UNIVERSITY OF NEW ORLEANS
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

ENCE 4323 DESIGN OF WATER AND WASTEWATER TREATMENT SYSTEMS (3 cr.)
MW 3:00 pm – 4:15 pm
EN 309

Prerequisite: Introduction to Environmental Engineering, ENCE 3323 (strictly enforced).

Instructor: Enrique J. La Motta, P.E.
Office hours: MW 1:00 – 3:00 pm, EN 815 or by appointment at CERM 102
E-mail address: elamotta@uno.edu
Phone: 280-6093

Student Learning Objectives:

Students who satisfactorily complete this course will be able to:

1. Apply chemical reaction engineering principles to select the most appropriate reactor type for water and wastewater treatment depending on the respective reaction kinetics.
2. Explain the physical, chemical and biological processes taking place in water and wastewater treatment plants.
3. Solve problems related to unit performance in conventional water and wastewater treatment plants.
4. Prepare a preliminary design of conventional water and wastewater treatment plants, and organize the results in a project report.
5. Work as team members and follow a prescribed work plan.

Attendance Policy:

Attendance is required. If you cannot attend class for some reason, call the instructor or the departmental secretary and explain why.

Required Textbooks:

optional ? *Unit Operations and Processes in Environmental Engineering*, Second Edition, by Tom D. Reynolds and Paul A. Richards, PWS Publishing Company, Boston, 1996.

Water Works Engineering, Planning, Design, Operation, by Syed R. Qasim, Edward M. Motley, and Guang Zhu, Prentice Hall, 2000.

Grading System

There will be three exams (two mid-term tests and the final exam, each with the same weight), worth 50 percent of the grade, five assignments, worth 20 percent of the grade, and a project, worth 30 percent of the grade.

The assignments and the project are not optional; they are mandatory. For every day of late submission of an assignment you will lose 10 points (in a 100-point scale).

The final letter grade is computed as follows: The overall numerical grade will be divided by the highest score in class, so that the best possible normalized score will be 100 points. If the normalized score is more than 90 points the grade will be an A; from 80 - 89, the grade will be a B; from 70 – 79, the grade will be a C; from 60 - 69, D; below 60, F.

Extra work to be completed by graduate students

Students enrolled in ENCE 4323G will be responsible for the material contained in Chapters 12 (Adsorption) and 18 (Stabilization ponds and aerated lagoons) of the textbook. Special assignments, and questions and problems dealing with these two chapters will be given in the final exam.

Academic Integrity

Academic dishonesty, including but not limited to, cheating and plagiarism in assignments, exams, and project, will not be tolerated. The instructor will assign a grade of Zero or "F" on the academic exercise (such as test, paper, project, assignment, computer program, etc.) in question. This action is subject to the following provisos:

a. This grade will not be dropped in the calculation of the final grade.

b. The instructor will not assign the student a semester letter grade of "F" for the course, unless the student's semester grade calculates to "F" as a consequence of the Zero or "F" given on the academic exercise, or unless a semester letter grade of "F" is the judgment arrived at in a subsequent Resolution Conference or UNO Judicial Committee Hearing.

sep. 1 2010

waste water

ENCE 4323

COURSE PROJECT

This is an open-ended preliminary design of a water treatment plant for a maximum daily flow rate of 1.55 m^3/s at the end of the design period. This preliminary design will closely follow the example presented in Qasim's book. Therefore, read in detail pages 91-117. We will use exactly the same hypothetical Modeltown, with the same raw water characteristics (except that we will have no algae, no iron and manganes) and proposed treatment facilities (except that we will not have either taste and odor control, nor iron and manganese removal).

TASK 1: Process Layout $\leq$ 3 pages

Draft Due 09/08/10

Your report should be a summary of pages 91-117 Qasim, adapted to the new flow rate, and it should include diagrams similar to Figures 5-5 and 5-6.

The Evaluation Scale for this project is:

- 1 for Poor
- 2 for Average
- 3 for Good
- 4 for Excellent.

Each task will be assessed on the following elements:

- Identification of design problem
- Appropriate assumptions are made
- Calculations are complete and accurate
- Equipment brochures are presented and used
- Quality and accuracy of design drawings
- Quality of technical report

The total project grade is worth 30% of the course grade. Task 1 is worth 10% of the total project grade.

ENCE 4323
Fall 2009
RAPID MIXING UNITS

Diffusion by Pressured Water Jets (Fig. 1)

- No additional head loss by the mixer
- Very effective
- Controllable degree of mixing
- Low power consumption. .
- But:
  - water must be free of suspended solids to prevent nozzle clogging,
  - prone to clogging by coagulant salts.
- Design criteria:
  - $G\bar{t}$ = 400 - 1600 (1000 average)
  - Minimum pressure, 0.7 kg/cm^2, with mixing jet velocity, 6 - 7.6 m/s at the orifice.

In-line static mixers (Fig. 6.28)

- No moving parts, no external energy to be input to the system
- Very effective
- Degree of mixing and mixing time are a function of flow rate
- Proprietary devices, cannot be designed by engineer
- Mixing time of 1 - 3 s and maximum head loss of 0.6 - 0.9 m
- Best choice for aluminum or iron salts
  - $G\bar{t}$ = 350 – 1700 (1000 average)
  - Contact times between 1 and 3 s.

In-line blenders

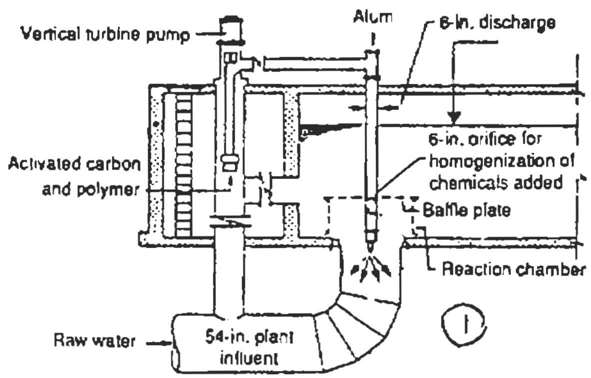
- G = 3000 – 5000 s^{-1}
- $G\bar{t}$ = 1500 – 5000
- Power consumption for mixing (typical) = 8.5 $kwatt/m^3.s$ (0.5 HP/mgd)
- $\bar{t}$ = 0.5 – 1 s
- Head loss through the unit = 0.3 – 1.0 m. Therefore, additional power is needed (2.7 – 8.7 $kwatt/m^3.s$) to overcome this head loss.

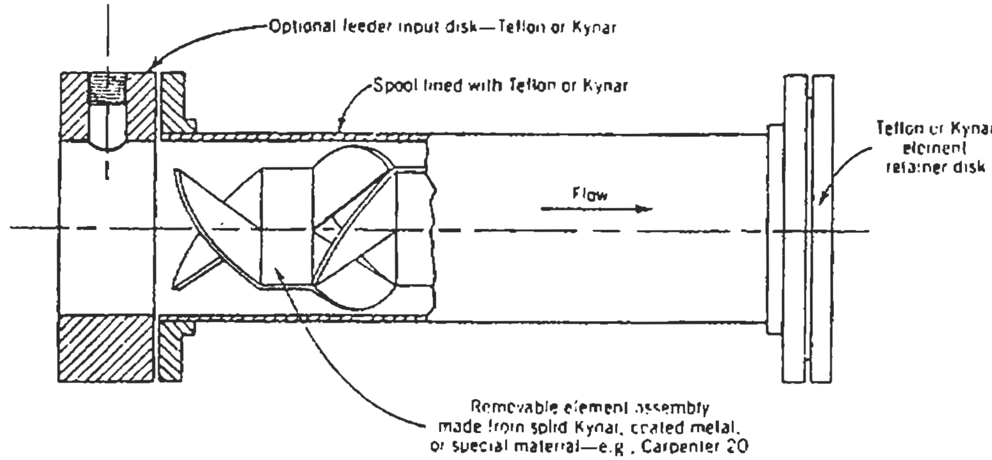
Hydraulic jumps (Fig. 8.10)

- Usually generated by Parshall flumes
  - Coagulant added upstream of jump
  - Typical G values: 800 s^{-1}
  - Contact time = 2 seconds

Mechanical flash mixing

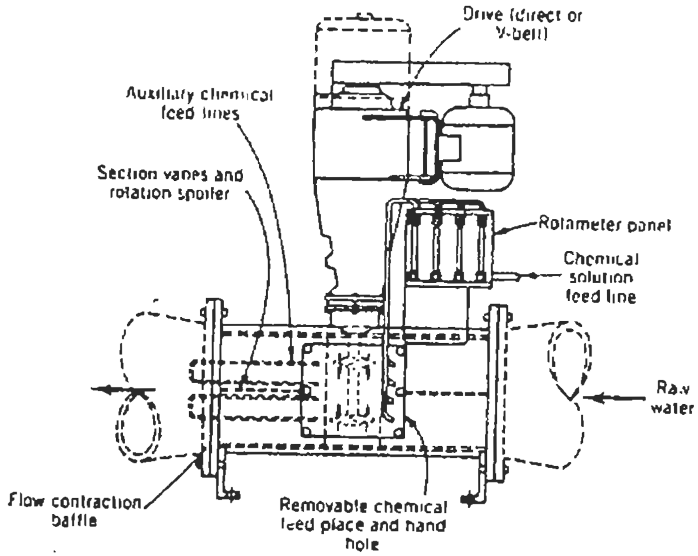
- Most frequently used in water treatment industry
- G = 300 s^{-1}
- Mixing time: 10 - 30 s
- Power requirements: 0.85 - 1 HP per MGD
- Serious disadvantages:
  - Lack of instantaneous mixing characteristics
  - Short-circuiting
  - Mixing period is too long for metallic coagulants
  - Shaft problems and gear drive failures in many installations





(e)

Figure 6.28 Rapid mixers used in practice. *(Continued)* (e) Static (motionless) mixer.



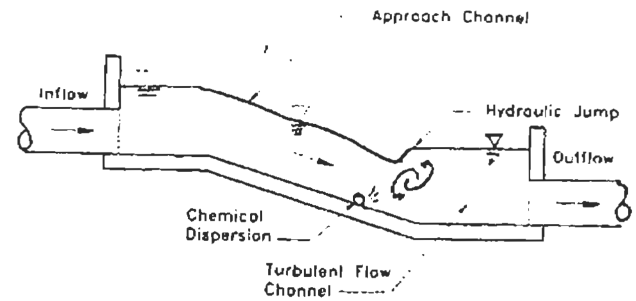
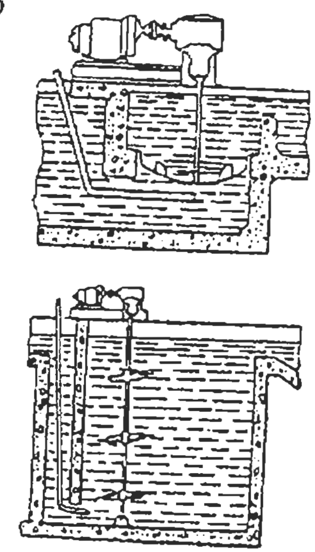


Figure 8-10 Typical rapid mixing utilizing a hydraulic jump.



CALCULATION OF LIME DOSAGE FOR ALUM NEUTRALIZATION

When aluminum sulfate (alum) is added to water, the following reaction takes place:

$$Al_2(SO_4)_3 \cdot 14.3\ H_2O + 6\ H_2O\ =\ 2\ Al(OH)_3\ (s) + 6H^+ + 3SO_4^{2-} + 14.3\ H_2O$$

The generation of $6H^+$ depresses the pH. If the pH drops too much, $Al(OH)_3$ (s) will not precipitate.

Bicarbonates present in natural waters serve as buffers:

$$HCO_3^- + H^+\ =\ H_2CO_3 \rightarrow\ CO_2 + H_2O$$

The overall reaction may be written as follows:

$$\begin{array}{rcl}
Al_2(SO_4)_3\text{á}14.3H_2O + 6H_2O & = & 2Al(OH)_3\ (s) + 6H^+ + 3SO_4^{2-} + 14.3H_2O \\
6HCO_3^- + 6H^+ & = & 6CO_2 + 6H_2O \\
\hline
Al_2(SO_4)_3\text{á}14.3H_2O + 6HCO_3^- & = & 2Al(OH)_3\ (s) + 3SO_4^{2-} + 6CO_2 + 14.3H_2O
\end{array}$$

Therefore, for every mole of alum (600 g), 6 moles of alkalinity (HCO_3^-) are consumed.

$$\text{Alkalinity consumed} = 6\ \text{moles}\ HCO_3^- \times \frac{1\ \text{eq}}{\text{mole}\ HCO_3^-} \times \frac{100\ \text{g}\ CaCO_3}{\text{mole}\ CaCO_3} \times \frac{1\ \text{mole}\ CaCO_3}{2\ \text{eq}}$$

$$\text{Alkalinity consumed} =\ 300\ \text{g as Ca}\ CO_3$$

Hence, 600 g of alum consume 300 g of alkalinity as $CaCO_3$. Therefore,

1 mg/l of alum consumes 0.5 mg/l of alkalinity as $CaCO_3$.

If water does not have sufficient alkalinity, must supplement alkalinity by adding lime, $Ca(OH)_2$:

$$\begin{array}{rcl}
Al_2(SO_4)_3 \bullet 14.3H_2O + 6H_2O & = & 2Al(OH)_3\ (s) + 6H^+ + 3SO_4^{2-} + 14.3H_2O \\
3Ca(OH)_2 + 6H^+ & = & 3Ca^{2+} + 6H_2O \\
\hline
Al_2(SO_4)_3 \bullet 14.3H_2O + 3Ca(OH)_2 & = & 2Al(OH)_3\ (s) + 3Ca^{2+} + 3SO_4^{2-} + 14.3H_2O
\end{array}$$

Therefore, we need 3 moles of lime for every mole of alum to be neutralized, or

$$\frac{3\ \text{moles lime} \times \dfrac{74\ \text{g lime}}{\text{mole lime}}}{1\ \text{mole} \times \dfrac{600\ \text{g alum}}{\text{mole alum}}} = \frac{0.37\text{g lime}}{\text{g alum}}$$

Example Assume an alum dosage of 50 mg/L, water alkalinity = 10 mg/L as $CaCO_3$. Find the chemical consumption for a treatment plant with a flow rate of 100 L/s.

Solution:

Only 2 x 10 mg/L of alum will be neutralized by the existing alkalinity. Therefore, 50 – 20 = 30 mg/L of alum must be neutralized with lime.

$$\text{Lime dosage} = 30 \frac{\text{mg alum}}{\text{L}} \times 0.37 \frac{\text{mg lime}}{\text{mg alum}} = 11.1 \frac{\text{mg lime}}{\text{L}}$$

If Q = 100 L/s:

Alum consumption = 50 mg/L x 100 L/s x 86400 s/d x 1kg/10^6 mg = 432 kg/d

Lime consumption = 11.1 mg/L x 100 L/s x 86400 s/d x 1 kg/10^6 mg = 96 kg/d

Design example of a rapid mixing unit

The water supply for a town is taken from a river with considerable variations in quality. The raw water analyses for a year are shown in Table 1, with typical coagulant doses obtained from jar tests. The design flows for 24-h operation are: average day = 43.8 L/s, maximum day = 65.7 L/s. Design the rapid mixing unit for this plant.

Table 1. Data for design, river source

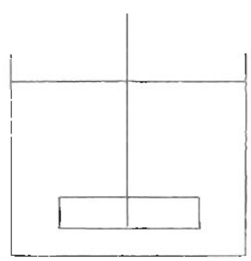
		Per cent occurrence						
Raw Water Analyses	Parameter	11	34	28	13	9	3	2
	Turbidity, ntu	28	45	81	126	140	180	>200
	Alklinity, mg/L as $CaCO_3$	86	132	92	84	93	77	82
	Temperature, °C	13	10	8	18	18	16	
Jar Tests	Alum, mg/L	18	27	36	28	41	31	36
	pH	6.4	6.7	6.4	6.4	6.4	6.2	6.4

ENCE 4323
TYPICAL FIRST-EXAM PROBLEMS
(Time available for each problem: 20 minutes)
SPRING 2009

The exam will have two problems very similar to the problems presented below (35 points each), and a set of 5 questions taken from your reading assignments (6 points each). The exam will be open book, open notes.

1. Two CSTRs connected in series give a total conversion x with a second-order reaction. The conversion in the first reactor is 85 percent, and the influent reactant concentration is 100 mg/L. Batch reactor tests on the same reaction gave a reactant half-life of 2 seconds with the same initial concentration (half-life is the time required for the concentration to drop to one-half or the original value). If the holding time in the second CSTR is 100 seconds, find the average retention time in the first one and the total conversion x. Answ: $\bar{t}_1 = 75.6$ s; x = 0.954

2. In a jar test to determine the proper coagulant dosage, a 1-liter jar with 600 ml of water is stirred with a 12-mm x 50-mm flat blade. The blade is mounted at the end of a vertical shaft which divides the blade in two identical arms, each with a blade 12-mm x 25-mm. Assuming r = 1.0 g/cm3 and m = 10-2 g/cm.s, find the rotational speed needed to obtain a velocity gradient of 60 s-1. Answ: 128 rpm.



3. Show that for any reaction kinetics N plug flow reactors connected in series are equivalent (i.e., they give the same conversion) to a single PFR whose volume is equal to the sum of the volumes of the N reactors. The N PFRs would process the same flow rate as the single PFR.

4. A jar test (a batch reactor where orthokinetic flocculation takes place) yields the results of turbidity remaining as a function of time given by the following equation:
ln f = - 0.32044 t, where f is the fraction of turbidity remaining in suspension after t minutes. Assuming that the same kinetic constant would be observed in a full-scale treatment plant, calculate the detention time you need to achieve 80% turbidity removal

using
a) A plug flow reactor. Answ: 5.02 min.
b) A single CSTR. Answ: 12.48 min.

5. To design a reactor several laboratory tests are run using a completely mixed reactor with a constant holding time of 100 seconds. The experimental results of these tests are the following:

CA0, mg/l	629	841	1262	2516	5018
CA, mg/l	4	8	12	16	18

Find the residence time needed in a CSTR to obtain a conversion of 90 per cent if the influent reactant concentration is 20 mg/l. **HINT: Plot 1/rA vs. CA.** Answ: 3.2 sec.

6. A water treatment plant has a single mechanical flocculator (assume CFSTR) with a detention time of 30 minutes. Its orthokinetic flocculation efficiency is the same as tbat obtained in a jar test apparatus (assume batch reactor) after a reaction time of 5 minutes. Find tbe flocculation efficiency. Answ: 94.6%

7. Determine the number of completely mixed chlorine contact chambers each having a detention time of 30 minutes that would be required in a series arrangement to reduce the bacterial count of a polluted water sample from 106 organisms/mL to 14.5 organisms/mL if the first-order removal rate constant is equal to 6.1 h-1. If a plug-flow chlorine contact chamber were used with the same detention time as the series of completely mixed chambers, what would the bacterial count be after treatment? Answ: N = 8; Count = 2.5 x 10^{-5} bacteria.

8. A 14-m wide, 18-m long, 4-m deep flocculator is equipped with a two-arm rotor to mix 440 l/s. The power consumed to move the rotor is 0.126 kw (1 watt = 1 kg m2/s3). Each rotor arm has two rectangular blades with the following velocities relative to the liquid: the internal one, 0.3 m/s, and the external one, 0.43 m/s. Assuming ρ = 1.0 g/cm3 and μ = 10-2 g/cm.s, find the total paddle area. Answ: A = 6.23 m^2.

9. A first-order reaction takes place in a CFSTR operating with a detention time of 1 hour. The conversion in this reactor is the same as that in a PFR operating with the same flow rate but with a retention time of 10 minutes. Find the kinetic constant. Answ: k = 0.292 min^{-1}

10. A second order reaction takes place in two CSTRs connected in series. The influent reactant concentration in the first reactor is 120 mg/L. Batch reactor tests on the same reaction gave a reactant half-life of 1 second with an initial concentration of 100 mg/L (half-life is the time required for the concentration to drop to one-half of the original value). If the holding times are 75 seconds in the first reactor, and 100 seconds, in the

A 15m [illegible] 20m long, [illegible] deep flocculation [illegible] 2 [illegible] rotor w/ a shaft located 15m. The [illegible] consumes [illegible] ($140 \frac{kg\,m^2}{s^3}$) each [illegible] has total [illegible]. It has 2 [illegible] rectangular blades w/ [illegible] velocities relative to the water: [illegible] 0.3 m/s [illegible], 0.13 m/s. Design [illegible] the total blade area to be [illegible] 15% of the tank cross sec. area parallel to [illegible] adequate mixing [illegible] of the [illegible] flow. Assuming

$\rho = 1000 \ kg/m^3$, $\mu = 1.0 \times 10^{-3} \ N/m \cdot s$, $C_D = 2.0$

(a) Find blade area req. [illegible]

(b) [illegible] velocity gradient (G)

(c) In addition [illegible] do you think this is a good design?

[illegible] blade

$F_D = \rho C_D A v^2$

[illegible]

$P_T = 2P [illegible]$

$P_T = 2\left(\frac{1}{2}\rho C_D A v_1^3 + \frac{1}{2}\rho C_D A v_2^3\right)$

$P = \rho C_D A (v_1^3 + v_2^3)$; $A = \dfrac{140 \frac{kg\,m^2}{s^3}}{1000 \frac{kg}{m^3}\left(2\left(0.43^3 + 0.3^3\right)\frac{m^3}{s^3}\right)} = 0.66 m^2$ [illegible] blade

$A_T = 4(0.66) = 2.63 m^2$

Tank $A = 15 \times 4 = 60 m^2$

[illegible] area should be [illegible] $0.15(60) = 9$ [illegible] $0.2(60)$ $12 m^2$

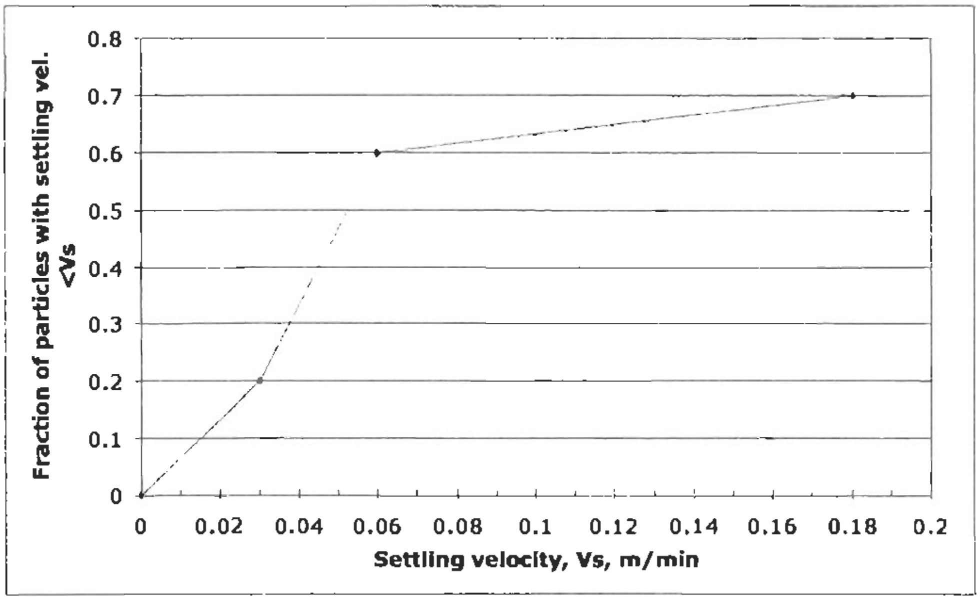
Blade [illegible]

$G = \sqrt{\dfrac{P_T}{\mu V}} = \sqrt{\dfrac{140}{10^{-3}(15)(4)(20)}} \rightarrow G = 10.8 \ s^{-1}$

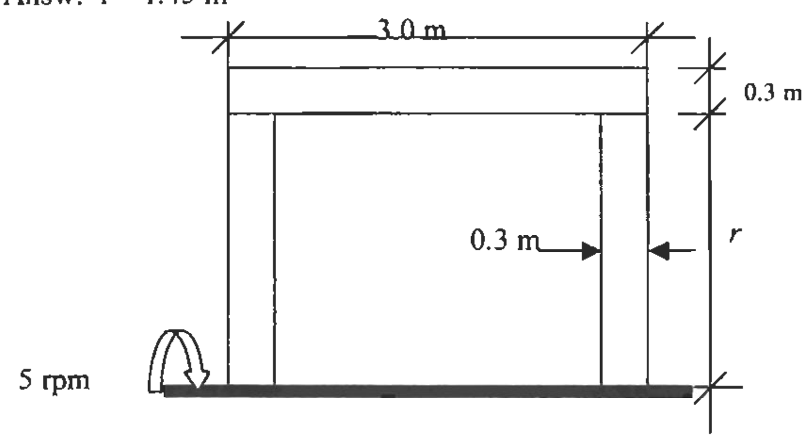
second CSTR, find the effluent concentrations in the first and in the second reactors. Answ: $C_{A1} = 12$ mg/L; $C_{A2} = 3$ mg/L.

11. The specific gravity of the particles being removed in a settling tank is 1.001 at 10°C. The tank overflow rate is 172.8 m3/m2.d. Find the diameter of the smallest particle that is 100% removed if is assumed that the particles are spherical. Answ: d = 0.25 cm.

12. The chart below shows the results of a discrete-particle settling test. Find the settling efficiency of an ideal tank operating at an overflow rate of 259.2 m/d. Answ: 75%.



13. A flocculation tank has the following dimensions: length = 5 m, width = 4 m, depth = 3 m. The rotor consists of a single arm with three blades assembled as shown in the sketch below. Find the value of the paddle radius r required to get a value of G = 50 s-1 using the following constants: $\mu = 1.6 \times 10^{-3}$ kg/m.s; n = 5 rpm; $C_D = 1.8$; k = 0.25; $\rho = 1000$ kg/m3. Answ: r = 1.45 m



14. A suspension of discrete particles having an average density of 1400 kg/m3 is to be treated in a settling tank designed for an overflow rate of 25 m3/m2.d. For the particle size distribution given below, determine the fraction removed. Anw: 0.46.

Particle Effective Diameter, mm	Mass Fraction
0.010	0.10
0.015	0.20
0.020	0.25
0.025	0.15
0.030	0.05
0.035	0.15
0.040	0.05
0.045	0.05

15. Find the dimensions of a sedimentation tank to remove 100 percent of spherical particles 0.5 mm in diameter, with specific gravity of 2.5. The liquid temperature is 10°C. Assume the flow rate through the tank is 100 L/s and that the horizontal velocity is 0.30 m/s. If you needed to change one of the design parameters provided, which one would you change? Anw: L = 3.6 m; W = 0.55; D = 0.6 m. Change horizontal velocity to between 3.0 to 4.5 m/min.

16. Determine the removal efficiency for a sedimentation basin designed with a critical velocity of 6.5 ft/h in treating a river water containing discrete particles whose settling velocities are distributed as given in the table below. Answ: 78%

Settling Vel., ft/h	0.0 - 1.5	1.5 - 3.0	3.0 - 4.5	4.5 - 6.0	6.0 - 7.5	7.5 - 9.0	9.0 - 10.5	10.5 - 12.0
Number of particles	20	40	80	120	100	70	20	10

17. The specific gravity of the particles being removed in a settling tank is 2.5 at 20°C. The average particle diameter is 1.0 mm. Initial graphical estimation indicates that the particle settling velocity is greater than 0.1 m/s, and that therefore, the particle settles in the transition region. Assuming spherical particles, find the settling velocity. Answ: 0.165 m/s.

18. Determine the theoretical power requirement and the paddle area required to achieve a G value of 50 s-1 in a flocculation tank with a volume of 3000 m^3. The mechanical flocculator consists of a paddle wheel with two arms, each with one blade parallel to the shaft. Assume the water temperature is 15°C, the coefficient of drag is 1.8, the paddle linear velocity is 0.6 m/s, and the relative velocity of the paddle with respect to the fluid is 75% of the linear velocity. Answ: Power = 8543 watt; A = 104.3 m^2.

) [illegible] pin floc basin [illegible]

[illegible]

[illegible] [illegible] disperse [illegible]

2) [illegible] primary [illegible]

[illegible] [illegible] adverse [illegible]

[illegible]

3) [illegible] suspension stable?

colloids are [illegible] in suspension [illegible] the colloids themselves. [illegible] natural [illegible] colloids remain in suspension because of the action of the repulsive [illegible]

4) what is Tapered flocculation? how [illegible]

The flo[illegible] decreasing G-values as it [illegible] through the flocculation basin.

5) Do you think trajectory of a discrete particle in a circular sedimentation tank would be straight or curved?

it will be curved [illegible] For rectangular settling [illegible] is linear, For circular settling [illegible] parabola

The horizontal velocity decreases in the radial direction

[illegible]

ENCE 4323
Old second exam problems

1995

1. Calculate the head loss through a clean sand filter with a gradation defined by the sieve analysis given below at a filtration rate of 0.0027 m/s. The bed has a depth of 0.70 m with a porosity of 0.45 and the grains of sand have a sphericity of 0.75. Assume the kinematic viscosity is 1.306×10^{-6} m^2/s.

Sieve designation number	8	12	16	20	30	40	50
Size of the opening, S, mm	2.38	1.68	1.19	0.84	0.59	0.42	0.297
Fraction of sand retained	0	0.02	0.25	0.47	0.24	0.02	0

Answ. Head loss = 0.31 m

2. The following are the turbulent and clean laminar head losses in a rapid granular filter operated under declining rate conditions:

- Sand: $hf_s = 53.1560\ V$
- Anthracite: $hf_a = 15.1460\ V$
- Drainage piping: $hf_d = 1441.9000\ V^2$
- False bottom: $hf_b = 0.7262\ V^2$
- Valves and fittings: $hf_v = 1510.0200\ V^2$

In all these expressions V is the filtration rate in m^3/s per m^2. The maximum available head for filtration is 1.15 m, and the dirty-filter head loss at the minimum filtration rate of 12.538 cm/min is 0.7666 m. Find the additional turbulent head loss that must be introduced by an orifice plate in the influent pipe to balance the filter hydraulics. Answ. Orifice head loss = 0.37 m

3. The turbulent and clean laminar head losses in a rapid granular filter operating under declining rate conditions are the same as those given in problem 2. The maximum available head for filtration is 1.15 m. If the average filtration rate is 20 cm/min, the minimum filtration rate is 70 per cent of the average rate, and the maximum filtration rate, controlled by an orifice plate, is 1.3 times the average rate, find the dirty-filter laminar head loss.
Answ.: Dirty-filter laminar loss = 0.902 m.

1996

1. A rapid sand filter has a sand bed 76.2 cm deep, with an initial porosity = 0.41. Pertinent data are:

Sieve size	% Weight Retained	Particle size (m)	Settling Velocity m/s
14-20	0.44	0.0010060	0.15252
20-28	14.33	0.0007111	0.10671
28-32	43.22	0.0005422	0.07747
32-35	27.02	0.0004572	0.06206
35-42	9.76	0.0003834	0.04854
42-48	4.22	0.0003225	0.03752
48-60	0.54	0.0002707	0.02847
60-65	0.29	0.0002274	0.02134
65-100	0.13	0.0001777	0.01391

Find the depth of the expanded bed if the backwash rate is 10.3 L/s.m^2. Answ: L = 1.33 m

2004

1. A completely mixed activated sludge plant works under the following conditions: influent flow rate = 60 000 m3/d, primary effluent VSS concentration = 100 mg/L, aerator volume = 8000 m3, MLVSS = 1800 mg/L, final clarifier effluent VSS = 60 mg/L, biomass production in the reactor = 0.5 kg VSS/m3.d, recycle sludge concentration = 12000 mg/L. Find the recycle flow rate, and the sludge wastage flow rate, assuming that the sludge is wasted from the recycle line. If the settling tank volume is 4000 m3, find the solids retention time. (Problem 1 was solved in class)

2. The head losses in a clean dual-media filter operating under declining rate conditions are the following:
   - Laminar, clean filter: hL = 78 V
   - Turbulent losses: hT = 3000 V2

   In all these expressions V is the filtration rate in m3/s per m2. The maximum available head for filtration is 3.0 m. An orifice plate is placed in the influent pipe to limit the maximum filtration rate. The minimum filtration rate is 2.7 x 10-3 m/s, and the dirty-filter laminar loss at the minimum filtration rate is 2.0 m. What is the orifice loss at the maximum filtration rate? The minimum filtration rate is 0.0027 m/s. Answ.: Orifice loss = 2.6 m.

3. The initial bed depth in a rapid sand filter is 1.0 m and the initial sand porosity is 0.43. The elevation of the edge of the wash water troughs, through which the wash water overflows into the trough, is 0.35 m above the sand surface. If all particles had a uniform size and the backwash rate is 0.35 cm/s, find the particle size of the largest particle that will be washed off into the troughs during filter backwash. Assume a water kinematic viscosity of 1.3101 x 10-6 m2/s, Richardson and Zaki n = 4.5, and a sand specific gravity of 2.5. Answ.: 0.03 cm.

2006

1. A completely mixed activated sludge plant works under the following conditions: influent flow rate = 50 000 m^3/d, primary effluent SS concentration = 150 mg/L, aerator volume = 8000 m^3, settling tank volume = 4000 m^3, MLSS = 3000 mg/L, final clarifier effluent SS = 25 mg/L, recycle sludge concentration = 10 000 mg/L, solids retention time = 3 days. Assuming that the sludge is wasted from the recycle line, find the sludge recycling flow rate. Answ.: Q_R = 19714 m^3/d.

2. The head losses in a clean dual-media filter operating under declining rate conditions are the following:
   - Laminar, clean filter: $h_L = 78\ V$
   - Turbulent losses: $h_T = 3000\ V^2$

   In all these expressions V is the filtration rate in m3/s per m2. The maximum available head for filtration is 3.0 m. An orifice plate is placed in the influent pipe to limit the maximum filtration rate. The minimum filtration rate is 2.7 x 10-3 m/s, and the dirty-filter laminar loss at the minimum filtration rate is 2.0 m. What is the orifice loss at the maximum filtration rate? Answ.: 2.6 m.

2007

1. A rapid sand filter has a 76.2-cm deep sand bed with an initial porosity of 0.41. Pertinent data are given in the table below. Find the depth of the expanded bed if the backwash rate is 10.2 L/s.m2.

Sieve size (Tyler)	% Weight Retained	Particle size (m)	Settling Velocity, m/s		
14-20	0.44	0.0010060	0.15252		
20-28	14.33	0.0007111	0.10671		
28-32	43.22	0.0005422	0.07747		
32-35	27.02	0.0004572	0.06206		
35-42	9.76	0.0003834	0.04854		
42-48	4.22	0.0003225	0.03752		
48-60	0.54	0.0002707	0.02847		
60-65	0.29	0.0002274	0.02134		
65-100	0.13	0.0001777	0.01391		

Answ.: 1.32 m.

2. A completely mixed activated sludge plant works under the following conditions: influent flow rate = 50 000 m^3/d, primary effluent SS concentration = 150 mg/L, aerator volume = 8000 m^3, settling tank volume = 4000 m^3, MLSS = 3000 mg/L, final clarifier effluent SS = 25 mg/L, recycle sludge concentration = 10 000 mg/L, solids retention time = 3 days. Assuming that the sludge is wasted from the recycle line, find: (a) the sludge recycling flow rate. Answ.: 19614 m^3/d, (b) the sludge wasting flow rate. Ans.: 1077.7 m^3/d.

2008

1. A water filtration plant produces 1.5 m^3/s at an average filtration rate of 12.50 $m^3/h.m^2$ when all units are operating; the filtration rate increases to 14.29 $m^3/h.m^2$ when one unit is out of service for backwashing. Each unit is backwashed for 7 minutes every 24 hours at a backwash rate of 48.9 m/hr. Find the following: (a) The number of filtration units. Answ.: N = 8 (b) The percentage of filter output used for backwashing. Answ.: 1.9%. (c) If the dual media is composed of anthracite with uniformity coefficient = 1.5, and sand, find the uniformity coefficient of the sand if it desired to have at least 15 cm of media intermixing after filter backwashing. Answ.: UC = 1.54.

2. The thickness of the gravel, sand, and water layers in a rapid sand filter are 0.6 m, 1.0 m, and 1.5 m, respectively. When the filter is backwashed at a constant rate of 60 cm/min all the sand is fluidized, and the head loss through the false bottom is 60 cm.

   A. What is the head loss through the sand and the gravel? Answ.: 1.12 m
   B. Assuming the backwash rate is increased to 75 cm/min, what is the total head loss through the sand, gravel and filter bottom? Assume that the backwash flow is laminar through the gravel, and turbulent through the false bottom. Answ: 2.09 m

head for filtration is 1.15 m. If the average filtration rate is 20 cm/min, the minimum filtration rate is 70 per cent of the average rate, and the maximum filtration rate is 1.3 times the average rate, find the dirty-filter laminar head loss assuming there is an orifice plate.

PART B

Answer the following questions **in the space provided**:

a) How do you determine the size of individual gravity granular filters?

p.152 : Plant capacity, filtration rate & # of units desired
Max size of individual units up to 450 m^2, More typical < 220 m^2

b) Give two advantages and two disadvantages of direct filtration.

p.153: Advantages : cost savings (elimination of sedimentation)
O&M costs may be reduced. Sludge is dense & more easily dewatered.
Disadvantages: Shorter filter runs
inability to handle large variations in solids loadings

c) How can you achieve coarse-to-fine granular beds in filters back washed by media fluidization and expansion?

Use dual media ; anthracite (lighter, coarser) & sand (finer, heavier)

d) How can you avoid the formation of mud balls in granular filters? Explain.

Air + water backwash

e) What is the difference between free residual chlorination and combined residual chlorination?

Free residual : $OCl^- + HOCl$

Combined : $NH_2Cl + NHCl_2 + NCl_3$
Mono di trichloramines } less efficient

u.w Oct.4 ①   Test I Oct. 13

$P_{10} : D_{10}$

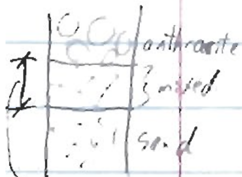
Rapid Sand filtration

- Classic Filter : sand w/ $P_{10} = 0.35 \to 0.55$; $U_c < 1.5$
- Particle size distribution follows log-normal distribution
- Backwashing arranges particle sizes from fine @ Top, coarse @ bottom

Duel media filter

- use less dense coarse, more dense fines

Attachment* on last class handout Fig 24, 25



- dashed line = sand, solid = anthracite alone
- dotted = duel media (both of above)
- there is evidence of better performance than sand alone
- * Fluidization backwash

15cm occurs when $\left[\dfrac{(P_{90})coal}{(P_{10})sand} \simeq 3 \text{ [recommended]}\right]$

$>> 15cm$ $\left[\dfrac{P_{90}\,Coal}{P_{10}\,Sand}\right] = 4$ we get substantial intermixing

* Advantage of duel media is Lost.

ratio = 2.0 - 2.5 very little mixing, get a sharp interface ∴ get clogging @ interface

To ensure fluidization of both media, sand P_{90} & anthracite P_{90} must have the same fluidization velocity

Typical media design:

media	Depth (cm)	U_c	P_{10} (mm)	ρ (g/cm³)	Hardness Moh scale
Anthracite	45-60	<1.8	$0.9 \to 1.2$	$1.5 \to 1.7$	$2 \to 3.55$
Sand	38 45	<1.5	$0.35 \to 0.55$	$2.5 \to 2.65$	>7

Ex. Specify sand & anthracite particle size distribution so that both will completely fluidize. Select backwash rate

Sol'n: Assume log-norm distribution

* Select $P_{10\ anthra.} = 0.9mm$ (Arbitrary), $U_{c\ anthra.} = 1.5$ (Arbitrary)

$P_{60\ anthra.} = U_{c\ anthra.}(P_{10\ anthra.}) = 1.5(0.9) = 1.35mm$

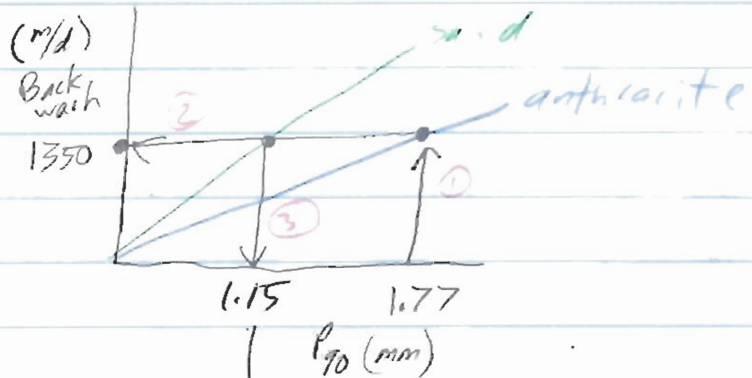
$P_{90\ antra.} = P_{10}(U_c)^{1.67} = 1.77mm$ ← Property of log-norm.

* Select Sand * For good media intermixing

$\rightarrow \frac{P_{90\ anthra.}}{P_{10\ sand}} = 3 \rightarrow P_{10\ sand} = 0.59mm$

ON HANDOUT FROM LAST CLASS use Backwash graph

Backwash rate = 1350 m/d (From chart)



→ $P_{90\ sand} = 1.15mm$ (From chart)

$U_{c\ sand} = \left(\frac{P_{90}}{P_{10}}\right)^{1/1.67}$ (property of log-norm) = 1.49

$P_{60\ sand} = U_c P_{10} = 0.88mm$

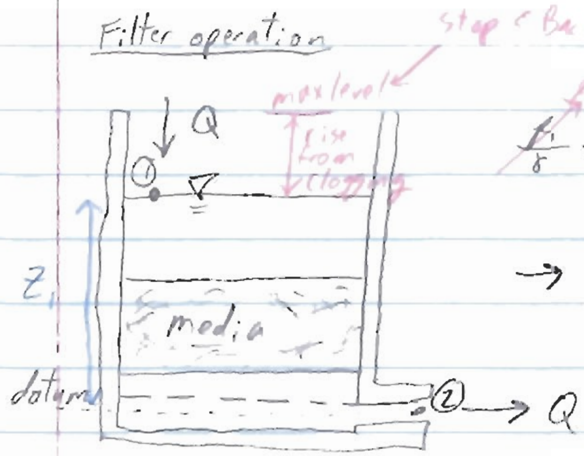
W.W. Oct. 4 (2)

Gravel layer

2 Purposes * Keep sand out of under drains * Provide uniform backwash water distribution

* usually 25-60cm of hard round stones w/ several sizes specified in fig. 27-18 of today's handout

Filter operation



Energy Bal. b/t ① & ②

$$\cancel{\frac{p_1}{\gamma}} + z_1 + \cancel{\frac{V_1^2}{2g}} = \frac{p_2}{\gamma} + \cancel{z_2} + \frac{V_2^2}{2g} + h_{L_{1-2}}$$

$$\rightarrow \frac{V_2^2}{2g} = z_1 - \frac{p_2}{\gamma} - h_{L_{1-2}} \qquad V_2 = \frac{Q}{A} \quad A_{pipe}$$

$$\hookrightarrow Q = A\sqrt{2g\left(z_1 - \frac{p_2}{\gamma} - h_{L_{1-2}}\right)} = \text{Const.}$$

(1) Keeping $\frac{p_2}{\gamma}$ = Cost. As filtration proceeds, $h_{L_{1-2}}$ increases ∴ to maintain cost. Q, z_1 must increase.

(2) If keeping z_1 constant (same water level) as $h_{L_{1-2}}$ increases, $\frac{p_2}{\gamma}$ must decrease. If $h_{L_{1-2}}$ is too large $\frac{p_2}{\gamma}$ may become neg & you will get air bubbles (Process called air binding)

Two methods of Controlling Filtration Rate

(1) Operating @ Constant Rate
* achieved by mechanical rate control
or * achieved by Influent flow splitting

(2) Operate @ declining filtration rate

Avg C

~~100~~/100 84/100

ENCE 4323 FIRST EXAM

October 13, 2010 Name: Donald Secollman

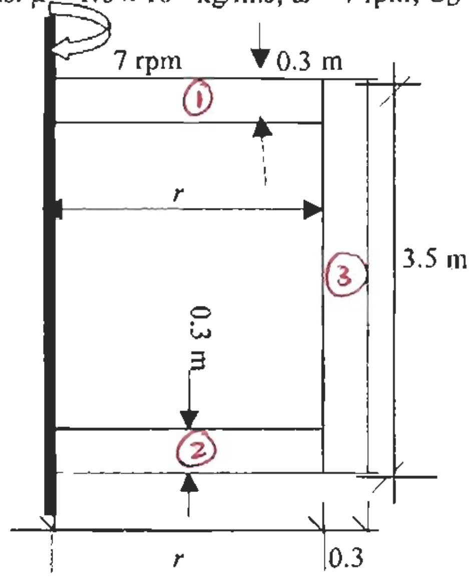
Instructions:

The test is open book, open notes. Time available: 1 hour. Complete both parts A and B.

PART A

Solve **only two** of the following three problems:

1. A flocculation tank has a vertical shaft with a paddle wheel consisting of a single arm with three blades assembled as shown in the sketch below. The tank has the following dimensions: length = 6 m, width = 6 m, water depth = 4.0 m. Find the value of the paddle radius r required to get a velocity gradient $G = 60\ s^{-1}$ using the following constants: $\mu = 1.6 \times 10^{-3}$ kg/m.s; $\omega = 7$ rpm; $C_D = 1.8$; $k = 0.25$; $\rho = 1000\ kg/m^3$



2. A first order reaction takes place in two CFSTRs connected in series. The influent reactant concentration in the first reactor is 200 mg/L. Batch reactor tests on the same reaction, with an initial concentration of 150 mg/L, gave a reactant half-life of 1.5 seconds (half-life is the time required for the concentration to drop to one-half of the original value). If the mean detention time in the first reactor is 150 seconds and 100 seconds in the second CFSTR, find the effluent concentrations in the first and in the second reactors.

3. A suspension of discrete particles having an average density of 1500 kg/m^3 is to be treated in a settling tank designed to remove 100% of particles with a diameter = 0.038 mm. The particle settling velocity distribution is given below. Find the total fraction of particles removed. The liquid kinematic viscosity is $1.3101 \times 10^{-6}\ m^2/s$, and the density is 1000 kg/m^3.

Particle settling velocity, m/s	Mass Fraction
2.5×10^{-5}	0.10
5.2×10^{-5}	0.20
9.2×10^{-5}	0.25
13.8×10^{-5}	0.15
21.2×10^{-5}	0.05
29.3×10^{-5}	0.15
36.0×10^{-5}	0.05
49.3×10^{-5}	0.05

Donald Serolleman

PART B 24/30

Answer the following questions **in the space provided**:

6 1. If you have a first order reaction, what type of continuous flow reactor would you recommend if you want to minimize the reactor size for a given conversion? Explain.

- 1 order rxn ?? they would be the same
* CFSTR is always > PFR for same conversion
* Vol. ratio ~~Hdbtr~~ V_{CFSTR}/V_{PFR} goes up with reaction order
* For same reaction V, PFR is more efficient than CFSTR

∴ recommend PFR

6 2. What is the main difference between primary and secondary drinking water standards?

Primary: * Federal law apply to public water systems
* Specify contaminants that may have adverse health effects
" for each contaminant a MCL or a treatment technique

Secondary: proposed & promulgated by EPA
* based on aesthetic considerations
* Not federally enforced (but possibly state enforced)

6 3. Can you remove colloidal particles by plain sedimentation? Give a brief explanation.

NO because Double Layer Theory! Particle repulsion,
- Colloidal stability takes place

6 4. What is tapered flocculation and how do you achieve it?

The flow is subjected to decreasing G values as it passes through the flocculation basin.
* Increase cross-sectional area.
* move from one basin to the next decreasing velocity gradient

0 5. Briefly explain how high rate settling works.

Flocculant solutions are added to water to produce flocculant (the attraction of smaller particles to become larger particles) which settle faster

2) 1^{st} order, C_{A_0} 200 mg/L → CFSTR $\bar{t} = 150\,s$ → C_{A_1} → CFSTR $\bar{t} = 100\,s$ → C_{A_2}

$\frac{C_{A_0}}{2}$ @ $\bar{t} = 1.5\,s$

Find C_{A_1} & C_{A_2}

28/35

Must use Batch reactor equation

−7

$$\bar{t}_{CFSTR} = \frac{C_{A_0} - C_A}{K\,C_A} = \frac{1}{K}\left(\frac{C_{A_0}}{C_A} - 1\right)$$

$$1.5\,s = \frac{1}{K}\left(\frac{C_{A_0}}{\frac{C_{A_0}}{2}} - 1\right) \quad 1.5\,s = \frac{1}{K}(2-1) = \frac{1}{K} \rightarrow K = 0.667\,\frac{l}{mg \cdot s}$$

1st CFSTR

$$\bar{t}_{150} = 150\,s = \frac{1}{0.667}\left(\frac{200}{C_{A_1}} - 1\right) \rightarrow \boxed{C_{A_1} = 1.979\,\frac{mg}{l}}$$

2nd CFSTR

$$\bar{t}_{100} = 100\,s = \frac{1}{0.667}\left(\frac{1.979}{C_{A_2}} - 1\right) \rightarrow \boxed{C_{A_2} = 0.0292\,\frac{mg}{l}}$$

1) ~~27~~ 32/35

$$F_D = C_D A \rho \frac{v^2}{2} \qquad P = F_D v = C_D A \rho \frac{v^3}{2} = \frac{\pi^3}{2} \rho C_D b (1-k)^3 \omega^3 (r_0 + r_i \ldots)(r_0 - r_i)$$

Not applicable for paddles 1 & 2

L-W ratio of paddles

5 → $C_D = 1.2$

20 → $C_D = 1.5$

∞ → $C_D = 1.9$

$\boxed{C_D = 1.8}$

$\boxed{\mu = 1.6 \times 10^{-3}\,\frac{kg}{m \cdot s}}$ $\boxed{\omega = 7\,rpm}$ $\boxed{K = 0.25}$ $\boxed{\rho = 1000\,\frac{kg}{m^3}}$

$\boxed{G = 60\,s^{-1}}$

↳ 0.11667 rps

0.

$$60\,s^{-1} = \left[\frac{\frac{\pi^3}{2}(1000)(1.8)(0.4219)(0.001588)\left(2(0.3)(r^3)(r) + (3.5)\left[((r+0.3)^3 + r^3) - ((r+0.3) - r\ldots\right.\right.}{1.6 \times 10^{-3}\ (6 \times 6 \times 4)}\right.$$

$$3600 = \frac{(18.696)\left\{0.6(r^4) + 3.5\left[((r+0.3)^3 + r) - ((r+0.3) - r)\right.\right.}{0.2304}$$

Simpler version on next page

$$3600 = \frac{37.39\left(0.6\left(r^4\right) + 3.5\left(\left(r+0.3\right)^4 - r^4\right)\right)}{0.2304}$$

$$829.4 = 22.1352\, r^4 + 130.87\left(\left(r+0.3\right)^4 - r^4\right)$$

Solve for r -3

ENCE 4323

Old second exam problems

1995

1. Calculate the head loss through a clean sand filter with a gradation defined by the sieve analysis given below at a filtration rate of 0.0027 m/s. The bed has a depth of 0.70 m with a porosity of 0.45 and the grains of sand have a sphericity of 0.75. Assume the kinematic viscosity is 1.306×10^{-6} m²/s.

Sieve designation number	12	16	20	30	40	50
Size of the opening, S, mm	1.68	1.19	0.84	0.59	0.42	0.297
Fraction of sand retained	0.02	0.25	0.47	0.24	0.02	

2. The following are the turbulent and clean laminar head losses in a rapid granular filter operated under declining rate conditions:

- Sand: $hf_s = 53.1560\ V$
- Anthracite: $hf_a = 15.1460\ V$ (68.302 V laminar)
- Drainage piping: $hf_d = 1441.9000\ V^2$
- False bottom: $hf_b = 0.7262\ V^2$ (2952.65 V² turbulent)
- Valves and fittings: $hf_v = 1510.0200\ V^2$

In all these expressions V is the filtration rate in m³/s per m². The maximum available head for filtration is 1.15 m, and the dirty-filter head loss at the minimum filtration rate of 12.538 cm/min is 0.7666 m. Find the additional turbulent head loss that must be introduced by an orifice plate in the influent pipe to balance the filter hydraulics. Plot at least five points of the dirty-filter laminar head loss and the total turbulent loss (drainage piping, false bottom, valves and fittings, and orifice plate) curves.

3. The turbulent and clean laminar head losses in a rapid granular filter operating under declining rate conditions are the same as those given in problem 2. The maximum available head for filtration is 1.15 m. If the average filtration rate is 20 cm/min, the minimum filtration rate is 70 per cent of the average rate, and the maximum filtration rate is 1.3 times the average rate, find the dirty-filter laminar head loss assuming there is an orifice plate.

(2) $H = K_1 V + K_2 V^2 + K_0 V^2$ {K_1 changes w/time, K_2 & K_0 = const.} {when clean => V_{max}; dirty => V_{min}}

V_{max} ... K_0 ... V_{max} (...) ...

(3) Solve K_0 ... dirty ...

1.

Sieve No	Opening, mm	Fraction retained	$d_i = \sqrt{d_{i-1} \times d_{i+1}}$	$\frac{p_i}{d_i^2}$
		0.02		
12	1.68			
		0.25	1.413	0.125
16	1.19			
		0.47	1.0	0.470
20	0.84			
		0.24	0.704	0.484
30	0.59			
		0.02	0.498	0.081
40	0.42			
			0.353	
50	0.297			
		10	5	1.16 mm^{-2} (5)

20

9.51 $^{KN}/_{m^3}$ = 51.4 lb/ft³

$1.16 \frac{1}{mm^2} \times \frac{1000\ mm}{m}$

$$\frac{h_0}{L} = \frac{180}{g} \nu\, v \frac{(1-f)^2}{f^3} \left(\frac{1}{\psi}\right)^2 \sum \frac{p_i}{d_i^2}$$

porosity   shape factor

$$\frac{h_0}{L} = \frac{180}{9.81} \times 1.306 \times 10^{-6} \times 0.0027 \times \frac{(1-0.45)^2}{0.45^3} \left(\frac{1}{0.75}\right)^2 \times 1.16 \times 10^{+6}$$

$$\frac{h_0}{L} = 0.4429 \ ; \quad h_0 = 0.31\ m$$

15

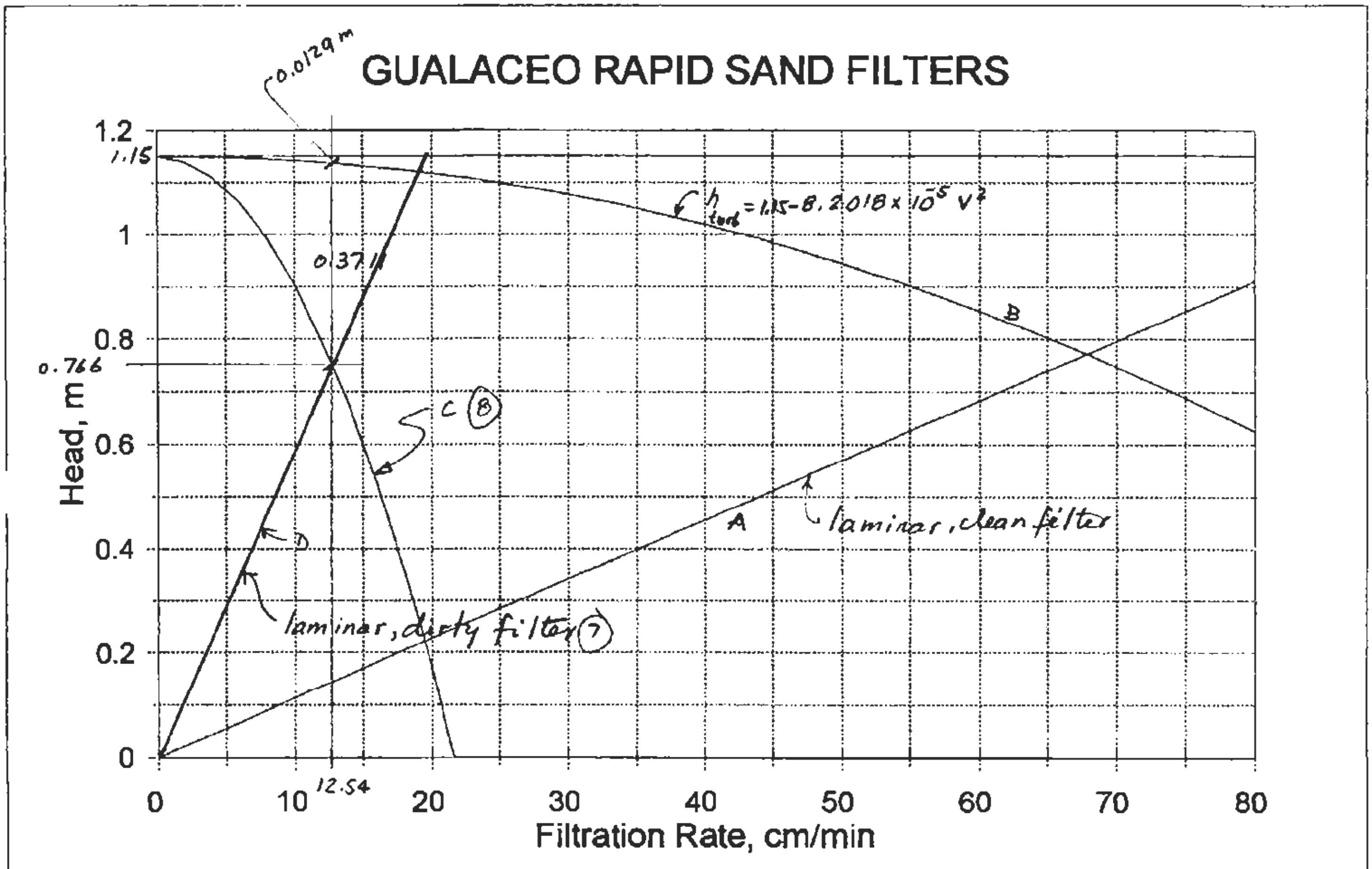
2. $h_{turb} = 2952.6462 \left(V \frac{cm}{min} \times \frac{1 min}{60 s} \times \frac{1 m}{100 cm}\right)^2$

$\therefore$ $h_{turb} = 8.2018 \times 10^{-5} V^2$; $V = 12.54$; $h_{turb} = 0.0129 \ m$

$h_{orifice} = 1.15 - 0.0129 - 0.766$; $h_{orifice} = 0.3711 \ m$

20

DON'T PAY ATTENTION TO THE GRAPHICAL SOLUTION



$12.54 \frac{cm}{min} \times \frac{1 min}{60 s} \times \frac{1 m}{100 cm} = 0.00209 \ m/s$

Curve C : $h_{orifice} = 0.3711 \left(\frac{V}{12.54}\right)^2$; $h_{orifice} = 0.00236 \ V^2$

$H = 1.15 - 8.2018 \times 10^{-5} V^2 - 0.00236 \ V^2$ (curve C) 8

Curve D : $H = \frac{0.7666}{12.54} V$ (V in cm/min) ; $\boxed{H = 0.0611 \ V}$ V in cm/s

7 $H = \frac{0.7666}{0.00209} V$ (V in m/s)

$\boxed{H = 366.79 \ V}$ V in m/s

$12.54 \frac{cm}{min} \times \frac{1 min}{60 s} \times \frac{1 m}{100 cm}$

3. $V_{avg} = 20\,cm/min$; $V_{min} = 14\,cm/min$, $V_{max} = 26\,cm/min$

Clean filter laminar loss $= 68.302\,V$ (V in m/s)

$= 0.01139\,V$ (V in cm/min)

@ $V = 26\,cm/min$, $h_{laminar} = 0.296\,m$

$h_{turb} = 8.2018 \times 10^{-5}\,(26)^2$

$= 0.055\,m$

20

$\therefore$ orifice loss $= 1.15 - 0.055 - 0.296$; orifice loss $= 0.799\,m$.

$v_{min} = a \cdot v_{av}$; $v_{max} = b \cdot v_{av}$.

$v_{av} = \dfrac{v_{min} + v_{max}}{2} = \dfrac{a \cdot v_{av} + b \cdot v_{av}}{2}$

$\therefore \boxed{a + b = 2}$ $a = 0.7$; $b = 1.3$

Recommended : $a = 0.7 - 0.8$; $b = 1.2 - 1.$

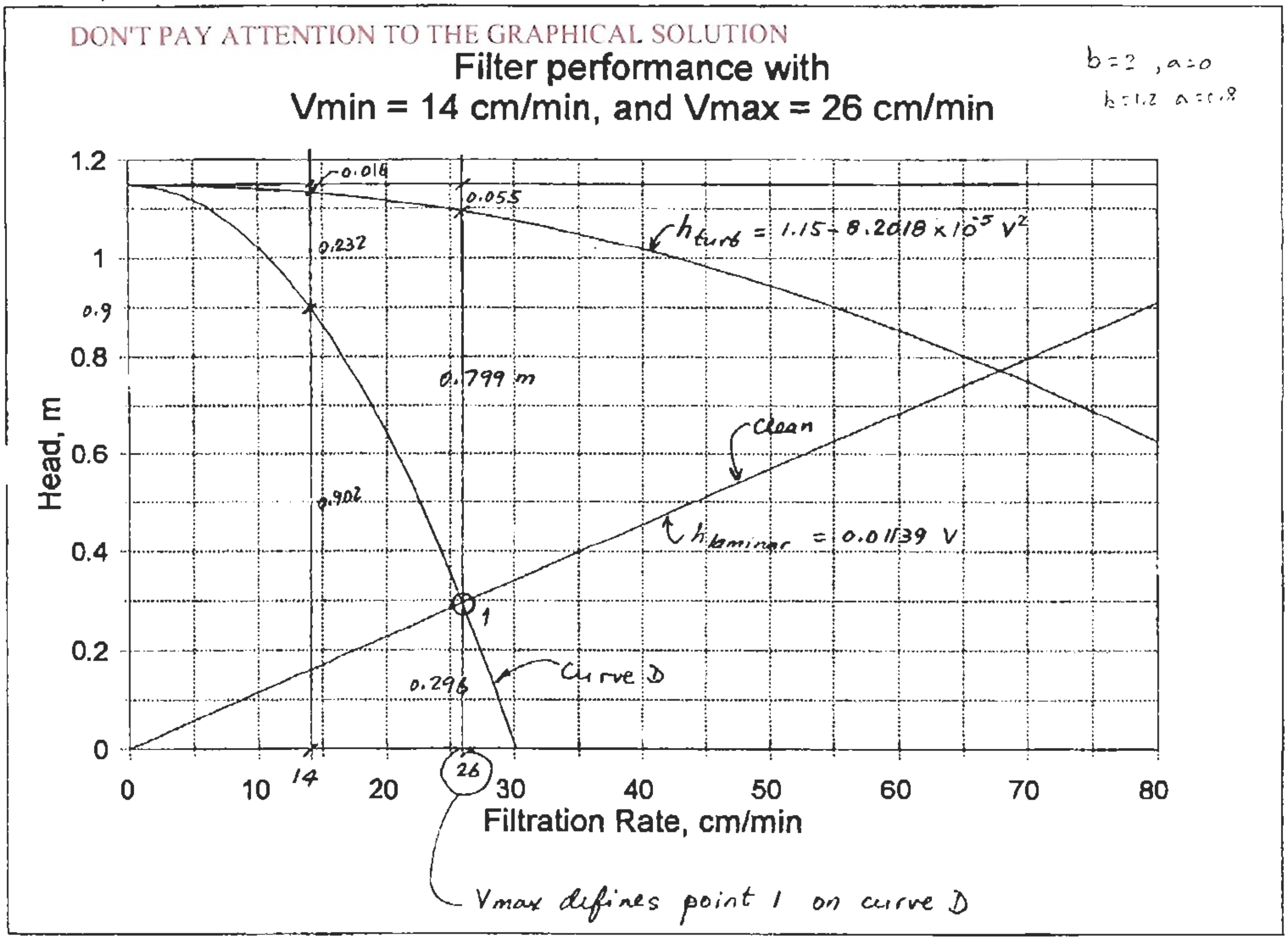
Additionally : $v_{min} = c \cdot v_{max}$

$a \cdot v_{av} = c \cdot b\,v_{av}$ $\therefore a = bc$

$bc + b = 2$; $b(c+1) = 2$

$\boxed{c = \frac{2}{b} - 1}$ $\therefore c = \frac{2}{1.3} - 1$

$c = 0.538$



7 orifice loss @ $V = 14\,cm/min$: $h_{orif} = 0.799 \left(\frac{V}{26}\right)^2 = 0.232\,m$

8 $\therefore$ dirty-filter laminar loss $= 1.15 - \underbrace{8.2018 \times 10^{-5}\,(14)^2}_{0.016} - 0.232$

laminar loss $= 0.902\,m$

This problem shows that by choosing Vmin & Vmax we can solve for orifice loss

SECOND

ENCE 4323 ~~FIRST~~ EXAM

November 24, 2004 Name: E. La Motta

Instructions:

a) The test is open book, open notes.
b) b) Time available: 1 hour.
c) Complete both parts A and B.

PART A

Solve **only two** of the following three problems:

1. A completely mixed activated sludge plant works under the following conditions: influent flow rate = 60 000 m3/d, primary effluent VSS concentration = 100 mg/L, aerator volume = 8000 m3, MLVSS = 1800 mg/L, final clarifier effluent VSS = 60 mg/L, biomass production in the reactor = 0.5 kg VSS/m3.d, recycle sludge concentration = 12000 mg/L. Find the recycle flow rate, and the sludge wastage flow rate, assuming that the sludge is wasted from the recycle line. If the settling tank volume is 4000 m3, find the solids retention time.

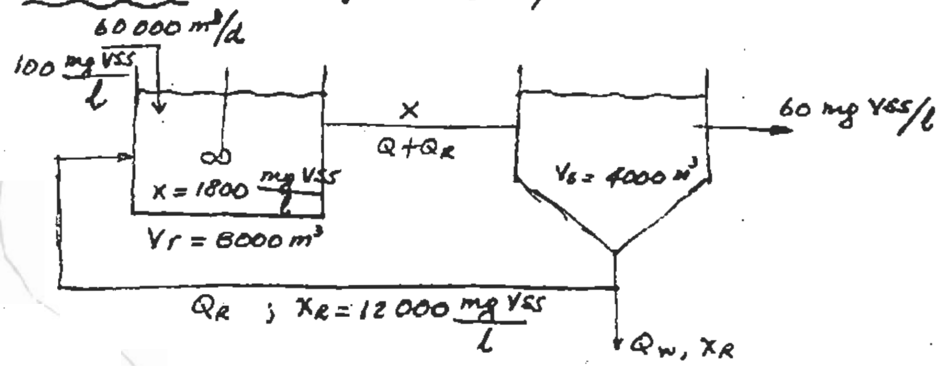
2. The head losses in a clean dual-media filter operating under declining rate conditions are the following:

   - Laminar, clean filter: $h_L = 78\ V$
   - Turbulent losses: $h_T = 3000\ V^2$

   In all these expressions V is the filtration rate in m^3/s per m^2. The maximum available head for filtration is 3.0 m. An orifice plate is placed in the influent pipe to limit the maximum filtration rate. The dirty-filter laminar loss at the minimum filtration rate is 2.0 m. What is the orifice loss at the maximum filtration rate? The min filtration rate is 2.7×10^{-3} m/s

3. The initial bed depth in a rapid sand filter is 1.0 m and the initial sand porosity is 0.43. The elevation of the edge of the wash water troughs, through which the washwater overflows into the trough, is 0.35 m above the sand surface. If all particles had a uniform size and the backwash rate is 0.35 cm/s, find the particle size of the largest particle that will be washed off into the troughs during filter backwash. Assume a water kinematic viscosity of $1.3101 \times 10^{-6}\ m^2/s$, and a sand specific gravity of 2.5. $n = 4.5$

Example $\quad r_g = 0.5\ kg\ VSS/m^3 \cdot d$



$\frac{mg}{l}\left(\frac{1}{1000}\right)$

Find : Q_R , Q_W , $\bar{t}_c$

• Solution :

– Eq. (2) : $Q X_i + V_r r_g = Q_W X_R + (Q - Q_W) X_e$; $Q_W = \dfrac{Q X_i + V_r \cdot r_g - Q X_e}{X_R - X_e}$

Need

$$60\,000 \frac{m^3}{d} \times 0.1 \frac{kg}{m^3} + 8000\, m^3 \times 0.5 \frac{kg}{m^3 \cdot d} = Q_W \cdot 12.0 \frac{kg}{m^3} + (60\,000 - Q_W) \times 0.06 \frac{kg}{m^3}$$

Solve for Q_W : $Q_W = 536\ m^3/d$

– Eq. (3) : $X = \dfrac{X_R (Q_R + Q_W) + X_e (Q - Q_W)}{Q + Q_R}$

$$1.8 \frac{kg}{m^3} = \frac{12.0 \frac{kg}{m^3}\left(Q_R + 536 \frac{m^3}{d}\right) + 0.06 \frac{kg}{m^3}(60\,000 - 536)\frac{m^3}{d}}{(60\,000 + Q_R)\frac{m^3}{d}}$$

Solve for Q_R ! $Q_R = 9608\ m^3/d$

– Eq. (6) : $\bar{t}_c = \dfrac{X\left(1 + \frac{V_s}{V_r}\right)}{\frac{X_i}{\bar{t}} + r_g}$

$$\bar{t}_c = \frac{1.8 \frac{kg}{m^3}\left(1 + \frac{4000}{8000}\right)}{\frac{0.1 \frac{kg}{m^3}}{8000\, m^3 / 60\,000 \frac{m^3}{d}} + 0.5 \frac{kg/m^3}{d}} \quad ; \quad \bar{t}_c = 2.2\ d$$

High 100
Avg 69.2
Low 46

ENCE 4323 SECOND EXAM

November 22, 2006 Name: E. La Motta

Instructions: The test is open book, open notes. Time available: 1 hour. Complete both parts A and B.

PART A (70 points)

Solve **only two** of the following three problems:

1. (35 points) A completely mixed activated sludge plant works under the following conditions: influent flow rate = 50 000 m^3/d, primary effluent SS concentration = 150 mg/L, aerator volume = 8000 m^3, settling tank volume = 4000 m^3, ML~~V~~SS = 3000 mg/L, final clarifier effluent SS = 25 mg/L, recycle sludge concentration = 10 000 mg/L, solids retention time = 3 days. Assuming that the sludge is wasted from the recycle line, find the sludge recycling flow rate.

   Not needed

   Not needed

   t_c

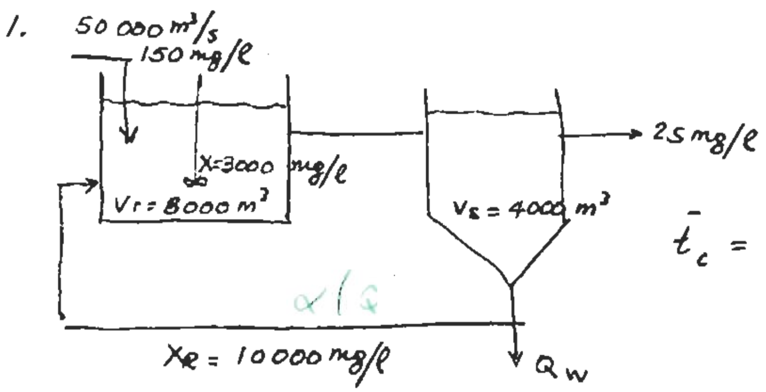
2. (35 points) The head losses in a clean dual-media filter operating under declining rate conditions are the following:

   - Laminar, clean filter: $h_L = 78\ V$
   - Turbulent losses: $h_T = 3000\ V^2$

   In all these expressions V is the filtration rate in m^3/s per m^2. The maximum available head for filtration is 3.0 m. An orifice plate is placed in the influent pipe to limit the maximum filtration rate. The minimum filtration rate is 2.7×10^{-3} m/s, and the dirty-filter laminar loss at the minimum filtration rate is 2.0 m. What is the orifice loss at the maximum filtration rate?

3. (35 points) The initial bed depth in a rapid sand filter is 1.0 m and the initial sand porosity is 0.43. The elevation of the edge of the wash water troughs, through which the washwater overflows into the trough, is 0.35 m above the sand surface. If all particles had a uniform size and the backwash rate is 0.35 cm/s, find the particle size of the largest particle that will be washed off into the troughs during filter backwash. Assume a water kinematic viscosity of $1.3101 \times 10^{-6}\ m^2/s$, a Richardson and Zaki exponent n = 4.5, and a sand specific gravity of 2.5.

1.



$\bar{t}_c = 3$ days

Eq. 9: $\alpha = \dfrac{X\left[1 - \frac{t}{\bar{t}_c}\left(1+\frac{V_s}{V_r}\right)\right]}{X_R - X}$ (12)

$\alpha = \dfrac{3.0}{10-3.0}\left[1 - \dfrac{0.16}{3.0}\left(1+\dfrac{4000}{8000}\right)\right]$

$\alpha = 0.3943$ (12)

$\therefore Q_R = 0.3943 \times 50\,000$ (11)
$= 19714$

• $\bar{t}_c = \dfrac{X\left(1+\frac{V_s}{V_r}\right)}{\frac{X_i}{\bar{t}} + r_g}$; $r_g = \dfrac{X\left(1+\frac{V_s}{V_r}\right)}{\bar{t}_c} - \dfrac{X_i}{\bar{t}}$

$\bar{t} = \dfrac{8000\ m^3}{50\,000\ m^3/d}$; $\bar{t} = 0.16\ d$

$r_g = \dfrac{3.0\ kg/m^3\left(1+\frac{4000}{8000}\right)}{3d} - \dfrac{0.15\ kg/m^3}{0.16\ d}$; $r_g = 0.5625\ \dfrac{kg/m^3}{d}$ (11)

• Eq. 2: $Q X_i + V_r \cdot r_g = Q_W X_R + (Q - Q_W) X_e$

Solving for Q_W: $Q_W = \dfrac{Q X_i + V_r \cdot r_g - Q X_e}{X_R - X_e}$

$$Q_W = \frac{50\,000\frac{m^3}{d} \times 0.15\ kg/m^3 + 8000\ m^3 \times 0.5625\ \frac{kg/d}{m^3} - 50000\frac{m^3}{d} \times 0.025\ kg/m^3}{(10 - 0.025)\ kg/m^3}$$

$Q_W = 1077.7\ m^3/d$ (12)

• Eq. 3: $QX + Q_R X = Q_R X_R + Q_W X_R + X_e(Q - Q_W)$

$Q_R(X_R - X) = QX - Q_W X_R - X_e(Q - Q_W)$

$$Q_R = \frac{QX - Q_W X_R - X_e(Q - Q_W)}{X_R - X}$$

$$Q_R = \frac{50\,000 \times 3.0 - 1077.7 \times 10 - 0.025(50000 - 1077.7)}{10 - 3}$$

$Q_R = 19{,}714\ \dfrac{m^3}{d}$ (12)

or, Eq. 1: $V_r \cdot r_g + Q X_i = (Q + Q_R)X - Q_R X_R$

$V_r r_g + Q X_i - QX = Q_R(X - X_R)$

$Q_R = \dfrac{QX - V_r r_g - Q X_i}{X_R - X}$, get same answer

$\frac{74}{100}$ C

ENCE 4323 SECOND EXAM

November 22, 2010 Name: Donald Scrolleman

Instructions: The test is open book, open notes. Time available: **1 hour**. Complete both parts A and B.

PART A (70 points)

Solve **only two** of the following three problems:

35/35

1. (35 points) A rapid sand filter has a 60-cm deep sand bed with an initial porosity of 0.40. Pertinent data are given in the table below. Find the depth of the expanded bed if the backwash rate is 48.9 m/h, assuming Richardson and Zaki's n = ~~0.45~~. 4.5

$L: 0,60m$ P_i in Le eqn.

V_B: → ~~0.815 m/s~~ 0.01358 m/s

$P_e=\left(\frac{V_B}{V_s}\right)^{\frac{1}{n}}$

$L_e = L(1-P)\sum \frac{P_i}{1-P_e}$

$L_e = 0.6(1-0.4)(3.60814)$

$\boxed{1.3\ m}$ ✓

Sieve size (Tyler)	~~%~~ Mass Retained P_i	Geometric Mean Particle size (m)	Settling Velocity, m/s V_s	P_e ✓	$\frac{P_i}{1-P_e}$
14-20	0.44 0.0044	0.0010060	0.15252	0,58425	0.01058
20-28	0.14,33	0.0007111	0.10671	0,6251	0,3899
28-32	0,43,22	0.0005422	0.07747	0,67916 ✓	1,3471
32-35	0.27,02	0.0004572	0.06206	0,71347 ✓	0.94301
35-42	0,09,76	0.0003834	0.04854	0,7535 ✓	0.39596
42-48	0.04,22	0.0003225	0.03752	0,7979 ✓	0.2088
48-60	0.00,54	0.0002707	0.02847	0.84836 ✓	0.03561
60-65	0.00.29	0.0002274	0.02134	0.9045 ✓	0.030363
65-100	0.00.13	0.0001777	0.01391	0.9947	0.246817
				Σ	$\boxed{3.60814}$ ✓

2. (35 points) A completely mixed activated sludge plant works under the following conditions: influent flow rate = 60 000 m^3/d, primary effluent SS concentration = 120 mg/L, aerator volume = 10 000 m^3, settling tank volume = 8000 m^3, MLSS = 3500 mg/L, final clarifier effluent SS = 20 mg/L, recycle sludge concentration = 12 000 mg/L, solids retention time = 5 days. Assuming that the sludge is wasted from the recycle line, find: (a) the sludge recycling ratio, (b) the biomass growth rate.

35/35

3. (35 points) The head losses in a clean dual-media filter operating under declining rate conditions are the following: Laminar, clean filter, h_L= 85 V; turbulent losses, except the orifice loss, h_T = 3500V^2. In all these expressions V is the filtration rate in m^3/s per m^2. The maximum available head for filtration is 2.5 m. An orifice plate is placed in the influent pipe to limit the maximum filtration rate. After the orifice is installed, the minimum filtration rate is 15 cm/min, and the dirty-filter laminar loss is 1.5 m. What is the orifice loss at both the minimum and maximum filtration rates?

V_{min}: 0,0025 m/s

$H: K_1V + K_2V^2 + K_oV^2$

Clean

$2.5 = 85(V_{max}) + 3500(V_{max})^2 + K_o(V_{max})^2$

$160000 V_{max}^2 + 85 V_{max} - 2.5 = 0 \rightarrow V_{max} = 0.0037$ ✓

Dirty $2.5 = 1.5 + 3500(0.0025)^2 + K_o(0.0025)^2 \rightarrow K_o = 156500$ ✓

∴ Dirty orifice loss = 0.978 m ✓

Clean orifice loss:

$K_o(V_{max})^2 = 156500(0.0037)^2 = \boxed{2.14\ m}$ ✓

Donald Swallerman

PART B (30 points) 4/30

Answer the following questions (6 points each) **in the space provided**:

1. Give at least three differences between rapid sand filters and slow sand filters.

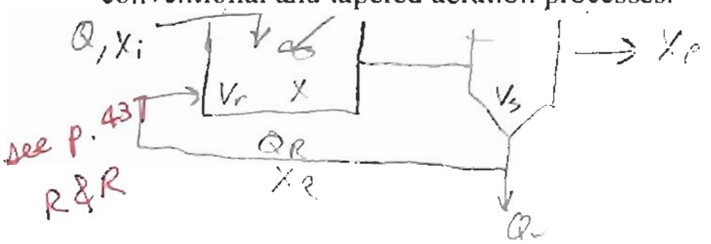
4

- Rapid filters uses smaller design ✓
- slow filters do not need to be backwashed or cleaned as often (longer filtration runs) ✓

X – Rapid filters can process more flow but don't do as well for large variations in solids

0

2. Give at least two advantages of the completely mixed activated sludge system over the conventional and tapered aeration processes.



see p. 437 R&R

creates a lower concentration of Xe by recycling sludge (& thus bacteria)

all of them recycle sludge

3. What is an oxidation ditch?

0

give O_2 to bacteria so that they will be able to have a better growth environment

4. Would you use the NRC formula to design a plastic media trickling filter tower? Explain. prevent too much hydraulic loading on media

0

See p. 538

5. Why do you need a grit chamber in a wastewater treatment plant? Explain.

0

To remove larger particles / trash from clogging system/pipes

NO ↑NO

ENCE 4323

Old Final Exam Problems

In addition to the problems given for the first and second exams, the following are typical final exam problems:

Assignment #4 #1

F95-3. A conventional activated sludge plant must treat a primary effluent flow rate of 4000 m^3/d, with a soluble BOD_5 of 200 mg/l. The organic loading in the aerator is 0.3 kg BOD_5/(d.kg VSS), and the ratio V/Q is 6 hours. Find the concentration of volatile suspended solids in the aerator.

F96-3. A sand filter has the following characteristics: size of sand particles = 0.5 mm (uniform), density of sand = 2600 kg/m^3, depth of filter bed = 0.6 m, bed porosity = 0.4, water density = 998.2 kg/m^3, particle density = 2600 kg/m^3, particle Reynolds Number = 34.71.

a) Determine the required backwash velocity to expand a granular-medium bed to a porosity of 0.7.

b) Determine the depth of the expanded bed.

Assignment #4 #2

F03-1 A wastewater treatment plant is planning to provide for separate anaerobic sludge digestion for its primary sludge. The plant receives an influent wastewater with the following characteristics: Average flow = 8000 m^3/d. Amount of suspended solids removed in the primary sedimentation = 200 mg/L. Volatile matter in the settled solids = 75% by mass. Water in untreated sludge = 96% by mass. Specific gravity of mineral solids = 2.6. Specific gravity of organic solids = 1.3. Find the required digester volume using an SRT of 12 d.

Assignment #4

F03P-1 A wastewater treatment plant is planning to provide for anaerobic sludge digestion for a mixture of primary sludge and waste activated sludge. The raw sludge characteristics are the following: **Primary sludge:** Specific gravity = 1.003; Solids concentration = 3.4 % by mass; Design flow = 420 m^3/d **Waste activated sludge:** Specific gravity = 1.005; Solids concentration = 0.23 % by mass; Design flow = 2500 m^3/d. The mixture of raw primary and waste sludge has specific gravity = 1.002, and it is sent to a thickener to increase the solids concentration to 3.5% by mass. Calculate the percent reduction in sludge volume. Please explain and justify any reasonable assumptions you make.

F04-1 Determine the liquid volume of sludge before and after digestion and the percent reduction for 500 kg (dry basis) of primary sludge with the following characteristics:

	Primary	Digested
Solids %	5	10

Volatile matter, %	60	60 (destroyed)
Specific gravity of fixed solids	2.5	2.5
Specific gravity of volatile solids	≈1.0	≈1.0

F04-3 Three completely mixed reactors are connected in series, and the system removes 99.998% of the first reactor influent reactant concentration. In these reactors, the reactant is removed by a first-order reaction ($k = 3\ d^{-1}$). The last two reactors are identical and have a detention time of 7 days each one. Find the detention time in the first reactor.

F04-4 A conventional activated sludge plant must treat a primary effluent flow rate of 8000 m^3/d, with a soluble BOD_5 of 100 mg/l. The organic loading in the aerator is 0.5 kg BOD_5/(d.kg VSS), and the hydraulic retention time is 5 hours. Find the concentration of volatile suspended solids in the aerator.

F05C. The Marrero wastewater treatment plant generates a total sludge flow rate of 31,408 gal/day, which is sent to the three aerobic digesters. Sludge is pumped out to the belt filter presses (sludge dewatering units) just from Monday through Friday, at such a rate that all the sludge generated in one week (seven days) is removed from the digesters by Friday. When sludge pumping to the belt presses starts on Moday the digesters are full at a total volume of 1,030,378 gallons. Find the mean sludge holding time.

S07-2 A conventional surface-water plant with coagulation, flocculation, sedimentation, and filtration produces a filtered water with a turbidity less than 0.3 NTU, pH 7, and temperature of 10°C at design flow of 2.5 mgd. After filtration, the water is chlorinated in a baffled reservoir with a contact time of 56 minutes.

a. What is the required free chlorine residual concentration?

b. If the plant were direct filtration without sedimentation, what would be the required free chlorine residual concentration?

F07-3 A tank initially contains 200 m^3 of water; however, due to a leak, 50 m^3 are lost after 2 hours. The rate of water loss is directly proportional to the square of the water volume remaining at any time. To compensate for the loss some water was added, but after 3 hours the water volume had been reduced to 150 m^3. How much water was added to the tank?

Solve <u>only three</u> of the following problems.

F07-3

1. Determine the liquid volume of sludge before and after digestion and the percent reduction for 500 kg (dry basis) of primary sludge with the following characteristics:

	Primary	**Digested**
Solids %	4.5	9.0
Volatile matter, %	60	50% is destroyed
Specific gravity of fixed solids	2.5	2.5
Specific gravity of volatile solids	1.0	1.0

2. The turbulent and clean laminar head losses in a rapid granular filter operating under declining rate conditions are the following:

- Sand: $hf_s = 53.2\ V$
- Anthracite: $hf_a = 15.2\ V$
- Drainage piping: $hf_d = 1441.9\ V^2$
- False bottom: $hf_b = 0.7\ V^2$
- Valves and fittings: $hf_v = 1510.0\ V^2$

In these equations, the head loss is in m, and the filtration rate, V, is in m/s. The maximum available head for filtration is 1.50 m. If the average filtration rate is 20 cm/min, the minimum filtration rate is 70 per cent of the average rate, and the maximum filtration rate is controlled by an orifice plate, find the dirty-filter laminar head loss.

3. A tank initially contains 200 m^3 of water; however, due to a leak, 50 m^3 are lost after 2 hours. The rate of water loss is directly proportional to the square of the water volume remaining at any time. To compensate for the loss some water was added, but after 3 hours the water volume had been reduced to 150 m^3. How much water was added to the tank?

4. The detention time in an ideal clarifier is 1.5 h, and its depth is 12 ft. If a full-length movable tray is set at a depth greater than 8 feet below the water surface, determine the percentage of discrete particles with a settling velocity v_s = 3 ft/h that are removed. Plot removal efficiency (%) vs. depth (ft).

Clean filter laminar loss = 68.4 V (V in m/s)
Turbulent loss = $2952.6\,V^2$
Orifice loss = $K_o V^2$

Average filtration rate : $V_{av} = 20 \frac{cm}{min} \times \frac{1\,min}{60\,s} \times \frac{1\,m}{100\,cm} = 3.333 \times 10^{-3}\,m/s$

Min. V : $V_{min} = 0.7 \times 3.333 \times 10^{-3}$; $\underline{V_{min} = 2.333 \times 10^{-3}\,m/s}$ ③

$V_{max} = 2V_{av} - V_{min}$; $V_{max} = 2 \times 3.333 \times 10^{-3} - 2.333 \times 10^{-3}$

$\underline{V_{max} = 4.333 \times 10^{-3}\,m/s}$ ④

• Clean filter : $1.50 = \underbrace{68.4 \times 4.333 \times 10^{-3}}_{laminar} + \underbrace{2952.6 \times (4.333 \times 10^{-3})^2}_{turbulent}$ + orifice loss ⑨

Orifice loss = 1.148 m $= K_o (4.333 \times 10^{-3})^2$ ∴ $\underline{K_o = 61144.44}$

• Dirty filter : $1.50 = h_{L_{laminar}} + 2952.6 (2.333 \times 10^{-3})^2 + 61144.44 (2.333 \times 10^{-3})^2$

$$\boxed{h_{L_{lam}} = 1.151\,m}$$ ⑨

—— o ——

F07-3

3. $-\frac{dV}{dt} = R\ m^3/h$; $-\frac{dV}{dt} = kV^2$; $-\frac{dV}{V^2} = k\,dt$

$\int_{V_o}^{V} \frac{dV}{V^2} = -k \int_0^t dt$; $kt = \frac{1}{V} - \frac{1}{V_o}$ ∴ $\underline{k = \frac{1}{t}\left(\frac{1}{V} - \frac{1}{V_o}\right)}$

$k = \frac{1}{2h}\left(\frac{1}{150} - \frac{1}{200}\right)\frac{1}{m^3}$; $\underline{k = 8.333 \times 10^{-4}\ h^{-1} m^{-3}}$

After adding water : $8.333 \times 10^{-4} \times 3h = \frac{1}{150} - \frac{1}{V_o} \Rightarrow V_o = 240\ m^3$

$\Delta V = 240.0 - 150$; $\boxed{\Delta V = 90.0\,m^3}$

PART B

Solve the following three problems. This part is closed book, closed notes.

F05C

1. The Marrero wastewater treatment plant generates a total sludge flow rate of 31,408 gal/day, which is sent to the three aerobic digesters. Sludge is pumped out to the belt filter presses (sludge dewatering units) just from Monday through Friday, at such a rate that all the sludge generated in one week (seven days) is removed from the digesters by Friday. When sludge pumping to the belt presses starts on Monday the digesters are full at a total volume of 1,030,378 gallons. Find the mean sludge holding time.

2. The following are the turbulent and clean laminar head losses in a rapid granular filter operated under declining rate conditions:

-	Sand:	hf_s	=	53.1560 V
-	Anthracite:	hf_a	=	15.1460 V
-	Drainage piping:	hf_d	=	1441.9000 V^2
-	False bottom:	hf_b	=	0.7262 V^2
-	Valves and fittings:	hf_v	=	1510.0200 V^2

In all these expressions V is the filtration rate in m^3/s per m^2. The maximum available head for filtration is 2.0 m. An orifice plate in the influent pipe fixes the maximum filtration rate at 24 cm/min. The dirty-filter laminar head loss at the minimum filtration rate is 1.412 m. Find the minimum filtration rate.

F96-3

3. A sand filter has the following characteristics: size of sand particles = 0.5 mm (uniform), density of sand = 2600 kg/m³, depth of filter bed = 0.6 m, bed porosity = 0.4, water density = 998.2 kg/m³, particle density = 2600 kg/m³, particle Reynolds Number = 34.71.

   a) Determine the required backwash velocity to expand a granular-medium bed to a porosity of 0.7.

   b) Determine the depth of the expanded bed. The following equations may be useful:

$$v_s = \sqrt{\frac{4}{3}\frac{g(\rho_p - \rho_w)d_p}{C_D \rho_w}}$$

$$C_D = \frac{24}{R_e} + \frac{3}{\sqrt{R_e}} + 0.34$$

$$v = v_s f_e^{4.5}; \quad \frac{L_e}{L} = \frac{1-f}{1-f_e}$$

where v is the backwash velocity, v_s is the settling velocity of an isolated particle, ρ_w is the water density, ρ_p is the particle density, d_p is the particle diameter, C_D is the particle drag coefficient, L is the depth of the unexpanded bed, L_e is the depth of the expanded bed, f is the initial porosity, and f_e is the porosity of the expanded bed.

$$v_s = \sqrt{\frac{4}{3}\frac{g(\rho_p - \rho_w)\,d_p}{C_D\,\rho_w}} \qquad (12.27)$$

b. Solve for the velocity using Eq. (12.27).

$$v_s^2 = \frac{(4/3)(9.81\ \text{m/s}^2)(2600 - 998.2)\text{kg/m}^3(5 \times 10^{-4}\ \text{m})}{0.91(998.2\ \text{kg/m}^3)}$$

$v_s = 0.11$ m/s

4. Repeat steps 2 and 3 to check the accuracy of the velocity computed in step 3b.
   a. Use the velocity computed in step 3b to estimate the new Reynolds number:

$$N_R = \frac{0.85(0.11)(5 \times 10^{-4})(998.2)}{1.002 \times 10^{-3}} = 46.5$$

   b. Compute the new C_D value:

$$C_D = \frac{24}{46.5} + \frac{3}{\sqrt{46.5}} + 0.34 = 1.30$$

   c. Compute the new velocity:

$$v_s^2 = \frac{(4/3)(9.81)(2600 - 998.2)(5 \times 10^{-4})}{1.30(998.2)} = 0.0081\ \text{m}^2/\text{s}^2$$

$v_s = 0.09$ m/s

5. Repeating steps 2 and 3 using the data from step 4 yields
   $N_R = 38.1$
   $C_D - 1.46$
   $v_s = 0.085$ m/s

6. Repeating steps 2 and 3 using the data from step 5 yields
   $N_R = 36.0$ USE FIG 25-2, get same answer
   $C_D = 1.51$
   $v_s = 0.083$ m/s 6

   The above estimate of the velocity is sufficiently accurate.

Quattro
Re = 34.7112
$V_s = 0.08253$
$C_D = 1.5406$ 6

F96-3

Key to problem solution

2. Determine the backwash velocity using Eq. (12.48).

$$v = v_s \alpha_e^{4.5} = 0.083\ \text{m/s}\,(0.7)^{4.5} = 0.0167\ \text{m/s}$$ 6

3. Determine the expanded bed depth using Eq. (12.49).

$$\frac{l_e}{l} = \frac{1 - \alpha}{1 - (v/v_s)^{0.22}}$$

$$l_e = \frac{0.6\ \text{m}\,(1 - 0.4)}{1 - (0.0167/0.083)^{0.22}} = 1.20\ \text{m}$$

must be = 0.7

7

PART B

Solve the following three problems. This part is closed book, closed notes.

F04-

1. Determine the liquid volume of sludge before and after digestion and the percent reduction for 500 kg (dry basis) of primary sludge with the following characteristics:

	Primary	Digested
Solids %	5	10
Volatile matter, %	60	60% is destroyed
Specific gravity of fixed solids	2.5	2.5
Specific gravity of volatile solids	1.0	1.0

The following equations may be useful: Assume $\rho_w = 1000\ kg/m^3$

$$\frac{1}{S_s} = \frac{F_f}{S_f} + \frac{F_v}{S_v}; \quad \frac{1}{S_{sl}} = \frac{F_s}{S_s} + \frac{F_w}{S_w}; \quad V = \frac{M_s}{\rho_{sl} F_s};$$

where:

S_s = specific gravity of the total solids solids
S_f = specific gravity of the fixed solids
S_v = specific gravity of the volatile solids
S_{sl} = specific gravity of the wet sludge
S_w = specific gravity of water
F_f = fraction of the total solids that are fixed solids
F_v = fraction of the total solids that are volatile solids
F_s = fraction of solids in the wet sludge
F_w = fraction of water in the wet sludge
V = volume of sludge, m^3
M_s = mass of dry solids, ~~m^3~~ kg
ρ_{sl} = density of wet sludge, kg/m^3

2. The turbulent and clean laminar head losses in a rapid granular filter operating under declining rate conditions are the following:

- Sand: $hf_s = 53.2\ V$
- Anthracite: $hf_a = 15.2\ V$
- Drainage piping: $hf_d = 1441.9\ V^2$
- False bottom: $hf_b = 0.7\ V^2$
- Valves and fittings: $hf_v = 1510.0\ V^2$

$\Big\}$ V in m/s

The maximum available head for filtration is 1.15 m. If the average filtration rate is 20 cm/min, the minimum filtration rate is 70 per cent of the average rate, and the maximum filtration rate, controlled by an orifice plate, is 1.3 times the average rate, find the dirty-filter laminar head loss. The following equation may be useful:

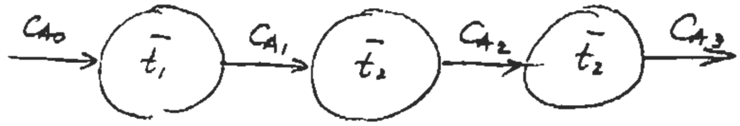
Max. Available head = Laminar losses + turbulent losses + orÄfice loss

F04-3

3. Three completely mixed reactors are connected in series, and the system removes 99.998% of the first reactor influent reactant concentration. In these reactors, the reactant is removed by a first-order reaction ($k = 3\ d^{-1}$). The last two reactors are identical and have a detention time of 7 days each one. Find the detention time in the first reactor. The following equation applies to a first-order reaction taking place in a single CFSTR:

$$\frac{C_{A0}}{C_A} = 1 + k\bar{t}$$

3.



$$\frac{C_{A3}}{C_{A0}} = 2\times10^{-5}$$

$k = 3\ d^{-1}$

$\bar{t}_2 = 7\ d$

$$\frac{C_{A0}}{C_{A3}} = 5\times10^{4} \quad (5)$$

$$\frac{C_{A0}}{C_{A1}} = 1 + k\bar{t}_1$$

$$\frac{C_{A1}}{C_{A2}} = 1 + k\bar{t}_2$$

$$\frac{C_{A2}}{C_{A3}} = 1 + k\bar{t}_2$$

$$\frac{C_{A0}}{\cancel{C_{A1}}} \times \frac{\cancel{C_{A1}}}{\cancel{C_{A2}}} \times \frac{\cancel{C_{A2}}}{C_{A3}} = (1 + k\bar{t}_1)(1 + k\bar{t}_2)^2$$

$$\frac{C_{A0}}{C_{A3}} = (1 + k\bar{t}_1)(1 + k\bar{t}_2)^2$$

(15)

$$\bar{t}_1 = \frac{\dfrac{C_{A0}/C_{A3}}{(1 + k\bar{t}_2)^2} - 1}{k} \quad ; \quad \bar{t}_1 = \frac{\dfrac{5\times10^4}{(1 + 3\times7)^2} - 1}{3} \quad (5)$$

$$\bar{t}_1 = 34.1\ d$$

ENCE 4323

Old Final Exam Problems

In addition to the problems given for the first and second exams, the following are typical final exam problems:

F95-3. A conventional activated sludge plant must treat a primary effluent flow rate of 4000 m^3/d, with a soluble BOD_5 of 200 mg/l. The organic loading in the aerator is 0.3 kg BOD_5/(d.kg VSS), and the ratio V/Q is 6 hours. Find the concentration of volatile suspended solids in the aerator. Answ.: X = 2667 mg/L.

F96-3. A sand filter has the following characteristics: size of sand particles = 0.5 mm (uniform), density of sand = 2600 kg/m^3, depth of filter bed = 0.6 m, bed porosity = 0.4, water density = 998.2 kg/m^3, particle density = 2600 kg/m^3, particle Reynolds Number = 34.71.

a) Determine the required backwash velocity to expand a granular-medium bed to a porosity of 0.7. Answ: 0.0167 m/s
b) Determine the depth of the expanded bed. Answ: 1.2 m.

F03-1 A wastewater treatment plant is planning to provide for separate anaerobic sludge digestion for its primary sludge. The plant receives an influent wastewater with the following characteristics: Average flow = 8000 m^3/d. Amount of suspended solids removed in the primary sedimentation = 200 mg/L. Volatile matter in the settled solids = 75% by mass. Water in untreated sludge = 96% by mass. Specific gravity of mineral solids = 2.6. Specific gravity of organic solids = 1.3. Find the required digester volume using an SRT of 12 d. Answ.: 473.7 m^3

F03P-1A wastewater treatment plant is planning to provide for anaerobic sludge digestion for a mixture of primary sludge and waste activated sludge. The raw sludge characteristics are the following: **Primary sludge:** Specific gravity = 1.003; Solids concentration = 3.4 % by mass; Design flow = 420 m^3/d **Waste activated sludge:** Specific gravity = 1.005; Solids concentration = 0.23 % by mass; Design flow = 2500 m^3/d. The mixture of raw primary and waste sludge has specific gravity = 1.002, and it is sent to a thickener to increase the solids concentration to 3.5% by mass. Calculate the percent reduction in sludge volume. Please explain and justify any reasonable assumptions you make. Answ.: 60%

F04-1 Determine the liquid volume of sludge before and after digestion and the percent reduction for 500 kg (dry basis) of primary sludge with the following characteristics:

	Primary	**Digested**
Solids %	5	10

ENCE 4323 FINAL EXAM

December 12, 1995 Name: ______________________

Instructions:

a) The test is closed book. However, you can use up to three sheets of information.
b) Time available: 2 hours.
c) Complete both parts A and B.

PART A

Solve only three of the following problems:

1. The following are the turbulent and clean laminar head losses in a rapid granular filter operated under declining rate conditions:

-	Sand:	hf_s	=	$53.1560\ V$	$68.302\ V$
-	Anthracite:	hf_a	=	$15.1460\ V$	
-	Drainage piping:	hf_d	=	$1441.9000\ V^2$	
-	False bottom:	hf_b	=	$0.7262\ V^2$	$2952.646\ V^2$
-	Valves and fittings:	hf_v	=	$1510.0200\ V^2$	

In all these expressions V is the filtration rate in m^3/s per m^2. The maximum available head for filtration is 2.0 m. An orifice plate in the influent pipe fixes the maximum filtration rate at 24 cm/min. The dirty-filter laminar head loss at the minimum filtration rate is 1.412 m. Find the minimum filtration rate.

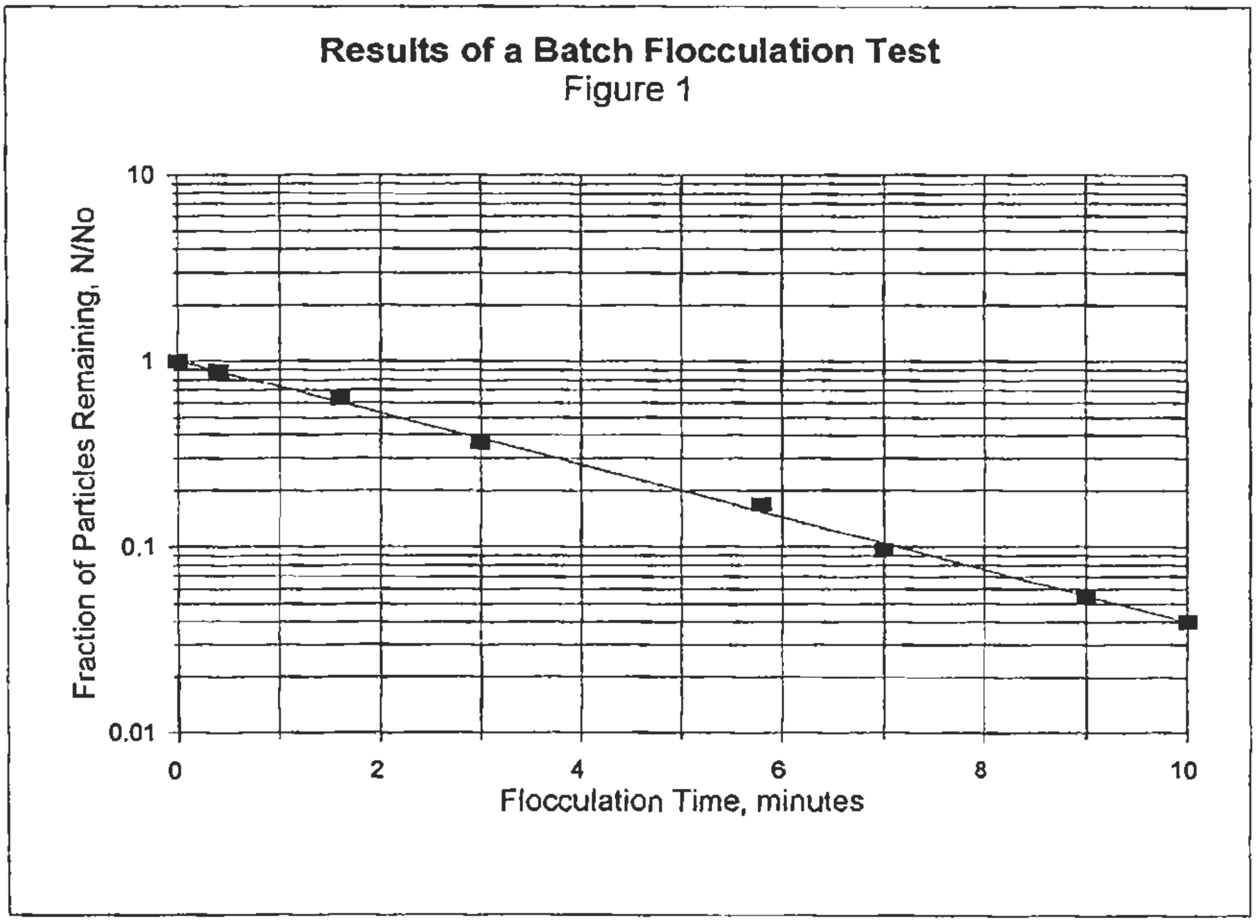
2. Find the dimensions of a sedimentation tank to remove 100 percent of spherical particles 0.5 mm in diameter, with specific gravity of 2.5 (particle Reynolds Number = 51.4). Assume the flow rate through the tank is 100 l/s.

3. Figure 1 shows the results of a batch flocculation test (first order reaction) in which samples were taken at certain times, and the respective fractions of particles remaining, N/N_0, were determined. Based on these results, we want to design a flocculator assuming that the term $(4/\pi)\ \alpha_0\ G\ \Omega$ observed in the flocculation test will be the same as in the real unit. First, find this term and, with it, calculate the detention time that will be needed to attain 90 percent particle removal, a) Using a single plug flow reactor; b) Using a single CFSTR.

   HINT: For a batch reactor handling a first order reaction you can use the following relationship:

$$\ln (N/N_0) = -\ (4/\pi)\ \alpha_0\ G\ \Omega\ t$$

t, minutes	N/No
0.0	1.000
0.4	0.880
1.6	0.630
3.0	0.360
5.8	0.170
7.0	0.096
9.0	0.055
10.0	0.040



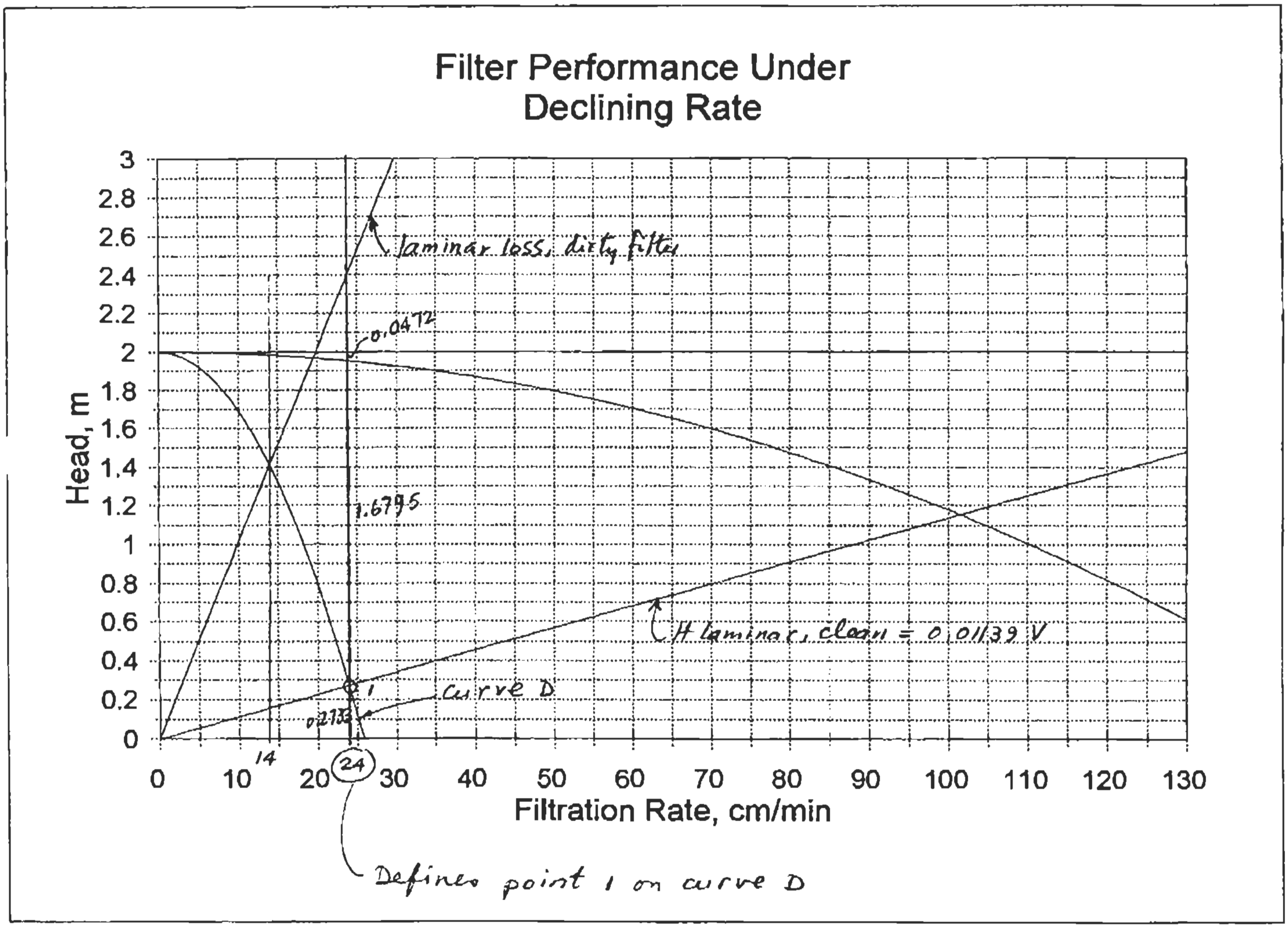
4. Design a bar rack and its channel so that the maximum velocity through the bars will be 0.7 m/s. Use bars with rectangular cross section, 9 mm × 50 mm, with a spacing of 25.0 mm between the parallel bars. The design flow rate is 150 l/s. Find the following: a) the number of bars; b) the channel dimensions (width, total depth) assuming a maximum head loss of 0.32 m; c) the head loss through the screen assuming it is 40 % clogged (i.e., the net area is 60 % of the clean-rack net area); d) draw a side view of the channel with the bar rack, showing the angle of the bar screen with the horizontal, and all the dimensions.

1. $h_{turb} = 8.2018 \times 10^{-5} V^2$; $h_{laminar}$ clean $= 0.01139 V$; $h_{available} = 2.0$

$V_{max} = 24$ cm/min

$H_{laminar}$, dirty filter $= 1.412m$

Find V_{min}



$h_{turb} = 8.2018 \times 10^{-5} V^2$ $\therefore$ @ $V = 24$, $h_{turb} = 0.0472$ m

$h_{laminar} = 0.01139 V$ @ $V = 24$, $h_{laminar} = 0.2733$ m

$\therefore h_{orifice} = 2.0 - 0.0472 - 0.2733$

$= 1.6795$

Orifice loss $= 1.6795 \left(\frac{V}{24}\right)^2$; 5

10

$0.0029158 V^2$ wrong head -3

@ V_{min}, $2.0 = 8.2018 \times 10^{-5} V^2 + 1.6795 \left(\frac{V}{24}\right)^2 + 1.412$ 10

$0.588 = 0.0029978 V^2$; $\boxed{V_{min} = 14 \text{ cm/min}}$

$0.0023 \frac{m}{s} = 14 \frac{cm}{min} \times \frac{1 m}{100 cm} \cdot \frac{1 min}{60 s}$

2\. $d_p = 0.5$ mm , $S_p = 2.5$, $R_e = 51.4$ ∴ transition zone
$Q = 100$ L/s

• Determine drag coeff : $C_D = \frac{24}{R_e} + \frac{3}{\sqrt{R_e}} + 0.34$; $C_D = 1.2254$ (3)

• $v_s = \sqrt{\frac{4g}{3C_D}(S_p - 1)d_p}$: $v_s = \sqrt{\frac{4 \times 981}{3 \times 1.2254}(2.5-1) \times 0.05}$ (4)

$v_s = 8.95$ cm/s $= \frac{Q}{A}$

∴ $A = \frac{0.1 \text{ m}^3/\text{s}}{0.0895 \text{ m/s}}$; $A = 1.12 \text{ m}^2$ ∴ $LW = 1.12 \text{ m}^2$ (6)

Assume $\frac{L}{W} = 4$ ∴ $4W^2 = 1.12$; $W = 0.53$ m
$L = 2.12$ m (6)

Use $\frac{L}{D} = 5$ ∴ $D = \frac{2.12}{5}$; $D = 0.42$ m (6)

yield $v_L = \frac{0.1 \text{ m}^3/\text{s}}{0.42 \times 0.53}$

$v_L = 0.45$ m/s

Assumed values : $W = 0.53$
$L = 1.5 \times 2.12$
$= 3.20$
$D = 0.70$ (0.38 for sludge accum.)

OR: If $v_L = 0.3$ m/s
$W \cdot D = \frac{0.1 \text{ m}^3/\text{s}}{0.3 \text{ m/s}}$
$D = \frac{1}{3W}$; $D = \frac{1}{3 \times 0.53}$
$D = 0.59$ m

4. $Q = 0.15\ m^3/s$; $V_{max} = 0.7\ m/s$; Approach $V = 0.3 - 0.6\ m/s$

Net area through bars $= \frac{0.15 m^3/s}{0.7 m/s} = 0.214\ m^2$

$\left.\begin{array}{l} a = 0.025 m \\ t = 0.009 m \end{array}\right\} \Rightarrow \frac{\text{Total area}}{\text{Net area}} \cong \frac{a+t}{a} = \frac{25+9}{25} = 1.36$

∴ Total area $= 1.36 \times 0.214$; Total area $= 0.291\ m^2$

Approach vel $= \frac{0.15 m^3/s}{0.291 m^2} = 0.515\ m/s$ (OK)

Select channel width $= 0.6 m \Rightarrow$ height $= \frac{0.291 m^2}{0.6 m} = 0.485 m$

(a) # bars :

Channel width $= (n+1)a + nt = W \Rightarrow n = \frac{W-a}{a+t}$

$n = \frac{0.6 - 0.025}{0.025 + 0.009}$; $n = 16.7 \Rightarrow n = 17$

(b) $W = 18 \times 0.025 + 17 \times 0.009$; $W = 0.603 m$

$\frac{\text{Total area}}{\text{Net area}} = \frac{(n+1)a + nt}{(n+1)a} = \frac{0.603}{18 \times 0.025} = 1.34$

Total area $= 1.34 \times 0.214 m^2 = 0.287 m^2$

∴ Water depth $= \frac{0.287 m^2}{0.6 m} = 0.476 m$

Free board $= 0.3 m$

Max head loss $= 0.324 m$

Total depth $= 1.1 m$

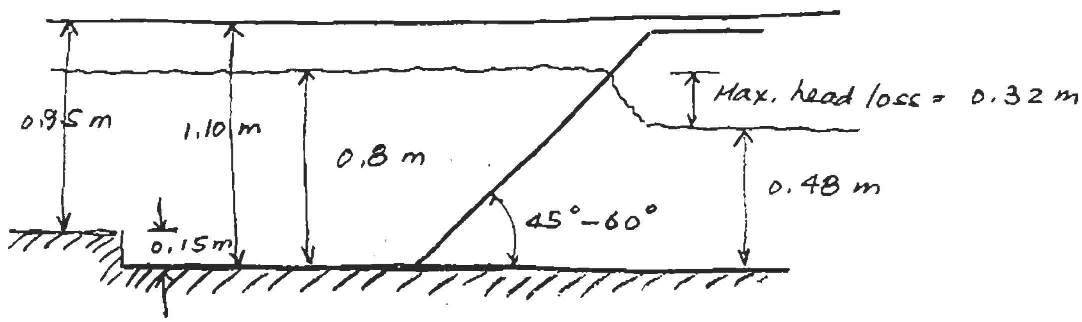
(c) Head loss when screen is 40% obstructed:

$V = \frac{0.15 m^3/s}{(0.214 \times 0.6) m^2}$; $V = 1.17 m/s$ (through bars)

$v = \frac{0.15 m^3/s}{0.287 m^2}$; $v = 0.52 m/s$ (approach)

$h_L = \frac{V^2 - v^2}{2g} \times \frac{1}{0.7}$; $h_L = \frac{1.17^2 - 0.52^2}{2 \times 9.81 \times 0.7}$; $h_L = 0.08 m$

(d)



TOO EASY !

ENCE 4323 FINAL EXAM

December 9, 1996

Name: OFICE COPY

Instructions:

a) Answer part A in a maximum of thirty minutes. You can only use your textbook as a reference. When you finish part A, close your book and continue with Part B. Part B is closed book, closed notes.

b) Total time available: 2 hours.

PART B

Solve the following three problems. This part is closed book, closed notes.

1. The Marrero wastewater treatment plant generates a total sludge flow rate of 31,408 gal/day, which is sent to the three aerobic digesters. Sludge is pumped out to the belt filter presses (sludge dewatering units) just from Monday through Friday, at such a rate that all the sludge generated in one week (seven days) is removed from the digesters by Friday. When sludge pumping to the belt presses starts on Monday the digesters are full at a total volume of 1,030,378 gallons. Find the mean sludge holding time.

2. The following are the turbulent and clean laminar head losses in a rapid granular filter operated under declining rate conditions:

-	Sand:	hf_s	=	53.1560 V
-	Anthracite:	hf_a	=	15.1460 V
-	Drainage piping:	hf_d	=	1441.9000 V^2
-	False bottom:	hf_b	=	0.7262 V^2
-	Valves and fittings:	hf_v	=	1510.0200 V^2

In all these expressions V is the filtration rate in m^3/s per m^2. The maximum available head for filtration is 2.0 m. An orifice plate in the influent pipe fixes the maximum filtration rate at 24 cm/min. The dirty-filter laminar head loss at the minimum filtration rate is 1.412 m. Find the minimum filtration rate.

3. A sand filter has the following characteristics: size of sand particles = 0.5 mm (uniform), density of sand = 2600 kg/m^3, depth of filter bed = 0.6 m, bed porosity = 0.4, water density = 998.2 kg/m^3, particle density = 2600 kg/m^3, particle Reynolds Number = 34.71.

   a) Determine the required backwash velocity to expand a granular-medium bed to a porosity of 0.7.

   b) Determine the depth of the expanded bed. The following equations may be useful:

$$v_s = \sqrt{\frac{4}{3}\frac{g(\rho_p - \rho_w)d_p}{C_D \rho_w}}$$

$$C_D = \frac{24}{R_e} + \frac{3}{\sqrt{R_e}} + 0.34$$

$$v = v_s f_e^{4.5}; \quad \frac{L_e}{L} = \frac{1-f}{1-f_e}$$

where v is the backwash velocity, v_s is the settling velocity of an isolated particle, ρ_w is the water density, ρ_p is the particle density, d_p is the particle diameter, C_D is the particle drag coefficient, L is the depth of the unexpanded bed, L_e is the depth of the expanded bed, f is the initial porosity, and f_e is the porosity of the expanded bed.

1

34. An aerobic sludge digester receives a constant sludge flow rate of 31408 gal/d. A sludge dewatering unit is fed from Monday through Friday at such a rate that all the sludge that entered the digester during the week is removed by Friday. When sludge starts being pumped out on Monday the sludge volume in the digester is 1 030 378 gal. Find the mean sludge detention time.

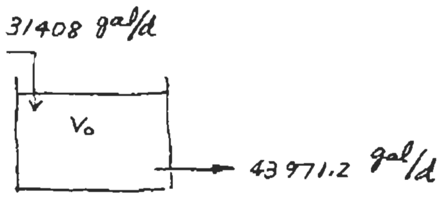
Solution

Vol. of sludge pumped during the week $= 31408\,\frac{gal}{d} \times 7$ days

$= 219\,856$ gal

$\therefore$ Pumping rate out of the digester $= 219\,856\ gal/5\,day$

$= 43\,971.2\ gal/d$ (5)



$$\frac{dV}{dt} = 31408 - 43971.2$$

$$= -12\,563.2\ gal/day \quad (5)$$

$$\int_{V_0}^{V_f} dV = -12\,563.2 \int_0^5 dt \quad ; \quad V_0 = 1\,030\,378$$

$$V_f - V_0 = -12563.2 \times 5 \quad ; \quad V_f = V_0 - 62816 \quad ; \quad V_f = 967\,562\ gal \quad (5)$$

$$\text{Average vol} = \frac{1030\,378 + 967\,562}{2} = 998970\ gal \quad (5)$$

$$\therefore\ \bar{t} = \frac{998970\ gal}{219\,856\ \frac{gal}{week}} \times 7\,\frac{days}{week} \quad ; \quad \bar{t} = 31.81\ days \quad (5)$$

If they use $\bar{t} = \dfrac{1\,030\,378}{31\,408} = 32.81$ (−20)

#2.

$h_{turb} = 8.2018 \times 10^{-5} V^2$; $h_{laminar}$ clean $= 0.01139\,V$; $h_{available} = 2.0$

$V_{max} = 24$ cm/min
$= 0.004$ m/s

$H_{laminar}$, dirty filter $= 1.412$m

Find V_{min}

$h_{turb} = 2952.6462\,V^2$; @ 0.004 m/s, $h_{turb} = 0.04724$ m

$h_{laminar} = 68.302\,V$; @ 0.004 m/s, $h_{laminar} = 0.2732$ m

$\therefore\ h_{orifice} = 2.0 - 0.0472 - 0.2732$; $\boxed{h_{orifice} = 1.6795\text{ m}}$

orifice loss $= 1.6796\left(\frac{V}{0.004}\right)^2$

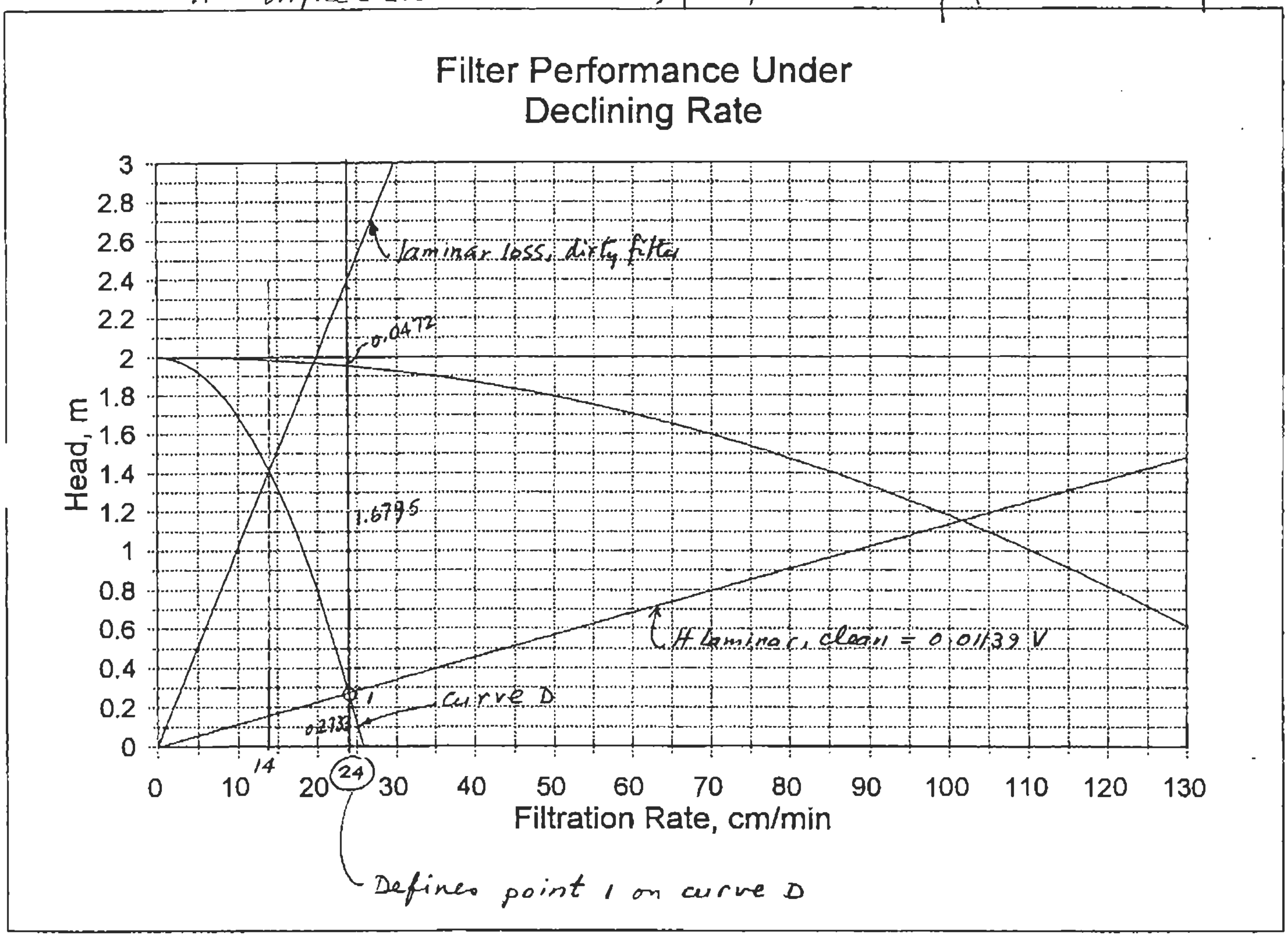
orifice loss $= 104971.9\,V^2$ (v, m/s)

@ V_{min}:

$2.0 = 2952.6462\,V^2 + 104972\,V^2 + 1.412$

$0.588 = 107924.5\,V^2$

$\boxed{V = 0.002334\text{ m/s}}$



$h_{turb} = 8.2018 \times 10^{-5} V^2$ $\therefore$ @ V = 24, $h_{turb} = 0.0472$ m

$h_{laminar} = 0.01139\,V$ @ V = 24, $h_{laminar} = 0.2733$ m

$\therefore\ h_{orifice} = 2.0 - 0.0472 - 0.2733$

$\boxed{h_{orif} = 1.6795\text{ m}}$

orifice loss $= 1.6795\left(\frac{V}{24}\right)^2$; 5 $0.0029158\,V^2$ wrong head -3

@ v_{min}, $2.0 = 8.2016 \times 10^{-5} V^2 + 1.6795\left(\frac{V}{24}\right)^2 + 1.412$ 10

$0.588 = 0.0029978\,V^2$; $\boxed{V_{min} = 14\text{ cm/min}}$

$$v_s = \sqrt{\frac{4}{3}\,\frac{g\,(\rho_p - \rho_w)\,d_p}{C_D\;\rho_w}} \qquad (12.27)$$

b. Solve for the velocity using Eq. (12.27).

$$v_s^2 = \frac{(4/3)(9.81\ \mathrm{m/s^2})(2600 - 998.2)\mathrm{kg/m^3}(5 \times 10^{-4}\ \mathrm{m})}{0.91(998.2\ \mathrm{kg/m^3})}$$

$$v_s = 0.11\ \mathrm{m/s}$$

4. Repeat steps 2 and 3 to check the accuracy of the velocity computed in step 3b.
   a. Use the velocity computed in step 3b to estimate the new Reynolds number:

$$N_R = \frac{0.85(0.11)(5 \times 10^{-4})(998.2)}{1.002 \times 10^{-3}}$$
$$= 46.5$$

   b. Compute the new C_D value:

$$C_D = \frac{24}{46.5} + \frac{3}{\sqrt{46.5}} + 0.34$$
$$= 1.30$$

   c. Compute the new velocity:

$$v_s^2 = \frac{(4/3)(9.81)(2600 - 998.2)(5 \times 10^{-4})}{1.30(998.2)}$$
$$= 0.0081\ \mathrm{m^2/s^2}$$
$$v_s = 0.09\ \mathrm{m/s}$$

5. Repeating steps 2 and 3 using the data from step 4 yields
   $N_R = 38.1$
   $C_D = 1.46$
   $v_s = 0.085\ \mathrm{m/s}$

6. Repeating steps 2 and 3 using the data from step 5 yields
   $N_R = 36.0$ USE FIG 25-2, get same answer
   $C_D = 1.51$
   $v_s = 0.083\ \mathrm{m/s}$ 6
   The above estimate of the velocity is sufficiently accurate.

Quattro
$Re = 34.7112$
$V_s = 0.08253$
$C_D = 1.5406$ 6

2. Determine the backwash velocity using Eq. (12.48).

$$v = v_s \alpha_e^{4.5}$$
$$= 0.083\ \mathrm{m/s}\ (0.7)^{4.5}$$
$$= 0.0167\ \mathrm{m/s} \quad 6$$

3. Determine the expanded bed depth using Eq. (12.49).

$$\frac{l_e}{l} = \frac{1 - \alpha}{1 - (v/v_s)^{0.22}}$$

$$l_e = \frac{0.6\ \mathrm{m}\ (1 - 0.4)}{1 - (0.0167/0.083)^{0.22}}$$
$$= 1.20\ \mathrm{m}$$

must be = 0.7

7

Key to problem solution

ENCE 4323 FINAL EXAM

December 9, 2004

Name: E. LaMotta

Instructions:

a) Answer part A in a maximum of thirty minutes. You can only use your textbook and your notes as reference. When you finish part A, close your book and continue with Part B. Part B is closed book, closed notes.

b) Total time available: 2 hours.

PART B

Solve the following three problems. This part is closed book, closed notes.

1. Determine the liquid volume of sludge before and after digestion and the percent reduction for 500 kg (dry basis) of primary sludge with the following characteristics:

	Primary	Digested
Solids %	5	10
Volatile matter, %	60	60% is destroyed
Specific gravity of fixed solids	2.5	2.5
Specific gravity of volatile solids	1.0	1.0

The following equations may be useful: Assume $\rho_w = 1000\ kg/m^3$

$$\frac{1}{S_s}=\frac{F_f}{S_f}+\frac{F_v}{S_v};\quad \frac{1}{S_{sl}}=\frac{F_s}{S_s}+\frac{F_w}{S_w};\quad V=\frac{M_s}{\rho_{sl}F_s};$$

where:

S_s = specific gravity of the total solids solids
S_f = specific gravity of the fixed solids
S_v = specific gravity of the volatile solids
S_{sl} = specific gravity of the wet sludge
S_w = specific gravity of water
F_f = fraction of the total solids that are fixed solids
F_v = fraction of the total solids that are volatile solids
F_s = fraction of solids in the wet sludge
F_w = fraction of water in the wet sludge
V = volume of sludge, m^3
M_s = mass of dry solids, ~~m^3~~ kg
ρ_{sl} = density of wet sludge, kg/m^3

2. The turbulent and clean laminar head losses in a rapid granular filter operating under declining rate conditions are the following:

$$\left.\begin{array}{llcl}
\text{- Sand:} & hf_s & = & 53.2\ V \\
\text{- Anthracite:} & hf_a & = & 15.2\ V \\
\text{- Drainage piping:} & hf_d & = & 1441.9\ V^2 \\
\text{- False bottom:} & hf_b & = & 0.7\ V^2 \\
\text{- Valves and fittings:} & hf_v & = & 1510.0\ V^2
\end{array}\right\}\ V \text{ in } m/s$$

The maximum available head for filtration is 1.15 m. If the average filtration rate is 20 cm/min, the minimum filtration rate is 70 per cent of the average rate, and the maximum filtration rate, controlled by an orifice plate, is 1.3 times the average rate, find the dirty-filter laminar head loss. The following equation may be useful:

Max. Available head = Laminar losses + turbulent losses + orÄfice loss

3. Three completely mixed reactors are connected in series, and the system removes 99.998% of the first reactor influent reactant concentration. In these reactors, the reactant is removed by a first-order reaction ($k = 3\ d^{-1}$). The last two reactors are identical and have a detention time of 7 days each one. Find the detention time in the first reactor. The following equation applies to a first-order reaction taking place in a single CFSTR:

$$\frac{C_{A0}}{C_A} = 1 + k\bar{t}$$

1. • Specific gravity of all the solids in the primary sludge :

$$\frac{1}{S_s} = \frac{F_f}{S_f} + \frac{F_v}{S_v} \quad ; \quad \frac{1}{S_s} = \frac{0.4}{2.5} + \frac{0.6}{1.0} \quad ; \quad S_s = 1.32 \text{ (primary solids)}$$ (3)

• Specific gravity of primary sludge :

$$\frac{1}{S_{sl}} = \frac{F_s}{S_s} + \frac{F_w}{S_w} \quad ; \quad \frac{1}{S_{sl}} = \frac{0.05}{1.32} + \frac{0.95}{1.0} \quad ; \quad S_{sl} = 1.01$$ (3)

$\rho_{sl} = 1010 \frac{kg}{m^3}$

$M_{sl} = 1010 \frac{kg}{m^3} \times 9.9\ m^3 = 101090\ kg$

• Liquid volume before digestion :

$$V = \frac{M_s}{\rho_{sl} \cdot F_s} \quad ; \quad V = \frac{500 \text{ kg dry solids}}{1010 \frac{\text{kg wet sludge}}{m^3 \text{ wet sludge}} \times \frac{0.05 \text{ kg dry solids}}{\text{kg wet sludge}}}$$

$V = 9.9\ m^3$ wet sludge (3)

• Sludge composition changes after digestion ∴ calculate specific gravity of solids after digestion:

– Fraction of volatile solids after digestion (40% remains)

$$F_v = \frac{\overbrace{0.4 \times 0.6}^{\text{volatile remaining}}}{\underbrace{0.4}_{\text{Fixed}} + \underbrace{0.4 \times 0.6}_{\text{volatile remaining}}} \quad ; \quad F_v = 0.375 \quad \therefore \quad F_f = 0.625$$ (4)

– Sp. gravity of digested solids :

$$\frac{1}{S_s} = \frac{0.625}{2.5} + \frac{0.375}{1.0} \quad ; \quad S_s = 1.6 \text{ (digested solids)}$$ (3)

$\frac{\cancel{500}^{1}}{\cancel{2500}_{5}} = 0.2$

– Sp. gravity of digested sludge :

$$\frac{1}{S_{ds}} = \frac{0.1}{1.6} + \frac{0.9}{1.0} \quad ; \quad S_{ds} = 1.04$$ (3)

• Volume of digested sludge :

$$V = \frac{0.4 \times 500\,kg + 0.6 \times 0.4 \times 500\,kg}{1040 \frac{kg}{m^3} \times 0.1} \quad ; \quad V = 3.1\ m^3 \text{ digested sludge}$$ (3)

• % vol. reduction $= \frac{9.9 - 3.1}{9.9} \times 100 = 68.7\%$ (3)

2. Laminar loss $= 68.4\,V$ (v in m/s)

Turbulent loss $= 2952.6\,V^2$

$V_{avg} = 20$ cm/min ; $V_{min} = 14$ cm/min $V_{max} = 26$ cm/min

$$V_{avg} = 20\,\frac{\text{cm}}{\text{min}} \times \frac{1\,\text{min}}{60\,\text{s}} \times \frac{1\,\text{m}}{100\,\text{cm}}$$

$$\left.\begin{aligned} V_{avg} &= 3.33\times10^{-3}\ \text{m/s} \\ V_{min} &= 2.33\times10^{-3}\ \text{m/s} \\ V_{max} &= 4.33\times10^{-3}\ \text{m/s} \end{aligned}\right\}\quad 5$$

- Clean filter (V_{max}):

$$1.15 = \underbrace{68.4\times4.33\times10^{-3}}_{\text{laminar}} + \underbrace{2952.6\,(4.33\times10^{-3})^2}_{\text{turb.}} + K_o\,(4.33\times10^{-3})^2$$

$K_o = 42{,}505.39$ (orifice coefficient) 10

- Dirty filter:

$$1.15 = \text{laminar} + 2952.6\times(2.33\times10^{-3})^2 + 42505.39\,(2.33\times10^{-3})^2$$

Laminar loss $= 0.903$ m 10

— o —

Alternate procedure:

$$\text{Orifice loss at } V_{max} = 1.15 - \underbrace{0.296}_{\text{laminar}} - \underbrace{0.055}_{\text{turb.}}$$

$= 0.799$ m.

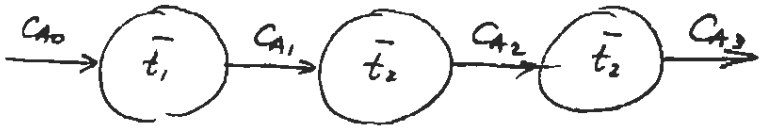
$$\text{Orifice loss at } V_{min} = 0.799\left(\frac{V_{min}}{V_{max}}\right)^2$$

$= 0.232$ m

$$\therefore \text{Dirty-filter laminar loss} = 1.15 - \underbrace{0.016}_{\text{turb.}} - \underbrace{0.232}_{\text{orifice}}$$

$= 0.903$ m

3.



$$\frac{C_{A3}}{C_{A0}} = 2\times10^{-5}$$

$$k = 3\ d^{-1}$$

$$\bar{t}_2 = 7\ d$$

$$\frac{C_{A0}}{C_{A3}} = 5\times10^{4} \quad 5$$

$$\frac{C_{A0}}{C_{A1}} = 1 + k\bar{t}_1$$

$$\frac{C_{A1}}{C_{A2}} = 1 + k\bar{t}_2$$

$$\frac{C_{A2}}{C_{A3}} = 1 + k\bar{t}_2$$

$$\frac{C_{A0}}{\cancel{C_{A1}}} \times \frac{\cancel{C_{A1}}}{\cancel{C_{A2}}} \times \frac{\cancel{C_{A2}}}{C_{A3}} = (1 + k\bar{t}_1)(1 + k\bar{t}_2)^2$$

$$\frac{C_{A0}}{C_{A3}} = (1 + k\bar{t}_1)(1 + k\bar{t}_2)^2 \quad 15$$

$$\bar{t}_1 = \frac{\dfrac{C_{A0}/C_{A3}}{(1 + k\bar{t}_2)^2} - 1}{k} \quad ; \quad \bar{t}_1 = \frac{\dfrac{5\times10^4}{(1 + 3\times7)^2} - 1}{3} \quad 5$$

$$\bar{t}_1 = 34.1\ d$$

December 6, 2006

ENCE 4323 FINAL EXAM

Name: E. LaMotte

Instructions: Answer both parts A and B. You can only use your textbook and your notes as reference. Total time available: 2 hours.

Solve <u>only three</u> of the following problems.

1. Determine the liquid volume of sludge before and after digestion and the percent reduction for 500 kg (dry basis) of primary sludge with the following characteristics:

	Primary	**Digested**
Solids %	4.5	9.0
Volatile matter, %	60	50% is destroyed
Specific gravity of fixed solids	2.5	2.5
Specific gravity of volatile solids	1.0	1.0

2. The turbulent and clean laminar head losses in a rapid granular filter operating under declining rate conditions are the following:

- Sand: $hf_s = 53.2\ V$
- Anthracite: $hf_a = 15.2\ V$
- Drainage piping: $hf_d = 1441.9\ V^2$
- False bottom: $hf_b = 0.7\ V^2$
- Valves and fittings: $hf_v = 1510.0\ V^2$

In these equations, the head loss is in m, and the filtration rate, V, is in m/s. The maximum available head for filtration is 1.50 m. If the average filtration rate is 20 cm/min, the minimum filtration rate is 70 per cent of the average rate, and the maximum filtration rate is controlled by an orifice plate, find the dirty-filter laminar head loss.

3. A tank initially contains 200 m^3 of water; however, due to a leak, 50 m^3 are lost after 2 hours. The rate of water loss is directly proportional to the square of the water volume remaining at any time. To compensate for the loss some water was added, but after 3 hours the water volume had been reduced to 150 m^3. How much water was added to the tank?

4. The detention time in an ideal clarifier is 1.5 h, and its depth is 12 ft. If a full-length movable tray is set at a depth greater than 8 feet below the water surface, determine the percentage of discrete particles with a settling velocity v_s = 3 ft/h that are removed. **Plot removal efficiency (%) vs. depth (ft).**

1. % solids in primary sludge = 4.5%
volatile solids = 60%
$S_f = 2.5 \quad \therefore \rho_f = 2500 \ kg/m^3$
$S_v = 1.0 \quad \therefore \rho_v = 1000 \ kg/m^3$

- Density of all solids, before digestion

$$\frac{1}{\rho_s} = \frac{F_v}{\rho_v} + \frac{F_f}{\rho_f} \ ; \ \frac{1}{\rho_s} = \frac{0.6}{1000} + \frac{0.4}{2500} \ ; \ \rho_s = 1315.78 \ kg/m^3 \qquad (2)$$

- Raw sludge density:

$$\frac{1}{\rho_{sl}} = \frac{F_s}{\rho_s} + \frac{F_w}{\rho_w} \ ; \ \frac{1}{\rho_{sl}} = \frac{0.045}{1315.78} + \frac{0.955}{1000} \ ; \ \rho_{sl} = 1010.92 \ \frac{kg}{m^3} \qquad (2)$$

- Liquid volume before digestion:

$$V_T = \frac{M_s}{F_s \cdot \rho_{sl}} \ ; \ V_T = \frac{500 \ kg}{0.045 \times 1010.92 \ \frac{kg}{m^3}} \ ; \ V_T = 10.99 \ m^3 \qquad (3)$$

- After digestion, 60% of org. matter is destroyed

Before digestion, solids = 40% fixed + 60% volatile
After digestion, solids = 40% fixed + 0.5×60% volatile
= 40 + 30 = 70

$$\% \text{ volatile solids after digestion} = \frac{30}{70} = 0.4286 \qquad (2)$$

After digestion ; $F_s = 0.09$, $F_w = 0.91$

$$\left.\begin{array}{l} F_v = 0.4286 \\ F_f = 0.5714 \end{array}\right\} \Rightarrow \frac{1}{\rho_s} = \frac{0.4286}{1000} + \frac{0.5714}{2500} \Rightarrow \rho_s = 1521.7 \ \frac{kg}{m^3} \qquad (3)$$

- Sludge density after digestion:

$$\frac{1}{\rho_{sl}} = \frac{0.09}{1521.7} + \frac{0.91}{1000} \ ; \ \rho_{sl} = 1031.84 \ kg/m^3 \qquad (3)$$

- Mass of solids after digestion : $M_s = \underbrace{0.4 \times 500}_{\text{fixed}} + \underbrace{0.6 \times 500 \times 0.5}_{\text{volatile remaining}} \ ; \ M_s = 350 \ kg$ (5)
- Liquid volume after digestion:

$$V_T = \frac{M_s}{F_s \cdot \rho_{sl}} = \frac{350 \ kg}{0.09 \times 1031.84 \ kg/m^3} \ ; \ V_T = 3.77 \ m^3 \qquad (3)$$

- % vol reduction = $\frac{10.99 - 3.77}{10.99} \times 100 = 65.7\%$ (2)

2. Clean filter laminar loss $= 68.4\,V$ (V in m/s)
Turbulent loss $= 2952.6\,V^2$
Orifice loss $= K_o\,V^2$

Average filtration rate : $V_{av} = 20\,\frac{cm}{min} \times \frac{1\,min}{60\,s} \times \frac{1\,m}{100\,cm} = 3.333 \times 10^{-3}\,m/s$

Min. V : $V_{min} = 0.7 \times 3.333 \times 10^{-3}$; $\underline{V_{min} = 2.333 \times 10^{-3}\ m/s}$ 3

$V_{max} = 2\,V_{av} - V_{min}$; $V_{max} = 2 \times 3.333 \times 10^{-3} - 2.333 \times 10^{-3}$

$\underline{V_{max} = 4.333 \times 10^{-3}\ m/s}$ 4

• Clean filter : $1.50 = \underbrace{68.4 \times 4.333 \times 10^{-3}}_{laminar} + \underbrace{2952.6 \times (4.333 \times 10^{-3})^2}_{turbulent}$ + orifice loss 9

Orifice loss $= 1.148\ m = K_o\,(4.333 \times 10^{-3})^2$ $\therefore$ $\underline{K_o = 61144.44}$

• Dirty filter : $1.50 = h_{L_{laminar}} + 2952.6\,(2.333 \times 10^{-3})^2 + 61144.44\,(2.333 \times 10^{-3})^2$

$\boxed{h_{L_{lam}} = 1.151\,m}$ 9

3. $-\frac{dV}{dt} = R\ m^3/h$; $-\frac{dV}{dt} = kV^2$; $-\frac{dV}{V^2} = k\,dt$

$\int_{V_o}^{V} \frac{dV}{V^2} = -k \int_0^t dt$; $kt = \frac{1}{V} - \frac{1}{V_o}$ $\therefore$ $\underline{k = \frac{1}{t}\left(\frac{1}{V} - \frac{1}{V_o}\right)}$

$k = \frac{1}{2h}\left(\frac{1}{150} - \frac{1}{200}\right)\frac{1}{m^3}$; $\underline{k = 8.333 \times 10^{-4}\ h^{-1}\,m^{-3}}$

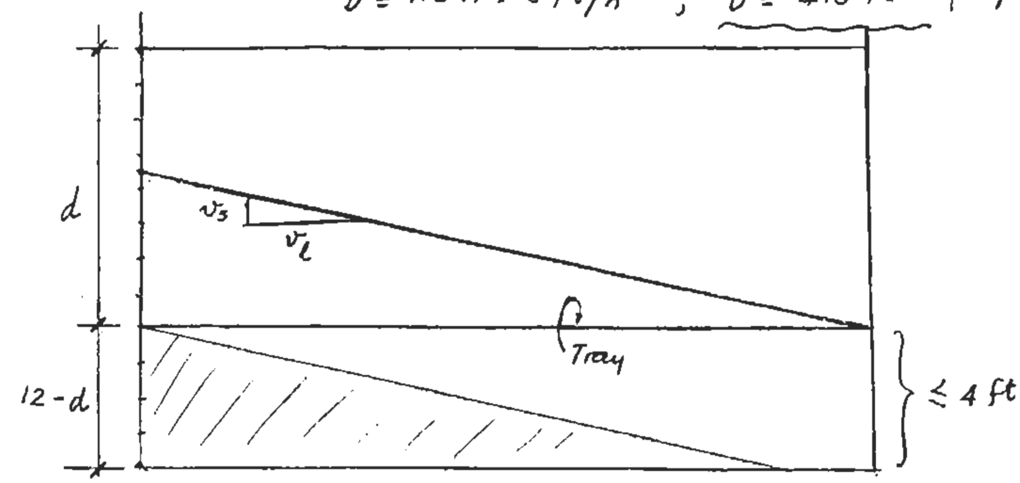
After adding water ; $8.333 \times 10^{-4} \times 3h = \frac{1}{150} - \frac{1}{V_o} \Rightarrow V_o = 240.\ m^3$

$\Delta V = 240.0 - 150$; $\boxed{\Delta V = 90.0\ m^3}$

4.

$$v_s = \frac{D}{\bar{t}} \quad \therefore \quad D = \bar{t} \times v_s$$

$$D = 1.5\,h \times 3\,ft/h \quad ; \quad \underbrace{D = 4.5\,ft} \quad (\text{Reference depth})$$



$$\text{Fraction removed} = \frac{\#\ \text{particles removed}}{\text{Total}\ \#\ \text{particles}}$$

Fraction removed: Above tray, $F_1 = \dfrac{4.5\,ft \times N\,part/ft}{d \times N\,part./ft}$; $F_1 = \dfrac{4.5}{d}$

Below tray : $F_2 = 1.0$ (all are removed)

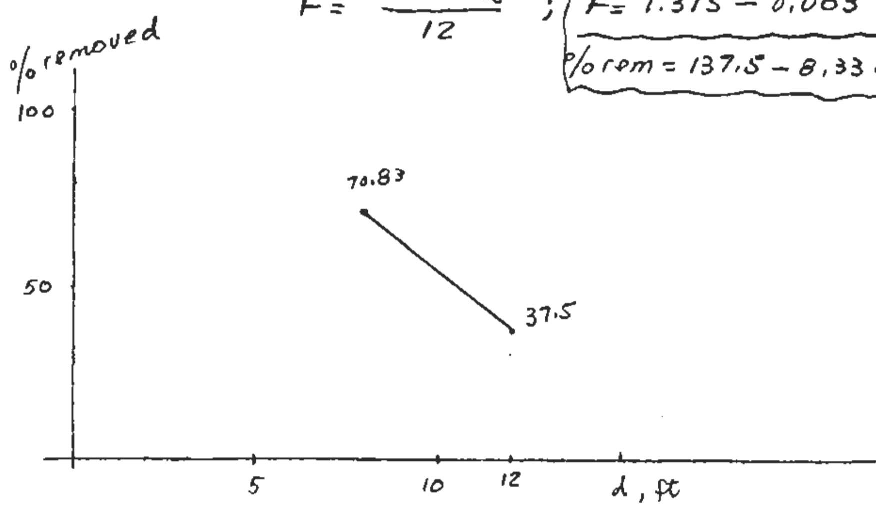
$$\text{Total \# particles removed} = \left(\frac{4.5}{d}\right)\left(d \times N\right) + 1.0 \times (12 - d)\,N$$

$$\text{Total \# particles entering tank} = 12\,ft \times N\,\frac{part.}{ft}$$

$$\text{Fraction removed} = \frac{\left(\frac{4.5}{\cancel{d}}\right)(\cancel{d}\cancel{N}) + (12-d)\cancel{N}}{12\,\cancel{N}}$$

$$F = \frac{16.5 - d}{12} \quad ; \quad \boxed{F = 1.375 - 0.083\,d}$$

$$\boxed{\%\text{rem} = 137.5 - 8.33\,d}$$



ENCE 4323 FINAL EXAM

December 4, 2007 Name:________________________

Instructions: Answer both parts A and B. You can only use your textbook and your notes as reference. Total time available: 2 hours.

PART A (25 points each problem)

Solve **only three** of the following problems.

1. A conventional surface-water filtration plant with coagulation, flocculation, sedimentation, and filtration produces a filtered water with a turbidity less than 0.3 NTU, pH 7.5, and temperature of 10°C at a design flow of 1.0 m^3/s. After filtration, the water is chlorinated in a baffled reservoir. The time of flow from the plant to the first consumer is 7.4 minutes.
   a) What is the required reservoir volume if the residual chlorine at the first consumer is 1.0 mg/L.?
   b) If the plant were a slow sand filtration plant, find the required chlorine residual at the first consumer using the same total contact time as in part (a).
   c) If the operating water temperature in the summer time is 20°C, and pH = 7.5, find the required residual chlorine concentration at the first consumer of the slow sand filtration plant of part (b).

2. 1000 kg (dry basis) of primary sludge with the characteristics listed below undergoes anaerobic digestion. Determine: a) the liquid sludge density before and after digestion; b) the volume of liquid sludge before and after digestion. c) the solids density before & after

	Primary	Digested
Solids %	4.3	8.6
Volatile matter, %	60	50% is destroyed
Specific gravity of fixed solids	2.5	2.5
Specific gravity of volatile solids	1.0	1.0

3. A tank initially contains 200 m^3 of water; however, due to a leak, 50 m^3 are lost after 2 hours. The rate of water loss is directly proportional to the square of the water volume remaining at any time. To compensate for the loss some water was added, but after 3 hours the water volume had been reduced to 150 m^3. How much water was added to the tank?

4. A water filtration plant produces 1.5 m^3/s at an average filtration rate of 12.50 $m^3/h.m^2$ when all units are operating; the filtration rate increases to 14.29 $m^3/h.m^2$ when one unit is out of service for backwashing. Each unit is backwashed for 7 minutes every 24 hours at a backwash rate of 48.9 m/hr. Find the following: (a) The number of filtration units. (b) The percentage of filter output used for backwashing. (c) If the dual media is composed of anthracite with uniformity coefficient = 1.5, and sand, find the uniformity coefficient of the sand if it desired to have at least 15 cm of media intermixing after filter backwashing.

2. % solids in primary sludge = 4.3%
Volatile solids = 60%
$S_f = 2.5$; $\rho_f = 2500\ kg/m^3$
$S_v = 1.0$; $\rho_v = 1000\ kg/m^3$

Density of all solids:

$$(6a)\quad \frac{1}{\rho_s} = \frac{F_v}{\rho_v} + \frac{F_f}{\rho_f} \ ; \quad \frac{1}{\rho_s} = \frac{0.6}{1000} + \frac{0.4}{2500} \ ; \quad \rho_s = 1315.78$$

$S_s = 1.32$

Sludge density: $\frac{1}{\rho_{sl}} = \frac{F_s}{\rho_s} + \frac{F_w}{\rho_w}$

$$\frac{1}{\rho_{sl}} = \frac{0.043}{1315.78} + \frac{0.957}{1000} \ ; \quad \rho_{sl} = 1010.43\ kg/m^3 \quad \text{Before} \quad (6)$$

$F_s = 0.043$; $F_v = 0.043 \times 0.6$; $F_v = 0.0258$

$F_f = 0.043 \times 0.4$; $F_f = 0.0172$

$$\text{Eq. 4:}\quad V_T = \frac{M_s}{F_s\,\rho_{sl}} \ ; \quad V_T = \frac{1000\ kg}{0.043 \times 1010.43} \ ; \quad V_T = 23.01\ m^3 \quad \text{Before} \quad (6)$$

After digestion, 50% of organic matter is destroyed

Before digestion : solids = 400 fixed + 600 volatile = 1000 kg
After digestion : solids = 400 fixed + 0.5 × 600
= 400 fixed + 300 volatile = 700 kg

Fraction vol. solids after digestion : $\text{Fraction}_v = \frac{300}{700} = 0.429$ (42.86%) (3)

F_s after digestion : $F_s = 0.086$ ∴ $F_v = 0.086 \times 0.4286 = 0.0369$

$F_f = 0.086 \times 0.5714 = 0.0491$

$F_w = 0.914$

$$\text{After digestion}: \frac{1}{\rho_{sl}} = \frac{0.0369}{1000} + \frac{0.0491}{2500} + \frac{0.914}{1000} \ ; \quad \rho_{sl} = 1030.38\ \frac{kg}{m^3} \quad (7)$$

after

Mass of sludge after digestion:

$$M_s = \underbrace{1000\ kg \times 0.4}_{\text{fixed}} + \underbrace{1000\ kg \times 0.5 \times 0.6}_{\text{volatile}} \ ; \quad M_s = 700\ kg$$

(remaining)

$$V_T = \frac{M_s}{F_s\,\rho_{sl}} \ ; \quad V_T = \frac{700}{0.086 \times 1030.38} \ ; \quad V_T = 7.9\ m^3 \quad \text{(After)} \quad (6)$$

$$\%\text{volume reduction} = \frac{23.01 - 7.9}{23.01} \times 100 = 65.67\%$$

except orifice loss

3. (35 points) The head losses in a clean dual-media filter operating under declining rate conditions are the following: Laminar, clean filter, $h_L = 78$ V; Turbulent losses, $h_T = 3000V^2$. In all these expressions V is the filtration rate in m^3/s per m^2. The maximum available head for filtration is 3.0 m. An orifice plate is placed in the influent pipe to limit the maximum filtration rate. The minimum filtration rate is 2.7×10^{-3} m/s, and the dirty-filter laminar loss at the minimum filtration rate is 2.0 m. What is the orifice loss at the maximum filtration rate?

Pertinent final exam problems

4. Design a bar rack and its channel so that the maximum velocity through the bars will be 0.7 m/s. Use bars with rectangular cross section, 9 mm × 50 mm, with a spacing of 25.0 mm between the parallel bars. The design flow rate is 150 l/s. Find the following: a) the number of bars; b) the channel dimensions (width, total depth) assuming a maximum head loss of 0.32 m; c) the head loss through the screen assuming it is 40 % clogged (i.e., the net area is 60 % of the clean-rack net area); d) draw a side view of the channel with the bar rack, showing the angle of the bar screen with the horizontal, and all the dimensions.

4. A water filtration plant produces 1.5 m^3/s at an average filtration rate of 12.50 $m^3/h.m^2$ when all units are operating; the filtration rate increases to 14.29 $m^3/h.m^2$ when one unit is out of service for backwashing. Each unit is backwashed for 7 minutes every 24 hours at a backwash rate of 48.9 m/hr. Find the following: (a) The number of filtration units. (b) The percentage of filter output used for backwashing. (c) If the dual media is composed of anthracite with uniformity coefficient = 1.5, and sand, find the uniformity coefficient of the sand if it desired to have at least 15 cm of media intermixing after filter backwashing.

3. A filter operates with a venturi-tube effluent rate controller and works at a constant rate of 28.3 l/s. The gravel, sand, and water (above de sand surface) depths are 0.6 m, 1.0 m, and 1.5 m, respectively. The water levels at both the filter box and the effluent channel remain constant at 3.1 m and 0.0 m, respectively. The head loss through the sand, the gravel, and the filter bottom is 30 cm at the beginning of the filter run, and 2.4 m at the end.

NO soln

a) What is the available head at the beginning and at the end of the filter run, and what is the head lost at the rate controller?

b) Assuming the rate controller works as an orifice, and that the head loss in the effluent pipe is negligible, calculate the ratio of the areas of the rate controller opening at the end and at the beginning of the run.

7. The thickness of the gravel, sand, and water layers in a rapid sand filter are 0.6 m, 1.0 m, and 1.5 m, respectively. When the filter is backwashed at a constant rate of 60 cm/min all the sand is fluidized, and the head loss through the false bottom is 60 cm.

A. What is the head loss through the sand and the gravel?

B. Assuming the backwash rate is increased to 75 cm/min, what is the total head loss through the sand, gravel and filter bottom? Assume that the backwash flow is laminar through the gravel, and turbulent through the false bottom.

4. $Q = 0.15\ m^3/s$; $V_{max} = 0.7\ m/s$; Approach $V = 0.3 - 0.6\ m/s$

Net area through bars $= \dfrac{0.15 m^3/s}{0.7\ m/s} = 0.214\ m^2$

$$\left.\begin{array}{l} a = 0.025\,m \\ t = 0.009\,m \end{array}\right\} \Rightarrow \frac{\text{Total area}}{\text{Net area}} \cong \frac{a+t}{a} = \frac{25+9}{25} = 1.36$$

$\therefore$ Total area $= 1.36 \times 0.214$; $\underline{\text{Total area} = 0.291\ m^2}$

Approach vel $= \dfrac{0.15\ m^3/s}{0.291\ m^2} = 0.515\ m/s$ (OK)

Select channel width $= 0.6\,m \Rightarrow$ height $= \dfrac{0.291\ m^2}{0.6\,m} = 0.485\ m$

(a) # bars :

Channel width $= (n+1)a + nt = W \Rightarrow n = \dfrac{w-a}{a+t}$

$n = \dfrac{0.6 - 0.025}{0.025 + 0.009}$; $n = 16.7 \Rightarrow \underline{n = 17}$

(b) $w = 18 \times 0.025 + 17 \times 0.009$; $\underline{W = 0.603\ m}$

$$\frac{\text{Total area}}{\text{Net area}} = \frac{(n+1)a + nt}{(n+1)a} = \frac{0.603}{18 \times 0.025} = 1.34$$

Total area $= 1.34 \times 0.214\ m^2 = 0.287\ m^2$

$\therefore$ water depth $= \dfrac{0.287\ m^2}{0.6\ \ m} = 0.476\ m$

Free board $= 0.3\ m$

Max head loss $= 0.324\ m$

Total depth $= 1.1\ m$

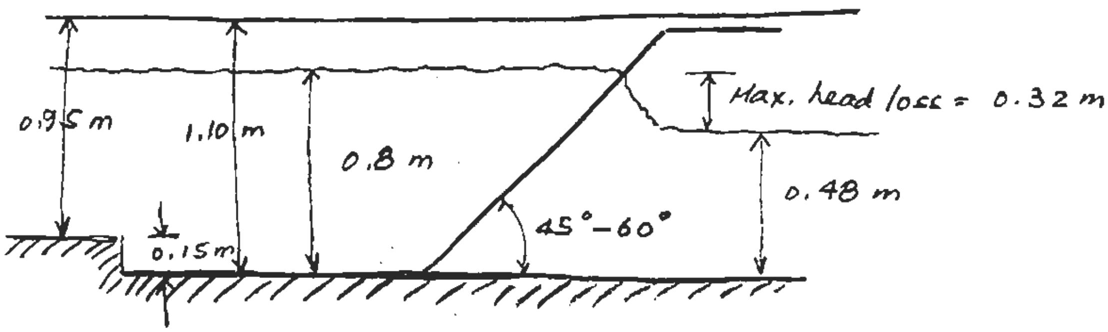
(c) Head loss when screen is 40% obstructed:

$V = \dfrac{0.15\ m^3/s}{(0.214 \times 0.6)\ m^2}$; $V = 1.17\ m/s$ (through bars)

$v = \dfrac{0.15\ m^3/s}{0.287\ m^2}$; $v = 0.52\ m/s$ (approach)

$h_L = \dfrac{V^2 - v^2}{2g} \times \dfrac{1}{0.7}$; $h_L = \dfrac{1.17^2 - 0.52^2}{2 \times 9.81 \times 0.7}$; $\underline{h_L = 0.08\ m}$

(d)



3.

$$-\frac{dV}{dt} = R \; m^3/h$$

$$-\frac{dV}{dt} = kV^2 \; ; \; -\frac{dV}{V^2} = k\,dt$$

$$\int_{V_0}^{V} \frac{dV}{V^2} = -k\int_0^t dt \;\Rightarrow\; kt = \frac{1}{V} - \frac{1}{V_0} \;,\; \underline{k = \frac{1}{t}\left(\frac{1}{V} - \frac{1}{V_0}\right)}$$

$$k = \frac{1}{2}\left(\frac{1}{150} - \frac{1}{200}\right) \;;\; \underline{k = 8.333 \times 10^{-4}}$$

After adding water : $8.333 \times 10^{-4} \times 3 = \frac{1}{150} - \frac{1}{V_0} \Rightarrow \underline{V_0 = 171.43\, m^3}$

Increase in vol $= 171.43 - 150$

$$= \underline{\underline{21.43\, m^3}}$$

4. $Q = 1.5\, m^3/s$, $V_{av.} = 12.5\, \frac{m^3/h}{m^2}$

At N-1 : $V = 14.29\, \frac{m^3/h}{m^2}$

BW rate $= 48.9\, \frac{m^3/h}{m^2}$

(9) (a) Total filter area $= \dfrac{1.5\, m^3/s \times 3600\, \frac{s}{h}}{12.5\, \frac{m^3/h}{m^2}} = 432\, m^2$

Flow through each filter

Area of each filter $= \dfrac{432}{N}$

When 1 filter is out of service : $\dfrac{\dfrac{1.5 \times 3600\; m^3/h}{N-1}}{\dfrac{432}{N}\; m^2} = 14.29\, \frac{m^3/h}{m^2}$

$$\frac{1.5 \times 3600\, N}{(N-1)\, 432} = 14.29 \;;\; \frac{N}{N-1} = 1.1432 \;\Rightarrow\; N = 1.1432N - 1.1432$$

$$N = \frac{1.1432}{0.1432} \;,\; \underline{\underline{N = 8}}$$

(8) (b) Vol. of wash water $= 48.9\, \frac{m^3/h}{m^2} \times 432\, m^2 \times \frac{7\, min}{d} \times \frac{1\,h}{60\, min} = 2464.56\, \frac{m^3}{d}$

% of production $= \dfrac{2464.56\; m^3/d}{1.5\, \frac{m^3}{s} \times 86400\; s/d} \times 100 = \underline{\underline{1.9\%}}$

(c) $(UC)_{anthr.} = 1.5$, BW rate $= 48.9 \frac{m^3/h}{m^2} = 20 \frac{gpm}{ft^2}$

(B) For 10% fluidization from chart, $(P_{90})_{sand} = 1.05$ mm

$(P_{90})_{coal} = 1.54$ mm

$$\frac{(P_{90})_{coal}}{(P_{10})_{sand}} = 3 \text{ (for 15 cm intermixing)}$$

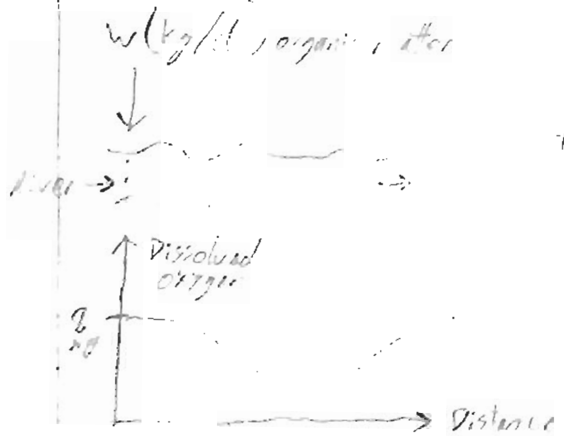
$$\therefore (P_{10})_{sand} = \frac{1.54}{3} = 0.51 \text{ mm}$$

$$(UC)_{sand} = \left(\frac{1.05}{0.51}\right)^{\frac{1}{1.67}} \quad ; \quad (UC)_{sand} = 1.54$$

wastewater ... T

Reactions & Reactors in environ. eng.

... : Reaction, Kinetics (as applied ...), mass balance



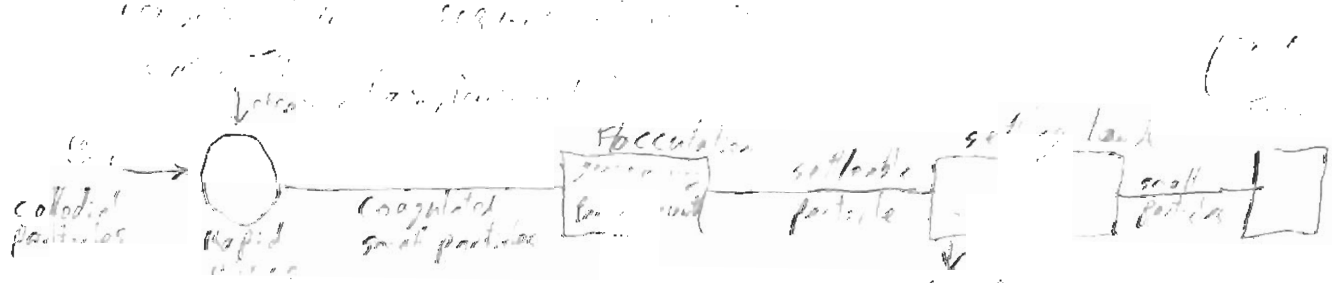
The reaction ... basically DO consumption by micro organism ... surface ...

("plug ...")

☆ Reactor config. defines the sys. performance

- Diff b/ tubular ... complete ...

... sequence ...



WW (2)

Kinetics of homogeneous reactions
- [illegible]
- [illegible]

Reac. 'A' is consumed @ const. rate of 20 $^{mg}/_{L}$
" 'B' " " " " " " 300 $^{mg}/_{L}$
- Need to remove 300 $^{mg}/_{L}$ [illegible]
- [illegible] Reactor size

A: Holding Time, $\bar{t}$: $\bar{t}_A = \frac{300 \, mg/L}{20 \, mg/L/d}$; $\bar{t}_A = 15\,d$

$\therefore$ $V_A = 15\,d \times 10\, m^3/d$, $\underline{V_A = 150\, m^3}$

$\bar{t}_B = \frac{300\, mg/L}{300\, mg/L/d}$; $\bar{t}_B = 1\,d$ $\therefore$ $V_B = 1\,d \times 10 \frac{m^3}{d}$; $\underline{V_B = 10\, m^3}$

Reaction Classification

Homogeneous: takes place in a single phase

Heterogeneous: requires more than one phase
Aeration (gas transfer) reqs gas & liquid
Solid dissolution eg salt in water (solid & liq)

Reaction Rate (r) [Reac. rate of A: r_A] [$\frac{mol/L}{s}$; $\frac{mg/L}{s}$]

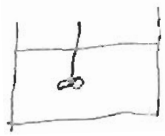
Mass Balance

M.B. of reactant 'A' in vol. element dV

4 things a reactant can do in vol. element

$$\begin{pmatrix}\text{mass of reactant}\\ \text{flow into vol. element}\end{pmatrix} - \begin{pmatrix}\text{mass of react.}\\ \text{leaving V.E.}\\ \text{element}\end{pmatrix} + \begin{pmatrix}\text{mass of react. A}\\ \text{converted by}\\ \text{reaction in vol. elem.}\end{pmatrix} = \begin{pmatrix}\text{Accumulation}\\ \text{of reactant 'A'}\\ \text{in vol. element}\end{pmatrix} \left[\frac{mol}{s}\right]$$

input — output — reaction — accumulation ww ③ Aug 23



<u>Batch reactor</u> : complete mixing ∴ composition is uniform

M.B. on react. 'A', / Batch reactor, is written around entire Vol. V

Input : $\varnothing$, output $\varnothing$

$$\underset{\text{input}}{\varnothing} - \underset{\text{output}}{\varnothing} + \underset{\text{reaction (reaction rate)}}{r_A\left[\frac{mol/L}{s}\right](V)[L]} = \underset{\text{Accumul.}}{\frac{dn_A}{dt}}$$

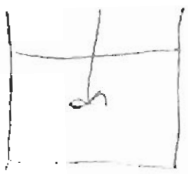
(r_A : reaction rate
n_A = # of moles of A
V : reactor volume)

$$\Rightarrow r_A = \frac{1}{V}\frac{dn_A}{dt}$$

in general : $n_A = f(t)$
$V = g(t)$

* aqueous systems V [illegible] $r_A = \dfrac{d\left(\frac{n_A}{V}\right)}{dt}$

$\dfrac{n_A}{V}$ concentration of A $(C_A)\left[\frac{mol}{L}\right]$; $r_A = \dfrac{dC_A}{dt}$



$t = 0$, C_A C_{A0}
$t = t_1$, C_A C_{A1}
$t = t_2$, C_A C_{A2}
⋮

$$dt = \frac{dC_A}{r_A} \xrightarrow{\text{integrate}} \int_0^t dt = \int_{C_{A0}}^{C_A}\frac{dC_A}{r_A} \Rightarrow \boxed{t = \int_{C_{A0}}^{C_A}\frac{dC_A}{r_A}}$$ Batch reactor

<u>Example</u> Batch reactor, first order reaction, 90% conversion in 5min. What reaction time is req. to get 5 mg/L @ the end of the reaction if $C_{A0} = 100$ mg/L ?

reaction order $r_A = k_n C_A^n$ if $n = \varnothing$: $r_A = k_0$
if $n = 1$: $r_A = k_1 C_A$ (1st order reaction)
if $n = 2$: $r_A = k_2 C_A^2$ (2nd order reaction)

Conversion (aka removal), (χ) : $\chi = \dfrac{C_{A0} - C_A}{C_{A0}} = 1 - \dfrac{C_A}{C_{A0}}$ ratio called fraction remaining

* here $\chi = 0.9$ ∴ $\dfrac{C_A}{C_{A0}} = 0.1$

$t = 5$min ; $t = \displaystyle\int_{C_{A0}}^{C_A}\frac{dC_A}{-k_1 C_A}$ → $t = -\dfrac{1}{k_1}\ln\left(\dfrac{C_A}{C_{A0}}\right)$ ⇒ $k_1 = -\dfrac{1}{t}\ln\left(\dfrac{C_A}{C_{A0}}\right)$

minus b/c consumptive

$k_1 = -\frac{1}{5}\ln(0.1) = 0.46\,\text{min}^{-1}$ $t = 0.46\,\text{min}^{-1}\ln\left(\frac{5}{100}\right) = 6.51\,\text{min}$

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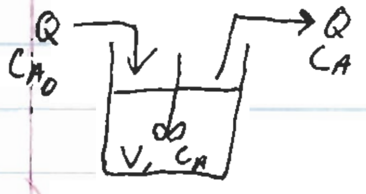
- reaction rate (well mixed, Batch reactor)
  - $r_A = \frac{dC_A}{dt}$ = slope of $C_A = f(t)$

    $r_A > \emptyset$ = productive reaction

    $r_A < \emptyset$ = consumptive
  - $t_{BATCH} = \int_{C_{A0}}^{C_A} \frac{dC_A}{r_A}$ $\quad r_A = k_n C_A^{\,n}$

    - First order reaction : $r_A = -k_1 C_A$: $t_{Batch} = -\frac{1}{k_1} \ln\left(\frac{C_A}{C_{A0}}\right)$

Continuous flow reactors



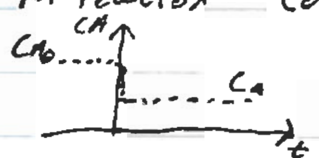
* Continuous flow stirred tank reactor (CFSTR)

(PFR) Plug Flow reactor

CFSTR

Assumptions : - $Q = C^{ST}$, Reactor Vol $= C^{ST}$ (V),

Completely mixed conditions ∴ Concentration in reactor = concentration in effluent stream



- mass bal. on 'A' : Accum = Input - Output + Reaction

  Accum $= V \frac{dC_A}{dt}$ $\left[L \cdot \frac{mol/L}{s} \right] = \emptyset$ (@ equilibrium, Steady State)

Input : $Q\left(\frac{L}{s}\right) \times C_{A0}\left(\frac{mol}{L}\right)$

Output : $Q\,C_A$

Reaction : $r_A \left[\frac{mol/L}{s}\right] \cdot V[L] = \left[\frac{mol}{s}\right]$

$\emptyset = Q(C_{A0} - C_A) + r_A V \rightarrow -r_A V = Q(C_{A0} - C_A)$

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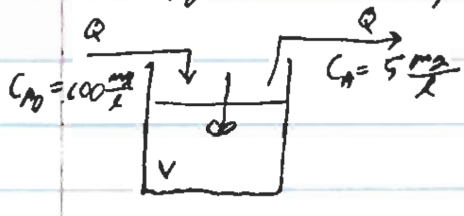
$$\rightarrow \quad \frac{V}{Q} = \frac{C_{A0} - C_A}{-r_A} \quad \left[\frac{l}{l/s} \right]$$

Define $\frac{V}{Q} = \bar{t}$, avg. detention time $\boxed{t_{CFSTR} = \frac{C_{A0} - C_A}{-r_A}}$

Example - batch reactor, what detention time would be needed if the reactor is a CFSTR? - First order, $k_1 = 0.46\ min^{-1}$, $C_{A_0} = 100\ mg/l$, $C_A = 5\ mg/l$, $t_{BATCH} = 6$



Soln: $t_{CFSTR} = \frac{C_{A0} - C_A}{-(-k_1 C_A)}$ ← b/c consumptive

$$t_{CFSTR} = \frac{100 - 5}{0.46(5)} \left[\frac{\frac{mg}{l}}{\frac{mg}{sl}} \right] = \boxed{41.3\ min}$$

* lower than what was needed for a continuous flow reactor in last class

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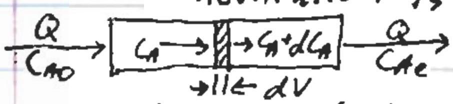
Plug Flow Reactor

Assumptions: - No mixing in the logitudinal direction

- Concentration is uniform at any cross section



mass balance is written around the differential element dV: Accum = Input - Output + Reaction

Steady State: $\emptyset = QC_A - Q(C_A + dC_A) + r_A \cdot dV$

$$\emptyset = \cancel{QC_A} - \cancel{QC_A} + Q\,dC_A + r_A\,dV \rightarrow dV = Q \frac{dC_A}{r_A}$$

$$\int_0^V dV = \int_{C_{A0}}^{C_{Ae}} Q \frac{dC_A}{r_A}$$

$$\boxed{\frac{V}{Q} = \bar{t}_{PFR} = \int_{C_{A0}}^{C_A} \frac{dC_A}{r_A}}$$

note Batch: $t_{BATCH} = \int_{C_{A0}}^{C_A} \frac{dC_A}{r_A}$

∴ in general, for same reaction time performance of batch ≡ PFR

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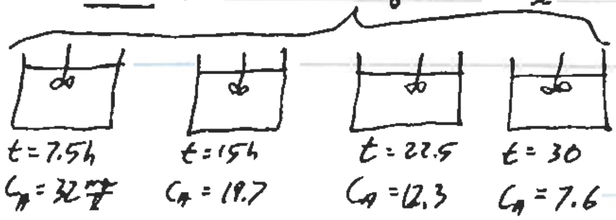
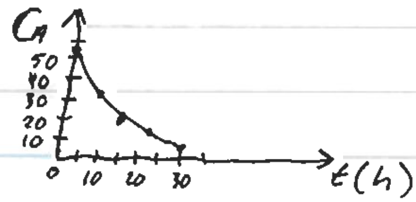
Example

Experiments are conducted in Batch reactor : $C_{A_0} = 50.8 \frac{mg}{\ell}$

$t(h)$	$C_A\left(\frac{mg}{\ell}\right)$
0	50.8
7.5	32.0
15.0	19.7
22.5	12.3
30.0	7.6





Find: (a) Reaction order & rate constant

(b) If $\bar{t}_{PFR} = 20h$, find C_{A_e} if $C_{A_0} = 60 \frac{mg}{\ell}$

Sol'n:

If $r_A = k_n C_A^{\,n}$

Trial & Error Proceedure

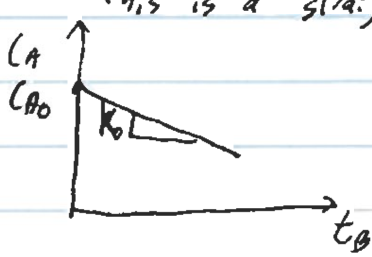
– make guess for 'n' (reaction order) & see if data falls on theoretical equ.

Assumption: (1) Zero-order : $r_A = -k_0$ b/c consumptive

$$\bar{t}_{BATCH} = \int_{C_{A_0}}^{C_A} \frac{dC_A}{r_A} \quad (\text{sub } -k_0 \text{ for } r_A)$$

$$\bar{t}_B = \frac{1}{-k_0}\int_{C_{A_0}}^{C_A} dC_A \rightarrow \bar{t}_B = \frac{1}{k_0}(C_{A0} - C_A) \rightarrow C_A = C_{A0} - k_0 t_B$$

This is a straight line $\therefore$ not zero order



$$t_B = -\frac{1}{K_1}(\ln C_A - \ln C_{A0})$$

$$-\frac{1}{K_1} t_B = \ln C_A - \ln C_{A0}$$

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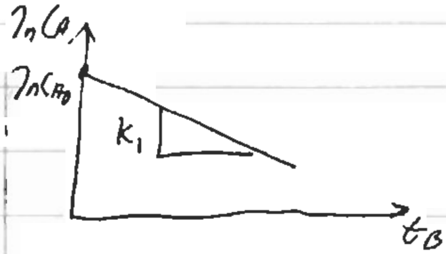
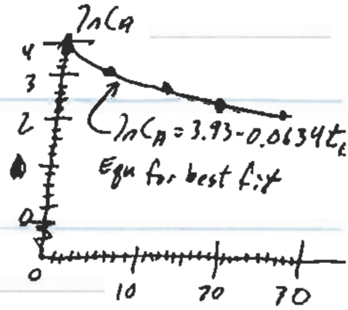
(2) Try First-order : $r_A = -k_1 C_A$

$$t_B = -\int_{C_{A0}}^{C_A} \frac{dC_A}{k_1 C_A} = -\frac{1}{k_1}\ln\left(\frac{C_A}{C_{A0}}\right) \rightarrow \ln(C_A) = \ln(C_{A0}) - k_1 t_B$$



t(h)	C_A	$\ln C_A$
0	50.8	3.93
7.5	32	3.47
15	19.7	2.98
22.5	12.7	2.51
30	7.6	2.03



* Brush up on excel & regression analysis

So, - (a) Reaction is first order, $\boxed{k_1 = 0.0634\ h^{-1}}$

* Now Part (b)

Since performance of the Batch reactor ≡ performance of a PFR,

for a PFR w/ 1st-order reaction : $\underbrace{t_{PFR}}_{20h} = \underbrace{-\frac{1}{k_1}}_{-\frac{1}{0.0634 h^{-1}}} \ln \frac{C_{Ae}}{C_{A0}}$ ← $60\ \frac{mg}{l}$

→ $\boxed{C_{Ae} = 16.9\ \frac{mg}{l}}$

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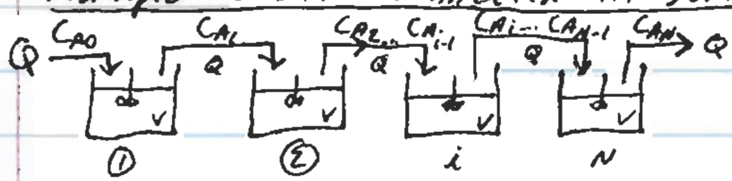
Comparison of Reactor Size

reaction order > ∅; if ∅ they are =

- CFSTR is always > PFR for same conversion
- Vol. ratio V_{CFSTR}/V_{PFR} ↑ w/ reaction order
- For same reactor Vol., PFR is more efficient than CFSTR

Multiple CFSTR connected in series



- All have identical $\bar{t} = \frac{V}{Q}$ (detention time)

First Order Consumptive reaction: $r_A = -k_1 C_A$

" ", CFSTR: $\bar{t} = \frac{1}{k}\left(\frac{C_{A0}}{C_A} - 1\right)$ [in general]

$$\rightarrow \frac{C_{A0}}{C_A} = 1 + k\bar{t}$$

First Tank: $\frac{C_{A0}}{C_A} = 1 + k\bar{t}$

Second tank: $\frac{C_{A1}}{C_{A_2}} = 1 + k\bar{t}$

i^{th} tank: $\frac{C_{A_{i-1}}}{C_{A_i}} = 1 + k\bar{t}$

N^{th} tank: $\frac{C_{A_{N-1}}}{C_{A_N}} = 1 + k\bar{t}$

* mult both sides keeping = to each other

$$\frac{C_{A0}}{\cancel{C_A}}\left(\frac{\cancel{C_{A1}}}{\cancel{C_{A_2}}}\right)\cdots\left(\frac{\cancel{C_{A_{i-1}}}}{\cancel{C_{A_i}}}\right)\cdots\left(\frac{\cancel{C_{A_{N-1}}}}{C_{AN}}\right) = (1 + kt)^N$$

$$\rightarrow \frac{C_{A0}}{C_{AN}} = (1 + k\bar{t})^N$$ * Solve for $\bar{t}$

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$$\rightarrow \quad \bar{t} = \frac{1}{k}\left[\left(\frac{C_{A0}}{C_{AN}}\right)^{\frac{1}{N}} - 1\right]$$

Total detention Time : $\bar{t}_T = N \cdot \bar{t}$; $\rightarrow \boxed{\bar{t}_T = \frac{N}{k}\left[\left(\frac{C_{A0}}{C_{AN}}\right)^{\frac{1}{N}} - 1\right]}$

Compare N identical CFSTRs w/ a single PFR, both handling same Q

First order reaction: $\bar{t}_{PFR} = \frac{1}{k} \ln\left(\frac{C_{A0}}{C_A}\right)$

For N CFSTRs : $\bar{t}_T = \frac{N}{k}\left[\left(\frac{C_{A0}}{C_{AN}}\right)^{\frac{1}{N}} - 1\right]$

by definition of $\bar{t} = \frac{V}{Q}$

Take $\frac{\bar{t}_T}{\bar{t}_{PFR}} = \frac{V_T}{V_{PFR}} = \frac{N\left[\left(\frac{C_{A0}}{C_A}\right)^{\frac{1}{N}} - 1\right]}{\ln\left(\frac{C_{A0}}{C_{A_e}}\right)}$ equ. 1

"X"

* Assuming conversions $\leftarrow \left(1 - \frac{C_A}{C_{A0}}\right)$ "Fraction removed"

$0.999 \therefore \frac{C_A}{C_{A0}} = 0.001 \rightarrow \frac{C_{A0}}{C_A} = \frac{1}{0.001}$

From handout

If $V_T = V_{PFR}$, & both handle same Q

$$N\left[\left(\frac{C_{A0}}{C_{AN}}\right)^{\frac{1}{N}} - 1\right] = \ln\left(\frac{C_{A0}}{C_A}\right)$$

* solve for conversion "X"

$$(X_N)_{CFSTR} = 1 - \left[1 + \frac{1}{N}\ln\left(\frac{1}{1 - X_{PFR}}\right)\right]^{\frac{1}{N}}$$

$(X_N)_{CFSTR}$ = conversion of N CFSTRs in series, X_{PFR} = Conversion of single PFR

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Examples: see hand-out

- Con't from hand out

Ex 1:

N	V_T
1	220
2	40
3	24.3
PFR	10.2

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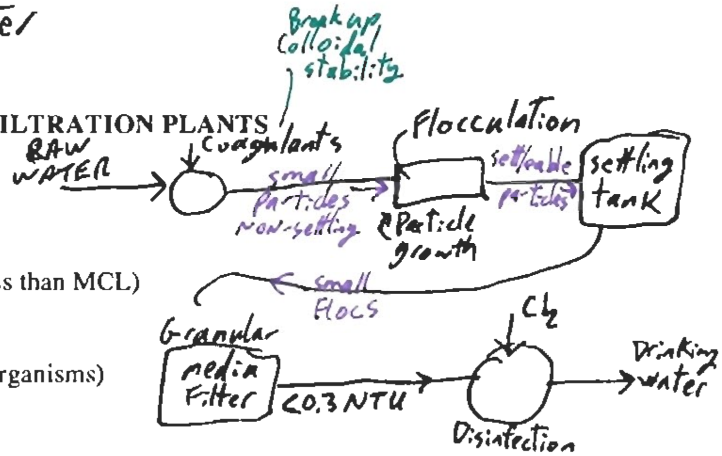
ENCE 4323

CONVENTIONAL RAPID SAND FILTRATION PLANTS



INTRODUCTION

- Surface waters usually contain
  - Dissolved substances (concentration must be less than MCL)
    - Inorganic
    - Organic
  - Suspended particles (inorganic, organic, microorganisms)
    - Settleable
    - Colloidal

Typical settling velocities

Type of particle	Size, mm	Settling velocity
Pebble	10	0.73 m/s
Coarse sand	1	0.23 m/s
Fine sand	10^{-1}	10^{-2} m/s
Silt	10^{-2}	8.6 m/d
Large colloid	10^{-4}	0.3 m/yr
Small colloid	10^{-6}	3 m/million yr

- Turbidity is the most common contaminant in surface waters
- EPA Enhanced Surface Water Treatment Rule specifies:
  - Turbidity < 0.3 NTU in at least 95 % of measurements taken each month
  - At no time turbidity can exceed 1 NTU.
- Turbidity is caused by colloidal particles; therefore, it cannot be removed by settling or plain filtration.
- Turbidity removal requires
  - colloid destabilization: rapid mixing
  - flocculation: particle growth until they become settleable
  - settling: removal of settleable floc particles
  - filtration: polishing, removal of microfloc that escape settling
  - disinfection: to kill bacteria, giardia, cryptosporidium, viruses

RAPID MIXING

can only be seen by electron-microscope

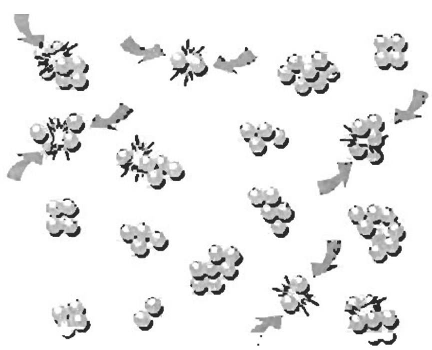
- Colloids: ultramicroscopic particles
  - Have large external surface area. E.g., 1 cm^3 divided in cube 10 nm each side has 600 m^2 of external surface area.
  - Have tendency to concentrate substances onto external surface
  - Develop a charge. This charge results in colloid stability.

Colloid Stability and Colloid Destabilization

Colloidall particles have a surface charge

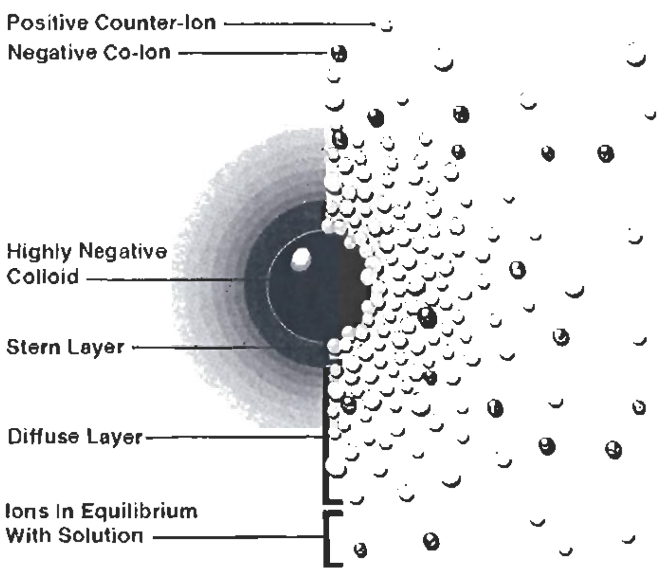
Charged Particles repel each other

If particle charge could be neutralized, particle aggregation would occur



Uncharged Particles are free to collide and aggregate.

Double Layer Theory

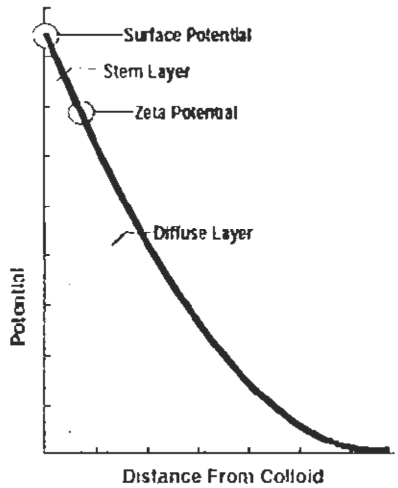


Two Ways to Visualize the Double Layer
The left view shows the change in charge density around the colloid. The right shows the distribution of positive and negative ions around the charged colloid.

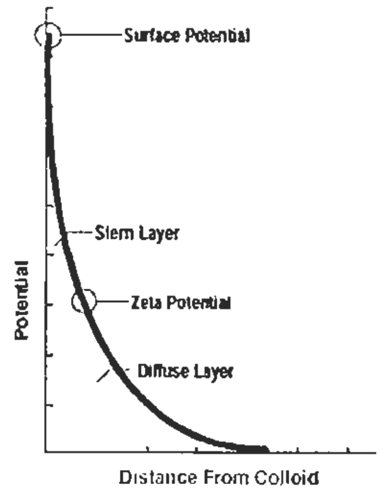
- When two colloidal particles are brought together, diffuse layers interact
- Particle repulsion occurs
- Colloidal stability takes place

Zeta Potential theory – particle repulsion is due to interaction b/t the zeta potential of the neighboring particles.

When colloidal particles move, they carry part of the diffuse layer. The potential at the plane of rupture is called zeta potential.



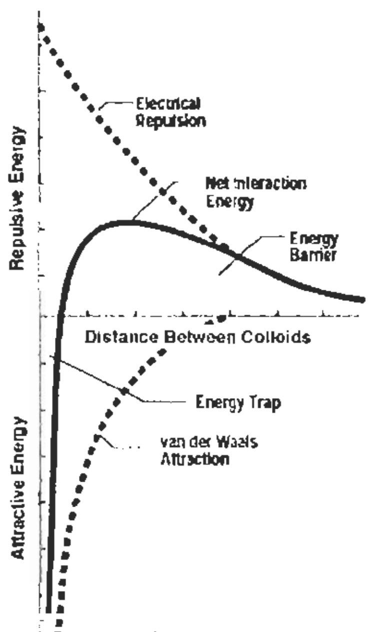
Fresh Water



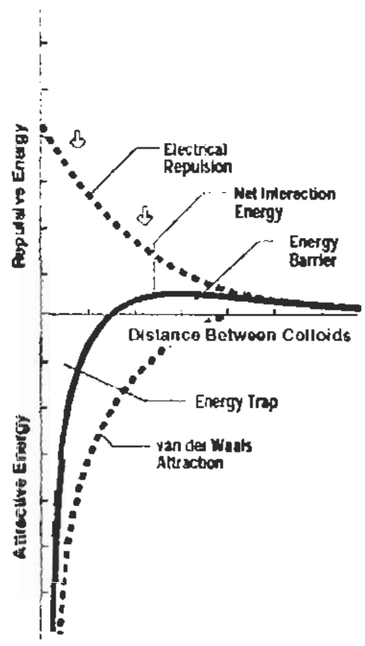
Saline Water

Zeta Potential vs Surface Potential
The relationship between Zeta Potential and Surface Potential depends on the level of ions in solution. In fresh water, the large double layer makes the zeta potential a good approximation of the surface potential. This does not hold true for saline waters due to double layer compression.

The net interaction energy



The energy barrier prevents particles from attaching



If the energy barrier is low enough, colloid attachment can occur.

Interaction
The net interaction curve is formed by subtracting the attraction curve from the repulsion curve

Charge Reduction
Coagulant addition lowers the surface charge and drops the repulsive energy curve. More coagulant can be added to completely eliminate the energy barrier

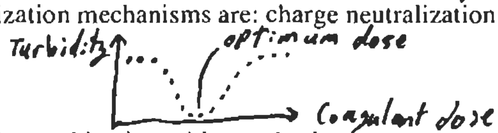
Ferric solutions are acidic: e.g., a 10^{-3} M solution of $FeCl_3$ has pH = 3.2
Polymerization: $2\ Fe(H_2O)_5OH^{2+} \rightarrow Fe_2(H_2O)_8(OH)_2^{4+} + 2H_2O$ ...
Similar reactions take place when we add aluminum salts.

In general:

$Me(H_2O)_6^{3+} \rightarrow$ (Simple Hydroxocomplexes) $\rightarrow$ (hydroxometal polymers) $\rightarrow Me(OH)_3(s)$

Four important observations when Fe and Al salts are used:

- Colloid destabilization is carried out by hydroxometal polymers
- There is a direct dependence between coagulant dose and colloid concentration
- Restabilization may occur by excess coagulant dose means regeneration of colloidal suspension
- Major destabilization mechanisms are: charge neutralization and sweep flocculation.



Synthetic polymers

- Used alone or in combination with metal salts
- Bridging model explains coagulation by polymers.

Kinetics of Particle Aggregation

- Particle destabilization results in microfloc generation: **coagulation** or perikinetic flocculation
- Further particle contact by velocity gradients: orthokinetic flocculation or, simply, **flocculation**

- **Rate of coagulation** given by:
  $r_c = k_c n^2$, where
  r_c= rate of coagulation, (particles/L)/s
  n = number of particles
  k_c = kinetic coefficient

  Second order reaction; therefore, PFR would be best choice

- **Rate of flocculation** given by:

  $r_f = k_f\, n$, where:
  $$k_f = \frac{4}{\pi}\alpha_0 \Omega G$$
  α_0 = fraction of collisions leading to permanent agglomeration
  Ω = volume of particles per unit volume of suspension
  G = velocity gradient

  First order reaction; therefore, PFR would be best choice

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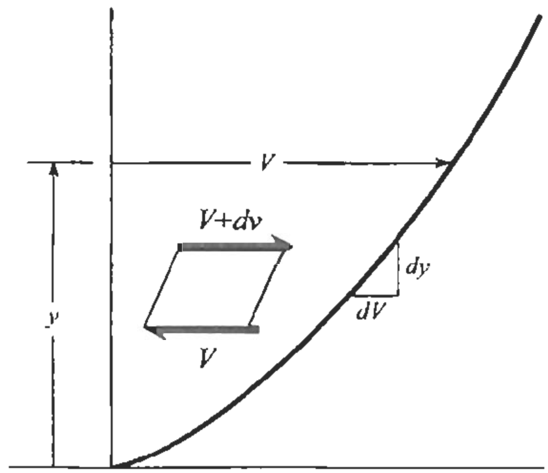
Viscosity

- Newton's Law of Viscosity $\tau = \mu \dfrac{dV}{dy}$
- Viscosity $\mu = \dfrac{\tau}{dV/dy}$
- Units $\dfrac{N/m^2}{\frac{m}{s}/m} = \dfrac{kg}{m \cdot s}$
- Water (@ 20°C)
  - $\mu = 1 \times 10^{-3}$ *kg/m.s*
- Air (@ 20°C)
  - $\mu = 1.8 \times 10^{-5}$ *kg/m.s*
- Kinematic viscosity $\nu = \dfrac{\mu}{\rho}$



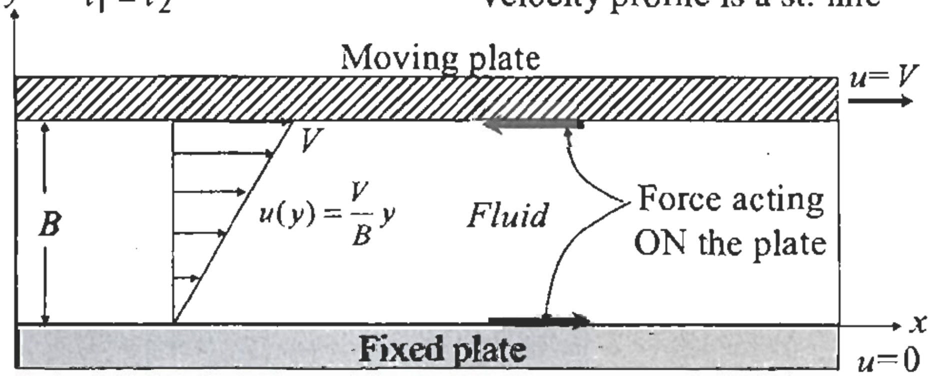
Flow between 2 plates

Force is same on top and bottom

$$\tau_1 = \mu \left.\frac{du}{dy}\right|_1 = \mu \left.\frac{du}{dy}\right|_2 = \tau_2$$

$$F_1 = \tau_1 A_1 = \tau_2 A_2 = F_2$$
$$A_1 = A_2$$
$$\tau_1 = \tau_2$$

Thus, slope of velocity profile is constant and velocity profile is a st. line



ENCE 4323
Fall 2009
RAPID MIXING UNITS

Diffusion by Pressured Water Jets (Fig. 1)

- No additional head loss by the mixer
- Very effective
- Controllable degree of mixing
- Low power consumption. .
- But:
  - water must be free of suspended solids to prevent nozzle clogging,
  - prone to clogging by coagulant salts.
- Design criteria:
  - $G\bar{t}$ = 400 - 1600 (1000 average) = [5 s]
  - Minimum pressure, 0.7 kg/cm^2, with mixing jet velocity, 6 - 7.6 m/s at the orifice.

In-line static mixers (Fig. 6.28)

- No moving parts, no external energy to be input to the system
- Very effective
- Degree of mixing and mixing time are a function of flow rate
- Proprietary devices, cannot be designed by engineer
- Mixing time of 1 - 3 s and maximum head loss of 0.6 - 0.9 m
- Best choice for aluminum or iron salts
  - $G\bar{t}$ = 350 – 1700 (1000 average)
  - Contact times between 1 and 3 s.

In-line blenders

- G = 3000 – 5000 s^{-1}
- $G\bar{t}$ = 1500 – 5000
- Power consumption for mixing (typical) = 8.5 kwatt/m^3.s (0.5 HP/mgd)
- $\bar{t}$ = 0.5 – 1 s
- Head loss through the unit = 0.3 – 1.0 m. Therefore, additional power is needed (2.7 – 8.7 kwatt/m^3.s) to overcome this head loss.

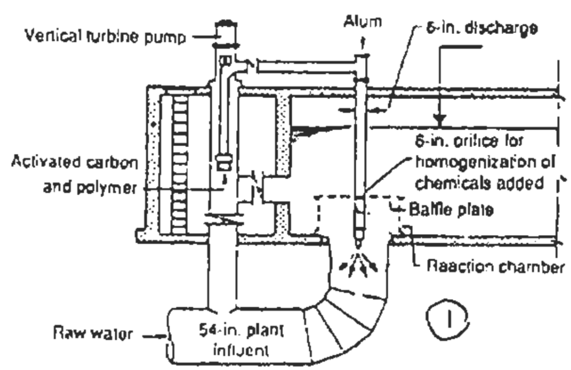
Hydraulic jumps (Fig. 8.10)

- Usually generated by Parshall flumes
  - Coagulant added upstream of jump
  - Typical G values: 800 s^{-1}
  - Contact time = 2 seconds

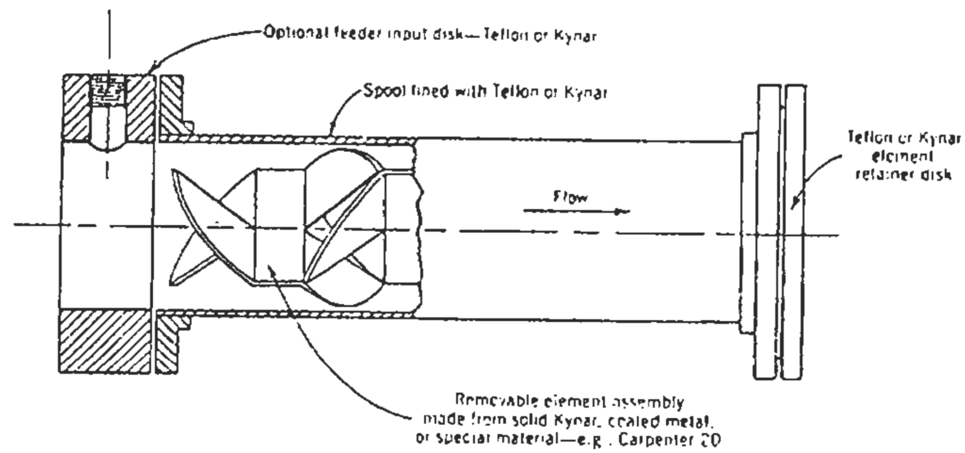
Mechanical flash mixing

- Most frequently used in water treatment industry
- G = 300 s^{-1}
- Mixing time: 10 - 30 s
- Power requirements: 0.85 - 1 HP per MGD
- Serious disadvantages:
  - Lack of instantaneous mixing characteristics
  - Short-circuiting
  - Mixing period is too long for metallic coagulants
  - Shaft problems and gear drive failures in many installations

Diffusion by pressurized water

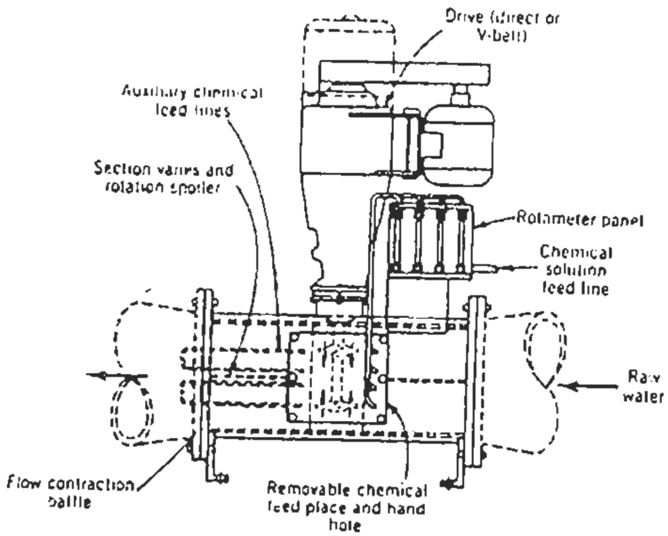


In-line static mixer



(e)

Figure 6.28 Rapid mixers used in practice. (*Continued*) (e) Static (motionless) mixer.



In-line blending

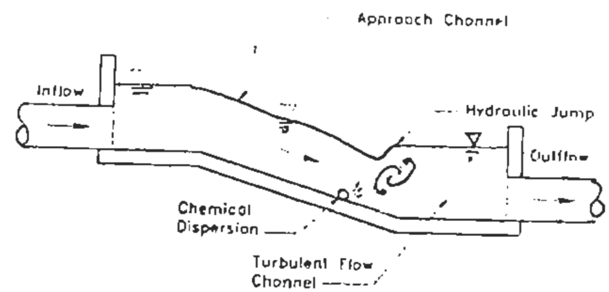
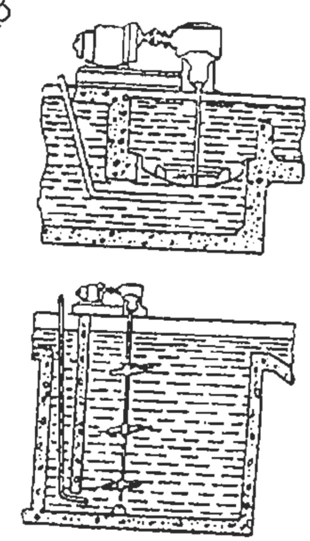


Figure 8-10 Typical rapid mixing utilizing a hydraulic jump.

Hydraulic Jump



Flash mixing

CALCULATION OF LIME DOSAGE FOR ALUM NEUTRALIZATION

When aluminum sulfate (alum) is added to water, the following reaction takes place:

$$Al_2(SO_4)_3 \cdot 14.3\ H_2O + 6\ H_2O\ =\ 2\ Al(OH)_3\ (s) + 6H^+ + 3SO_4^{2-} + 14.3\ H_2O$$

solid

The generation of $6H^+$ depresses the pH. If the pH drops too much, $Al(OH)_3$ (s) will not precipitate.

Aluminum Hydroxide

Bicarbonates present in natural waters serve as buffers:

$$HCO_3^- + H^+\ =\ H_2CO_3 \rightarrow\ CO_2 + H_2O$$

The overall reaction may be written as follows:

$Al_2(SO_4)_3$á$14.3H_2O + 6H_2O$	=	$2Al(OH)_3\ (s) + 6H^+ + 3SO_4^{2-} + 14.3H_2O$
$6HCO_3^- + 6H^+$	=	$6CO_2 + 6H_2O$
$Al_2(SO_4)_3$á$14.3H_2O + 6HCO_3^-$	=	$2Al(OH)_3\ (s) + 3SO_4^{2-} + 6CO_2 + 14.3H_2O$

Therefore, for every mole of alum (600 g), 6 moles of alkalinity (HCO_3^-) are consumed.

$$\text{Alkalinity consumed} = 6 \text{ moles } HCO_3^- \times \frac{1 \text{ eq}}{\text{mole } HCO_3^-} \times \frac{100 \text{ g } CaCO_3}{\text{mole } CaCO_3} \times \frac{1 \text{ mole } CaCO_3}{2 \text{ eq}}$$

$$\text{Alkalinity consumed} =\ 300 \text{ g as Ca } CO_3$$

Hence, 600 g of alum consume 300 g of alkalinity as $CaCO_3$. Therefore,

$$\boxed{1 \text{ mg/l of alum consumes } 0.5 \text{ mg/l of alkalinity as } CaCO_3.}$$

If water does not have sufficient alkalinity, must supplement alkalinity by adding lime, $Ca(OH)_2$:

$Al_2(SO_4)_3 \bullet 14.3H_2O + 6H_2O$	=	$2Al(OH)_3\ (s) + 6H^+ + 3SO_4^{2-} + 14.3H_2O$
$3Ca(OH)_2 + 6H^+$	=	$3Ca^{2+} + 6H_2O$
$Al_2(SO_4)_3 \bullet 14.3H_2O + 3Ca(OH)_2$	=	$2Al(OH)_3\ (s) + 3Ca^{2+} + 3SO_4^{2-} + 14.3H_2O$

Therefore, we need 3 moles of lime for every mole of alum to be neutralized, or

$$\frac{3 \text{ moles lime} \times \dfrac{74 \text{ g lime}}{\text{mole lime}}}{1 \text{ mole} \times \dfrac{600 \text{ g alum}}{\text{mole alum}}} = \frac{0.37\text{g lime}}{\text{g alum}}$$

Example Assume an alum dosage of 50 mg/L, water alkalinity = 10 mg/L as $CaCO_3$. Find the chemical consumption for a treatment plant with a flow rate of 100 L/s.

Solution:

Only 2 x 10 mg/L of alum will be neutralized by the existing alkalinity. Therefore, 50 – 20 = 30 mg/L of alum must be neutralized with lime.

$$\text{Lime dosage} = 30 \frac{\text{mg alum}}{\text{L}} \times 0.37 \frac{\text{mg lime}}{\text{mg alum}} = 11.1 \frac{\text{mg lime}}{\text{L}}$$

If Q = 100 L/s:

Alum consumption = 50 mg/L x 100 L/s x 86400 s/d x 1kg/10^6 mg = 432 kg/d

Lime consumption = 11.1 mg/L x 100 L/s x 86400 s/d x 1 kg/10^6 mg = 96 kg/d

Design example of a rapid mixing unit

The water supply for a town is taken from a river with considerable variations in quality. The raw water analyses for a year are shown in Table 1, with typical coagulant doses obtained from jar tests. The design flows for 24-h operation are: average day = 43.8 L/s, maximum day = 65.7 L/s. Design the rapid mixing unit for this plant.

Table 1. Data for design, river source

		Per cent occurrence						
Raw Water Analyses	Parameter	11	34	28	13	9	3	2
	Turbidity, ntu	28	45	81	126	140	180	>200
	Alklinity, mg/L as $CaCO_3$	86	132	92	84	93	77	82
	Temperature, °C	13	10	8	18	18	16	
Jar Tests	Alum, mg/L	18	27	36	28	41	31	36
	pH	6.4	6.7	6.4	6.4	6.4	6.2	6.4

Highest Alum dosage = 41 mg/L ; lowest alk = 77 mg/L as $CaCO_3$

Avg. daily water demand = 43.8 L/s

$Q_{max\ day}$ = demand on the day of max consumption @ the end of design period.

$\frac{Q_{max}}{Q_{avg}} = 1.2 - 1.8$ $\quad Q_{max\ day}$ = plant capacity = 65.7 L/s

- select mechanical blend.
- $G = 3000 - 4000\ s^{-1}$
- $G\bar{t} = 1500 - 5000$

Typical power consumption, $\frac{P}{Q} = 8.5\ \frac{kW}{L/s}\left(\frac{1000\ L}{m^3}\right) = 8500\ \frac{watt}{m^3/s} \rightarrow \frac{kg\ m^2}{s^2}$

$\bar{t} = 0.5 s - 1.0 s$

$G = \sqrt{\frac{P}{V\mu}}$; $G\bar{t} = \frac{V}{Q}\sqrt{\frac{\left(\frac{P}{Q}\right)Q}{V\mu}}$; $G\bar{t} = \sqrt{\bar{t}\,\frac{(P/Q)}{\mu}}$

Since 1 mg/L alum consumes 0.5 mg/L of alkalinity

Total alk consumed = 41 $\frac{mg\ alum}{L}$, 0.5 $\left(\frac{mg/L\ alk}{mg/L\ alum}\right)$ = 20.5 mg/L

∴ we have sufficient alk, no supplemental lime is needed

@ 8°C : $\mu = 0.001387\ \frac{kg}{m \cdot s}$; 18°C : $\mu = 0.0010603\ \frac{kg}{m \cdot s}$

select $\bar{t}$ = 0.53 s (Guess)

$G\bar{t}_{8°C} = \sqrt{0.53\ \frac{8500\ \frac{kg}{ms^2}}{0.001387\ \frac{kg}{m \cdot s}}} = 1802$ OKAY

$G\bar{t}_{18°C} = \sqrt{0.53\ \frac{8500}{0.0010603}}$; $G\bar{t} = 2061$ OKAY

$Q = 65.7\ \frac{L}{s}\left(\frac{1\ MGD}{43.8\ L/s}\right) = 1.5\ MGD$

Select 8" Diameter from chart

Length = 42"

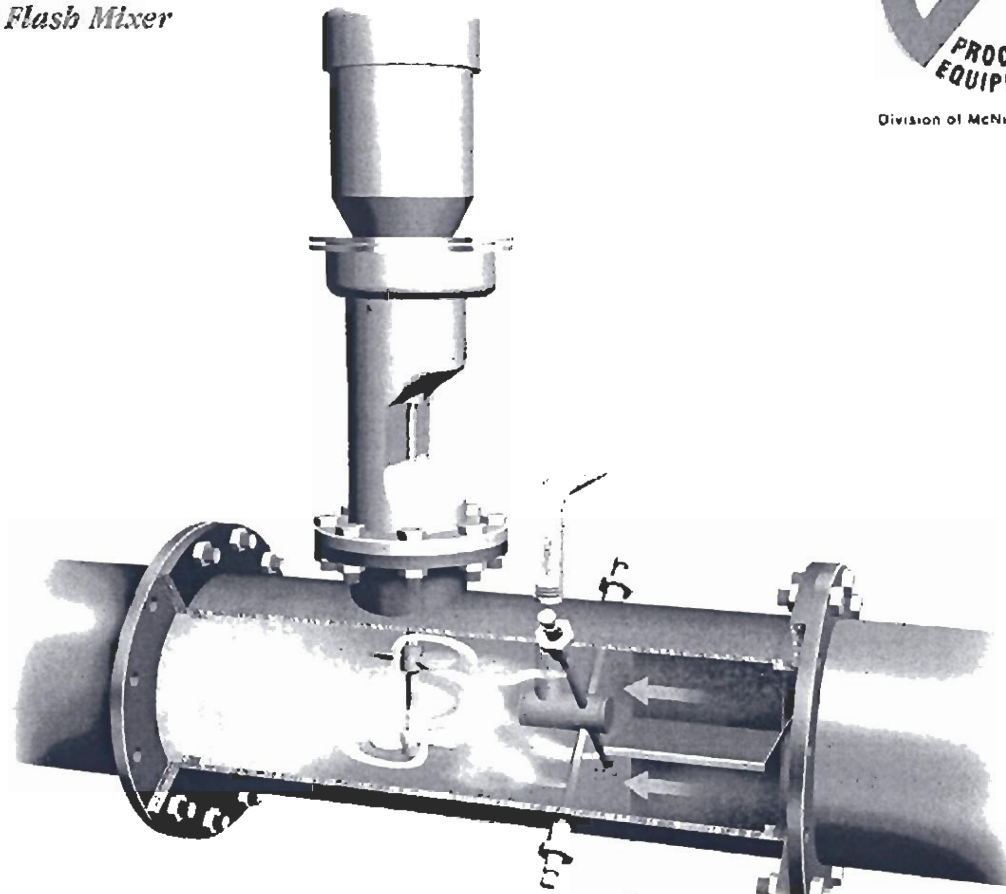
$\bar{t} = \frac{\frac{\pi}{4}(8")^2\left(0.0254\ \frac{m}{in}\right)^2(42")\left(0.0254\ \frac{m}{in}\right)}{0.0657\ \frac{m^3}{s}} = 0.53 s$

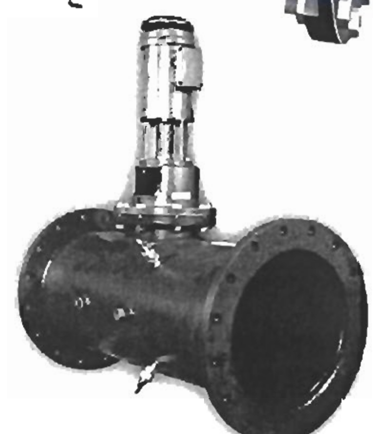
WALKER PROCESS EQUIPMENT

Division of McNish Corporation

InstoMix

In-Line Flash Mixer



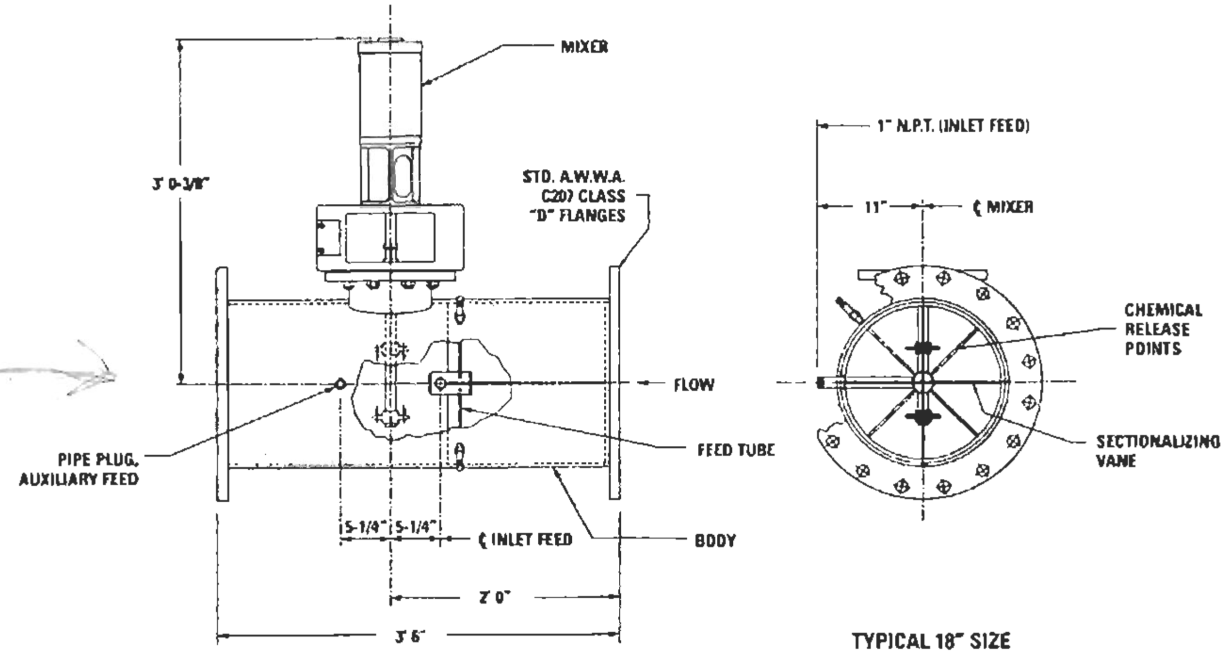


Instantaneous Mixing to Disperse Solutions

The In-Line InstoMix by Walker Process provides high-energy flash mixing to instantaneously (within milliseconds) disperse coagulant and other flocculent solutions into raw water flow.

The InstoMix In-Line Flash Chemical Mixer by Walker Process:

- **Efficiently distributes small coagulant flow to large water flow.**
- **Provides very high G-value for instantaneous flash mixing and high diffusion efficiency.**
- **Distributes injected solutions within 10 milliseconds.**
- **Provides a more predictabla and settleable floc.**
- **Reduces overuse of coagulants.**
- **Incorporates low energy input and low head loss.**



TYPICAL 18" SIZE

Homogeneous, Millisecond Coagulant Blending

InstoMix In-Line Mixers provide continuous, instantaneous blending of coagulant in raw water prior to flocculation. The homogeneous, millisecond blending of coagulant results in optimum floc formation and maximizes chemical economy. Compact in-line units are constructed for flange mounting directly in the pipeline and are equipped with an internal feed manifold designed to distribute solutions uniformly throughout the sectionalized mixer body. The agitator (mixer) can be custom sized to produce a desired G-Value.

InstoMix units are available for 8-inch through 72-inch diameter pipelines.

Sizes - Diameter	8"	12"	18"	24"	30"	36"	48"	60"	72"
Flow Range MGD	1.0-1.8	1.8-4.0	4.0-9.0	8.0-16.0	12.0-25.0	16.0-37.0	33.0-65.0	50.0-100.0	75.0-145.0

Body	Carbon Steel Sch 40 pipe, NSF-Approved epoxy coated interior
Manifold	316 stainless steel
Mounting	Horizontal - Flanged Mounted
Mixer	Direct connected, flange mounted, 316 stainless steel impellers and shaft

Flash mixing coagulants and other chemicals is necessary because of the minute amounts of solutions added to the relatively large amount of raw water treated. Because a rapid chemical reaction starts the instant alum or other coagulant is blended with raw water, there must be instant diffusion of the coagulant solution or many particles will be missed, resulting in an overall higher turbidity or excessive use of coagulant.

Walker Process Equipment
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840 North Russell Avenue • Aurora, IL 60506 • Phone: 630-892-7921 • Fax: 630-892-7951
E-mail: walker.process@walker-process.com
www.walker-process.com

Wastewater Sep 8 ①

shear stress; dynamic viscosity

$$\tau = \mu \frac{dV}{dy}, \quad \mu = \frac{\tau}{\frac{dV}{dy}}, \quad \nu \; [=] \; \frac{m^2}{s}$$

velocity gradient

call $\frac{dV}{dy} = G$, velocity gradient $[s^{-1}]$

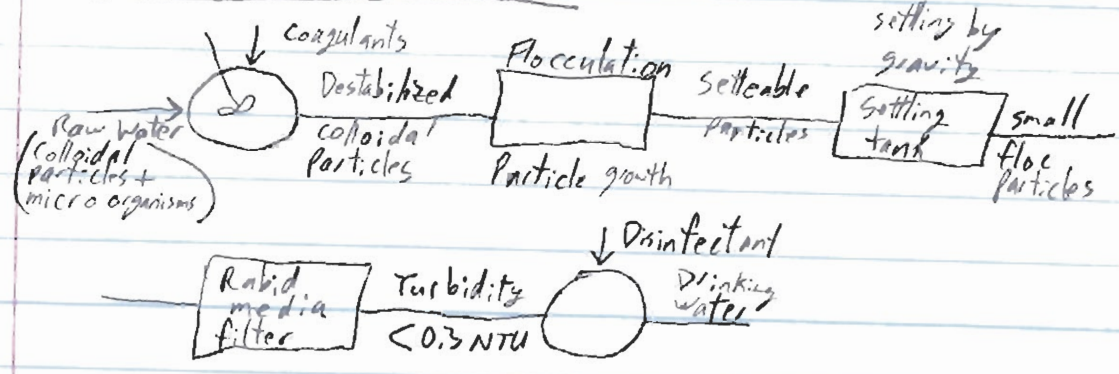
$$\tau = \mu G \quad ①$$

power per unit vol. req'd to transport a fluid under vel. gradient G

- Camp & Stein (1943) demonstrated $P = \tau G$ ②

$$① \to ② : \; P = (\mu G) G; \quad G = \sqrt{\frac{P}{\mu}} = \sqrt{\frac{P}{V\mu}} \; [=] \; \sqrt{\frac{\frac{kg\,m^2}{s^2}}{m^3 \frac{kg}{m \cdot s}}} = s^{-1}$$

Rapid mixing units



TASK 2 DESIGN
RAPID MIXING UNIT

Wastewater Sep 8 ②

select:
- static in-line mixer
- mechanical in-line mixer
- parshall flume

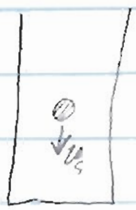
only chemicals to be added:
- Alum
  or ferric chloride
- No lime

Komax mixers

W.W Sep 20 ①

Discrete particle settling:

spherical particles $v_s = \sqrt{\frac{4}{3}\frac{g}{C_D}\left(\frac{\rho_s \rho_l}{\rho_l}\right)d_p}$ (equ 'B')



ρ_s = solid density, ρ_l = liquid density, C_D = drag coefficient

Laminar Flow: $R_e < 1$, where $R_e = \frac{d_p v_s}{\nu}$ — Kinematic viscosity

$C_D = \frac{24}{R_e} \Rightarrow v_s = \frac{g}{18.75\mu}(\rho_s - \rho_l)d_p^2$ (stokes equ)

Turbulent: $R_e > 2000$, $C_D \simeq 0.4 \Rightarrow v_s = \sqrt{3.3 g\, d_p (1-S_s)}$, $S_s = \frac{\rho_s - \rho_l}{\rho_l}$

Transition: $C_D = \frac{24}{R_e} + \frac{3}{\sqrt{R_e}} + 0.34$ (equ 'A')

A procedure to find

Goal Seek:

* Assume v_s
* Calculate $R_e = \frac{d_p v_s}{\nu}$
* " C_D w/ equ 'A'
* " v_s w/ equ 'B'
* " $\Delta v_s = (v_s)_{assumed} - (v_s)_{calculated}$
* If $\Delta v_s = 0$, we have solution

Better Procedure

Replace equ 'A' in equ 'B': $v_s = \left[\frac{\frac{4}{3} g (1-S_s) d_p}{\frac{24(\nu)}{d_p(v_s)} + 3\sqrt{\frac{\nu}{d_s(v_s)}} + 0.34}\right]^{0.5}$

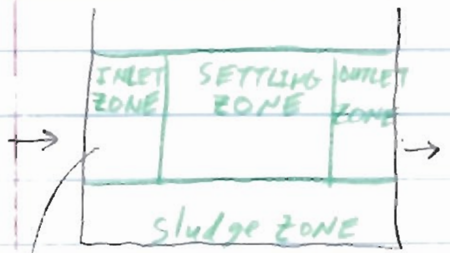
Fig 25.1 (old handout gives C_D)

" 25.2 (" ") use to get v_s

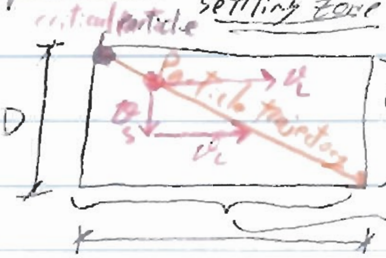
W.W. Sep 20 (2)

Ideal Settling of descrete particles

* assumes PFR



assume particles are uniformly distributed along depth



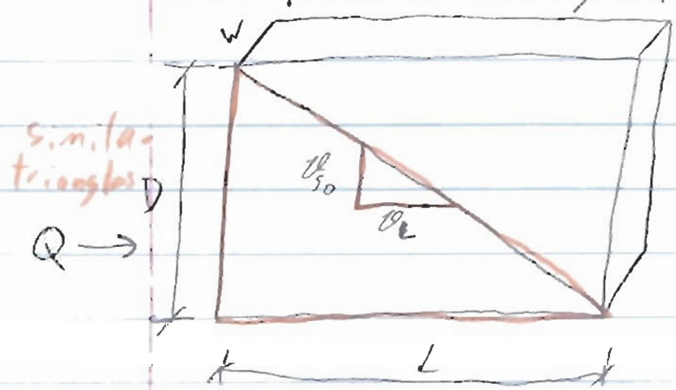
v_s < critical

if trajectory above orange then particle is considered NOT removed

If below the considered removed.

v_s > critical

$Q = v_L$ (cross-sec Area)



$$\frac{v_{s0}}{D} = \frac{v_L}{L} \cdot \frac{W}{W} \;;\; v_{s0} = \frac{v_L(w)(D)}{L(w)}$$

Top Area "A"

$$v_{s0} = \frac{Q}{A}, \text{ "over flow rate"}$$

remember, top of tank Area

$$v_{s0} = \frac{Q}{A} \cdot \frac{D}{D} = \frac{QD}{\forall_{tank}} = \frac{D}{\forall/Q} = \boxed{\frac{D}{\bar{t}}}$$

$\bar{t}$, mean detention time

Example: Design grit chamber to remove sand particles w/ $d_p = 0.1$mm,

See handout

$Q = 4.4\ m^3/s$, $Temp = 10°C$, $\mu_{10°C} = 1.3077\times10^{-3}\ \frac{kg}{m\cdot s}$; $\nu_{10°C} = 1.371\times10^{-6}\ \frac{m^2}{s}$

$R_e = \frac{v_L(A_x)}{\nu(P)} < 86{,}000$, $F_r = \frac{v_L^2(P)}{g(A_x)} > 10^{-5}$

P = wetted perimeter

Solution: $d_p = 0.01\,cm = 10^{-2}\,cm$, $S_s = 2.5$ (Assume if not given for SAND)

$v_s = 0.6\ cm/s$ (From chart on previous handout)

$Re = \frac{10^{-4}m\,(6\times10^{-3}\,m/s)}{1.37\times10^{-6}\,m^2/s} = 0.44 < 1$ ∴ Laminar ∴ can use Stokes

$$\rightarrow v_s = \frac{g}{18.75\mu}(\rho_s - \rho_l)d_p^2 = \frac{9.81\ m/s^2}{18.75(1.3077\times10^{-3}\frac{kg}{m\cdot s})}\left(2500-1000\right)\frac{kg}{m^3}\left(1\times10^{-4}m\right)^2$$

$$= 6\times10^{-3}\ m/s$$

wk: sep 20 (2)

Design overflow rate: $v_{so} = 6\times10^{-3}$ m/s (3600 s/h) = 21.6 m/h b/t 10 & 25

so meet criteria in handout

Factor to consider inlet & outlet ZONES. usually = 1.5

* select 2 tanks in parallel
* tank length $L = \frac{v_L (D)}{v_{so}} (k)$
* select v_L = 3 m/min (per criteria on handout) = 0.05 m/s
* " depth = $\boxed{3.7m}$ (12 ft) (per " " ")
* " Length = $\frac{0.05 \text{ m/s} (3.7m)}{6\times10^{-3} \text{ m/s}} (1.5)$ = 46.25m ~ $\boxed{46 m}$
* Top Area = $\frac{Q}{v_{so}}$ = $\frac{4.4 \text{ m/s} \left(\frac{1}{2} \text{ \# of tanks}\right)}{6\times10^{-3} \text{ m/s}}$ = 366.7 m² = L × w

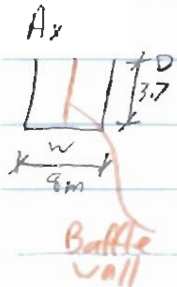
$\therefore$ w = $\frac{366.7m^2}{46}$ = 7.97 ~ $\boxed{8 m}$

Check $v_L = \frac{Q}{A_x} = \frac{4.4 \text{ m/s} \left(\frac{1}{2}\right)}{8m(3.7m)}$ = 0.074 m/s = 4.45 m/min < 4.5 OKAY

(W D)

Check $\frac{L}{W} = \frac{46m}{8m}$ = 5.75 > 4 OKAY

check $\frac{L}{D} = \frac{46m}{3.7m}$ = 16.4 > 6 OKAY



check tank Re = $\frac{v_L}{\nu}\left(\frac{A_x}{P}\right) = \frac{0.074 \text{ m/s}}{1.371\times10^{-6} \text{ m}^2/s}\left(\frac{8m(3.7m)}{8m+3.7m+3.7m}\right)$ = 103744 > 86000 recommended NOT OKAY

Need to lower Re

by putting Baffle wall v_L, ν, .. = same; however W is cut in half

re-calc Re = $\frac{0.074 \text{ m/s}}{1.371\times10^{-6} \text{ m}^2/s}\left(\frac{4(3.7)}{4+2(3.7)}\right)$; Re = 70,073 OKAY

Check $F_r = \frac{v_L^2 (P)}{g(A_x)} = \frac{(0.074 \text{ m/s})^2 (4+2(3.7))}{9.81 \text{ m/s}^2 (4(3.7))}$ = $4.3\times10^{-4} > 10^{-5}$ OKAY

W.W.
Sep 20

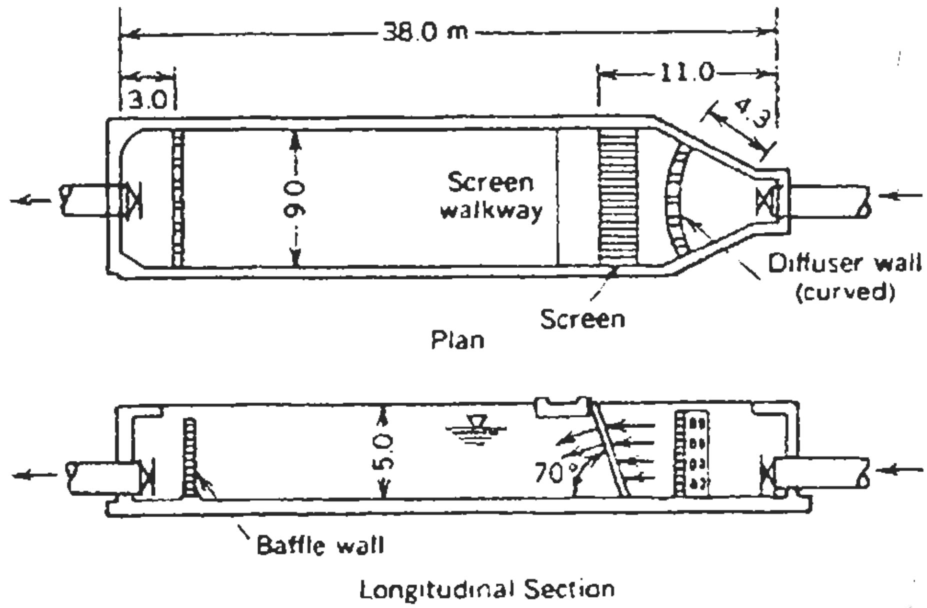


Figure 4.5-2 Grit chamber.

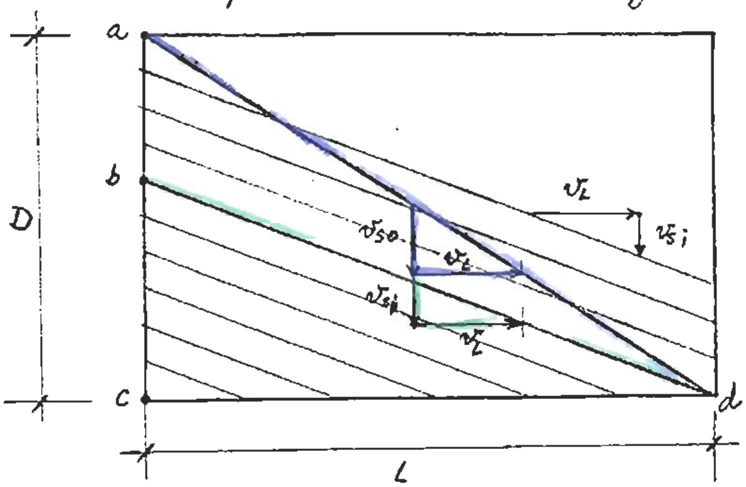
Generally, the grit to be removed is sand or silt with diameters exceeding 0.1 mm or larger than No. 100 mesh (0.15 mm). Grit any smaller than this does not pose a major threat to the pumps and pipelines. Figure 4.5-2 is a grit chamber designed to treat 35 mgd (1.5 m^3/s) of flow and has been performing well since 1955; the design is based on the hydraulic scale model study.

Design Criteria

Number of tanks	Two tanks (one with a bypass line may be used as an alternative)
Water depth	10 to 13 ft (3 to 4 m) with a grit remover; 11.5 to 16 ft (3.5 to 5 m) without a grit remover
Length/width ratio	Minimum of 4 : 1
Length/water depth ratio	Minimum of 6 : 1
Mean flow velocity	10 to 15 ft/min (3 to 4.5 m/min)
Detention time	6 to 15 min
Surface loading	4 to 10 gpm/ft^2 (10 to 25 m/h)

Removal of particles with different settling velocities

Analyze particles with settling velocity $v_{si} < v_{so}$



$$\frac{L}{v_L} = \frac{bc}{v_{si}}$$

$$\frac{L}{v_L} = \frac{ac}{v_{so}}$$

$$\therefore \frac{bc}{v_{si}} = \frac{ac}{v_{so}}$$

$$\Rightarrow \boxed{\frac{bc}{ac} = \frac{v_{si}}{v_{so}}} \quad (1)$$

Assumptions:

- All particles with settling velocity $>v_{so}$ will be removed
- Particles are uniformly distributed throughout depth D at N particles per m of depth
- Of the particles with settling velocity $< v_{so}$, only those reaching the bottom will be removed (triangle bcd).

$$\text{Fraction removed} = \frac{\text{\#particles removed}}{\text{total \#particles}}$$

$$\text{Fraction removed} = \frac{(bc) \times N \dfrac{\text{particles}}{\text{m}}}{(ac) \times N \dfrac{\text{particles}}{\text{m}}}$$

$$\textit{Fraction} \quad \textit{removed} = \frac{bc}{ac}$$

By Eq. 1, $\boxed{\text{Fraction removed} = \frac{v_{si}}{v_{so}}}$

Example: Determine the removal efficiency of a sedimentation basin designed with a critical velocity of 6.5 ft/h, when treating a river water containing discrete particles whose settling velocities are distributed as given in the table below.

Settling Vel., ft/h	0.0 - 1.5	1.5 - 3.0	3.0 - 4.5	4.5 - 6.0	6.0 - 7.5	7.5 - 9.0	9.0 - 10.5	10.5 - 12.0
Number of particles	20	40	80	120	100	70	20	10

Average vs, ft/h	# particles	Fraction removed $\frac{v_s}{v_{so}} = \frac{v_s}{6.5}$	# particles removed
0.75	20	0.115	2
2.25	40	0.346	14
3.75	80	0.577	46
5.25	120	0.808	97
6.75	100	1.0	100
8.25	70	1.0	70
9.75	20	1.0	20
11.25	10	1.0	10
	Total = 460		Total = 359

$$\text{Removal efficiency} = \frac{359}{460} \times 100 = 78.04\%$$

General Appproach

Suppose we take N particles with settling velocity $< v_{so}$.
If we call Δy_i the fraction of particles with settling velocity $v_{si} < v_{so}$,

assume that Δy_1 is the fraction of particles with settling velocity v_{s1}

Δy_2 is the fraction of particles with settling velocity v_2

Δy_3 is the fraction of particles with settling velocity v_{s3}

Δy_4 is the fraction of particles with settling velocity v_{s4}

Δy_5 is the fraction of particles with settling velocity v_{s5}

$\Sigma = \Delta y_1 + \Delta y_2 + \Delta y_3 + \Delta y_4 + \Delta y_5 = y_0$ have settling velocities $v_{si} < v_{so}$.

Of these particles, the observed removal will be:

$$\text{Removal} = \Delta y_1 \frac{v_{s_1}}{v_{s_0}} + \Delta y_2 \frac{v_{s_2}}{v_{s_0}} + \Delta y_3 \frac{v_{s_3}}{v_{s_0}} + \Delta y_4 \frac{v_{s_4}}{v_{s_0}} + \Delta y_5 \frac{v_{s_5}}{v_{s_0}} = \sum_{i=1}^{i=N} \frac{v_{s_i}}{v_{s_0}} \Delta y_i$$

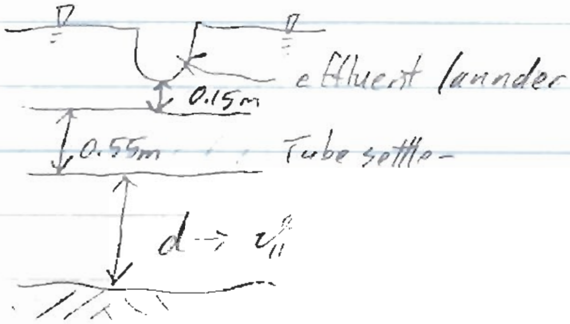
Or, in general, the removal of particles with $v_{si} < v_{so}$ will be

$$\boxed{\text{Removal} = \int_0^{y_0} \frac{v_s}{v_{s_0}} dy = \frac{1}{v_{s_0}} \int_0^{y_0} v_s\, dy}$$

w.w. Sep 27 ①

Ex. Design a tube settler sediment tank for $Q = 2\ m^3/s$ to remove alum floc w/ $v_{s0} = 0.9\ m/h$

* 2 tanks in parallel, $Q = 1.0\ m^3/s$
* Surface Area covered w/ settler module : $L = 34m$, $W = 18m$
* Total length = 45 m
* Water depth



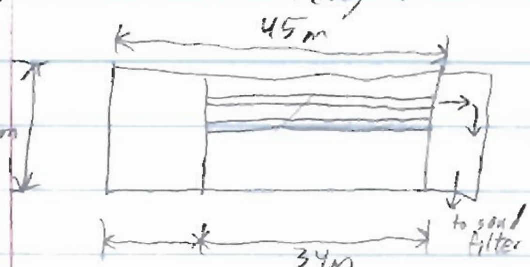
manufacter's recom'd : $v_H \leq 0.015\ m/s$

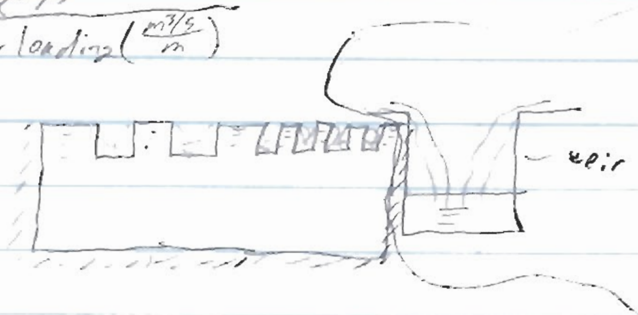
$$v_H = \frac{Q}{w(d)} \rightarrow d = \frac{Q}{v_H(w)} = 3.7m$$

see Handout from last class

Table 10.6

Total weir Length : $L = \dfrac{Q\ m^3/s}{\text{weir loading}\left(\frac{m^3/s}{m}\right)}$





Launder weir loading : $3.75 \rightarrow 15\ \frac{m^3/h}{m}$

* assume 6 longitudinal launders ∴ 10 weirs $\left(34\ \frac{m}{weir}\right) = 340m$

$$\text{weir loading} = \frac{3600\ m^3/h}{340\ m} = 10.6\ \frac{m^3/h}{m}$$

$\frac{\text{million gal/ac}}{1}$; $\frac{\text{gal/min}}{ft^2}$

w.w. sep. 29 ②

mgad : million gallon per ac day

* gal per min. sqft

Design Procedure :

- * select manufacturer / tube settler
- * choose design overflow rate recom'd by them (overflow rate O.R.)
- * calc. area covered by the tube settlers : $A = \frac{Q \; m^3/d}{O.R. \; \frac{m^3/d}{m^2}}$
- * select width & calc. Length covered w/ the module.
- * calc. total length
- * determine water depth following previous procedure (p. 1), weir length, launder arrangem
- * check hydraulic behavior
  - * tube Re, Fr, Det. time inside tubes, vel. under tube settler, tank Re under tube settler (Tank Re < 20,000)

Rapid media filters

see Hand out

(anthracite over sand)

Filtration : Removal of fine particles that escape the settling tank

* Effluent must have turbidity < 0.3 NTU

* Filtration is req. by the surface water treatment (SWTR)

Two kinds : * Rapid Filters * Slow Filters

$$\text{Rate of Filtration} = \frac{Q}{\text{Top surface area}}$$

To approx Ideal Filter use less dense coarse material & finer sands — the leads to dual media filter

Filter media

* classical sand filter uses sand w/ effective size = 0.35 → 0.55 mm

" $C_u < 1.5$ (uniformity coefficient) $= \frac{D_{60}}{D_{10}}$

Mixture of different particle sizes : log-normal distribution

* After Back washing we get stratification (Fines = top, coarser = bottom) which leads to rapid clogging of rapid filter

69/100

4-24) $n = 2$, $C_0 = 20\ mg/L$, 1^{st} order, $k_1 = 0.35\ d^{-1}$

25/25

$\theta_1 = \frac{20000 m^3}{4000 m^3/d} = 5d \qquad \theta_2 = \frac{12000 m^3}{4000 m^3/d} = 3d$

(1) $\theta_1 = \frac{C_{A_0} - C_A}{K_1 C_A} \rightarrow C_A \theta_1 K_1 - C_{A_0} + C_A = 0 \rightarrow C_A(\theta_1 K_1 - 1) = C_{A_0}$

$\rightarrow C_{A_1} = \frac{C_{A_0}}{\theta_1 K_1 + 1} = \frac{20\ mg/L}{5d(0.35d^{-1})+1} = \boxed{7.27\ mg/L}$ ✓

(2) $C_{A_2} = \frac{7.27}{3(0.35)+1} = \boxed{3.55\ mg/L}$ ✓

4-25) $V = 0.4\ m/s$, $Q = 4000\ m^3/d \left(\frac{d}{24h}\right)\left(\frac{h}{60 min}\right)\left(\frac{min}{60s}\right) = 0.046296\ m^3/s$

20/25

$Q = AV \rightarrow 0.046267 = A(0.4) \rightarrow A = 0.1157\ m^2$

easier: $t = \frac{3000 m}{0.4 m/s}$

$V = (3000m)(0.1157m^2) = 347.2\ m^3$

$\theta_R = \frac{V_{river}}{Q} = \frac{347.2 m^3}{4000\ m^3/d} = 0.0868\ d$ ✓, $C_R = \frac{7.27}{0.0868(0.35)+1} = 7.06\ mg/L$

$C_L = \frac{7.06}{3(0.35)+1} = \boxed{3.44\ mg/L}$

River = PFR -5

4-23) $\bar{t} = 30 min$, $C_0 = 10^6\ no/mL$, $C_n = 14.5\ no/mL$, 1^{st} order, $K_1 = 6.1\ h^{-1}$

15/25

Eq. 3.48 $\quad \frac{C_A}{C_{A_0}} = \left(\frac{1}{1+K\theta}\right)^n = \frac{14.5}{10^6} = \left(\frac{1}{1+(6.1)(0.5)}\right)^n \rightarrow n = 7.97$ ✓

$\boxed{\text{Number of reactions needed} = 8}$ ✓

PFR ? -10

4-28) (a) $\bar{t}_{PFR} = \frac{1}{k_2 C_{A0}}\left[\frac{C_{A0}}{C_{Ae}} - 1\right] \rightarrow 1d = \frac{1}{1\,\frac{m^3}{kg \cdot d}\left(1\,\frac{kg}{m^3}\right)}\left[\frac{1\,\frac{kg}{m^3}}{C_{Ae}} - 1\right]$

9/25

$\rightarrow C_{Ae} = 0.5\ kg/m^3$ ✓

$\bar{t}_{CFSTR} = \frac{1}{k_2 C_{Ae}}\left[\frac{C_{A0}}{C_{Ae}} - 1\right] \rightarrow \frac{1}{(1) C_{Ae}}\left[\frac{0.5}{C_{Ae}} - 1\right] = \left(\frac{0.5}{C_{Ae}^2} - \frac{1}{C_{Ae}}\right) C_{Ae}^2$

$\rightarrow C_{Ae}^2 + C_{Ae} - 0.5 = \emptyset$

$C_{Ae} = \frac{-1 \pm \sqrt{1^2 - 4(1)(-0.5)}}{2(1)} = \boxed{0.366\ kg/m^3}$ ✓

(b) $\bar{t}_{CFSTR} = \frac{1}{k_2 C_{Ae}}\left[\frac{C_{A0}}{C_{Ae}} - 1\right] \rightarrow 1 = \frac{1}{(1) C_{Ae}}\left[\frac{1}{C_{Ae}} - 1\right] = \frac{1}{C_{Ae}^2} - \frac{1}{C_{Ae}}$

$\rightarrow C_{Ae}^2 = 1 - C_{Ae} \rightarrow C_{Ae}^2 + C_{Ae} - 1 = \emptyset$

$C_{Ae} = \frac{-1 \pm \sqrt{1^2 - 4(1)(-1)}}{2(1)} = \frac{-1 \pm \sqrt{5}}{2} = 0.618\ kg/m^3$ ✓

$\bar{t}_{PFR} = \frac{1}{k_2 C_{A0}}\left[\frac{C_{A0}}{C_{Ae}} - 1\right] \rightarrow 1 = \frac{1}{(1)(0.618)}\left[\frac{0.618}{C_{Ae}} - 1\right]$

$\rightarrow \boxed{C_{Ae} = 0.382\ kg/m^3}$ ✓

First order -8
zero order -8

wastewater

ENCE 4323
Assignment No. 1
Due 9/8/10

4–23 Determine the number of completely mixed chlorine contact chambers each having a detention time of 30 min that would be required in a series arrangement to reduce the bacterial count of a treated effluent from 10^6 to 14.5 organisms/mL if the first-order removal rate constant is equal to 6.1 h^{-1}. If a plug-flow chlorine contact chamber were used with the same detention time as the series of completely mixed chambers, what would the bacterial count be after treatmen

4–24 The concentration of UBOD in a river entering the first of two lakes that are connected in a series is equal to 20 mg/L. If the first-order BOD reaction rate constant (K) equals 0.35 d^{-1} and complete mixing occurs in each lake, what is the concentration of UBOD at the outlet of each lake? The flow in the river is equal to 4000 m^3/d and the volume of the first and second lake is 20 and 12,000 m^3, respectively. Assume steady-state conditions.

4–25 In Prob. 4–24, if the length of the river connection between the two lakes is equal to 3 km and the velocity in the river is equal to 0.4 m/s, determine the concentration of the UBOD in the effluent from the second lake.

4–28 If second-order reaction kinetics are applicable ($r = -kC^2$), determine the effluent concentration for each of the reactor systems shown on Fig. 4–28. To simplify the computations, assume that the following data apply:

$$k = 1.0 \text{ m}^3/\text{kg}\cdot\text{d}$$

$$Q = 1.0 \text{ m}^3/\text{d}$$

$$V_{PFR} = 1.0 \text{ m}^3$$

$$V_{CMR} = 1.0 \text{ m}^3$$

$$C_o = 1.0 \text{ kg/m}^3$$

Explain your results. What would happen if first- or zero-order kinetics are applicable?

Note: Figure 4-28 shows two different reactor systems:

(a) A PFR followed by a CFTR

(b) A CFSTR followed by PFR

Donald Scrolleman

68/100

ENCE 4323

Assignment No. 2
Due October 4, 2010

Solve the following problems:

1. The rate of flow through an ideal clarifier is 100 L/s, the detention time is 1.5 h, and its depth is 4.0 m. To improve the removal efficiency of discrete particles with settling velocity v_s = 1.2 m/h, a full-length movable tray is set below the water surface. Plot the efficiency as a function of the tray depth.

2. A sedimentation basin is to be designed so that it will remove 100 percent of all particles which have a settling velocity of 0.5 mm/s.

   a) For a flow of 15 m^3/min, determine the appropriate dimensions for a rectangular basin in which the length is 4 times the width. The detention time is 2 h.

   b) Determine the total weir length required if the weir overflow rate is 250 m^3/(m.d). Show how you would locate this weir in a sketch of the basin.

3. Column settling tests of a Type II suspension have produced the results presented in the following table The initial TSS concentration of the completely mixed suspension was 208 mg/L. The suspension will be treated for TSS removal at a flow rate of 2000 m^3/d.

Time, minutes	Percent TSS removed at the indicated depth (m)					
	1.0	1.5	2.0	2.5	3.0	3.5
80	72	68	64	59	53	46
90	76	72	67	64	57	51
100	79	76	72	66	62	54
110	83	77	73	70	64	58
120	87	83	77	74	68	65
130	92	89	84	80	74	69
140	96	93	88	85	82	79

What is the residence time required to achieve at least 85% TSS removal if the settling zone depth is 3.0 m? What is the volume of the settling zone?

10/34

1) $Q = 100\ L/s$, $\bar{t} = 1.5h$, $d = 4m$, $v_s = 1.2\ m/h$

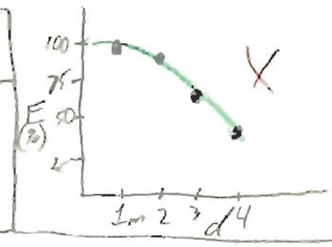
$v_{50} = 4m / 1.5h = 2.67\ m/h$

Fraction Removed $= \frac{v_{si}}{v_{50}}$ @ $d = 4m$ $= \frac{1.2}{2.67} = 0.449 = 45\%$

$v_{si}\,\bar{t} = d_{ideal}$

$E = \frac{v_{si}\,\bar{t}}{d}$

d	Efficiency
1m	100%
2m	90%
3m	60%
4m	45%



X

$1.2(1.5) = 1.8$

* Correction to ABOVE

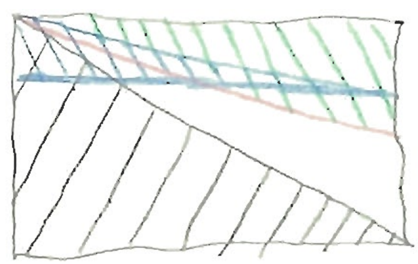
?

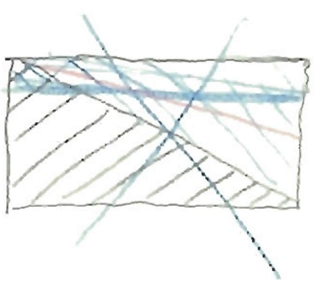
X

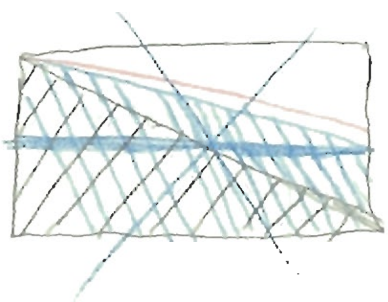
$$E = 2E_{clarifier} - E_{tray} = \frac{v_{si}\bar{t}}{d_{clarifier}} + \frac{v_{si}\bar{t}}{d_{tray}} - \frac{v_s\bar{t}}{d_{clarifier} - d_{tray}}$$

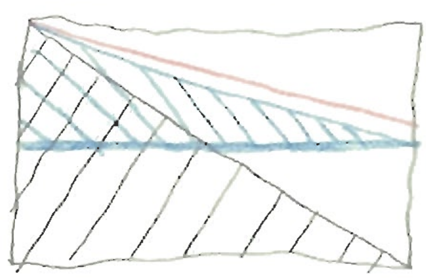
$$= \frac{(1.2)(1.5)}{4} + \left(\frac{1.2(1.5)}{d_{tray}}\right) - \left(\frac{(1.2)(1.5)}{4 - d_{tray}}\right) = 0.45$$

d_{tray}	Eff.
1 m	100









33/33

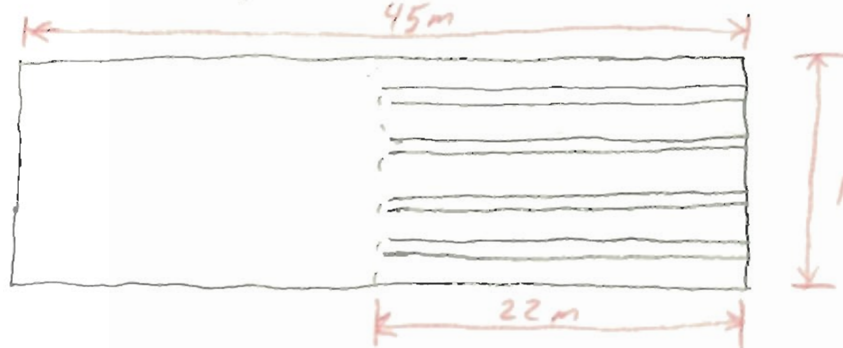
2) $A = \frac{Q}{V_s} = \frac{15\ m^3/min}{0.03\ m/min} = 500\ m^2$; $A = LW = 4(W)(W) = 500\ m^2 \rightarrow \boxed{W = 11.18\ m \quad L = 44.72\ m}$ ✓

$\forall = Qt = 15\ m^3/min\left(2h\left(\frac{60\ min}{hr}\right)\right) = 1800\ m^3$; $\forall = AD \rightarrow 1800\ m^3 = 500\ m^2\ D \rightarrow \boxed{D = 3.6\ m}$

$L_w = \frac{Q}{weir\ O/F\ rate} = \frac{15\ m^3/min\left(\frac{60\ min}{hr}\right)\left(\frac{24\ hr}{d}\right)}{250\ m^3/m \cdot d} = \boxed{86.4\ m}$ ✓

* choose 4 weirs → $\frac{86.4\ m}{4} = 21.6\ m$

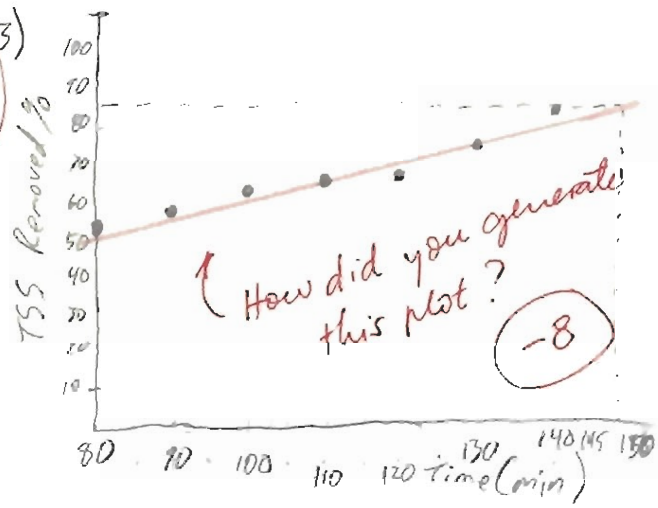
PLAN:



✓

25/33

3)



Residence time @ 85% removal
d = 3m
$\cong \boxed{148}$

$\forall = Qt = 2000\ m^3/d\left(148\ min\right)\left(\frac{hr}{60\ min}\right)\left(\frac{d}{24\ hr}\right)$

$\boxed{\forall = 206\ m^3}$

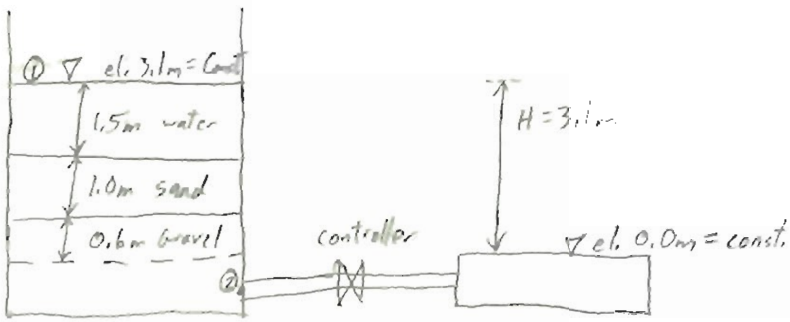
90/100

1) Rapid sand filter, $Q = 28.3\ L/s = 0.0283\ m^3/s$

33/33

$h_{L_{1-2}\ \text{beginning}} = 0.30\ m$

$h_{L_{1-2}\ \text{end}} = 2.4\ m$



(a) $h_{L\ \text{controller beginning}} = 3.1 - 0.3 = \boxed{2.8\,m}$ ✓

(a) $h_{L\ \text{controller end}}\ 3.1 - 2.4 = \boxed{0.7\,m}$ ✓

(a) Avail head @ beginning & end $= \boxed{3.1\,m}$ ✓

(b) end: $0.6\ m/s = C\sqrt{2(9.81)(0.7)} \rightarrow C = 0.1619$ ✓

Beggining $V = 0.1619\sqrt{2(9.81)(2.8)} = \boxed{1.2\ m/s}$ ✓

---

2) $\Sigma h_L = \underbrace{2952.6V^2}_{\text{turbulent}} + \underbrace{68.3V}_{\text{Laminar}}$

Min filtration rate $= 12.54\ \frac{cm}{min} = 0.00209$

Dirty filter head loss $= 0.77\,m$

33/33

Do not include b/c clean

$1.15\,m = 0.77\,m + 2952.6(0.00209)^2 + \cancel{(68.3)(0.00209)} + K_{valve}(0.00209)^2$

$\rightarrow K_{valve} = 84041$ ✓

$84041 + 2952.6 = 86994$ ✓

$V_{max}: \quad 1.15 = 86994(V^2) + 68.3(V)$

$V = 0.00326\ \frac{m}{s}$

$h_{L\ valve} = 84041(0.00326)^2 = \boxed{0.89\,m}$ at max rate

orifise

clean $H = K_1 V_{max} + K_2 V_{max}^2 + K_o V_{max}^2 + h_c$ clean filter

Dirty $H = K_1 V_{min} + K_2 V_{min}^2 + K_o V_{min}^2 + h_c$ dirty filter

3) Avg filtration rate : $0.00333 \frac{m}{s}$ min rate = $0.00233 \frac{m}{s}$

max rate = $0.00433 \frac{m}{s}$

$\frac{24}{34}$

dirty filter

-10

clean filter

$$1.15 = 0.77 + 2952.6(0.00433)^2 + K_{valve}(0.00433)^2$$

$$K_{valve} = 17315$$

$$1.15 = h_{L_{laminar}} + 2952.6(0.00233)^2 + 17315(0.00433)^2$$

$$h_{L_{laminar}} = \boxed{0.809\ m}$$

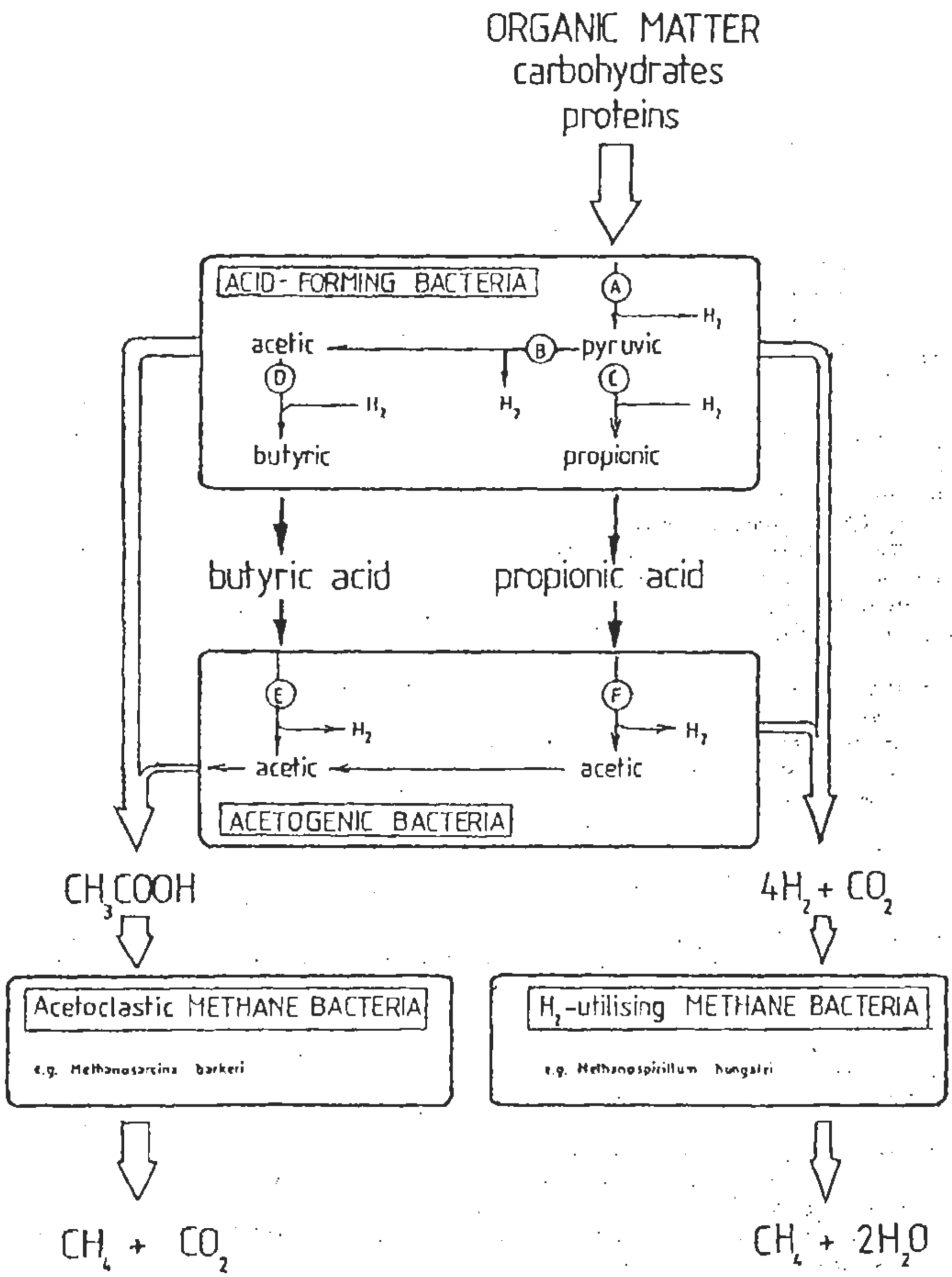


Fig. 1.1 The microbial ecology of the anaerobic digestion process (Mosey, 1982)

ADVANTAGES AND DISADVANTAGES OF ANAEROBIC SLUDGE DIGESTION

The principal advantages of anaerobic sludge digestion compared to other methods of sludge stabilization include:

- Production of methane gas, which is a useable source of energy. The process is a net energy producer at most treatment facilities in which anaerobic sludge digestion is used. The energy produced is in excess to that required to maintain the temperature of the digesting sludge and to meet the energy requirements for mixing. The surplus energy may be used to heat buildings, to drive the engines for the aeration blowers, or to generate electricity that can be used to drive the sewage pumps.
- Reduction in the mass and volume of the sludge through the conversion of organic matter in the volatile solids to methane, carbon dioxide, and water. Solids destruction usually is approximately 25–45% of the feed sludge solids and can result in reduction in the cost of sludge disposal.
- Production of a solids residue that may be used as a soil conditioner. The anaerobically digested sludge contains nitrogen and phosphorus and other nutrients as well as organic material that can improve the fertility and texture of soils. The odor associated with raw sludge is markedly reduced to a musty odor by anaerobic digestion.
- Pathogens associated with the feed sludge are inactivated during the anaerobic digestion process.

The principal disadvantages of anaerobic sludge digestion are:

- The capital costs are high. Large, covered tanks along with pumps for feeding and circulating sludge, heat exchangers and compressor for gas mixing are required.
- Long hydraulic detention times, in excess of ten days, are required to develop and maintain a population of methane-producing bacteria.
- The quality characteristics of the supernatant from anaerobic sludge digestion are poor. The supernatants contain suspended solids, dissolved and particulate organic materials (oxygen-consuming compounds), nitrogen, and phosphorus. This return flow adds to the solids, oxygen demand and nutrient loads to the treatment system.
- It requires skilled operators.

TABLE 5.3. Environmental and Operating Conditions for Maximum Methane Production during Anaerobic Digestion of Wastewater Sludges.

Variable	Optimum	Extreme
pH	6.8–7.4	6.4–7.8
Oxidation Reduction Potential (ORP) (mv)	−520 to −530	−490 to −550
Volatile Acids (mg/L as acetic acid)	50–500	>2,000
Alkalinity (mg/L as $CaCO_3$)	1,500–3,000	1,000–5,000
Temperature		
Mesophilic	86–95°F	68–104°F
	30–35°C	20–40°C
Thermophilic	122–132°F	113–140°F
	50–56°C	45–60°C
Hydraulic Detention Time (days)	10–15	7–30
Gas Composition		
Methane (CH_4) (%v)	65–70	60–75
Carbon Dioxide (CO_2) (%v)	30–35	25–40

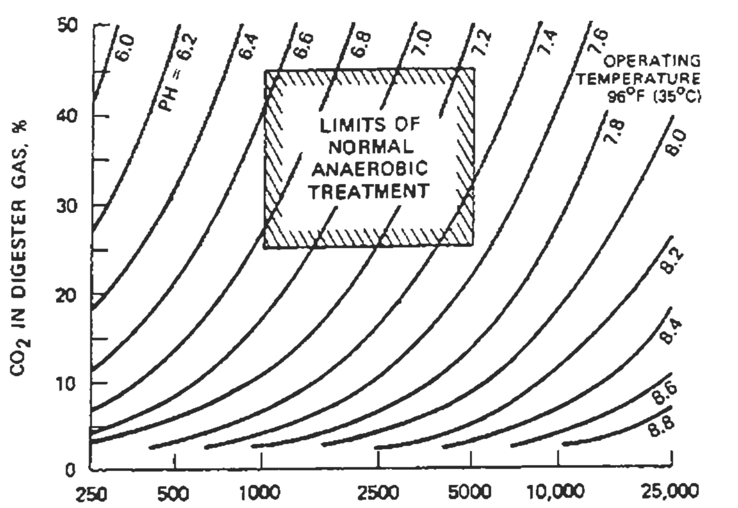


Figure 5.3 Relationship between pH, CO_2 and biocarbonate alkalinity.

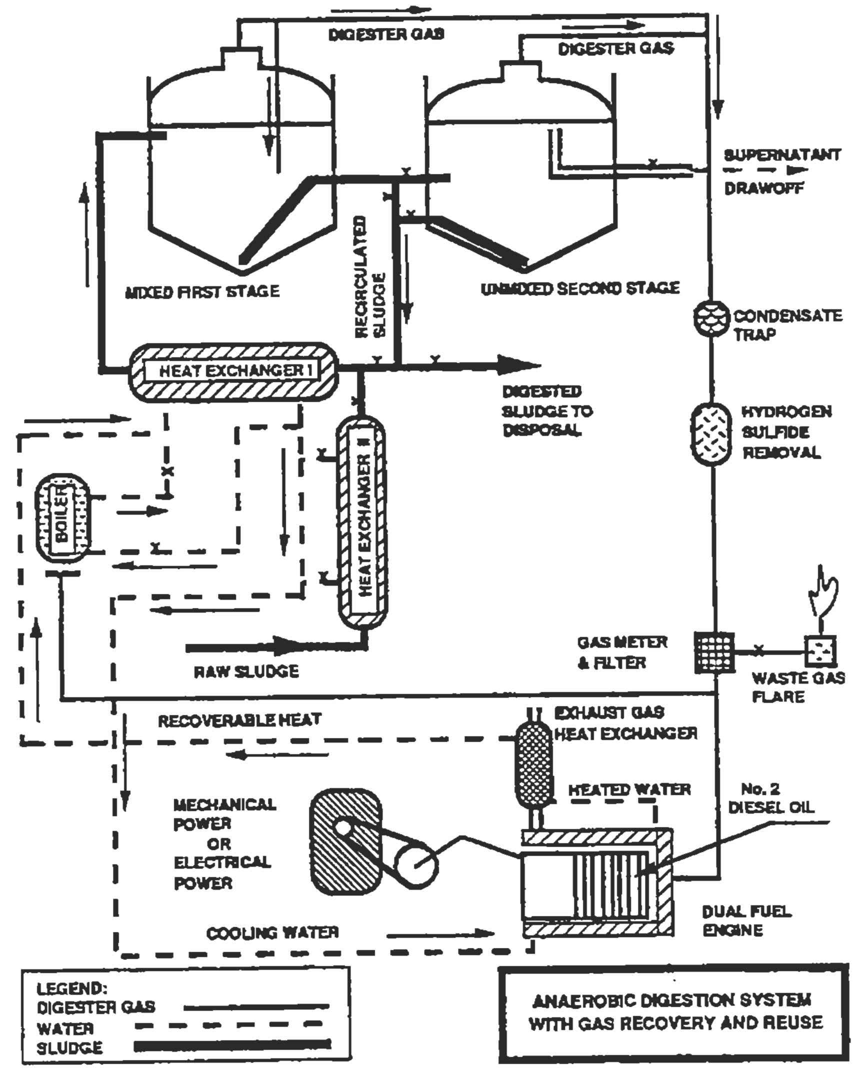


Figure 5.5 Anaerobic digestion system with gas recovery and reuse.

Mass balance on solids

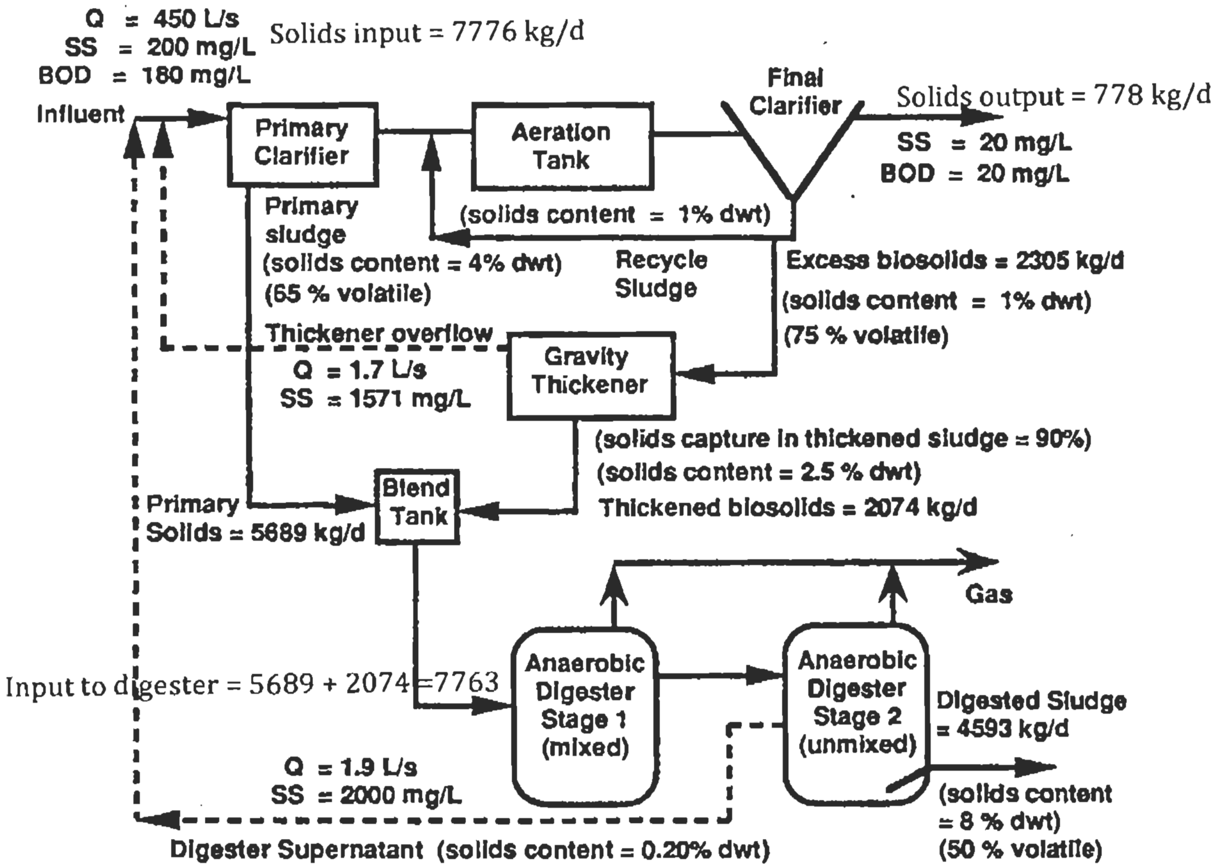
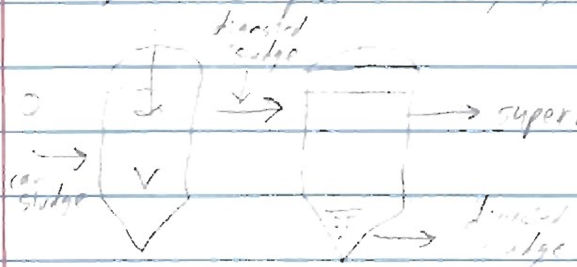


Figure 5.7 Solids mass balance for anaerobic sludge digestion system.

Solids input = 7776 kg/d
Solids output = 778 + 4593 = 5371 kg/d
Solids converted to gas = 7776 – 5371 = 2405 kg/d
Per cent solids destruction = (2405/7776)x100 = 30.9%

[illegible]

Design of complete-mix, high-rate anaerobic digester



* w/o cell / sludge recycle.

$\bar{t} = \frac{V}{Q} = \bar{t}_c$ [illegible] determin[illegible]

Recommended $\bar{t}_c$:

Temp (°C)	Design $\bar{t}_c$ (days)
18	28
24	20
30	14
35	10

min $\bar{t}_c = 10$ d

Relationship b/t $\bar{t}_c$ & biomass growth

$P_x = \frac{YQ(S_0 - S_e)}{1 + K_d \bar{t}_c}$; K_d = endogenous respiration coeff. [d^{-1}]

P_x = biomass growth rate $\left[\frac{kg\ VSS}{d}\right]$ S_0 = influent BOD of raw sludge

Y = yield coeff. $\left[\frac{kg\ VSS}{kg\ BOD\ utilized}\right]$ S_e = effluent BOD

Ex:

Amt. of suspended solids removed from sludge $= 0.15\ \frac{kg\ dry\ solids}{m^3\ sewage}$

BOD raw sludge $= 0.14\ \frac{kg\ BOD}{m^3\ sludge}$; solids concentration in raw sludge = 5%

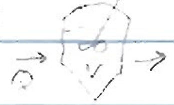
S.G. of dry sludge = 1.25 ; Plant liquid flow rate = 38000 m³/d

Assume: $\bar{t}_c = 10d$ (35°C) ; waste utilization eff. = 80%

$Y = 0.05\ \frac{kg\ VSS}{kg\ BOD\ utilized}$

Find: Digester Vol, solids production rate, amt. of methane produced

1) Digester Vol:



$\bar{t}_c = \frac{V}{Q} = \bar{t}$; sludge flow rate $= \frac{\text{mass dry solids produced}}{\text{solids concentration in wet sludge}}$

mass of solids $= 0.15\ \frac{kg\ dry\ sol}{m^3\ sewage}\left(38000\ \frac{m^3\ sewage}{d}\right) = 5700\ \frac{kg\ dry\ solids}{d}$

solids concentration in wet sludge $\frac{M_s}{V_T} = F_s\, \rho_{sl}$ (Eq 4) M_s = mass solids, V_T = [illegible] wet sludge, F_s = fraction solids in wet sludge, ρ_{sl} = wet sludge density

$\frac{1}{\rho_{sl}} = \frac{F_s}{\rho_s} + \frac{F_w}{\rho_w} \rightarrow \frac{1}{\rho_{sl}} = \frac{0.05}{1250} + \frac{0.95}{1000} \Rightarrow \rho_{sl} = 1010.1\ \frac{kg\ wet\ sludge}{m^3\ wet\ sludge}$

(S.G. $\cdot \rho_w$)

$\frac{M_s}{V_T} = 0.05\ \frac{kg\ dry\ solids}{kg\ wet\ sludge}\left(1010.1\ \frac{kg\ wet\ sludge}{m^3\ wet\ sludge}\right) = 50.5\ \frac{kg\ dry\ solids}{m^3\ wet\ sludge}$

$Q = \frac{5700}{50.5} = 112.9\ \frac{m^3\ wet\ sludge}{d}$

cont

Given

1) * sum h_L w/ V (laminar) + h_L V^2 (turblent)

* Avail. H for fitration = 1.15m ; V_{min} = 12.538 cm/min

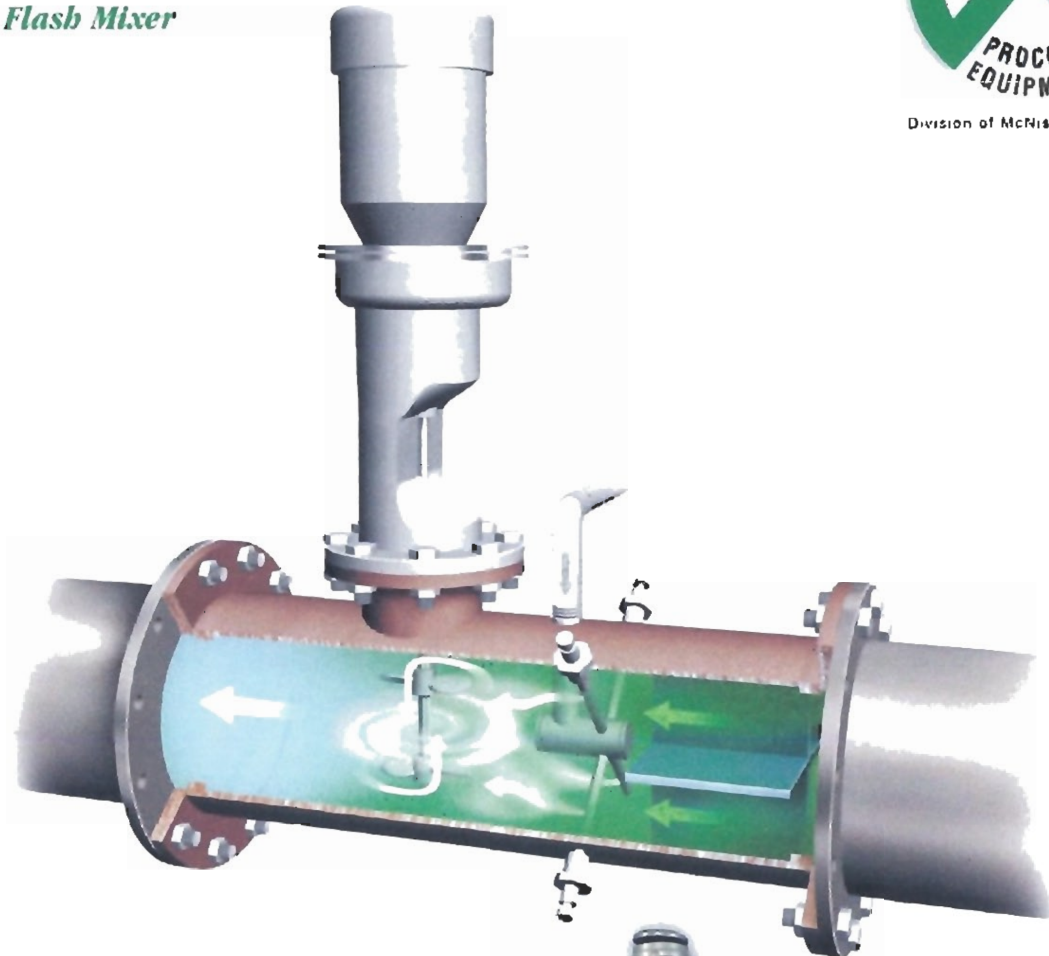
* Dirty filter h_L for V_{min} is 0.7666 m

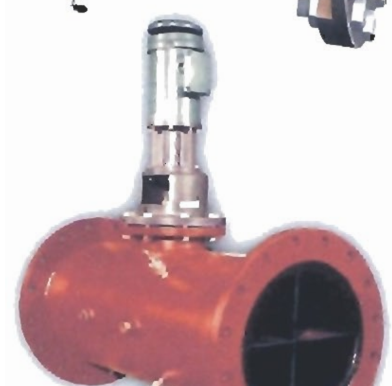
* Find Additional Turbulent h_L by orifice plate in Influent Pipe to balance filter hydraulics

* Plot 5 pts. of dirty filter laminar head loss & total turbulent loss curves

InstoMix
In-Line Flash Mixer

WALKER PROCESS EQUIPMENT
Division of McNish Corporation



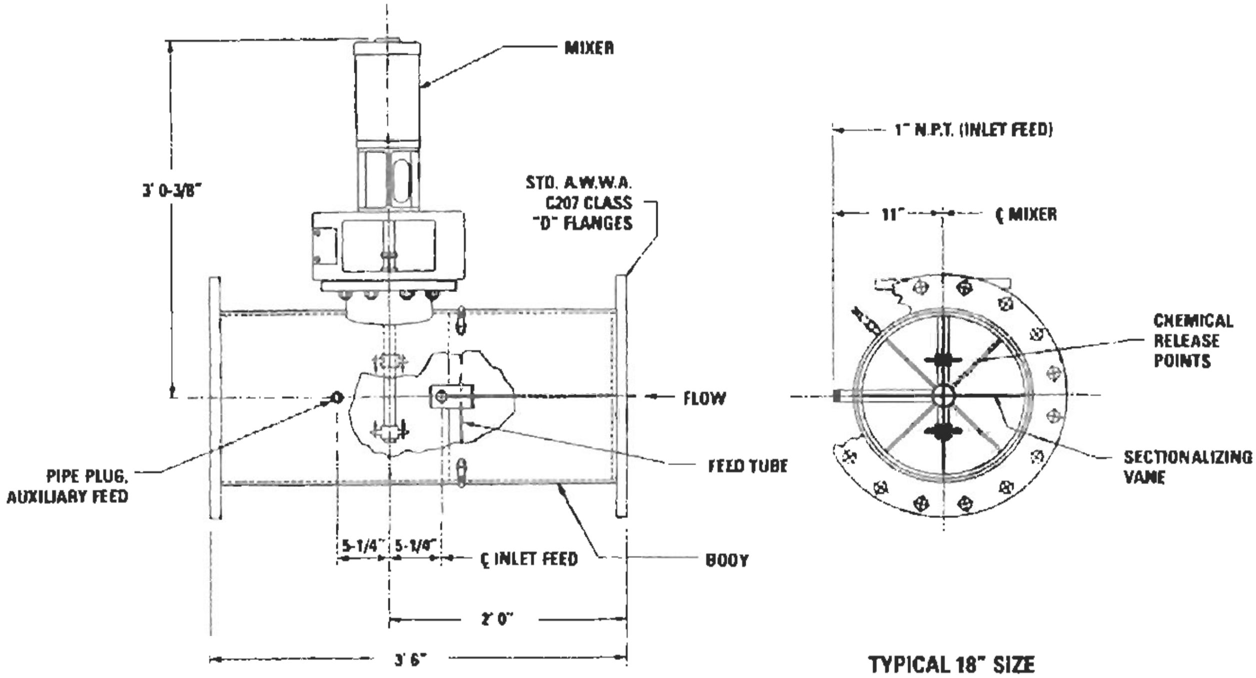


Instantaneous Mixing to Disperse Solutions

The In-Line InstoMix by Walker Process provides high-energy flash mixing to instantaneously (within milliseconds) disperse coagulant and other flocculent solutions into raw water flow.

The InstoMix In-Line Flash Chemical Mixer by Walker Process:

- **Efficiently distributes small coagulant flow to large water flow.**
- **Provides very high G-value for instantaneous flash mixing and high diffusion efficiency.**
- **Distributes injected solutions within 10 milliseconds.**
- **Provides a more predictable and settleable floc.**
- **Reduces overuse of coagulants.**
- **Incorporates low energy input and low head loss.**



TYPICAL 18" SIZE

Homogeneous, Millisecond Coagulant Blending

InstoMix In-Line Mixers provide continuous, instantaneous blending of coagulant in raw water prior to flocculation. The homogeneous, millisecond blending of coagulant results in optimum floc formation and maximizes chemical economy. Compact in-line units are constructed for flange mounting directly in the pipeline and are equipped with an internal feed manifold designed to distribute solutions uniformly throughout the sectionalized mixer body. The agitator (mixer) can be custom sized to produce a desired G-Value.

InstoMix units are available for 8-inch through 72-inch diameter pipelines.

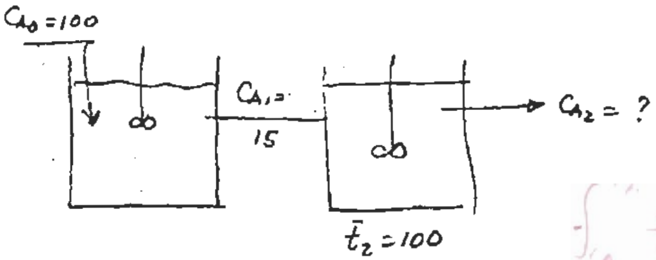
Sizes - Diameter	8"	12"	18"	24"	30"	36"	48"	60"	72"
Flow Range MGD	1.0-1.8	1.8-4.0	4.0-9.0	8.0-16.0	12.0-25.0	16.0-37.0	33.0-65.0	50.0-100.0	75.0-145.0

Body	Carbon Steel Sch 40 pipe, NSF-Approved epoxy coated interior
Manifold	316 stainless steel
Mounting	Horizontal - Flanged Mounted
Mixer	Direct connected, flange mounted, 316 stainless steel impellers and shaft

Flash mixing coagulants and other chemicals is necessary because of the minute amounts of solutions added to the relatively large amount of raw water treated. Because a rapid chemical reaction starts the instant alum or other coagulant is blended with raw water, there must be instant diffusion of the coagulant solution or many particles will be missed, resulting in an overall higher turbidity or excessive use of coagulant.

Walker Process Equipment
Division of McNish Corporation
840 North Russell Avenue • Aurora, IL 60506 • Phone: 630-892-7921 • Fax: 630-892-7951
E-mail: walker.process@walker-process.com
www.walker-process.com

1.



$C_{A_0} = 100$

$\frac{C_{A_1}}{C_{A_0}} = 0.15 \quad \therefore \quad C_{A_1} = 15$ (5)

Second order, batch : $t = \frac{1}{k}\left(\frac{1}{C_A} - \frac{1}{C_{A_0}}\right)$, $t_{1/2} = 2$ sec.

If $t = t_{1/2}$, $C_A = C_{A_0}/2 \quad \therefore \quad 2 = \frac{1}{k}\left(\frac{1}{C_{A_0}/2} - \frac{1}{C_{A_0}}\right)$; $\boxed{k = 0.005 \, \frac{l}{mg \cdot s}}$ (10)

1st reactor : CFSTR $\quad \bar{t}_1 = \frac{1}{kC_{A_1}}\left(\frac{C_{A_0}}{C_{A_1}} - 1\right)$; $t_1 = \frac{1}{0.005 \times 15}\left(6.666 - 1\right)$ [redacted]

$\frac{100}{15}$

$\bar{t}_1 = 75.55$ sec.

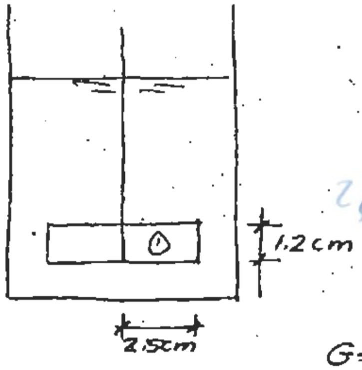
2nd reactor : CFSTR $\quad \bar{t}_2 = \frac{1}{kC_{A_2}}\left(\frac{C_{A_1}}{C_{A_2}} - 1\right)$; $100 = \frac{1}{0.005 \times C_{A_2}}\left(\frac{15}{C_{A_2}} - 1\right)$ (7)

$0.5\, C_{A_2}^2 + C_{A_2} - 15 = 0$

$C_{A_2} = \frac{-1 + \sqrt{1 + 4 \times 0.5 \times 15}}{2 \times 0.5}$; $C_{A_2} = 4.57$ mg/l (8)

$\therefore$ Conversion $= 1 - \frac{4.57}{100}$; $\boxed{x = 0.9543}$ (5)

2.



Blade ① : $P_1 = 31 C_D \rho b \left[(1-k)n\right]^3 (r_o^4 - r_i^4)$

Use $\rho = 1\ g/cm^3$; $b = 1.2\ cm$; $k = 0.25$; $C_D = 1.8$

2 sides $P_T = 2 \times 31 \times 1.8 \times 1 \times 1.2 \times 0.75^3\ n^3 \times 2.5^4$

$P_T = 2206.93\ n^3\ \dfrac{g\ cm^2}{s^3}$

$G = \sqrt{\dfrac{P_T}{\mu V}}$; $G^2 = \dfrac{P_T}{\mu V}$ $\therefore$ $P_T = G^2 \mu V$

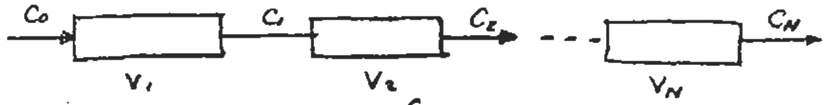
$P_T = 60^2\ s^{-2} \times 10^{-2}\ \dfrac{g}{cm \cdot s} \times 600\ cm^3$; $P_T = 21600$ ~~watts~~ $\dfrac{g\ cm^2}{s^3}$

$\therefore$ $21600 = 2206.93\ n^3$; $n^3 = 9.787$; $n = 2.14\ rps$
$= 128\ rpm$

$P_T = 21600\ \dfrac{1}{s^2} \cdot \dfrac{g}{cm \cdot s} \cdot cm^3$; $P_T = 21600\ \dfrac{g \cdot cm^2}{s^3} \times \dfrac{1\ kg}{1000\ g} \times \dfrac{1\ m^2}{10^4\ cm^2}$

$= 2.16 \times 10^{-3}$ watts

Stead,

3. 

1st reactor: $\dfrac{V_1}{Q} = -\displaystyle\int_{C_0}^{C_1} \frac{dc}{r}$

2nd reactor: $\dfrac{V_2}{Q} = -\displaystyle\int_{C_1}^{C_2} \frac{dc}{r}$

Nth reactor $\dfrac{V_N}{Q} = -\displaystyle\int_{C_{N-1}}^{C_N} \frac{dc}{r}$

$$\therefore \quad \frac{V_1 + V_2 + V_3 + \cdots V_N}{Q} = -\left[\int_{C_0}^{C_1} \frac{dc}{r} + \int_{C_1}^{C_2} \frac{dc}{r} + \cdots \int_{C_{N-1}}^{C_N} \frac{dc}{r}\right]$$

$$\frac{V_{TOTAL}}{Q} = -\int_{C_0}^{C_N} \frac{dc}{r} \Rightarrow \bar{t}_{Total} = -\int_{C_0}^{C_N} \frac{dc}{r}$$

4

3. Orthokinetic flocculation is first order:

$$\ln \frac{C}{C_0} = \overset{0}{\cancel{-0.01276}} - 0.32044\,t \qquad \text{line of best fit}$$

Batch, first order: $\ln \frac{C}{C_0} = -kt$ $\quad \therefore \; k = 0.32044 \text{ min}^{-1}$ (8)

a). $\bar{t}_{PFR} = \frac{1}{k} \ln \frac{C_0}{C}$ (5)

Removal = 80% $\;\therefore\; \frac{C}{C_0} = 0.2 \;\Rightarrow\; \frac{C_0}{C} = 5$ (5)

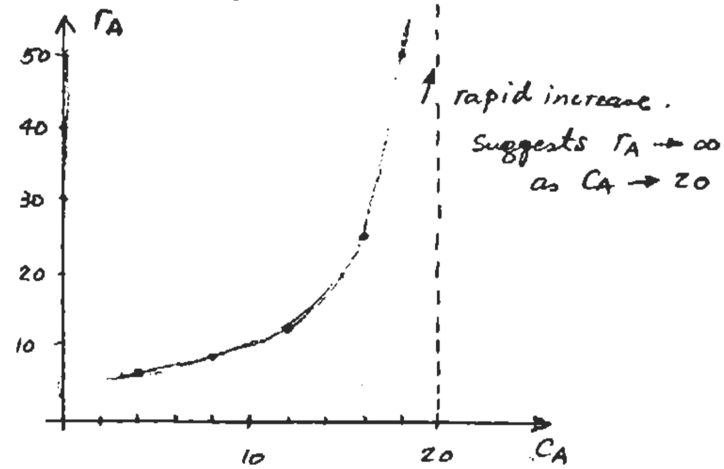
$\bar{t}_{PFR} = \frac{1}{0.32044} \ln 5$; $\bar{t}_{PFR} = 5.02 \text{ min}$ (6)

b.) CSTR: $\bar{t} = \frac{C_0 - C}{kC}$; $\bar{t} = \frac{1}{k}\left(\frac{C_0}{C} - 1\right)$ (5)

$\bar{t} = \frac{1}{0.32} \cdot (5-1)$; $\bar{t}_{CSTR} = 12.48 \text{ min}$ (6)

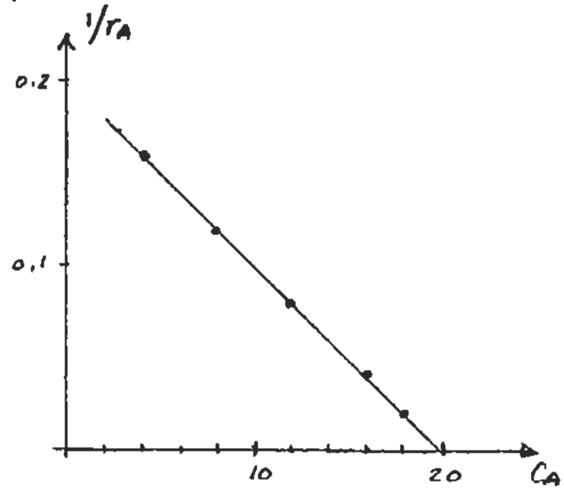
(5) $\bar{t} = \frac{1}{r_A}(C_{A_0} - C_A) \quad \therefore \quad r_A = \frac{C_{A_0} - C_A}{\bar{t}}$; Assume $r_A = k\,C_A^{\,n}$

C_{A_0}	C_A	r_A
629	4	6.25
841	8	8.33
1262	12	12.50
2516	16	25.00
5018	18	50.00



Try plotting $\frac{1}{r_A}$ vs C_A :

C_A	$1/r_A$
4	0.16
8	0.12
12	0,08
16	0.04
18	0.02



Get linear plot $\therefore \quad \frac{1}{r_A} = a + b\,C_A$

Use 2 points $\left\{ \begin{array}{l} 0.16 = a + b \cdot 4 \\ 0.02 = a + b \cdot 18 \end{array} \right\} \Rightarrow \begin{array}{l} a = 0.2 \\ b = -0.01 \end{array}$

Equation of straight line : $\boxed{\frac{1}{r_A} = 0.2 - 0.01\,C_A}$

$\bar{t}_{CFSTR} = \frac{1}{r_A}(C_{A_0} - C_A)$; $\bar{t}_{CFSTR} = (0.2 - 0.01\,C_A)(C_{A_0} - C_A)$

If $C_{A_0} = 20$, $C_A = 2$, $\bar{t}_{CFSTR} = (0,02 - 0.01 \times 2)(20 - 2)$

$\bar{t}_{CFSTR} = 3.2$ sec.

6. Jar test : batch reactor , N_o = initial # particles , N = # particles

First order reaction : $t_{batch} = \frac{1}{k} \ln \frac{N_o}{N}$, $t = 5\,min$

$5k = \ln \frac{N_o}{N}$; $k = \frac{1}{5} \ln \frac{N_o}{N}$

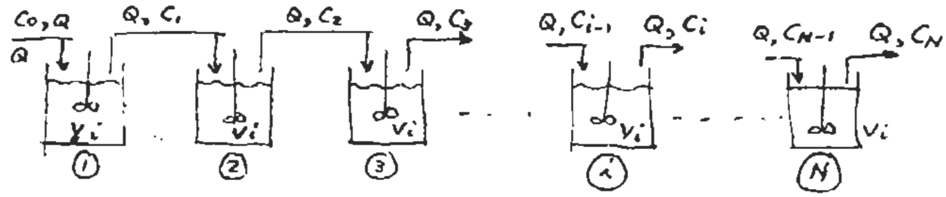
CFSTR : $\bar{t}_{CFSTR} = \frac{1}{k}\left(\frac{N_o}{N} - 1\right) = 30$; $k = \frac{1}{30}\left(\frac{N_o}{N} - 1\right)$

$\therefore \frac{1}{5} \ln \frac{N_o}{N} = \frac{1}{30}\left(\frac{N_o}{N} - 1\right)$; $\frac{N_o}{N} = 1 + 6 \ln \frac{N_o}{N}$

Using calculator : $\frac{N_o}{N} = 18.5 \Rightarrow \frac{N}{N_o} = 0.054$

Efficiency = 94.6 %

7.



First-order reaction:

First reactor : $\frac{C_0}{C_1} = 1 + k_1 \bar{t}_i$

Second reactor : $\frac{C_1}{C_2} = 1 + k_1 \bar{t}_i$

ith reactor : $\frac{C_{i-1}}{C_i} = 1 + k_1 \bar{t}_i$

Nth reactor : $\frac{C_{N-1}}{C_N} = 1 + k_1 \bar{t}_i$

$\Big\}$ N equations

Multiply all equations:

$$\frac{C_0}{\cancel{C_1}} \times \frac{C_1}{C_2} \times \dots \times \frac{C_{i-1}}{C_i} \times \dots \frac{C_{N-1}}{C_N} = (1 + k_1 t_i)^N$$

$$\boxed{\frac{C_0}{C_N} = (1 + k_1 t_i)^N} \Rightarrow \boxed{N = \frac{\ln\left(\frac{C_0}{C_N}\right)}{\ln(1 + k_1 \bar{t}_i)}}$$

Pertinent data:

$C_0 = 10^6$ bact/ml $\qquad k_1 = 6.1\ h^{-1}$

$C_N = 14.5$ bact./ml $\qquad \bar{t}_i = 0.5\ h$

$$N = \frac{\ln\left(\frac{10^6}{14.5}\right)}{\ln(1 + 6.1 \times 0.5)} \quad ; \quad N = 7.97 \simeq \underline{\underline{8}}$$

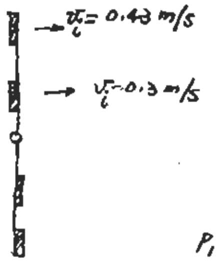
- PFR, first-order: $\ln \frac{C_0}{C} = k_1 \bar{t}_{PFR} \Rightarrow \boxed{\frac{C}{C_0} = e^{-k_1 \bar{t}_{PFR}}}$

$\bar{t}_{PFR} = 8 \times 0.5\ h = 4\ h.$

$\therefore C = 10^6 \times e^{-6.1 \times 4}$; $\underline{C = 2.53 \times 10^{-5} \approx 0}$ $\quad \therefore$ PFR is more efficient than 5 tanks in series.

$\boxed{\text{CHLORINE CONTACT CHAMBERS ARE PFR}}$

8.



Drag force: $F_D = \frac{1}{2} \rho C_D A_b v^2$

Power: $P = F_D \cdot v$

$\therefore \quad P = \frac{1}{2} \rho C_D A_b v^3$; v = impeller velocity relative to the liquid

$v = (1-k) v_i \quad \therefore \quad P = \frac{1}{2} \rho C_D A_b (1-k)^3 v_i^3$

$P_1 = \frac{1}{2} C_D \rho A_b (1-k)^3 v_{i_1}^3$ $\quad A_b$ = area of each blade

$P_2 = \frac{1}{2} C_D \rho A_b (1-k)^3 v_{i_2}^3$

For 1 arm: $P = \frac{1}{2} C_D \rho A_b (1-k)^3 (v_{i_1}^3 + v_{i_2}^3)$

For 2 arms: $P_T = C_D \rho A_b (1-k)^3 (v_{i_1}^3 + v_{i_2}^3)$

$P_T = 126 \frac{kg\, m^2}{s^3}$, $C_D = 1.8$; $k = 0.25$, $\rho = 1000 \frac{kg}{m^3}$

$$A_b = \frac{P_T}{C_D \rho (1-k)^3 (v_{i_1}^3 + v_{i_2}^3)}$$

$$= \frac{126 \frac{kg\, m^2}{s^3}}{1.8 \times 1000 \frac{kg}{m^3} (0.75)^3 (0.3^3 + 0.43^3) \frac{m^3}{s^3}}$$

$= 1.56\ m^2 \quad \therefore \quad A_T = 4 \text{ blades} \times 1.56 \frac{m^2}{\text{blade}}$ ⑤ ; $\underline{A_T = 6.23\ m^2}$ ⑳

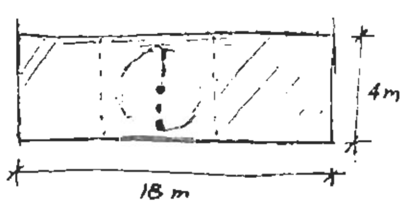
$A_x = 4 \times 14 = 56 m^2$; $0.2 A_x = 11.2 m^2$ ∴ $\underline{A_T < 0.2 A_x}$ OK. } ⑤

$A_x = 4 \times 14 = 56\ m^2$; Blade area fraction $= \frac{6.23\ m^2}{56\ m^2} = 0.111$ ⑤

a) $11.1\% < 15\%$ ∴ Unsatisfactory. ⑤

b) $G = \sqrt{\frac{P}{\mu V}}$; $G = \sqrt{\frac{126}{10^{-3} \times \underbrace{(14 \times 18 \times 4)}_{= 1008\ m^3}}}$; $\underline{G = 11.2\ s^{-1}}$

c)



There is a large volume that will not be mixed

∴ poor design.

1. 1^{st} order CFSTR $- \bar{t} = 1h$

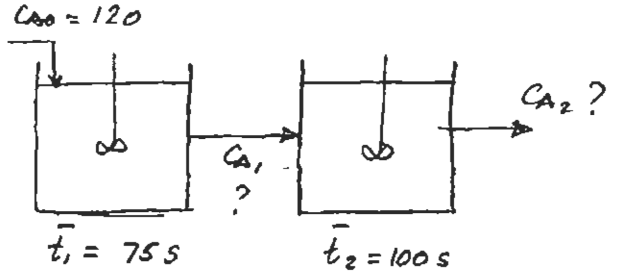
(a) PFR, same conversion in 10 min, Find k.

CFSTR: $\dfrac{C_A}{C_{A_0}} = \dfrac{1}{1+k\bar{t}}$; $\dfrac{C_A}{C_{A_0}} = \dfrac{1}{1+60k}$ or $x = \dfrac{k\bar{t}_{CFSTR}}{1+k\bar{t}_{CFSTR}}$

PFR: $\dfrac{C_A}{C_{A_0}} = e^{-\bar{t}k}$; $\dfrac{C_A}{C_{A_0}} = e^{-10k}$ or $x = 1-e^{-k\bar{t}_{PFR}}$

$1+60k = e^{+10k}$; $\boxed{k = 0.29183\ min^{-1}}$ $\Rightarrow \dfrac{C_A}{C_{A_0}} = 0.054$

1, (10)



$C_{A0} = 120$

Second order reaction, batch reactor, $C_{A0} = 100$, $t_{1/2} = 1$ sec.

$$t_{batch} = \frac{1}{k}\left(\frac{1}{C_A} - \frac{1}{C_{A0}}\right)$$

$$1 = \frac{1}{k}\left(\frac{1}{C_{A0}/2} - \frac{1}{C_{A0}}\right) \; ; \; C_{A0} = 100 \text{ mg/l}$$

$$1 = \frac{1}{k}\left(\frac{1}{50} - \frac{1}{100}\right) \; ; \; \boxed{k = 0.01 \frac{l}{mg \cdot s}}$$

1st reactor (CFSTR): $\bar{t}_1 = \dfrac{1}{kC_{A_1}}\left(\dfrac{C_{A0}}{C_{A_1}} - 1\right)$

$$75 = \frac{1}{0.01\,C_{A_1}}\left(\frac{120}{C_{A_1}} - 1\right) \; ; \; \underline{C_{A_1} = 12 \text{ mg/l}}$$

2nd reactor (CFSTR): $100 = \dfrac{1}{kC_{A_2}}\left(\dfrac{12}{C_{A_2}} - 1\right)$; $\underline{C_{A_2} = 3}$

2. $S_s = 1.001$ at $10°C$. $OR = 172.8\ m/d$. Find particle diameter.

(11) $v_{s0} = 172.8\ \frac{m}{d} \times \frac{100\,cm}{m} \times \frac{1\,d}{86400\,s}$; $v_{s0} = 0.2\ cm/s$

$\underbrace{d_p \cong 0.27\,cm}_{\text{graphically}}$; $\nu_{10°C} = 1.3101 \times 10^{-6}\ m^2/s$

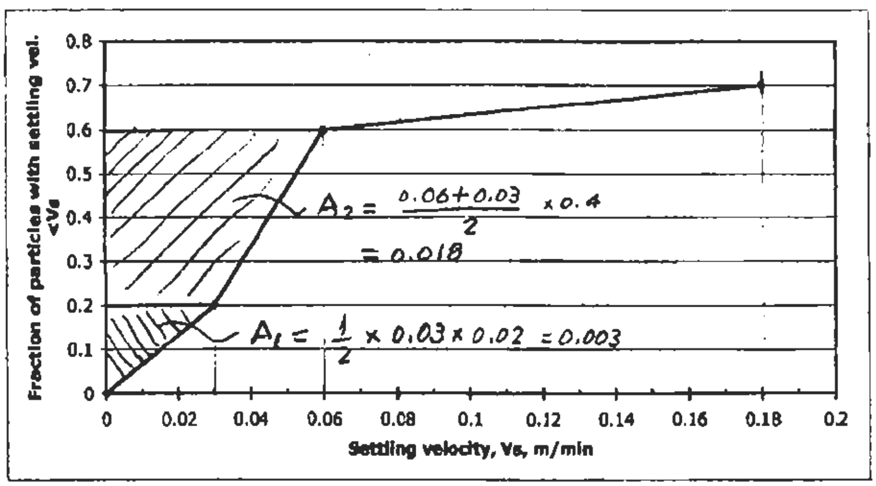
Using the formula :
$$v_s = \left[\frac{\frac{4}{3} g\,(S_s - 1)\,d_p}{\frac{24\nu}{d_p \cdot v_s} + 3\sqrt{\frac{\nu}{d_p \cdot v_s}} + 0.34}\right]^{0.5}$$

get : $d_p = 0.0025\ m$ or $d_p = 0.25\,cm$

Check Re : $Re = \frac{d_p \cdot v_s}{\nu} = \frac{0.0025\,m \times 0.002\ m/s}{1.3101 \times 10^{-6}}$

$Re = 3.82 > 2$ ∴ Transition region

12 = (3.) The chart below shows the results of a discrete-particle settling test. Find the settling efficiency of an ideal tank operating at an overflow rate of 86.4 m/d.



Total area $= 0.021 \frac{m}{min}$

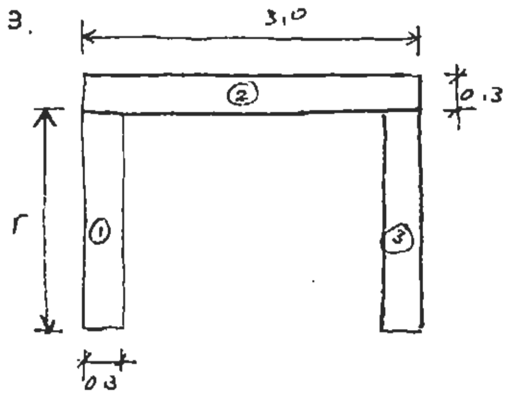
Removal $= 1 - y_0 + \frac{1}{v_{s0}} \int_0^{y_0} v_s \, dy$; $v_{s0} = 86.4 \frac{m}{d} \times \frac{1\,d}{86400\,s}$; $v_{s0} = 0.06$ m/min

$\therefore y_0 = 0.6$

Removal $= 1 - 06 + \frac{1}{0.06} \times 0.021$; Removal $= 0.75$

or 75%

13.



Length = 5 m

width = 4 m

Depth = 3 m

$\Big\}$ V = 60 m³

$\mu = 1.6 \times 10^{-3}$ kg/m.s

$\rho = 1000$ kg/m³

$C_D = 1.8$

$N = 5$ rpm

$k = 0.25$

$G = 50 \ s^{-1}$

$$P = 1.4352 \times 10^{-4} \, C_D \, \rho \, b \, N^3 (1-k)^3 (r_o^4 - r_i^4)$$

Paddles ① & ③ : $P = 1.4352 \times 10^{-4} \times 1.8 \times 1000 \times 0.3 \times 5^3 (0.75)^3 (r^4)$

Paddle 2 : $P = 1.4352 \times 10^{-4} \times 1.8 \times 1000 \times 3.0 \times 5^3 \times 0.75^3 \left[(r+0.3)^4 - r^4\right]$

$$P_T = 8.1738 \, r^4 + 40.869 \left[(r+0.3)^4 - r^4\right]$$

$$G = \sqrt{\frac{P}{\mu V}} \quad ; \quad 50 s^{-1} = \sqrt{\frac{8.1738 r^4 + 40.869\left[(r+0.3)^4 - r^4\right]}{1.6 \times 10^{-3} \times 60}}$$

$$r = 1.452 \text{ m}$$

$$P_T = 2 \times 31 \, \rho \, C_D \, b_1 \, (1-k)^3 n^3 r^4 + 31 \, \rho \, C_D \, b_2 \, (1-k)^3 n^3 \left[(r+0.3)^4 - r^4\right]$$

2. (14)

ANALYSIS OF DISCRETE PARTICLE SETTLING

A suspension of particles having an average density of 1400 kg/m^3 is to be treated in a tank designed for an overflow rate of 25 m^3/m$^2\cdot$d. For the particle size distribution given, determine the fraction F_r removed.

EFFECTIVE DIAMETER, mm	MASS FRACTION
0.010	0.10
0.015	0.20
0.020	0.25
0.025	0.15
0.030	0.05
0.035	0.15
0.040	0.05
0.045	0.05

Laminar $(R_e<1)$ $C_D = \frac{24}{Re}$

$V_s = \frac{g}{18\mu}(\rho_s-\rho_l)d^2$

SOLUTION:

1. Apply Eq. (12.27) to determine the particle velocity for each size and use the overflow rate to determine the fraction removed in each group.

turbulent $(R_e>2000)$ $C_D = 0.4$ $V_s = \sqrt{3.33gd\left(1-\frac{\rho_s}{\rho_l}\right)}$

$$v_s = \sqrt{\frac{4}{3}\frac{(9.81)(400)d_p}{C_D(1000)}}$$

$$= 2.29\left(\frac{d_p}{C_D}\right)^{1/2} \text{ m/s}$$

Trans. $C_D = \frac{24}{R_e} + \frac{3}{\sqrt{R_e}} + 0.34$

$$v_{sc} = \frac{25 \text{ m}^3/\text{m}^2\cdot\text{d}}{86{,}400 \text{ s/d}} = 2.89\times10^{-4} \text{ m/s}$$

$R_e = \frac{d_p V_s}{\nu}$

When $N_R > 0.3$ the problem must be solved by trial and error. For this problem the values of N_R are all less than 0.3, so Eq. (12.28) Stoke's law can be used.

d_p, mm	MASS FRACTION	STOKES' LAW VELOCITY, v_s, m/s	N_R	v_s/v_{sc}	MASS FRACTION REMOVED	MASS FRACTION REMAINING
0.010	0.10	2.18×10^{-5}	2.21×10^{-4}	0.075	0.008	0.092
0.015	0.20	4.90×10^{-5}	7.41×10^{-4}	0.169	0.034	0.166
0.020	0.25	8.72×10^{-5}	1.71×10^{-3}	0.301	0.075	0.175
0.025	0.15	13.62×10^{-5}	3.4×10^{-3}	0.471	0.071	0.079
0.030	0.05	19.62×10^{-5}	5.8×10^{-3}	0.678	0.034	0.016
0.035	0.15	26.71×10^{-5}	9.4×10^{-3}	0.923	0.138	0.012
0.040	0.05	34.88×10^{-5}	1.4×10^{-2}	0.205	0.050	0.000
0.045	0.05	44.15×10^{-5}	2.0×10^{-2}	1.526	0.050	0.000
Total	1.00				0.460	0.540

3. (15)

Use $v_{so} = \left[\dfrac{\frac{4}{3} g (S_s - 1) d_p}{\dfrac{24\nu}{d_p \cdot v_s} + 3\sqrt{\dfrac{\nu}{d_p \cdot v_s}} + 0.34} \right]^{1/2}$

$d_p = 5 \times 10^{-4} m$

$S_s = 2.65$

$\mu_{10} = 1.307 \times 10^{-3} \frac{kg}{m \cdot s}$

$\rho_{10} = 999.7 \frac{kg}{m^3}$

$\therefore \nu = 1.307 \times 10^{-6} \frac{m^2}{s}$ (8)

$V_{so} = V_s$ for 100% removal

Using calculator: $v_{s_o} = 8.07 \times 10^{-2} m/s$

Want to remove 100% of these particles $\therefore v_{so} = 8.07 \times 10^{-2} m/s$

$A = \frac{Q}{v_{so}}$; $A = \frac{0.1 \, m^3/s}{8.07 \times 10^{-2} \, m/s}$; $A = 1.24 \, m^2$. (2)

$v_L = 0.3 \frac{m}{s} \Rightarrow A_x = \frac{0.1 \, m^3/s}{0.3 \, m/s}$; $A_x = 0.33 \, m^2$ (2)

$\left. \begin{array}{l} WL = 1.24 \, m^2 \\ WD = 0.33 \, m^2 \end{array} \right\} \frac{L}{D} = 3.75$ (3)

(3)

Assume $D = 0.6 m \Rightarrow L = 3.75 \times 0.6$; $L = 2.25 m$.

$W = \frac{1.24}{2.25}$; $W = 0.55 \, m$. (3)

Use $L = 1.5 \times 2.25$; $L = 3.4 \, m$, $W = 0.55 m$, $D = 0.6 m$ (3)

Check recommendations:

$\frac{L}{W} \geq 4$: $\frac{L}{W} = \frac{3.4}{0.55} = 6.2$ OK (2)

$\frac{L}{D} \geq 6$: $\frac{L}{D} = \frac{3.4}{0.6} = 5.7 \therefore$ use $\frac{L}{D} = 6$, $L = 6 \times 0.6$

$L = 3.6 \, m$ (2)

Check Re & Fr $\quad R = \frac{0.55 \times 0.6}{2 \times 0.6 + 0.55}$; $R = 0.189 m$

$Re = \frac{v_L \cdot R}{\nu} = \frac{0.3 \, m/s \times 0.189 m}{1.307 \times 10^{-6} \, m^2/s}$; $Re = 43381 < 86\,000$ OK (2)

$F_R = \frac{v_L^2}{gR} = \frac{0.3^2}{9.81 \times 0.189}$; $F_R = 4.85 \times 10^{-2} > 10^{-5}$ OK (2)

$v_L = 0.3 \frac{m}{s} \times 60 \frac{s}{min}$; $v_L = 18 \frac{m}{min}$ > max. recommended (3–4.5 m/min) (3)

$\therefore$ change v_L

1b

2.

v_s ft/h	Avg v_s, ft/h	# particles	Fraction Removed $v_s/v_{s0} = v_s/6.5$	# particles removed
0-1.5	0.75	20	0.115	2
1.5-3.0	2.25	40	0.346	14
3.0-4.5	3.75	80	0.577	46
4.5-6.0	5.25	120	0.808	97
6.0-7.5	6.75	100	1.0	100
7.5-9.0	8.25	70	1.0	70
9.0-10.5	9.75	20	1.0	20
10.5-12.0	11.25	10	1.0	10
		460		359

$$\text{Removal efficiency} = \frac{359}{460} \times 100$$

$$= 78.04\%$$

3.

(17)

$$V_s = \sqrt{\dfrac{\frac{4}{3} g (S_s - 1) d_p}{\dfrac{24\nu}{d_p V_s} + 3\left(\dfrac{\nu}{d_p V_s}\right)^{0.5} + 0.34}}$$

$$V_s^2 \left(\frac{24\nu}{d_p V_s}\right) + 3 V_s^{3/2} \left(\frac{\nu}{d_p}\right)^{0.5} + 0.34 V_s^2 = \frac{4}{3} g (S_s - 1) d_p$$

$$0.34 V_s^2 + 3 V_s^{3/2} \left(\frac{\nu}{d_p}\right)^{0.5} + \frac{24\nu}{d_p} V_s - \frac{4}{3} g (S_s - 1) d_p = 0$$

$$0.34 V_s^2 + 3 V_s^{3/2} \left(\frac{1.0105 \times 10^{-6}}{10^{-3}}\right)^{0.5} + \frac{24 \times 1.0105 \times 10^{-6}}{10^{-3}} V_s - \frac{4}{3} \times 9.81 (1.5) \times 10^{-3} = 0$$

$$V_s^2 + 0.2805 V_s^{1.5} + 0.0713 V_s - 0.0577 = 0$$ (40)

$V_s = 0.166$ m/s (10)

If they simply stay at $V_s = \sqrt{\cdots}$ (30)

(18)

3. Example 5.4, p. 358 M&E

1. Find the power requirements:

$$P = G^2 \mu V \; ; \quad \mu_{15°C} = 1.139 \times 10^{-3}\ N{\cdot}s/m^2$$

$$P = (50\,s^{-1})^2 \times 1.139 \times 10^{-3}\ \frac{N{\cdot}s}{m^2} \times 3000\ m^3 \; ; \quad P = 8542.5\ \frac{kg \cdot m^2}{s^3}$$ (9)

$$P_1 = \frac{1}{2} C_D \rho A_b (1-k)^3 v_i^3$$ (9)

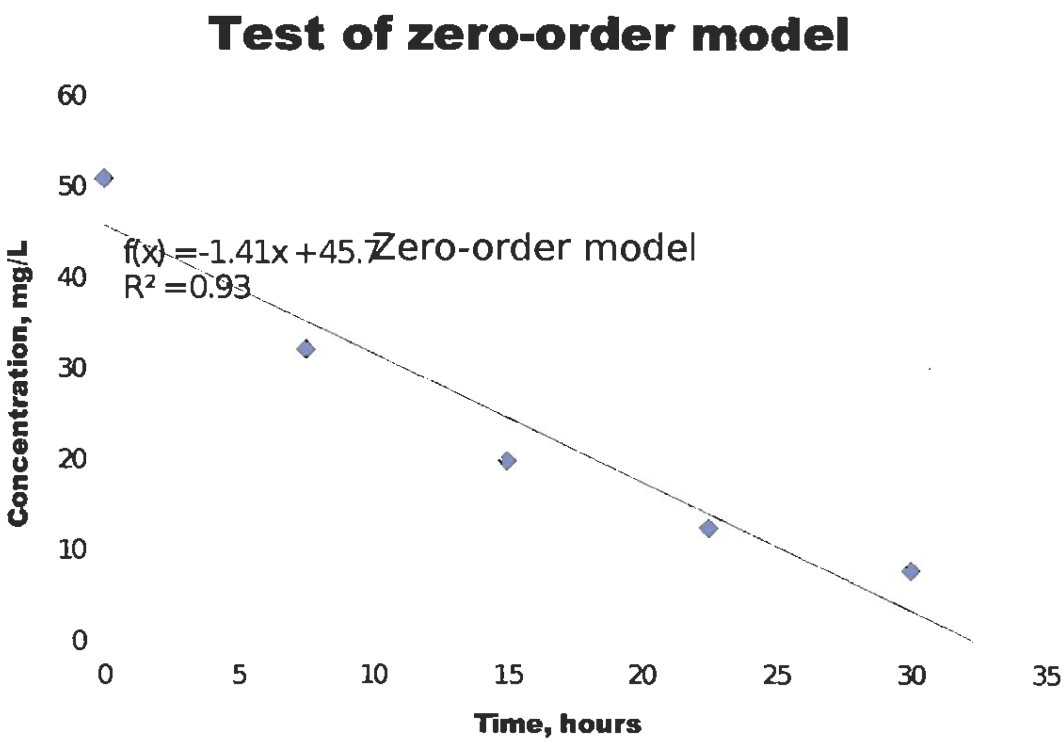
$$P_{Total} = C_D \rho A_b (1-k)^3 v_i^3 \; ; \quad \rho_{15°C} = 999.1\ kg/m^3$$

$$A_b = \frac{8542.5\ kg \cdot m^2/s^3}{1.8 \times 999.1\ \frac{kg}{m^3}\ (1-0.25)^3 \times 0.6^3\ \frac{m^3}{s^3}} \; ; \quad A_b = 52.12\ m^2$$ (9)

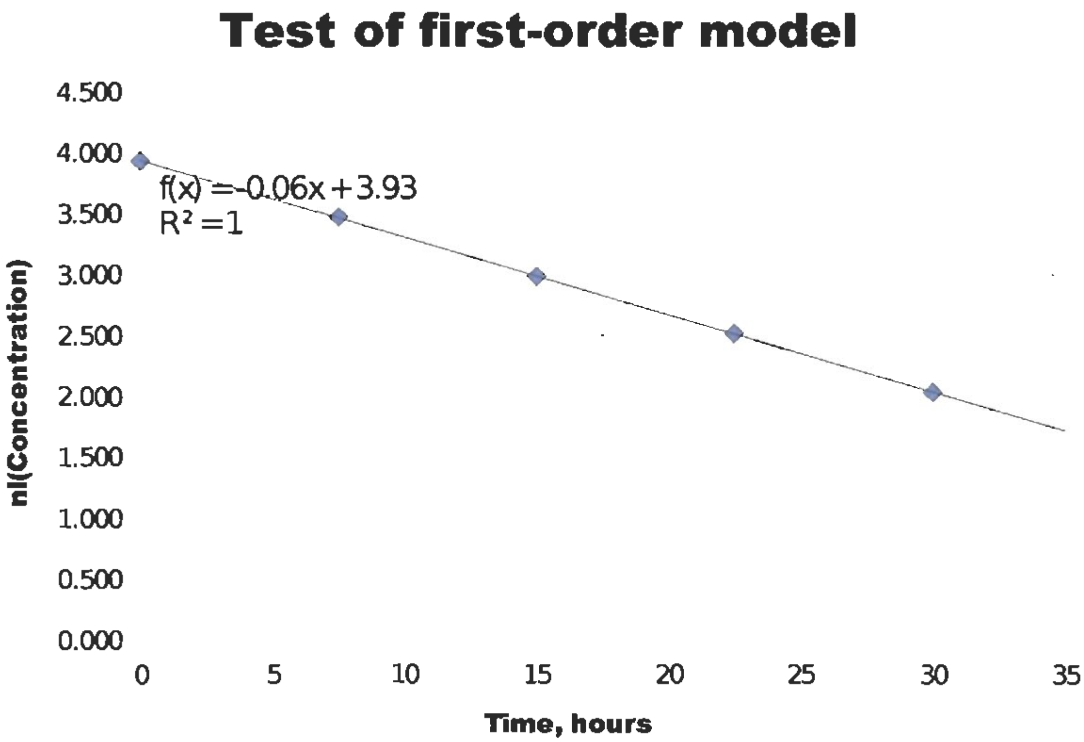
$\therefore$ Total area $= 2 \times 52.12$
$= 104.3\ m^2$ (8)

Problem 3.1, p. 64 Reynolds and Richards

t, hours	C_A, mg/L	ln C_A
0	50.8	3.928
7.5	32	3.466
15	19.7	2.981
22.5	12.3	2.510
30	7.6	2.028



First order model



EPA National Primary Drinking Water Standards

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal
OC	Acrylamide	TT8	Nervous system or blood problems;	Added to water during sewage/wastewater increased risk of cancer treatment	zero
OC	Alachlor	0.002	Eye, liver, kidney or spleen problems; anemia; increased risk of cancer	Runoff from herbicide used on row crops	zero
R	Alpha particles	15 picocuries per Liter (pCi/L)	Increased risk of cancer	Erosion of natural deposits of certain minerals that are radioactive and may emit a form of radiation known as alpha radiation	zero
IOC	Antimony	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder	0.006
IOC	Arsenic	0.010 as of 1/23/06	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards, runoff from glass & electronics production wastes	0
IOC	Asbestos (fibers >10 micrometers)	7 million fibers per Liter (MFL)	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits	7 MFL
OC	Atrazine	0.003	Cardiovascular system or reproductive problems	Runoff from herbicide used on row crops	0.003
IOC	Barium	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits	2
OC	Benzene	0.005	Anemia; decrease in blood platelets; increased risk of cancer	Discharge from factories; leaching from gas storage tanks and landfills	zero
OC	Benzo(a)pyrene (PAHs)	0.0002	Reproductive difficulties; increased risk of cancer	Leaching from linings of water storage tanks and distribution lines	zero
IOC	Beryllium	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries	0.004
R	Beta particles and photon emitters	4 millirems per year	Increased risk of cancer	Decay of natural and man-made deposits of certain minerals that are radioactive and may emit forms of radiation known as photons and beta radiation	zero
DBP	Bromate	0.010	Increased risk of cancer	Byproduct of drinking water disinfection	zero
IOC	Cadmium	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints	0.005
OC	Carbofuran	0.04	Problems with blood, nervous system, or reproductive system	Leaching of soil fumigant used on rice and alfalfa	0.04
OC	Carbon tetrachloride	0.005	Liver problems; increased risk of cancer	Discharge from chemical plants and other industrial activities	zero
D	Chloramines (as Cl_2)	MRDL=4.0[1]	Eye/nose irritation; stomach discomfort, anemia	Water additive used to control microbes	MRDLG=4[1]

LEGEND

D	Disinfectant	IOC	Inorganic Chemical	OC	Organic Chemical
DBP	Disinfection Byproduct	M	Microorganism	R	Radionuclides

	Contaminent	MCL or TT[1] (mg/L)[2]	Potential health effects from exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal
OC	Chlordane	0.002	Liver or nervous system problems; increased risk of cancer	Residue of banned termiticide	zero
D	Chlorine (as Cl_2)	MRDL=4.0[1]	Eye/nose irritation; stomach discomfort	Water additive used to control microbes	MRDLG=4[1]
D	Chlorine dioxide (as ClO_2)	MRDL=0.8[1]	Anemia; infants & young children: nervous system effects	Water additive used to control microbes	MRDLG=0.8[1]
DBP	Chlorite	1.0	Anemia; infants & young children: nervous system effects	Byproduct of drinking water disinfection	0.8
OC	Chlorobenzene	0.1	Liver or kidney problems	Discharge from chemical and agricultural chemical factories	0.1
IOC	Chromium (total)	0.1	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits	0.1
IOC	Copper	TT[7]; Action Level = 1.3	Short term exposure: Gastrointestinal distress. Long term exposure: Liver or kidney damage. People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level	Corrosion of household plumbing systems; erosion of natural deposits	1.3
M	*Cryptosporidium*	TT[3]	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	zero
IOC	Cyanide (as free cyanide)	0.2	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories	0.2
OC	2,4-D	0.07	Kidney, liver, or adrenal gland problems	Runoff from herbicide used on row crops	0.07
OC	Dalapon	0.2	Minor kidney changes	Runoff from herbicide used on rights of way	0.2
OC	1,2-Dibromo-3-chloropropa ne (DBCP)	0.0002	Reproductive difficulties; increased risk of cancer	Runoff/leaching from soil fumigant used on soybeans, cotton, pineapples, and orchards	zero
OC	o-Dichlorobenzene	0.6	Liver, kidney, or circulatory system problems	Discharge from industrial chemical factories	0.6
OC	p-Dichlorobenzene	0.075	Anemia; liver, kidney or spleen damage; changes in blood	Discharge from industrial chemical factories	0.075
OC	1,2-Dichloroethane	0.005	Increased risk of cancer	Discharge from industrial chemical factories	zero
OC	1,1-Dichloroethylene	0.007	Liver problems	Discharge from industrial chemical factories	0.007
OC	cis-1,2-Dichloroethylene	0.07	Liver problems	Discharge from industrial chemical factories	0.07
OC	trans-1,2-Dichloroethylene	0.1	Liver problems	Discharge from industrial chemical factories	0.1
OC	Dichloromethane	0.005	Liver problems; increased risk of cancer	Discharge from drug and chemical factories	zero
OC	1,2-Dichloropropane	0.005	Increased risk of cancer	Discharge from industrial chemical factories	zero
OC	Di(2-ethylhexyl) adipate	0.4	Weight loss, live problems, or possible reproductive difficulties	Discharge from chemical factories	0.4
OC	Di(2-ethylhexyl) phthalate	0.006	Reproductive difficulties; liver problems; increased risk of cancer	Discharge from rubber and chemical factories	zero
OC	Dinoseb	0.007	Reproductive difficulties	Runoff from herbicide used on soybeans and vegetables	0.007
OC	Dioxin (2,3,7,8-TCDD)	0.00000003	Reproductive difficulties; increased risk of cancer	Emissions from waste incineration and other combustion; discharge from chemical factories	zero
OC	Diquat	0.02	Cataracts	Runoff from herbicide use	0.02
OC	Endothall	0.1	Stomach and intestinal problems	Runoff from herbicide use	0.1

LEGEND

D	Disinfectant	IOC	Inorganic Chemical	OC	Organic Chemical
DBP	Disinfection Byproduct	M	Microorganism	R	Radionuclides

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal
OC	Endrin	0.002	Liver problems	Residue of banned insecticide	0.002
OC	Epichlorohydrin	TT[8]	Increased cancer risk, and over a long period of time, stomach problems	Discharge from industrial chemical factories; an impurity of some water treatment chemicals	zero
OC	Ethylbenzene	0.7	Liver or kidneys problems	Discharge from petroleum refineries	0.7
OC	Ethylene dibromide	0.00005	Problems with liver, stomach, reproductive system, or kidneys; increased risk of cancer	Discharge from petroleum refineries	zero
IOC	Fluoride	4.0	Bone disease (pain and tenderness of the bones); Children may get mottled teeth	Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories	4.0
M	*Giardia lamblia*	TT[3]	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	zero
OC	Glyphosate	0.7	Kidney problems; reproductive difficulties	Runoff from herbicide use	0.7
DBP	Haloacetic acids (HAA5)	0.060	Increased risk of cancer	Byproduct of drinking water disinfection	n/a[6]
OC	Heptachlor	0.0004	Liver damage; increased risk of cancer	Residue of banned termiticide	zero
OC	Heptachlor epoxide	0.0002	Liver damage; increased risk of cancer	Breakdown of heptachlor	zero
M	Heterotrophic plate count (HPC)	TT[3]	HPC has no health effects; it is an analytic method used to measure the variety of bacteria that are common in water. The lower the concentration of bacteria in drinking water, the better maintained the water system is.	HPC measures a range of bacteria that are naturally present in the environment	n/a
OC	Hexachlorobenzene	0.001	Liver or kidney problems; reproductive difficulties; increased risk of cancer	Discharge from metal refineries and agricultural chemical factories	zero
OC	Hexachlorocyclopentadiene	0.05	Kidney or stomach problems	Discharge from chemical factories	0.05
IOC	Lead	TT[7]; Action Level = 0.015	Infants and children: Delays in physical or mental development; children could show slight deficits in attention span and learning abilities; Adults: Kidney problems; high blood pressure	Corrosion of household plumbing systems; erosion of natural deposits	zero
M	*Legionella*	TT[3]	Legionnaire's Disease, a type of pneumonia	Found naturally in water; multiplies in heating systems	zero
OC	Lindane	0.0002	Liver or kidney problems	Runoff/leaching from insecticide used on cattle, lumber, gardens	0.0002
IOC	Mercury (inorganic)	0.002	Kidney damage	Erosion of natural deposits; discharge from refineries and factories; runoff from landfills and croplands	0.002
OC	Methoxychlor	0.04	Reproductive difficulties	Runoff/leaching from insecticide used on fruits, vegetables, alfalfa, livestock	0.04
IOC	Nitrate (measured as Nitrogen)	10	Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits	10
IOC	Nitrite (measured as Nitrogen)	1	Infants below the age of six months who drink water containing nitrite in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits	1

LEGEND

D	Disinfectant	IOC	Inorganic Chemical	OC	Organic Chemical
DBP	Disinfection Byproduct	M	Microorganism	R	Radionuclides

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal
OC	Oxamyl (Vydate)	0.2	Slight nervous system effects	Runoff/leaching from insecticide used on apples, potatoes, and tomatoes	0.2
OC	Pentachlorophenol	0.001	Liver or kidney problems; increased cancer risk	Discharge from wood preserving factories	zero
OC	Picloram	0.5	Liver problems	Herbicide runoff	0.5
OC	Polychlorinated biphenyls (PCBs)	0.0005	Skin changes; thymus gland problems; immune deficiencies; reproductive or nervous system difficulties; increased risk of cancer	Runoff from landfills; discharge of waste chemicals	zero
R	Radium 226 and Radium 228 (combined)	5 pCi/L	Increased risk of cancer	Erosion of natural deposits	zero
IOC	Selenium	0.05	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum refineries; erosion of natural deposits; discharge from mines	0.05
OC	Simazine	0.004	Problems with blood	Herbicide runoff	0.004
OC	Styrene	0.1	Liver, kidney, or circulatory system problems	Discharge from rubber and plastic factories; leaching from landfills	0.1
OC	Tetrachloroethylene	0.005	Liver problems; increased risk of cancer	Discharge from factories and dry cleaners	zero
IOC	Thallium	0.002	Hair loss; changes in blood; kidney, intestine, or liver problems	Leaching from ore-processing sites; discharge from electronics, glass, and drug factories	0.0005
OC	Toluene	1	Nervous system, kidney, or liver problems	Discharge from petroleum factories	1
M	Total Coliforms (including fecal coliform and *E. coli*)	5.0%[4]	Not a health threat in itself; it is used to indicate whether other potentially harmful bacteria may be present[5]	Coliforms are naturally present in the environment as well as feces; fecal coliforms and *E. coli* only come from human and animal fecal waste.	zero
DBP	Total Trihalomethanes (TTHMs)	0.10 0.080 after 12/31/03	Liver, kidney or central nervous system problems; increased risk of cancer	Byproduct of drinking water disinfection	n/a[6]
OC	Toxaphene	0.003	Kidney, liver, or thyroid problems; increased risk of cancer	Runoff/leaching from insecticide used on cotton and cattle	zero
OC	2,4,5-TP (Silvex)	0.05	Liver problems	Residue of banned herbicide	0.05
OC	1,2,4-Trichlorobenzene	0.07	Changes in adrenal glands	Discharge from textile finishing factories	0.07
OC	1,1,1-Trichloroethane	0.2	Liver, nervous system, or circulatory problems	Discharge from metal degreasing sites and other factories	0.20
OC	1,1,2-Trichloroethane	0.005	Liver, kidney, or immune system problems	Discharge from industrial chemical factories	0.003
OC	Trichloroethylene	0.005	Liver problems; increased risk of cancer	Discharge from metal degreasing sites and other factories	zero
M	Turbidity	TT[3]	Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (e.g., whether disease-causing organisms are present). Higher turbidity levels are often associated with higher levels of disease-causing micro-organisms such as viruses, parasites and some bacteria. These organisms can cause symptoms such as nausea, cramps, diarrhea, and associated headaches.	Soil runoff	n/a
R	Uranium	30 ug/L as of 12/08/03	Increased risk of cancer, kidney toxicity	Erosion of natural deposits	zero

LEGEND

D	Disinfectant	IOC	Inorganic Chemical	OC	Organic Chemical
DBP	Disinfection Byproduct	M	Microorganism	R	Radionuclides

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal
OC	Vinyl chloride	0.002	Increased risk of cancer	Leaching from PVC pipes; discharge from plastic factories	zero
M	Viruses (enteric)	TT[3]	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	zero
OC	Xylenes (total)	10	Nervous system damage	Discharge from petroleum factories; discharge from chemical factories	10

NOTES

1 Definitions

- Maximum Contaminant Level Goal (MCLG)—The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.
- Maximum Contaminant Level (MCL)—The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards.
- Maximum Residual Disinfectant Level Goal (MRDLG)—The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.
- Maximum Residual Disinfectant Level (MRDL)—The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.
- Treatment Technique (TT)—A required process intended to reduce the level of a contaminant in drinking water.

2 Units are in milligrams per liter (mg/L) unless otherwise noted. Milligrams per liter are equivalent to parts per million (ppm).

3 EPA's surface water treatment rules require systems using surface water or ground water under the direct influence of surface water to (1) disinfect their water, and (2) filter their water or meet criteria for avoiding filtration so that the following contaminants are controlled at the following levels:

- *Cryptosporidium* (as of 1/1/02 for systems serving >10,000 and 1/14/05 for systems serving <10,000) 99% removal.
- *Giardia lamblia*: 99.9% removal/inactivation
- Viruses: 99.99% removal/inactivation
- *Legionella*: No limit, but EPA believes that if *Giardia* and viruses are removed/inactivated, *Legionella* will also be controlled.
- Turbidity: At no time can turbidity (cloudiness of water) go above 5 nephelolometric turbidity units (NTU); systems that filter must ensure that the turbidity go no higher than 1 NTU (0.5 NTU for conventional or direct filtration) in at least 95% of the daily samples in any month. As of January 1, 2002, for systems servicing >10,000, and January 14, 2005, for systems servicing <10,000, turbidity may never exceed 1 NTU, and must not exceed 0.3 NTU in 95% of daily samples in any month.
- HPC: No more than 500 bacterial colonies per milliliter.
- Long Term 1 Enhanced Surface Water Treatment (Effective Date: January 14, 2005); Surface water systems or (GWUDI) systems serving fewer than 10,000 people must comply with the applicable Long Term 1 Enhanced Surface Water Treatment Rule provisions (e.g. turbidity standards, individual filter monitoring, *Cryptosporidium* removal requirements, updated watershed control requirements for unfiltered systems).
- Filter Backwash Recycling: The Filter Backwash Recycling Rule requires systems that recycle to return specific recycle flows through all processes of the system's existing conventional or direct filtration system or at an alternate location approved by the state.

4 No more than 5.0% samples total coliform-positive in a month. (For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month.) Every sample that has total coliform must be analyzed for either fecal coliforms or *E. coli* if two consecutive TC-positive samples, and one is also positive for *E. coli* fecal coliforms, system has an acute MCL violation.

5 Fecal coliform and *E. coli* are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Disease-causing microbes (pathogens) in these wastes can cause diarrhea, cramps, nausea, headaches, or other symptoms. These pathogens may pose a special health risk for infants, young children, and people with severely compromised immune systems.

6 Although there is no collective MCLG for this contaminant group, there are individual MCLGs for some of the individual contaminants:

- Haloacetic acids: dichloroacetic acid (zero); trichloroacetic acid (0.3 mg/L)
- Trihalomethanes: bromodichloromethane (zero); bromoform (zero); dibromochloromethane (0.06 mg/L)

7 Lead and copper are regulated by a Treatment Technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water samples exceed the action level, water systems must take additional steps. For copper, the action level is 1.3 mg/L, and for lead is 0.015 mg/L.

8 Each water system must certify, in writing, to the state (using third-party or manufacturer's certification) that when it uses acrylamide and/or epichlorohydrin to treat water, the combination (or product) of dose and monomer level does not exceed the levels specified, as follows: Acrylamide = 0.05% dosed at 1 mg/L (or equivalent); Epichlorohydrin = 0.01% dosed at 20 mg/L (or equivalent).

LEGEND

D	Disinfectant	IOC	Inorganic Chemical	OC	Organic Chemical
DBP	Disinfection Byproduct	M	Microorganism	R	Radionuclides

National Secondary Drinking Water Standards

National Secondary Drinking Water Standards are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. EPA recommends secondary standards to water systems but does not require systems to comply. However, states may choose to adopt them as enforceable standards.

Contaminant	Secondary Standard
Aluminum	0.05 to 0.2 mg/L
Chloride	250 mg/L
Color	15 (color units)
Copper	1.0 mg/L
Corrosivity	noncorrosive
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor number
pH	6.5-8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

Office of Water (4606M)
EPA 816-F-03-016
www.epa.gov/safewater
June 2003

ENCE 4323

SETTLING VELOCITY OF DISCRETE PARTICLES

g =	9.81	m/s^2
Particle density =	1400	kg/m^3
Fluid density =	1000	kg/m^3
Kinematic viscosity =	1.31E-06	m^2/s
Particle diameter =	1.00E-05	m

Using Goal Seek, cell B16 must be zero while cell B12 gives the settling velocity

Assumed Vs =	1.661780E-05
Re =	1.268534E-04
C_D =	1.894615E+05
Calculated Vs =	1.661780E-05
ssumed Vs - Calc. Vs =	0.000000E+00

ENCE 4323
COURSE PROJECT

This is an open-ended preliminary design of a water treatment plant for a maximum daily flow rate of 1.0 m^3/s at the end of the design period. This preliminary design will closely follow the example presented in Qasim's book. Therefore, read in detail pp. 91-117. We will use exactly the same hypothetical Modeltwon, with the same raw water characteristics and proposed treatment facilities.

TASK 4: High-rate, tube settler sedimentation basins
DRAFT DUE 11/9/09

Prepare the preliminary design of the high-rate sedimentation tanks using an approach **similar** to that presented in Section 9.3, Qasim's book, adapted to the case of **high-rate tube settlers** (for example, see http://www.brentwood-ind.com/water/tubesettlersystems.html). Do not use exactly the same approach presented in the book because it corresponds to conventional settling tanks.

Your report should include engineering drawings similar to Figures 9-14, 9-15, 9-16, 9-17, 9-18, and 9-20. You should also submit brochures of the settling modules you will be using in your project.

ENCE 4323
COURSE PROJECT
Final report due date: 12/2/09

This is an open-ended preliminary design of a water treatment plant for a maximum daily flow rate of 1.0 m^3/s at the end of the design period. This preliminary design will closely follow the example presented in Qasim's book. Therefore, read in detail pp. 91-117. We will use exactly the same hypothetical Modeltwon, with the same raw water characteristics and proposed treatment facilities.

TASKS 5 and 6: Filtration-disinfection
DRAFT DUE 11/23/09

5. Prepare the preliminary design of a dual media (anthracite-sand) filter and submit:

- All calculations, including:
  - Number of filtration units
  - Filter box dimensions: surface area, box depth...
  - Media particle size specifications and media depth
  - Water depth, upstream and downstream
  - Design or selection of commercially available drainage system
  - Design or selection of commercially available surface backwash system
  - Dimensions of the filter piping system: influent, effluent, wash water, drainage
  - Backwash system: backwash water troughs, gullet, elevated tank, pipe and fittings.
- Engineering drawings, and catalogs of the equipment to be used.

6. Prepare the design of a disinfection system including:

- All calculations:
  - Reactor volume and dimensions. Assume the first user is located at 1000 m from the water treatment plant. Make any other assumptions you deem necessary, stating them clearly.
  - Chlorine dosage.
- Engineering drawings, and catalogs of the equipment to be used.

ENCE 4323
COURSE PROJECT

This is an open-ended preliminary design of a water treatment plant for a maximum daily flow rate of 1.55 m^3/s at the end of the design period. This preliminary design will closely follow the example presented in Qasim's book. Therefore, read in detail pp. 91-117. We will use exactly the same hypothetical Modeltwon, with the same raw water characteristics and proposed treatment facilities.

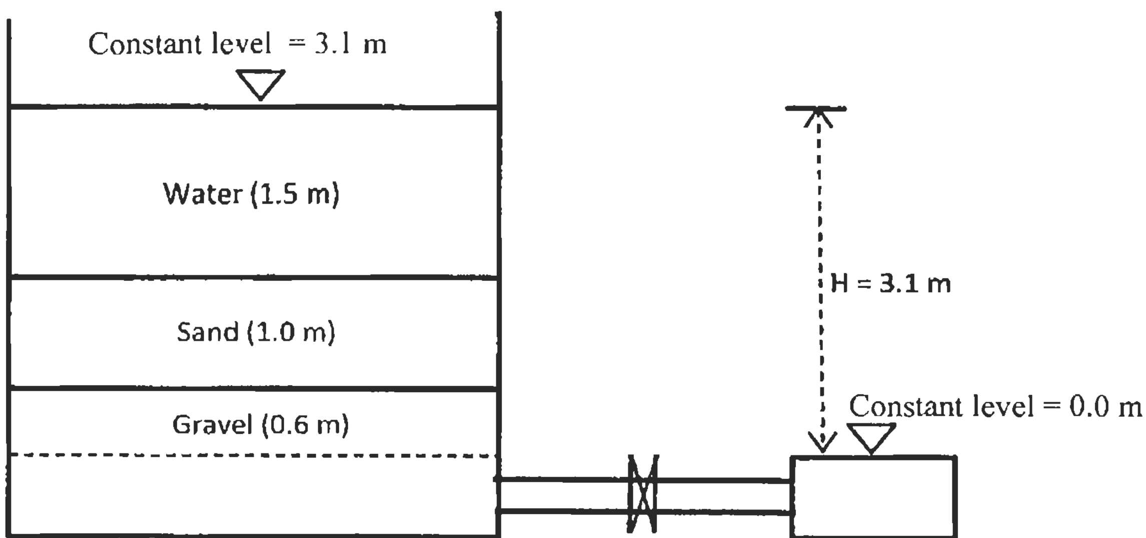
TASK 4: High-rate, tube settler sedimentation basins
DRAFT DUE 11/1/10

Prepare the preliminary design of the high-rate sedimentation tanks using an approach **similar** to that presented in Section 9.3, Qasim's book, adapted to the case of **high-rate tube settlers** (for example, see http://www.brentwood-ind.com/water/tubesettlersystems.html). Do not use exactly the same approach presented in the book because it corresponds to conventional settling tanks.

Your report should include engineering drawings similar to Figures 9-14, 9-15, 9-16, 9-17, 9-18, and 9-20. You should also submit brochures of the settling modules you will be using in your project.

ENCE 4323
Assignment No. 3 – Due 10/27/10

1. A rapid sand filter operates with an effluent rate controller provided with a gate valve, and works at a constant rate of 28.3 L/s. The gravel, sand, and water depths are 0.6 m, 1.0 m, and 1.5 m, respectively (see attached graph below). The water level at the filter box is fixed at an elevation of 3.1 m, and the water level at the effluent channel remains constant at 0.0 m. The head loss through the sand, the gravel, and the filter bottom is 30 cm at the beginning of the filter run, and 2.4 m at the end.
   a) What is the available head at the beginning and at the end of the filter run, and what is the head lost at the rate controller?
   b) Assume that the rate controller works as an orifice, i.e. $V = c\sqrt{2gh_L}$, and that the head loss in the effluent pipe is negligible. If the velocity through the rate controller at the end of the run is 0.6 m/s, calculate the velocity through the rate controller at the beginning of the run.



2. The following are the turbulent and clean laminar head losses in a rapid granular filter operated under declining rate conditions:
   - Sand: $h_{Ls} = 53.2\ V$
   - Anthracite: $h_{La} = 15.1\ V$
   - Drainage pipes $h_{Ld} = 1441.9\ V^2$
   - False bottom: $h_{Lb} = 0.7\ V^2$
   - Minor losses: $h_{Lm} = 1510.0\ V^2$

   In all these expression, V is the filtration rate expressed in m/s. The maximum available head for filtration is 1.15 m, and the dirty-filter head loss at the minimum filtration rate of 12.54 cm/min is 0.77 m. Find the additional turbulent head loss that must be introduced by an orifice plate in the influent pipe to balance the filter hydraulics.

3. The turbulent and clean laminar head losses in a rapid granular filter operating under declining rate conditions are the same as those given in problem 2. The maximum available head for filtration is 1.15 m. If the average filtration rate is 20 cm/min, the minimum filtration rate is 70 % of the average rate, and the maximum filtration rate is 1.3 times the average rate, find the dirty-filter laminar head loss assuming there is an orfice plate in the influent pipe to balance the filter hydraulics.

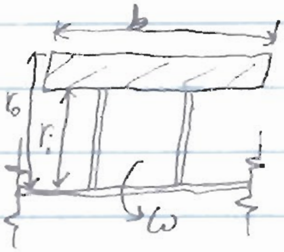
W.Water Sep 15 ①

Flocculation

Power req'd to move board @ rotational speed (ω)

$$P = \pi^3 C_D \rho b (1-k)^3 \omega^3 (r_o^4 - r_i^4)$$

20.65

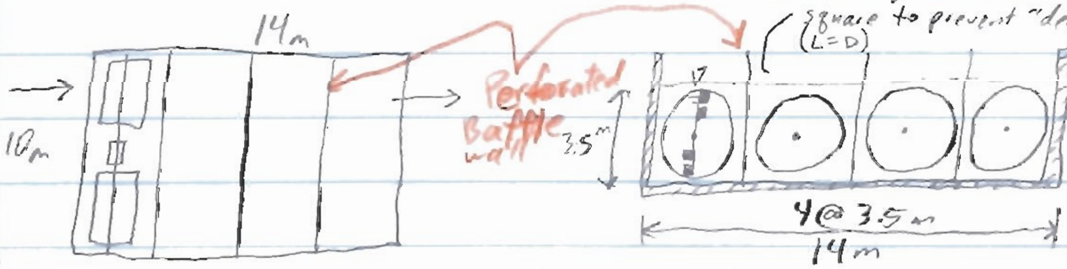


Ex. Design a flocculator for $Q = 390 \frac{L}{s}$ ($Q_{max, day}$)

Recommendations: * Select $\bar{t} = 20$ min, $Vol = 0.39 \frac{m^3}{s} (20 min)(60 \frac{s}{min}) = 468 m^3$

Q t Total tank Vol

* Select tank depth: 3.5m ($\simeq$ 10ft) (recommended)
* Tank surface Area $A = \frac{468 m^3}{3.5 m} = 134 m^2$ (Say 10m × 14m)



divide into 4 compartments

3 compartments min

* 4 tanks in series separated by baffle walls
* Select paddle surface area (total paddle area per compartment = (0.15→0.2) × tank cross sect. area)

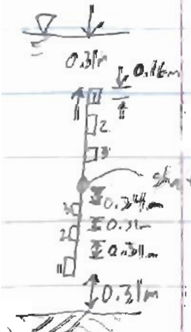
→ Select: $A_p = 0.2 (10m)(3.5m) = 7m^2$

÷ 2 wheels per compartment = $3.5 m^2$ per wheel.

→ Select board dimensions → $0.16 m \times 3.5 m = 0.56 m^2$

→ select 2 rotors per shaft, ea. w/ 2 arms, 3 paddles per arm

⇒ $2 \text{ rotors} \left(2 \frac{\text{arms}}{\text{rotor}}\right)\left(3 \frac{\text{paddles}}{\text{Arm}}\right)\left(0.56 \frac{m^2}{\text{paddle}}\right) = 6.72 m^2 < 7 m^2$



Paddle	r_i	r_o
1	1.28	1.44
2	0.81	0.97
3	0.34	0.50

w.w. sep. 15 (2)

Assume: $C_D = 1.8$, $\rho = 1000\ kg/m^3$, $\omega = 0.1\ rps$, $k = 0.25$

$b = 3.5\ m$, μ (kenimatic viscocity) $= 1.6 \times 10^{-3}\ kg/m \cdot s$

$$P = \underbrace{\pi^3 C_D \rho b \left[(1-k)\omega\right]^3}_{82.39} (r_o^4 - r_i^4)$$

Paddle	r_i	r_o	P [W]
1	1.28	1.44	133.09
2	0.81	0.97	37.47
3	0.34	0.50	4.05
Σ			176.62 (For one Arm)

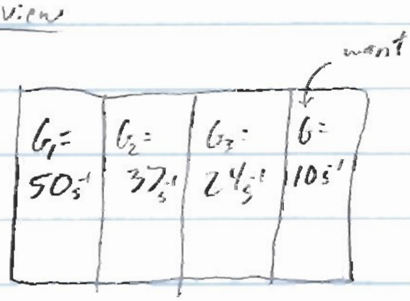
× 2 arms = P to move one rotor (AKA wheel)

so total P_T per shaft $= 176.62 \frac{W}{arm}\left(2 \frac{arms}{rotor}\right)\left(2 \frac{rotors}{shaft}\right) = \underline{698.5\ W}$

$$G \text{ (velociy gradient)} = \sqrt{\frac{P}{\mu V}} = \sqrt{\frac{498.5 \frac{kg \cdot m^2}{s^2}}{1.6 \times 10^{-3} \frac{kg}{m \cdot s}(3.5(3.5(10)))[m^3]}}$$

$\rightarrow \underline{G = 59.7\ s^{-1}}$ corresponding to $\omega = 0.1\ rps$

Plan view



Find ω in ea. compartment to achieve desired value of G

$$G = \underbrace{\sqrt{\frac{\Sigma \pi^3 C_D \rho b (1-k)^3 (r_o^4 - r_i^4)}{\mu V}}}_{\text{since camber are = this is constant}} \omega^{3/2}$$

$$\frac{G_1}{G_2} = \left(\frac{\omega_1}{\omega_2}\right)^{3/2} \longrightarrow \omega_2 = \omega_1 \left(\frac{G_2}{G_1}\right)^{2/3}$$

$\omega_1 = 0.1\ rps$, $G_1 = 59.7\ s^{-1}$ $\rightarrow$ $\omega_2 = 0.0065\ G_2^{2/3}$

Compartment	G [s^{-1}]	ω rps	ω rpm
1	50	0.089	5.3
2	37	0.073	4.4
3	24	0.054	3.3
4	10	0.03	1.8

w.w sep 15 (2)

Finnally

Check max tip speed (b/t 0.15 m/s & 1.0 m/s) To prevent floc breakup

v_i (impeller velocity) $= 2\pi r_o \omega$

First chamber : $v_i = 2\pi (1.44_m)(0.089 \frac{rad}{s}) = 0.81\ m/s$ OKAY

∴ Design = OKAY

→ rapid mix → Flocculator → settling tank → Filters → Disinfection

Sedimentation (several places @ a plant)

Two most important settling processes:

- * Grit removal (sand particles, descrete particles) * usually done at source (water intake)
  - remove "descrete" particles (aka: maintain their shape, etc.. maintain their properties) settle independently from each other.
- * Flocculent particles (do not maintain their size/characteristics)

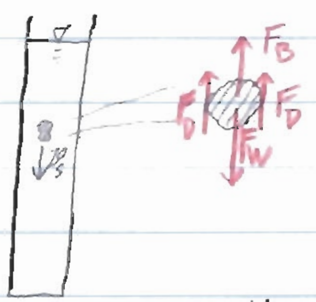
Descrete Particle Settling

ρ_s = solid density [$\frac{kg}{m^3}$], $\forall_p$ = partical vol. [m

ρ_l = liquid density

g = gravity accel. [m/s

A_p = projected area [m^2]



Force Balance

weight Buoyancy Drag Force

$$\emptyset = F_W - F_B - F_D$$

$$= (\rho_s \forall_p g) - (\rho_l \forall_p g) - \left(\tfrac{1}{2} C_D A_p \rho_l v_s^2\right)$$

$$\longrightarrow v_s = \frac{2g(\rho_s - \rho_l)}{C_D \rho_l}\left(\frac{\forall_p}{A_p}\right)$$

☆ If sphere $\frac{\forall_p}{A_p} = \frac{\frac{\pi}{6} d_p^3}{\frac{\pi}{4} d_p^2} = \frac{2}{3} d_p$

– sub in : $v_s = \sqrt{\frac{4g}{3C_D}\left(\frac{\rho_s - \rho_l}{\rho_l}\right) d_p}$ (Newtons Law)

$A_? = 0.2(30m)(4m) = 24 m^2$

$1 ft = 0.3048 m$

$\frac{A_?}{6 \text{ wheels (rotor)}} = 4 m^2/\text{wheel}$

$\frac{1 ft}{0.3048 m}(4.5 m) = 14.76 ft$

$14 ft\left(\frac{0.3048 m}{ft}\right) = \boxed{4.27 m}$

select board dimensions

$\frac{\cancel{0.3048 m}}{0.1524 m} \times 4.27 m \left(2'' \times 12'' \times 14' \text{ board}\right) = \cancel{1.3015} = 0.6507 m^2$

$12''\left(\frac{1 ft}{12''}\right)\left(\frac{0.3048 m}{1 ft}\right) = 0.3048$

$6 \text{ rotors per shaft}\left(\frac{2 \text{ arms}}{\text{rotor}}\right)\left(\frac{3 \text{ paddles}}{\text{arm}}\right)\left(\frac{\overset{0.6507 m^2}{\cancel{1.3015 m^2}}}{\text{paddle}}\right) = \cancel{46.85} m^2$

$= 23.4 m^2$

4.38

2.19

$2.19 - (0.1524(3)) = 1.733$ $/3 = 0.578 m$

$\frac{G_a}{G_t} = \left(\frac{\omega_a}{\omega_t}\right)^{3/2} \rightarrow \frac{\overset{111.33}{\cancel{99.58}}}{50} = \left(\frac{0.1}{\omega_t}\right)^{3/2} \rightarrow \omega_t = 0.1\left(\frac{50}{\underset{111.33}{\cancel{99.58}}}\right)^{2/3} = \overset{0.0586}{\cancel{0.0632}}$ r/s

1'' 0

$\frac{Kg}{m \cdot s}$ $\frac{N \cdot s}{m^2}$ $0 \frac{N}{m^2}$

9032.28

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COURSE PROJECT

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TASK 3: Flocculation basins
DRAFT DUE 10/20/10

Prepare the preliminary design of the mechanical flocculators using an approach similar to that presented on pp. 272-287 Qasim, adapted to the new flow rate.

Do not use 3 stages, as in the book. Rather, use 4 stages, with the velocity gradient ranging from 50 sec^{-1} in the first stage down to 10 sec^{-1} in the fourth stage. Show all your calculations of velocity gradient in each compartment.

Use baffle walls between flocculation stages, and a diffuser wall between the last flocculation chamber and the sedimentation tank. Your report should include engineering drawings similar to Figures 8-16, 8-17, 8-19, and 8-21, and brochures of the mechanical equipment you have selected for the flocculators. It should include the design of the diffuser walls.

wastewater Sep. 13

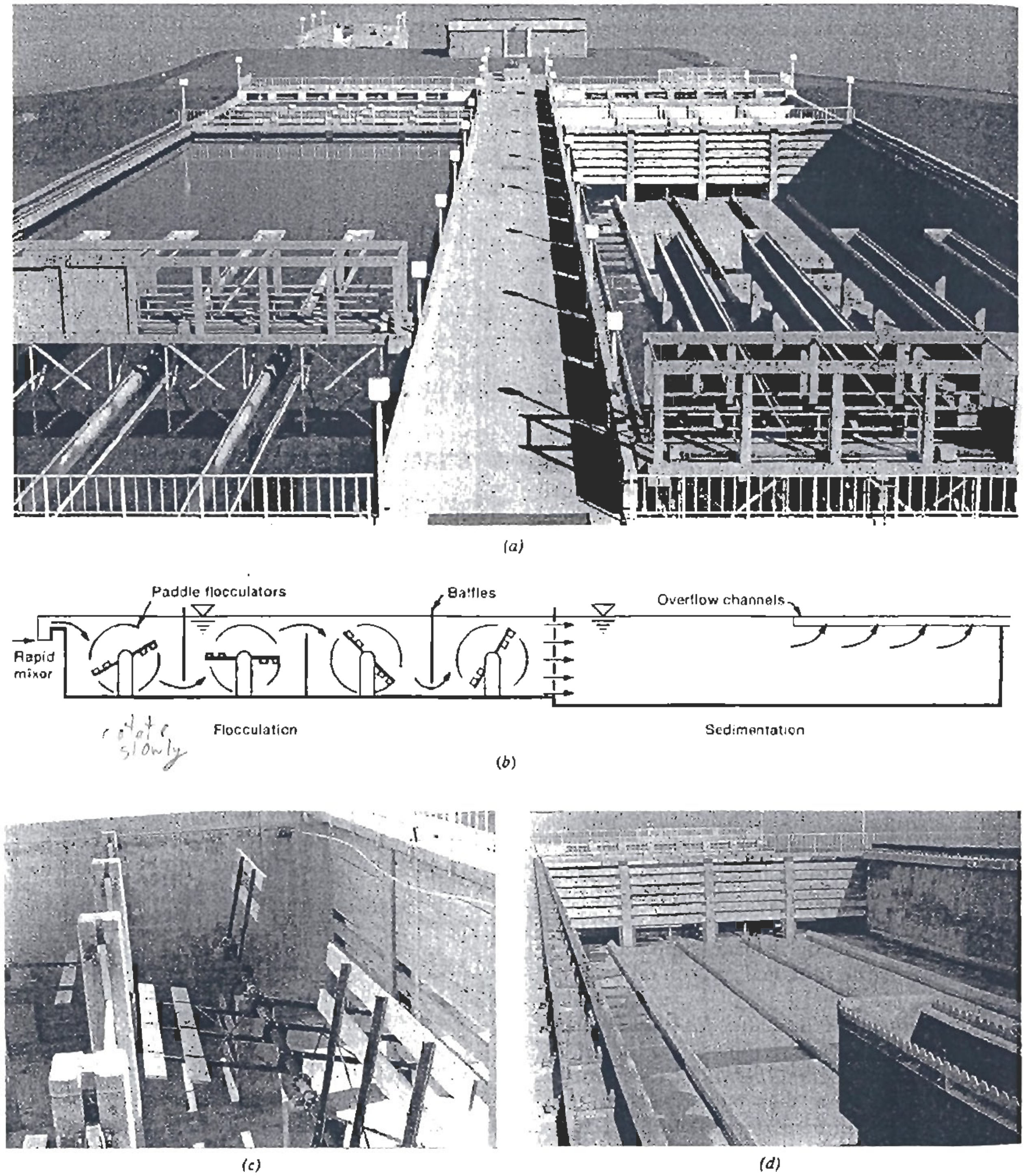
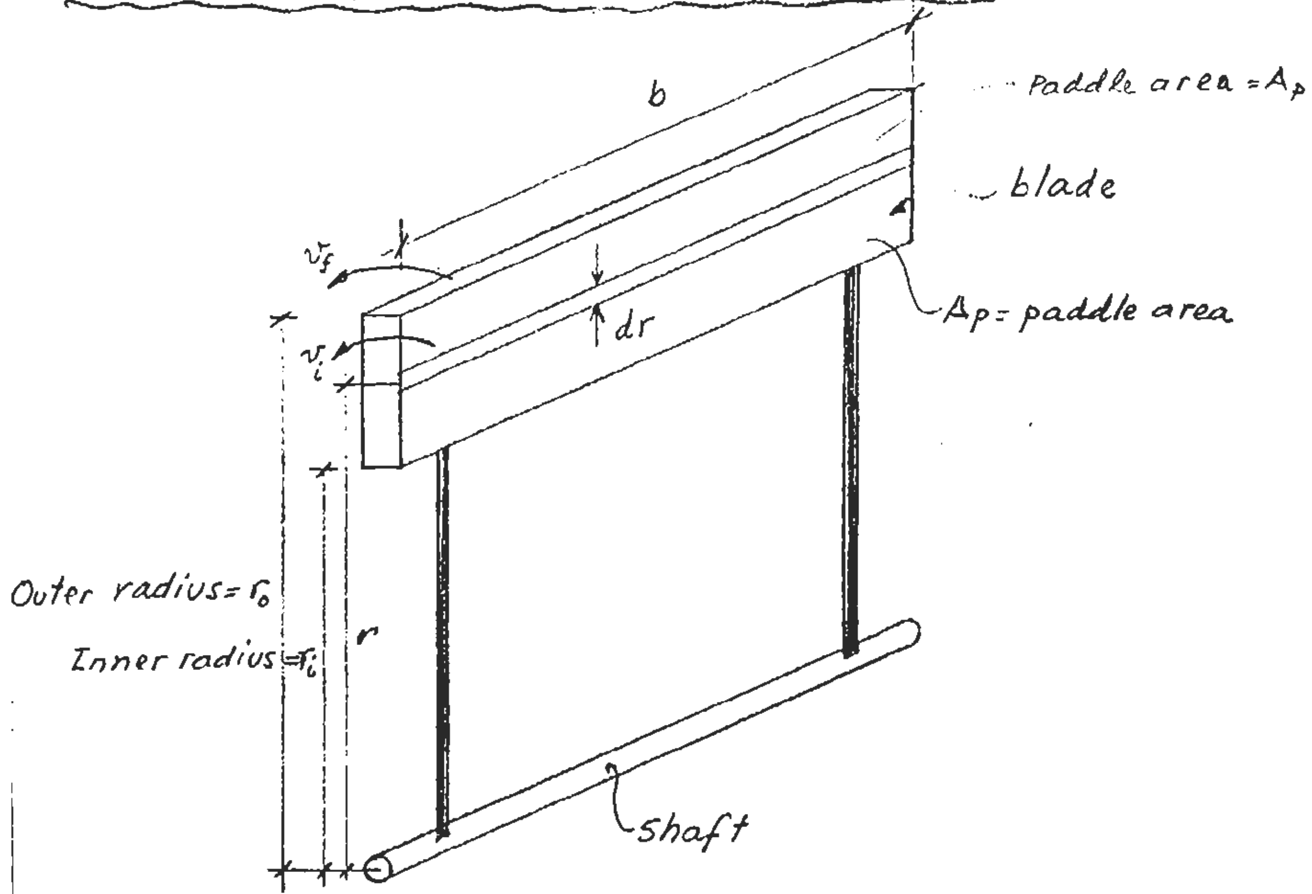


Figure 7–6
In-line rapid mixing, flocculation, and sedimentation in water treatment.

wastewater Sep. 13

Power consumption in mechanical flocculators



v_f = fluid velocity ; v_i = impeller velocity

v: relative vel. of impeller w/ respect to fluid ($v = v_i - v_f$)

Drag force req'd to move a mass of water @ vel. v:

$F_D = C_D \cdot A_p\,[m^2] \cdot \left[\rho \left[\frac{kg}{m^3}\right] \cdot \frac{v^2}{2}\left[\frac{m^2}{s^2}\right]\right] [=] \frac{kg \cdot m}{s^2} = N \rightarrow \boxed{F_D = \frac{1}{2}\rho C_D A_p v^2}$

A_p = paddle surface

$\rho \frac{v^2}{2}$ dynamic pressure $\left[\frac{N}{m^2}\right]$

C_D = drag coefficient (1.5 – 2.0 for flat blades)

Power needed: $P = F_D v$ ∴ $P = \frac{1}{2}\rho C_D A_p v^3$ (eq. 8-16, p. 198 R&R)

* If $r_0 >> r_i$: Power imparted to the fluid by an elemental paddle Area, dA_p:

$dP = \frac{1}{2}\rho C_D v^3 dA_p$; $dA_p = b\,dr$

$dP = \frac{1}{2}\rho C_D v^3 b\,dr$

integrate: $P = \frac{1}{2}\rho C_D b \int_{r_i}^{r_0} v^3 dr$

Express v as $f(r)$

Over

Define $k = \frac{v_f}{v_i}$; $v_f = k v_i$; $v = v_i - v_f$; $v = (1-k) v_i$

$v_i = 2\pi r \omega$ (ω = rotational speed in rev/s ; r = radius of differential area)

$v = (1-k) 2\pi r \omega$ (now sub. into power eqn.)

$$P = \frac{1}{2} \rho C_D b (2\pi\omega)^3 \int_{r_i}^{r_0} r^3 \, dr = \frac{(2\pi)^3}{2(4)} \rho C_D b (1-k)^3 \omega^3 (r_0^4 - r_i^4)$$

$$P = \pi^3 \rho C_D b (1-k)^3 \omega^3 (r_0^4 - r_i^4)$$

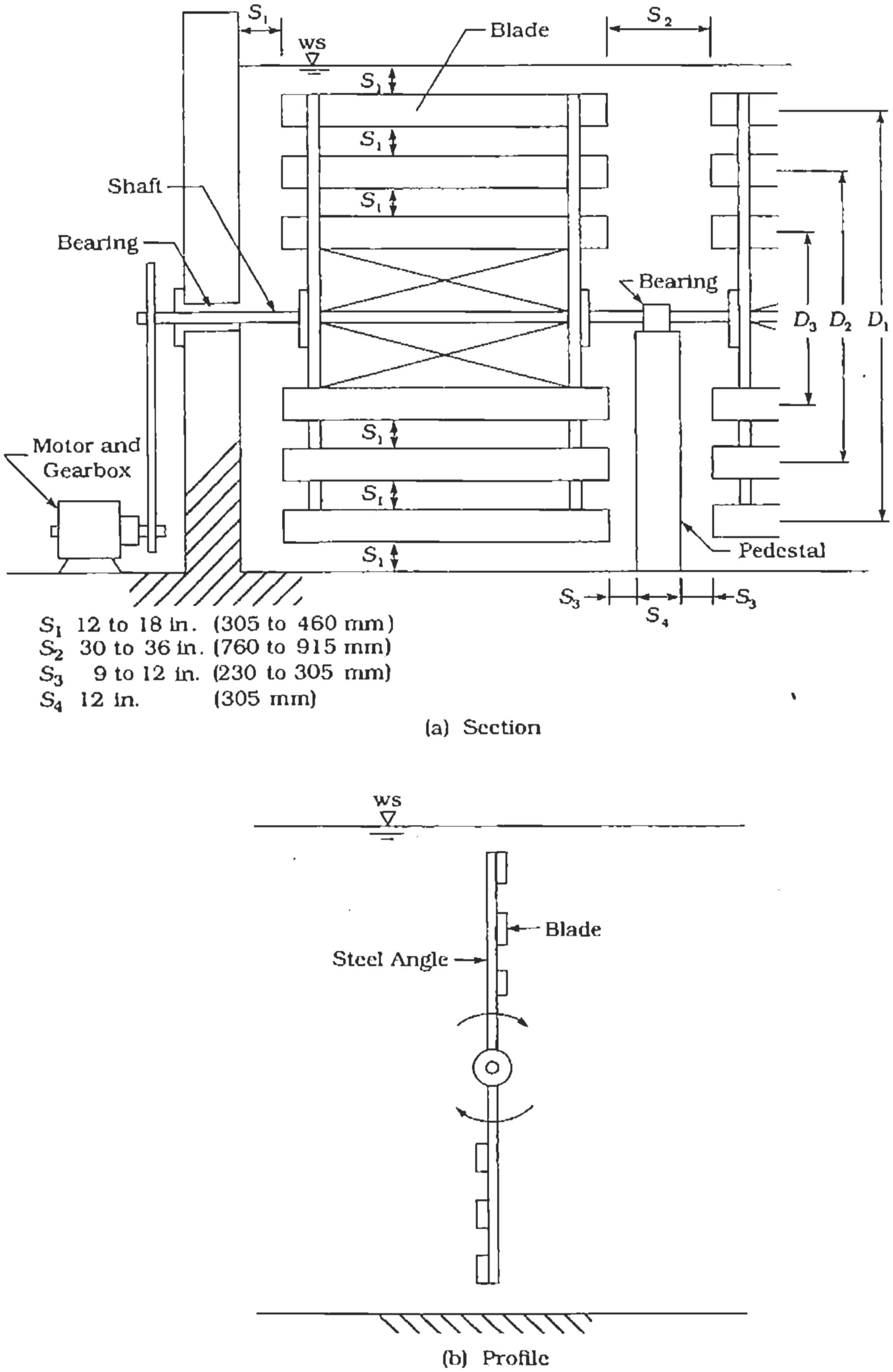


FIGURE 8.18 *Horizontal-Shaft Flocculation Paddle Wheels*

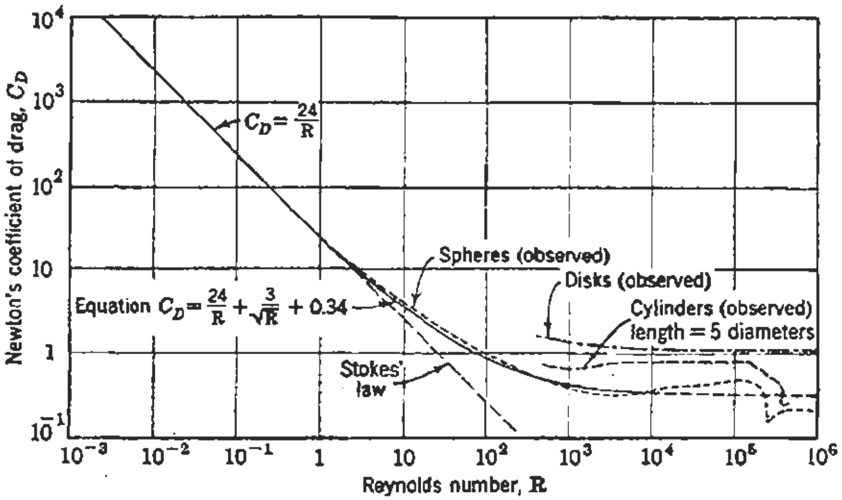


Fig. 25-1. Newton's coefficient of drag for varying magnitudes of Reynolds number. [Observed curves after T. R. Camp, *Trans. Am. Soc. Civil Engrs.*, *103*, 897 (1946).]

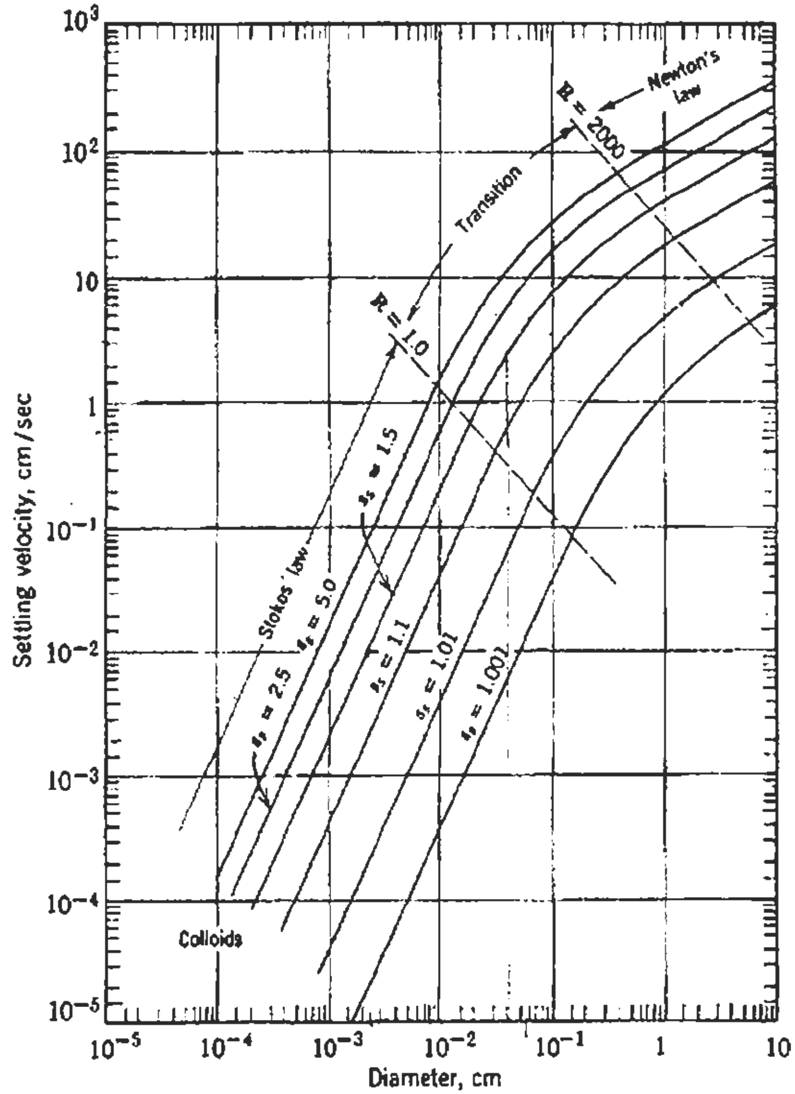


Fig. 25-2. Settling and rising velocities of discrete spherical particles in quiescent water at 10 C. For other temperatures, multiply the Stokes values by $\nu/(1.31 \times 10^{-2})$, where ν is the kinematic viscosity at the stated temperature.

Wastewater sep 13 ①

Flocculation units

- Promote particle growth
- Get heavy, settleable particles

Rate of flocculation $\left(r_f = \frac{4}{\pi} \alpha_0 \, \Omega \, G \, n \right)$ $\left[\frac{\text{Particle/time}}{\forall} \right]$ (First order)

α_0 = coefficient

Ω = vol. of particles per total vol. of suspension

G = velocity gradient $[s^{-1}]$

n = # of particles remaining un-flocculated

CFSTR: detention time, $\bar{t} = \frac{\pi}{4 \alpha_0 G \Omega} \left(\frac{n_0}{n} - 1 \right)$

n_0 = inital # of particles

$$\frac{n}{n_0} = \frac{1}{1 + \frac{4 \alpha_0}{\pi} G \bar{t} \Omega}$$, fraction remaining

Plug Flow $$\frac{n}{n_0} = e^{\left(-\frac{4 \alpha_0}{\pi} G \bar{t} \Omega \right)}$$

objective is to make $\frac{n}{n_0}$ as small as possible

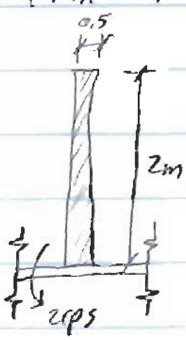
do so by

* G: use recommended values not to exceed # to break up floc
* $\bar{t}$: usually b/t 20-30 min, too large gets expensive
* Ω: best to use sludge blanket reactors to promote better particle contact

wastewater sep 13 ②

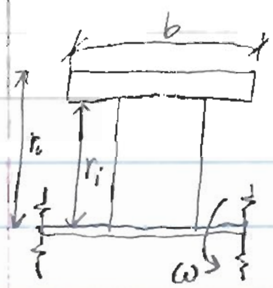
*see handout

Example Find P req'd to rotate blade; Assume $C_D = 1.8$, $\mu = 1.6\times10^{-3}\ \frac{kg}{m\cdot s}$, $k = 0.25$



Eq. 8.66 R&R $P = C_D A_p \rho \frac{v^3}{2}$

Express v in terms of r & rotational speed



$$\left.\begin{aligned} v &= (1-k)v_i \\ v_i &= 2\pi r\omega \qquad r = \frac{r_o+r_i}{2} \end{aligned}\right\} \quad v = (1-k)(2\pi\omega)\left(\frac{r_o+r_i}{2}\right)$$

$$\therefore P = \frac{C_D}{2} A_p \rho (1-k)^3 (2\pi)^3 \omega^3 \frac{(r_o-r_i)^3}{2^3}$$

$$\rightarrow P = \frac{\pi^3}{2} C_D \rho (1-k)^3 \omega^3 b (r_o-r_i)(r_o+r_i)^3$$

$$P = 15.5\overset{C_D}{(1.8)}\overset{\rho}{\left(1000\tfrac{kg}{m^3}\right)}(1-\overset{k}{0.25})^3(\overset{\omega}{2^3})(\overset{b}{0.5})(\overset{r_o}{2}-\overset{r_i}{0})(\overset{r_o}{2}+\overset{r_i}{0})^3$$

$P = \underline{\underline{753\ kW}}$ (R&R equ.)

** Now using general equ. derived on handout

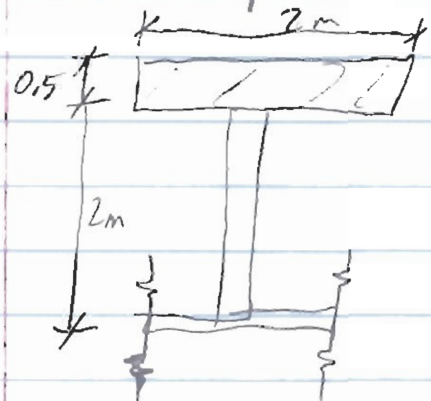
$$P = \pi^3 C_D \rho b (1-k)^3 \omega^3 (r_o^4 - r_i^4)$$

$$= 31(1.8)(1000)(0.5)(1-0.25)^3(2^3)(2^4-0)$$

$$= \underline{\underline{1507\ kW}}$$ (Twice As much) ☆☆

wrong b/c it take average vel.

wastewater sep. 13 3



eq. 8.16:

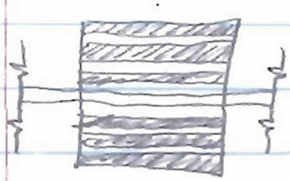
$$P = \frac{\pi^3}{2} C_D \rho b (1-k)^3 \omega^3 (r_o - r_i)(r_o + r_i)^3$$
$$= 15.5 (1.8)(1000)(2)(1-0.25)^3(2^3)(2.5-2.0)(2.5+2.0)^3$$

$P = \underline{\underline{8581\ kW}}$ Now this is more accurate

Difference $\approx 1.2\%$

General equ

$$P = \pi^3 C_D \rho b (1-k)^3 \omega^3 (r_o^4 - r_i^4) = \underline{8686\ kw}$$



$P_T = \Sigma P_i$

Practical Recommendations:

- Hydraulic detention time: 20-40 min
- Modern trend: $\bar{t}$ = 20 min based on Qmax day
- # of Arms: 2 Arms w/ 3 paddles/arm
- # of tanks in series ≥ 3
- velocity Gradient: use 75 s^{-1} in 1st tank, taper off to 10 s^{-1} in last tank
- Total blade area < 20% area of the plane of rotation of blades (Plane ∥ to shaft) to prevent rotation of water w/ the paddles
- Linear vel. @ tip of blades: b/t $\underline{0.15\ m/s}$ & $1.0\ m/s$
  - 0.15 m/s: best for last chamber
  - 1.0 m/s: could be in 1st chamber

W.W. Sep. 79 FILTER

Table 27-1 General Features of Construction and Operation of Conventional Slow and Rapid Sand Filters*

	Slow Sand Filters	Rapid Sand Filters
Rate of filtration	**1 to 3 to 10 mgad**	**100 to 125 to 300 mgad**†
Size of bed	**Large, ½ acre**	**Small, 1/100 to 1/10 acre**
Depth of bed	12 in. of **gravel**; 42 in. of sand, usually reduced to no less than 24 in. by scraping	18 in. of **gravel**; 30 in. of sand, or less; not reduced by washing
Size of sand‡	Effective size 0.25 to 0.3 to 0.35 mm; coefficient of nonuniformity 2 to 2.5 to 3	0.45 mm and higher; coefficient of nonuniformity 1.5 and lower, depending on underdrainage system
Grain size distribution of sand in filter	Unstratified	Stratified with smallest or lightest grains at top and coarsest or heaviest at bottom
Underdrainage system	Split tile laterals laid in coarse stone and discharging into tile or concrete main drains	(1) Perforated pipe laterals discharging into pipe mains; (2) porous plates above inlet box; (3) porous blocks with included channels
Loss of head	0.2 ft initial to 4 ft final	1 ft initial to 8 or 9 ft final
Length of run between cleanings	20 to 30 to 60 days	12 to 24 to 72 hr
Penetration of suspended matter	Superficial	Deep
Method of Cleaning	(1) Scraping off surface layer of sand and washing and storing cleaned sand for periodic resanding of bed; (2) washing surface sand in place by washer traveling over sand bed	Dislodging and removing suspended matter by upward flow or backwashing, which fluidizes the bed. Possible use of water or air jets, or mechanical rakes to improve scour
Amount of wash water used in cleaning sand	0.2 to 0.6% of water filtered	1 to 4 to 6% of water filtered
Preparatory treatment of water	Generally none	Coagulation, flocculation, and sedimentation
Supplementary treatment of water	Chlorination	Chlorination
Cost of construction, U.S.A.	Relatively high	Relatively low
Cost of operation	Relatively low where sand is cleaned in place	Relatively high
Depreciation cost	Relatively low	Relatively high

* The most common values are shown in boldface type.
† 125 mgad = 2 gpm per sq ft = 16 ft per hr = 125 m per day.

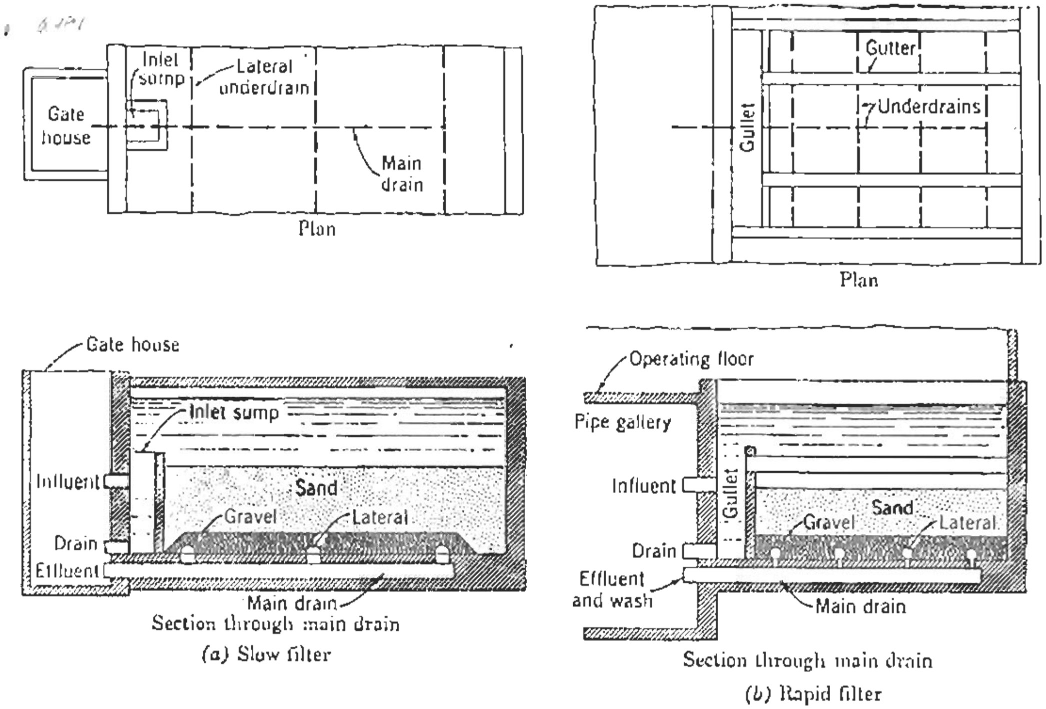


Fig. 27-1. Diagrammatic sections through and simplified plans of (a) a slow and (b) a rapid sand filter.

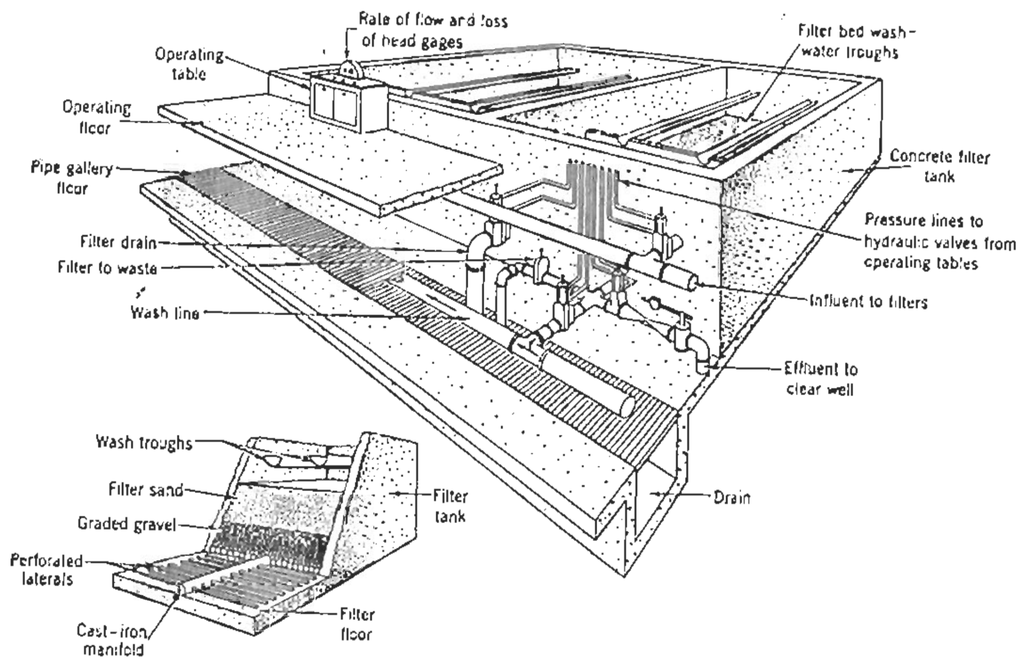


Fig. 27-15. Rapid filters and accessory equipment. (After C. P. Hoover, *Water Supply and Treatment*, National Lime Association.)

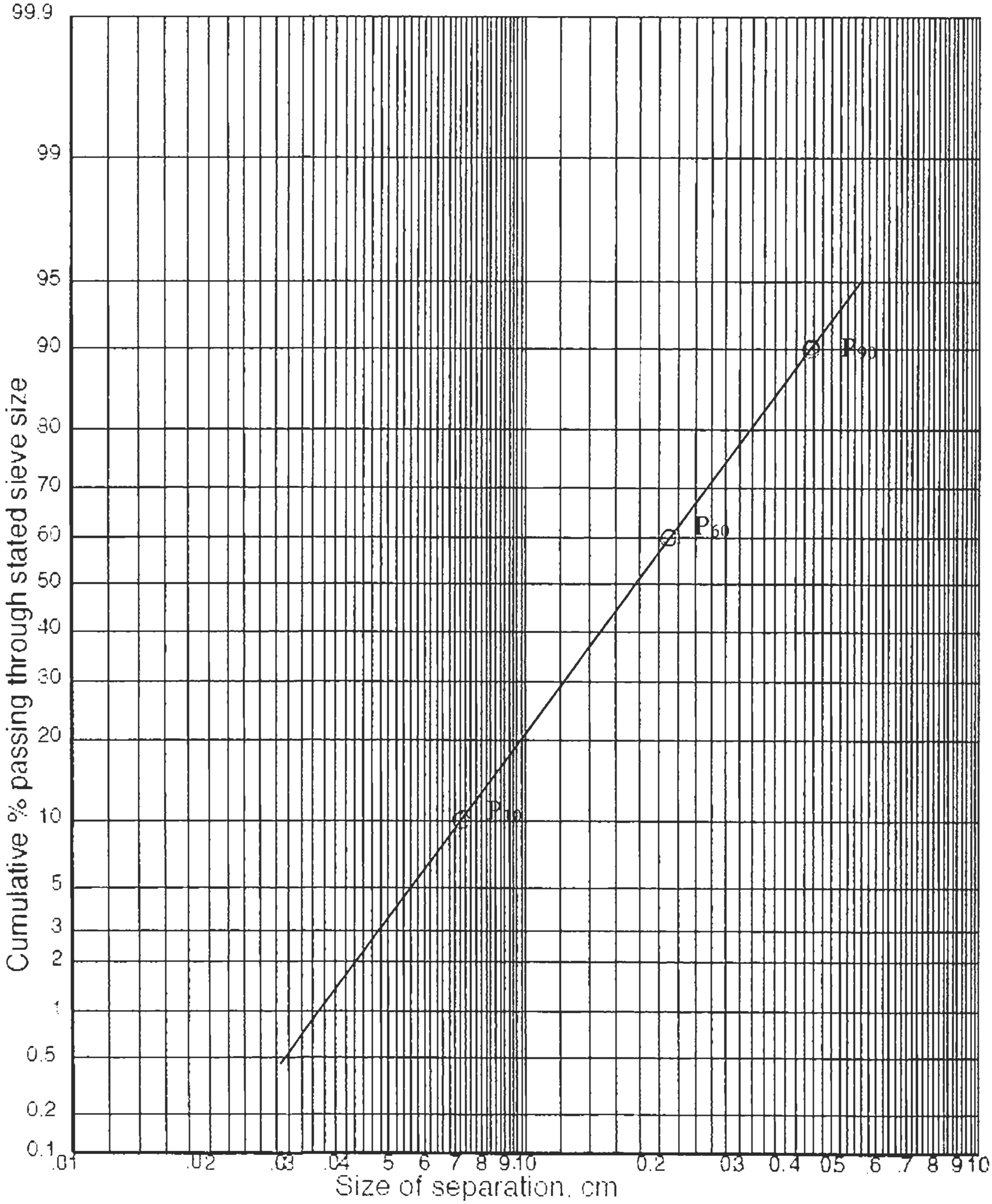
Properties of the log-normal particle size distribution

$$P_{90} = P_{10} UC^{1.67}$$

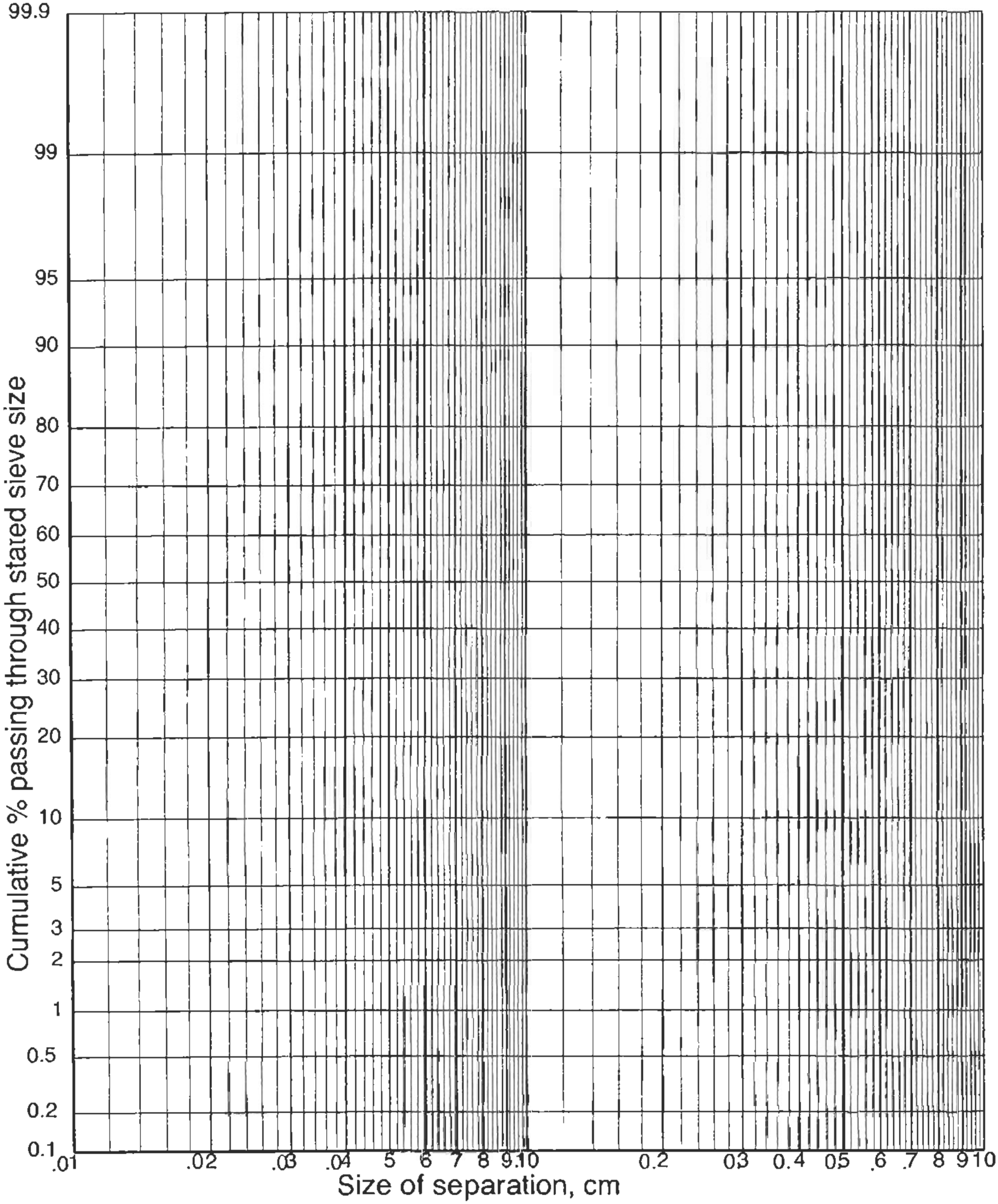
$$\text{Geometric standard deviation: } \sigma_G = \frac{P_{84.1}}{P_{50}} = \frac{P_{50}}{P_{15.9}} = \left(\frac{P_{90}}{P_{10}}\right)^{0.391}$$

$P_{10} = P_{50}\sigma_G^{-1.282}$, P_{50} = geometric mean

$$UC = \frac{P_{60}}{P_{10}} = \sigma_G^{1.535}$$



Log-normal particle size distribution



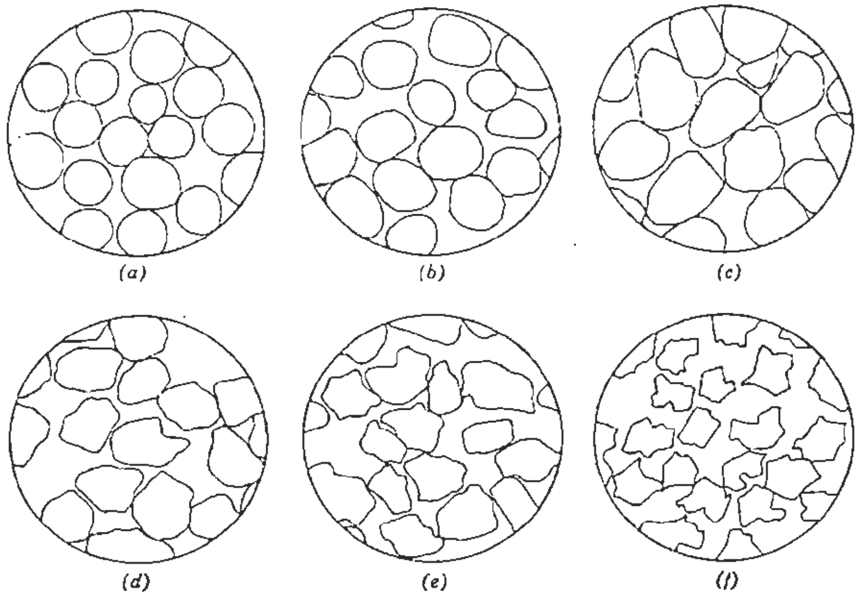


Fig. 27-4. Sphericity and shape factors of granular (not flakelike) materials and typical porosities associated with them in stratified rapid sand-filter beds.

Description	Sphericity, ψ	Shape Factor, S	Typical Porosity, f
(*a*) Spherical	1.00	6.0	0.38
(*b*) Rounded	0.98	6.1	0.38
(*c*) Worn	0.94	6.4	0.39
(*d*) Sharp	0.81	7.4	0.40
(*e*) Angular	0.78	7.7	0.43
(*f*) Crushed	0.70	8.5	0.48

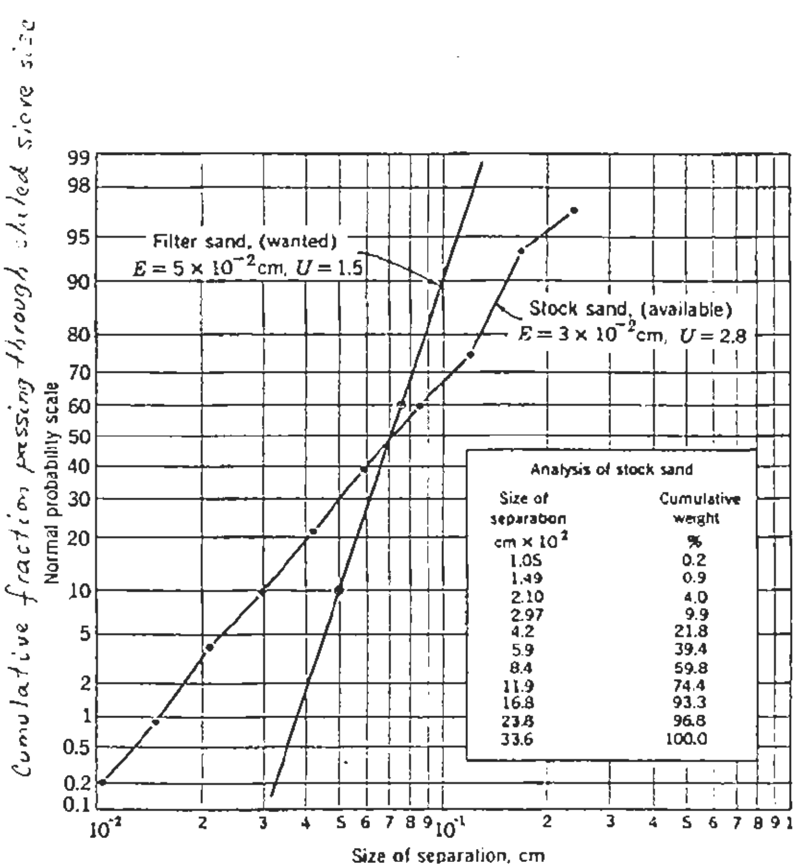
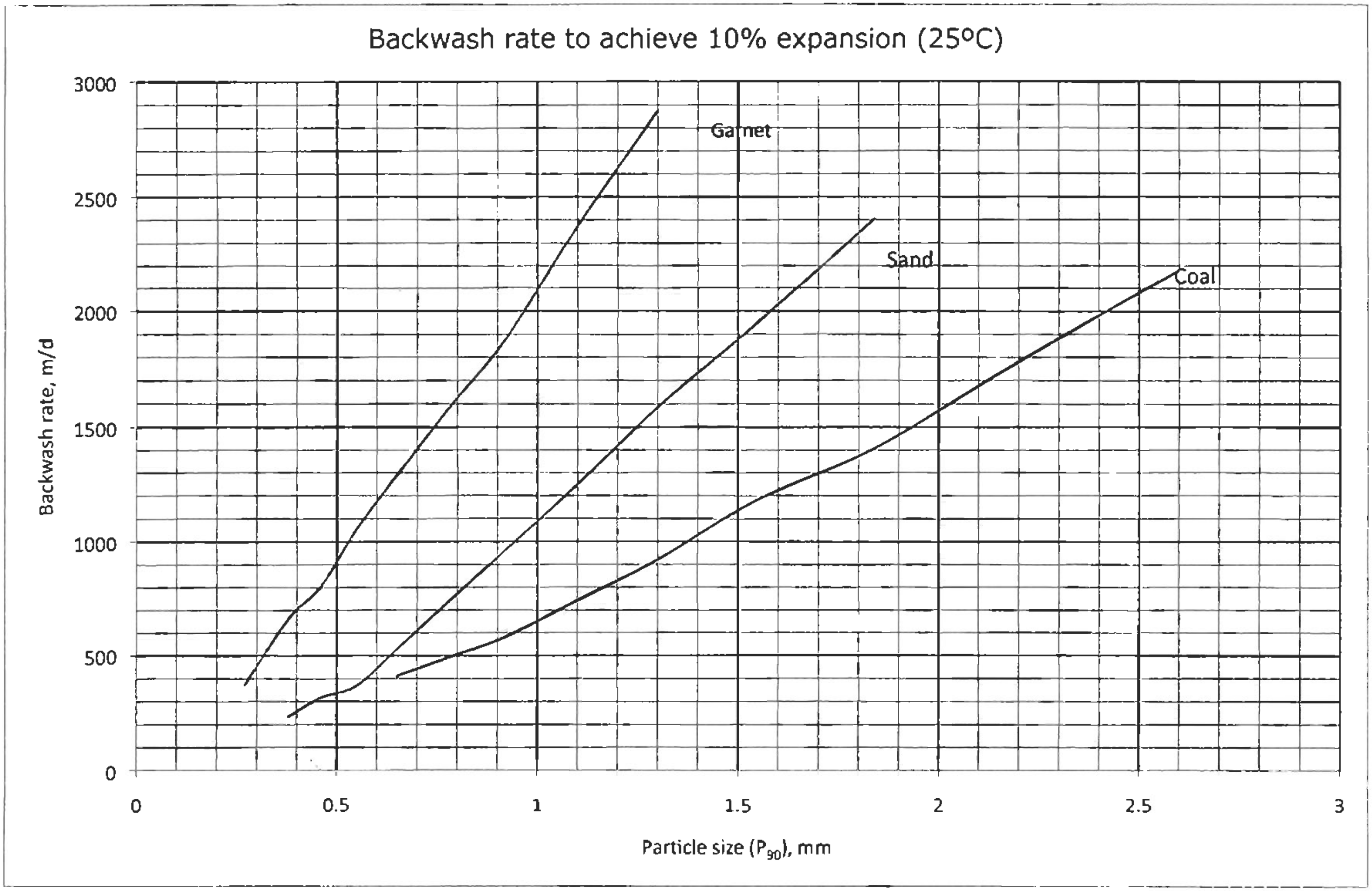


Fig. 27-3. Grain size distribution of a stock sand and required sizing of a filter sand.

Table 27-2 U.S. Sieve Series

Sieve Designation, Number*	Size of Opening, mm	Sieve Designation, Number	Size of Opening, mm
200	0.074	20	0.84
140	0.105	(18)	(1.00)
100	0.149	16	1.19
70	0.210	12	1.68
50	0.297	8	2.38
40	0.42	6	3.36
30	0.59	4	4.76

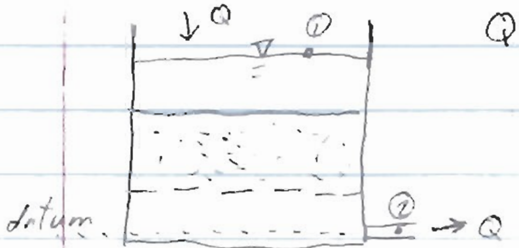
* Approximately the number of meshes per inch.


Backwash rate to achieve 10% expansion (25°C)
Backwash rate, m/d
3000
2500
2000
1500
1000
500
0
0
0.5
1
1.5
2
2.5
3
Particle size (P_{90}), mm
Garnet
Sand
Coal

W.W. Oct 11 ①

Filter Operation

will increase w/ time b/c pore get cloged



$$Q = A\sqrt{2g\left(z_1 - \frac{p_2}{\gamma} - h_{L_{1-2}}\right)} = \text{const.}$$

(1) Keep $\frac{p_2}{\gamma}$ cost. ∴ z_1 must increase w/time to keep Q const.

operator will have a max z_1 to indicate when to backwash.

(2) keep z_1 cost. ∴ $\frac{p_2}{\gamma}$ must decrease w/ time

* it is possible for $\frac{p_2}{\gamma}$ to become neg & cause air binding,

2 methods of filter operation

(1) Const. rate of filtration

achieved by: Mechanical rate control or Influent flow splitting

(2) Declining rate of filtration

See Oct 14 handout

ANTHRACITE

Sieve No.	Size, mm	Cumulative % passing sieve	pi	Geometric mean, di, cm	p/d_i^2	
7	2.8	100				
			0.001	0.257	0.015	= 0.001/0.257²
8	2.36	99.9				
			0.012	0.217	0.254	
9	2	98.7				
			0.067	0.184	1.971	
10	1.7	92				
			0.24	0.154	10.084	
12	1.4	68				
			0.35	0.129	21.186	
14	1.18	33				
			0.23	0.109	19.492	
16	1	10				
			0.082	0.092	9.647	= 0.082/0.092²
20	0.85	1.8				
			0.018	0.000		
pan	0	0				
				Σ=	62.649	

SAND

Sieve No.	Size, mm	Cumulative % passing sieve	pi	Geometric mean, di, cm	p/d_i^2
14	1.18	99.8			
			0.02	0.109	1.695
16	1	97.8			
			0.108	0.092	12.706
20	0.85	87			
			0.29	0.078	48.053
24	0.71	58			
			0.34	0.065	79.812
28	0.6	24			
			0.19	0.055	63.333
32	0.5	5			
			0.044	0.046	20.706
35	0.425	0.6			
			0.0058	0.039	3.844
42	0.355	0.02			
			0.0002	0.000	
pan	0	0			
				Σ=	230.149

Anthracite head loss:

$$\frac{h_0}{L}=\frac{180}{981\frac{cm}{s^2}}\times 0.01003\frac{cm^2}{s}\times v\frac{cm}{\min}\times\frac{1\min}{60s}\times\frac{(1-0.56)^2}{0.56^2}\times\frac{1}{0.52^2}\times 62.649\frac{1}{cm^2}$$

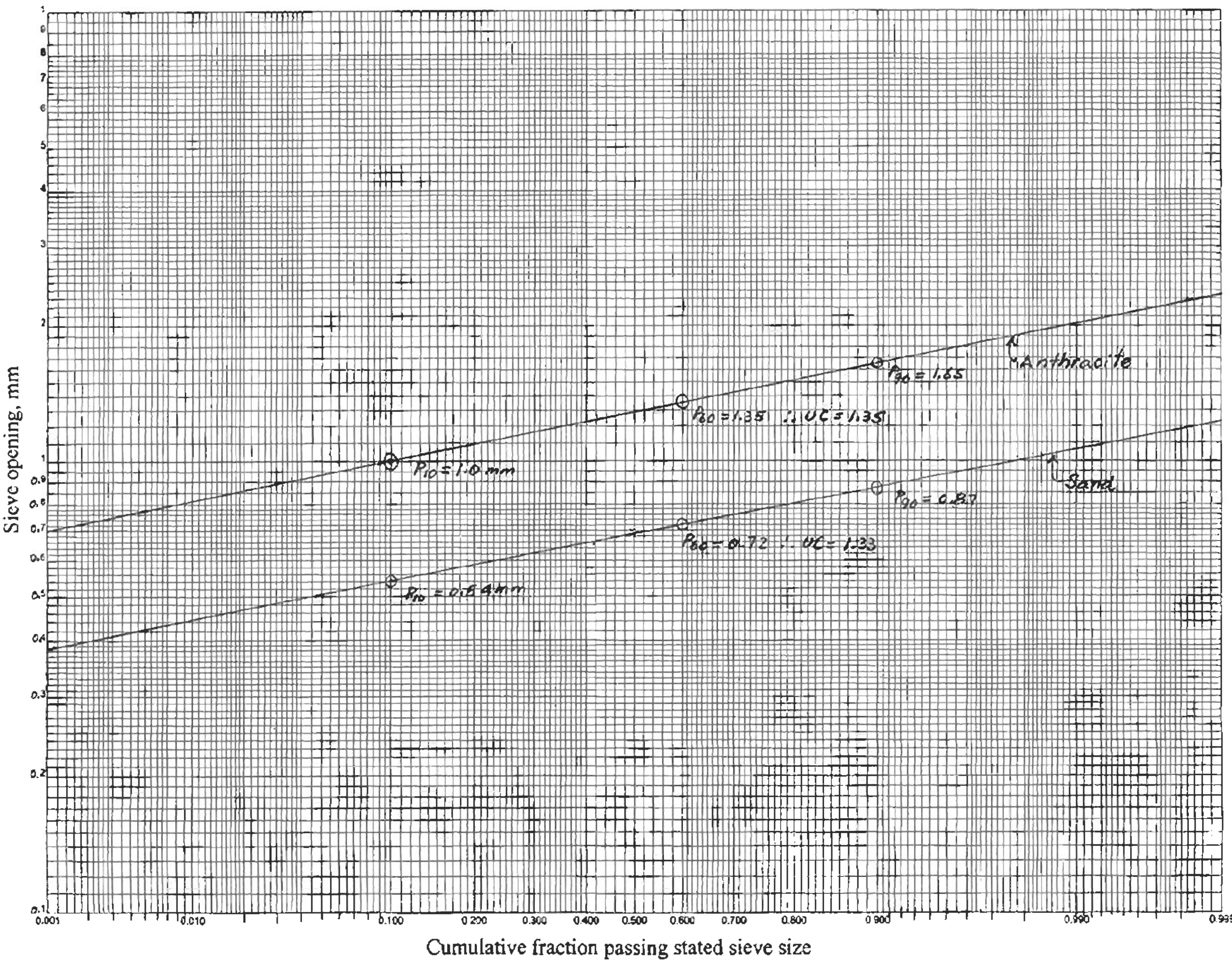
$$\frac{h_0}{L}=0.0079v;\quad h_0=0.0079\times 0.45\times v;\quad h_0=0.003525v$$

Sand head loss:

$$\frac{h_0}{L}=\frac{180}{981\frac{cm}{s^2}}\times 0.01003\frac{cm^2}{s}\times v\frac{cm}{\min}\times\frac{1\min}{60s}\times\frac{(1-0.42)^2}{0.42^2}\times\frac{1}{0.75^2}\times 230.149\frac{1}{cm^2}$$

$$\frac{h_0}{L}=0.057v;\quad h_0=0.057\times 0.30\times v;\quad h_0=0.0171v$$

Total Laminar Head Loss = 0.003525v + 0.0171v; h_0 = 0.02063v, (v = cm/min)


Sieve opening, mm
Cumulative fraction passing stated sieve size
Anthracite
Sand
$P_{10} = 1.0$ mm
$P_{60} = 1.35$ ∴ UC = 1.35
$P_{90} = 1.65$
$P_{10} = 0.54$ mm
$P_{60} = 0.72$ ∴ UC = 1.33
$P_{90} = 0.87$

W.W. Oct '11

27-18 Filter Gravel

Perforated pipe grids are only one part of an underdrainage system. The other part comprises the stone and gravel that surround the grid and support the sand bed. This system of collecting and distributing waterways is seldom less than 10 or more than 24 in. thick. For particles sized by screening, the depth, l, in inches, of a component gravel layer of size d in., where $d > 3/64$ in., may be estimated with much success from the following equation:

$$l = k(\log d + 1.40). \qquad (27\text{-}28)$$

Here k varies numerically from 10 to 14.[18] Stones as large as 3 in., but generally no larger than 2 in., are placed near the pipes. To keep the

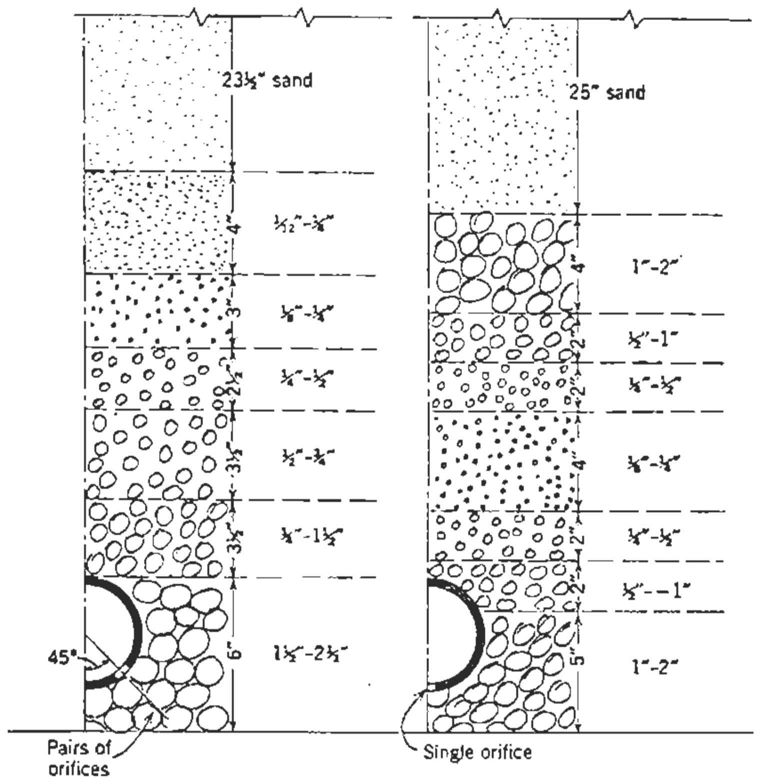


Fig. 27-9. (*a*) Asymmetrical and (*b*) symmetrical sequences of gravel below a sand bed.

[18] J. R. Baylis, Filter Bed Troubles and Their Elimination, *J. New England Water Works Assoc.*, **51**, 17 (1937).

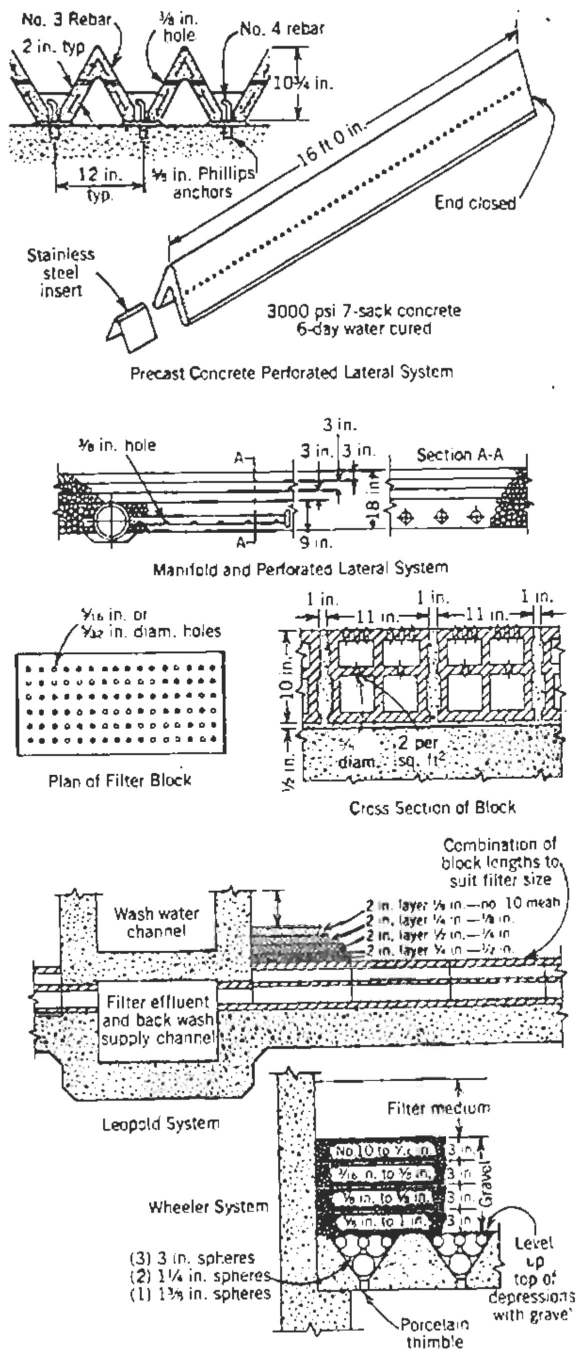
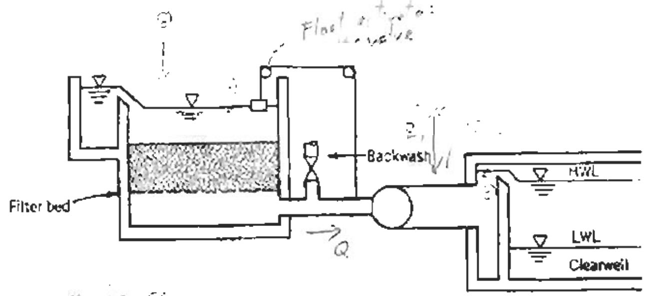


FIGURE 21-37. Filter underdrain systems.



Constant Level Filtration
(Influent control, level sensor & modulating valve)

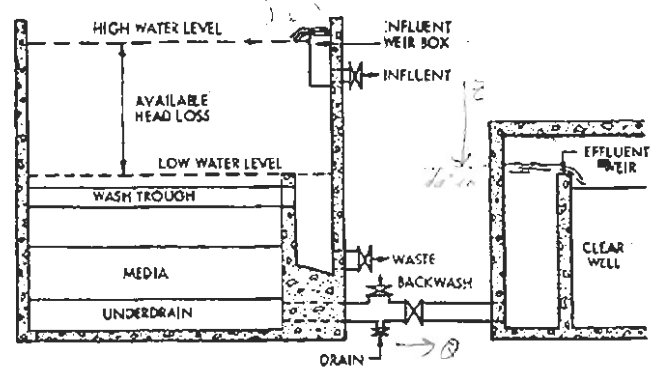
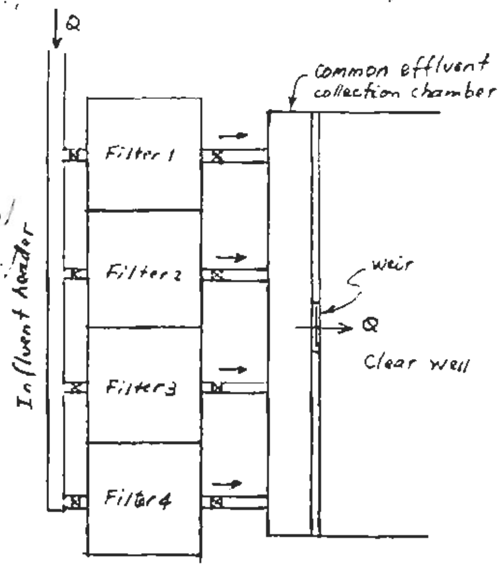


Figure 4-3 Gravity filter arrangement for rate control by influent flow splitting.



Plan view of 4 declining rate filters

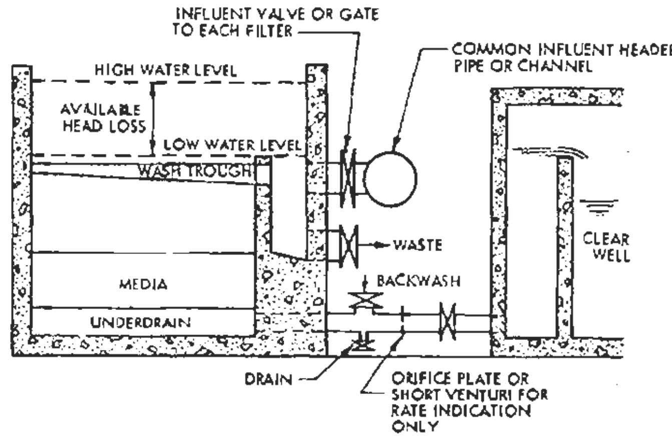


Figure 4-4 Gravity filter arranged for variable declining rate of filtration.

ENCE 4323

HEAD LOSS THROUGH CLEAN FILTERS

Flow through filtering media (sand, anthracite, gravel) is laminar.

- Poiseulle's equation for laminar flow in circular conduits (head loss is proportional to velocity):

$$h_0 = k \frac{\mu}{\rho} \frac{L}{D^2} \frac{v_i}{g}$$

where:

h_0	=	head loss
k	=	constant
μ	=	water absolute viscosity
ρ	=	water density
L	=	conduit length
D	=	conduit diameter
v_i	=	velocity
g	=	gravity constant

- Consider that water flowing through a filter is flowing through many conduits with irregular cross section.
- Substitute D = 4R (R = hydraulic radius) in Poiseulle's equation:

$$h_0 = \frac{k}{16} \frac{\mu}{\rho} \frac{L}{R^2} \frac{v_i}{g}$$

v_i = interstitial velocity
L = bed depth.

- By definition,

$$\text{R} = \frac{\text{Cross sectional area}}{\text{Wetted perimeter}} \times \frac{\text{Conduit length}}{\text{Conduit length}}$$

$$\text{R} = \frac{\text{Total pore volume}}{\text{Sand external surface area}}$$

Pore Volume = (bed porosity) x (total volume).

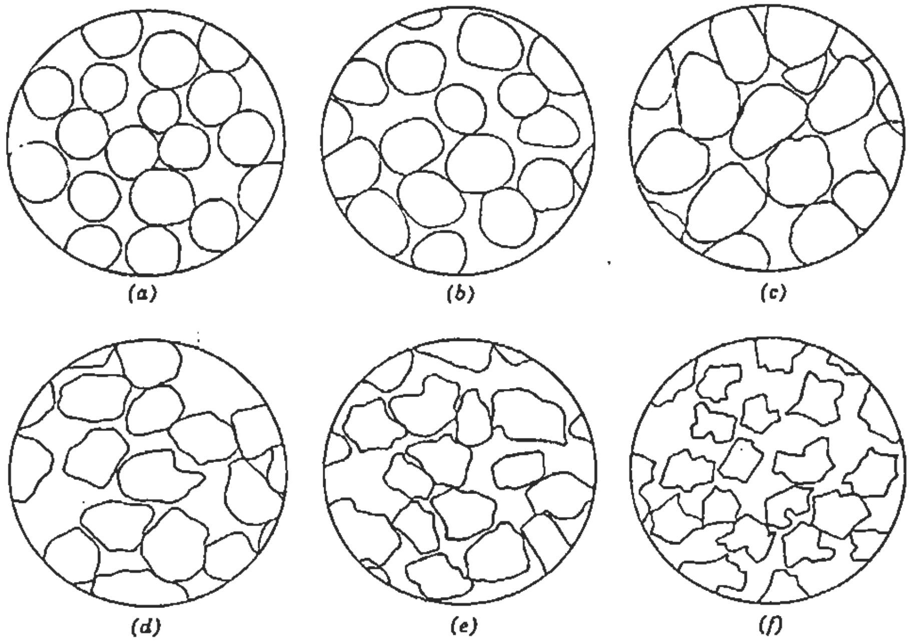


Fig. 27-4. Sphericity and shape factors of granular (not flakelike) materials and typical porosities associated with them in stratified rapid sand-filter beds.

Description	Sphericity, ψ	Shape Factor, S	Typical Porosity, f ε
(a) Spherical	1.00	6.0	0.38
(b) Rounded	0.98	6.1	0.38
(c) Worn	0.94	6.4	0.39
(d) Sharp	0.81	7.4	0.40
(e) Angular	0.78	7.7	0.43
(f) Crushed	0.70	8.5	0.48

$\psi = \frac{\text{diameter of equivalent-volume sphere}}{\text{sand particle diameter}}$

$S = \frac{6}{\psi}$

- Substitute hydraulic radius and interstitial velocity in Poiseulle's equation:

$$h_0 = \frac{k}{16}\frac{\mu}{\rho}\frac{L}{g}\frac{\frac{v}{\varepsilon}}{\left(\frac{\varepsilon}{1-\varepsilon}\psi\frac{d}{6}\right)^2}$$

$$\frac{h_0}{L} = \frac{K}{g}\frac{\mu}{\rho}v\frac{(1-\varepsilon)^2}{\varepsilon^3}\left(\frac{6}{\psi}\right)^2\left(\frac{1}{d}\right)^2 ; \; K \cong 5.0$$

$$\boxed{\frac{h_0}{L} = \frac{180}{g}\frac{\mu}{\rho}v\frac{(1-\varepsilon)^2}{\varepsilon^3}\left(\frac{1}{\psi}\right)^2\left(\frac{1}{d}\right)^2}$$

Fair and Hatch equation **for uniform-size**, clean sand beds.

FAIR AND HATCH'S APPROACH FOR STRATIFIED BEDS

- Bed is composed of n layers of thickness L_i, such that $\Sigma L_i = L$.
- Assume $L_i = p_i L$, where p_i is the fraction by weight of particles with size d_i,
- $d_i = (d_{i-1} \times d_{i+1})^{1/2}$. geometric mean particle dia.
- Apply Fair and Hatch's equation to layer i:

$$h_i = \frac{180}{g}\frac{\mu}{\rho} v \frac{(1-\varepsilon)^2}{\varepsilon^3} L_i \frac{1}{\psi^2 d_i^2}$$

But, since $h_0 = \sum_{i=1}^{n} h_i$, we can write

$$h_0 = \frac{180}{g}\frac{\mu}{\rho} v \frac{(1-\varepsilon)^2}{\varepsilon^3}\left(\frac{1}{\psi}\right)^2 \sum_{i=1}^{n}\frac{L_i}{d_i^2}$$

$$h_0 = \frac{180}{g}\frac{\mu}{\rho} v \frac{(1-\varepsilon)^2}{\varepsilon^3}\left(\frac{1}{\psi}\right)^2 \sum_{i=1}^{n}\frac{p_i L}{d_i^2}$$

$$\boxed{\frac{h_0}{L} = \frac{180}{g}\frac{\mu}{\rho} v \frac{(1-\varepsilon)^2}{\varepsilon^3}\left(\frac{1}{\psi}\right)^2 \sum_{i=1}^{n}\frac{p_i}{d_i^2}}$$

- Notice that $\frac{h_0}{L} = (\text{constant})(v)$, which is Darcy's law for flow in porous media. Darcy's law is usually written as $v = P\frac{h_0}{L}$, where P is the permeability coefficient.

Example: Filter media (30 cm sand $P_{10} = 0.54$ mm UC = 1.3? ε = 0.4? $\psi = 0.75$
(45 cm Anthracite P_{10}: 1 mm UC 1.35 ε - 0.56 ψ - 0.57)

Find clean media head loss:

$$h_0 = \frac{180}{g} L \frac{\mu}{\rho} \frac{(1-\varepsilon)^2}{\varepsilon^3}\left(\frac{1}{\psi}\right)^2\left(\sum \frac{p_i}{d_i^2}\right)(v)$$

Assume log normal particle size distribution

$P_{90,\,sand} = P_{10,\,sand}(UC)_{sand}^{1.67} = 0.87$ mm; $P_{90,\,Anthra.} = 1.65$ mm

See Hand out (Graph & chart)

W.W. Oct. 20 ①

see handout

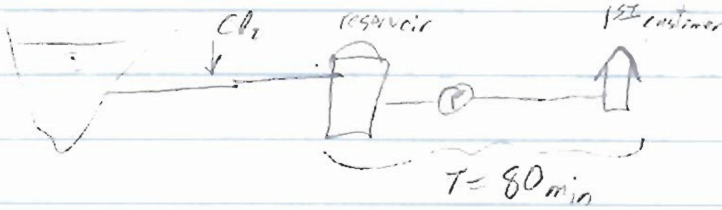
SWTR requires 99.9% removal of Giardia & 99.99% removal of viruses.

Plants w/out filtration must satisfy CT criteria presented in Table D (check B.B.)

see handout ②

Example (non. filtration plant)

SWTR surface water treatment rule



water temp = 15°C, pH = 7.5, Free residual Cl @ 1st cust = 1.4 mg/l

Find if disinfection req. are being met.

Table D-4 (ph = 7.5, Cl_2 = 1.4 mg/l)

→ Min. $CT_{99.9}$ = 94 (required)

Actual CT = 80 min (1.4 mg/l) = 112 (OKAY)

Assume we have microorganism removal @ 2 locations

$$N_0 \rightarrow \overset{Cl_2}{(C_1T_1)} \xrightarrow{N_1} \overset{Cl_2}{(C_2T_2)} \rightarrow N_2$$

# of Giardia

STWR req 3-log removal of Giardia $\left(\frac{N_2}{N_0}\right) = 10^{-3}$ (99.9% removal

$\log \frac{N_0}{N_2} = 3$ (3 log removal)

Overall sys must provide $CT_{99.9}$ specified in Tables D

Assumption in SWTR : $$\frac{\log\left(\frac{N_0}{N_1}\right)}{\log\left(\frac{N_0}{N_2}\right)} = \frac{C_1T_1}{CT_{99.9}}$$

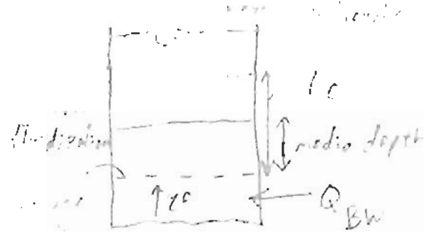
and $$\frac{\log\left(\frac{N_1}{N_2}\right)}{\log\left(\frac{N_0}{N_2}\right)} = \frac{C_2T_2}{CT_{99.9}}$$ ← specified in tables D

A conventional filtration plant removes 2.5-log of Giardia
other filtration types (direct, slow, diatomaceous earth)
remove 2-log removal

N_0 Giardia → [conventional plant] $\xrightarrow{N_1}$ (C_2T_2, Cl_2) → N_2

$$\log\frac{N_0}{N_2} = 3 \quad \text{(for Giardia)}$$
$$\log\frac{N_0}{N_1} = 2.5 \quad \text{(conventional filtration plant)}$$
$$\therefore \log\frac{N_1}{N_2} = \text{must be difference} = 0.5$$

$$\rightarrow C_2T_2 = \left(\frac{0.5}{3}\right) CT_{99.9} = 0.167\ CT_{99.9}$$



ENCE 4323

PREDICTING BED EXPANSION DURING FILTER BACKWASH

Call:

L	=	Thickness of unexpanded filter media during filtration
L_e	=	Thickness of expanded filter media during backwashing
e	=	Bed expansion
ε	=	Porosity of the unexpanded filter media during normal filter operation
ε_e	=	Porosity of the expanded media during backwashing
V_s	=	Volume of solid particles in the filter
V_T	=	Total volume of the filter
A	=	Filter top surface area
v	=	Backwash rate
v_s	=	Settling velocity of single particles
n	=	Exponent in Richardson and Zaki equation ($n = 4.5 - 5$)

Define bed expansion by: $e = (L_e - L)/L$ ......(1)

Bed porosity is given by: $\varepsilon = (V_T - V_s)/V_T$ ......(2)

From (2) the total volume is given by: $V_T = V_s/(1-\varepsilon)$ ......(3)

Since $V_T = A\,L$, $A\,L = V_s/(1-\varepsilon)$ ......(4)

Similarly, the total volume of the expanded bed during backwashing can be expressed as follows:

$$A\,L_e = V_s/(1-\varepsilon_e) \quad \text{......(5)}$$

Combining equations (4) and (5) we get:

$$\frac{L_e}{L} = \frac{1-\varepsilon}{1-\varepsilon_e} \quad \text{......(6)}$$

The porosity of the expanded bed, ε_e, can be estimated by Richardson and Zaki equation:

$$\varepsilon_e = \left(\frac{v}{v_s}\right)^{\frac{1}{n}} \quad \text{......(7)}$$

$(0.75L + P) < H_o < (L + P)$

$1.5H_o < S < 2H_o$

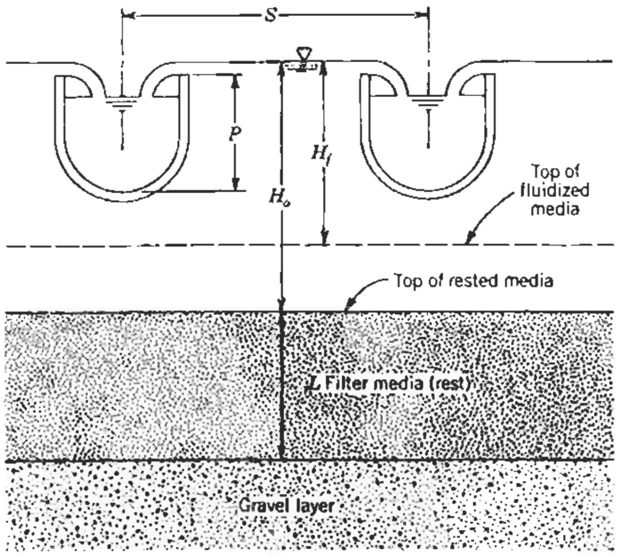


FIGURE 21-35. Height and spacing of wash troughs.

higher upflow velocity when flow gets above the trough bottom elevation and the U-shaped troughs allow for thinner walls because of a higher moment of inertia and greater structural integrity. The bottom of the wash trough should not be flat because froth and suspended matter is often trapped under the trough bottom and may never be washed out.

In either case, the troughs should be large enough to carry the maximum expected wash rate with 5–10 cm free-fall into the trough at the upper end. They should also provide a free-fall to the main collection outlet gullet at the lower end. The bottom of the trough may be either horizontal or sloping.

The required cross-sectional area of the wash trough for a given design flow can be quickly estimated from Figure 21-36. For troughs that have level inverts and rectangular cross section, required trough height can be computed by the following formula:

$$\text{Minimum trough height} = \left(\frac{Q}{1.4B}\right)^{2/3} + \text{free board}$$

where Q is the total flow rate of discharge (m^3/sec), B is the inside width of the trough (m), and, freeboard should be a minimum of 50 mm (2 in.).

Filter Underdrains

Filter underdrainage systems differ primarily due to the different filter-washing systems and filter types

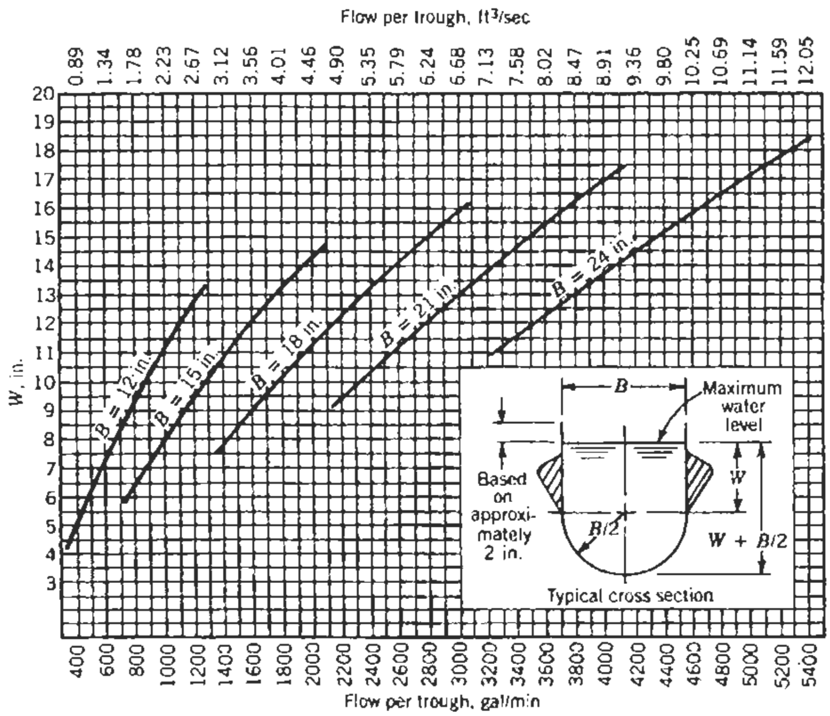


FIGURE 21-36. Wash-through sizing diagram. (Courtesy of Leopold Co.)

h_0

y_c (critical depth)

outlet

$h_0 = \ldots$

$h_0^{3/2}$

$\sqrt{h^2 + \frac{2q^2 \ldots}{g b^2 h}}$

$q = \frac{Q_{outlet}}{b}$

(Taken from "Surface Water Treatment: The New Rules,"
by Harry von Huben, American Water Works Association, 1991)

CT Tables for Various Disinfectants

CT VALUES ($CT_{99.9}$) FOR 99.9 PERCENT INACTIVATION OF *GIARDIA* CYSTS BY FREE CHLORINE

NOTE: These *CT* values achieve greater than a 99.99 percent inactivation of viruses. *CT* values between the indicated pH values may be determined by linear interpolation. *CT* values between the indicated temperatures of different tables may be determined by linear interpolation. If no interpolation is used, use the $CT_{99.9}$ value at the lower temperature and at the higher pH.

Table D-1 Water Temperature 0.5°C (32°F) or Lower

Free Residual, *mg/L*	pH						
	<6.0	6.5	7.0	7.5	8.0	8.5	<9.0
<0.4	137	163	195	237	277	329	390
0.6	141	168	200	239	288	342	407
0.8	145	172	205	246	295	354	422
1.0	148	176	210	253	304	365	437
1.2	152	180	215	259	313	376	451
1.4	165	184	221	268	321	387	464
1.6	157	189	225	273	329	397	477
1.8	162	193	231	279	338	407	489
2.0	165	197	236	286	346	417	500
2.2	169	201	242	297	353	425	511
2.4	172	205	247	298	361	435	522
2.6	175	209	252	304	368	444	633
2.8	178	213	257	310	375	452	643
3.0	181	217	261	316	382	460	552

Source: Federal Register, *June 29, 1989*

Table D-2 Water Temperature 5.0°C (41°F)

Free Residual, *mg/L*	pH						
	≤6.0	6.5	7.0	7.5	8.0	8.5	≤9.0
≤0.4	97	117	139	168	198	206	279
0.6	100	120	143	171	204	244	291
0.8	103	122	146	175	210	252	301
1.0	105	125	149	179	216	260	312
1.2	107	127	152	183	221	267	320
1.4	109	130	165	187	227	274	329
1.6	111	132	158	192	232	281	337
1.8	114	135	162	196	238	287	345
2.0	115	138	165	200	243	294	353
2.2	118	140	169	204	248	300	361
2.4	120	143	172	209	253	306	363
2.6	122	148	175	213	258	312	376
2.8	124	148	178	217	263	318	382
3.0	126	151	182	221	265	324	389

Source: Federal Register, *June 29, 1989.*

Table D-3 Water Temperature 10.0°C (50°F)

Free Residual, *mg/L*	pH						
	≤6.0	6.5	7.0	7.5	8.0	8.5	≤9.0
≤0.4	73	88	104	125	149	177	209
0.6	75	90	107	128	153	183	218
0.8	78	92	110	131	158	189	226
1.0	79	94	112	134	162	195	234
1.2	80	95	114	137	168	200	240
1.4	82	98	116	140	170	206	247
1.6	83	99	119	144	174	211	253
1.8	88	101	122	147	179	215	259
2.0	87	104	124	150	182	221	265
2.2	89	105	127	153	186	225	271
2.4	90	107	129	157	190	230	276
2.6	92	110	131	160	194	234	281
2.8	93	111	134	163	197	239	287
3.0	95	113	137	166	201	243	292

Source: Federal Register, *June 29, 1989.*

Table D-4 Water Temperature 15.0°C (59°F)

Free Residual, *mg/L*	pH						
	≤6.0	6.5	7.0	7.5	8.0	8.5	≤9.0
≤0.4	49	59	70	83	99	118	140
0.6	50	60	72	86	102	122	146
0.8	52	61	73	68	105	126	151
1.0	53	63	75	90	108	130	156
1.2	54	64	76	92	111	134	160
1.4	55	65	78	94	114	137	165
1.6	58	66	79	96	116	141	169
1.8	57	68	81	98	119	144	173
2.0	58	69	83	100	122	147	177
2.2	59	70	85	102	124	150	181
2.4	60	72	86	105	127	153	184
2.6	61	73	88	107	129	156	188
2.8	62	74	89	109	132	159	191
3.0	63	76	91	111	134	162	195

Source: Federal Register, *June 29, 1989.*

more table → B.B.

($1\% \cong 10000\ mg/l$)

So large, multi day rain event creates 4x flow. Such that pumps may need to Bypass raw sewage to canals!!!

W.W. Oct. 24 ①

Wastewater Treatment

wastewater : water-carried wastes removed from residences, institutions, commercial, & industrial establishments

PLUS Groundwater infiltration, surface water, & illegal stormwater discharges

sewage : municipal waste water, flows through sanitary sewer system

sewerage : system comprising of sanitary sewer sys & wastewater treatment plant

W.W. contains ~ 800 mg/l of total solids ~ 0.08% solids

∴ 99.92% is water

560 mg/l "dissolved" solids (actually, filterable solids that pass through 2-μm filter

The filter let colloidal particles flow through

240 mg/l are suspended : retain in filter

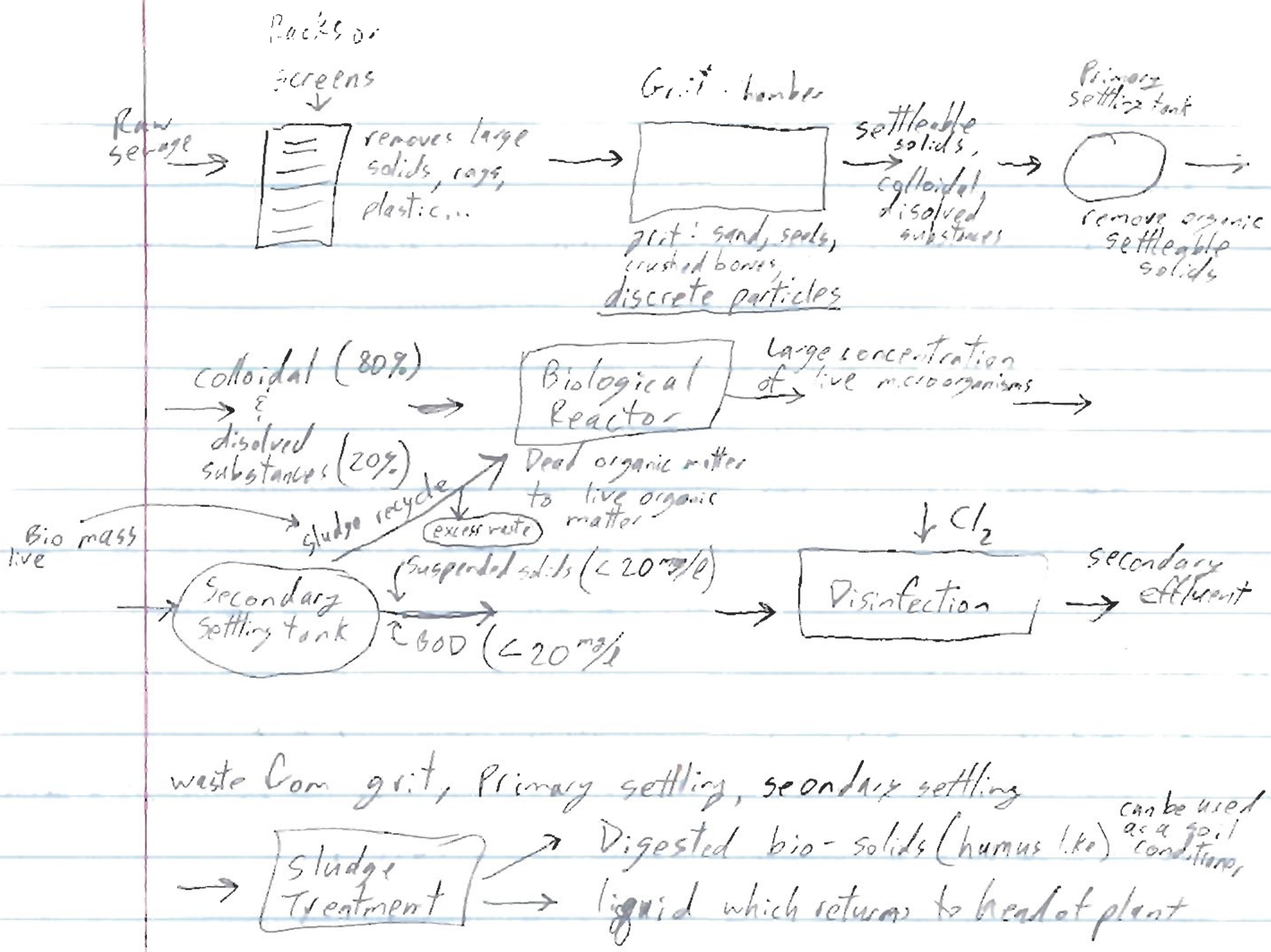
Volitile : 265 volatile Disolved
$\underline{165}$ " suspended
430 mg/l ← organic

organic matter : * protein : 40 → 60 %
* carbohydrates : 25-50%
} biodegradable ∴ consume O_2 in a stream
* oil & Fat : 10%

w.w. treatment objective : Secondary Treatment { * Removal of settleble & Floatable solids, oxygen demanding substances & pathogens

Tertiary treatment { * removal of Nitrogen & phosphorus

* Advanced treatment - removal of additional substances



Screens

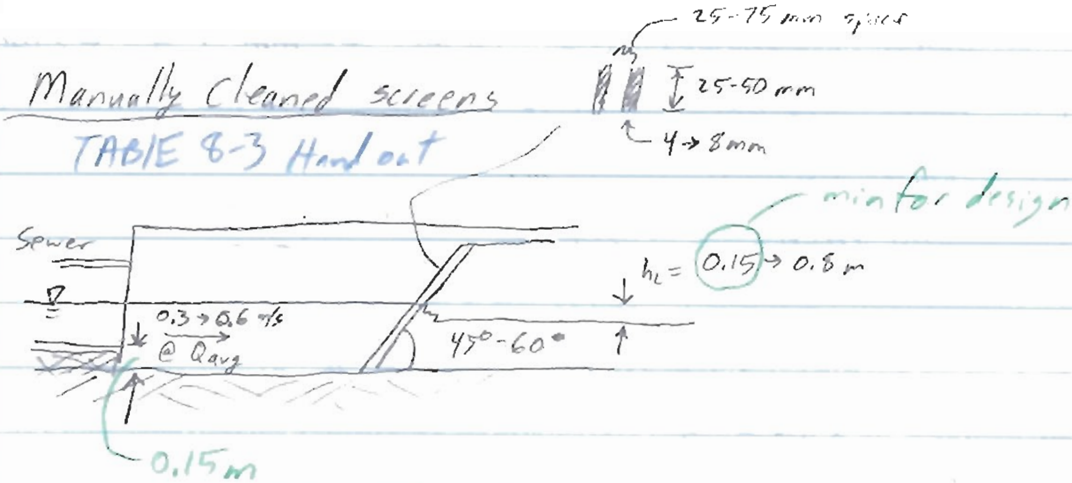
see Table 4-1 of handout

* remove large solids, protects pipes, valves, ...
* Protection of pumping equipment (becoming less important)
* can be manually or mechanically cleaned
* Comminutors (grinders)

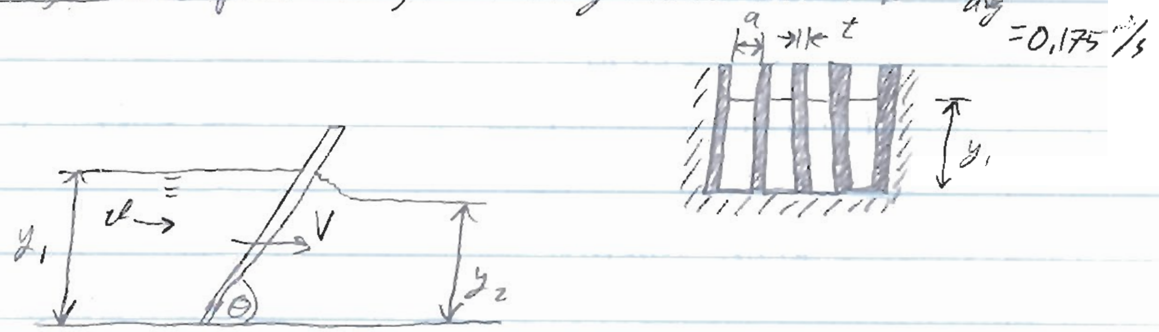
W.W. Oct 25 ②

Manually Cleaned screens

TABLE 8-3 Handout



Design example: design a manually cleaned screen for $Q_{avg} = 175\ L/s = 0.175\ m^3/s$



select $\theta = 45°$

$$\text{Total area} = [(n+1)a + nt]\,y_1$$

# of bars

$$\text{Net area} = (n+1)\,a\,y_1$$

$$\frac{\text{Total area}}{\text{Net area}} = \frac{[(n+1)a + nt]\,y_1}{(n+1)\,a\,y_1} \quad \therefore \quad \frac{\text{Net area}}{\text{Total area}} = \frac{a}{a + \left(\frac{n}{n+1}\right)t}$$

If n is large, $\frac{n}{n+1} \simeq 1 \quad \therefore \quad \text{Net area} = \left(\frac{a}{a+t}\right)(\text{total area})$

t
$\downarrow$
* select rectangular bars : 8mm × 25 mm , a = 25mm
* select approach velocity : v = 0.4 m/s @ Q_{avg}

(cross-sectional)
$\therefore$ Total Area $= \frac{0.175 \text{ m}^3/\text{s}}{0.4 \text{ m/s}} = \underline{0.4375 \text{ m}^2}$

$\therefore$ Net Area $= \left(\frac{a}{a+t}\right)(\text{Tot. Area}) = \frac{25}{25+8}(0.4375) = 0.331 \text{ m}^2$

$\therefore V = \frac{0.175 \text{ m}^3/\text{s}}{0.331 \text{ m}^2} = 0.53$ (b/t 0.4 → 0.75 m/s ∴ OKAY)

* Choose channel width = min 0.6m, max 4.3m per recommendation
select $W = 0.6$ m
$\therefore (n+1)(a) + n(t) = W \Rightarrow n+1(0.025) + n(0.008) = 0.6$m
$\Rightarrow n = 17.4 = 18$
True channel width : $W = 19(0.025) + 18(0.008) = 0.62$ m

* Calc. upstream depth
$y_1 = \frac{\text{Total Area}}{W} = \frac{0.4375 \text{ m}^2}{0.62 \text{ m}} = 0.707$ m (needed to get v = 0.4 m/s)

* calc head loss

W.W. Oct. 25 (1)

TABLE 5.2 *Typical Characteristics of Untreated Municipal Wastewater in the United States*

CONSTITUENT	CONCENTRATION		
	Strong	Medium	Weak
Solids, total:	1250	800	450
Dissolved, total:	890	560	350
Fixed	295	295	185
Volatile	595	265	165
Suspended, total:	360	240	100
Fixed	145	75	25
Volatile	215	165	75
Settleable solids, mℓ/ℓ	7	5	3
Biochemical oxygen demand, 5-day, 20°C (BOD$_5$, 20°C)	400	200	100
Total organic carbon (TOC)	290	145	75
Chemical oxygen demand (COD)	910	455	230
Nitrogen (total as N):	75	40	16
Organic	40	20	8
Free ammonia	35	20	8
Nitrites	0	0	0
Nitrates	0	0	0
Phosphorus (total as P):	15	8	4
Organic	5	3	1
Inorganic	10	5	3
Chlorides[a]	83	42	21
Alkalinity (as $CaCO_3$)[a]	200	100	50
Grease	40	20	5

All values except settleable solids are expressed in mg/ℓ.
1 mg/ℓ = 1 g/m^3

[a] Values should be increased by the amount in the domestic water supply.

Adapted from *Water Supply and Sewerage* by E. W. Steel, 4th ed. Copyright © 1960 by McGraw-Hill Book Company, Inc.; and from *Wastewater Engineering: Treatment, Disposal and Reuse* by Metcalf and Eddy, Inc., 3rd ed. Copyright © 1991 by McGraw-Hill, Inc. Reproduced with permission of McGraw-Hill, Inc.

TABLE 8-1 Description of Coarse Screens

Type	Location	Description
Bar racks or bar screens	Ahead of pumps and grit removal facilities	Bar racks may be manually cleaned or mechanically cleaned. Manually cleaned racks are provided at small wastewater treatment facilities.
Coarse woven-wire media screens	Behind racks or ahead of trickling filters	These are flat-, basket-, cage-, or disk-type screens used to remove relatively smaller particles. The screens are cleaned by removing them from the channel. The new types of coarse screens use moving screens. They are similar to fine screens in design. They have vertical or drum-type arrangement with wire mesh or screen cloth. The solids are continuously removed into the receiving troughs. The openings may vary from 3 to 20 mm depending on the needs for solids removal.
Comminutor	Used in conjunction with coarse screens	Comminutors are grinders that cut up the materials retained over screens. They utilize cutting teeth or shredding devices on a rotating or oscillating drum that pass through stationary combs, screen, or disks. Large objects are shredded that pass through thin openings or slots 0.6–1 cm. The comminutors are almost submerged. Manufacturers' rating tables are available for different capacity ranges, channel dimensions, submergence, and power requirements. Provision to bypass the comminutor is always made.

TABLE 8-3 Design Factors for Manually Cleaned and Mechanically Cleaned Bar Racks

Design Factor	Manually Cleaned	Mechanically Cleaned
Approach Velocity (m/s)	0.3–0.6	0.6–1.0
Bar size		
Width (mm)	4–8	8–10
Depth (mm)	25–50	50–75
Clear spacing between bars (mm)	25–75	10–50
Slope from horizontal (degrees)	45–60	75–85
Allowable head loss, clogged screen (mm)	150	150
Maximum head loss, clogged screen (mm)	800	800

Source: Adapted in part from Refs. 1, 3, and 6

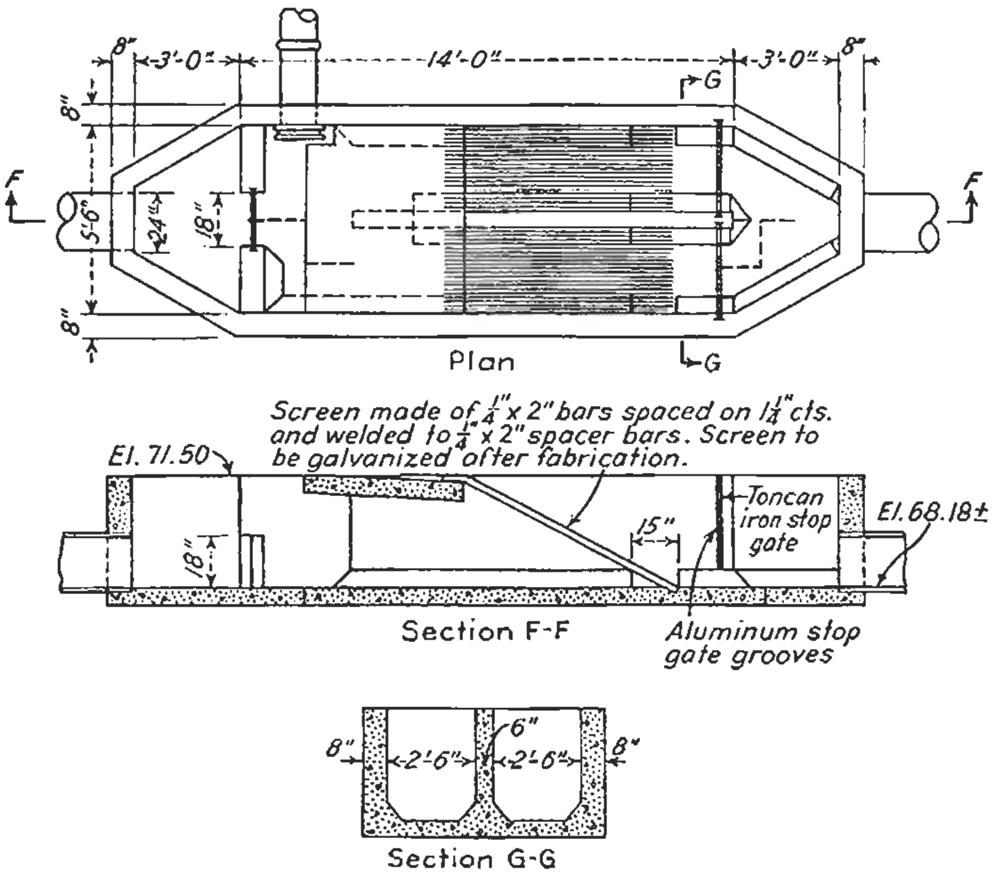


Fig. 17–2. Screen chamber at Mendota, Ill.

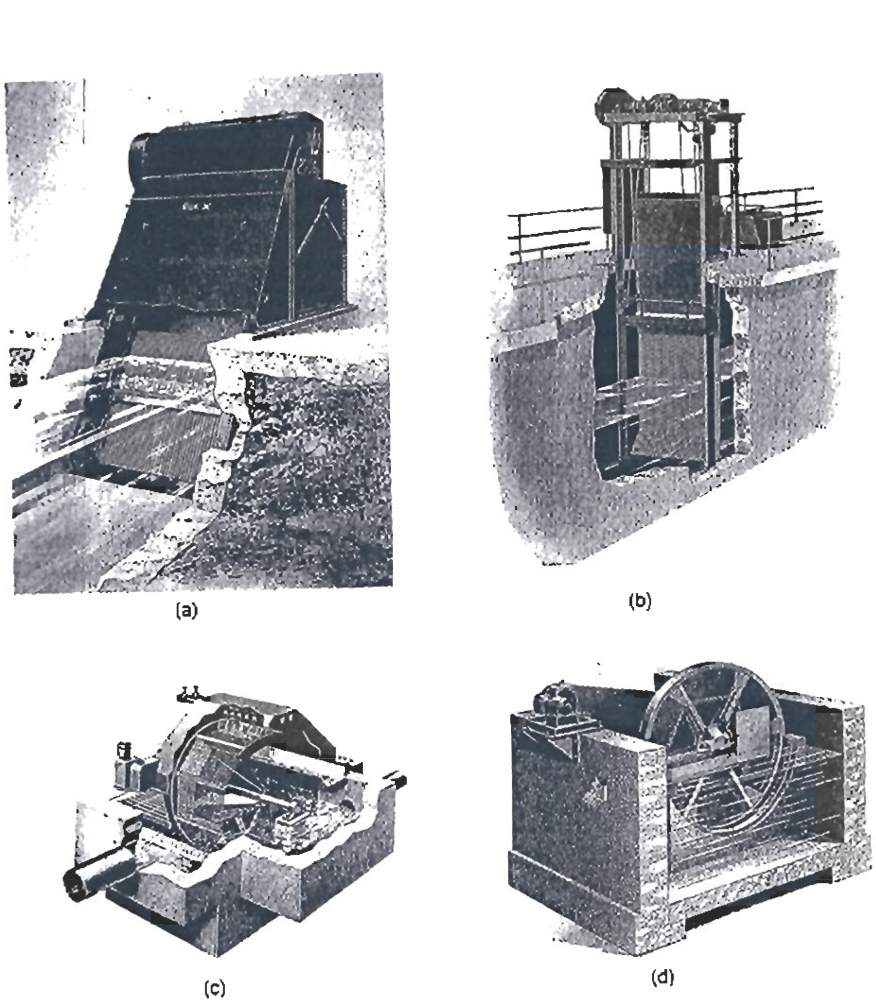


Figure 8-1 Details of Bar Rack and Coarse Screen. (a) Inclined rack, front cleaned. (b) Cable operated bar rack. (Courtesy Envirex Inc., a Rexnord Company.) (c) Revolving drum screens. (d) Revolving disc screen. (Courtesy FMC Corporation, Material Handling Systems Division.)

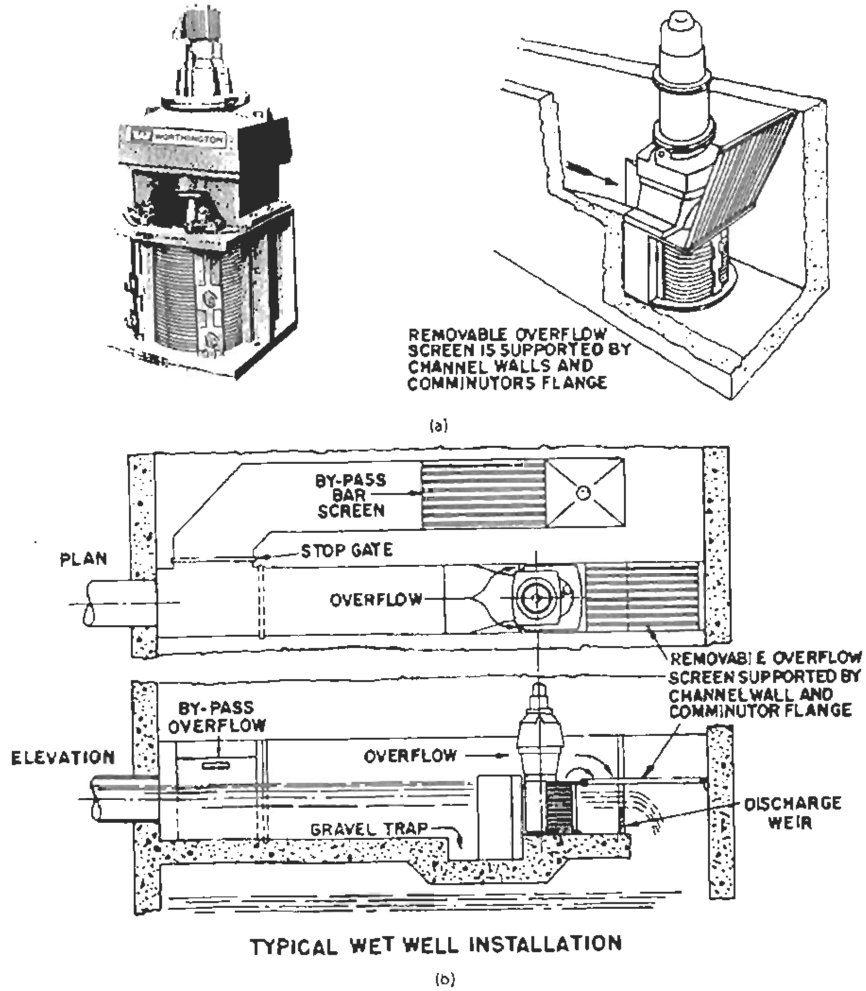
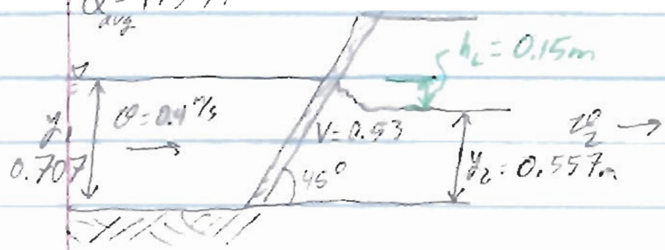


Figure 8-2 Details of Comminutor. (a) Comminutor assembly. (b) Typical wet well installation. (Courtesy Worthington Pump Corporation.)

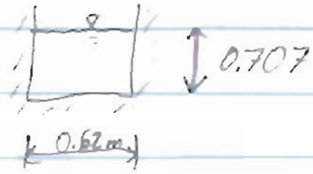
W.W. oct. 27 ①

$Q_{avg} = 175\ L/s$



18 bars, 25 mm × 8mm, spaced 25mm

cross section before screen



* Calc head loss Recommended min = 0.15m, max = 0.18m

Metcalf & Eddy: $h_L = \frac{V^2 - v^2}{2g}\left(\frac{1}{k}\right)$ $\quad k = 0.7$

$h_L = 8.7 \times 10^{-3}\ m$ (clean rack)

$\therefore$ use min value, $h_L = 0.15m$ $\therefore y_2 = 0.707 - 0.15 = 0.557m$

$v_2 = \frac{0.175\ m^3/s}{(0.557m)(0.62m)} = 0.507\ m/s$

check $y_1 + \frac{v_1^2}{2g} = y_2 + \frac{v_2^2}{2g} + h_L$

$$0.707 + \frac{0.4^2}{2(9.81)} = 0.557 + \frac{(.507)^2}{2(9.81)} + h_L$$

$\rightarrow h_L = 0.145\ m$ OKAY

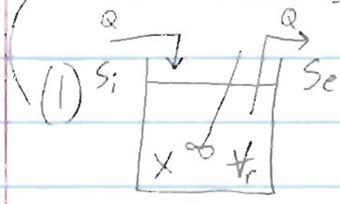
see handout

OVER

Biological w.w. Treatment

Dead organic matter $\xrightarrow[O_2]{\text{micro org}}$ CO_2 / H_2O + Live Biomass
(colloidial & dissolved)
← need to force bacteria to self flocculate

Biological treatment
(1) Suspended growth : activated sludge process
(2) Attached growth : trickling filters & other biofilm reactors



S_i = influent desolved substrate ← organic matter concentration
S_e = effluent " " "
X = Biomass concentration ; $\forall_r$ = reactor Vol.

U = food uptake rate $\frac{\text{kg substrate/kg biomass}}{d}$

ENCE 4323

GRIT REMOVAL

- Two characteristics of grit:
  - Non biodegradable
  - Settling velocity > settling velocity of organic matter.

Grit removal has three major purposes:

- Protection of moving mechanical equipment from abrasion
- Reduction of pipe clogging caused by grit deposition at pipe bends
- Reduction of frequent digester and settling tank cleaning. Digester protection is most important.

Particles to be removed: ≥ 0.2 mm, $v_s \geq 1.15$ m/min

Process consists of keeping constant flow velocity in the chamber so as to remove grit while avoiding settling of organic matter.

Three kinds of grit chambers:

- Horizontal flow: water flows through the chamber in the longitudinal direction.
- Aerated grit chamber: spiral flow in the chamber
- Vortex.

Horizontal Flow Grit Chambers

Flow through velocity must be maintained between 0.25 and 0.4 m/s. Good design value: $v_L = 0.3$ m/s

But: variable flow rate $\Rightarrow$ variable depth $\Rightarrow$ variable velocity.

Why? Manning's formula for rectangular channels of width = w and water depth = D:

Constant

$$Q = \frac{(wD)^{5/3}}{n} \frac{S^{1/2}}{(2D+w)^{2/3}}$$ If Q varies, D will vary.

If D varies,

from $v = \frac{1}{n}\left(\frac{wD}{2D+w}\right)^{2/3} S^{1/2}$, we see that v will vary.

To get constant velocity under variable flow rate, use a control section.

- Control section: Section that uniquely establishes the elevation of the hydraulic and energy gradients. Depth is fixed by energy considerations independently of such factors as channel roughness and slope.
- At the control section,
  - depth of flow = critical depth
  - flow velocity = critical velocity
  - $\boxed{\frac{v_c^2}{2g} = \frac{D_c}{2}}$, which is a hydraulic property of a control section

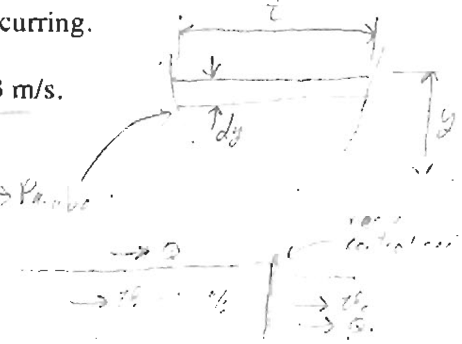
Design [illegible] for [illegible] of [illegible]
on next page →

CONTROL SECTIONS USED IN PRACTICE

1. Rectangular control section downstream of a grit chamber with trapezoidal cross section

Write the basic formula of critical depth $\boxed{\dfrac{v_c^2}{2g} = \dfrac{D_c}{2}}$ in terms of flow rate:

$\dfrac{Q^2}{2g.A_{critical}^2} = \dfrac{D_c}{2}$; but $A_c = wD_c$ $\therefore$ $\boxed{Q = w\sqrt{g}D_c^{3/2}}$ This is the flow rate through a rectangular opening at which critical depth is occurring.



Let us find the shape of the channel that will give us a constant velocity of 0.3 m/s.

The cross sectional area is $A = \int_0^y t dy$, where t is the width at depth y

The flow rate through this channel would be: $Q = v\int_0^y t dy = 0.3\dfrac{m}{s}\int_0^y t dy$

This flow rate must be equal to the flow rate through the control section:

$0.3\int_0^y t\,dy = w\sqrt{g}\,y^{3/2}$; differentiating both sides of the equality get:

$$0.3t dy = w\sqrt{g}\left(\frac{3}{2}y^{1/2}dy\right)$$

that finally leads to $\boxed{y = \left(\dfrac{0.2}{w\sqrt{g}}\right)^2 t^2}$, which is the equation of a parabola.

Therefore, if the control section is rectangular, the upstream channel must have a parabolic cross section. In practice, the parabolic cross section is approximated by a trapezoidal cross section (see Fig. 7.6, p. 140 R&R)

make

Assume

$$\sqrt{2ag}\,(h+\tfrac{2}{3}$$

assuming

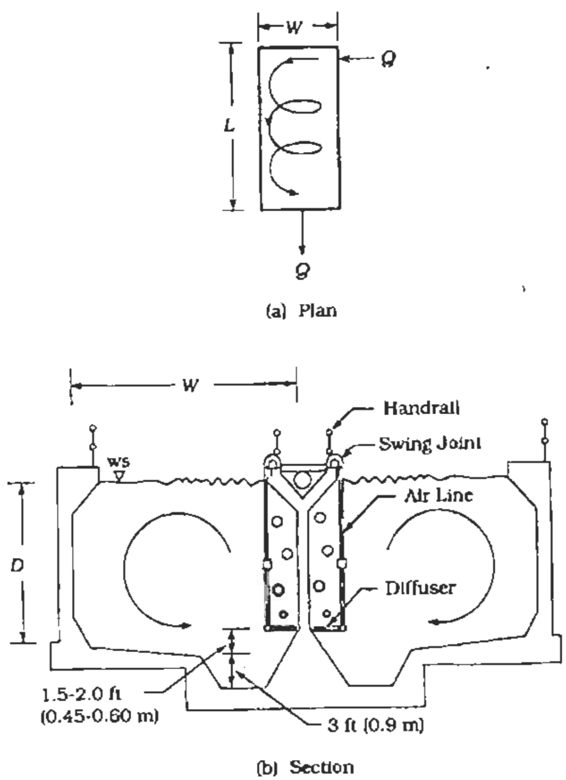


FIGURE 7.14 *Aerated Grit Chamber with Spiral-Roll Flow*
Adapted from *Wastewater Engineering: Treatment, Disposal and Reuse*, 3rd ed. by Metcalf & Eddy, Inc. Copyright © 1991 by McGraw-Hill, Inc. Reprinted by permission.

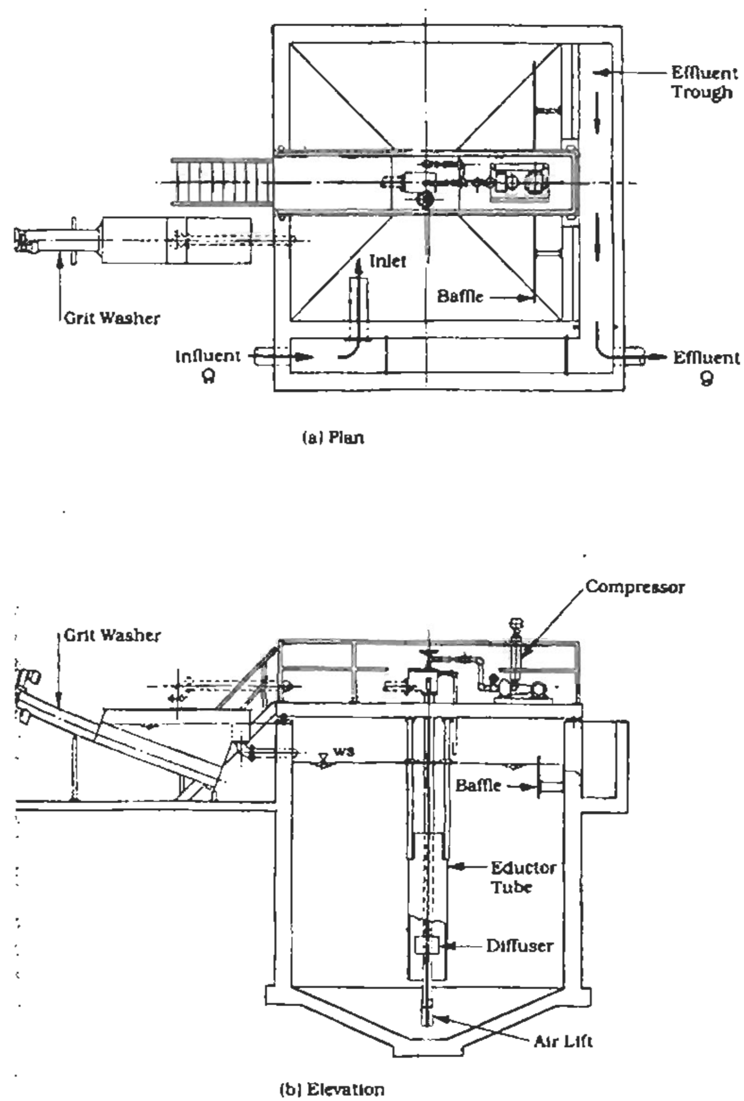
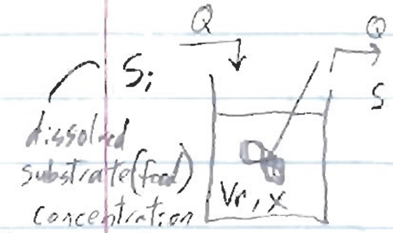


FIGURE 7.15 *Aerated Grit Removal Chamber*
Courtesy of Walker Process Equipment; Division of McNish Corporation.

WW Nov 1 ①

Suspended Growth Reactors



V_r = reactor Vol.

X = concentration of live biomass $\left[\frac{kg\ biomass}{m^3}\right]$

U = food uptake rate (negative), $\frac{kg\ substrate/kg\ biomass}{day}$

$\left[\frac{kg\ substrate}{m^3}\right]$ → BOD (Biochemical oxygen demand), COD (chemical oxygen demand

Use mass balance to find S (mass bal. on desolved substrate)

Assume S.S. → Accumulation = Input - Output + Reaction $[kg/d]$ = ∅

$$\emptyset = Q\tfrac{m^3}{d}\left(S_i\ \tfrac{kg\ substrate}{m^3}\right) - Q(S) + U(X)(V_r)$$

$$\rightarrow \emptyset = Q(S_i - S) + UXV_r \quad \text{(divide by Q; Solve for S)}$$

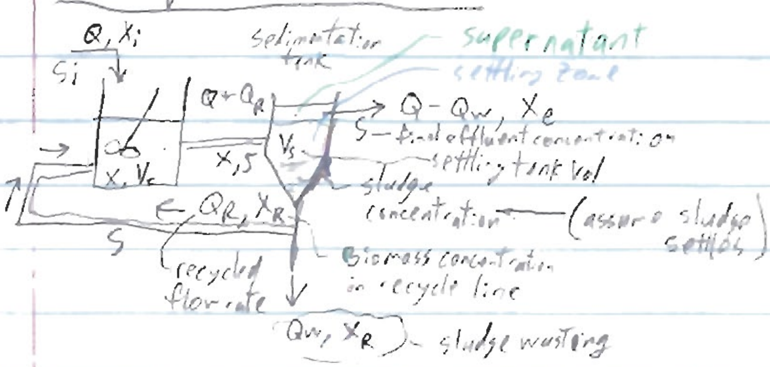
$$\rightarrow S = S_i + UX\bar{t} \quad \left\{\bar{t} = \frac{V_r}{Q}\right\}$$

* In the case of CFR the only real way to impact (↓) S is to ↑ $\bar{t}$, this results in higher construction cost (b/c usually done by ↑ ∀)

Example: aerated lagoon → $\bar{t}$ = 7-30 days

* we could try to ↑ X but in practice X = 100-400 $\frac{mg}{l}$
* " " " " ↑ U (can not change how fast bac. eat)

Attempt to ↑ X



Assume: There is no substrate consumption in the settling tank

(Activated Sludge Sys)

Now write mass balance on substrate around reactor only

Assume S.S.

$$\emptyset = \underbrace{Q(S_i) + Q_r(S)}_{\text{Input}} - \underbrace{(Q+Q_r)S}_{\text{output}} + \underbrace{U V_r X}_{\text{reaction}}$$

$$\emptyset = QS_i + \cancel{Q_r S} - QS + \cancel{Q_r S} + U V_r X$$

$$= QS_i - QS + U V_r X \quad (\div \text{ by } Q, \text{ solve for } S)$$

$$\rightarrow S = S_i + U X \tau \quad (\text{Same equ as before})$$

Now will demonstrate that X is larger than previous equ.; To find X → write mass bal. on biomass

assume S.S.

$$\emptyset = \underbrace{QX_i + Q_R(X_R)}_{\text{input}} - \underbrace{(Q+Q_R)X}_{\text{output}} + \underbrace{r_g}_{\text{rate of groth } \left[\frac{\text{kg biomass}}{m^3 \cdot d}\right]}(V_r)$$

$$\rightarrow \boxed{QX_i + V_r(r_g) = (Q+Q_R)X - Q_R X_R} \quad ①$$

Equilibrium: mass of solids produced = mass of solids removed

$$\underbrace{QX_i}_{\text{what is added}} + \underbrace{V_r(r_g)}_{\text{what is growing}} = \underbrace{Q_w(X_R)}_{\text{wasted}} + \underbrace{(Q-Q_w)X_e}_{\text{effluent}} \quad ②$$

① = ② $\quad (Q+Q_R)X - (Q_R X_R) = Q_w X_R + (Q-Q_w)X_e$

solve for X

$$X = \frac{X_R(Q_R+Q_w) + X_e(Q-Q_w)}{Q+Q_R}$$

multiply right by $\frac{\frac{1}{Q}}{\frac{1}{Q}}$

call $\alpha = \frac{Q_R}{Q}$ (recycle ratio)

& $w = \frac{Q_w}{Q}$ (wasting ratio)

$$\boxed{X = \frac{X_R(\alpha+w) + X_e(1-w)}{1+\alpha}} \quad ④$$

Realistic Numbers

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assume $X_R = 8000 \frac{mg}{L}$; $X_e = 20 \frac{mg}{L}$, $\alpha = 0.7$, $w = 0.05$

$X = 3540 \frac{mg}{L}$

since X varies 100-400 from previous equ. we have made our reactor ~ 10× smaller

Calc cell detention time (solids retention time), $\bar{t}_c$

Define $\bar{t}_c = \frac{\text{mass of solid in sys.}}{\text{Rate of solids withdrawn}} = \frac{X(V_r) + X(V_s)}{(Q-Q_w)X_e + Q_w(X_r)}$

$$\boxed{\bar{t}_c = \frac{X(V_r + V_s)}{(Q-Q_w)X_e + Q_w(X_r)}} \quad (5)$$

useing (2)

$$\bar{t}_c = \frac{X(V_r + V_s)}{Q X_i + V_r(r_g)} \quad (5a) \quad \text{mul. by } \frac{\frac{1}{V_r}}{\frac{1}{V_r}}$$

$$\boxed{\bar{t}_c = \frac{X\left(1 + \frac{V_s}{V_r}\right)}{\frac{X_i}{\bar{t}} + r_g}} \quad (6)$$

From 5a: $Q X_i + V_r r_g = \frac{V_r X}{\bar{t}_c}\left(1 + \frac{V_s}{V_r}\right)$ (7)

(1) = (7) $(Q + Q_r)X - Q_R(X_R) = \frac{V_r X}{\bar{t}_c}\left(1 + \frac{V_s}{V_r}\right)$ solve for $\bar{t}_c$

$$\star \quad \boxed{\bar{t}_c = \frac{\bar{t} X\left(1 + \frac{V_s}{V_r}\right)}{X - \alpha(X_R - X)}} \quad (8)$$

Assume $X = 3540 \frac{mg}{L}$, $X_R = 8000 \frac{mg}{L}$, $\alpha = 0.7$, $w = 0.05$

$\bar{t}_c = 16.9(\bar{t})$ ∴ cell det. time = 17 times the

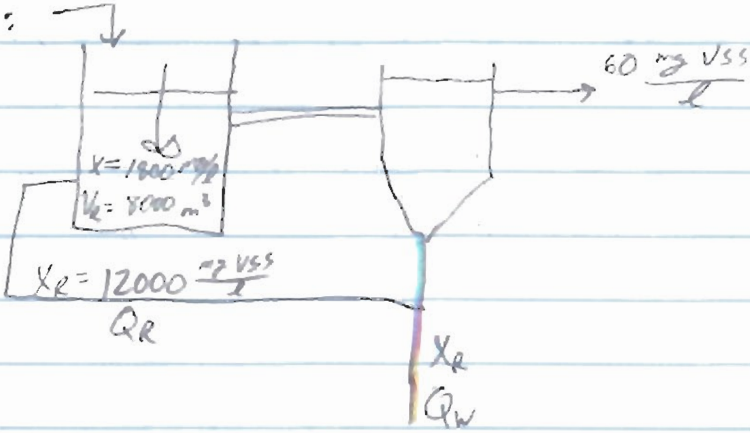
Get good floc. if $\bar{t}_c \geq 3d$

100 mg/l VSS (Volatile suspended Solids)

60000 $\frac{m^3}{d}$ Find Q_R, Q_w, $\bar{t}_c$

Example:

$r_g = 0.5 \frac{kg\,VSS}{m^3\,d}$



Solution

equ. (2) $Q X_i + V_r r_g = Q_w X_R + (Q - Q_w) X_e$

solve for $Q_w = 536\ m^3/d$

equ (3) $X = \dfrac{X_R(Q_R + Q_w) + X_e(Q - Q_w)}{Q + Q_R}$

solve for $Q_R = 9608\ m^3/d$

equ (6) $\bar{t}_c = \dfrac{X\left(1 + \frac{V_s}{V_r}\right)}{\frac{X_i}{\bar{t}} + r_g} = 2.2\,d$

$\bar{t} = \dfrac{V_r}{Q}$

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Ex. $V_s = 140\,m^3$, $V_r = 170\,m^3$, $X = 3300\,\frac{mg}{L}$, $X_R = 10600\,\frac{mg}{L}$

$Q = 6170\,m^3/d$ Find recycle ratio $\left(\alpha = \frac{Q_R}{Q}\right)$

so that $\bar{t}_c = 3\,days$

Equ. 8 $\bar{t}_c = \dfrac{\bar{t}\,X\left(1+\frac{V_s}{V_r}\right)}{X - \alpha\left(X_R - X\right)}$ $\rightarrow$ $\boxed{\alpha = \dfrac{X\left[1-\frac{\bar{t}}{\bar{t}_c}\left(1+\frac{V_s}{V_r}\right)\right]}{X_R - X}}$ 9

$$\alpha = \frac{3.3\,\frac{kg}{m^3}\left[1-\frac{(170/6170)\,d}{3d}\left(1+\frac{140\,m^3}{170\,m^3}\right)\right]}{(10.6-3.3)\,kg/m^3} = 0.444$$

---

sludge production

material balance on cells:

$\begin{pmatrix}\text{net rate}\\\text{of growth}\end{pmatrix} = \begin{pmatrix}\text{Increase due}\\\text{to synthesis}\end{pmatrix} - \begin{pmatrix}\text{Decrease due to}\\\text{cell decay}\end{pmatrix}$ Eq 15.88 p. 467 KE[illegible]

Yield coeff. decay coeff. $[d^{-1}]$

$$r_g\left[\frac{kg/m^3}{d}\right] = -U\,X\,Y - k_e\,X \leftarrow \frac{kg\ biomass}{m^3}$$

$\frac{kg\ substrate/d}{kg\ biomass}$ $\frac{kg\ biomass}{m^3}$

$$\rightarrow \boxed{-U = \frac{1}{Y}\left(\frac{r_g}{X} + k_e\right)} \quad 10$$

From mass bal. on substrate

$-U = \dfrac{S_i - S}{X\bar{t}}$ set = to 10 & solve for $V_r(r_g)$

$$\rightarrow \boxed{V_r\left(r_g\right) = YQ\left(S_i - S\right) - k_e X V_r} \quad 11$$

combine 11 & 7

$$\boxed{\frac{V_r}{Q} = \bar{t} = \frac{\bar{t}_c\left[X_i + Y\left(S_i - S\right)\right]}{X\left(1+\frac{V_s}{V_r} + k_e\bar{t}_c\right)}} \quad 12$$

use to calc. V_r

To find V_r : * select values of Y & k_e (eg, table 15.7 p. 477 K_{i_R})

* select $\bar{E}_c \geq 3d$
* select $\frac{V_s}{V_r}$
* For desired value of $S_i - S$, for a known X_i, Calc V_r, after selecting X.

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(Taken From "Wastewater Treatment Plants, Planning, Design, and Operation," Second edition by Syed Qasim, Technomic Publishing Company)

$\theta_c = \frac{\text{mass of cells in reactor}}{\text{rate of cell withdrawal}}$ (M/Vc)

TABLE 13-3 Description and Design Parameters of Various Activated Sludge Process Modifications

Process Modification	Brief Description	Flow Regime	Sludge Retention Time, θ_c (d)	Food to MO Ratio[a] (d^{-1})	Aerator Loading[b] (kg/m^3d)	MLSS[c] (mg/L)	Aeration Period (h)	Recirculation Ratio Q_r/Q
Conventional	The influent and returned sludge enter the tank at the head end of the basin and are mixed by the aeration system [Figure 13-5(a)].	Plug	5–15	0.2–0.4 ($\frac{Q S_i}{X V_r}$ [g substrate / d kg biomass])	0.3–0.6	1500–3000	4–8	0.25–0.5
Tapered aeration	The tapered aeration system is similar to the conventional activated sludge process. The major difference is in arrangement of the diffusers. The diffusers are close together at the influent end where more oxygen is needed. The spacing of diffusers is increased toward the other end of the aeration basin.	Plug	5–15	0.2–0.4	0.3–0.6	1500–3000	4–8	0.25–0.5
Step-feed aeration	The influent is applied at several points in the aeration basin. Generally, the tank is subdivided into three or more parallel channels with around-the-end baffles, and the influent is applied at separate channels or steps. The oxygen demand is uniformly distributed [Figure 13-5(b)].	Plug	5–15	0.2–0.4	0.6–1.0	2000–3500	3–5	0.25–0.75
Complete-mix aeration	The influent and the returned sludge are mixed and applied at several points along the length and width of the basin. The contents are mixed, and the MLSS flows across the tank to the effluent channel. The oxygen demand and organic loading are uniform along the entire length of the basin [Figure 13-4(c)].	Complete mix	5–15	0.2–0.6	0.8–2.0	3000–6000	3–5	0.25–1.00
Extended aeration (oxidation ditch)	The extended aeration process utilizes a large aeration basin where high population of MO is maintained. It is used for small flows from subdivisions, schools, etc. Prefabricated package plants utilize this process extensively. Oxidation ditch is a variation of extended aeration process. It has a channel in shape of a race track. Rotors are used to supply oxygen and maintain circulation [Figure 13-5(d)].	Complete mix or plug	20–30	0.05–0.15	0.1–0.4	3000–6000	18–36	0.5–2.0

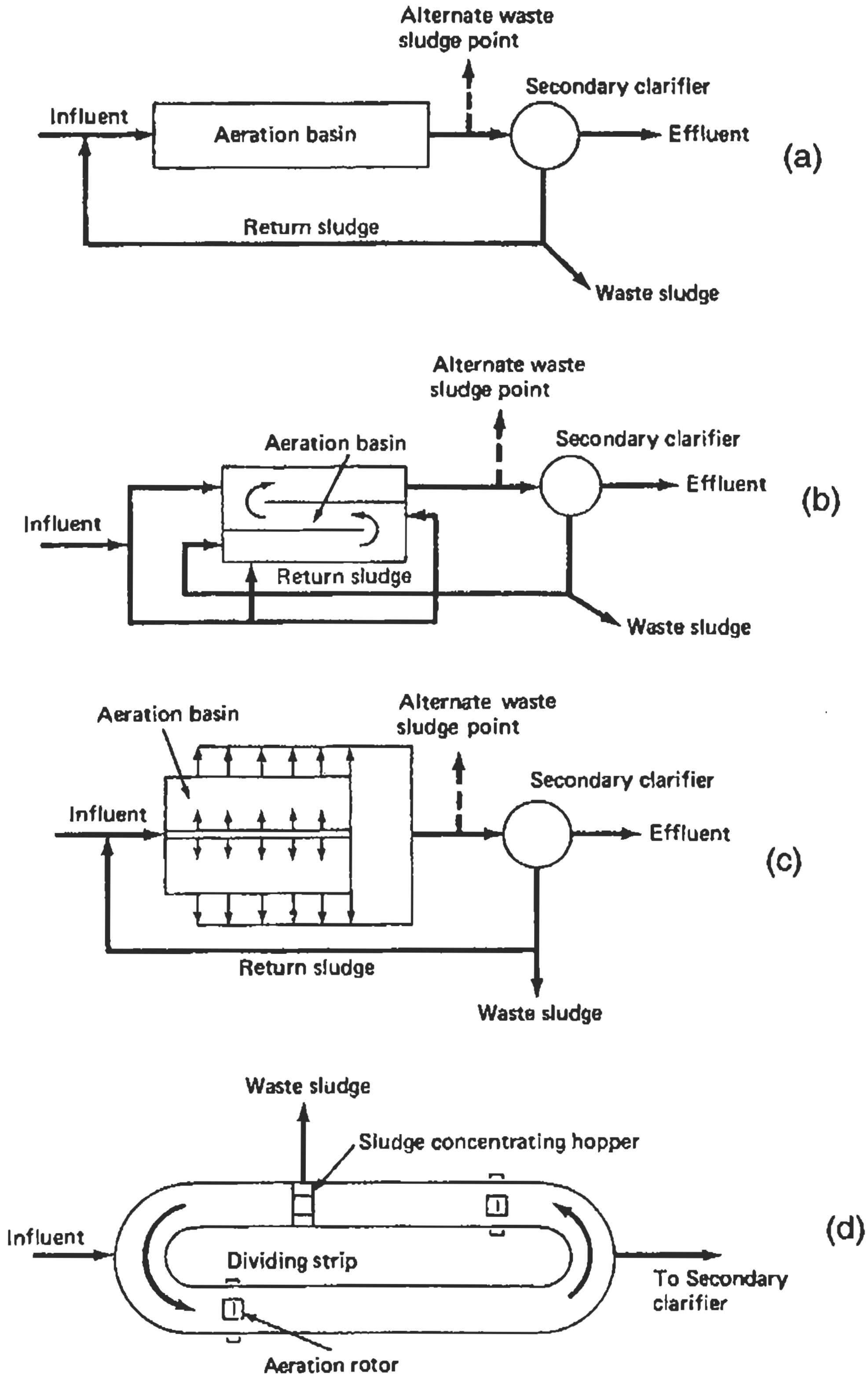
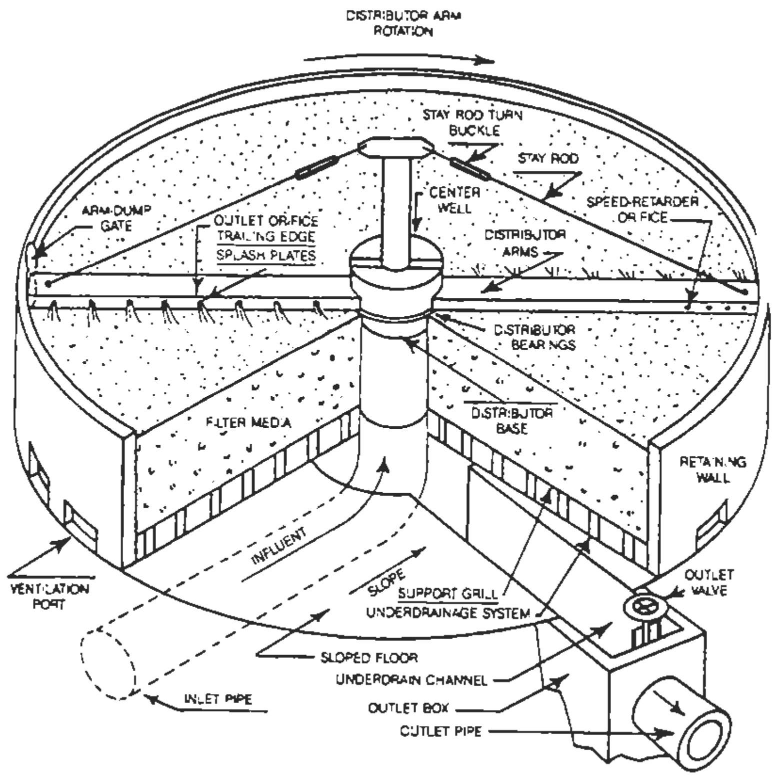
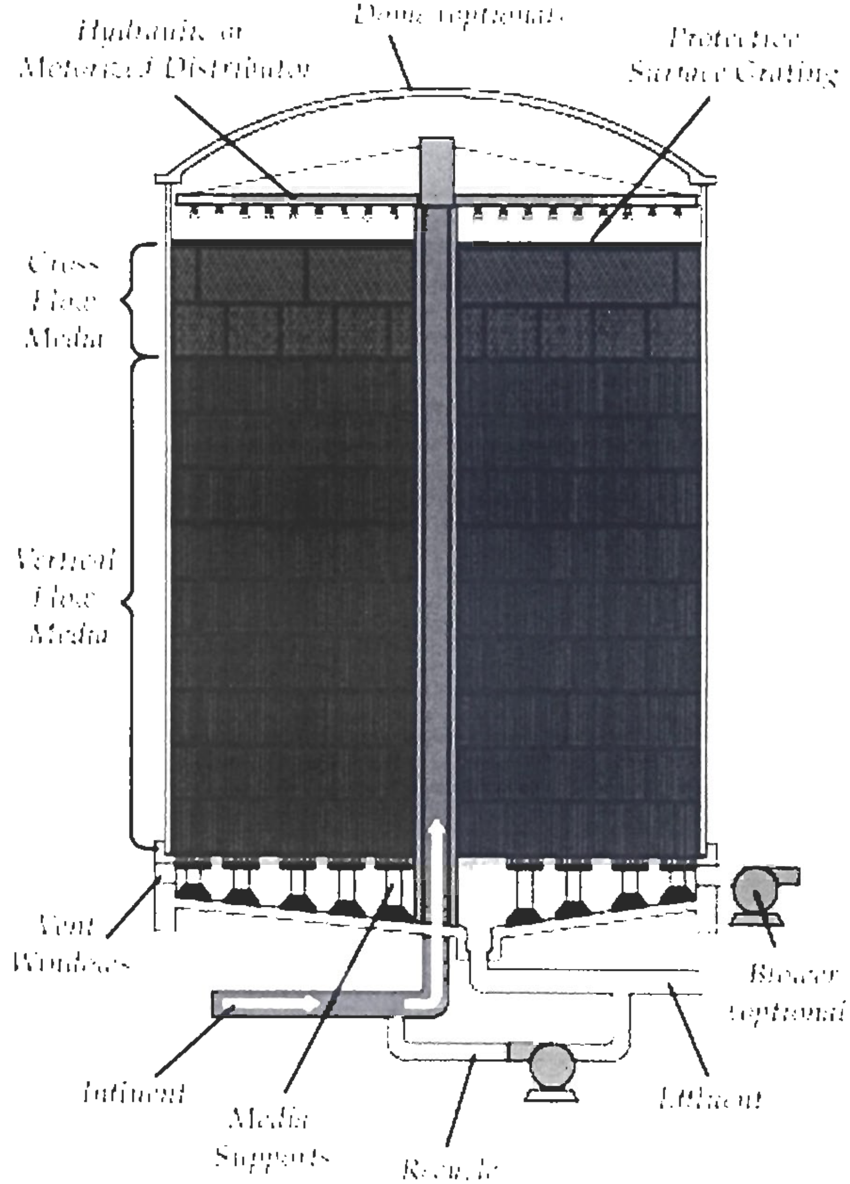


Figure 13-5 Modifications of the activated sludge process: (a) conventional, (b) step aeration, (c) complete mix, (d) oxidation ditch.



Source: Metcalf & Eddy, Inc. and Tchobonaglous, 1998.

FIGURE 1 TYPICAL TRICKLING FILTER



Plastic media trickling filter (Brentwood Industries)

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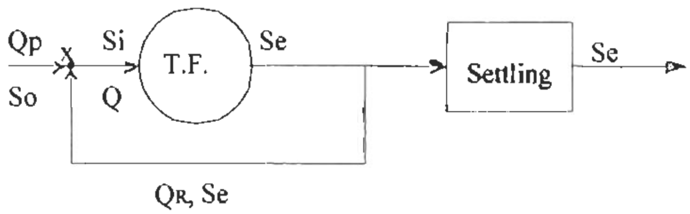
TRICKLING FILTER DESIGN – PLASTIC PACKING

Most common formula is Eckenfelder's formula:

$$\frac{S_e}{S_i} = \exp\left[-k_T D S_a^m \left(\frac{A}{Q}\right)^n\right]$$

where:

S_e	=	BOD_5 of settled effluent from the filter, mg/L
S_i	=	BOD_5 of settled influent wastewater applied to the filter, mg/L
k_T	=	removal rate constant, m/d at temperature T°C, given by: $k_{T_2} = k_{T_1}\theta^{(T_2 - T_1)}$
θ	=	temperature correction coefficient (commonly, $\theta = 1.08$)
$k_{15°C}$	=	0.025 - 0.06 m/d
D	=	filter depth, m
S_a	=	specific media surface area, m^2/m^3
A	=	filter top surface area, m^2
Q	=	volumetric flow rate applied to the filter, m^3/d
Q_p	=	plant flow rate, m^3/d



Mass balance at x: $Q_p S_0 + Q_R S_e = (Q_p + Q_R) S_i \quad \therefore \quad S_i = \dfrac{Q_p S_0 + Q_R S_e}{Q_p + Q_R}$

Divide numerator and denominator by Q_p: $S_i = \dfrac{S_0 + \alpha S_e}{1 + \alpha}, \quad or \quad \alpha = \dfrac{S_0 - S_i}{S_i - S_e} \quad$ where $\alpha = \dfrac{Q_R}{Q_p}$

see notes

Example: Design a plastic-medium tower filter to replace some existing facultative ponds that are now used to treat wastes from a rural community in which a small vegetable cannery is located. The following information and data apply.

1. Design domestic wastewater flowrate = 10 000 m^3/d
2. Sustained-peak seasonal cannery flowrate (May through October) = 5000 m^3/d.
3. Average year-round domestic BOD_5 = 220 mg/L; Industrial waste BOD = 1000 mg/L
4. Temperature data: Sustained low for May and October = 20°C; sustained low for January = 0°C
5. Effluent BOD_5 requirement = 30 mg/L
6. BOD_5 removal rate constant at 25°C = 0.1 m/d
7. Temperature correction coefficient = 1.08
8. Specific area of filter packing material = 85 m^2/m^3
9. Maximum allowable filter height because of local site restrictions = 10 m
10. The value of the coefficients *m* and *n* in Eckenfelder's Eq. were found to be = 1.0

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TRICKLING Filters

* BOD removal in rock T.F. – NRC formula (1946) – Empirical
  * Single or first stage

efficiency of BOD removal $= E_1 = \dfrac{100}{1 + 0.4432\sqrt{\dfrac{W_1}{VF}}}$

W_1 = BOD loading to filter $\left[\dfrac{kg\,BOD}{d}\right]$

V = empty tank Vol., occupied by media

F = recirculation factor $= \dfrac{1+\alpha}{\left(1+\dfrac{\alpha}{10}\right)^2}$; $\alpha = \dfrac{Q_R}{Q}$

* 2nd stage BOD removal

$$E_2 = \frac{100}{1 + \dfrac{0.4432}{1 - \dfrac{E_1}{100}}\left(\sqrt{\dfrac{W_2}{VF}}\right)}$$

metric units

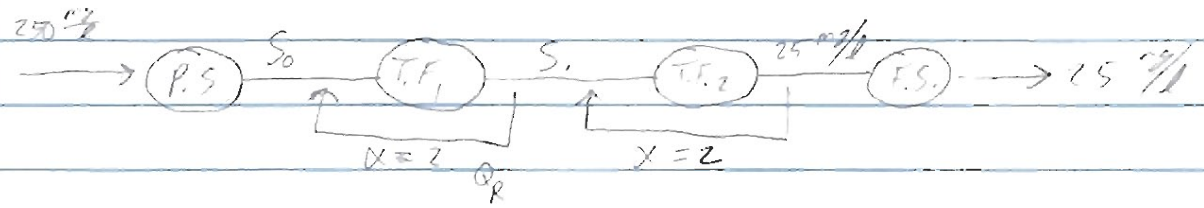
Effect of temperature $E_{T(°C)} = E_{20}(1.035)^{T-20}$

Example (US units) BOD = 250 mg/l, 2-stage T.F., final effluent = 25 mg/l

Filter depth = 6 ft, $\alpha = 2.0$, $Q = 2$ mgd, temp = 20°C.

BOD removal in primary clarifier = 35 %

If $E_1 = E_2$, find filter dia.



$$\left.\begin{aligned} E_1 &= \left(1 - \frac{S_1}{S_0}\right)100 \\ E_2 &= \left(1 - \frac{S_2}{S_1}\right)100 \end{aligned}\right\} \quad E_T = \left(1 - \frac{S_2}{S_0}\right)100$$

$\Rightarrow E_T = E_1 + E_2 (100 - E_1)$

primary clarifier removal

$S_o = 250\ mg/l\,(1-0.35) = 162.5\ mg/l$

$E_T = \left(1 - \frac{25}{162.5}\right)(100) = \underline{84.62\%}$

If $E_1 = E_2 \rightarrow 84.62 = E_1 + E_1(100 - E_1)$

$E_1 = E_2 = \underline{60.78\%}$

USE NRC equ. (for U.S. units)

$$E_1 = \frac{100}{1 + 0.0561\sqrt{\frac{W_1}{VF}}} \qquad W_1 = \frac{lb\ BOD}{d},\ V = 10^3\ ft^3 \qquad F = \frac{1+\alpha}{\left(1+\frac{\alpha}{10}\right)^2} = \underline{2.08}$$

$W_1 = Q[mgd]\left(S_o\left[\frac{mg}{l}\right]\right)\left(8.34\ \frac{lb/d}{mgd\left(\frac{mg}{l}\right)}\right)$ * This does not include recycled Q_R

$W_1 = 2(162.5)(8.34) = 2710\ lb/d$

$$60.78 = \frac{100}{1 + 0.0561\sqrt{\frac{2710}{V(2.08)}}} \rightarrow V = 9.834\times10^3\ ft^3$$

Since depth = 6'

$A = \frac{9834\ ft^3}{6\ ft} = 1639\ ft^3 \rightarrow$ Diameter = $\boxed{45.7\ ft}$

BOD loading to second filter: $W_2 = \frac{(100 - E_1)}{100}(W_1) = \underline{1063\ lb/d}$

$$E_2 = \frac{100}{1 + \frac{0.0561}{1 - \frac{E_1}{100}}\sqrt{\frac{W_2}{V_2 F}}} \rightarrow (E_1 = E_2) \rightarrow V_2 = 2.029\times10^3\ ft^3$$

60.78

$\therefore$ diameter 2 = $\boxed{21.1\ ft}$

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* see handout

Important design criteria for plastic media filters

1) Organic Loading (OL)

$$OL = \frac{Q_p(S_o)}{A(D)} = 0.32 \to 1 \left[\frac{kg\ BOD}{m^3 d}\right]$$

2) hydraulic loading (HL)

$$HL = \frac{Q_p + Q_R}{A} \geq 44 \frac{m^3/d}{m^2}$$

3) Avoid oxygen limitations : $S_i \leq 350\ ^{mg\,BOD}/_{l}$

+ to prevent anoxic conditions in the filter

Eample on handout

* correct k for temp (may - Oct)

$$k_{20°} = k_{25°}\,\theta^{T-25} \qquad k_{20} = 0.1\,^{m}/_{d}\,(1.08)^{20-25} = 0.068\ ^{m}/_{d}$$

winter : $k_{0} = 0.1(1.08)^{0-25}$ $0.015\ ^{m}/_{d}$

* Calc min reaction rate

To avoid Oxygen limitations, $S_i \leq 350\ ^{mg}/_{l}$

$$\alpha_0 = \frac{S_o - S_i \leftarrow 350}{S_i - S_e \leftarrow 30}$$

$10000\ ^{m^3}/_{d}$ $Q = 15000\ ^{m^3}/_{d},\ S_o$

BOD: $270\ ^{mg}/_{l}$

$5000\ ^{m^3}/_{d}$

$1000\ ^{mg}/_{l}$

industrial

$$S_o = \frac{10000(270) + 5000(1000)}{15000} = 480\ ^{mg}/_{l}$$

$$\therefore\ \alpha_0 = \frac{480 - 350}{350 - 30} = 0.41 \text{ (min value)}$$

COMPARISON OF REACTOR SIZE FOR THE SAME PERFORMANCE

assuming same Q for each

Reaction Order	$\bar{t}_{CFSTR}$	$\bar{t}_{PFR}$	$\dfrac{\bar{t}_{CFSTR}}{\bar{t}_{PFR}}$
Zero: $r_A = -k_0$	$\bar{t}_{CFSTR} = \dfrac{C_{A_0} - C_A}{k_0}$	$\bar{t}_{PFR} = \dfrac{C_{A_0} - C_A}{k_0}$	$\dfrac{\bar{t}_{CFSTR}}{\bar{t}_{PFR}} = 1$
First: $r_A = -k_1 C_A$	$\bar{t}_{CFSTR} = \dfrac{C_{A_0} - C_A}{k_1 C_A}$	$\bar{t}_{PFR} = \dfrac{1}{k_1}\ln\dfrac{C_{A_0}}{C_{A_e}}$	$\dfrac{\bar{t}_{CFSTR}}{\bar{t}_{PFR}} = \dfrac{\dfrac{C_{A_0}}{C_A} - 1}{\ln\dfrac{C_{A_0}}{C_A}}$
Second: $r_A = -k_1 C_A^2$	$\bar{t}_{CFSTR} = \dfrac{1}{k_2 C_A}\left(\dfrac{C_{A_0}}{C_A} - 1\right)$	$\bar{t}_{PFR} = \dfrac{1}{k_2 C_{A_0}}\left(\dfrac{C_{A_0}}{C_{A_e}} - 1\right)$	$\dfrac{\bar{t}_{CFSTR}}{\bar{t}_{PFR}} = \dfrac{C_{A_0}}{C_A}$

Conversion	$(t_{CSTR})/(t_{PFR})$		Conversion	$(t_{CSTR})/(t_{PFR})$		Conversion	$(t_{CSTR})/(t_{PFR})$	
	First order	2nd. ord.		First order	2nd. ord.		First ord.	2nd. ord.
0.999	144.62	1000.00	0.66	1.80	2.94	0.32	1.22	1.47
0.99	21.50	100.00	0.65	1.77	2.86	0.31	1.21	1.45
0.98	12.53	50.00	0.64	1.74	2.78	0.30	1.20	1.43
0.97	9.22	33.33	0.63	1.71	2.70	0.29	1.19	1.41
0.96	7.46	25.00	0.62	1.69	2.63	0.28	1.18	1.39
0.95	6.34	20.00	0.61	1.66	2.56	0.27	1.18	1.37
0.94	5.57	16.67	0.60	1.64	2.50	0.26	1.17	1.35
0.93	5.00	14.29	0.59	1.61	2.44	0.25	1.16	1.33
0.92	4.55	12.50	0.58	1.59	2.38	0.24	1.15	1.32
0.91	4.20	11.11	0.57	1.57	2.33	0.23	1.14	1.30
0.90	3.91	10.00	0.56	1.55	2.27	0.22	1.14	1.28
0.89	3.67	9.09	0.55	1.53	2.22	0.21	1.13	1.27
0.88	3.46	8.33	0.54	1.51	2.17	0.20	1.12	1.25
0.87	3.28	7.69	0.53	1.49	2.13	0.19	1.11	1.23
0.86	3.12	7.14	0.52	1.48	2.08	0.18	1.11	1.22
0.85	2.99	6.67	0.51	1.46	2.04	0.17	1.10	1.20
0.84	2.86	6.25	0.50	1.44	2.00	0.16	1.09	1.19
0.83	2.76	5.88	0.49	1.43	1.96	0.15	1.09	1.18
0.82	2.66	5.56	0.48	1.41	1.92	0.14	1.08	1.16
0.81	2.57	5.26	0.47	1.40	1.89	0.13	1.07	1.15
0.80	2.49	5.00	0.46	1.38	1.85	0.12	1.07	1.14
0.79	2.41	4.76	0.45	1.37	1.82	0.11	1.06	1.12
0.78	2.34	4.55	0.44	1.36	1.79	0.10	1.05	1.11
0.77	2.28	4.35	0.43	1.34	1.75	0.09	1.05	1.10
0.76	2.22	4.17	0.42	1.33	1.72	0.08	1.04	1.09
0.75	2.16	4.00	0.41	1.32	1.69	0.07	1.04	1.08
0.74	2.11	3.85	0.40	1.31	1.67	0.06	1.03	1.06
0.73	2.06	3.70	0.39	1.29	1.64	0.05	1.03	1.05
0.72	2.02	3.57	0.38	1.28	1.61	0.04	1.02	1.04
0.71	1.98	3.45	0.37	1.27	1.59	0.03	1.02	1.03
0.70	1.94	3.33	0.36	1.26	1.56	0.02	1.01	1.02
0.69	1.90	3.23	0.35	1.25	1.54	0.01	1.01	1.01
0.68	1.86	3.12	0.34	1.24	1.52			
0.67	1.83	3.03	0.33	1.23	1.49			

Conversion $= 1 - \dfrac{C_A}{C_{A_0}}$

Conclusions from this table
- CFSTR is always larger than PFR for same Q & conversion $r_A > 0$
- Vol ratio incr. w/ reaction order
- It will be shown that for the same reactor vol PFR is always more efficient than CFSTR

waste water

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SIZE COMPARISON BETWEEN N EQUAL-SIZED CSTRs CONNECTED IN SERIES AND SINGLE PFR (FIRST-ORDER REACTION) - Eq. 1

Conversion	Ratio of V_T to V_{PFR} for N =					
	1	2	3	4	6	10
0.999	144.6201	8.8662	3.9087	2.6772	1.8781	1.4408
0.99	21.4976	3.9087	2.3723	1.8781	1.5041	1.2701
0.98	12.5255	3.1038	2.0583	1.6965	1.4101	1.2238
0.97	9.2208	2.7226	1.8978	1.6002	1.3585	1.1978
0.96	7.4560	2.4853	1.7932	1.5360	1.3234	1.1797
0.95	6.3424	2.3181	1.7169	1.4884	1.2969	1.1659
0.94	5.5686	2.1913	1.6575	1.4509	1.2758	1.1548
0.93	4.9960	2.0905	1.6092	1.4201	1.2583	1.1456
0.92	4.5531	2.0078	1.5688	1.3941	1.2434	1.1376
0.91	4.1991	1.9380	1.5342	1.3717	1.2304	1.1307
0.90	3.9087	1.8781	1.5041	1.3520	1.2190	1.1245
0.89	3.6656	1.8259	1.4775	1.3345	1.2087	1.1190
0.88	3.4587	1.7797	1.4537	1.3188	1.1995	1.1139
0.87	3.2802	1.7385	1.4322	1.3045	1.1910	1.1093
0.86	3.1244	1.7014	1.4127	1.2915	1.1833	1.1051
0.85	2.9870	1.6678	1.3949	1.2795	1.1762	1.1012
0.84	2.8648	1.6370	1.3784	1.2685	1.1695	1.0975
0.83	2.7553	1.6088	1.3632	1.2582	1.1633	1.0941
0.82	2.6566	1.5827	1.3490	1.2486	1.1575	1.0909
0.81	2.5670	1.5585	1.3358	1.2396	1.1521	1.0878
0.80	2.4853	1.5360	1.3234	1.2311	1.1470	1.0850
0.79	2.4105	1.5150	1.3117	1.2231	1.1421	1.0823
0.78	2.3416	1.4953	1.3008	1.2156	1.1375	1.0797
0.77	2.2779	1.4767	1.2904	1.2084	1.1331	1.0772
0.76	2.2189	1.4592	1.2805	1.2016	1.1289	1.0749
0.75	2.1640	1.4427	1.2712	1.1952	1.1250	1.0726
0.74	2.1128	1.4270	1.2623	1.1890	1.1212	1.0705
0.73	2.0649	1.4122	1.2538	1.1831	1.1175	1.0684
0.72	2.0200	1.3980	1.2456	1.1774	1.1140	1.0664
0.71	1.9778	1.3846	1.2379	1.1720	1.1106	1.0645
0.70	1.9380	1.3717	1.2304	1.1668	1.1074	1.0627
0.69	1.9005	1.3594	1.2233	1.1618	1.1043	1.0609
0.68	1.8650	1.3476	1.2164	1.1570	1.1013	1.0592
0.67	1.8313	1.3363	1.2098	1.1523	1.0984	1.0575
0.66	1.7994	1.3255	1.2034	1.1478	1.0955	1.0559
0.65	1.7690	1.3151	1.1973	1.1435	1.0928	1.0544
0.64	1.7401	1.3051	1.1914	1.1393	1.0902	1.0529
0.63	1.7125	1.2954	1.1856	1.1353	1.0876	1.0514
0.62	1.6862	1.2861	1.1801	1.1313	1.0851	1.0500
0.61	1.6611	1.2771	1.1747	1.1275	1.0827	1.0486
0.60	1.6370	1.2685	1.1695	1.1238	1.0804	1.0472
0.59	1.6140	1.2601	1.1645	1.1202	1.0781	1.0459
0.58	1.5919	1.2519	1.1596	1.1167	1.0759	1.0447
0.57	1.5706	1.2441	1.1548	1.1133	1.0737	1.0434
0.56	1.5503	1.2365	1.1502	1.1100	1.0716	1.0422
0.55	1.5306	1.2291	1.1457	1.1068	1.0696	1.0410
0.54	1.5117	1.2219	1.1413	1.1037	1.0676	1.0399
0.53	1.4935	1.2149	1.1371	1.1006	1.0656	1.0387
0.52	1.4760	1.2082	1.1329	1.0976	1.0637	1.0376
0.51	1.4591	1.2016	1.1289	1.0947	1.0619	1.0365

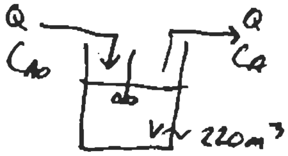
Conversion	Ratio of V_T to V_{PFR} for N =					
	1	2	3	4	6	10
0.50	1.4427	1.1952	1.1250	1.0919	1.0601	1.0355
0.49	1.4269	1.1889	1.1211	1.0891	1.0583	1.0344
0.48	1.4116	1.1829	1.1174	1.0864	1.0565	1.0334
0.47	1.3968	1.1769	1.1137	1.0837	1.0548	1.0324
0.46	1.3825	1.1712	1.1101	1.0811	1.0532	1.0315
0.45	1.3686	1.1655	1.1066	1.0786	1.0515	1.0305
0.44	1.3551	1.1600	1.1032	1.0761	1.0499	1.0296
0.43	1.3420	1.1547	1.0998	1.0737	1.0483	1.0286
0.42	1.3294	1.1494	1.0965	1.0713	1.0468	1.0277
0.41	1.3170	1.1443	1.0933	1.0690	1.0453	1.0269
0.40	1.3051	1.1393	1.0902	1.0667	1.0438	1.0260
0.39	1.2934	1.1344	1.0871	1.0644	1.0423	1.0251
0.38	1.2821	1.1296	1.0841	1.0622	1.0409	1.0243
0.37	1.2711	1.1249	1.0811	1.0600	1.0395	1.0235
0.36	1.2604	1.1204	1.0782	1.0579	1.0381	1.0227
0.35	1.2500	1.1159	1.0754	1.0558	1.0368	1.0219
0.34	1.2398	1.1115	1.0726	1.0538	1.0354	1.0211
0.33	1.2299	1.1072	1.0698	1.0518	1.0341	1.0203
0.32	1.2202	1.1029	1.0671	1.0498	1.0328	1.0195
0.31	1.2108	1.0988	1.0645	1.0479	1.0316	1.0188
0.30	1.2016	1.0947	1.0619	1.0459	1.0303	1.0180
0.29	1.1926	1.0907	1.0593	1.0441	1.0291	1.0173
0.28	1.1838	1.0868	1.0568	1.0422	1.0279	1.0166
0.27	1.1752	1.0830	1.0543	1.0404	1.0267	1.0159
0.26	1.1669	1.0792	1.0519	1.0386	1.0255	1.0152
0.25	1.1587	1.0755	1.0495	1.0368	1.0244	1.0145
0.24	1.1507	1.0719	1.0472	1.0351	1.0232	1.0138
0.23	1.1429	1.0683	1.0449	1.0334	1.0221	1.0132
0.22	1.1352	1.0648	1.0426	1.0317	1.0210	1.0125
0.21	1.1277	1.0613	1.0403	1.0301	1.0199	1.0119
0.20	1.1204	1.0579	1.0381	1.0284	1.0188	1.0112
0.19	1.1132	1.0546	1.0360	1.0268	1.0178	1.0106
0.18	1.1061	1.0513	1.0338	1.0252	1.0167	1.0100
0.17	1.0992	1.0481	1.0317	1.0237	1.0157	1.0094
0.16	1.0925	1.0449	1.0296	1.0221	1.0147	1.0088
0.15	1.0858	1.0418	1.0276	1.0206	1.0137	1.0082
0.14	1.0794	1.0387	1.0256	1.0191	1.0127	1.0076
0.13	1.0730	1.0356	1.0236	1.0176	1.0117	1.0070
0.12	1.0667	1.0327	1.0216	1.0162	1.0107	1.0064
0.11	1.0606	1.0297	1.0197	1.0147	1.0098	1.0058
0.10	1.0546	1.0268	1.0178	1.0133	1.0088	1.0053
0.09	1.0487	1.0240	1.0159	1.0119	1.0079	1.0047
0.08	1.0429	1.0211	1.0140	1.0105	1.0070	1.0042
0.07	1.0372	1.0184	1.0122	1.0091	1.0061	1.0036
0.06	1.0316	1.0156	1.0104	1.0078	1.0052	1.0031
0.05	1.0261	1.0129	1.0086	1.0064	1.0043	1.0026
0.04	1.0207	1.0103	1.0068	1.0051	1.0034	1.0020
0.03	1.0154	1.0077	1.0051	1.0038	1.0025	1.0015
0.02	1.0102	1.0051	1.0034	1.0025	1.0017	1.0010
0.01	1.0050	1.0025	1.0017	1.0013	1.0008	1.0005

Examples on last page

PERFORMANCE COMPARISON BETWEEN N CFSTRs CONNECTED IN SERIES AND A SINGLE PFR, BOTH WITH THE SAME RETENTION TIME (FIRST ORDER REACTION) - Eq. 2

PFR Conversion	Conversion in N CFSTRs for N =				
	1	2	4	6	10
0.00	0.00000	0.00000	0.00000	0.00000	0.00000
0.01	0.00995	0.00998	0.00999	0.00999	0.01000
0.02	0.01980	0.01990	0.01995	0.01997	0.01998
0.03	0.02956	0.02978	0.02989	0.02993	0.02996
0.04	0.03922	0.03961	0.03980	0.03987	0.03992
0.05	0.04879	0.04939	0.04969	0.04979	0.04988
0.06	0.05827	0.05912	0.05955	0.05970	0.05982
0.07	0.06766	0.06880	0.06939	0.06960	0.06976
0.08	0.07696	0.07844	0.07921	0.07947	0.07968
0.09	0.08618	0.08804	0.08900	0.08933	0.08960
0.10	0.09532	0.09758	0.09877	0.09918	0.09950
0.11	0.10437	0.10709	0.10852	0.10901	0.10940
0.12	0.11334	0.11654	0.11824	0.11882	0.11929
0.13	0.12224	0.12596	0.12794	0.12861	0.12916
0.14	0.13106	0.13533	0.13761	0.13840	0.13903
0.15	0.13980	0.14466	0.14726	0.14816	0.14889
0.16	0.14847	0.15394	0.15689	0.15791	0.15874
0.17	0.15706	0.16319	0.16650	0.16764	0.16858
0.18	0.16559	0.17239	0.17608	0.17736	0.17840
0.19	0.17405	0.18155	0.18564	0.18707	0.18822
0.20	0.18243	0.19067	0.19518	0.19675	0.19804
0.21	0.19076	0.19975	0.20470	0.20643	0.20784
0.22	0.19901	0.20879	0.21420	0.21609	0.21763
0.23	0.20721	0.21780	0.22367	0.22573	0.22741
0.24	0.21534	0.22676	0.23313	0.23536	0.23718
0.25	0.22341	0.23569	0.24256	0.24497	0.24695
0.26	0.23142	0.24458	0.25197	0.25457	0.25670
0.27	0.23938	0.25344	0.26136	0.26415	0.26645
0.28	0.24727	0.26226	0.27073	0.27372	0.27619
0.29	0.25512	0.27104	0.28008	0.28328	0.28592
0.30	0.26290	0.27979	0.28941	0.29282	0.29564
0.31	0.27064	0.28850	0.29872	0.30235	0.30535
0.32	0.27832	0.29718	0.30801	0.31187	0.31505
0.33	0.28596	0.30583	0.31728	0.32137	0.32475
0.34	0.29354	0.31445	0.32654	0.33086	0.33443
0.35	0.30108	0.32303	0.33577	0.34033	0.34411
0.36	0.30857	0.33159	0.34499	0.34980	0.35378
0.37	0.31602	0.34011	0.35419	0.35925	0.36344
0.38	0.32343	0.34860	0.36337	0.36868	0.37310
0.39	0.33079	0.35707	0.37253	0.37811	0.38274
0.40	0.33811	0.36551	0.38168	0.38752	0.39238
0.41	0.34539	0.37392	0.39081	0.39692	0.40201
0.42	0.35264	0.38230	0.39992	0.40631	0.41164
0.43	0.35984	0.39066	0.40902	0.41569	0.42125
0.44	0.36702	0.39899	0.41810	0.42506	0.43086
0.45	0.37415	0.40730	0.42717	0.43441	0.44046
0.46	0.38126	0.41558	0.43622	0.44376	0.45006
0.47	0.38833	0.42385	0.44526	0.45310	0.45965
0.48	0.39538	0.43209	0.45429	0.46242	0.46923
0.49	0.40239	0.44031	0.46330	0.47174	0.47881

PFR Conversion	Conversion in N CFSTRs for N =				
	1	2	4	6	10
0.50	0.40938	0.44851	0.47230	0.48105	0.48838
0.51	0.41635	0.45669	0.48129	0.49035	0.49795
0.52	0.42329	0.46485	0.49027	0.49964	0.50751
0.53	0.43021	0.47300	0.49924	0.50893	0.51707
0.54	0.43710	0.48113	0.50820	0.51820	0.52662
0.55	0.44398	0.48925	0.51715	0.52747	0.53617
0.56	0.45085	0.49736	0.52609	0.53674	0.54571
0.57	0.45769	0.50545	0.53502	0.54600	0.55525
0.58	0.46452	0.51353	0.54395	0.55525	0.56479
0.59	0.47135	0.52161	0.55287	0.56450	0.57432
0.60	0.47816	0.52967	0.56178	0.57375	0.58385
0.61	0.48496	0.53774	0.57069	0.58299	0.59338
0.62	0.49176	0.54579	0.57960	0.59223	0.60291
0.63	0.49856	0.55385	0.58851	0.60147	0.61244
0.64	0.50535	0.56190	0.59742	0.61071	0.62196
0.65	0.51215	0.56996	0.60633	0.61995	0.63149
0.66	0.51896	0.57802	0.61524	0.62919	0.64102
0.67	0.52577	0.58608	0.62415	0.63844	0.65055
0.68	0.53259	0.59416	0.63307	0.64769	0.66009
0.69	0.53942	0.60224	0.64200	0.65695	0.66962
0.70	0.54627	0.61034	0.65094	0.66621	0.67917
0.71	0.55315	0.61846	0.65989	0.67548	0.68871
0.72	0.56005	0.62660	0.66885	0.68476	0.69827
0.73	0.56697	0.63476	0.67783	0.69406	0.70783
0.74	0.57394	0.64295	0.68683	0.70337	0.71741
0.75	0.58094	0.65117	0.69586	0.71269	0.72699
0.76	0.58799	0.65943	0.70490	0.72204	0.73659
0.77	0.59509	0.66774	0.71398	0.73141	0.74620
0.78	0.60225	0.67609	0.72309	0.74080	0.75583
0.79	0.60947	0.68450	0.73224	0.75022	0.76548
0.80	0.61678	0.69297	0.74144	0.75968	0.77515
0.81	0.62416	0.70151	0.75068	0.76917	0.78485
0.82	0.63165	0.71014	0.75999	0.77871	0.79458
0.83	0.63924	0.71886	0.76935	0.78830	0.80433
0.84	0.64697	0.72768	0.77879	0.79794	0.81413
0.85	0.65483	0.73663	0.78832	0.80765	0.82397
0.86	0.66286	0.74571	0.79794	0.81743	0.83386
0.87	0.67108	0.75495	0.80768	0.82730	0.84381
0.88	0.67951	0.76438	0.81754	0.83726	0.85382
0.89	0.68821	0.77403	0.82756	0.84734	0.86391
0.90	0.69721	0.78393	0.83776	0.85756	0.87410
0.91	0.70657	0.79413	0.84817	0.86794	0.88439
0.92	0.71637	0.80471	0.85884	0.87852	0.89481
0.93	0.72672	0.81574	0.86982	0.88933	0.90539
0.94	0.73777	0.82735	0.88121	0.90045	0.91618
0.95	0.74973	0.83973	0.89312	0.91196	0.92722
0.96	0.76297	0.85314	0.90573	0.92400	0.93862
0.97	0.77810	0.86808	0.91937	0.93679	0.95051
0.98	0.79642	0.88556	0.93467	0.95080	0.96318
0.99	0.82159	0.90832	0.95331	0.96721	0.97736



$X = 0.99 \rightarrow \therefore \frac{C_A}{C_{A0}} = 0.01 \quad \therefore \frac{C_{A0}}{C_A} = 100$

ENCE 4323

Examples of Reactors Connected in Series

Example 1. A first-order reaction takes place in a single CFSTR whose volume is 220 m^3 with a conversion of 99%. For the same conversion, what total volume of a series of identical CFSTRs is needed if N = 2, N = 3, N = 4 for the same flow rate?

- identical N reactors in series: $\frac{C_{A0}}{C_{AN}} = (1+k\bar{t})^N$
- initial condition N=1: $\frac{1}{0.01} = 100 = (1+k\bar{t}_1)^1 \therefore k\bar{t}_1 = 99$
- N=2: $100 = (1+k\bar{t}_2)^2 \therefore k\bar{t}_2 = 9$ $\quad \frac{C_{A2}}{C_{A0}} = 0.01$ (b/c same performance)

$$\frac{(V/Q)_{N=1}}{(V/Q)_{N=2}} = \frac{99}{9} = 11$$

$$\frac{220}{(V)_{N=2}} = 20 m^3$$

$$(V_T)_{N=2} = 40 m^3$$

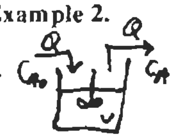
- N=3: $\frac{C_{A3}}{C_{A0}} = 0.01 \therefore \frac{C_{A0}}{C_{A3}} = 100; \ 100 = (1+k\bar{t}_3)^3 \rightarrow k\bar{t}_3 = 3.64$

$\frac{(k\bar{t})_{N=1}}{(k\bar{t})_{N=3}} = \frac{99}{3.64}; \ \frac{220}{V_3} = 27.19; \ V_3 = 8.09; \ V_{T(N=3)} = 24.3 m^3$

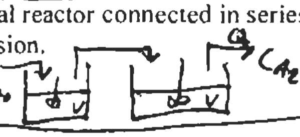
N=∞: $\frac{\bar{t}_{CFSTR}}{\bar{t}_{PFR}} = \frac{\frac{C_{A0}}{C_A} - 1}{\ln\left(\frac{C_{A0}}{C_A}\right)}; \ \frac{V_{CFSTR}}{V_{PFR}} = \frac{99}{\ln(100)}; \ \frac{220}{V_{PFR}} = 21.5 \rightarrow V_{PFR} = 10.2 m^3$

+ con't on Aug 30 notes

Example 2. Assume 80 % reactant removal is obtained in a single CFSTR. Add an identical reactor connected in series to treat the same flow rate. If the reaction is first order, find the new total conversion.

Initial: 

$X = 0.8 \therefore \frac{C_A}{C_{A0}} = 0.2 \rightarrow \frac{C_{A0}}{C_A} = 5$

Final 

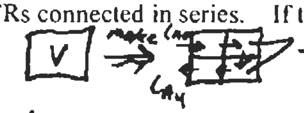
N=1: $5 = (1+k\bar{t})^1 \rightarrow k\bar{t} = 4$

Final situation: $\frac{C_{A0}}{C_{A2}} = (1+k\bar{t})^2$ $\boxed{k\bar{t} = 4 \text{ b/c identical reactors}}$ $\rightarrow \frac{C_{A2}}{C_{A0}} = 0.04 \therefore X_{N=2} = 0.96$

Example 3. Assume 80 % reactant removal is obtained in a single CFSTR. To improve the reactor performance the plant operator divided this reactor into four identical CFSTRs connected in series. If the reaction is first order, and the flow rate is the same, find the new conversion.

$X = 0.8 \therefore \frac{C_A}{C_{A0}} = 0.2 \rightarrow k\bar{t}_1 = 4$ (see above)

$kt_4 = \frac{kt_1}{4} = 1$ ← b/c Vol. change



$\frac{C_{A0}}{C_{A4}} = (1+k\bar{t}_4)^4; \ \frac{C_{A0}}{C_{A4}} = (1+1)^4 = 16; \ X = 0.938$

Example 4. Assume 80 % reactant removal is obtained in a single CFSTR. To increase the plant capacity the plant operator divided this reactor into four identical CFSTRs connected in series. If the reaction is first order and the overall plant removal is to be maintained at 80 %, find the new flow rate that can be handled by this system.

$\frac{C_A}{C_{A0}} = 0.2 \therefore k\bar{t} = 4$

$\frac{C_{A0}}{C_{A4}} = (1+k\bar{t}_2)^4; \ 5 = (1+k\bar{t}_2)^4; \ k\bar{t}_2 = 0.495; \ (k\bar{t}_2)_T = 4(0.495) = 1.981$

$\frac{C_{A4}}{C_{A0}} = 0.2$

$\frac{1}{0.2} = 5$

$$\frac{\cancel{k}\left(\frac{\cancel{V}}{Q_1}\right)_{N=1}}{\cancel{k}\left(\frac{\cancel{V}}{Q_2}\right)_{N=4}} = \frac{4}{1.981} \rightarrow Q_2 = 2.02(Q_1)$$

99.9% removal → fraction remaining, $\frac{N}{N_o} = 10^{-3}$ → $\frac{N_o}{N} = 10^3$ → $\log \frac{N_o}{N} = 3$

which is why it is called 3 log removal

wastewater

ENCE 4323 9-1-10

Drinking Water Standards

- US Safe Drinking Water Act - Passed in 1974, amended in 1996
  - o Establishes maximum contaminant levels (MCL), which are enforceable.
  - o EPA establishes MCL goals not enforceable
  - o Despite shortcomings, SDWA is the most advanced standard in the world.

- The SDWA establishes two kinds of standards: primary and secondary
  - o The National **Primary** Drinking Water Regulations - posted on blackboard
    - Federal law
    - Apply to public water systems
    - Specify contaminants that may have adverse effect on human health
    - Specify for each contaminant a MCL or a treatment technique (TT).
    - For - Disinfectants - Disinfectant by products - Inorganic chemicals - Organic " - Microorganisms - Radionucleid
  - o The National **Secondary** Drinking Water Regulations: proposed & promulgated by the EPA.
    - Based on aesthetic (as opposed to health) considerations
    - Not federally enforceable
    - Some states have adopted them as enforceable.
    - such as too much iron which can stain or discolor clothes, bath tubs, etc...
    - + Turbidity & microorg. use TT ("cloudyness of water")
- June 29, 1989: USEPA enacted the Surface Water Treatment Rule (SWTR) which applies to public water systems that use
  - o surface water as a source
  - o groundwater that might become contaminated by surface water

- SWTR stipulates removal or inactivation of disease-causing microorganisms.
  - o Removal: filtration
  - o Inactivation: disinfection

- SWTR emphasizes treatment techniques rather than MCLs for microorganisms (see handout "EPA National Primary Drinking water Standards").

Waterborne diseases

- Drinking water in the US is the safest in the world. No cholera in the US; however, cholera is prevalent in Central and South America.
- Between 1971 and 1988: more than 500 outbreaks of waterborne diseases in the US. 110 000 people were infected.
- Most frequently reported: acute gastrointestinal illness (AGI).
- Protozoa of concern: Giardia lamblia and Cryptosporidium
  - o Giardiasis: severe intestinal ailment that causes severe dehydration, weight loss, and fatigue.
  - o Giardiasis is associated with **unfiltered surface water** that has not been disinfected sufficiently to kill protozoan cysts.
  - o Cryptosporidium has recently been linked to human illness. Little information on treatment needed to kill it.

- Bacteria and viruses of concern:
  - o Coliform bacteria
  - o Legionella: Legionnaire's disease and Pontiac fever
  - o Heterotrophic plate count (HPC) bacteria
  - o Waterborne viruses

- Giardia cysts and viruses are among the most resistant waterborne pathogens. Absence of coliforms **does not** indicate absence of Giardia, viruses, and Legionella.

SWTR Requirements

- FACT: Properly designed and operated filtration and disinfection systems
  - Can routinely achieve 99.9% reduction of viable Giardia cysts and 99.99% reduction in viruses.
  - Have **never** been implicated in waterborne Giardiasis or illnesses caused by viruses.

- SWTR requires that treatment of surface water or groundwater under the direct influence of surface water must remove:
  - 99.9% (3-log removal) of Giardia: fraction remaining = 10^{-3}
  - 99.99% (4-log removal) of viruses: Fraction remaining = 10^{-4}

- SWTR: disinfection **must** be included in treatment of **all** surface water

Disinfectants/Disinfection By-products Rule (D/DBP Rule)

- Published in *Federal Register*, 12/16/98
- Use of best available technology to remove trihalomethanes: chloroform, bromodichloromethane, dibromochloromethane, bromoform (MCL = 0.080 mg/L); haloacetic acids: trichloroacetic acid, dichloroacetic acid, monochloroacetic acid, dibromoacetic acid, monobromoacetic acid (MCL = 0.060 mg/L); bromate ion (MCL = 0.010 mg/L); and chlorite ion (MCL = 1.0 mg/L).
- Enhanced Coagulation Requirements
  - Required % removals of TOC by enhanced coagulation to limit formation of DBPs.

Source water TOC, mg/L	Source water alkalinity, mg/L as $CaCO_3$		
	0-60	>60-120	>120
>2 - 4	35	25	15
>4 - 8	45	35	25
>8	50	40	30

Enhanced Surface Water Treatment Rule (Federal register, Vol. 63, No. 241, 12/16/98)

- Minimum removal of *Cryptosporidium* is 2 log.
- Turbidity < 0.3 ntu in at least 95% of monthly measurements, and must never exceed 1.0 ntu.
- Systems with filtration that meet turbidity requirements are granted 2 log reduction credit of *Cryptosporidium*.
- All filtration systems serving over 10,000 people must monitor turbidity continuously and report violations to state on monthly basis.

Donald Sacolleman

ENCE 4323

Assignment #4 – Due 12/1/10

100
– 50 (5 days late)
50/100

Solve the following problems:

1. A conventional activated sludge plant must treat a primary effluent flow rate of 4000 m^3/d, with a soluble BOD_5 of 200 mg/l. The organic loading in the aerator is 0.3 kg BOD_5/(d.kg VSS), and the ratio V/Q is 6 hours. Find the concentration of volatile suspended solids in the aerator.

2. A wastewater treatment plant is planning to provide for separate anaerobic sludge digestion for its primary sludge. The plant receives an influent wastewater with the following characteristics: Average flow = 8000 m^3/d. Amount of suspended solids removed in the primary sedimentation = 200 mg/L. Volatile matter in the settled solids = 75% by mass. Water in untreated sludge = 96% by mass. Specific gravity of mineral solids = 2.6. Specific gravity of organic solids = 1.3. Find the required digester volume using an SRT of 12 d.

3. A wastewater treatment plant is planning to provide for anaerobic sludge digestion for a mixture of primary sludge and waste activated sludge. The raw sludge characteristics are the following: **Primary sludge:** Specific gravity = 1.003; Solids concentration = 3.4 % by mass; Design flow = 420 m^3/d. **Waste activated sludge:** Specific gravity = 1.005; Solids concentration = 5.66 % by mass; Design flow = 250 m^3/d. The mixture of raw primary and waste sludge has specific gravity = 1.004, and it is sent to a thickener to increase the solids concentration to 7% by mass. Calculate the percent reduction in sludge mass.

4. Determine the liquid volume of sludge before and after digestion and the percent reduction for 500 kg (dry basis) of primary sludge with the following characteristics:

	Primary	**Digested**
Solids %	5	10
Volatile matter, %	60	60 (destroyed)
Specific gravity of fixed solids	2.5	2.5
Specific gravity of volatile solids	≈1.0	≈1.0

Wastewater H.W. 4 Donald Sevoltsman p. 1 of 4

1) $Q = 4000 \ m^3/d$, $S_i = 200 \ mg/l$, Food to micro. org. ratio $= 0.3 \frac{kg \ BOD_5}{d \cdot kg \ VSS}$

$\frac{V}{Q} = 6$ hrs. solve for X.

25/25

Sol'n: $V_r = \bar{t}Q = 4000 \ m^3/d \ (6 \ hrs)\left(\frac{1 \ d}{24 \ hrs}\right) = 1000 \ m^3$ ✓

$$X = \frac{4000 \ m^3/d \left(200 \ \frac{mg \ BOD_5}{l}\right)\left(\frac{1 \ g}{1000 \ mg}\right)\left(\frac{kg}{1000 \ g}\right)}{0.3 \ \frac{kg \ BOD_5}{d \cdot kg \ VSS}\left(1000 \ m^3\right)\left(\frac{kg}{1000 \ g}\right)\left(\frac{g}{1000 \ mg}\right)} = \boxed{2667 \ \frac{mg \ VSS}{l}}$$

2) $8000\ m^3/d = Q$

25/25

S.S. removal in sedimentation $= 200\ mg/l = 0.2\ kg/m^3$

$t_c = 12\ d$, 4% solids, 96% water, 75% of volatile solids

25% mineral, $G_s(\text{mineral}) = 2.6$, $G_s(\text{Volatile}) = 1.3$

3% volatile, 1% mineral, 96% water $\quad \frac{1}{\rho_{sl}} = \frac{0.03}{1300} + \frac{0.01}{2600} + \frac{0.96}{1000}$

$\rightarrow \rho_{sl} = 1013.25\ \frac{\text{kg wet sludge}}{m^3}$

$\frac{M_s}{V_T} = 0.04\left(1013.25\ \frac{kg}{m^3}\right) = 40.53\ \frac{\text{kg solids}}{m^3\ \text{sludge}}$

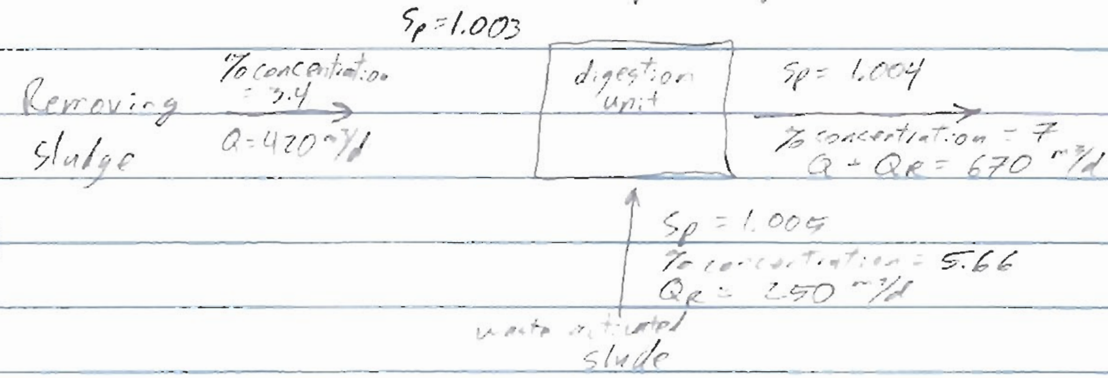
$Q = \frac{\left(0.2\ \frac{\text{kg solids}}{m^3}\right)\left(8000\ m^3/d\right)}{40.53\ \frac{\text{kg solids}}{m^3\ \text{sludge}}} = 39.48\ \frac{m^3\ \text{wet sludge}}{d}$

$V = 12d\left(39.48\ m^3/d\right) = \boxed{473.8\ m^3}$ ✓

w.w. H.W.4 Donald Jerolleman p. 3 of 4

3)

25/25



% reduction in sludge mass = $100\,(1 - f_m)$

$$f_m = \frac{(M_T)_1}{(M_T)_0} = \frac{1 + \left(\frac{F_w}{F_s}\right)_F}{1 + \left(\frac{F_w}{F_s}\right)_0}$$

% solids w/ digestion

$$\% \text{ solids} = \frac{420}{670}(3.4) + \frac{250}{670}(5.66) = 4.24\% \text{ of solids}$$

$$f_m = \frac{1 + \frac{1 - 0.07}{0.07}}{1 + \frac{1 - 0.0424}{0.0424}} = 0.61$$

% reduction in sludge mass = $100\,(1 - 0.61) = 39.47\%$

4) S_s (all solids in primary sludge): $\frac{1}{S_s} = \frac{F_f}{S_f} + \frac{F_v}{S_v} = \frac{0.4}{2.5} + \frac{0.6}{1} \rightarrow \boxed{S_s = 1.32}$

25/25

S_{sl} (of primary sludge): $\frac{1}{S_{sl}} = \frac{F_s}{S_s} + \frac{F_w}{S_w} = \frac{0.05}{1.32} + \frac{0.92}{1} \Rightarrow \boxed{S_{sl} = 1.01}$

Liquid Vol. before digestion: $V = \frac{M_s}{\rho_{sl} F_s} = \frac{500 \text{ kg}\cdot\text{d solids}}{1010 \frac{\text{kg wet sludge}}{\text{m}^3 \text{ wet sludge}}\left(0.05 \frac{\text{kg dry solids}}{\text{kg wet sludge}}\right)}$

$= \boxed{9.9 \text{ m}^3 \text{ wet sludge}}$ ✓

After Digestion

Fraction of volatile solids = 40% remains $F_v = \frac{0.4(0.6)}{0.4 + 0.4(0.6)} = \boxed{0.375}$ ✓

$\therefore \boxed{F_f = 0.625}$ ✓

S_s (Digested solids) $\Rightarrow \frac{1}{S_s} = \frac{0.625}{2.5} + \frac{0.375}{1} \rightarrow \boxed{S_s = 1.6}$

S_{ds} (Digested sludge) $\Rightarrow \frac{1}{S_{ds}} = \frac{0.1}{1.6} + \frac{0.9}{1} \rightarrow \boxed{S_{ds} = 1.04}$ ✓

Vol. of digested sludge:

$V = \frac{0.4(500 \text{ kg}) + 0.6(0.4)(500 \text{ kg})}{1040 \text{ kg/m}^3 (0.1)} = \boxed{3.1 \text{ m}^3 \text{ Digested sludge}}$ ✓

% Vol. Reduction $= \frac{9.9 - 3.1}{9.9}(100) = \boxed{68.7\%}$ ✓

			Assesment Elements	Layout	Mixing	Flocculation	Settling	Filtration	Disinfection	Hydraulic grad.	Total
		a	Identification of design problem	4	4	4	4	4	4	4	
		b	Appropriate assumptions are made	4	4	4	4	4	4	4	
		c	Calculations are complete and acurate	4	4	4	4	4	4	4	
		d	Equipment brochures are presented and used	4	4	4	4	4	4	4	
		e	Quality and accuracy of design drawings	4	4	4	4	4	4	4	
		f	Quality of technical report	4	4	4	4	4	4	4	
			Total fraction (= Total/24)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
	Maximum grade		Weight	0.1	0.08	0.19	0.20	0.28	0.05	0.10	1.00
			Score out of 4.0	0.40	0.32	0.76	0.80	1.12	0.20	0.40	4.00
			Assesment Elements	Layout	Mixing	Flocculation	Settling	Filtration	Disinfection	Hydraulic grad.	Total
Group 7	Jerolleman Jr,Donald Francis	a	Identification of design problem	4	4	4	4				
		b	Appropriate assumptions are made	4	3	4	2				
	Nguyen,Thuyan Duong	c	Calculations are complete and acurate	3	3	3	3				
		d	Equipment brochures are presented and used	4	2	4	2				
	Olds,Roderick Duane	e	Quality and accuracy of design drawings	2	0	1	0				
		f	Quality of technical report	4	3	3	3				
	Ory,Joseph Alphonse		Total fraction (= Total/24)	0.88	0.63	0.79	0.58	0.00	0.00	0.00	
			Weight	0.1	0.08	0.19	0.20	0.28	0.05	0.10	1.00
			Score out of 4.0	0.35	0.20	0.60	0.47	0.00	0.00	0.00	1.62

ENCE 4323 – Fall 2010

Group 7

Donald Jerolleman

Theyan Nguyen

Joseph Ory

Roderick Olds

TASK 4 – High Rate Tube Settler Sedimentation Basins

It should be the same number as flocculator

- Choose two parallel sedimentation tanks (Q for each = $0.\cancel{775}$ .3875 $\frac{m^3}{s}$)
- Manufacturer: Brentwood (http://www.brentwood-ind.com/water/tubesettlersystems.html)
  - Model Number: IFR-6030
    - Overflow Rate (O.R.): $6.11\,\frac{m}{hr}$
    - Vertical Height: 0.762 m
    - Length: 0.889 m
    - $\Theta = 60°$
    - Plan View Area per tube (A_x): 0.003629 m^2
    - Recommendation: $V_H \leq 0.015\,\frac{m}{s}$

YES

8,331 #[illegible]

- $A = \frac{Q}{O.R.} = \frac{\cancel{0.775}\ .3875\,\frac{m^3}{s}}{6.11\frac{m}{h}\times\frac{h}{3600\,s}} = \cancel{456.6}\ 228.3\,m^2$
- Select W = 12 m → L = A/W = 456.6 / 12 = 38.05 m → Use L = 39 m   15.025   20
  - Actual Area = 12 x 39 = ~~468~~ m^2 240
  - .3875/240 = 5.81 m/hr Q/A_{actual} = 0.775/468 = 5.96 m/hr → table 10.6 OKAY
  - $V_L = \frac{Q}{A \times \sin\theta} = \frac{\cancel{0.775}\ .3875}{\cancel{468}\times\sin 60}$ (240 x sin 60) $= \cancel{0.001912}\,\frac{m}{s} = \cancel{0.11473}\,\frac{m}{min}$ → Table 10.6 OKAY
    0.001864 = 0.11186

- Hydraulic Radius of Tube Settler
  - $R = \frac{A_x}{P} = \frac{0.003629}{4\times0.06024} = 0.0151\,m$
  - $R_e = \frac{V_L \times R}{\vartheta_{5°C}} = \frac{0.001912\times0.0151}{1.519\times10^{-6}} = 19.01 < 50\ \therefore OKAY$
  - $F_r = \frac{V_L^2}{g\times R} = \frac{0.001912^2}{9.81\times0.0151} = 0.0000247 > 0.00001\ \therefore OKAY$

- Detention Time
  - $t = \frac{l}{V_L} = \frac{0.889}{0.001912} = 464.96\,s = 7.75\,min$ → Table 10.6 OKAY

- Total Tank Length
  - $L_t = \frac{39}{0.75} = 52\,m$

- Depth of Water   water
  - $d = \frac{Q}{W\times V_H} = \frac{\cancel{0.775}\ .3875}{12\times0.015} = \cancel{4.31}\ 2.15\,m$

ce depth. If you ~~reduce~~ increase the # of tanks, this will reduce the flow rate and the depth.
depth under the tubes, + vertical tube
height + distance between bottom of
[illegible] and top of tube, + [illegible]

tank depth

Sludge collection [illegible]

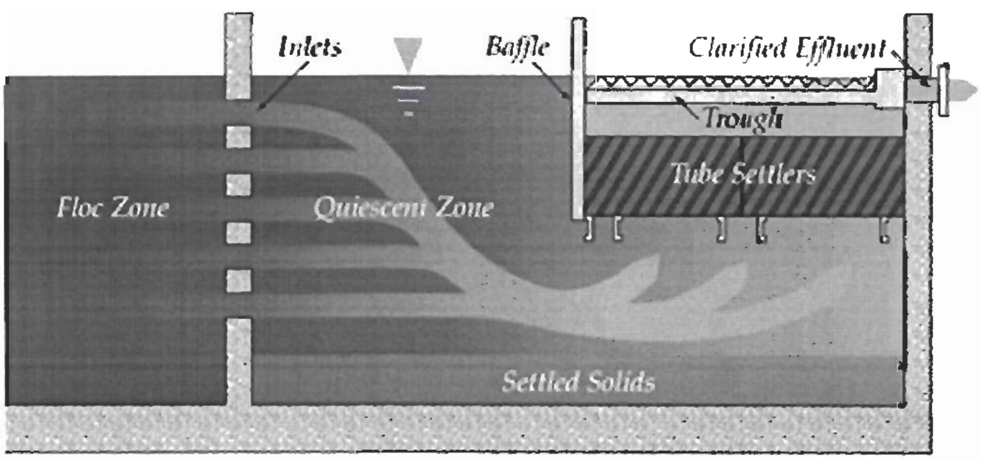
- Total Weir Length
  - Assume 6 launders → 10 weirs x(39 m/weir) = 390 m
  - Weir Loading = $\frac{0.775\times3600\frac{s}{hr}}{390} = 7.15\frac{m^2}{hr}$ → Table 10.6 OKAY
- Check Tank Reynolds Number under tube settler
  - $R = \frac{12\times4.31}{(2\times12)+(2\times4.31)} = 1.585$
  - $R_e = \frac{0.001912\times1.5855}{1.519\times10^{-6}} = 2000 < 20000 \therefore OKAY$

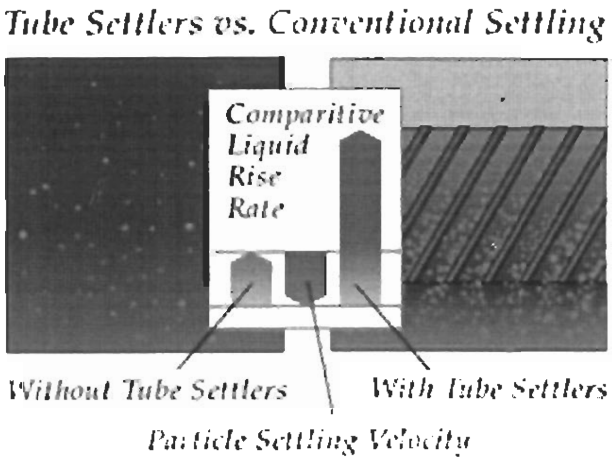
TUBE SETTLER	VERTICAL HEIGHT	TUBE LENGTH**	TYPICAL DESIGN APPLICATION RATE	AVAILABLE SETTLING AREA****
20"	20.00" (508 mm)	23.09" (586 mm)	1.50 gpm/ft2 (3.66 m/hr)	10.3 ft2/ft2 (10.3 m2/m2)
IFR-6024*	24.00" (610 mm)	27.71" (704 mm)	2.00 gpm/ft2*** (4.89 m/hr)	12.3 ft2/ft2 (12.3 m2/m2)
IFR-6030*	30.00" (762 mm)	34.64" (880 mm)	2.50 gpm/ft2 (6.11 m/hr)	15.4 ft2/ft2 (15.4 m2/m2)
IFR-6036*	36.00" (914 mm)	41.57" (1056 mm)	3.00 gpm/ft2 (7.33 m/hr)	18.5 ft2/ft2 (18.5 m2/m2)
IFR-6041*	41.00" (1041 mm)	47.34" (1202 mm)	3.50 gpm/ft2 (8.56 m/hr)	21.0 ft2/ft2 (21.0 m2/m2)

* Brentwood Tube Settlers
** Tube length is based on an angle of 60°
*** Some states are limited by the 10 States Standards application rate of 2.0 gpm/ft2 (4.89 m/hr)
**** Tube settling area per plan area

Tube Settler Systems For Clarification

Tube settlers and parallel plates increase the settling capacity of circular clarifiers and/or rectangular sedimentation basins by reducing the vertical distance a floc particle must settle before agglomerating to form larger particles.





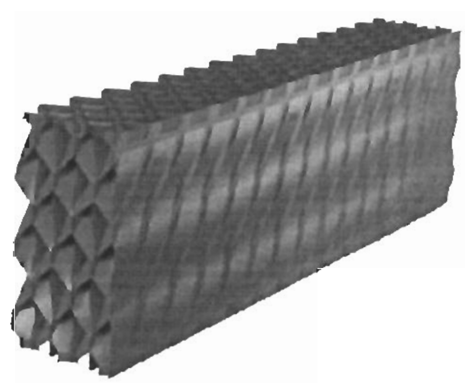
Tube settlers use multiple tubular channels sloped at an angle of 60° and adjacent to each other, which combine to form an increased effective settling area. This provides for a particle settling depth that is significantly less than the settling depth of a conventional clarifier, reducing settling times.

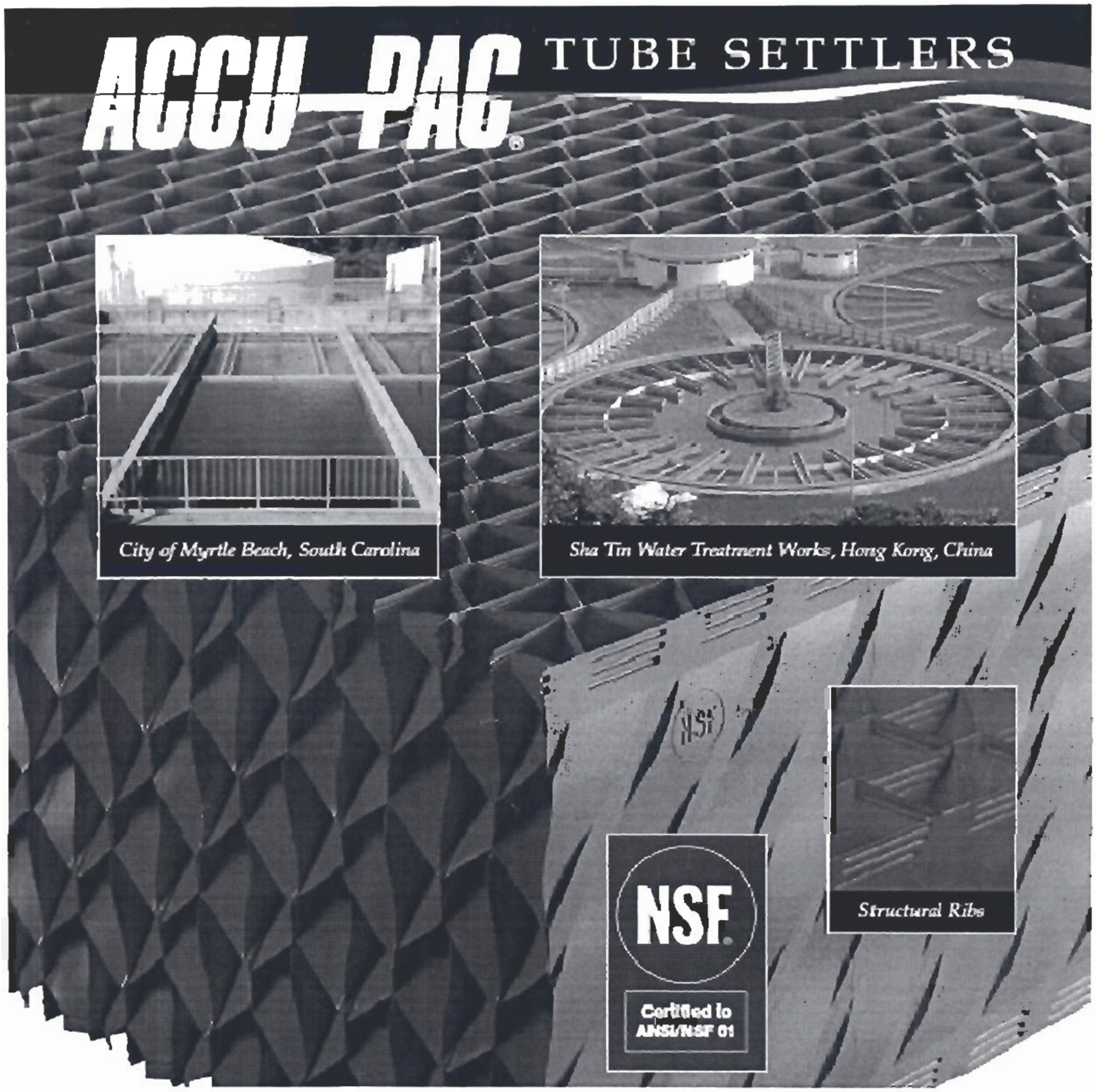
Tube settlers capture the settleable fine floc that escapes the clarification zone beneath the tube settlers and allows the larger floc to travel to the tank bottom in a more settleable form. The tube settler's channel collects solids into a compact mass which promotes the solids to slide down the tube channel.

Why Tube Settlers?

Tube settlers offer an inexpensive method of upgrading existing water treatment plant clarifiers and sedimentation basins to improve performance. They can also reduce the tankage/footprint required in new installations or improve the performance of existing settling basins by reducing the solids loading on downstream filters.

Made of lightweight PVC, tube settlers can be easily supported with minimal structures that often incorporate the effluent trough supports. They are available in a variety of module sizes and tube lengths to fit any tank geometry, with custom design and engineering offered by the manufacturer.





City of Myrtle Beach, South Carolina

Sha Tin Water Treatment Works, Hong Kong, China

Structural Ribs

1996

1. A rapid sand filter has a sand bed 76.2 cm deep, with an initial porosity = 0.41. Pertinent data are:

Sieve size	% Weight Retained	Particle size (m)	Settling Velocity m/s
14-20	0.44	0.0010060	0.15252
20-28	14.33	0.0007111	0.10671
28-32	43.22	0.0005422	0.07747
32-35	27.02	0.0004572	0.06206
35-42	9.76	0.0003834	0.04854
42-48	4.22	0.0003225	0.03752
48-60	0.54	0.0002707	0.02847
60-65	0.29	0.0002274	0.02134
65-100	0.13	0.0001777	0.01391

Find the depth of the expanded bed if the backwash rate is 10.3 $L/s.m^2$.

2004

2. The head losses in a clean dual-media filter operating under declining rate conditions are the following:

- Laminar, clean filter: $h_L = 78\ V$
- Turbulent losses: $h_T = 3000\ V^2$

In all these expressions V is the filtration rate in m^3/s per m^2. The maximum available head for filtration is 3.0 m. An orifice plate is placed in the influent pipe to limit the maximum filtration rate. The dirty-filter laminar loss at the minimum filtration rate is 2.0 m. What is the orifice loss at the maximum filtration rate? The min filtration rate is 2.7×10^{-3} m/s

3. The initial bed depth in a rapid sand filter is 1.0 m and the initial sand porosity is 0.43. The elevation of the edge of the wash water troughs, through which the washwater overflows into the trough, is 0.35 m above the sand surface. If all particles had a uniform size and the backwash rate is 0.35 cm/s, find the particle size of the largest particle that will be washed off into the troughs during filter backwash. Assume a water kinematic viscosity of $1.3101 \times 10^{-6}\ m^2/s$, and a sand specific gravity of 2.5. $n = 4.5$

1996

PART B

Solve the following two problems:

1. A rapid sand filter has a sand bed 76.2 cm in depth. Pertinent data are: $f = 0.41$

Sieve size	% Weight Retained	Particle size (m)	Settling Velocity m/s	f_e	$p/(1-f)$
14-20	0.44 (0.0044)	0.0010060	0.15252	*0.55152*	*0.00981*
20-28	14.33	0.0007111	0.10671	*0.59660*	*0.35523*
28-32	43.22	0.0005422	0.07747	*0.64016*	*1.20108*
32-35	27.02	0.0004572	0.06206	*0.67216*	*0.82418*
35-42	9.76	0.0003834	0.04854	*0.70949*	*0.33596*
42-48	4.22	0.0003225	0.03752	*0.75086*	*0.16938*
48-60	0.54	0.0002707	0.02847	*0.79786*	*0.02671*
60-65	0.29	0.0002274	0.02134	*0.85014*	*0.01935*
65-100	0.13	0.0001777	0.01391	*0.93404*	*0.01971*
				$\Sigma =$	*2.96141*

Find the depth of the expanded bed if the backwash rate is 10.2 L/s.m². Pertinent equations are:

$$v = 10.2\ \frac{L/s}{m^2} \times \frac{1\ m^3}{1000\ L}\ ;\ v = 0.0102\ m/s$$

$$f_e = \left(\frac{v}{v_s}\right)^{\frac{1}{n}}$$

$$L_e = L(1-f)\sum_{i=1}^{m}\frac{p_i}{1-f_{e_i}}\ ;\ L_e = 0.762\times(1-0.41)\times 2.96$$

$$\boxed{L_e = 1.33\ m}$$

where L is the thickness of unexpanded filter media during filtration, L_e is the thickness of expanded filter media during backwashing, f is the porosity of the unexpanded filter media during normal filter operation, p_i is the fraction of particles of a stated size in layer *i*, f_{ei} is the porosity of each expanded layer *i* during backwashing, v is the backwash rate, v_s is the settling velocity of single particles, n is the exponent in Richardson and Zaki equation (n = 4.5).

2. The rate of flow through an ideal clarifier is 2.0 MGD, the detention time is 1 h, and its depth is 10 ft. If a full-length movable tray is set at a depth greater than 7 feet below the water surface, determine the percentage of discrete particles with a settling velocity v_s = 3 ft/h that are removed. Plot removal efficiency vs. depth.

1.

using $\left(\frac{v}{v_s}\right)^{1/4.5}$

% Weight Retained	d (m)	Re	Cd	Settling Velocity Assumed m/s	Settling Velocity Computed m/s	fe	x/(1-fe)
0.44	0.0010060	87.83783	0.93333	0.15252	0.15252	0.54821	0.00974
14.33	0.0007111	43.44028	1.34765	0.10671	0.10671	0.59350	0.35252
43.22	0.0005422	24.04549	1.94990	0.07747	0.07747	0.63728	1.19155
27.02	0.0004572	16.24358	2.56186	0.06206	0.06206	0.66947	0.81747
9.76	0.0003834	10.65441	3.51168	0.04854	0.04854	0.70704	0.33315
4.22	0.0003225	6.92707	4.94452	0.03752	0.03752	0.74869	0.16792
0.54	0.0002707	4.41197	7.20800	0.02847	0.02847	0.79604	0.02648
0.29	0.0002274	2.77741	10.78126	0.02134	0.02134	0.84874	0.01917
0.13	0.0001777	1.41494	19.82393	0.01391	0.01391	0.93340	0.01952
						Σ =	2.93750
						Le =	1.32099

2. ✓ Laminar, clean $h_L = 78\,V$, V in m/s

✓ Turbulent $h_T = 3000\,V^2$ (except orifice)

✓ Max. available head = 3 m

✓ Dirty-filter laminar loss is 2 m, $\boxed{\text{and orifice loss} = 0.978\text{ m}}$

✓ at a min filtration rate of 2.7×10^{-3} m/s

What is the orifice loss at max. rate?

At min. filtration rate:

$$3\,m = \underbrace{2.0}_{\text{laminar}} + \underbrace{3000 \times (2.7 \times 10^{-3})^2}_{\text{turb.}} + \underbrace{K_o\,(2.7 \times 10^{-3})^2}_{0.978}$$

$$\boxed{K_o = 134\,174.2}$$

10

At max filtration rate.

$$3.0 = 78\,V_{max} + 3000\,V_{max}^2 + 134\,172.2\,V_{max}^2$$

$$137\,172.2\,V_{max}^2 + 78\,V_{max} - 3.0 = 0$$

$$V_{max}^2 + 5.686 \times 10^{-4}\,V_{max} - 2.187 \times 10^{-5} = 0$$

$$V_{max} = 4.4 \times 10^{-3}\text{ m/s}$$

$$= 380\text{ m/d} \quad \text{OK.}$$

15

$$\text{Orifice loss} = 134\,174.2 \times (4.4 \times 10^{-3})^2$$

$$= \underline{2.6\text{ m}}$$

10

3. If backwash rate = $0.35 \frac{cm}{s}$ find particle size of the largest particle that will be removed from the filter bed by backwashing.

$\nu = 1.3101 \times 10^{-6}\ m^2/s$, $SP = 2.5$

Elevation of troughs = 1.35 m

Initial bed depth = 1.0

Initial sand porosity = 0.43

initial bed depth

$$\varepsilon_e = 1 - \frac{L}{L_e}(1-\varepsilon) \quad ; \quad \varepsilon_e = 1 - \frac{1.0}{1.35}(1-0.43)$$

expanded bed depth

initial porosity

$$\varepsilon_e = 0.578$$

given

Richardson & Zaki : $v = v_s \, \varepsilon_e^{\,n}$; $v_s = \dfrac{0.35}{0.578^{4.5}}$; $v_s = 4.124 \frac{cm}{s}$

given backwash rate

$d_p \cong 0.0003\ m$, $\underline{d_p = 3 \times 10^{-2}\ cm}$

From chart, we are in the transition region

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COMPLETE-MIX ACTIVATED SLUDGE WITH SLUDGE RECYCLE
SUMMARY OF EQUATIONS
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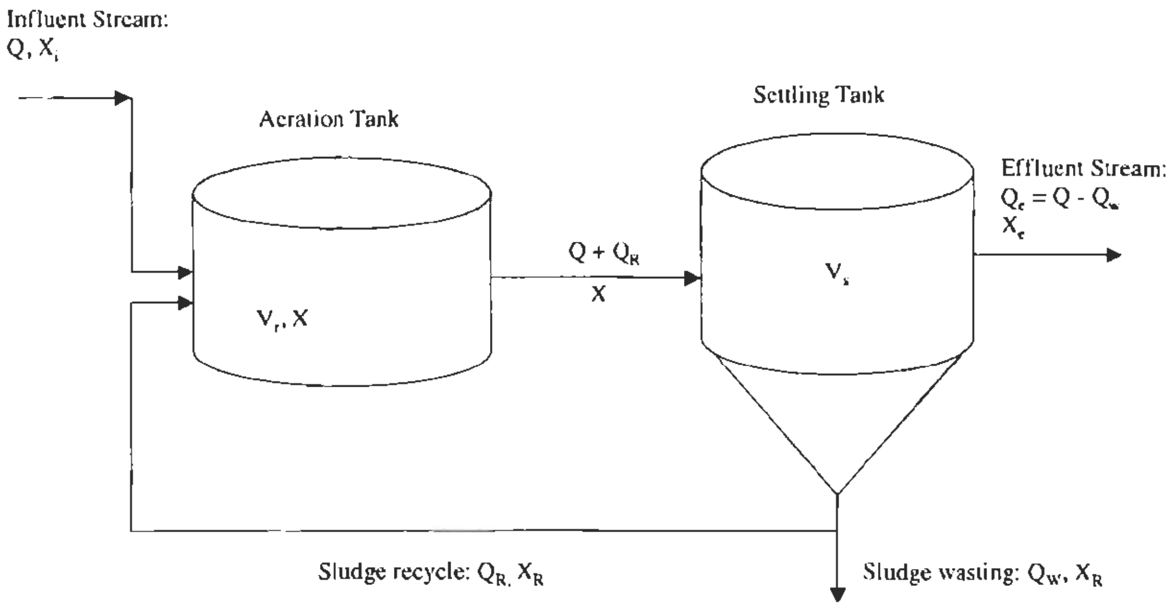

- Mass balance on suspended solids in the aerator, steady state conditions:

$$V_r r_g + QX_i = (Q + Q_R)X - Q_R X_R \tag{1}$$

In the diagram and in Eq. 1:

Q	=	influent flow rate, m^3/d
Q_R	=	recycle flow rate, m^3/d
Q_w	=	waste sludge flow rate, m^3/d
r_g	=	rate of growth of suspended solids, kg SS/kg MLSS.d
V_r	=	reactor (aerator) volume, m^3
V_s	=	settling tank volume, m^3
X	=	MLSS concentration in the aerator, kg/m^3
X_i	=	SS concentration in the influent to the aerator, kg/m^3
X_e	=	SS concentration in the final effluent, kg/m^3
X_R	=	SS concentration in the recycle line, kg/m^3
X_w	=	SS concentration in the waste stream, kg/m^3

- Equilibrium of solids in the system: Mass produced - Mass removed = Accumulation. For a system with no accumulation of solids:

$$V_r r_g + QX_i = Q_w X_R + (Q - Q_w) X_e \tag{2}$$

Equating (1) and (2) and solving for X:

$$X = \frac{X_R(Q_R + Q_w) + X_e(Q - Q_w)}{Q + Q_R} \tag{3}$$

- Dividing through by Q:

$$X = \frac{X_R(\alpha + w) + X_e(1 - w)}{1 + \alpha} \tag{4}$$

where $\alpha = Q_R/Q$, is the recycle ratio
$w = Q_w/Q$, is the wastage ratio

- Definition of solids retention time:

$$\bar{t}_c = \frac{\text{Mass of solids in the system (aerator + settling tank)}}{\text{Rate of solids withdrawal from the system}}$$

Assuming that, under equilibrium conditions, the average concentration of solids in the settling tank is the same as the concentration in the aerator:

$$\bar{t}_c = \frac{XV_r\left(1 + \frac{V_s}{V_r}\right)}{Q_w X_R + (Q - Q_w) X_e} \tag{5}$$

Combining (5) and (2):

$$\bar{t}_c = \frac{X\left(1 + \frac{V_s}{V_r}\right)}{\frac{X_i}{\bar{t}} + r_g} \tag{6}$$

The combination of (5) and (2) can also be written as:

$$QX_i + r_g V_r = \frac{V_r X}{\bar{t}_c}\left(1 + \frac{V_s}{V_r}\right) \tag{7}$$

Equating (1) and (7):

$$\bar{t}_c = \frac{X\,\bar{t}\left(1+\dfrac{V_s}{V_r}\right)}{X-\alpha\left(X_R - X\right)} \tag{8}$$

Solving for α:

$$\alpha = \frac{X\left[1-\dfrac{\bar{t}}{\bar{t}_c}\left(1+\dfrac{V_s}{V_r}\right)\right]}{X_R - X} \tag{9}$$

- Relationship between substrate uptake rate and biomass growth rate:

$$-U = \frac{1}{Y}\left(\frac{r_g}{X}+k_e\right) \tag{10}$$

where	U	=	substrate uptake rate, (kg substrate/d)/kg biomass
	Y	=	yield coefficient, kg biomass/kg substrate
	r_g	=	rate of biomass growth, (kg biomass/m^3)/d
	k_e	=	endogenous respiration coefficient, 1/d

From mass balance on substrate,

$$-U = \frac{S_i - S}{X\left(\dfrac{V_r}{Q}\right)} \tag{10a}$$

Equating (10) to (10a) get:

$$V_r r_g = QY\left(S_i - S\right) - k_e X V_r \tag{11}$$

Replacing (11) in (7) and solving for the hydraulic retention time finally get the following design equation:

$$\bar{t} = \frac{\bar{t}_c\left[X_i + Y\left(S_i - S\right)\right]}{X\left(1+\dfrac{V_s}{V_r}+k_e\bar{t}_c\right)} \tag{12}$$

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(Taken From "Wastewater Treatment Plants, Planning, Design, and Operation," Second edition by Syed Qasim, Technomic Publishing Company)

TABLE 13-3 Description and Design Parameters of Various Activated Sludge Process Modifications

Process Modification	Brief Description	Flow Regime	Sludge Retention Time, θ_c (d)	Food to MO Ratio[a] (d^{-1})	Aerator Loading[b] (kg/m^3d)	MLSS[c] (mg/L)	Aeration Period (h)	Recirculation Ratio Q_r/Q
Conventional	The influent and returned sludge enter the tank at the head end of the basin and are mixed by the aeration system [Figure 13-5(a)].	Plug	5–15	0.2–0.4	0.3–0.6	1500–3000	4–8	0.25–0.5
Tapered aeration	The tapered aeration system is similar to the conventional activated sludge process. The major difference is in arrangement of the diffusers. The diffusers are close together at the influent end where more oxygen is needed. The spacing of diffusers is increased toward the other end of the aeration basin.	Plug	5–15	0.2–0.4	0.3–0.6	1500–3000	4–8	0.25–0.5
Step-feed aeration	The influent is applied at several points in the aeration basin. Generally, the tank is subdivided into three or more parallel channels with around-the-end baffles, and the influent is applied at separate channels or steps. The oxygen demand is uniformly distributed [Figure 13-5(b)].	Plug	5–15	0.2–0.4	0.6–1.0	2000–3500	3–5	0.25–0.75

TABLE 13-3 Description and Design Parameters of Various Activated Sludge Process Modifications—cont'd

Process Modification	Brief Description	Flow Regime	Sludge Retention Time, θ_c (d)	Food to MO Ratio[a] (d^{-1})	Aerator Loading[b] (kg/m^3d)	MLSS[c] (mg/L)	Aeration Period (h)	Recirculation Ratio Q_r/Q
High-purity oxygen	Oxygen is diffused into covered aeration tanks. A portion of gas is wasted from the tank to reduce the concentration of CO_2. The process is suitable for high-strength wastes where space may be limited. Special equipment for generation of oxygen is needed [Figure 13-5(i)].	Complete mix	8–20	0.25–1.0	1.6–3.3	6000–8000	2–5	0.25–0.5

[a]Food-to-microorganism ratio (*F/M*) is kg BOD_5 applied per day per kg of MLVSS in the aeration basin.
[b]Aerator loading is kg of BOD_5 applied per day per cubic meter of aeration capacity.
[c]Generally, the ratio of MLVSS to MLSS is 0.75–0.85.
[d]Values for nitrification tank are based on influent BOD_5 = 50 mg/L.
[e]MLSS varies during fill-and-draw cycles.
[f]Contact tank.
[g]Reaeration or stabilization tank.
Source: Adapted in part from Refs. 4–12.

TABLE 13-3 *Description and Design Parameters of Various Activated Sludge Process Modifications—cont'd*

Process Modification	Brief Description	Flow Regime	Sludge Retention Time, θ_c (d)	Food to MO Ratio[a] (d^{-1})	Aerator Loading[b] (kg/m^3d)	MLSS[c] (mg/L)	Aeration Period (h)	Recirculation Ratio Q_r/Q
Complete-mix aeration	The influent and the returned sludge are mixed and applied at several points along the length and width of the basin. The contents are mixed, and the MLSS flows across the tank to the effluent channel. The oxygen demand and organic loading are uniform along the entire length of the basin [Figure 13-4(c)].	Complete mix	5–15	0.2–0.6	0.8–2.0	3000–6000	3–5	0.25–1.00
Modified aeration	This process is used as an intermediate treatment to reduce the organic loading in subsequent process. It is similar to conventional treatment. Shorter aeration period, low MLSS and high *F/M* ratio are utilized.	Plug	0.2–0.5	1.5–5.0	1.2–2.4	200–1000	1.5–3	0.05–0.25
High-rate aeration	The process is similar to a conventional treatment process. High MLSS concentration and high volumetric loading are applied. This way low mean cell residence time and a high *F/M* ratio are achieved. Aeration period is relatively short. Aeration and mixing is achieved by mechanical mixers.	Plug	3–10	0.4–1.5	2.0–15	3000–6000	2–4	0.5–2.0
Extended aeration (oxidation ditch)	The extended aeration process utilizes a large aeration basin where high population of MO is maintained. It is used for small flows from subdivisions, schools, etc. Prefabricated package plants utilize this process extensively. Oxidation ditch is a variation of extended aeration process. It has a channel in shape of a race track. Rotors are used to supply oxygen and maintain circulation [Figure 13-5(d)].	Complete mix or plug	20–30	0.05–0.15	0.1–0.4	3000–6000	18–36	0.5–2.0
Single-stage nitrification	Carbon oxidation and nitrification are carried out into one aeration basin. High mean cell residence time and low *F/M* ratio are utilized. Aeration period is relatively high.	Plug	10–20	0.05–0.2	0.08–0.3	1500–3500	6–15	0.5–1.5

TABLE 13-3 *Description and Design Parameters of Various Activated Sludge Process Modifications—cont'd*

Process Modification	Brief Description	Flow Regime	Sludge Retention Time, θ_c (d)	Food to MO Ratio[a] (d^{-1})	Aerator Loading[b] (kg/m^3d)	MLSS[c] (mg/L)	Aeration Period (h)	Recirculation Ratio Q_r/Q
Separate-stage nitrification	Two-stage aeration is applied. In the first stage BOD is reduced. The reactor is similar to high-rate aeration. In the second reactor nitrification is achieved. The process may commonly be an add-on to an existing activated sludge plant to enhance nitrification [Figure 13-5(e)].	Plug	2–5 (8–15)[d]	0.5–1.5 (0.1–0.3)[d]	1.2–2.4 (0.3–0.8)[d]	2000–3000 (2000–4000)	1–3 (2–4)	0.2–0.5 (0.2–0.5)
Deep shaft	It is an aerobic biological subsurface wastewater treatment process. A vertical shaft about 100–150 m (330–500 ft) deep is drilled and lined with steel shell. A concentric downcomer brings MLSS, which is aerated and passes into the riser section. The shaft replaces the primary clarifier and aeration basin. The solids/liquid separation is achieved in a flotation tank [Figure 13-5(f)].	Plug	2–5	0.5–1.2	0.5–1.5	4000–7000	0.5–2	0.2–0.5
Sequencing batch reactor	This is a fill-and-draw-type reactor that acts as aeration basin and final clarifier. MLSS remains in the reactor. Primary clarification is generally not needed. Some nitrogen and phosphorus removal is also achieved [Figure 13-5(g)].	Complete-mix	Not applicable	0.05–0.30	0.20–0.70	1500–5000[e]	4–9	Not applicable
Contact stabilization	The activated sludge is mixed with influent in the contact tank in which the organics are absorbed by MO. The MLSS is settled in the clarifier. The returned sludge is aerated in the reaeration basin to stabilize the organics. The process requires approximately 50 percent less tank volume [Figure 13-5(h)].	Plug	5–15	0.2–0.6	1.0–1.2	1000–4000[f] 4000–10000[g]	0.5–1.0[f] 3.0–6.0[g]	0.5–1.0
Kraus process	This is a variation of step aeration process. Used commonly for industrial wastes low in nitrogen. In a separate aeration basin the digester supernatant is mixed with the return sludge to provide needed nutrients. This returned sludge is added into the aeration basin at desired locations.	Plug	5–15	0.3–1.0	0.5–1.5	2000–3000	4–8	0.5–1.0

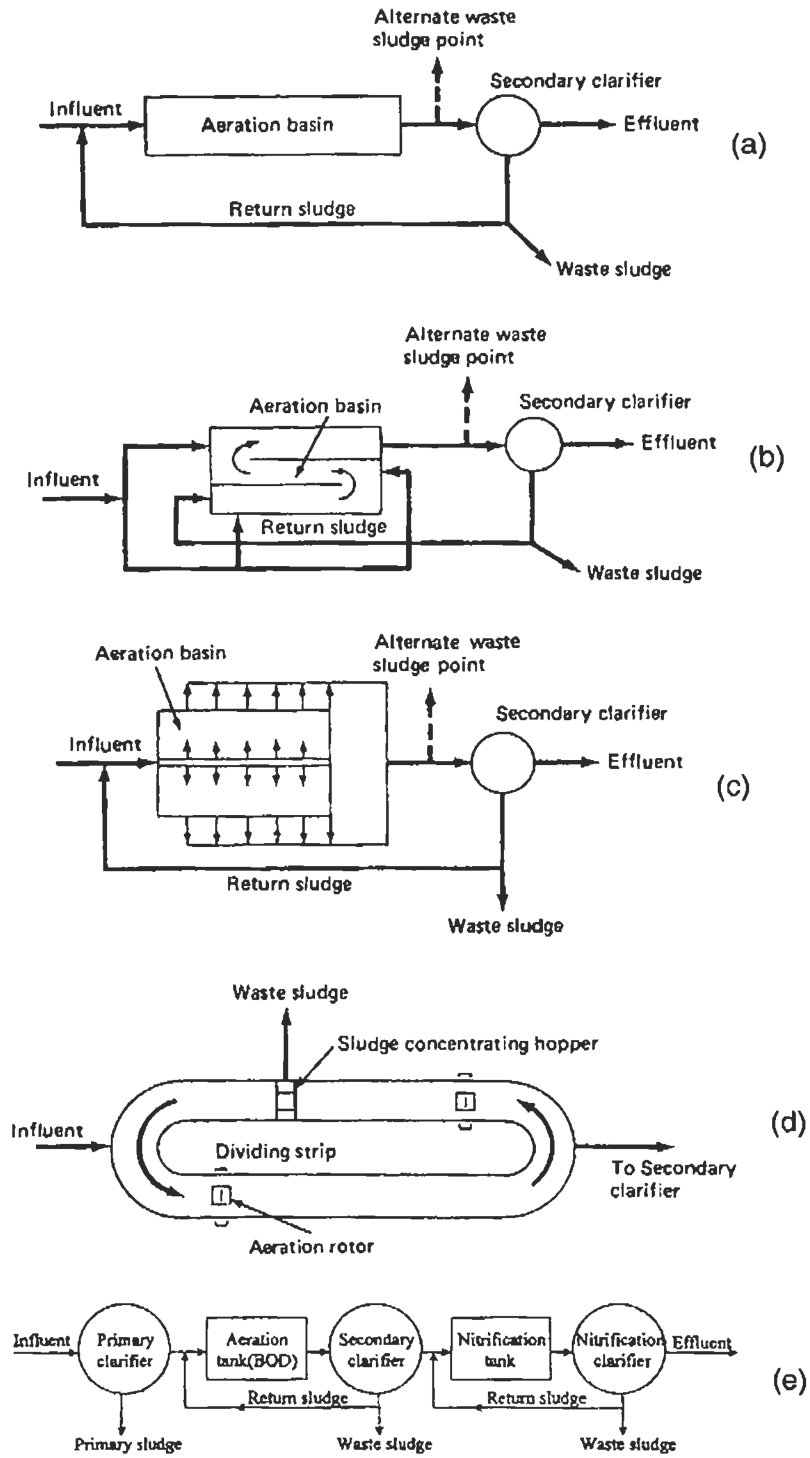

Figure 13-5 Modifications of Activated Sludge Process (from Refs. 4–12): (a) conventional, (b) step aeration, (c) complete mix, (d) oxidation ditch, (e) carbon oxidation and nitrification in separate stage.

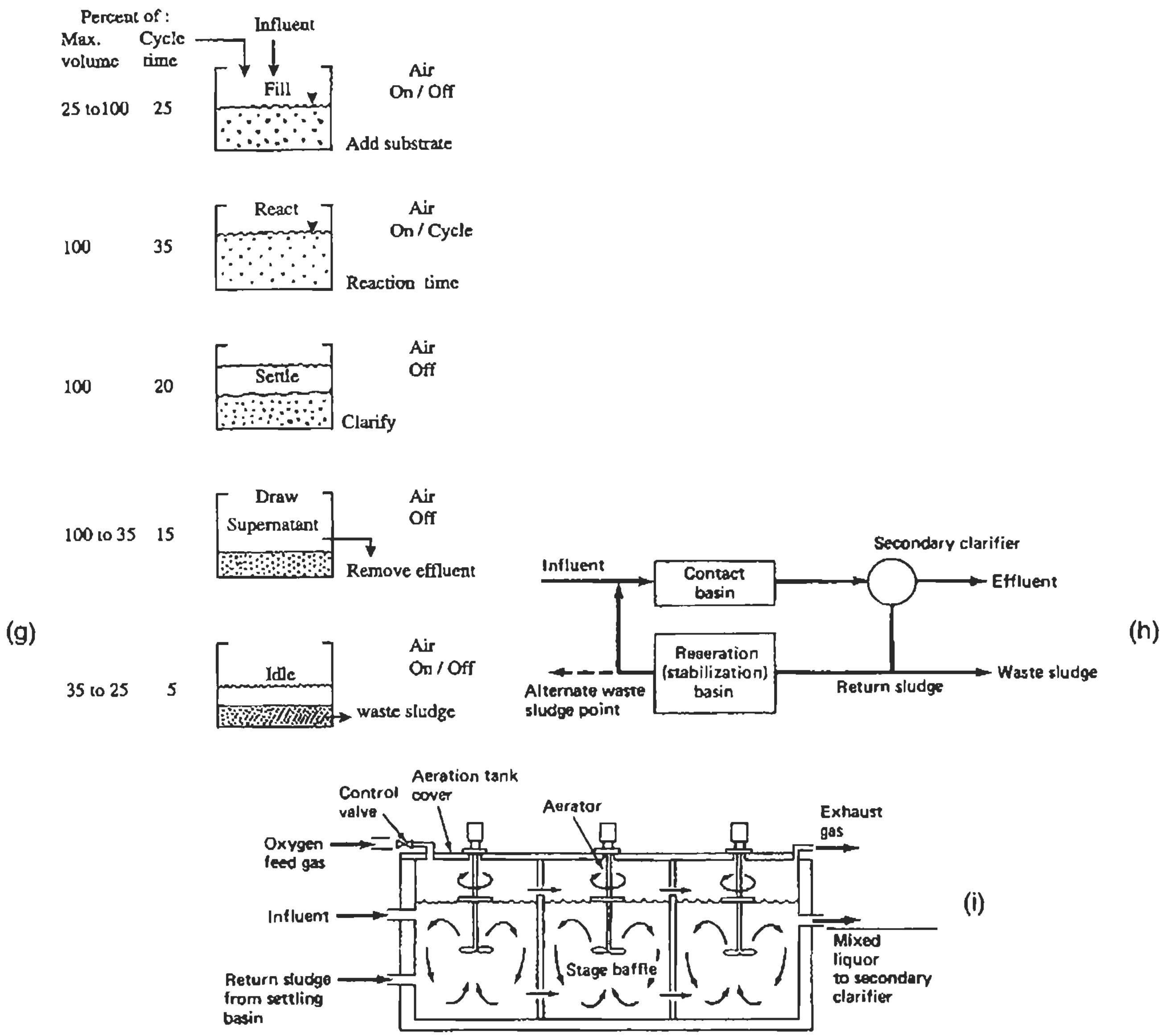

Figure 13-5—cont'd (g) operational stages of sequencing batch reactor, (h) contact stabilization, and (i) multistage pure oxygen system.