______ | ______

H = ____________ m

Therefore,

V = ____________ m^3

N = ____________

L = ____________ m

W = ____________ m

H = ____________ m

4. Primary Filter Design (Sundstrom and Klei, p233 – 234)

What is the recommended process feed rate to the primary filter?

____________ to ____________ $\frac{kg}{m^2 \cdot h}$

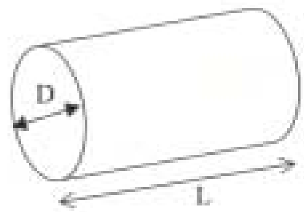
What is your decision? ____________ $\frac{kg}{m^2 \cdot h}$

Why did you make this decision?

Sundstrom and Klei, p233

What is the maximum available Diameter for a Rotary Vacuum Filter? _______ m

What is the maximum available Length for a Rotary Vacuum Filter? _______ m



Surface Area = Π D L

Cake Solids Rate = SS Flow Rate of Stream 5 = __________ $\frac{lb}{d}$

lb	1 d	0.454 kg	=	$\frac{kg}{h}$
d	24 h	1 lb		

Area needed =

kg	
h	$\frac{kg}{m^2 \cdot h}$

= __________ m^2

$A = \Pi\, D\, L = (3.14)(5)(6) = 94.2\ m^2$

of area is available in one maximum size filter

Is one filter 5m diameter and 6 m long adequate? ________

Therefore,

N = __________

D = __________ m

L = __________ m

5. Secondary Filter (Sundstrom and Klei, p 234)

What is the recommended activated Sludge process rate to the secondary filter

________ to ________ $\frac{kg}{m^2 \cdot h}$

What is you decision? ____________ $\frac{kg}{m^2 \cdot h}$

Why did you make this decision?

Cake Solids Rate = SS Flow Rate of Stream 14 = ____________ $\frac{lb}{d}$

lb	1 d	0.454 kg		
d	24 h	1 lb	=	$\frac{kg}{h}$

Area needed = $\frac{kg}{h}$ | $\frac{kg}{m^2 \cdot h}$ = ____________ m^2

$A = \Pi D L = (3.14)(5)(6) = 94.2\ m^2$

of area is available in one maximum size filter

Is one filter 5m diameter 6 m long adequate? ________

Therefore,

N = __________

D = __________ m

L = __________ m

3.5 Cost Estimation of Plant

Reference

Susuma Kawamura, "Integrated Design of Water Treatment Facilities"

p 41, Fig 2.3.12-1 Construction Cost Estimate

p 42, Fig 2.3.12-2 Operating and Maintenance Costs

1. Construction Cost

What is your plant capacity? ____________ $^{lb}/_{d}$ feed (Stream 1)

________ lb	1gal	________	= ________ Mgd
d	8.34 lb	1,000,000	

What is the construction cost?

Construction $Cost_1$ = $ ______________ for year ____________.

Construction Costs can be adjusted for inflation by the Engineering News-Record Construction Cost Index (ENR).

What is the ENR Index for Fig 2.3-12-1?

ENR_1 = __________ for year ________.

What is the current ENR Index? (The most recent copy of the Engineering News Record is on the Second Floor of the Library. The ENR Construction Cost Index is near the back of the Journal)

Hence,

ENR_2 = ____________ for year _________, and

$$\frac{\text{Construction Cost}_1}{\text{ENR Index}_1} = \frac{\text{Construction Cost}_2}{\text{ENR Index}_2}$$

$$\text{Construction Cost}_2 = \text{Construction Cost}_1\left(\frac{\text{ENR}_2}{\text{ENR}_1}\right) = \underline{\qquad\qquad\qquad}$$

Construction Cost $_2$ = ____________________ for year __________

2. The Operating and Maintenance Cost

The Operating and Maintenance Cost (OMC) can be estimated in the same manner. Hence, from Figure 2.3-12.2, p42, Kawamura, Susuma, "Integrated Design of Water Treatment Facilities"

OMC_1 = ____________________ for year ___________

ENR_1 = ____________________ for year ___________

ENR_2 = ____________________ for year ___________

Hence,

$$OMC_2 = OMC_1\left(\frac{ENR_2}{ENR_1}\right) = \underline{\qquad\qquad\qquad}$$

Therefore,

the estimated Operating and Maintenance Cost

= ________________ for year _______.

4. References

[1] Sundstrom, D.W. and Klei, H.E., "Wastewater Treatment" Prentice Hall, Inc., Englewood Cliffs, New Jersey, 07632, 1979

[2] "Physical-Chemical Wastewater Treatment Plant Design", EPA Technology Transfer Seminar Publication, 1973

[3] Cameron, William and Cross, Jr., Frank L., "Operation and Maintenance of Sewage Treatment Plants", Technomic Publishing Co., Westport, CT 06880, 1976

[4] "Ocean Water For Today: What is Wastewater Treatment?", Water Environment Federation, Alexandria, VA 22314, 1994

[5] "Construction Costs For Municipal Wastewater Conveyance Systems: 1973-1977, U.S.E.P.A., 430/9-77-015, Technical Report, MCD-39

[6] Kawamura, Susumu, "Integrated Design of Water Treatment Facilities", John Wiley and Sons, Inc, New York, New York, 1991

[7] "Design of Municipal Wastewater Treatment Plants" Water Environment Federation, American Society of Civil Engineers, 1992

5. Nomenclature

d = days

h = hours

kg = kilograms

lb_m = pounds mass

m = meters

mg = milligrams

$\frac{mg}{mg}$ = milligrams of component in stream per milligram of total stream

$\frac{mg}{L}$ = milligrams per liter of solution