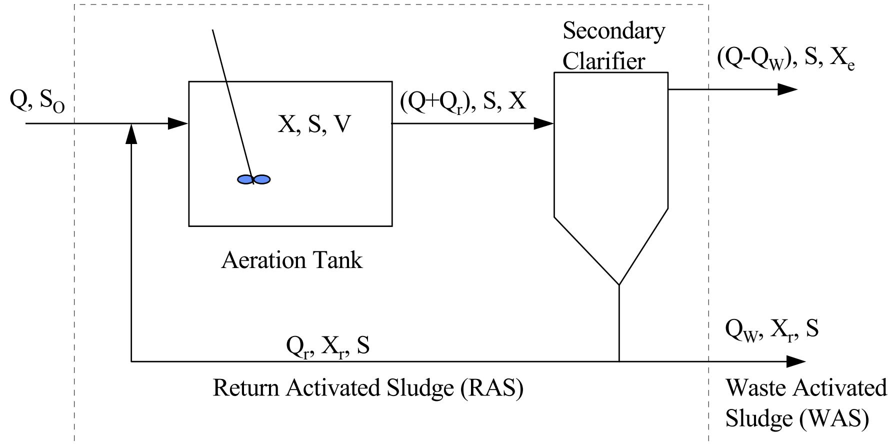
Completely Mixed Activated Sludge (CMAS) Bioreactor Design Equations



Mass Balance:

Biomass:

$$QX_O + V\left(\frac{\mu_{max}\, SX}{K_S + S} - k_d X\right) = (Q - Q_w)\, X_e + Q_w\, X_w$$

Substrate:

$$QS_O - V\left(\frac{\mu_{max}\, SX}{Y(K_S + S)}\right) = (Q - Q_w)\, S_e + Q_w\, S_w$$

where Q, Q_w = influent flow and waste flow, respectively, m^3/d

V = volume of aeration basin, m^3

$:_{max}$ = maximum specific growth rate coefficient, h^{-1}

K_S = half saturation coefficient, mg/L

k_d = decay coefficient, h^{-1}

X_O, X, X_e, X_w = biomass in influent, bioreactor, effluent, and waste, mg/L as MLVSS

S = soluble substrate concentration in bioreactor, mg/L as BOD or COD

S_O = influent substrate concentration, mg/L as BOD or COD

Y = biomass yield, mg biomass formed/ mg substrate utilized (mg VSS/ mg BOD)

Assumptions:

1. Influent and effluent ____________________ concentration is negligible
2. Aeration basin is a _____________________ CSTR, $S = S_w = S_e$
3. All reactions occur in _____________________ basin

Then:

$$\frac{\mu_{max}\, S}{K_S + S} = \frac{Q_w X_w}{VX} + k_d \quad ; \quad \frac{\mu_{max}\, S}{K_S + S} = \frac{QY}{VX}(S_O - S)$$

Observe:

$$\frac{Q}{V} = \frac{1}{\theta} \quad ; \quad \frac{Q_w X_w}{VX} = \frac{1}{\theta_c}$$

Where θ = the hydraulic retention time, HRT, and θ_c = the solids residence time, SRT. This results in the following design equations:

$$S = \frac{K_S\left(1 + k_d\,\theta_c\right)}{\theta_c\left(\mu_{max} - k_d\right) - 1} \quad ; \quad \theta_c = \frac{K_S + S}{S\left(\mu_{max} - k_d\right) - K_S\,k_d} \quad ; \quad X = \frac{\theta_c\,Y\left(S_O - S\right)}{\theta\left(1 + k_d\,\theta_c\right)}$$

The minimum soluble BOD concentration that can be achieved as $\theta_c \to \infty$:

$$S_{min} = \frac{K_S\,k_d}{\mu_{max} - k_d}$$

The minimum θ_c achievable as $\mu \to \mu_{max}$:

$$\theta_{c_{min}} = \frac{K_S + S_O}{S_O\left(\mu_{max} - k_d\right) - K_S\,k_d}$$

<u>Steps for Activated Sludge Design</u>

1. Establish effluent soluble BOD_5 allowable to meet BOD_5 and SS effluent limits.

2. Determine what θ_c is required to meet the effluent soluble BOD_5 allowable.

3. Solve for the mixed liquor volatile suspended solids, MLVSS, concentration given a particular hydraulic residence time, θ. Or solve for θ given a particular MLVSS.

4. Calculate the return activated sludge (RAS) flow, Q_r, and concentration, X_r'.

$$X_r' Q_r = X'(Q_r + Q) \quad ; \quad X_r' = 10^6/SVI$$

where X' = MLSS, mg/L (X' typically is approximately $1.2 \times X$)
X_r' = RAS concentration, mg/L
Q_r = RAS flow rate, m^3/s

Find X_r' using the sludge volume index, SVI, from the following figure:

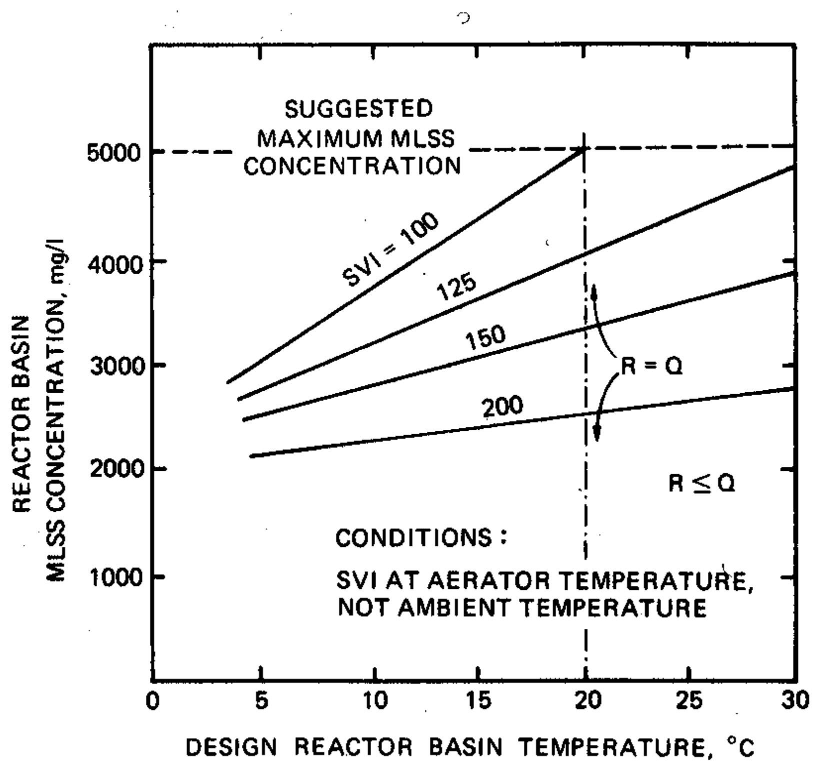


FIGURE 14-10. Recommended maximum MLSS design versus temperature and SVI.

5. Sludge production can be estimated as follows:

$$P_X = Y_{OBS}\, Q\, (S_O - S)\, \frac{kg}{1000\ g}$$

where:
P_X = sludge production, kg/d
Y_{OBS} = observed growth yield, mg biomass formed, VSS/ mg BOD_5 utilized
Q = influent flow, m^3/d
S_O = influent BOD_5
S = effluent BOD_5

Y_{OBS} can be estimated as :

$$Y_{OBS} = \frac{Y}{1 + k_d \cdot \theta_c}$$

6. Oxygen requirement for carbonaceous BOD removal can be calculated as:

$$O_2\ req = \left(\frac{Q(S_O - S)}{f} \cdot \frac{kg}{1000\ g} \right) - 1.42 \cdot P_X$$

where f = the conversion from BOD_5 to BOD_L, (0.45- 0.68)

When nitrification is occurring the oxygen requirement can be calculated as:

$$O_2\ req = \left(\frac{Q(S_O - S)}{f} \cdot \frac{kg}{1000\ g} \right) - 1.42 \cdot P_X + 4.57\ Q\ (N_O - N) \cdot \frac{kg}{1000\ g}$$

where N_O and N are the influent and effluent NH_4-N concentrations, respectively.

7. Calculate the alkalinity consumed.

The conversion of NH_3-N to nitrate not only requires oxygen but it also consumes considerable amount of alkalinity (7.1 mg/L as $CaCO_3$ for every mg/L NH_3-N):

alk consumed (kg/d) = Q (N_O - N) " 7.1 mg/L as $CaCO_3$/mg NH_4-N " (kg/1000 g)

8. **Settling Tank Design**

The design of primary and secondary settling tanks can be done on the basis of settling tests and/or established design criteria. In general, the design of tanks must meet established overflow rate and weir loading criteria.

10 State Standards Criteria

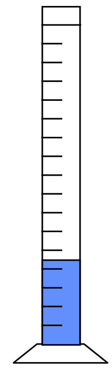
Criteria	Primary Settling Tanks		Secondary Settling Tanks	
Overflow Rate, $m^3/m^2 \cdot d$ OR = Q/A	Avg	Peak	Peak	
	41	61	49	
Weir Loading, $m^3/m \cdot d$ WL = Q/L	< 1 mgd	> 1 mgd	< 1 mgd	> 1 mgd
	124	186	124	186

Activated Sludge Operational Considerations

An operator of an activated sludge plant is concerned with three things:

1. E__________________ quality (BOD_5 and SS)
2. S____________________ characteristics of the biomass (SVI)
3. Sludge w_______________________ or solids inventory (θ_c, F/M)

These three objectives/operational parameters are interrelated. A good settling sludge will produce good effluent quality. Maintaining the proper solids inventory will produce a good settling sludge. Controlling 2_c will maintain the proper solids inventory.



SVI - Sludge v__________________ index.

C Measure of s_________________ characteristics of biomass.

C Measured in a g________________ cylinder after 30 minutes of settling.

C Units of mL/g.

C A d____________________ SVI is in the range of 75 - 150.

Sludge Bulking

C Sludge bulking is the condition where the SVI is h_________ and the suspended solids are not settling in the secondary settling tank.

C It is usually an indication of **f______________________ organisms** - long string-like organisms which outcompete the flocculent organisms because of their large surface area.

C Filamentous organisms can be caused by

a) l_________ F/M ratio
b) l_________ DO
c) nutrient d__________________
d) l_________ pH
e) i_________________ or toxicity

F/M Ratio

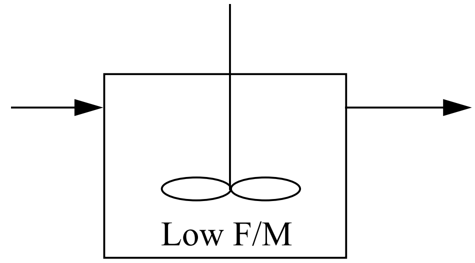
C The f____________ to m__________________________ (F/M) ratio is an alternative control parameter to 2_c for the operation of an activated sludge plant.

$$\frac{F}{M} = \frac{Q\ S_O}{V\ X} = \frac{mg\ BOD_5/dD}{mg\ MLVSS}$$

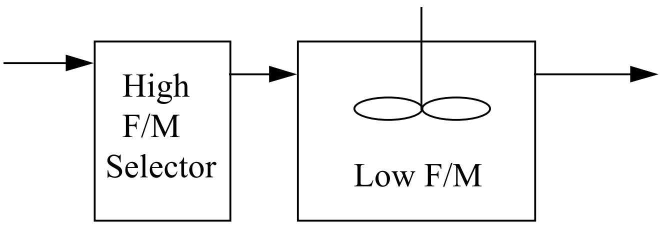
Note: the F/M ratio is inversely proportional to 2_c.

C Low F/M ratios are typical in c_____________________ mixed activated sludge (CMAS) systems.

C CMAS systems, consequently, often have filamentous b_______________ problems.



Single Tank CMAS



CMAS with Selector

C By using a **s________________**, the F/M in the first compartment of an activated sludge system can be increased, giving the f___________________ microorganisms a competitive advantage.

SUMMARY OF ACRONYMS

SRT S__________________ retention time, also referred to as 2_c. The SRT is the major design variable for the activated sludge process. The longer the SRT, the lower the effluent soluble BOD.

MLSS Mixed l____________________ suspended solids concentration. A measure of the total solids (fixed solids plus volatile solids) in the activated sludge process.

MLVSS Mixed liquor v__________________ suspended solids concentration. A measure of the volatile solids in the activated sludge process. The MLVSS concentration is often used as an estimate of the biomass concentration.

SVI S___________________ volume index. Used as a measure of settleability of solids in the activated sludge process. SVI is determined by taking a sample of mixed liquor from the aeration basin and letting it settle for 30 minutes. The volume of solids after 30 minutes divided by the mass of solids equals the SVI (units of mL/g).

F:M F__________________ to microorganism ratio. A low F:M ratio is desirable since it will be an indication of good substrate removal. Low F:M ratios may promote the growth of nuisance organisms, such as filamentous microorganisms, however.

RAS R___________________ activated sludge. This is the active biomass or sludge returned to the aeration basin from the underflow of the secondary settling tank (or clarifier).