CHAPTER 7

ACTIVATED SLUDGE SYSTEM

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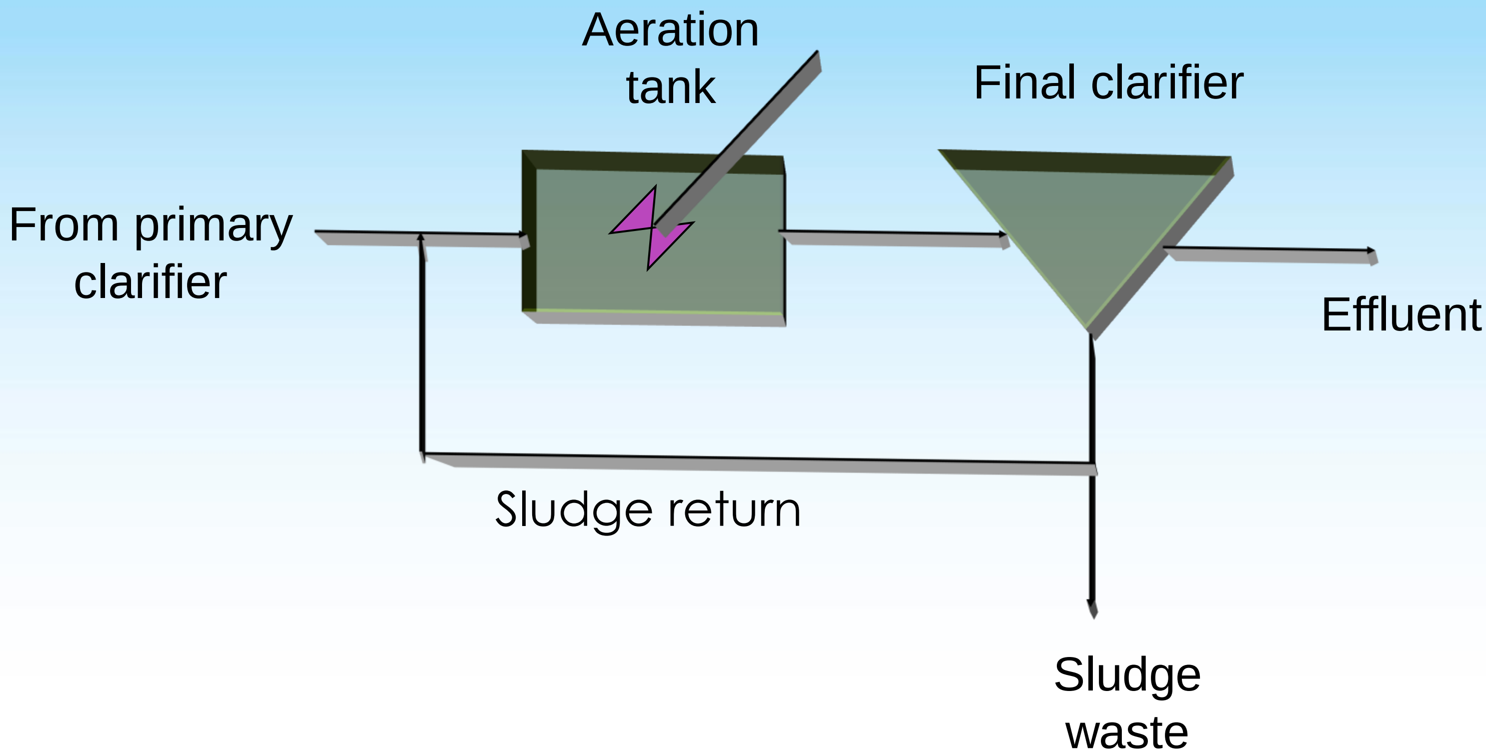
CONVENTIONAL ACTIVATED SLUDGE

- Suspended growth type
- Unique – the name activated sludge was originated in referring to the return sludge (biomass), since these masses of microorganisms were observed to be very "active" in removing soluble organic matter from solution.
- Wastewater is fed continuously into an aerated tank, where the microorganism metabolize and biologically flocculate the organics.


Aeration
tank
Final clarifier
From primary
clarifier
Effluent
Sludge return
Sludge
waste

MAJOR COMPONENTS

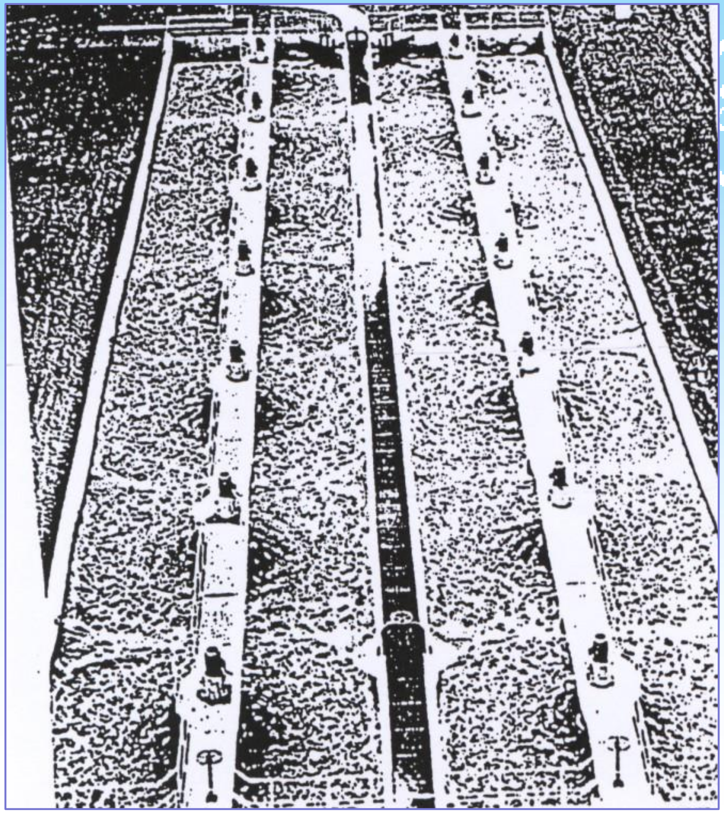
- Aeration tank/reactor
- Sedimentation tank/secondary settling tank/final clarifier

CONVENTIONAL ACTIVATED SLUDGE

- Microorganisms (activated sludge/biomass) are settled in the final clarifier and returned to the aeration tank.
- Clear supernatant from the final clarifier is the plant effluent.
- Excess activated sludge is wasted from the system to maintain the proper food/microorganism ratio (F/M) and sludge age to ensure optimum operation.

AERATION TANK

- Organic matter decompose in aerobic condition
- Air (oxygen) is supplied through:
  - Mechanical aerator or diffuser
  - Or both
  - Air supply also gives mixing in wastewater
- Combination of wastewater, suspended solids and microorganisms is called “mixed liquor suspended solids (MLSS)”



Mechanical Surface Aerator

Diffusers

Aeration Tank

Aeration Tank

SECONDARY SETTLING TANK/SEDIMENTATION TANK

- Serves as a solid separation unit in which the cells (biomass) from the reactor are separated (settled) and returned to the reactor.

ADVANTAGES

- High quality of effluent (95% BOD removal)
- Effluent quality is controlled by sludge return

DISADVANTAGES

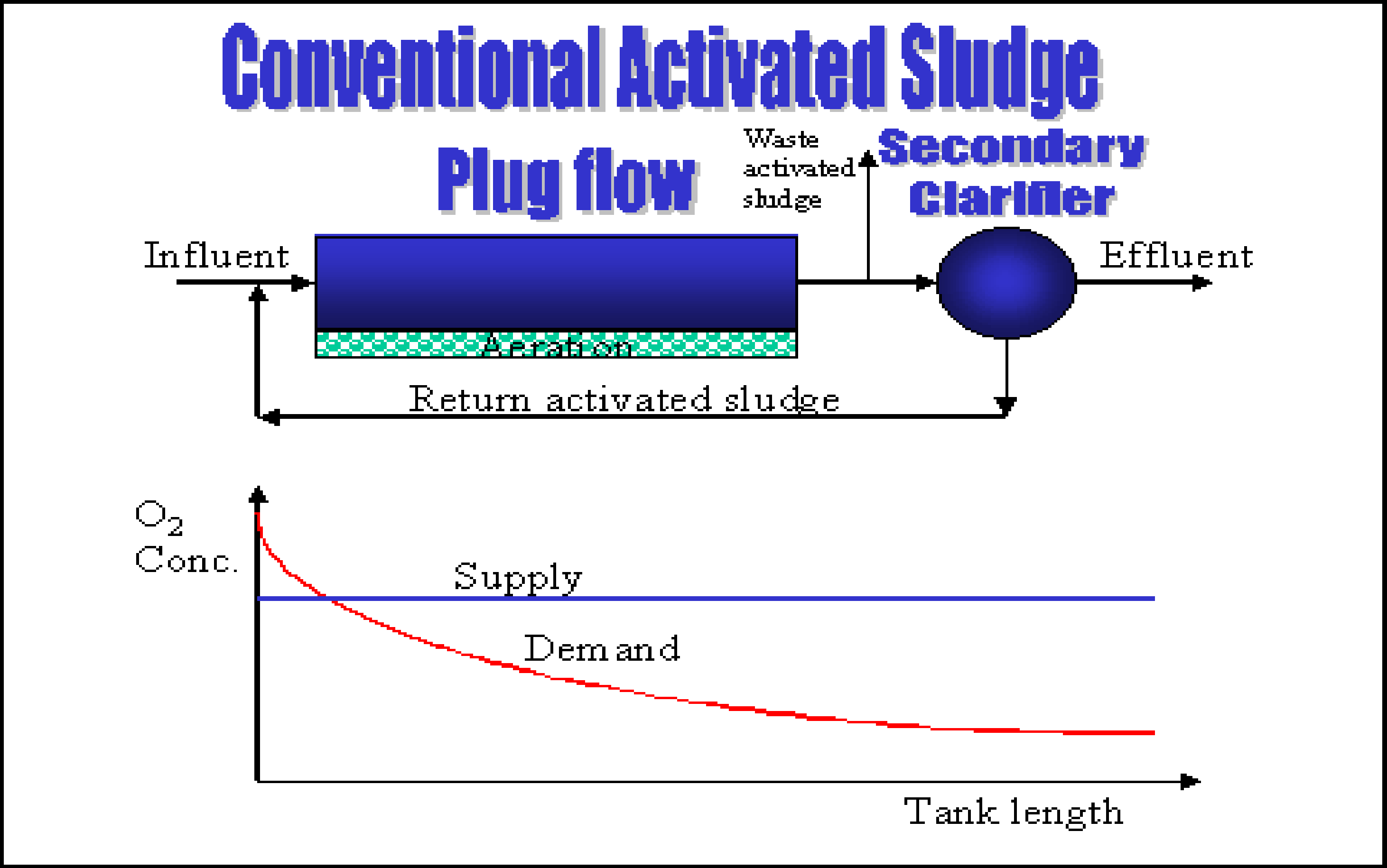
- Need high skill labor
- High capital, operation and maintenance costs

REACTOR DESIGN

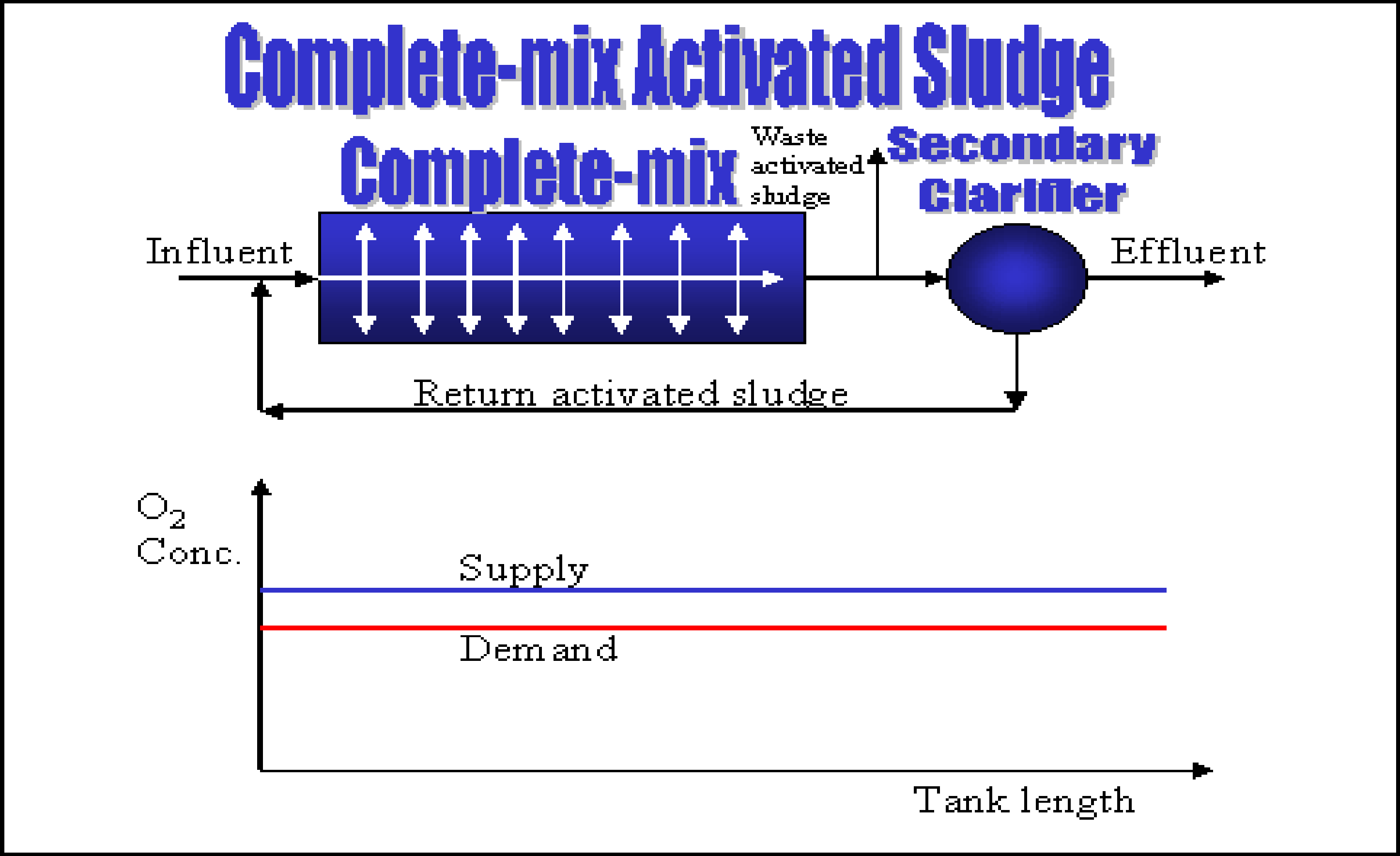
Plug flow system

Complete mix system

Plug Flow System

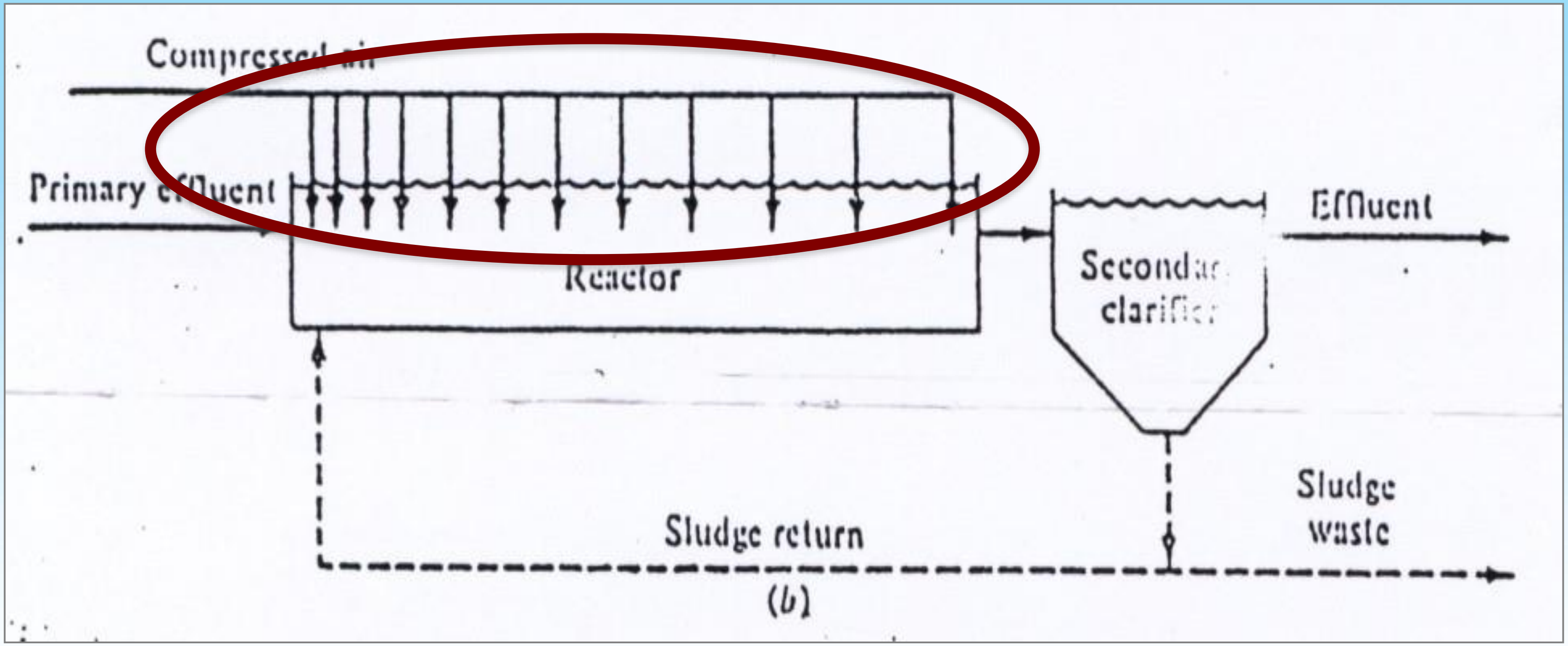


Complete Mix System



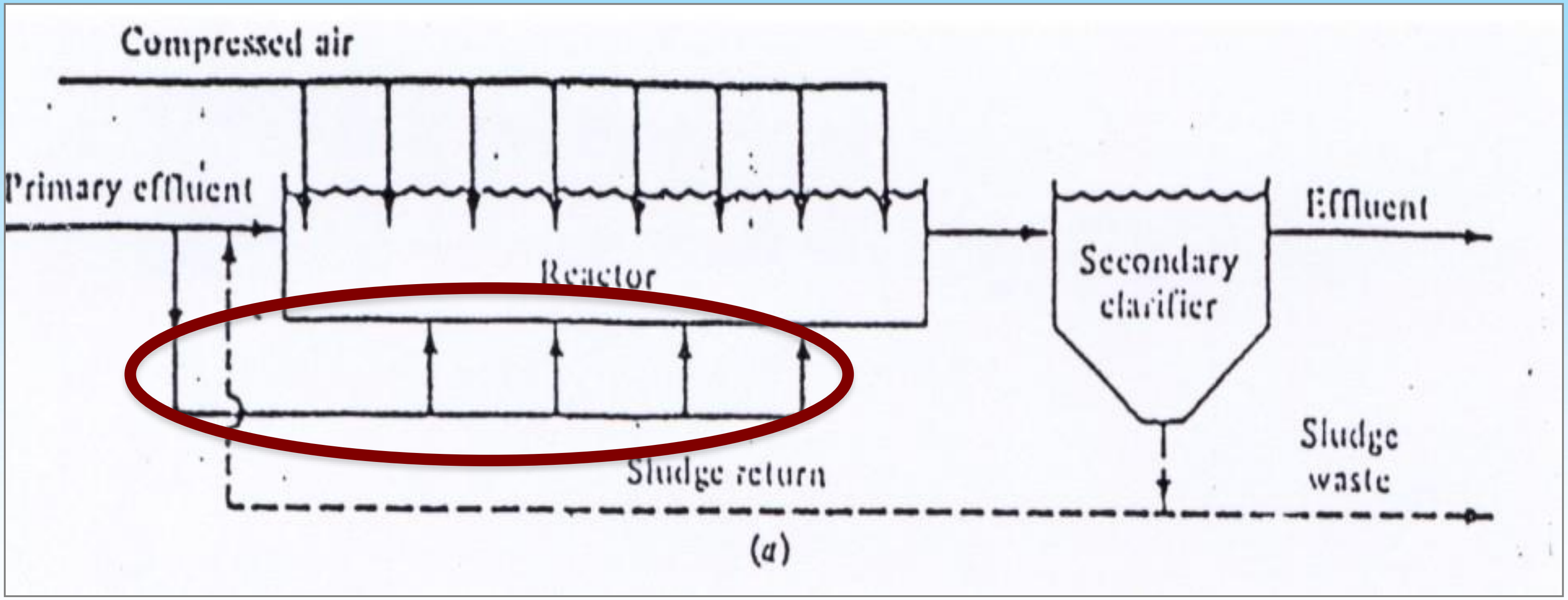
MODIFICATION

- Tapered aeration
- Step aeration
- Oxidation-ditch
- Extended aeration (EA)
- Sequencing Batch Reactor (SBR)



Tapered Aeration

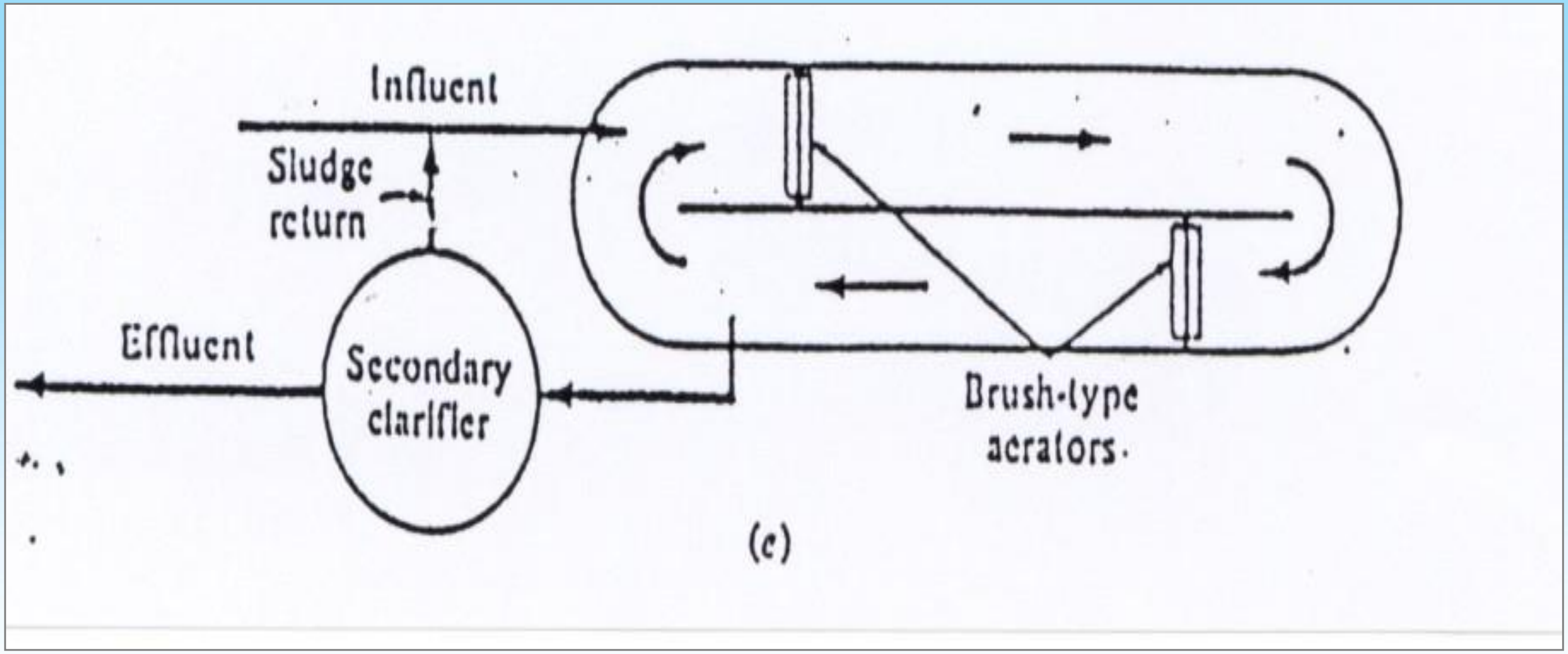
Air is added in proportion to BOD exerted



Step Aeration (similar to complete mix flow)
Influent addition at intermediate points provides more uniform BOD removal throughout tank

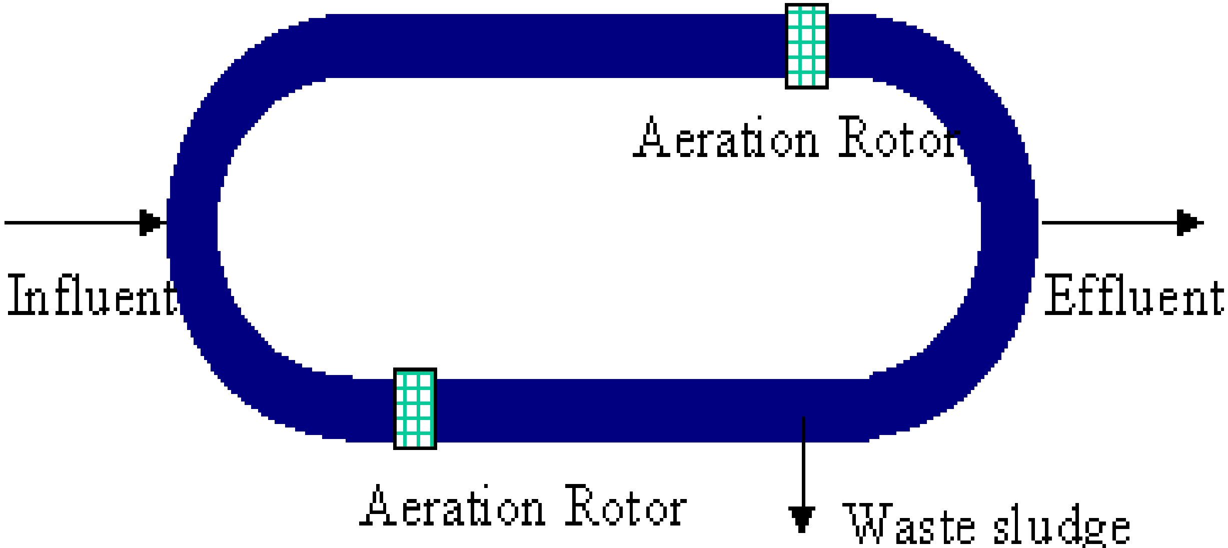
Contact Stabilization

- **wastewater is contacted with the microorganisms for a much shorter time (1 to 2 hours).**
- **After settling, the activated sludge is pumped to a re-aeration tank where the microorganisms metabolize the nutrients they have extracted from the waste.**
- **More suitable for large variations in flow or BOD loading.**

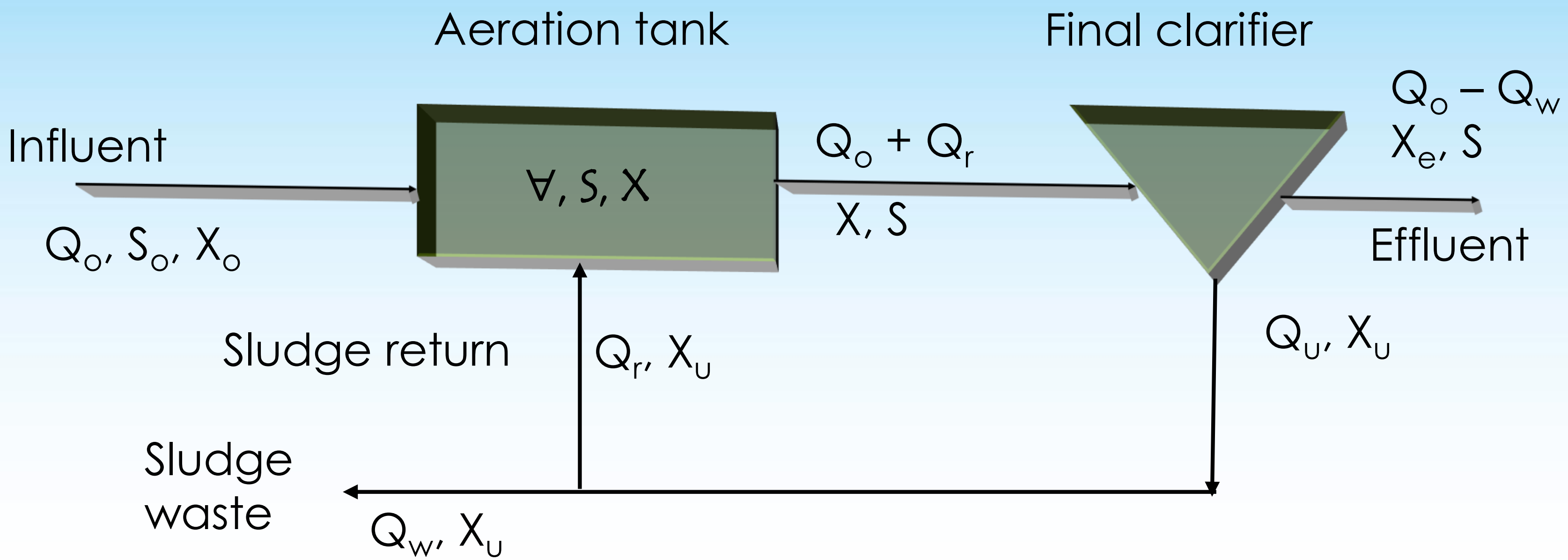


Oxidation Ditch
Plan view

Oxidation Ditch



REACTOR DESIGN



Schematic of Complete-Mix Reactor

Mass balance in the system:

Suspended Solids:

Biomass in + Biomass Growth = Biomass Out (effluent + wasted sludge)

$$Q_o X_o + \forall\left(\frac{k_o X S}{K_s + S} - k_d X\right) = (Q_o - Q_w) X_e + Q_w X_u \qquad 7.1$$

where

Q_o, Q_w	= Influent and waste-sludge flow rate, m^3/d
X_o, X, X_e, X_u	= biomass concentrations in influent, reactor, effluent and clarifier underflow(waste sludge), respectively, kg/m^3
S_o, S	= soluble food concentration in the influent and reactor, respectively, kg/m^3
$\forall$	= volume of reactor, m^3
K_s	= half saturation constant,kg/m^3
K_o	= maximum growth rate constant, d^{-1}
K_d	= endogenous decay rate constant, d^{-1}

<u>Substrate/Food</u>:

Food In – Food Consumed = Food Out

$$Q_o S_o - \forall \frac{k_o S X}{Y(K_s + S)} = (Q_o - Q_w) S + Q_w S \qquad (7.2)$$

Where

Y = decimal fraction of food mass converted to biomass

= (mg/L biomass/mg/L food utilized)

<u>Assumptions:</u>

- The influent and effluent biomass concentrations are negligible compared to biomass at other points in the system
- The influent food concentration S_o is immediately diluted to the reactor concentration S because of the complete-mix regime
- All reactions occur in the reactor. Therefore, the volume, $\forall$ represents the volume of the reactor only

With these assumptions, Eqs. (7.1) and (7.2) are rearranged as follows:

$$\frac{k_o S}{K_s + S} = \frac{Q_w X_u}{\forall X} + k_d \qquad (7.3)$$

$$\frac{k_o S}{K_s + S} = \frac{Q_o}{\forall}\frac{Y}{X}(S_o - S) \qquad (7.4)$$

Combining Eq. (7.3) and (7.4) gives:

$$\frac{Q_w X_u}{\forall X} = \frac{Q_o}{\forall}\frac{Y}{X}(S_o - S) - k_d \qquad (7.5)$$

The hydraulic detention time in the aeration tank/reactor:

$$t = \frac{\forall}{Q_o} \qquad (7.6)$$

The mean cell-residence time (SRT/sludge age / the average time that cell (microorganisms) spend in the reactor)

$$t_c = \frac{\forall X}{Q_w X_u} \qquad (7.7)$$

Substituting Eqs. (7.6) and (7.7) into Eq. (7.5):

$$\frac{1}{t_c} = \frac{Y(S_o - S)}{tX} - k_d \qquad (7.8)$$

The concentration of biomass in the reactor (MLSS) is found by solving Eq. (7.8):

$$X = \frac{t_c Y(S_o - S)}{t(1 + k_d t_c)} \qquad (7.9)$$

The volumetric loading rate, $\forall_L$ is the mass of BOD in the influent divided by the volume of the reactor,

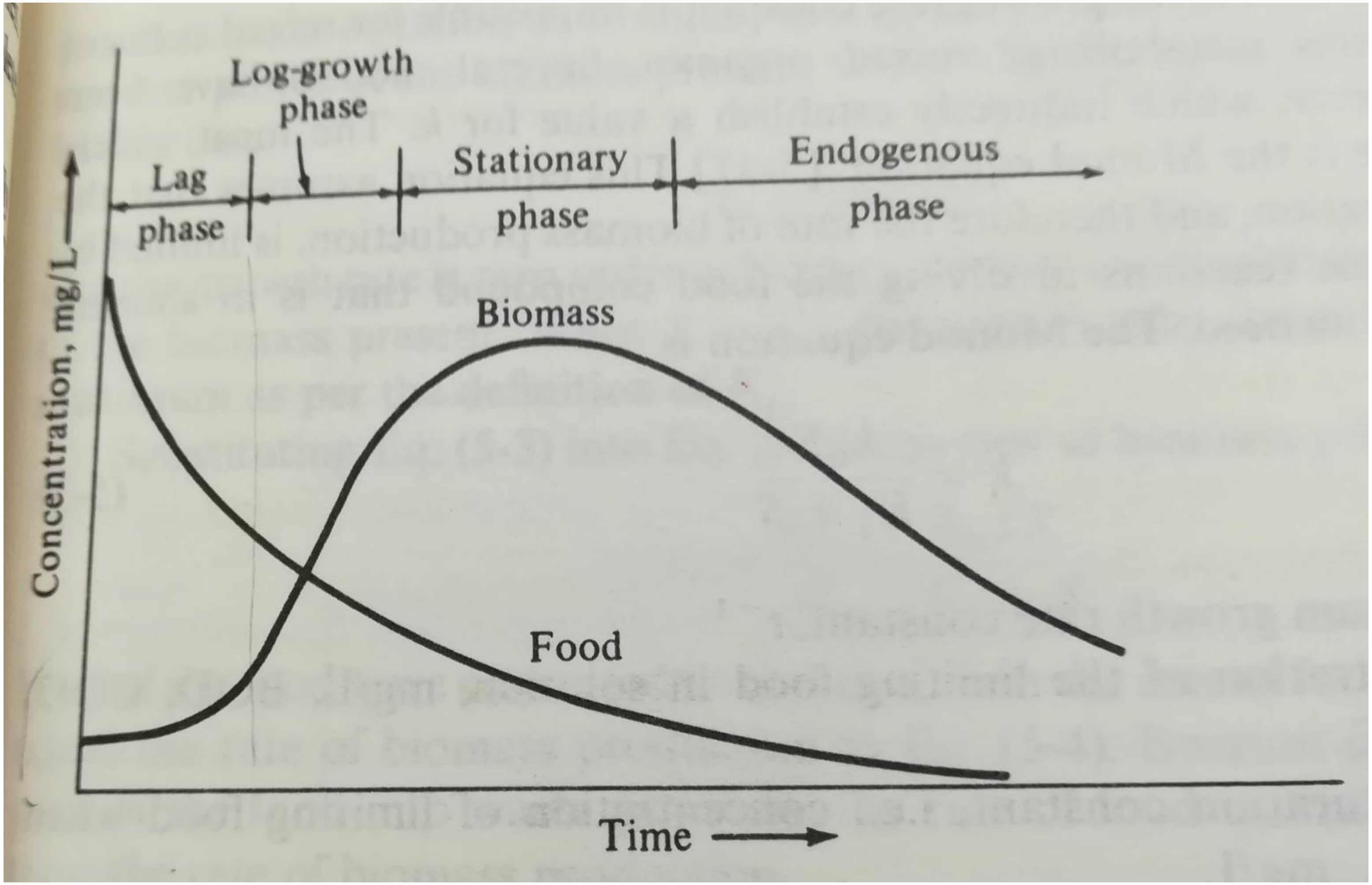
$$\forall_L = \frac{Q_o S_o}{\forall} \qquad (7.10)$$

The food-to-microorganisms ratio is used to express BOD loadings with regard to the biomass in the reactor,

$$\frac{F}{M} = \frac{QS_o}{\forall X} \quad (7.11)$$

The recirculation ratio is

$$R = \frac{Q_r}{Q} \quad (7.12)$$



Biomass growth and food utilization

EXAMPLE

An activated sludge system is to be used for secondary treatment of 10,000 m^3/d of municipal wastewater. After primary clarification, the BOD is 150 mg/L, and it is desired to have not more than 5 mg/L BOD in the effluent. A completely mixed reactor is to be used, and pilot-plant analysis has established the following kinetic values: $Y = 0.5$ kg/kg, $k_d = 0.05 d^{-1}$. Assuming an MLSS concentration of 3000 mg/L, an underflow concentration of 10,000 mg/L from the secondary clarifier, determine:

a) the volume of the reactor
b) the mass and volume of solids that must be wasted each day
c) the recycle ratio

SOLUTION

$$\frac{1}{t_c} = \frac{QY(S_o - S)}{\forall X} - k_d$$

1. Select t_c = 10 day, solve Eq.(7.8) with t = ∀/Q

$$0.1 = \frac{10{,}000(0.5)(0.15 - 0.005)}{\forall 3.0} - 0.05$$

∀ = 1611 m^3

2. Use Eq. (7.7):

$$t_c = \frac{\forall X}{Q_w X_u} \longrightarrow Q_W X_u = \frac{\forall X}{t_c}$$

Mass of solids wasted/day

$$\Rightarrow Q_W X_u = \frac{1611(3.0)}{10} = 483.3 kg/day$$

Volume of solids wasted/day

$$Q_W = \frac{483.3 kg/d}{10 kg/m^3} = 48.3 m^3/day$$

3. A mass balance around the secondary clarifier can be written as follows:

$$(Q_o + Q_r)X = (Q_o - Q_w)X_e + (Q_r + Q_w)X_u$$

Assuming that the solids in the effluent are negligible compared to the influents and underflow (*Xe* << *X*):

$$(Q_o + Q_r)X = 0 + (Q_r + Q_w)X_u$$

$$Q_r = \frac{QX - Q_w X_u}{X_u - X}$$

$$Q_r = \frac{(10{,}000 m^3/d(3.0 kg/m^3)) - 483.3 kg/d}{10 kg/m^3 - 3 kg/m^3}$$

$$= 4217 m^3/d$$

$\therefore$ The recirculation ratio is

$$R = \frac{Q_r}{Q} = \frac{4217}{10{,}000} = 0.42$$

EXTENDED AERATION

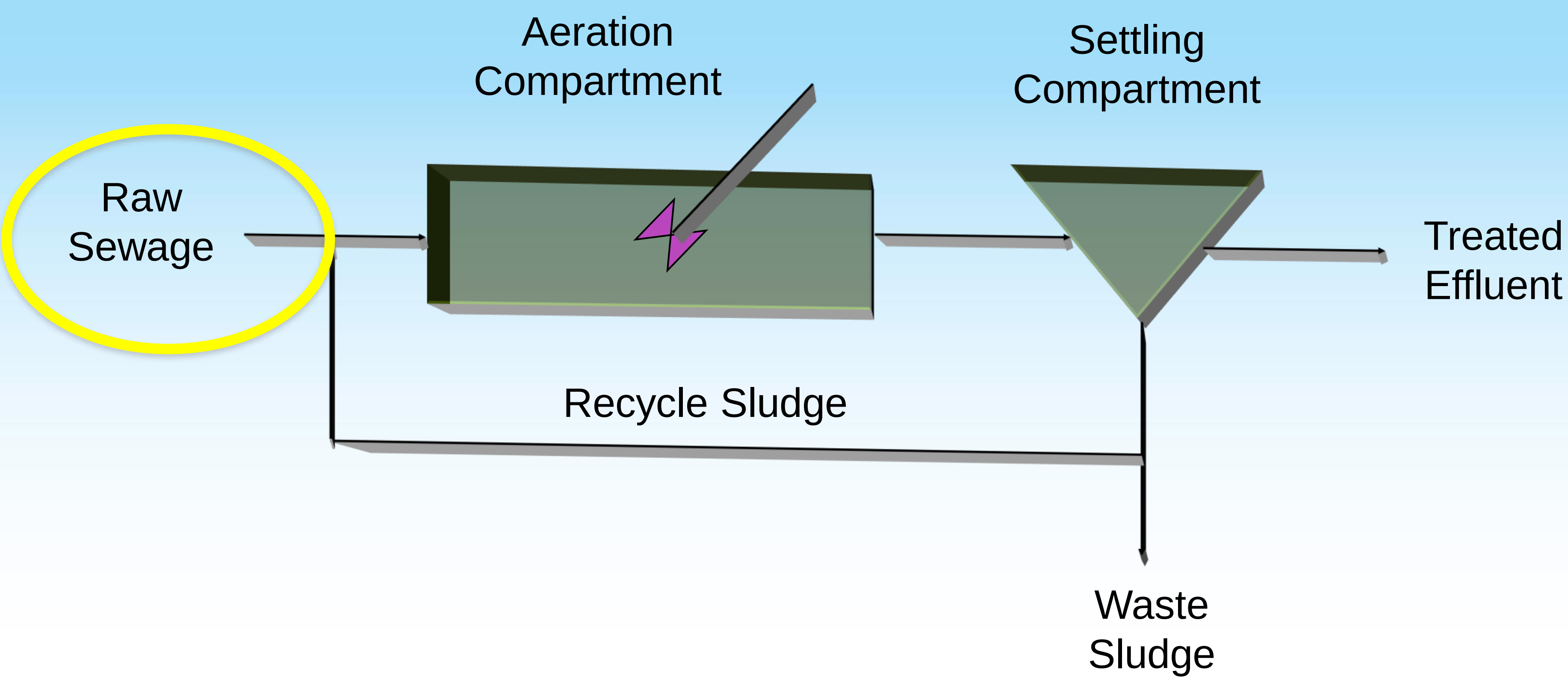
- Popular in treating small flows (schools, trailer parks, villages) *(Low BOD loading)*.
- Continuous complete mixing is applied by diffused air or mechanical mixers.
- Aeration periods 24-36 hr.

- **Stable biological process. Can accept intermittent loads without upset.**

EXTENDED AERATION (CONT')

- Sewage, which will usually be screened, flow to the aeration compartment where it is aerated in admixture with activated sludge.

- The sludge is separated from the mixed liquor in the settlement compartment, AND is recycled to the aeration compartment either by gravity pump or air lift pump.



Schematic Flow Chart of an Extended Aeration System

DESIGN AND OPERATIONAL PARAMETERS

F/M Ratio	: 0.05 – 0.15 kg BOD/kg MLSS.day
HRT	: 18 – 24 hours
SRT	: 20 – 30 days
Volumetric Loading	: 0.16 – 0.40 kgBOD/m^3
MLSS concentration	: 3000 – 6000 mg/L
Recycle Ratio	: 0.75 – 1.50
Air supply	: 90 – 125 m^3/kgBOD removed

EXAMPLE

An Extended Aeration STP treats 1500 m^3 of sewage daily with a BOD concentration of 300 mg/L. Calculate the volume required for the aeration compartment. Hence, check the Hydraulic Retention Time and the volumetric loading. Determine the quantity of sludge wasted per day. Assume a MLSS concentration of 3500 mg/L and a Solids Retention Time of 25 days.

SOLUTION

Choose F/M ratio as 0.1 kg BOD/kg MLSS.d.

$$\frac{F}{M} = \frac{QS_o}{\forall X} \longrightarrow 0.1 = \frac{1500 \times 0.3}{\forall \times 3.5}$$

$$\therefore \forall = 1286 m^3$$

$$HRT = \frac{\forall}{Q} = \frac{1286}{1500} \times 24$$

= 20.6 hours   OK

(18 < HRT < 24)

Volumetric loading = $\frac{QS_o}{\forall}$

$$= \frac{1500 \times 0.3}{1286}$$

= 0.35 kgBOD/m^3

(OK : 0.16 < $\forall_L$ < 0.40)

$$SRT = \frac{\forall X}{Q_w X_u}$$

$\therefore$ Quantity of sludge wasted, $Q_w X_u$

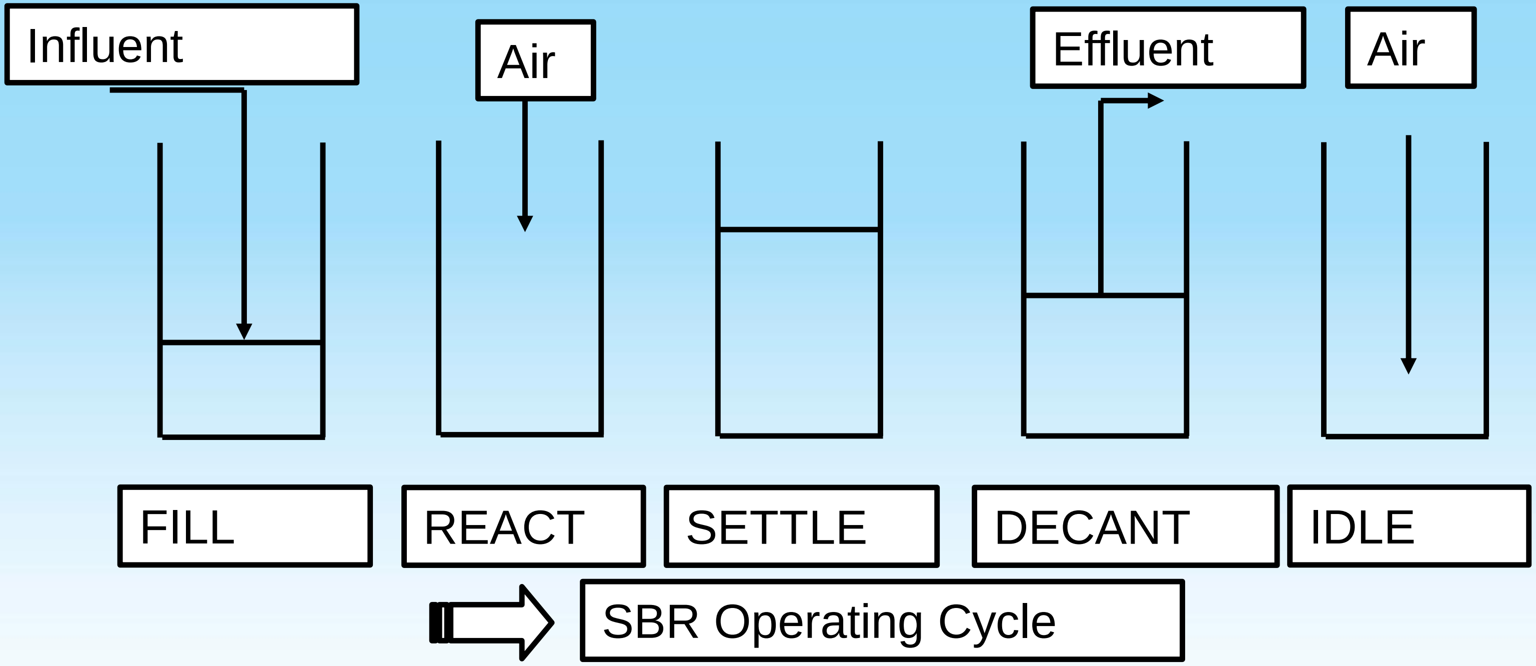
$$= \frac{1286 \times 3.5}{25} = 180 \text{ kg/day}$$

SEQUENCING BATCH REACTORS (SBR)

- SBR is a fill and draw activated sludge system.
- In this system, wastewater is added to a single batch reactor and then discharged.
- Equalization, aeration and clarification (sedimentation) are all achieved in a single batch reactor using a time control sequence. (In a conventional activated sludge system, these unit processes would be accomplished by using separate tanks).

SBR (CONT')

- To optimize the performance of the system, two or more batch reactors are used in a predetermined sequence of operations.
- SBR systems have been successfully used to treat both municipal and industrial wastewater.
- They are uniquely suited for wastewater treatment application characterized by low or intermittent flow conditions.



Operating Phases:

Fill : Wastewater enters the reactor.

React : Wastewater is aerated. Reaction time depends on the effluent quality required.

Settle : Biomass separation from final effluent. Reactor acts like a sedimentation tank.

Decant : Final effluent is drawn out of reactor leaving behind the settled sludge.

Idle : Time between decanting and fill. Time range between zero to a few days depending on the wastewater flow.

ADVANTAGES	DISADVANTAGES
• Require less space since equalization, biological treatment and sedimentation can be achieved in a single reactor • Operating flexibility and control • Capital cost savings by eliminating clarifiers and other equipments	• Higher level of sophistication (timing units and automated controls) • Higher level of maintenance • Potential discharging of settled sludge during decant phase

A completely mixed activated sludge process is used to treat a wastewater flow of 1 MLD, having a BOD_5 of 200 mg/L. The biomass concentration in the aeration tank is 2,000 mg/L, and the concentration of the net biomass leaving the system every day is 50 mg/L. The aeration tank has a volume of 200 m^3.

(i) What is the HRT of the wastewater in the aeration tank?

(ii**) What is the average time for which the biomass stays at the system?**

Q_o = 1 MLD = 1,000 m^3/day

S_o = 200 mg/L

MLSS = X = 2,000 mg/L

X_w = 50 mg/L

V = 200 m^3.

HRT = (V/Q) = (200/1,000) = 0.2 days = 4.8 hrs.

(ii)

Mean cell residence time:

$$t_c = \frac{\forall X}{Q_w X_u} = \frac{Total\ biomass\ present\ in\ the\ system}{Net\ biomass\ leaving\ the\ system\ per\ day}$$

$$\mathrm{Q_{in} = Q_{out} \rightarrow Q_w = Q = 1\ MLD}$$

$$\mathrm{t_c = \frac{(200 \times 2{,}000)/1{,}000}{(1{,}000 \times 50)/1{,}000} = \frac{400\ kg}{50\ kg/d} = 8days}$$