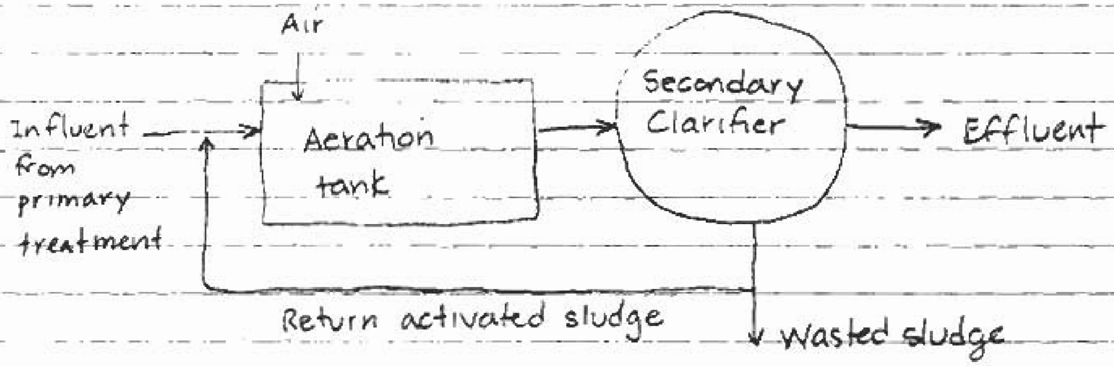
Lecture 18 - Activated sludge treatment



Aeration tank - contains mixed liquor - 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 and rotifers (up to 5% of biomass)
  - Protozoa predate on bacteria (contribute to K_e)
  - Help create good sludge quality
- 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

MLSS is key component in AST

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

Bacteria then solubilize 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 clarifier
Also, excess food carries into effluent → treatment efficiency is poor

x

From Eq 36 of last lecture:

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

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

all other variables being constant

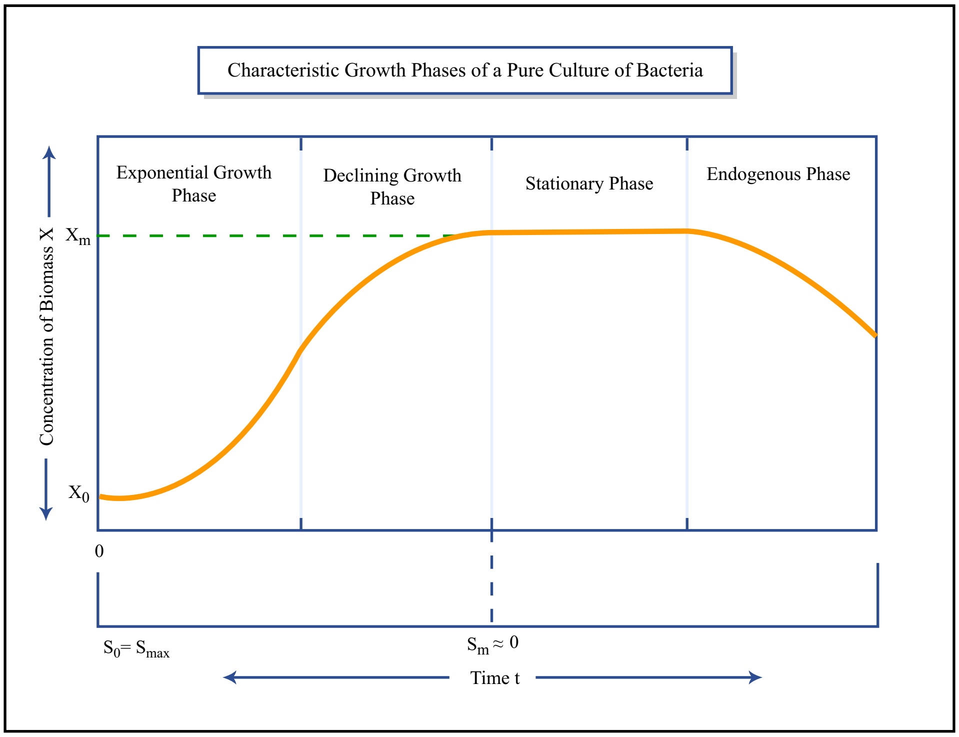


Figure by MIT OCW.

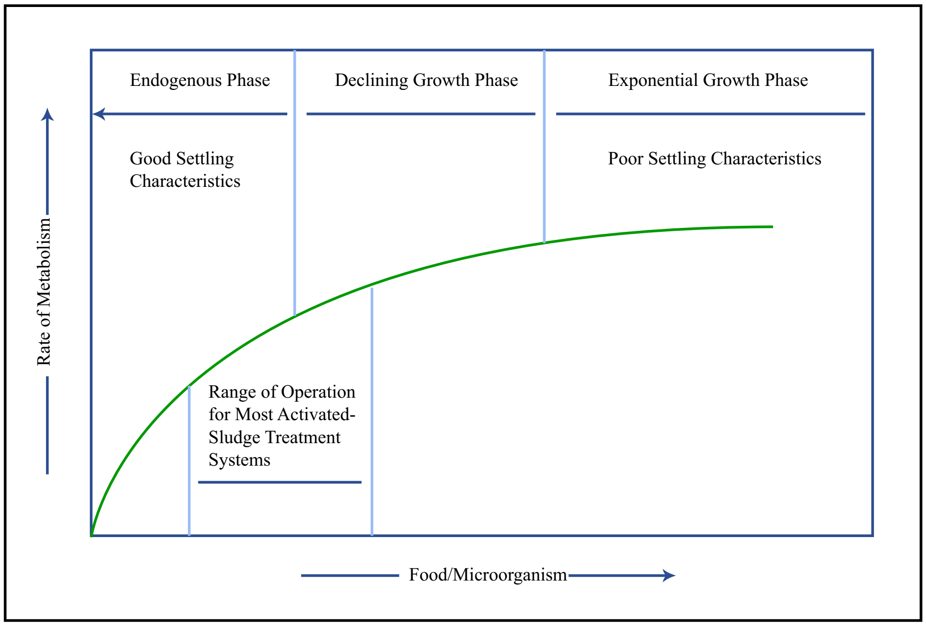


Figure by MIT OCW.

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_e 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" - pg 7

zo-eh-glee-ah

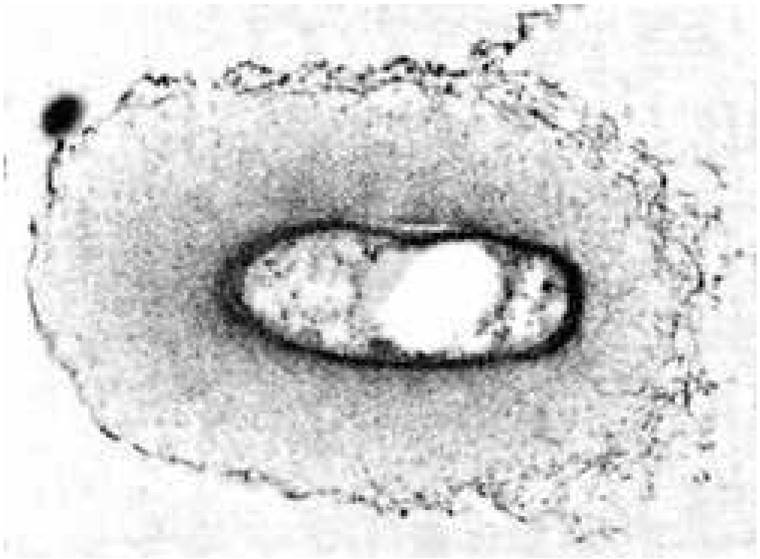
But, good aeration is needed for live cells to create polysaccharide gums that make up slime

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

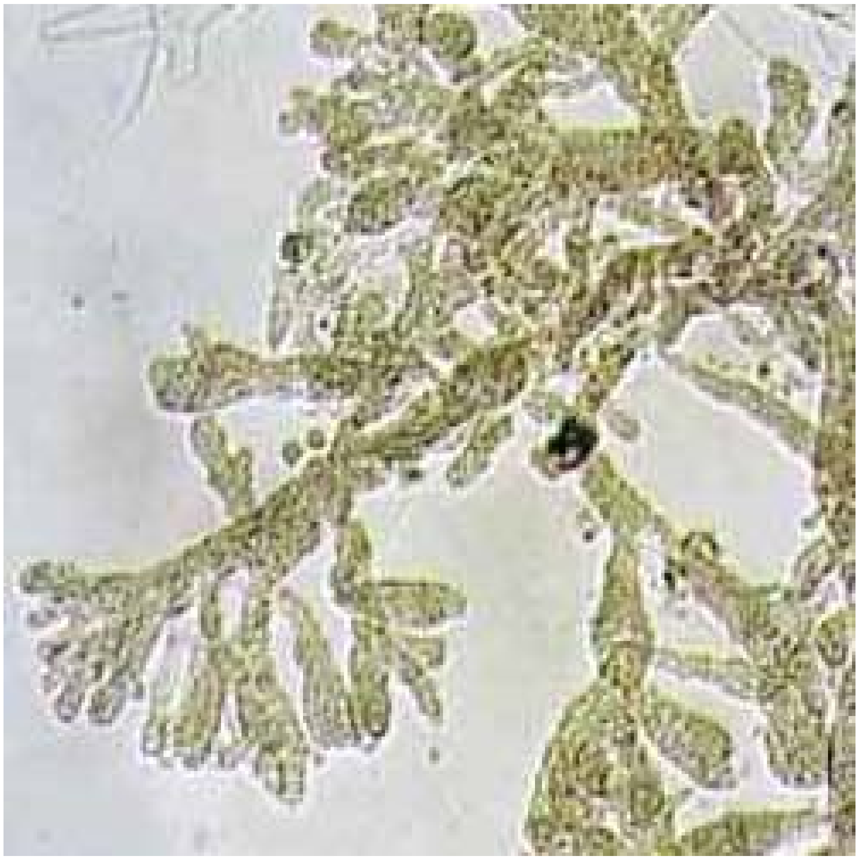
Generally favorable conditions:

$SRT = \Theta_c = 5 \text{ to } 15 \text{ days}$

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 (see pgs 9 and 10)

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

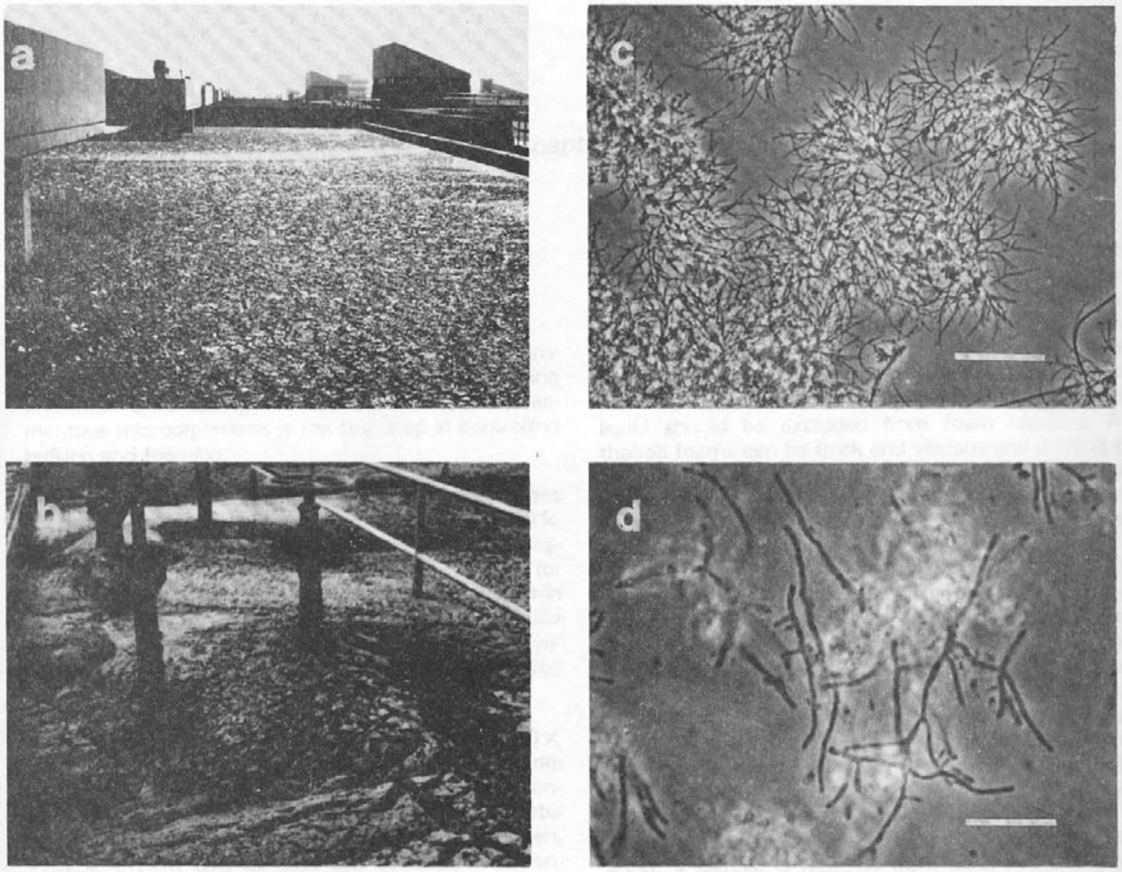
Droste (1997) and M&E say low F/M ratio, long sludge age, high temp. favor Nocardia growth and cause bulking sludge and foaming

activatedsludge.info says same conditions also favor Microthrix parvicella (pg 9) 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)

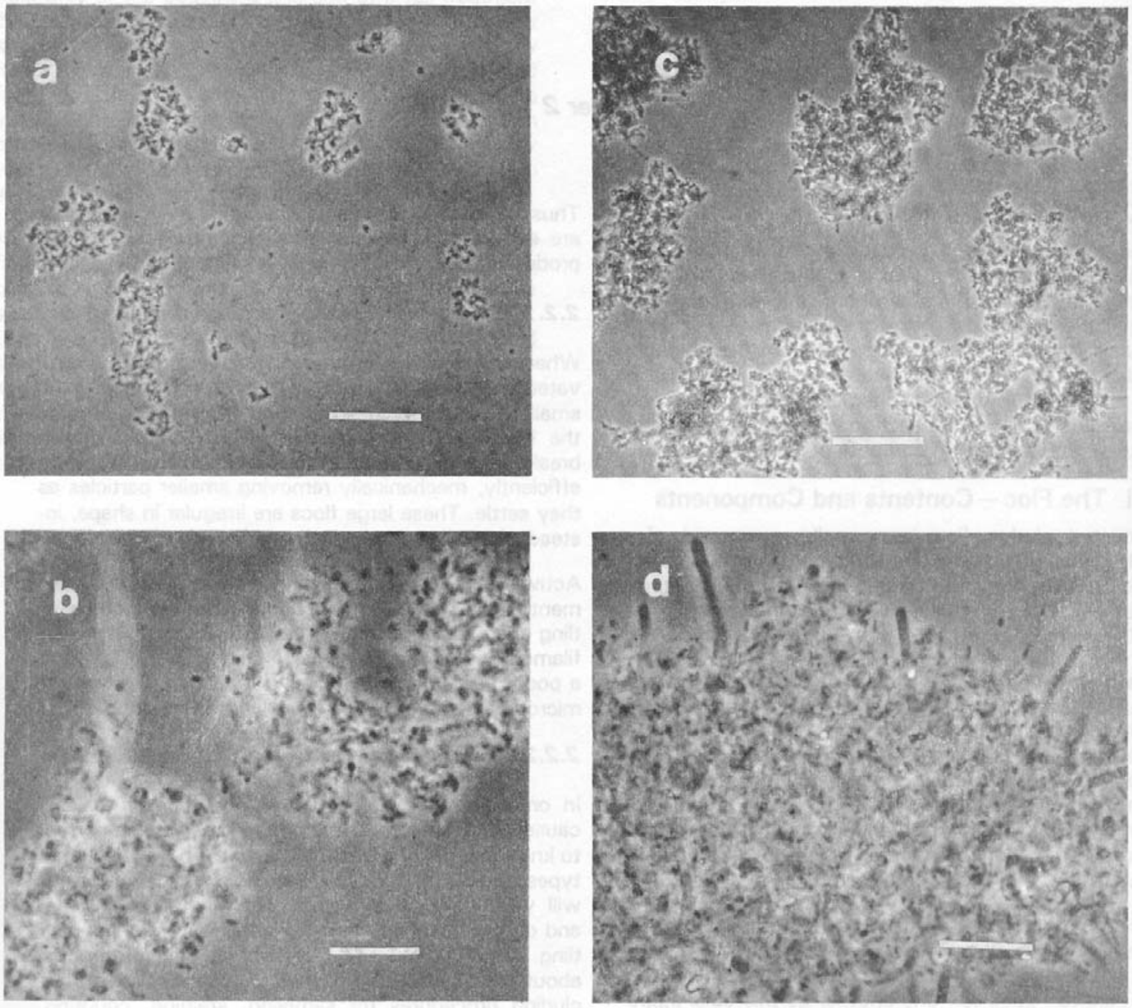
All of these considerations illustrate complexity of the activated sludge "ecosystem" and of AST treatment

Figure 12. *Nocardia* foaming in activated sludge: *a.* and *b.* foam on the aeration basin; *c.* and *d.* microscopic appearance of Nocardia foam (*c.* 400× phase contrast; bar = 25 μm; *d.* 1000× phase contrast; bar = 10 μm).



From: Bartell, T., 1987. Summary Report: The Causes and Control of Activated Sludge Bulking and Foaming. Report Number EPA-625-8-87-012. Center for Environmental Research Information, U.S. Environmental Protection Agency, Cincinnati, Ohio. July 1987.

Figure 1. Microscopic appearance of activated sludge flocs: *a.* small, weak flocs (pin-floc) (100 × phase contrast); *b.* small, weak flocs (100 × phase contrast); *c.* flocs containing microorganisms (100 × phase contrast); *d.* floc containing filamentous microorganisms "network" or "backbone" (1000 × phase contrast) (*a* and *c* bar = 100μm; *b* and *d* bar = 10μm).



From: Bartell, T., 1987. Summary Report: The Causes and Control of Activated Sludge Bulking and Foaming. Report Number EPA-625-8-87-012. Center for Environmental Research Information, U.S. Environmental Protection Agency, Cincinnati, Ohio. July 1987.

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

$$= Q_e X_e + Q_w X_r$$ Eq. 20 of Lecture 19

1.42 is g COD/g biomass per Lecture 15, 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):

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

Typical volumetric air rates are $62 \frac{m^3 \text{ air}}{\text{kg BOD5}}$
(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 13-15 illustrate alternative transfer mechanisms:

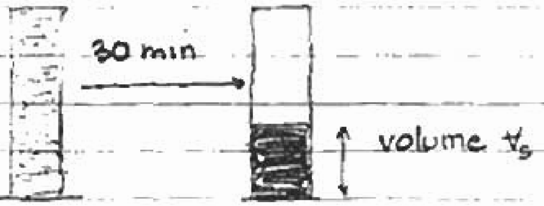
		transfer eff.
Pg 13	Fine bubble diffuser – total floor coverage –	20-32%
	side wall installation –	11-15
Pg 14	Jet aerators (fine bubble)	22-27
	Static aerators	12-14
Pg 15	Mechanical surface aerators	2.5-3.5

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

To see fine-bubble diffusers, go to:

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

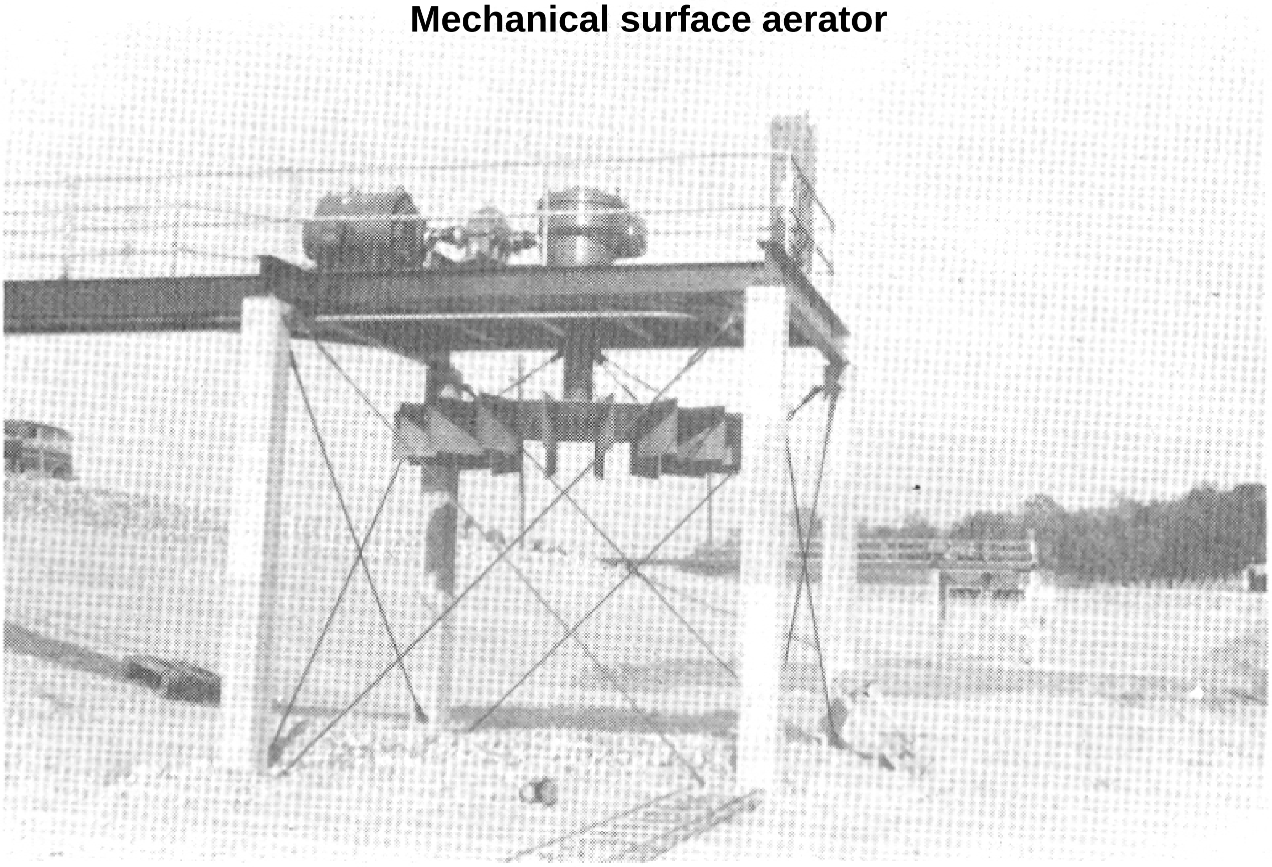
http://www.sequencertech.com/equipment/equipment_aeration/fine_bubble.htm

To see jet aerators, go to:

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

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

Mechanical surface aerator

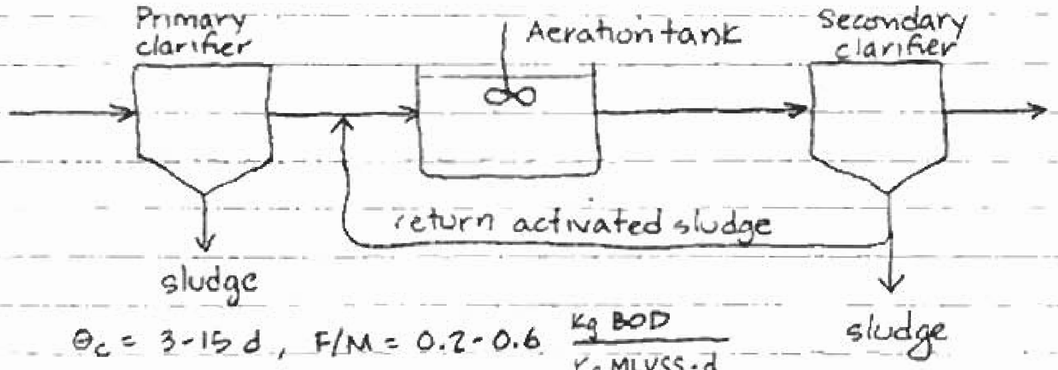


Source: PHS, 1962. Bio-Oxidation of Industrial Wastes. Robert A. Taft Sanitary Engineering Center, U.S. Public Health Service, Cincinnati, Ohio. January 1962.

AST Designs - M&E lists 16 different variations

x

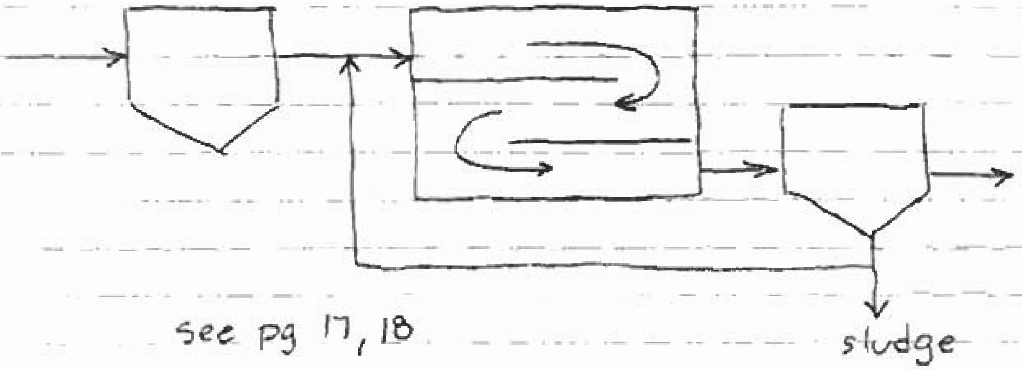
Complete mix (basis for equations in last lecture



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

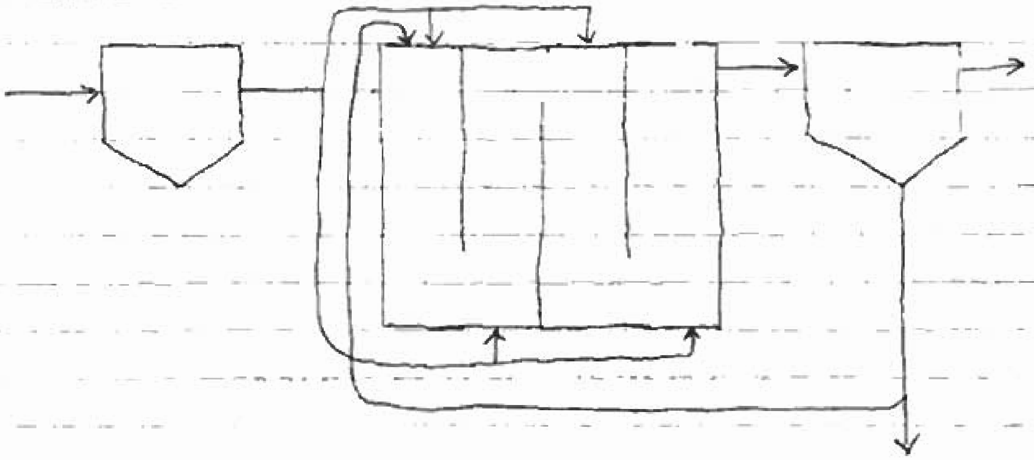
Conventional plug flow, high rate aeration

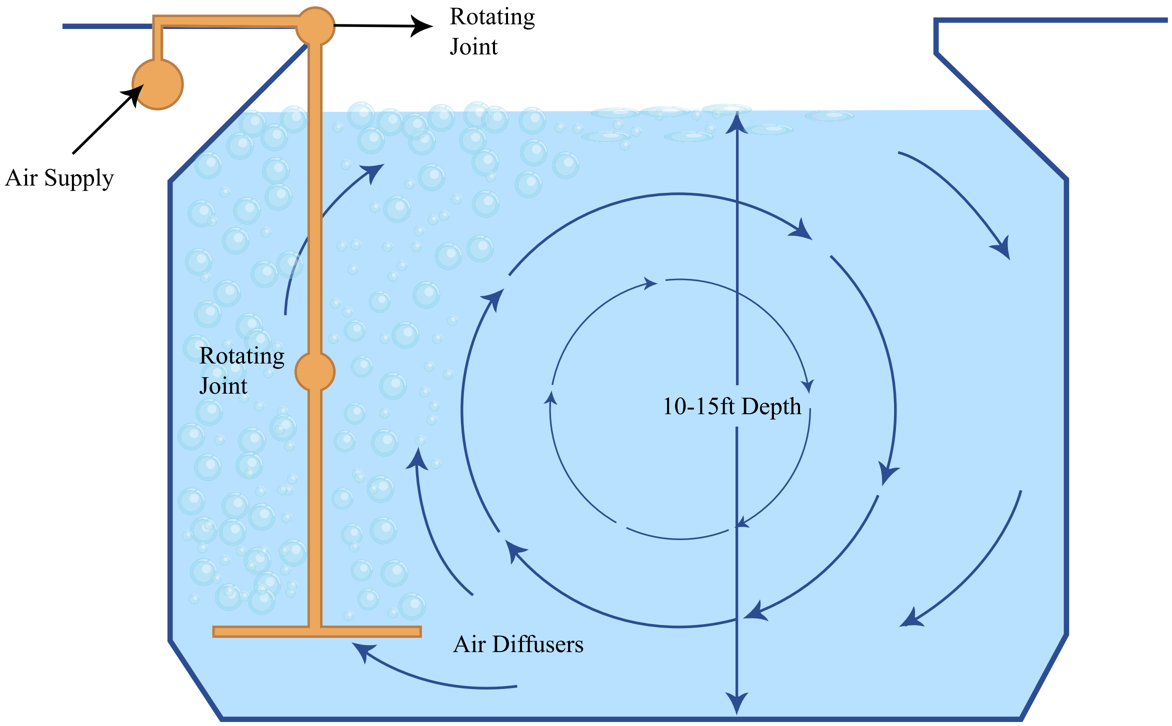
θ_c = 3-15 days, F/M = 0.2-0.4 θ_c = 0.5-2 days F/M = 1.5-2 $\frac{\text{kg BOD}}{\text{kg MLVSS}\cdot\text{d}}$



see pg 17, 18

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.

Aeration tank

Source: Ward, Ben, 2005. Irvine Ranch Water District of California's Water Reclamation Plant. Student project for Course 1.85. May 2005.

Extended aeration AST - pg. 20-21

"Race-track" design
For smaller communities

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

Easy to operate & install
small footprint
Low sludge yield
—
Large energy demand
Difficulty with changes in wastewater

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

Reynold/Richards has discussion of design alternatives - pp 440-450

summary of operating characteristics on pg. 22

To see pictures of a “racetrack” extended-aeration activated sludge treatment plant, please see Figure 12.37 in Viessman, W., Jr., and M. J. Hammer. *Water Supply and Pollution Control.* 7th ed. Upper Saddle River, NJ: Pearson Education, Inc., 2005.
An image of this type of system can be seen at: http://www.environmental-expert.com/technology/dorr-oliver/dorr-oliver.htm. Click on the link for EIMCO® Carrousel® denitIR® System

To see an image of the mechanical aerator used at an extended-aeration activated sludge treatment plant, please see Figure 12.38 in Viessman, W., Jr., and M. J. Hammer. *Water Supply and Pollution Control*. 7th ed. Upper Saddle River, NJ: Pearson Education, Inc., 2005.
Images of this type of system can be seen at: http://canadawater.ca/purestream/low_speed_surface.htm

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™)	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.