Activated Sludge Processes

CE - 370

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Introduction

- Basic processes and operations in wastewater treatment
  - Primary treatment:
    - Screens, grit removal, and primary sedimentation.
  - Secondary treatment:
    - Aeration tank
    - Secondary sedimentation
  - Tertiary treatment:
    - Nutrient removal
    - Filtration
  - Disinfection:
    - Chlorination
    - UV

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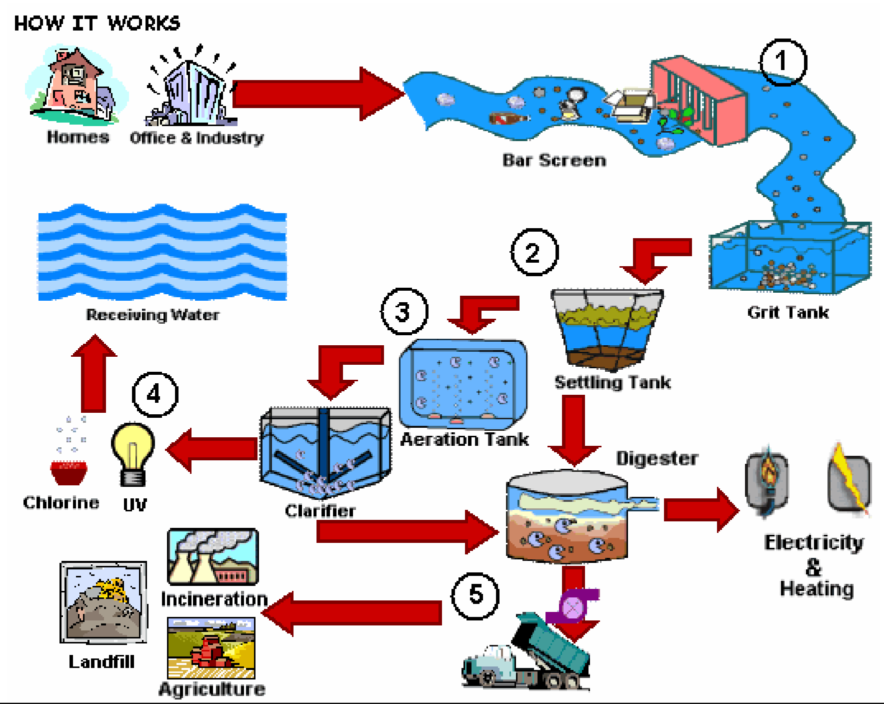

Basics of Activated Sludge Process

- The basic AS process consists of
  - A reactor in which the microorganisms responsible for treatment are kept in suspension and aerated
  - Liquid-solids separation, usually sedimentation tank
  - A recycle system for returning solids removed from the liquid-solids separation unit back to the reactor
- Important feature of the AS process is:
  - Formation of flocculent settleable solids that can be removed by gravity settling
- Activated Sludge process utilizes:
  - Fluidized microorganisms
  - Mixed growth microorganisms
  - Aerobic conditions

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Microorganisms

- Use organic materials in wastewater as substrates
- Thus, they remove organic materials by microbial respiration and synthesis

MLSS

- Concentration of suspended solids in the reactor
- Ranges between 2000 and 4000 mg/l

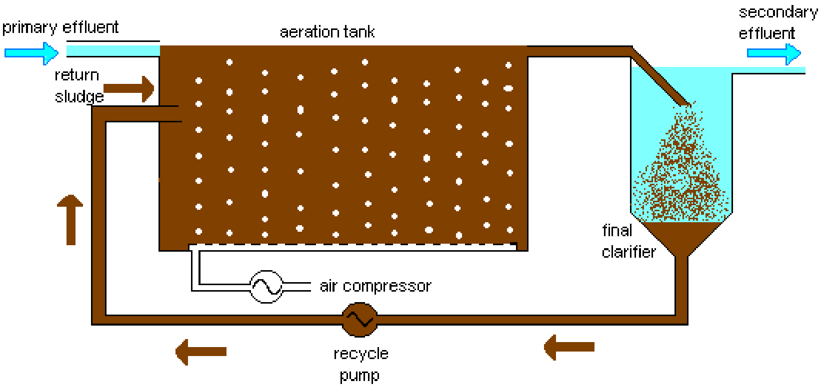
MLVSS

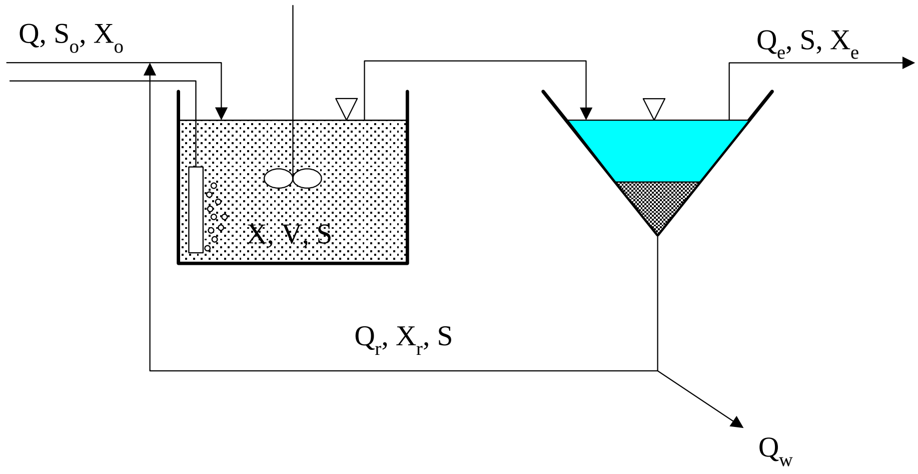
- Concentration of volatile suspended solids
- Used to indicate the mass of microorganisms
- Ranges between 80-90% of MLSS

Flows

- Feed wastewater (Q)
- Waste activated sludge (Q_w)
- Recycled activated sludge (R)

Activated Sludge Process





Q, S_o, X_o
Q_e, S, X_e
X, V, S
Q_r, X_r, S
Q_w

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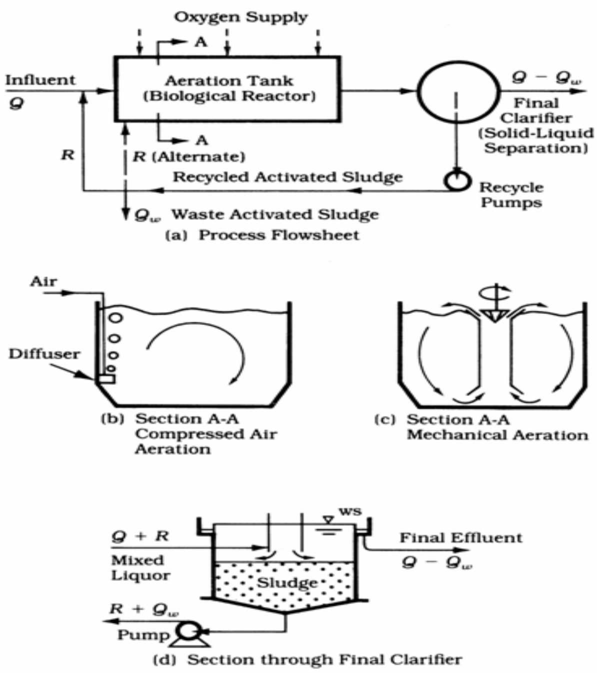

Oxygen Supply
A
Influent
Q
Aeration Tank
(Biological Reactor)
Q − Q_w
Final
Clarifier
(Solid-Liquid
Separation)
A
R
R (Alternate)
Recycled Activated Sludge
Recycle
Pumps
Q_w Waste Activated Sludge
(a) Process Flowsheet
Air
Diffuser
(b) Section A-A
Compressed Air
Aeration
(c) Section A-A
Mechanical Aeration
WS
Q + R
Mixed
Liquor
Final Effluent
Q − Q_w
Sludge
R + Q_w
Pump
(d) Section through Final Clarifier

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- Oxygen Supply
  - Diffused compressed air
  - Mechanical surface aeration
  - Pure oxygen
- Purposes of aeration
  - Provides oxygen required for aerobic bio-oxidation
  - Provides sufficient mixing for adequate contact between activated sludge and organic substances
- In order to maintain the desired MLSS in the aeration tank, R/Q ratio must be calculated

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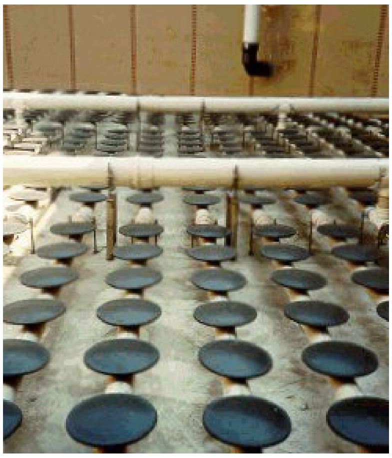
Diffuser



Non buoyant design.
•Micro fine bubbles

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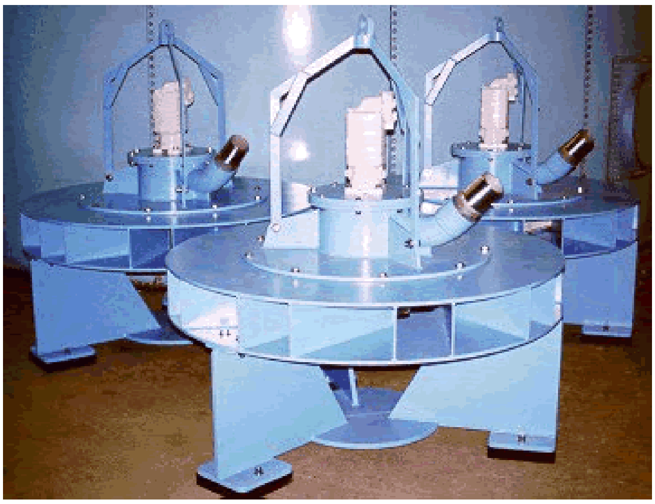

Submersible Aerator/Mixer

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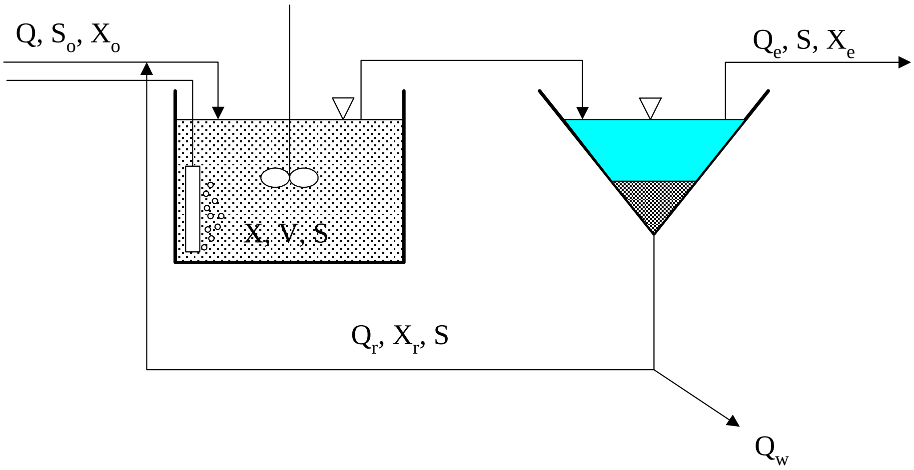

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Calculate (R / Q) Ratio

- Calculate the Sludge Density Index (SDI)
  - Sample MLSS from downstream of aeration tank
  - Determine SS in MLSS
  - Place 1 liter of the MLSS in 1-liter graduate cylinder
  - Settle the sludge for 30 minutes
  - Measure volume occupied by settled sludge
  - Compute SS in settled sludge in mg/l
  - SS represents SDI
  - The test approximates the settling that occurs in final clarifier
- If SDI = 10,000 mg/l and MLSS must be 2,500 mg/l
- Then, Q(0) + R(10,000) = (Q+R)(2500)
- R/Q = (2500)/(7500) = (1/3) = 33.3 %
- So, R is 33.3% of feed wastewater (Q)

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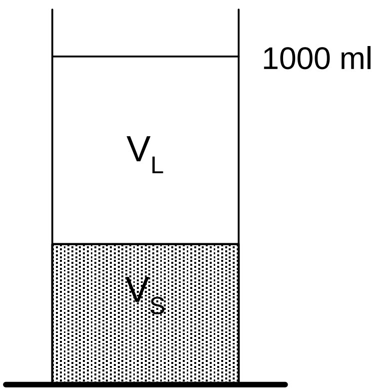

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- Sludge Volume Index (SVI) = 1/ SDI
  - Is the volume in ml occupied by 1 gram of settled activated sludge
  - It is a measure of settling characteristics of sludge
  - Is between 50 and 150 ml/gm, if process is operated properly
- Why Q_w?
  - Microbes utilize organic substances for respiration and synthesis of new cells
  - The net cell production (Q_w) must be removed from the system to maintain constant MLSS
  - Qw is usually 1 to 6 % of feed wastewater flowrate (Q)

- Common organic materials in municipal wastewater are:
  - Carbohydrates (C, H, O0
  - Fats (C, H, O)
  - Proteins (C, H, O, N, S, P)
  - Urea (C, H, O, N)
  - Soaps (C, H, O)
  - Detergents (C, H, O, P)
  - Traces of
    - Pesticides
    - Herbicides
    - Other agricultural chemicals
- Activated sludge can be represented by:
  - $C_5H_7O_2N$
  - Has a molecular weight of 113

Design

- To design of AS, the following must be determined:
  - Volume of reactor
    - Number of basins
    - Dimensions of each basin
  - Volume of reactor is determined from:
    - Kinetic relationships
    - Space loading relationships
    - Empirical relationships
  - Sludge production per day (X_w), kg/day
  - Oxygen required per day (O_r), kg/day
  - Final clarifier
    - Number of basins

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Biological Kinetics

- 1. Michaelis – Menten Concept

$$-\frac{1}{X}\frac{dS}{dt} = k_s\left(\frac{S}{K_m + S}\right)$$

- **(1/X)(ds/dt) = specific rate of substrate utilization**
- **(ds/dt) = rate of substrate utilization**
- **k_s = maximum rate of substrate utilization**
- **K_m = substrate concentration when the rate of utilization is half maximum rate**
- **S = substrate concentration**

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$$-\frac{1}{X}\frac{dS}{dt}=k_s\left(\frac{S}{K_m+S}\right).......(1)$$

- If S is very large, Km can be neglected, therefore S cancels out and the reaction is zero order in substrate. K is the rate constant for zero-order reaction.

$$-\frac{1}{X}\frac{dS}{dt}=k_s=K......(2)$$

- If S is relatively small, it can be neglected in the denominator and the reaction is first-order in substrate. K is the rate constant for the first-order reaction

$$-\frac{1}{X}\frac{dS}{dt}=\frac{k_s}{K_m}(S)=KS......(3)$$

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- Rearrange and integrate Equation (2)

$$\int_{S_0}^{S_t} dS=-K\overline{X}\int_0^t dt$$

$$yields$$

$$S_t-S_0=-K\overline{X}t$$

$$or$$

$$S_t=S_0-K\overline{X}t......(4)$$

- $\overline{X}$ = average cell mass concentration during the biochemical reaction, that is $\overline{X}=(X_0+X_t)/2$
- S_t = substrate concentration at time t
- S_0 = substrate concentration at time t = 0

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Rearrange and integrate Equation (3)

$$\int_{S_0}^{S_t} \frac{dS}{S} = -K\overline{X}\int_0^t dt$$

yields

$$\ln S_t - \ln S_0 = -K\overline{X}t$$

or

$$\ln S_t = \ln S_0 - K\overline{X}t......(5)$$

- $\overline{X}$ = average cell mass concentration during the biochemical reaction, that is $\overline{X} = (X_0 + X_t)/2$
- S_t = substrate concentration at time t
- S_0 = substrate concentration at time t = 0

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Equations (4) and (5) are in the form of

- y = mx + b
- Plotting S_t on y-axis versus $\overline{X}t$ on the x-axis on arithmetical paper produce a straight line with a slope of –K for equation (4).
- Plotting S_t on y-axis versus $\overline{X}t$ on the x-axis on semilog paper produce a straight line with a slope of –K for equation (5).

The substrate could be

- The BOD_5
- Biodegradable part of COD
- Biodegradable fraction of TOC
- Biodegradable of any other organic matter

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Rate Constant, K

- Depends on the specific wastewater
- For domestic wastewater, it ranges between 0.1 to 1.25 liter/(gram MLSS)(hr) using BOD_5
- Should be determined using lab-scale or pilot-scale studies
- In the absence of studies, K between 0.1 and 0.4 liter/(gram MLSS)(hr) is recommended

TABLE 15.1 *Reaction Orders and Rate Constants for Some Selected Wastewaters*

TYPE OF WASTEWATER	PSEUDOREACTION ORDER	REACTION RATE CONSTANT K^a ℓ/(gm MLVSS)(hr) AT 25°C
Pulp and paper mill	First	0.375
Pulp and paper mill	First	0.528
Chemical manufacture	First	0.479
Chemical manufacture	First	0.601
Oil refinery	First	0.504
Oil refinery	First	0.660
Petrochemical manufacture	First	0.592
Petrochemical manufacture	First	0.686
Petrochemical manufacture	First	0.713
Petrochemical manufacture	First	0.911
Petrochemical manufacture	First	1.221
Petrochemical manufacture	First	1.333
Municipal (domestic)	First	1.717

[a] Based on biodegradable total organic carbon (TOC).

Example on Biochemical Kinetics

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EXAMPLE 15.1 AND 15.1 SI *Biochemical Kinetics*

A kinetic study of a soluble organic wastewater has been done in the laboratory using a batch reactor inoculated from a parent acclimated culture developed in a continuous-flow activated sludge reactor. The COD and MLSS concentrations for the various reaction times were as shown in Table 15.2.

At 24 hours, the $BOD_5 = 4.2$ mg/ℓ, the $BOD_5 = 0.35\ BOD_u$ (ultimate first-stage BOD), and the BOD_u is equal to the degradable COD. The MLVSS = 88% of the MLSS. Determine the reaction order and the reaction rate constant in terms of MLSS and MLVSS.

TABLE 15.2 *Kinetic Data from Batch Test*

REACTION TIME (hr)	COD (mg/ℓ)	MLSS (mg/ℓ)
0	680	1910
1	440	2180
2	240	2210
3	165	2190
4	128	2130
5	115	2090
24	102	1860

SOLUTION The nondegradable COD is equal to the COD at 24 hours minus the BOD_u or $102 - 4.2/0.35 = 102 - 12 = 90$ mg/ℓ. Assuming a pseudo–first-order reaction, the data are shown in Table 15.3 for a time up to 5 hours. The data point at 24 hours is not used in the reduced data in Table 15.3, because the COD is so low that it will not give a representative point.

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TABLE 15.3 ***Reduced Data from Batch Test***

TIME, t (hr)	DEGRADABLE COD (mg/ℓ)	X MLSS (mg/ℓ)	$\bar{X}$ MLSS (mg/ℓ)	$\bar{X}t$ (mg/ℓ)(hr)
0	590	1910		
1	350	2180	2045	2,045
2	150	2210	2060	4,120
3	75	2190	2050	6,150
4	38	2130	2020	8,080
5	25	2090	2000	10,000

The plot of $\ln S_t$ versus $\bar{X}t$ is shown in Figure 15.8. Since it is a straight line, the reaction is pseudo-first order and from the slope, K (MLSS) = 0.316 ℓ/(gm MLSS-hr). K (MLVSS) = K (MLSS)/0.88; therefore, K (MLVSS) = 0.316/0.88 or K (MLVSS) = 0.359 ℓ/(gm MLVSS-hr).

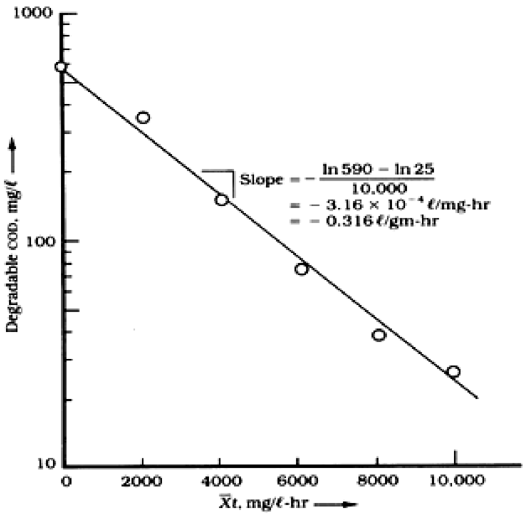

FIGURE 15.8 *Graph for Example 15.1 and 15.1 SI*