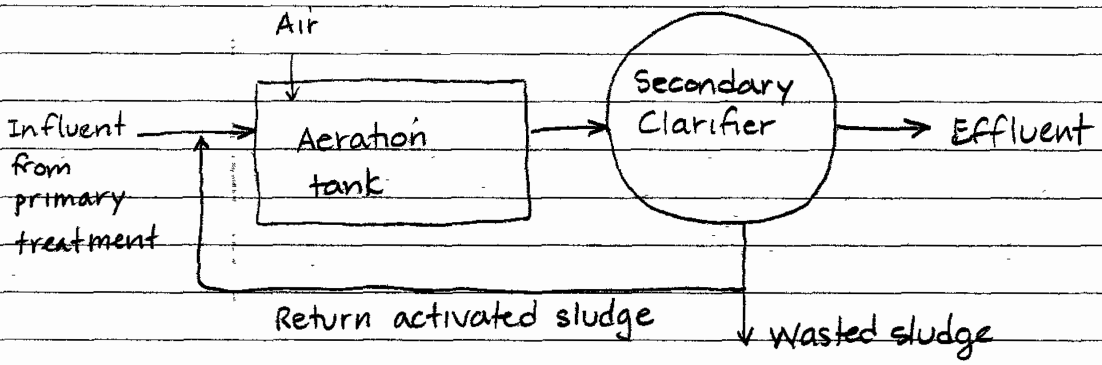
Lecture 20 - Activated sludge treatment



Aeration tank - contains <u>mixed liquor</u> - combination of influent wastewater and return (recycled) activated sludge

Mixed liquor includes

Mixed liquor suspended solids (MLSS)
Volatile suspended solids - ignited at 500°C (MLVSS)
generally taken to represent microorganisms in the wastewater

MLVSS consists of

Bacteria - generally soil rather than enteric bacteria

both aerobes and facultative aerobes

"Slime" - usually in flocs composed of:
extracellular polymeric substances ("slime") - polysaccarides, proteins, nucleic acids, lipids, etc.
live bacterial cells
cell debris (dead, lysed cells)

MLVSS contains (continued)

some free (possibly motile) cells

Protozoa (see page 3)
stalked protozoa attached to flocs
Free-swimming protozoa

Protozoa predate on bacteria
(contribute to K_d)

Nonbiodegradable organic matter
(e.g. coffee grounds, rice hulls)

MLSS also contains

Inert suspended solids or Fixed suspended solids (FSS)
Non-organic solids (e.g. clay particles)

Typical breakdown of raw wastewater

Influent total suspended solids (TSS) - 220 mg/L
Influent VSS - 200 mg/L
Influent FSS - 20 mg/L

Non-biodegradable VSS - 90 mg/L

Typical values for aeration tank mixed liquor

MLSS - 2500 mg/L (1500 - 4000 mg/L)
MLVSS - 2000 mg/L

For an image of activated sludge, please see the Vessman and Hammer textbook, page 539.

Viessman, W., Jr., and M. J. Hammer. *Water Supply and Pollution Control*. 7th ed. Pearson Education, Inc., Upper Saddle River, NJ: Pearson Prentice Hall, 2005. ISBN: 0131409700.

MLSS is key component in AST

MLSS rapidly (20 - 45 minutes) adsorbs organic matter in wastewater influent

Bacteria then solobilize and oxidize organic matter

State of bacteria controls nature of floc

F/M ratio dictates character of bacteria and floc (Figure pg. 5)

At high F/M ratio:

There is excess food

Bacteria are growing fast, slime layer is thin

Bacteria have energy to swim to food and food is plentiful → favors motile bacteria

Result is small floc ("pin floc") that does not settle well in secondary clarifer

Also, excess food carries into effluent → treatment efficiency is poor

Eq 39 from Lecture 17; pg. 12

$$\frac{1}{\theta_c} = Y \frac{F}{M} E - k_d$$

If $\frac{F}{M}$ goes up, E goes down,

all other variables being constant

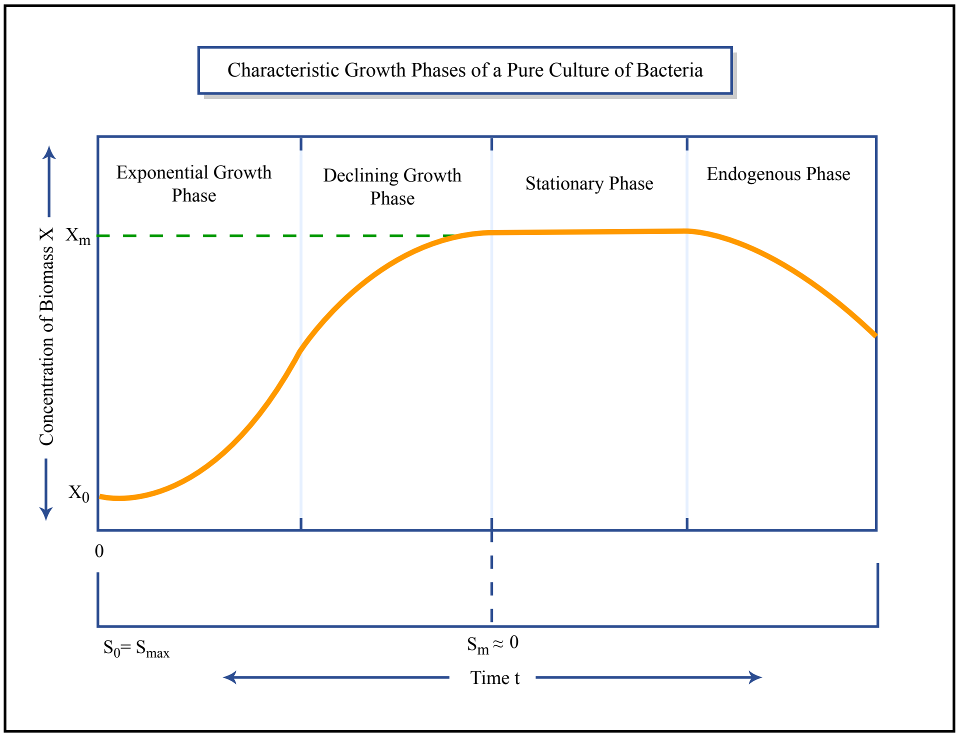


Figure by MIT OCW.

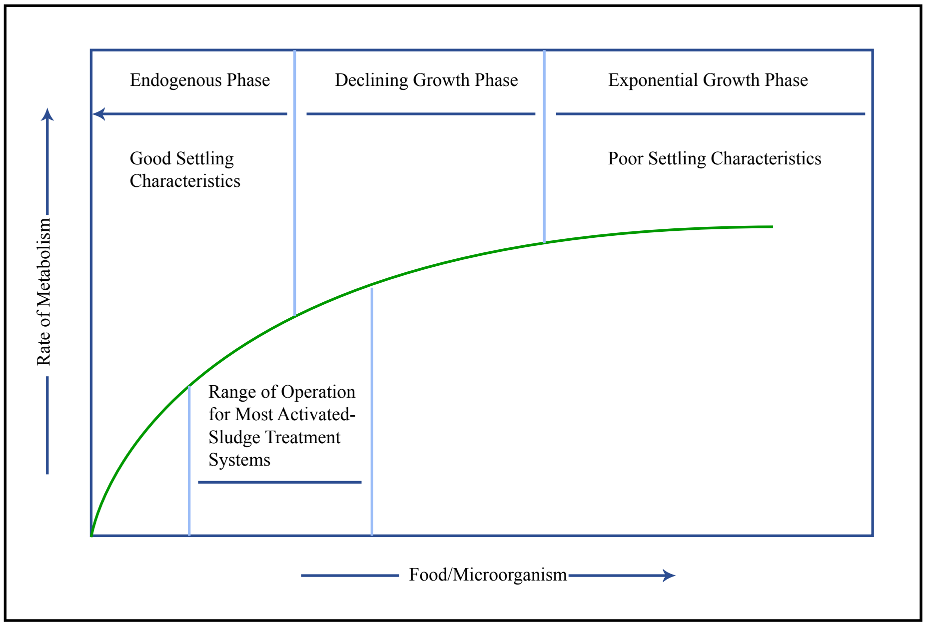


Figure by MIT OCW.

Adpated from: Viessman, W., Jr., and M. J. Hammer. *Water Supply and Pollution Control*. 7th ed. Upper Saddle River, NJ: Pearson Education, Inc., 2005, pp. 530, 534.

At low F/M ratio:

Cells are starved - undergoing endogenous respiration

Cells undergoing relatively high death (lysis), predation, respiration (K_d increased)

Nearly all substrate is consumed (high treatment efficiency)

Cells are mostly attached to flocs

Result is good settling floc → good efficiency in secondary clarifier

Cell slime layers are thickest at start of endogenous growth phase - creates best conditions for flocculation

Slime layers shed by dying cells create a gelatinous "glue" that holds floc together - call zoogloea "animal glue"

zo-eh-glee-ah

But, good aeration is needed for live cells to create polysaccharide gums that make up slime

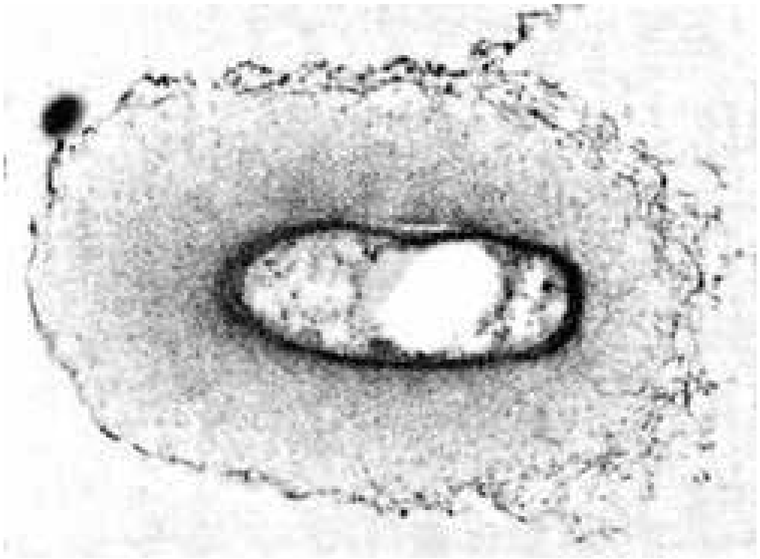
Bottom figure on page 5 shows optimal zone for operating aeration basin: endogenous to declining growth phase, low F/M ratios

Generally favorable conditions:

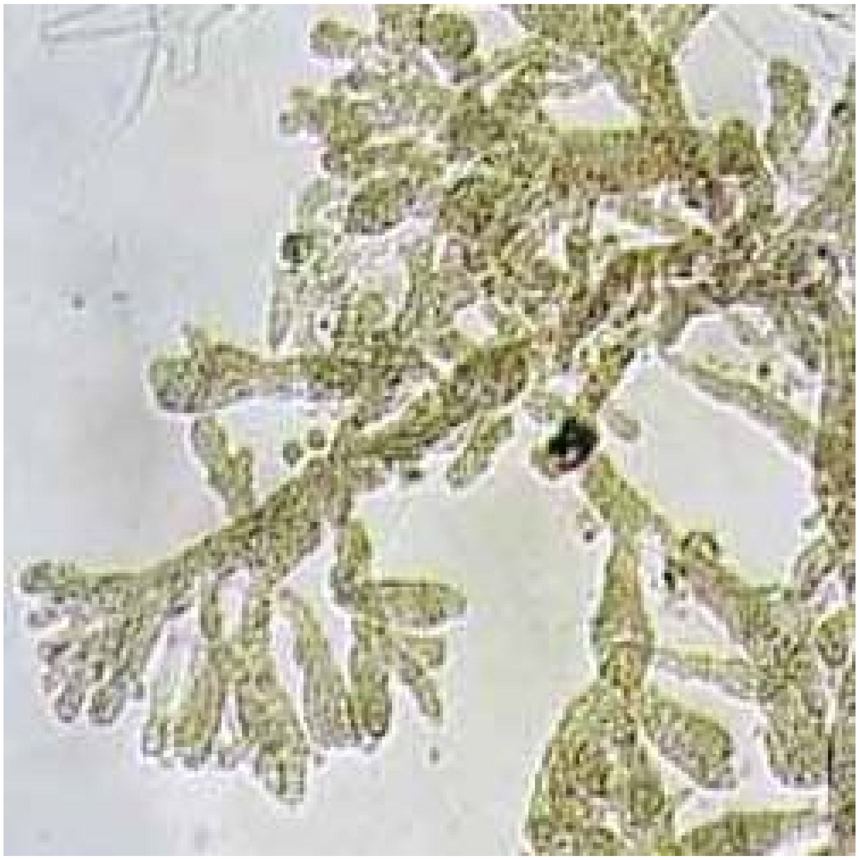
$SRT = \theta_c = 5$ to 15 days

F/M = 0.2 to 0.4 Kg BOD5/ Kg MLSS•day

0.3 to 0.6 Kg COD/ Kg MLSS•day



Bacteria with slime layer



Activated sludge floc with slime

F/M ratio also affects bulking sludge

Growth of filamentous microorganisms cause bulking sludge

Bulking sludge settles poorly, accumulates in secondary clarifier, may even form foam that overtops clarifier sidewalls

Causes are not terribly well understood:

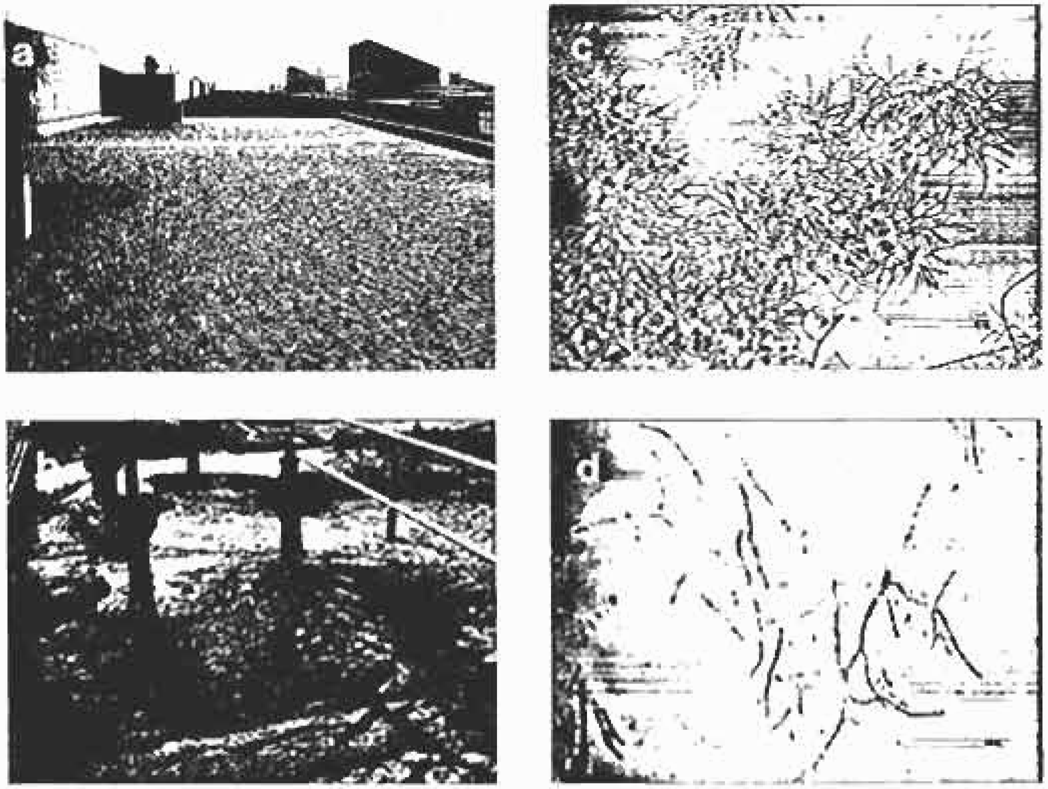
Reynolds and Richards (1996) say high F/M ratio (≳ 0.8 Kg BOD5/Kg MLSS·day) encourage growth of Sphaerotilus and cause bulking sludge

Droste (1997) and M&E say low F/M ratio, long sludge age, high temp. favor Nocardia growth and cause bulking sludge and foaming

activatedsludge.info says same conditions also favor Microthrix parvicella (pg 8) along with low temp, long-chain fatty acid substrates

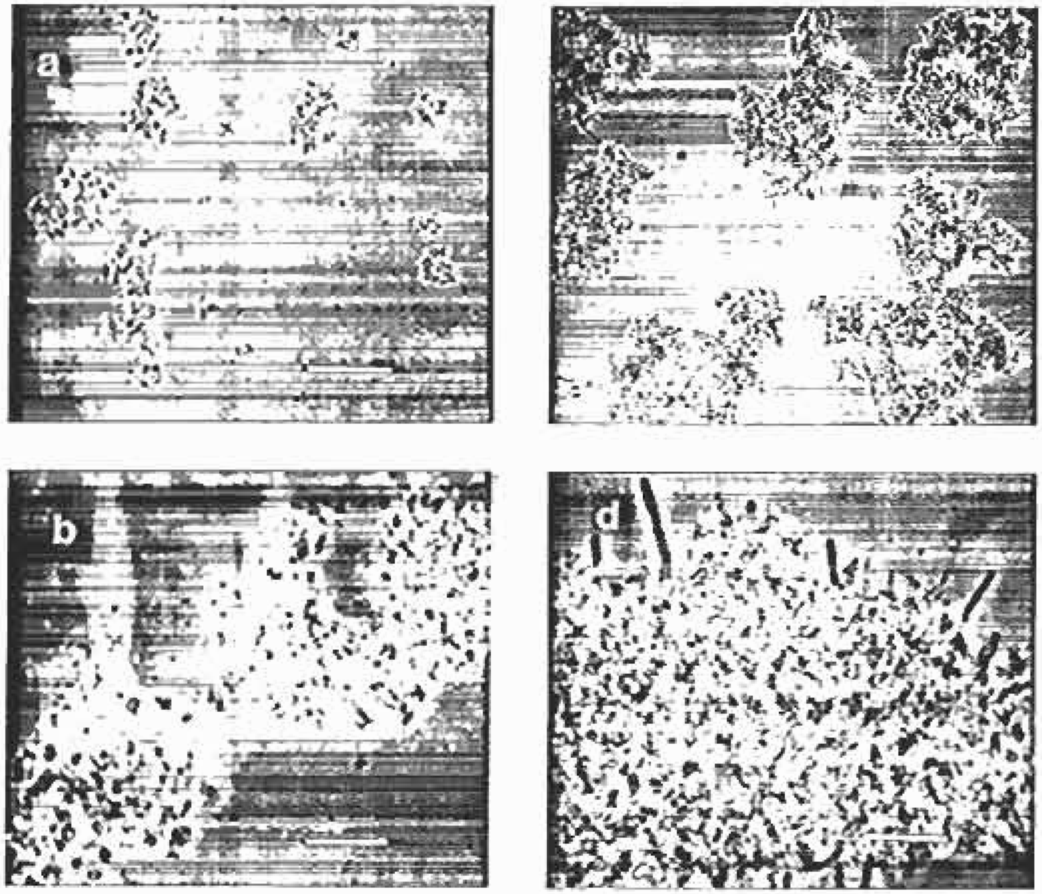
Can also get non-filamentous bulking (a.k.a. viscous bulking, slime bulking) from excess production of bacterial slime - sometimes occur when nutrient conc. inadequate (www.activatedsludge.info/resources/visbulk.asp)

All of these considerations illustrate complexity of the activated sludge "ecosystem" and of AST treatment



Nocardia foaming in activated sludge: a. and b. foam on the aeration basin; c. and d. microscopic appearance of Nocardia foam (c. 400 x phase contrast; bar = 25 µm; d. 1000 x phase contrast; bar = 10 µm).

Courtesy of Environmental Protection Agency



Microscopic appearance of activated sludge flocs: a. small, weak flocs (pin-floc) (100 x phase contrast); b. small, weak flocs (100 x phase contrast); c. flocs containing microorganisms (100 x phase contrast); d. floc containing filamentous organisms "network" or "backbone" (1000 x phase contrast) (a and c bar = 100 µm; b and d bar = 10 µm).

Courtesy of Environmental Protection Agency

Oxygen required in aeration tank

Oxygen required ($kg\,O_2/day$)

$$R_{O_2} = Q(S_{in} - S) - 1.42\,P$$

P is sludge production rate kg VSS/d

$= Q_e X_e + Q_w X_r$ per Lecture 17, Eq 23

1.42 is g COD/g biomass per Lecture 14, pg 9

1.42P is subtracted because it represents the portion of substrate that gets converted to biomass and then removed from system before it exerts its oxygen demand

Oxygen uptake rate is O_2 required per unit volume of aeration tank:

$$OUR = \frac{R_{O_2}}{\forall} = \frac{S_{in} - S}{t_R} - 1.42\,\frac{P}{\forall}$$

This can be shown to equal (Haas, 1979):

$$OUR = \frac{S_{in} - S}{t_R} - 1.42\,\frac{(S_{in} - S)}{t_R\,(1 + k_d \theta_c)}$$

Typical volumetric air rates are $62\,\frac{m^3\ air}{kg\ BOD5}$
(per M&E, 1979, pg. 477)

Reference: Haas, Charles N., 1979. Oxygen uptake rate as an activated sludge control parameter. Journal Water Pollution Control Federation, Vol. 51, No. 5, Pp. 938-943, July 1979.

Minimum required DO conc. is 0.2 to 2.0 mg/L (0.5 for conventional AST)

Various mechanisms are used to transfer O_2 into water

$$O_2 \text{ transfer efficiency} = \frac{O_2 \text{ mass dissolved in water}}{O_2 \text{ mass applied as gas}}$$

Pages 11-13 illustrate alternative transfer mechanisms:

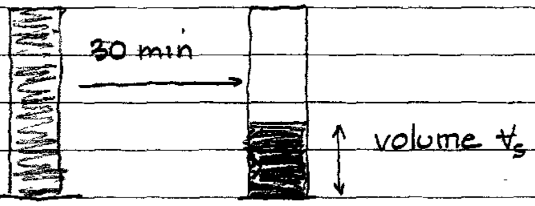
		transfer eff.
Pg 11	Fine bubble diffuser – total floor coverage –	20-32%
	side wall installation –	11-15
Pg 12	Jet aerators (fine bubble)	22-27
	Static aerators	12-14
Pg 13	Mechanical surface aerators	2.5-3.5

Secondary clarifier

Principles same as sedimentation tanks (Lecture 5 & 6)

Properties of sludge are special consideration

1-liter sample of sludge settled in 1-liter graduated cylinder for 30 minutes:



Sludge density index, SDI = TSS of settled sludge (mg/L) = X_r

1/SDI = Sludge volume index, SVI (usually 50-150 mL/g)

Low SVI → good settling sludge

Please point your browser to the following links for examples of fine bubble diffusers:

http://www.proequipment.com/aeration/disktype.htm

http://www.sequencertech.com/equipment/equipment_aeration/fine_bubble.htm

Please point your browser to the following links for examples of static aerators:

http://www.aquaculture.ugent.be//coursmat/autom/pic/stat.jpg

http://www.sequencertech.com/equipment/equipment_aeration/jet_aeration.htm

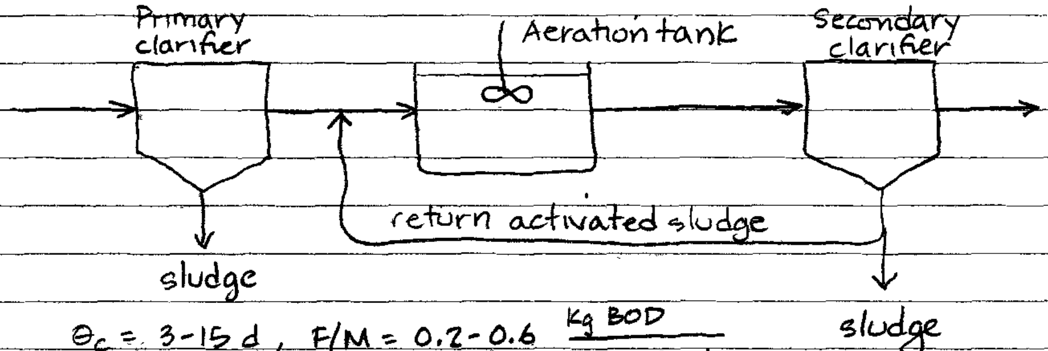
Please point your browser to the following links for examples of surface aerators:

http://www.en-found.com/sur.htm

http://perso.wanadoo.fr/isma/en_aerateur-de-surface-aerostar-documentation-photos.html

AST Designs - M&E lists 16 different variations

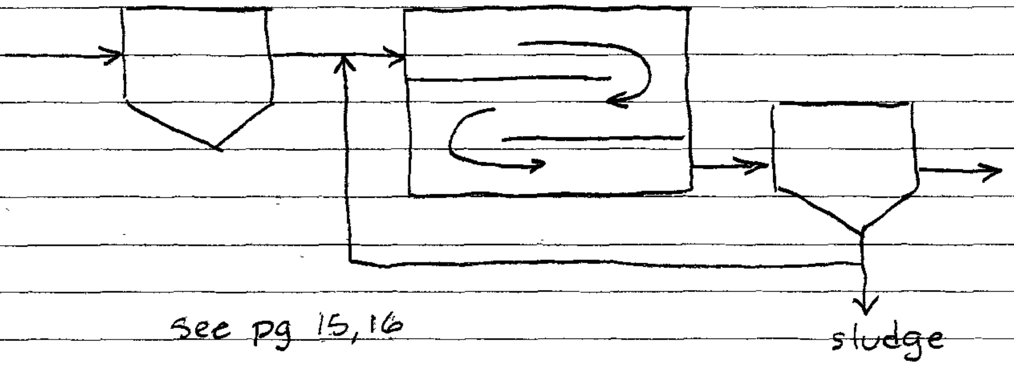
Complete mix (basis for equations in lecture 17)



θ_c = 3-15 d, F/M = 0.2-0.6 $\frac{\text{kg BOD}}{\text{kg MLVSS} \cdot \text{d}}$

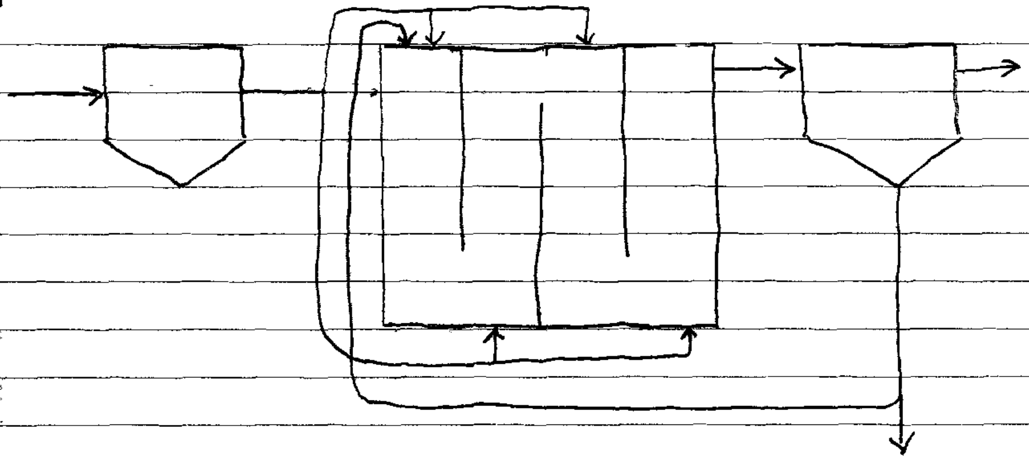
conventional plug flow, high rate aeration

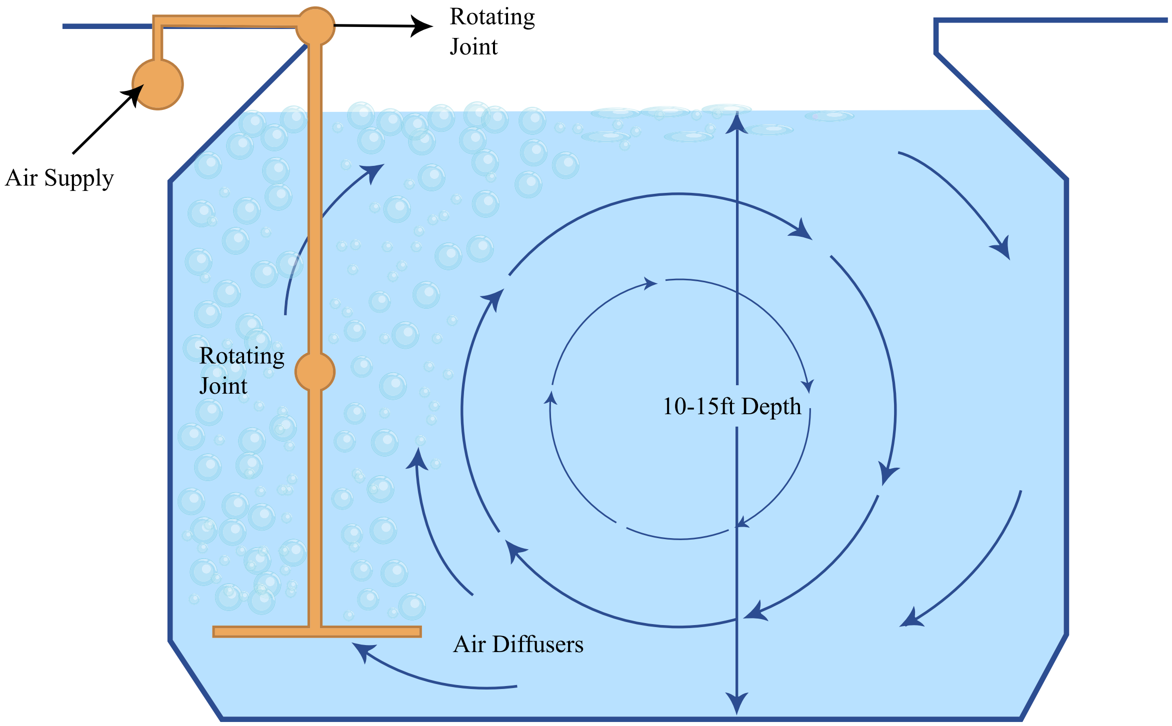
θ_c = 3-15 days, F/M = 0.2-0.4 θ_c = 0.5 - 2 days   F/M = 1.5-2 $\frac{\text{kg BOD}}{\text{kg MLVSS} \cdot \text{d}}$



see pg 15, 16

Step feed





Cross section of a typical aeration tank illustrating the spiral flow pattern created by aeration along one side.

Figure by MIT OCW.

Adpated from: Viessman, W., Jr., and M. J. Hammer. *Water Supply and Pollution Control*. 7th ed. Upper Saddle River, NJ: Pearson Education, Inc., 2005, p. 580.

Please point your browser to the following link for an example of a Primary Aeration Tank:

http://www.college.ucla.edu/webproject/micro7/studentprojects7/Rader/asludge2.htm

Extended aeration AST – pg. 18

"Race-track" design
For smaller communities

SRT = 20 - 40 days
F/M = 0.04 - 0.1

High purity oxygen AST

Uses pure oxygen in covered aeration tanks
Allows reduced aeration period
SRT = 1-4 d, F/M = 0.5-1.0

Textbook has good discussion of design alternatives - pp 578-591

summary of operating characteristics on pg. 19

Please see Figures 12-37 and 12-38 in the Viessman and Hammer textbook for images of activated sludge plants and different types of aerators.

Viessman, W., Jr., and M. J. Hammer. *Water Supply and Pollution Control*. 7th ed. Pearson Education, Inc., Upper Saddle River, NJ: Pearson Prentice Hall, 2005. ISBN: 0131409700.

Typical Design Parameters for Commonly Used Activated-Sludge Processes[a]

Process Name	Type of Reactor	SRT, d	F/M kg BOD/kg MLVSS.d	Volumetric Loading		MLSS, mg / L	Total τ, h	RAS, % of Influent[e]
				lb BOD / 1000 ft^3.d	kg BOD / m^3.d			
High-rate Aeration	Plug Flow	0.5-2	1.5-2.0	75-150	1.2-2.4	200-1000	1.5-3	100-150
Contact Stabilization	Plug Flow	5-10	0.2-0.6	60-75	1.0-1.3	1000-3000[b] 6000-10000[c]	0.5-1[b] 2-4[c]	50-150
High-Purity Oxygen	Plug Flow	1-4	0.5-1.0	80-200	1.3-3.2	2000-5000	1-3	25-50
Conventional Plug Flow	Plug Flow	3-15	0.2-0.4	20-40	0.3-0.7	1000-3000	4-8	25-75[f]
Step Feed	Plug Flow	3-15	0.2-0.4	40-60	7.0-1.0	1500-4000	3-5	25-75
Complete Mix	CMAS	3-15	0.2-0.6	20-100	0.3-1.6	1500-4000	3-5	25-100[f]
Extended Aeration	Plug Flow	20-40	0.04-0.10	5-15	0.1-0.3	2000-5000	20-30	50-150
Oxidation Ditch	Plug Flow	15-30	0.04-0.10	5-15	0.1-0.3	3000-5000	15-30	75-150
Batch Decant	Batch	12-25	0.04-0.10	5-15	0.1-0.3	2000-5000[d]	20-40	NA
Sequencing Batch Reactor	Batch	10-30	0.04-0.10	5-15	0.1-0.3	2000-5000[d]	15-40	NA
Countercurrent Aeration System (CCAS^{TM})	Plug Flow	10-30	0.04-0.10	5-10	0.1-0.3	2000-4000	15-40	25-75[f]

a = Adapted from WEF (1998); Crites & Tchobanoglous (1998).

b = MLSS & detention time in contact basin.

c = MLSS & detention time in stabilization basin.

d = Also used at intermediate SRTs.

e = Based on average flow.

f = For nitrification, rates may be increased by 25 to 50%.

NA = Not Applicable.

Figure by MIT OCW.

Adapted from: G. Tchobanoglous, F. L. Burton, and H. D. Stensel. *Wastewater Engineering: Treatment and Reuse*. 4th ed. Metcalf & Eddy Inc., New York, NY: McGraw-Hill, 2003, p. 747.

Use of Lecture 17 models in designing AST

1. Q, S_{in} are given

2. Regulations dictate S or E: $E = \frac{S_{in} - S}{S}$

3. Select desired θ_c and X (MLVSS)

4. Bench-scale studies determine Y, K_d, K_s, μ_{max}, SVI

5. $\frac{1}{\theta_c} = Y \frac{F}{M} E - K_d \longrightarrow \frac{F}{M}$ (Eq 39)

6. $\frac{F}{M} = \frac{S_{in}}{t_R X} \longrightarrow t_R$ (Eq 37)

7. $t_R = \frac{\forall}{Q} \rightarrow \forall$

8. $X_r = 1/SVI$

9. $\theta_c = \frac{t_R}{1 + R - R(X_r/X)} \rightarrow R$ (Eq. 33)

10. $R = Q_r/Q \rightarrow Q_r$

11. $P = \forall(\mu_g - k_d)X \rightarrow P$ (Eq 23)
sludge prod. rate

12. $P = Q_e X_e + Q_w X_r$ (Eq 23)
$= (Q - Q_r)X_e + Q_w X_r \rightarrow X_e$

13. $R_{O_2} = Q(S_{in} - S) - 1.42P \rightarrow R_{O_2}$