19.1.3 Limitations of ASP

For treatment of wastewater with high organic matter concentration, say if the resulting COD concentration in the aeration tank after dilution is in few thousands mg/L, then it will produce biomass of about 50% of the COD concentration. With original biomass concentration plus the generated biomass, the total biomass concentration in the system will be higher. This may pose the difficulty of operating ASP such as uniform aerating the system at such concentration, and settling and recirculation of the sludge. Hence, this process is not recommended for first stage treatment of high concentrated organic wastewaters.

19.1.4 Kinetics of the Bacterial Growth in Activated Sludge Process

During oxidation of organic matter in ASP following reaction occurs

$$\underset{\text{(organic matter)}}{COHNS} + O_2 + \text{nutrients} \xrightarrow[\text{(bacteria)}]{} CO_2 + NH_3 + \underset{\text{(new cell)}}{C_5H_7O_2N} + \text{Other products}$$

Under endogenous respiration the reaction is

$$\underset{\substack{\text{(cell)}\\113}}{C_5H_7O_2N} + \underset{160}{5\,O_2} \xrightarrow[\text{(bacteria)}]{} 5CO_2 + 2H_2O + NH_3 + \text{energy}$$

The above equation for endogenous respiration tells that for 1 unit mass of cell 160/113 = 1.42 times oxygen is required.

The biomass is the matter of interest rather than the number of organisms for the mixed cultures in the activated sludge process. The rate of biomass increase during the log growth phase is directly proportional to the initial biomass concentration, which is represented by the following first order equation

$$\frac{dX}{dt} = \mu X \qquad (1)$$

Where $\frac{dX}{dt}$ = growth rate of biomass (g/m^3.d)

X = biomass concentration (g/m^3)

μ = specific growth rate constant (d^{-1}). It is the mass of the cells produced per unit mass of the cells present per unit time

If the biomass concentration is X_o, at time t = 0, then integrating Eq. (1),

$$\int_{X_0}^{X} \frac{dX}{X} = \int_0^t \mu \, dt$$

$$ln \frac{X}{X_0} = \mu t$$

$$X = X_0 \, e^{\mu t} \tag{2}$$

The exponential growth rate of the bacteria (Eq. 2) occurs as long as there is no change in the biomass composition or environmental condition.

Monod (1949) showed experimentally that the biomass growth rate was a function of biomass concentration and limiting nutrient concentration. The Monod's equation for biomass growth rate is expressed as

$$\mu = \mu_m \frac{S}{K_s + S} \tag{3}$$

Where S = limiting substrate concentration (g/m^3)

μ_m = maximum biomass growth rate (d^{-1})

K_s = half saturation constant, i.e. substrate concentration at one half maximum growth rate (concentration of S when $\mu = \mu_m/2$, g/m^3)

Eq. (3) assumes only the growth of the microorganisms. However, there is simultaneous die-off of microorganisms. Therefore, an endogenous decay is used to take account of die-off. Hence, Eq. (1) becomes

$$\frac{dX}{dt} = \mu X - k_d X$$

$$\frac{dX}{dt} = \left(\frac{\mu_m S}{K_s + S}\right) X - k_d X \tag{4}$$

Where k_d = endogenous decay rate (d^{-1}). The k_d value is in the range of 0.04 to 0.075 per day, typically 0.06 per day.

If all the substrate (organic food, *S*) could be converted to biomass, then the substrate utilization rate is

$$-\frac{dS}{dt} = \frac{dX}{dt} \quad (5)$$

However, all the substrates cannot be converted to biomass because of catabolic reaction i.e., energy generation from oxidation of biomass is must for supporting anabolic reaction (biomass synthesis) in the conversion process. Therefore, a yield coefficient ($Y < 1$) is introduced such that the substrate utilization rate is higher than the biomass growth rate.

$$-\frac{dS}{dt} = \frac{1}{Y}\frac{dX}{dt} \quad (6)$$

$$-\frac{dS}{dt} = \frac{1}{Y}\frac{\mu_m SX}{k_S + S} \quad (7)$$

Where Y = yield coefficient i.e., fraction of substrate converted to biomass, (g/m^3 of biomass) / (g/m^3 of substrate). The value of *Y* typically varies from 0.4 to 0.8 mg VSS/mg BOD (0.25 to 0.4 mg VSS/mg COD) in aerobic systems.

19.1.5 Process Analysis of Completely Mixed Reactor With Recycle

Kinetic models, which have been proposed to describe the activated sludge process, have been developed on the basis of steady-state conditions within the treatment system. The complete mix reactor with sludge recycle is considered in the following discussion as a model for activated sludge process. The schematic flow diagram shown in Figure 19.11 includes the nomenclature used in the following mass balance equations.

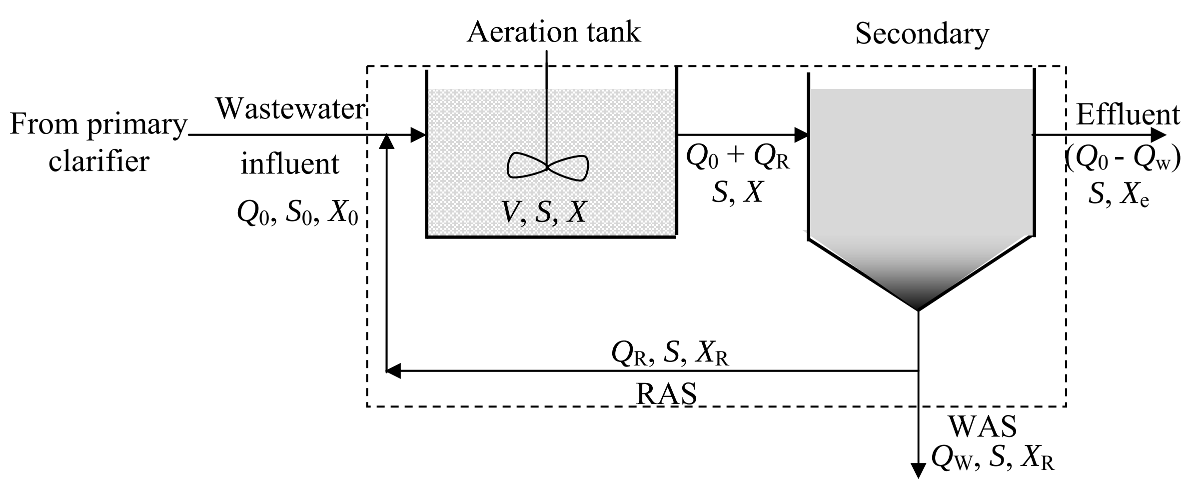

Figure 19.11 Typical flow scheme for a complete mix activated sludge system

The mass balance equations used to develop the kinetic models is based on the following assumptions:

- The biomass concentration in the influent is negligible.
- There is complete mixing in the aeration tank.
- The substrate concentration in the influent wastewater remains constant.
- Waste stabilization occurs only in the aeration tank. All reactions take place in the aeration basin so that the substrate in the aeration basin is of the same concentration as the substrate in the secondary clarifier and in the effluent.
- There is no microbial degradation of organic matter and no biomass growth in the secondary clarifier.
- Steady state conditions prevail throughout the system.
- The volume used for calculation of mean cell residence time includes volume of the aeration tank only.

Biomass mass balance

A mass balance for the microorganisms in the complete mix reactor (Figure 19.11) can be written as follows:

$$\begin{array}{c}\text{Net rate of change in}\\ \text{biomass inside the}\\ \text{system boundary}\end{array} = \begin{array}{c}\text{Rate at which}\\ \text{biomass enters in}\\ \text{the system}\end{array} - \begin{array}{c}\text{Rate at which}\\ \text{biomass leaves}\\ \text{the system}\end{array} \qquad (8)$$

The above mass balance statement can be simplified to

$$\text{Accumulation} = \begin{array}{c}\text{Inflow of}\\ \text{biomass}\end{array} + \begin{array}{c}\text{Net growth}\\ \text{of biomass}\end{array} - \begin{array}{c}\text{Outflow of}\\ \text{biomass}\end{array} \qquad (9)$$

It is assumed that steady state condition prevails in the system; hence accumulation of biomass in the system will be zero. Therefore,

$$\begin{matrix}\text{Influent} \\ \text{biomass}\end{matrix} + \begin{matrix}\text{Biomass} \\ \text{production}\end{matrix} = \begin{matrix}\text{Effluent} \\ \text{biomass}\end{matrix} + \begin{matrix}\text{Wasted} \\ \text{biomass}\end{matrix} \tag{10}$$

$$Q_0 X_0 + V \frac{\mathrm{d}X}{\mathrm{d}t} = (Q_0 - Q_\mathrm{W}) X_\mathrm{e} + Q_\mathrm{W} X_\mathrm{R} \tag{11}$$

Where Q_0 = Influent flow rate (m^3/d)

X_0 = Influent biomass concentration (g/m^3)

V = Volume of the aeration basin (m^3)

Q_W = Flow rate of waste sludge (m^3/d)

X_e = Effluent biomass concentration (g/m^3)

X_R = Biomass concentration in the return sludge (g/m^3)

It is assumed that the biomass concentration in the influent wastewater and in the effluent from the clarifier is negligible, i.e., $X_0 = X_\mathrm{e} = 0$. Therefore, Eq. 11 becomes

$$V \frac{\mathrm{d}X}{\mathrm{d}t} = Q_\mathrm{W} X_\mathrm{R} \tag{12}$$

Substituting Eq. 4 in Eq. 12,

$$V \left[\left(\frac{\mu_\mathrm{m} S}{K_\mathrm{s} + S}\right) X - k_\mathrm{d} X\right] = Q_\mathrm{W} X_\mathrm{R} \tag{13}$$

$$\left(\frac{\mu_\mathrm{m} S}{K_\mathrm{s} + S}\right) = \frac{Q_\mathrm{W} X_\mathrm{R}}{VX} + k_\mathrm{d} \tag{14}$$

If r'_g is net growth of microorganisms, then from equation 13, $r'_g = Q_w X_R/V$

Or we can write $Q_w X_R/V.X = r'_g /X$ (15)

Also, $r'_g = -Y.r_{su} - k_d.X$ (16)

Where, r_{su} is the substrate utilization rate, mass/unit volume.time

Substituting in Eq. 15.

$$Q_w X_R/V.X = -Y.r_{su}/X - k_d \qquad (17)$$

The right hand side of the equation is the reciprocal of the mean cell residence time θ_c

Therefore, $$1/\theta_c = -(Y.r_{su}/X) - k_d \qquad (18)$$

Now, $$r_{su} = - Q(So - S)/V = (So - S)/\theta \qquad (19)$$

Where θ = hydraulic retention time (d)

So = Influent substrate concentration

S = Effluent substrate concentration

From Eq. 19 and Eq. 18

$$1/\theta_c = [Y(So - S)/\theta.X] - k_d \qquad (20)$$

Solving for X and substituting $\theta = V/Q$

$$V = \frac{Q.\theta_c.Y((So - S)}{X(1+ k_d.\theta_c)} \qquad (21)$$

Equation 21 is used for calculating volume of the aeration tank when the kinetic coefficients are known.

Substrate mass balance

A mass balance for the substrate in the complete mix reactor (Figure 19.11) using the control volume of the aeration basin and the clarifier can be written as follows:

Net rate of change in substrate inside the system boundary	=	Rate at which substrate enters in the system	-	Rate at which substrate leaves the system	(22)

Considering steady state condition prevailing in the system, the above mass balance for the substrate can be simplified to

$$\text{Inflow of substrate} - \text{Consumption of substrate} = \text{Outflow of substrate} + \text{Wasted substrate} \quad (23)$$

$$Q_0 S_0 - V \frac{dS}{dt} = (Q_0 - Q_W) S + Q_W S \quad (24)$$

Where, S_0 = substrate concentration in the influent (g/m^3)

Substituting Eq. 7 in Eq. 24

$$Q_0 S_0 - V \left[\frac{1}{Y}\left(\frac{\mu_m S X}{k_S + S}\right)\right] = (Q_0 - Q_W) S + Q_W S \quad (25)$$

Rearranging Eq. 25, we get

$$\frac{\mu_m S X}{k_S + S} = \frac{Q_0 Y}{V X} (S_0 - S) \quad (26)$$

Rearranging after combining with Eq. 14

$$S = \frac{K_s\,(1 + k_d.\theta_c)}{\theta_c(YK - k_d) - 1} \quad (27)$$

Where K = μ_m/Y i.e., it is maximum rate of substrate utilization per unit mass of microorganism.

Hydraulic retention time (HRT)

The hydraulic retention time is calculated as

$$\theta = \frac{V}{Q_0} \quad (28)$$

The usual practice is to keep the detention period between 5 to 8 hours while treating sewage. The volume of aeration tank is also decided by considering the return sludge, which is about 25 to 50% of the wastewater volume.

Mean cell residence time (MCRT)

The mean cell residence time (MCRT) of microorganisms in the system is the length of time the microorganisms stay in the process. This is also called the solids retention time (SRT) or the sludge age. This is expressed as

$$\theta_C = \text{total biomass in the aeration basin/biomass wasted per unit time (d)}$$

$$\theta_C = \frac{VX}{Q_W X_R + (Q_0 - Q_W)X_e} \tag{29}$$

As the value of X_e is negligible, Eq. 29 reduces to

$$\theta_C = \frac{VX}{Q_W X_R} \tag{30}$$

The MCRT is higher than the HRT as a fraction of the sludge is recycled back to the aeration basin.