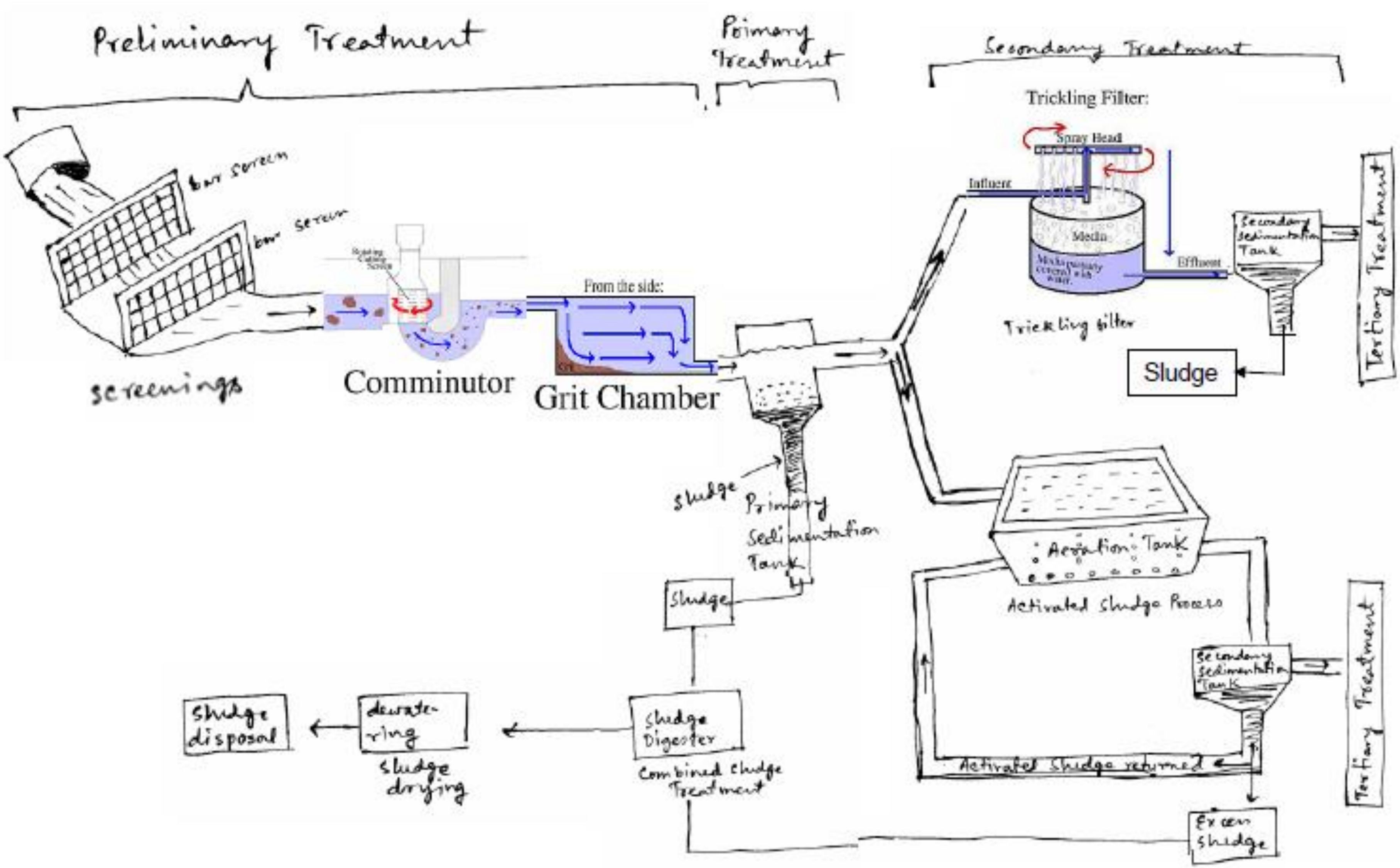
Wastewater Treatment

Sewage treatment is a multi-stage process:

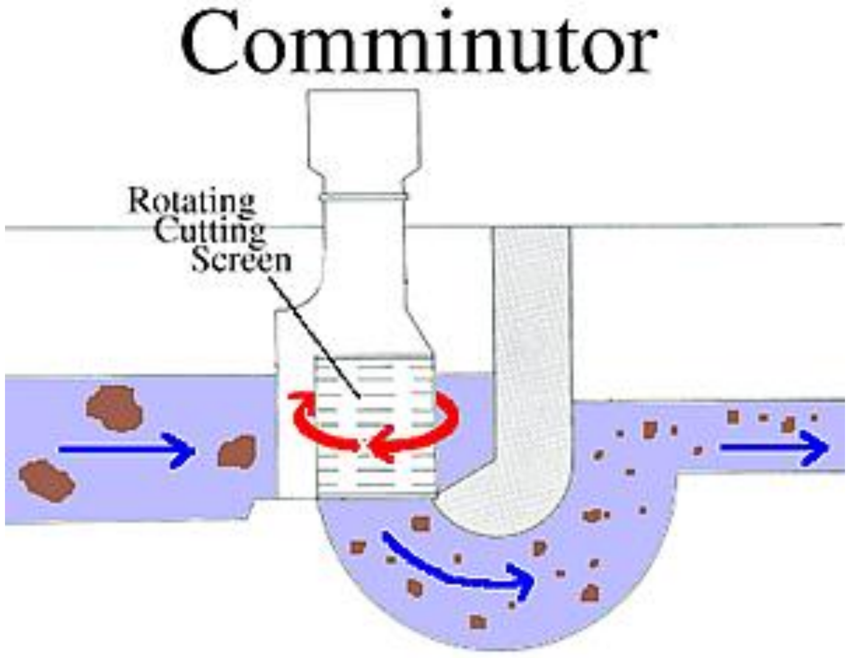
❖ **Preliminary, Primary, Secondary, Tertiary**.



Unit Operations/Processes	Functions	Treatment Devices
Screening	Removal of large floating, suspended and settleable solids	BAR SCREEN. **Screens** are made of long, closely spaced, narrow metal bars
Comminution	breaking up of solids into pieces	COMMINUTOR
Grit Removal	Removal of grit (inorganic solids)	Grit chamber
Primary treatment	Removal of inorganic suspended solids	Primary sedimentation tank
Secondary Treatment	Removal of BIO-degradable organic solids	Trickling filter / Aeration tank / Rotating biological contactor
Tertiary Treatment	Variety of chemicals including non-degradable organic solids, inorganic materials like heavy metals, ammonia, disease causing pathogens, colour & odor producing substances etc.	Variety of methods and equipments are used

Preliminary Treatment

Bar Screen



Q. Design a screen chamber with max. flow **(Q)** of 0.15 m^3/s of domestic wastewater.

Width to depth ratio is 1.5: 1.

Velocity of wastewater (v_h) = 0.75m/s.

The clear opening of the chamber = 25mm and diameter of each bar = 10 mm.

Calculate

(a) the no. of bars.

(b) Exact area through which water can pass

(c) Effective cross sectional area of channel

Channel dimensions:

$$A_x = \frac{\text{Rate of flow } (Q_{max})}{\text{velocity of waste water } (V_n)}$$

$A_x \rightarrow$ cross sectional area.

$$\therefore A_x = \frac{0.15 \ m^3/s}{0.75 \ m/s} = 0.2 \ m^2$$

Width : Depth $= 1.5 : 1$

B : D

$\therefore B = 1.5D$

$A_x = 1.5D \times D$

$\therefore 0.2 \ m^2 = 1.5D^2$

$$\therefore D = \sqrt{\frac{0.2}{1.5}} \ m = 0.4 \ m$$

Hence: $B = 1.5 \times 0.4 = 0.6 \ m$

Let the no. of bars be 'n'.

[opening $(n+1)$] + [width of bars $\times n$] $= 0.6$

$\therefore\ 0.025(n+1) + 0.01n = 0.6$

$\therefore\ 0.035n = 0.575$

$\therefore\ n = 16$

Exact area from which water can pass:

Effective width' (B_e) of the channel :-

B_E = total width − width of 16 bars

$= 0.6m - (0.01 \times 16)m$

$= 0.44\ m$

Hence, effective cross sectional area of channel

$A = 0.44 \times 0.4 \quad (B \times D)$

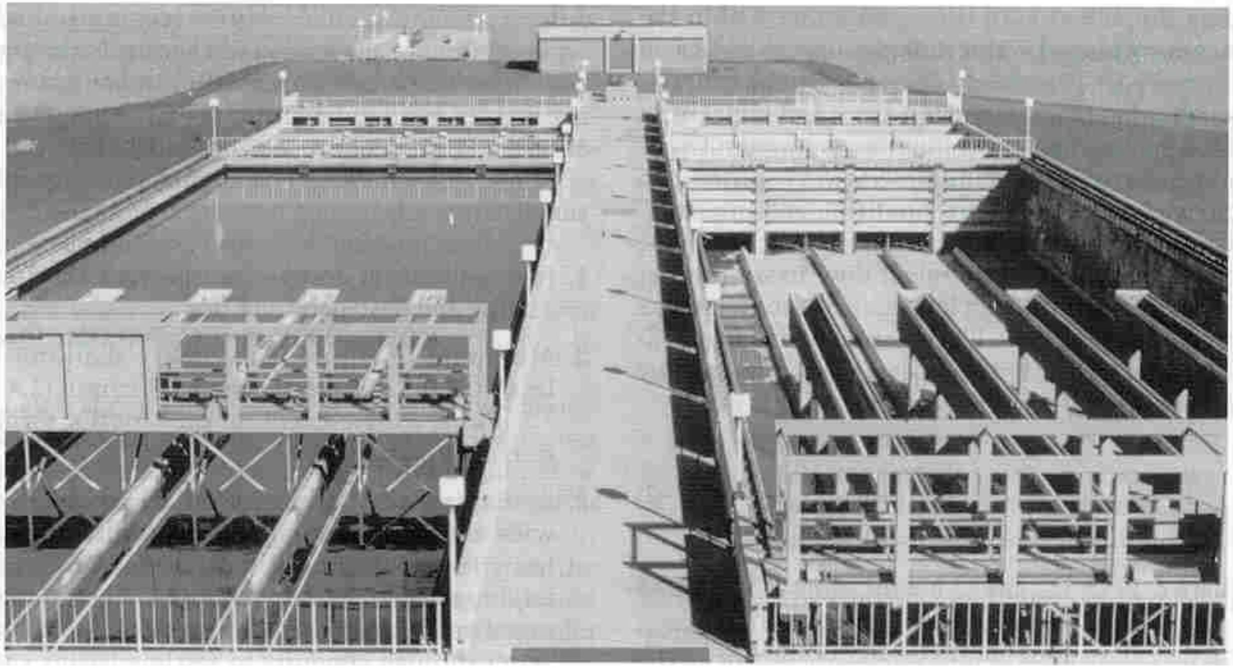
$= 0.176\ m^2$

Velocity of flow through screen bar :-

$$V = \frac{0.15 \ m^3/s}{0.176 \ m^2}$$

$$= 0.852 \ m/s \simeq 0.9 \ m/s$$

Grit removal :



Grit Chamber

- ***Inert dense material such as sand, broken glass, silt, and pebbles is called grit.***

A ww treatment plant receives a flow of 35,000 m^3/d (d → day). Calculate the particle settling velocity (v_s), surface area, vol & retentⁿ time of a 3 m deep horizontal flow grit chamber which removes grit with a specific gravity of $\simeq 1.9$ & size of 0.2 mm temp 22°c, viscosity of water = 1.002×10^{-3} kg $(ms)^{-1}$

Calculate the particle settling velocity (v_s) using Stokes' Law.

$$v_s = \frac{g \cdot (\rho_p - \rho_w) \cdot d^2}{18\mu}$$

$$v_s = \frac{9.81 \cdot (1.9 - 1.0) \cdot 998 \cdot (0.2x10^{-3})^2}{18 \cdot 1.002x10^{-3}}$$

$$v_s = 0.02\, m \cdot s^{-1} \;\; or \;\; 1728\, m \cdot d^{-1}$$

Calculate the required surface area of the tank.

$$v_h = \frac{Q}{A} \quad or \quad A = \frac{Q}{v_h}$$

$$A = \frac{35000}{1728} = 20.25\, m^2$$

Calculate the tank volume.

$$V = A \cdot H = 20.25 \cdot 3 = 60.75\, m^3$$

Calculate the detention time.

$$\theta = \frac{\mathrm{V}}{\mathrm{Q}} = \frac{60.75}{35000} = 0.0017\ \mathrm{d} = 2.5\ \mathrm{min}$$

Primary Treatment

Primary sedimentation tank :

Primary Sedimentation Tank

Alum ($Al_2(SO_4)_3 \bullet 18H_2O$) forms gelatinous metal hydroxide precipitate at high pH, it eventually settle downs by gravity and it settle downs along with the colloidal particles.

REACTION : $\mathbf{Al_2(SO_4)_3 + 3Ca(OH)_2 \rightarrow 2Al(OH)_3 + 3CaSO_4}$

Q. **Determine quantity and volume of sludge** produced in **10 days** in the treatment of 10MLD of domestic wastewater with following condition:

(i) Suspended solid in wastewater = 250 g/m3
(ii) SS removal efficiency of primary tank = 60%
(iii) Concentration of solids in sludge = 6 %
(iv) Density of water = 1000 Kg/m3
(v) Solids contribution per capita = 75 g
(vi) Specific gravity of sludge = 1.03

Also **calculate volume of sedimentation tank and no. of people** residing in that in that locality.

1 ML = 1 million litre = 10^6 L

$\boxed{1 L = 10^{-3} m^3}$

Quantity of sludge = produced SS removal efficiency × SS in water × Volume of ww per day

$= 0.60 \times 250\ g/m^3 \times 10 \times 10^3\ m^3/d$

$= 0.60 \times 250 \times 10^{-3}\ kg/m^3 \times 10 \times 10^3\ m^3/d$

$= 1500\ kg/d$

$$\textbf{Volume of sludge} = \frac{\text{Quantity of sludge produced}}{\text{Density of water} \times \text{Specific gravity of sludge} \times \text{percentagen of solids in sludge}}$$

$$= \frac{1500 \text{ kg/d}}{1000 \text{ kg/m}^3 \times 1.03 \times 0.06} = 25 \text{ m}^3/\text{d}$$

$$\textbf{Retention time} = \frac{\text{Volume of Primary Tank}}{\text{Volume of sludge produced per day}}$$

Vol. of primary sedimentatⁿ tank $= 25 \text{ m}^3/\text{d} \times 10 \text{d}$
$= 250 \text{ m}^3$

$$\text{Total person} = \frac{\text{total sludge produced}}{\text{per capita solids contributⁿ}}$$

$$= \frac{1500 \text{ kg/d}}{75 \text{ g/capita}} = \frac{1500 \times 10^3 \text{ g/d}}{75 \text{g/capita/d}}$$

$= 20000$ persons.

Secondary Treatment

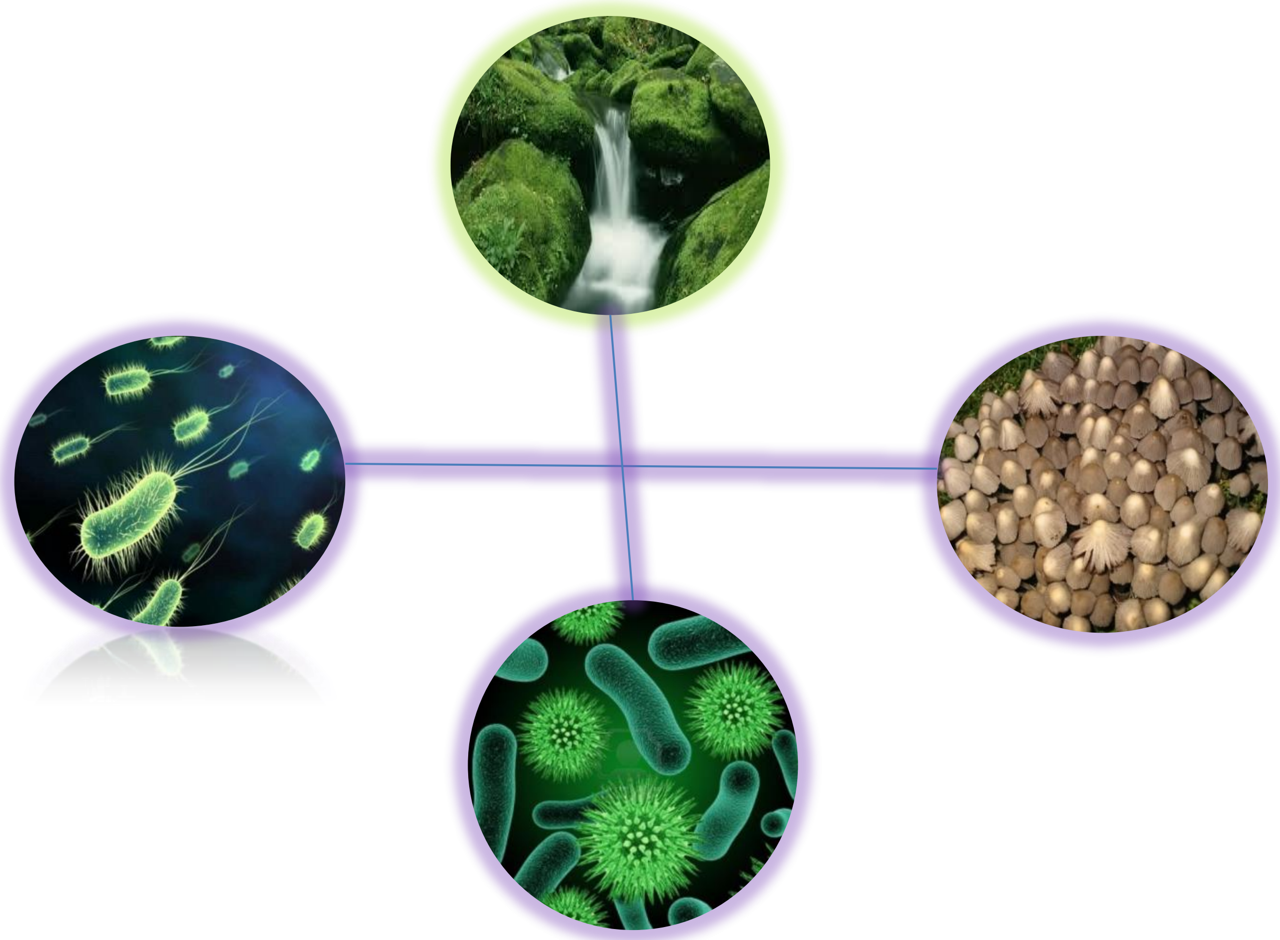
Trickling Filter Method

- Some tanks are more than 200 feet in diameter
- sufficient amount of oxygen, blower may be used.
- Ample supply of oxygen
- microbes decompose the biodegradable organic matter

Air is circulated upward through the spaces among the stones providing sufficient oxygen for the metabolic processes.

Trickling Filter Method

Major Players



- Microorganisms are used to destroy waste materials.
- Microorganisms include:
  - **Bacteria (aerobic and anaerobic)**
  - **Fungi**
  - **Algae**
  - **Actinomycetes (filamentous bacteria**).

➢ **Sludge is produced by this process and these *sludges comprise remaining undecomposed solids found in wastewater plus organisms used* in the treatment process.**

➢ ***These sludges reach the secondary basin and collected from the bottom of the secondary basin***

Q. A wastewater treatment plant receives a flow of 35,000 m^3/d containing BOD of 250 mg/L. Primary treatment removes 25% of organic matter. Calculate the no. of trickling filters with diameter of 60 m which would accommodate an organic load (concn of microbes) of 250 $g/m^2/d$.

Ans: Total amt of org matter entering the trickling filter $= 250\ mg/L \times 0.75 \times 35,000\ m^3/d$

$= 250 \times 10^{-3} g \times 10^{3}\ g/m^3 \times 0.75 \times 35000\ m^3/d$

$1L = 10^{-3} m^3$

$= 6562500\ g/d$

Total area required $= \dfrac{\text{Total org. matter in WW}}{\text{Org. load} \equiv \text{microbes}}$

$= \dfrac{6562500\ g/d}{250\ g/m^2/d} = 26250\ m^2$

Area of each trickling filter with diameter of 60 m

$= \pi r^2$

$= 2831\ m^2$

Hence no of trickling filter reqd $= \dfrac{26250\ m^2}{2831\ m^2} \simeq 10.$

(a) If rate of O_2 required per kg of organic matter decomposed = 2 kg O_2

(b) at 0°c & 1 atm pressure density of air = 1201 kg/m^3

(c) O_2 content in air = 20.95 % ≈ 21 %

~~Amount of O_2 required~~ Calc amt of oxygen ~~reqd~~ and air reqd

= ~~Rate~~

Amount of O_2 required

= rate of O_2 required per kg of organic matter decomposed × total org. matter destroyed per day

= 2 kg of O_2 × 6562500 g/d (prev. qn.)

= 13125 kg O_2/d

$$K_T = K_{20}\,\theta^{(T-20)}$$

$\hookrightarrow$ temp (°c)

K_{20} = rate const at standard of 20°c

θ = has a value of 1.135 for temp. b/w 4-20°c & 1.047 for temp. b/w 20-30°c

$$BOD_t = L_0 (1 - e^{-kt})$$

$\hookrightarrow$ time

L_0 = ultimate BOD

k = rate of biodecompositn rxn (d⁻¹)

t = time required to carry out exp.

A WW sample has an ultimate BOD equal to 300 mg/L. At 20°c, the 5 day BOD was 200 mg/L & the rxn rate const. was $0.227 d^{-1}$. What would be the 5 day BOD of this waste at 25°c ?

$L_0 = 300 \text{ mg/L}$

$K_{25} = K_{20}\,\theta^{(25-20)} = 0.227(1.047)^5 = 0.277 d^{-1}$

$BOD_5 = L_0(1 - e^{-k \times 5})$

$= 300(1 - e^{-0.277 \times 5})$

$= 225 \text{ mg/L}$

$BOD(25) > BOD(20)$

Q. A wastewater treatment plant receives a flow of 35,000 m3/d containing BOD of 250 mg/m3. Primary treatment removes 25% of organic matter. Food to microorganism ratio (F/M ratio) = 2d^{-1}. The biological mass in the basin will be maintained at 2000mg/L

Calculate

(i) the volume of aeration basin.

(ii) Approximate retention time (required time to run the plant)

Ans:

$$\mathbf{F/M} = \frac{\text{Rate of flow} \times \text{Concn of org matter in ww}}{\text{Volume of aeration tank} \times \text{Concn of biological mass}}$$ **= Weight of the sludges produced per day**

S_0 = Concn of organic matter present in the wastewater

S_0 = Concn of organic matter present in the wastewater

= $250\ m^{-3} \times 0.75 \times 10^{-3}$ Kg

= 0.1875 kg m^{-3}

2000 mg/L = 2Kg/m^3

$$\textbf{F/M} = \frac{\text{Rate of flow} \times \text{Concn of org matter in ww}}{\text{Volume of aeration tank} \times \text{Concn of biological mass}} = \mathbf{2d^{-1}}$$

$$\mathbf{2d^{-1}} = \frac{35{,}000\ m3/d \times 0.1875\ kg\ m^{-3}}{V \times 2\ kg\ m^{-3}}$$

V = **1640 m³**

Retention time = V/Q

$$= \frac{\mathbf{1640\ m^3}}{35{,}000\ m3/d}$$

= 0.047 d

= 1.1 h

Sludge Treatment

Anaerobic Digestion

WHAT DOES SLUDGE LOOK LIKE

Anaerobic Digestion : Fundamental Microbiology

- Sludges generated at primary and secondary sedimentation tank are pumped to anaerobic digesters.
- “***Digestion***" :
- ***Digester*** : An air-tight container where the *substrates are heated and the fermentation process takes place*
- *Anaerobic : in the absence of air*
- Mesophilic: organisms whose growth is optimum within 30 to 45°C.
- Thermophilic: organisms whose growth is optimum within 45 to 70°C
- $C_6H_{12}O_6 \longrightarrow 3CH_4 + 3CO_2 +$ ....

Anaerobic digester

Two end products of Anaerobic Digestion

(a) Energy from sludge Treatment (biogas formation)

(b) Sludge cake formation : used as fertilizer

• (a) Energy from sludge Treatment

Composition of biogas is

50 to 75 per cent CH_4 and

25 to 45 per cent CO_2 together with minor quantities of nitrogen (< 1%), hydrogen (< 1%), ammonia (< 1%) and hydrogen sulphide (< 1%).

Biogas may be used as the source of alternative energy.

(b) Fertilizer pellets from Sludge Treatment

- After the sludge digestion, the sludge is dewatered and hence the ***volume is reduced***.
- This dried sludge is called a ***sludge cake***.
- ***sludge cakes are turn into fertilizer pellets*** and can be used as fertilizer. The product is then sold to the local market.

Advantages of anaerobic digestion:

(a) Less energy is required : 0.5 -0.75kWh energy is needed for every 1 kg of COD removal by anaerobic process.

(b) Energy generation in the form of methane gas : 1.16kWh energy is produced for every 1 kg of COD removal by anaerobic process. *The caloric value of the biogas is about 5.5–6.0 kWh m^{-3}. This corresponds to about 0.5 L of diesel oil.*

(c) Less sludge generation : Anaerobic process produces only 20% of sludge that of aerobic process.

(d) Production of sludge cake :

Tertiary treatment :

Final cleanup of the water effluent
from the secondary treatment

REMOVAL OF ARSENIC

Arsenic, a toxic **metalloid** → not allowed more than 10 μg per liter of water
Arsenic usually is present in water as As(V) → H2AsO4- and HAsO42-.
Groundwater supplies → if contains the **more toxic As(III)** then,
a. Chlorine, ozone, or permanganate oxidants → to convert the As(III) to the As(V)
b. Coagulation with aluminum sulfate, iron(III) salts and with lime effectively removes arsenic.
c. Arsenic can also be removed from water by anion-exchange resins (that bind with the anionic arsenic)

REMOVAL OF NITROGEN (AMMONIA)

Next to phosphorus, nitrogen is the nutrient most commonly removed. Nitrogen in municipal wastewater → generally present as **organic nitrogen** or **ammonia**.

b) Nitrification followed by denitrification is arguably the most effective technique for the removal of nitrogen from wastewater. Again this is a **biological process**. This is the only biological process in the tertiary wastewater treatment.

I) ammonia and organic nitrogen compounds are completely converted into nitrate under strongly aerobic conditions

$$2NH_4^+ + 3O_2 \xrightarrow{\textit{Nitrosomonas}} 4H^+ + 2NO_2^- + 2H_2O$$
$$2NO_2^- + O_2 \xrightarrow{\textit{Nitrobacter}} 2NO_3^-$$

II) The second step → reduction of nitrate to nitrogen gas. This reaction is also bacterially catalyzed and requires a carbon source and a reducing agent such as methanol, CH3OH

$$6NO_3^- + 5CH_3OH + 6H^+ \text{ (Denitrifying bacteria) } \rightarrow 3N_2(g) + 5CO_2 + 13H_2O$$

c) CHLORINATION FOR REMOVING AMMONIA

Chlorination can be used to remove dissolved ammonium ion from wastewater by the chemical reactions :

In water chlorine, rapidly hydrolyzes

$$Cl_2 + H_2O \rightarrow H^+ + Cl^- + HOCl$$

$$NH_4^+ + HOCl \rightarrow NH_2Cl \text{ (monochloramine)} + H_2O + H^+$$

$$NH_2Cl + HOCl \rightarrow NHCl_2 \text{ (dichloramine)} + H_2O$$ *(causes 'smell' and 'chlorine odour')*

$$NHCl_2 + HOCl \rightarrow NCl_3 \text{ (trichloramine)} + H_2O$$

- ***Chloramines cause the "chlorine" smell***
- The trichloramines are especially irritating to the eyes, nose and lungs.
- ***Trichloramine is unstable, breaks down to N_2***

The overall reaction for complete nitrification of ammonia by chlorine oxidation is

$$2\,NH_3 + 3\,HOCl \rightarrow N_2 + 3\,HCl + 3\,H_2O$$

$$2\,NH_3 + 3\,Cl_2 \rightarrow N_2(g) + 6\,H^+ + 6\,Cl^-$$

Example: 2: A flow of 850,000 gpd requires a dose of 25 mg/L chlorine. If sodium hypochlorite is 15 percent available chlorine, how many pounds per day are needed?

$$\text{Lbs/day} = \text{conc. (mg/L)} \times \text{flow (MGD)} \times \frac{8.34\ \text{lbs}}{\text{gal}}$$

Answer: 25 mg/L × 0.85 mgd × 8.34/0.15 = 1,181 lb/d sodium hypochlorite.

Water disinfection

Secondary sewage effluent often contains a number of disease-causing microorganisms, requiring disinfection.

Common Disinfection Agents

(a) chlorine and chloramines; **(b)** bleaching powder etc

DISINFECTION WITH Chlorine and chloramines

$$Cl_2 + H_2O \rightarrow H^+ + Cl^- + HOCl$$

HOCl is a weak acid that dissociates

$$HOCl \rightleftarrows H^+ + OCl^-$$

- The two chemical species formed by chlorine in water, (HOCl and OCl-), are known as free available chlorine
- Free available chlorine is very effective in killing bacteriabut not virus.

$$NH_4^+ + HOCl \rightarrow NH_2Cl\ (\text{monochloramine}) + H_2O + H^+$$

$$NH_2Cl + HOCl \rightarrow NHCl_2\ (\text{dichloramine}) + H_2O$$

$$NHCl_2 + HOCl \rightarrow NCl_3\ (\text{trichloramine}) + H_2O$$

- The chloramines are called combined available chlorine.
- These are weaker disinfectant than free available chlorine, (40-60% less effective than free available chlorine.

Break Point Chlorination

- If the water to be chlorinated contains significant amounts of ammonia, then addition of sufficient amount of chlorine will form monochloramine to di- or tri-chloramines (ie., ***all present ammonia is oxidized***).
- The ratio of Cl:N (***7.6:1 (mg/L:mg/L)***) at which all ammonia present in the water has been oxidized to nitrogen gas (which leaves the system) is known as breakpoint
- At breakpoint, i.e., the dip in the breakpoint curve, oxidation of ammonium ion is essentially complete. The overall breakpoint reaction is as follows:

$$2NH_3 + 3HOCl \rightarrow N_2 + 3H_2O + 3H^+ + 3Cl^-$$

$$2\ NH_3 + 3\ Cl_2 \rightarrow N_2(g) + 6\ H^+ + 6\ Cl^-.$$

- Chlorination beyond this point ensures formation of "free available chlorine". It is known as "breakpoint chlorination"

The excess chlorine may be removed

(i) by filtering the overchlorinated water through activated carbon.

(ii) by addition of a small % of SO_2, Na_2SO_3 or $Na_2S_2O_3$.

$$SO_2 + Cl_2 + 2H_2O \longrightarrow H_2SO_4 + 2HCl$$

$$Na_2SO_3 + Cl_2 + 2H_2O \longrightarrow Na_2SO_4 + 2HCl$$

b) Removal of microorganisms by adding beaching powder:

In small water-works, about 1 Kg of bleaching powder per 1000kiloliters of water is mixed and water is allowed to stand undisturbed for several hours. This produces hypochlorous acid.

$$Ca(OCl)Cl + 2H_2O \longrightarrow Ca(OH)_2 + Cl_2$$

$$Cl_2 + 2H_2O \longrightarrow HOCl + OCl^- \text{ (Hypochlorite ion)}$$

Removal of Taste and Odor :

- ✓ Both organic and inorganic substances may produce ***taste, odor, and color in water***. So, before we supply the treated water for domestic purpose, we should remove these taste, odor or colour producing substances.

Odor producing substances:

- ❑ The most commonly reported taste and odor compounds, geosmin and methylisoborneol are produced in surface water sources by naturally occurring cyanobacteria (blue-green algae).
- ❑ Geosmin and MIB typically produce earthy or musty tastes and odors in water

Various processes are used to remove agents that cause taste & odor.

i) Simple aeration can remove ***volatile materials,*** such as odorous hydrogen sulfide.

ii) ***For non-volatile metabolic products*** by bacteria***, oxidation that destroys organics usually removes taste, odor, and color.*** Chlorine, Potassium permanganate, chlorine dioxide can be used.

iii) Ozone Water Treatment : Ozone used by itself or UV has been found to be effective in removing geosmin and MIB.