The F/M ratio

The food to microorganism (*F*/*M*) ratio is one of the significant design and operational parameters of activated sludge systems. A balance between substrate consumption and biomass generation helps in achieving system equilibrium. The *F*/*M* ratio is responsible for the decomposition of organic matter. The type of activated sludge system can be defined by its *F*/*M* ratio.

- Extended aeration, $0.05 < F/M < 0.15$
- Conventional activated sludge system, $0.2 < F/M < 0.5$
- Completely mixed, $0.2 < F/M < 1.0$
- High rate, $0.4 < F/M < 1.5$

The F/M ratio, kg BOD_5/kg MLVSS.d, is determined as follows:

$$F/M = \frac{[\text{BOD of wastewater (g/m}^3)]\,[\text{Influent flow rate (m}^3\text{/d)}]}{[\text{Reactor volume (m}^3)]\,[\text{Reactor biomass (g/m}^3)]} \quad (31)$$

$$F/M = \frac{S_0\, Q_0}{V\, X} \quad (32)$$

Substituting Eq. 21 into Eq. 26

$$F/M = \frac{S_0}{\theta\, X} \quad (33)$$

Excess sludge wasting

The excess sludge remaining in the secondary clarifier after being recycled to the aeration basin has to be wasted to maintain a steady level of MLSS in the system. The excess sludge quantity increases with increase in *F*/*M* ratio and decreases with increase in temperature. The excess sludge wasting can be accomplished either from the sludge wasting line or directly from the aeration basin as mixed liquor. Although sludge wasting from sludge return line is conventional, it is more desirable to waste the excess sludge from the aeration basin for better plant control. Sludge wasting from aeration basin is also beneficial for subsequent sludge thickening operations, as it has been established that higher solid concentrations can be achieved when dilute mixed liquor is thickened rather than the concentrated sludge (McCarty, 1966).

The excess sludge generation under steady state may be estimated from Eq. 29 or from

$$P_x = Y_{obs}\, Q_0\, (S_0 - S)\, x\, 10^{-3} \quad (34)$$

Where, P_x = net waste activated sludge produced each day, kg/d

Y_{obs} = Observed sludge yield = $Y/(1 + k_d \,.\, \theta_c)$

Sludge recycling

The MLSS concentration in the aeration tank is controlled by the sludge recirculation rate and the sludge settleability and thickening in the secondary clarifier.

$$\frac{Q_R}{Q} = \frac{X}{X_R - X} \quad (35)$$

Where, Q_R is recycle rate, Q flow rate of wastewater, X is MLSS in aeration tank, and X_R is SS concentration in return sludge. The sludge setteleability is determined by sludge volume index (SVI). If it is assumed that sedimentation of suspended solids in laboratory is similar to that in the secondary clarifier, then $X_R = 10^6/SVI$. Values of SVI between 50 and 150 mL/g indicate good settling of the suspended solids. The X_R value may not be taken as more than 10000 g/m^3 unless separate thickeners are provided to concentrate the settled solids or secondary clarifier is designed to have a higher value.

Oxygen requirement

Oxygen is used as an electron acceptor in the energy metabolism of the aerobic heterotrophic microorganisms present in the activated sludge process. Oxygen is required in the activated sludge process for oxidation of the influent organic matter along with cell growth and endogenous respiration of the microorganisms. The aeration equipments must be capable of maintaining a dissolved oxygen level of about 2 mg/L in the aeration basin while providing thorough mixing of the solid and liquid phase.

The oxygen requirement for an activated sludge system can be estimated by knowing the ultimate BOD of the wastewater and the amount of biomass wasted from the system each day (Metcalf and Eddy, 2003). If all the substrate removed by the microorganisms is totally oxidized for energy purpose, then the total oxygen requirement is calculated as:

$$\text{Total } O_2 \text{ requirement} \left(\frac{\text{g}}{\text{d}}\right) = \frac{Q\,(S_0 - S)}{f} \qquad (35)$$

Where f = ratio of BOD_5 to ultimate BOD

But, all the substrate oxidized is not used for energy. A portion of the substrate is utilized for synthesis of new biomass. As it is assumed that the system is under steady state condition, there is no accumulation of biomass and the amount of biomass produced is equal to the amount of biomass wasted. Therefore, the equivalent amount of substrate synthesized to new biomass is not oxidized in the system and exerts no oxygen demand. The oxygen requirement for oxidizing 1 unit of biomass = 1.42 units. The oxygen requirement for oxidation of biomass produced as a result of substrate utilization is required to be subtracted from the theoretical oxygen requirement given by Eq. 35 to get the actual oxygen requirement.

$$\text{Total } O_2 \text{ requirement (g/d)} = \frac{Q\,(S_0 - S)}{f} - 1.42\, Q_W X_R \qquad (36)$$

The above equations (Eq. 36) do not account for nitrification oxygen requirements. The carbonaceous oxygen requirement is only considered in these equations. When nitrification has to be considered, the oxygen requirement will be:

$$\text{Total } O_2 \text{ requirement (g/d)} = \frac{Q\,(S_0 - S)}{f} - 1.42\, Q_W X_R + 4.57\, Q(N_o - N)$$

Where, N_o is the influent TKN concentration, mg/L, N is the effluent TKN concentration, mg/L and 4.57 is the conversion factor for amount of oxygen required for complete oxidation of TKN.

The air supply in aeration tank must be adequate to:

- Satisfy the BOD of the wastewater
- Satisfy the endogenous respiration of the microorganisms
- Provide adequate mixing (15 to 30 KW/10^3 m^3) to keep biomass in suspension.

- Maintain minimum DO of 1 to 2 mg/L throughout the aeration tank.

Typical air requirement for conventional ASP is 30 to 55 m^3/kg of BOD removed. For fine air bubble diffusers it is 24 to 36 m^3/kg of BOD removed. For extended aeration ASP the air requirement is higher of the order of 75 to 115 m^3/kg of BOD removed. To meet the peak demand the safety factor of 2 should be used while designing aeration equipment.

Example:1

Design a complete mixed activated sludge process aeration tank for treatment of 4 MLD sewage having BOD concentration of 180 mg/L. The effluent should have soluble BOD of 20 mg/L or less. Consider the following:

MLVSS/MLSS = 0.8

Return sludge SS concentration = 10000 mg/L

MLVSS in aeration tank = 3500 mg/L

Mean cell residence time adopted in design is 10 days

Solution

a) Treatment efficiency based on soluble BOD

$$\eta = (180 - 20)*100/180 = 88.89\%$$

b) Calculation of reactor volume, Q = 4 MLD = 4000 m^3/d, Y = 0.5 mg/mg, k_d = 0.06 per day

$$V = \frac{Q.\theta_c.Y((So - S)}{X(1+ k_d.\theta_c)}$$

Therefore,

$$V = \frac{4000\ x\ 0.5\ x\ 10\ (180 - 20)}{3500(1+ 0.06\ x\ 10)}$$

$$= 571.43\ m^3$$

c) Calculate HRT

$$\theta = V/Q = 571.43 * 24 / 4000 = 3.43\ h\ \text{(within 3 to 5 h)}$$

d) Check for F/M

$$F/M = \frac{Q.S_0}{V\,X} = 4000 * 180/(571.43 * 3500) = 0.36\ \text{kg BOD/kg VSS.d (within 0.2 – 0.6)}$$

e) Check for volumetric loading

$= Q \cdot So / V = 4000 * 180 * 10^{-3}/571.43 = 1.26$ kg BOD/m^3.d (within 0.8 to 2.0)

f) Quantity of sludge waste

$Y_{obs} = Y/(1 + k_d \cdot \theta_c) = 0.5/(1 + 0.06*10) = 0.3125$ mg/mg

Therefore, mass of volatile waste activated sludge

$P_x = Y_{obs}\, Q_0\, (S_0 - S)\, x\, 10^{-3} = 0.3125 * 4000\,(180 - 20) * 10^{-3}$

= 200 kg VSS/day

Therefore, mass of sludge based on total SS = 200/0.8 = 250 kg SS/d

g) Sludge waste volume based on mean cell residence time

$\theta_C = \frac{VX}{Q_W X_R} = 571.43 * 3500 / (Q_w * 10000*0.8) = 10$ days

Hence, $Q_w = 25.0$ m^3/d (when wasting is done from the recycled line of SST)

h) Estimation of recirculation ratio

$3500\,(Q + Q_R) = 8000\, Q_R$

Therefore, $Q_R/Q = 0.78$

i) Estimation of air requirement

Total O_2 requirement (g/d) = $\frac{Q\,(S_0 - S)}{f} - 1.42\, Q_W X_R$

kg of oxygen required = $(4000(180 - 20) * 10^{-3})/0.68 - 1.42 * 25 * 8000 * 10^{-3}$

= 657.17 Kg O_2/d

j) Volume of air required, considering air contain 23% oxygen by weight and density of air 1.201 kg/m^3

= 657.17/(1.201 * 0.23) = 2357.34 m^3/d

Considering oxygen transfer efficiency of 8%, the air required = 2357.34/0.08 = 29466.75 m^3/d

= 20.46 m^3/min

Considering safety factor of 2, the air requirement is = 2 x 20.46 = 40.92 m^3/min

k) Check for air volume

Air requirement per unit volume = 29466.75 / 4000 = 7.37 m^3/m^3

(Within the limit of 3.75 to 15 m^3/m^3)

Air requirement per kg of BOD_5 = 29466.75 / [(180-20) * 4000 * 10^{-3}] = 46.04 m^3/kg of BOD_5 (within the limit of 30 to 55 m^3/kg of BOD_5)