Water and Wastewater

- ✓ Globally, 80% of wastewater flows back into the ecosystem without being treated or reused, contributing to a situation where around 1.8 billion people use a source of drinking water contaminated with faeces, putting them at risk of contracting cholera, dysentery, typhoid and polio.
- ✓ Industrial water consumption is responsible for 22% of global water use.
- ✓ On average, high-income countries treat about 70% of the municipal and industrial **wastewater** they generate. That ratio drops to 38% in upper middle-income countries and to 28% in lower middle-income countries. In low-income countries, only 8% undergoes treatment of any kind
- ✓ 70 percent of **India's water** supply is contaminated.
  Globally, **India** is **ranked** 120th among 122 countries in WaterAid's **water quality index**.
- ✓ **A water quality index (WQI)provides a single number (like a grade) that expresses overall water quality at a certain location and time based on several water quality parameters. The objective of an index is to turn complex water quality data into information that is understandable and useable by the public.**
- ✓ India uses the largest quantity of groundwater – 24% of global total, more than China and US combined . It is the third largest 'exporter' of groundwater – 12% of the global total.

Standard equations for WQI are available. It uses measured values of water quality parameters such as pH, total dissolved solids, total suspended solids, chloride, sulfate, fluoride, nitrate, etc with some weight factor for each parameter.

Water quality Index Level	Water Quality Status
0-25	Excellent water quality
26-50	Good water quality
51-75	Poor water quality
76-100	Very poor water quality
>100	Unsuitable for drinking

A Few Snapshots of Water and Wastewater Scenario

Example of EXPORT of groundwater: In 2014-15, India exported 37.2 lakh tonnes of basmati. To export this rice, the country used around 10 trillion litres of water, meaning India virtually exported 10 trillion litres of water

Around four billion people – more than 55% of world's population - experience severe water scarcity during at least one month of the year

By 2040, it is predicted that **33 countries are likely to face extremely high water stress** - including 15 in the Middle East, most of Northern Africa, Pakistan, Turkey, Afghanistan and Spain. Many - including **India, China, Southern Africa, USA and Australia - will face high water stress.**

Considering rice consumption, a family of four consumes approximately 84,600 litres of **virtual water** in a month

Globally 2.1 billion people live without safe water at home

India's capacity to treat is approximately or 22,963 million litres per day (MLD) 37% of its **wastewater**,
Daily **sewage** generation is approximately 61,754 MLD according to the 2015 report of the Central Pollution Control Board.May 15, 20

Wastewater Treatment

❖Purpose

To manage water discharged from households, businesses, and industries to reduce the threat of water pollution.

Wastewater: broadly of two types

Municipal wastewater (or sewage , from households and other sources)

> **Contains normally has BOD, some COD, oils and grease, Suspended Solids, and some trace contaminants.**

Industrial wastewater

> **Contains significant amounts of other contaminants such as toxic and non-degradable organics, heavy metal ions etc**
>
> **Needs special treatment for decontamination.**

Municipal Sewage Treatment is described here.

Suspended solids, BOD, some COD and pathogenic bacteria are required to be removed; there may be many other contaminants (see slide set 2)

Municipal Sewage Treatment

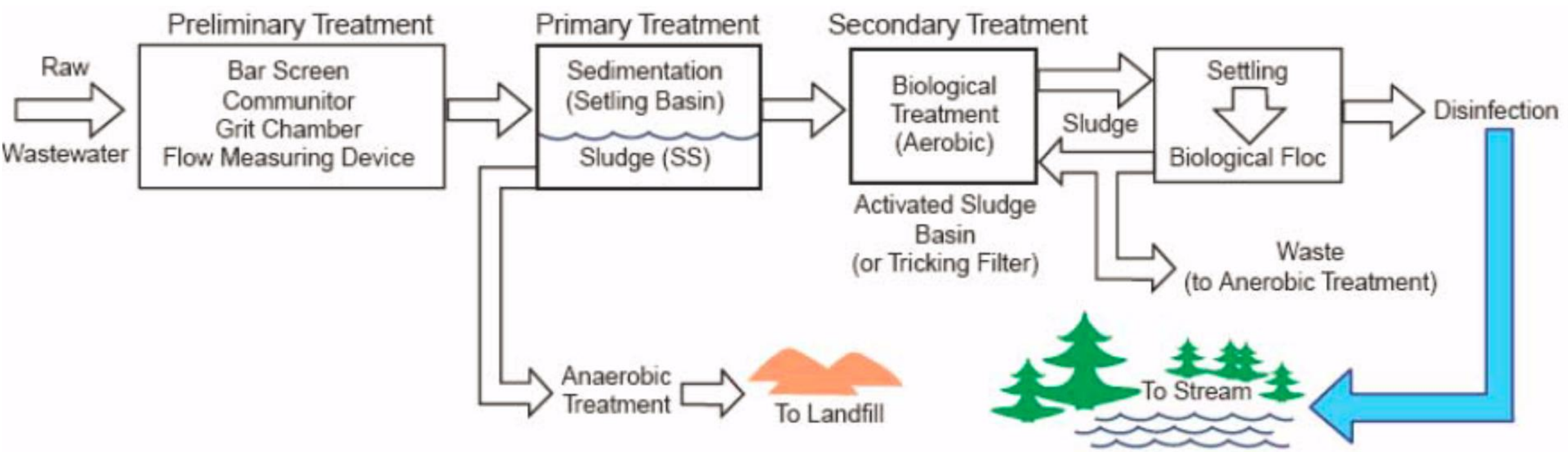
There are three major steps – preliminary treatment, primary treatment, secondary treatment and tertiary (or advanced) treatment.

Primary Treatment – Removal of suspended materials. First the course materials and grits are removed.

Secondary Treatment – This is a microbial process in which the biodegradable materials are consumed by bacteria.

Tertiary Treatment – removes the organics of inorganics in solution generally by adsorption. Often this step is eliminated. The treated water is chlorinated/disinfected if the bacterial count in it is above acceptable limit.

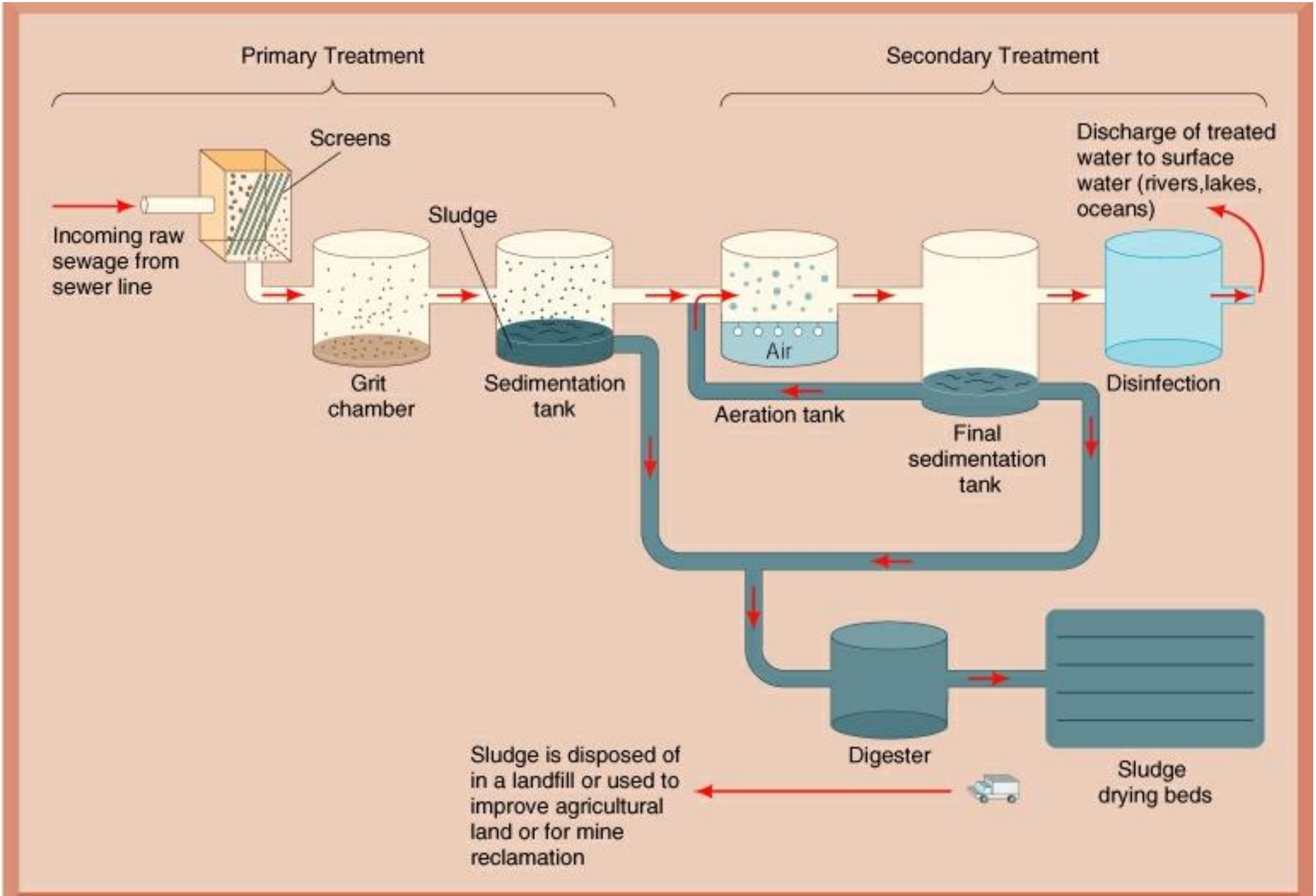
- Pre-treatment
- Preliminary treatment
- Primary treatment
- Secondary treatment
- Sludge (biosolids) disposal



Schematic of a Typical Wastewater Treatment Plant

Major Steps are already described in the previous slide

Wastewater Treatment – Alternative Schematic Flow Diagram



- Water moves toward the wastewater plant primarily by gravity flow
- Lift stations pump water from low lying areas over hills or if proper land slope is not available.

The sewage flows through the grit chamber (normally gravity flow; pumping is done if required slope is not there). A bar screen is used to remove coarse materials by a 'bar screen' (steel bars, spaced 2-4 cm). The water then goes to the Grit Chambers where suspended sand particles and other small particles settle down. Sometimes floating oils and grease is skimmed out from the top of the water in the grit chamber.

- Bar Screen

  - catches large objects that have gotten into sewer system such as bricks, bottles, pieces of wood, etc.

Grit Chamber

Bar Screen

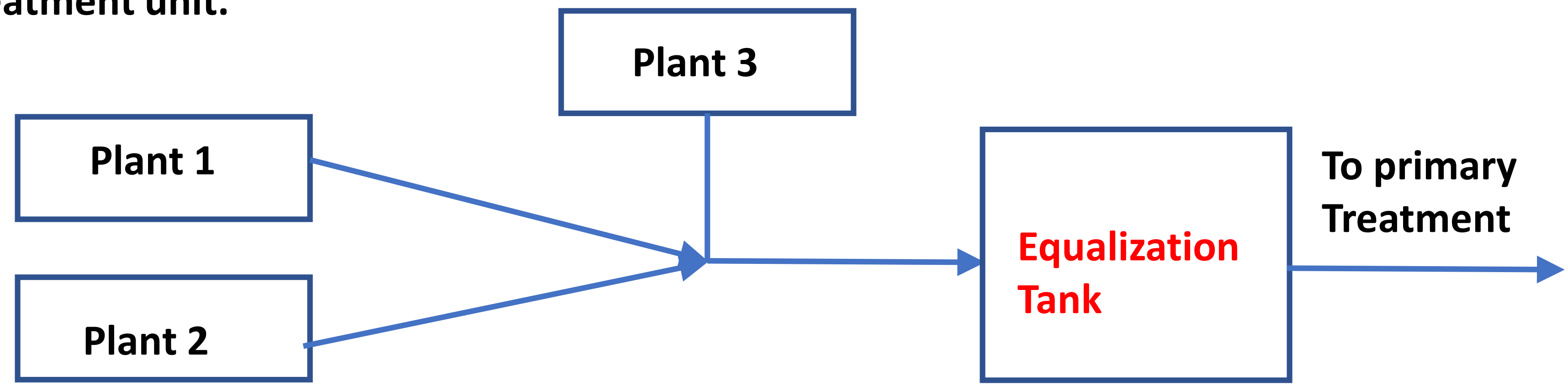
The water from the Grit Chamber, now free from coarse suspended particles, goes to the Primary Settling Tank. This is a large tank that allows enough residence time (5-10 h). It has a rotor that help in formation of bigger particles by flocking and settling of the suspended particles which are mostly organic. About 60% of the suspended particles settle and about 40% of the BOD is removed. The sludge is removed continuously from the bottom and goes to an anerobic digestion unit where biogas is generated. It can be used as a fuel.

The residue of sludge digestion is dried and used as a manure or for landfilling.

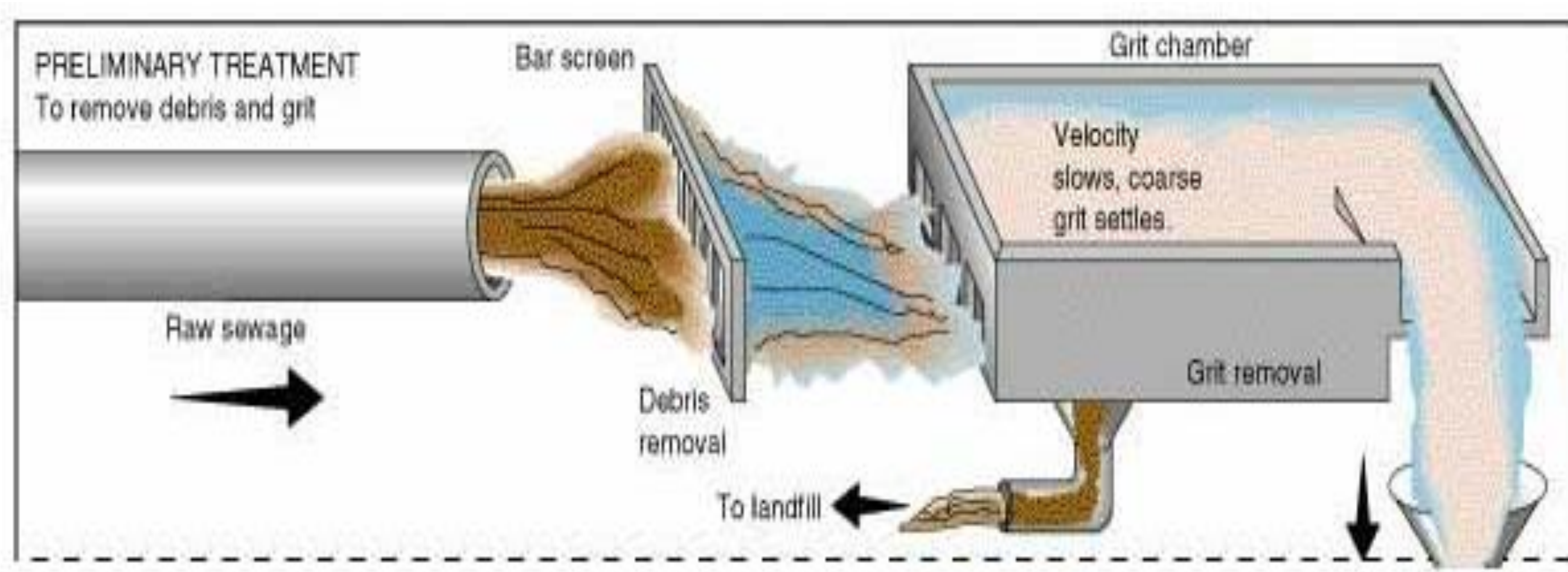
Flow Equalization

Wastewater generation, either municipal or industrial, rarely occurs at a steady rate. It varies from hour to hour. For example, municipal wastewater generation is minimum during late night to very early morning because of lesser human activities. It picks up from the morning slowly increasing for a few hours and then becomes nearly steady till evening. Then it slows down. Industrial wastewater generation remains nearly steady for continuously operating plants but varies widely for batch operating plants. Sometimes wastewater is released from different plants in an industry at varying rates.

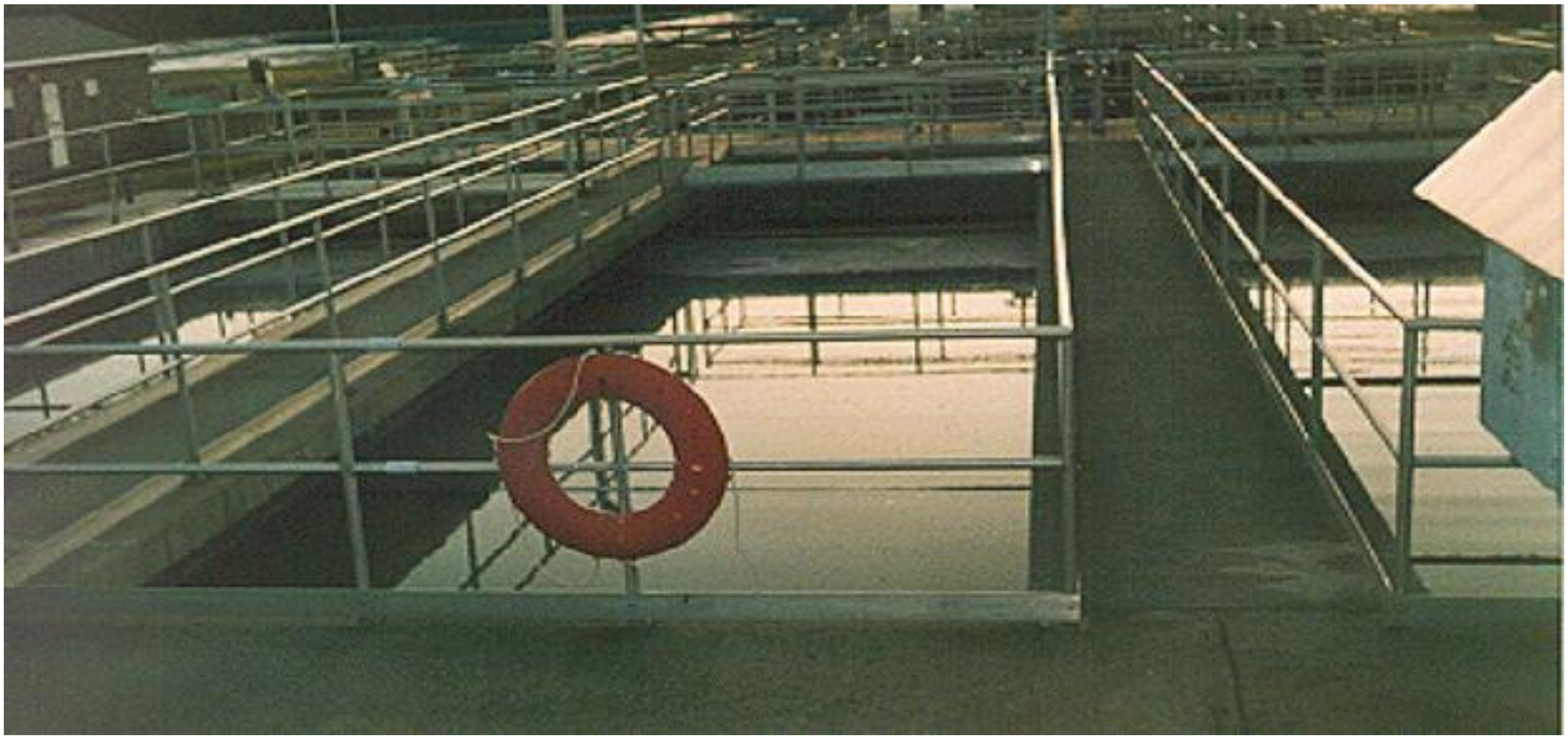
Such variations in waste water generation will cause changes in the influent to the wastewater treatment unit. In order to keep the influent rate to the treatment unit steady, the raw wastewater leaving the bar screen and grit chamber flows into a large tank called Equalization Tank or Equalizer from which the water is pumped to the treatment unit at an average rate. The equalization tank is a buffer tank where the wastewater gets mixed and ensures a uniform quality and flow are of the influent to the treatment unit.



- Preliminary Treatment
  - removes large objects and non-degradable materials
  - protects pumps and equipment from damage
  - bar screen and grit chamber

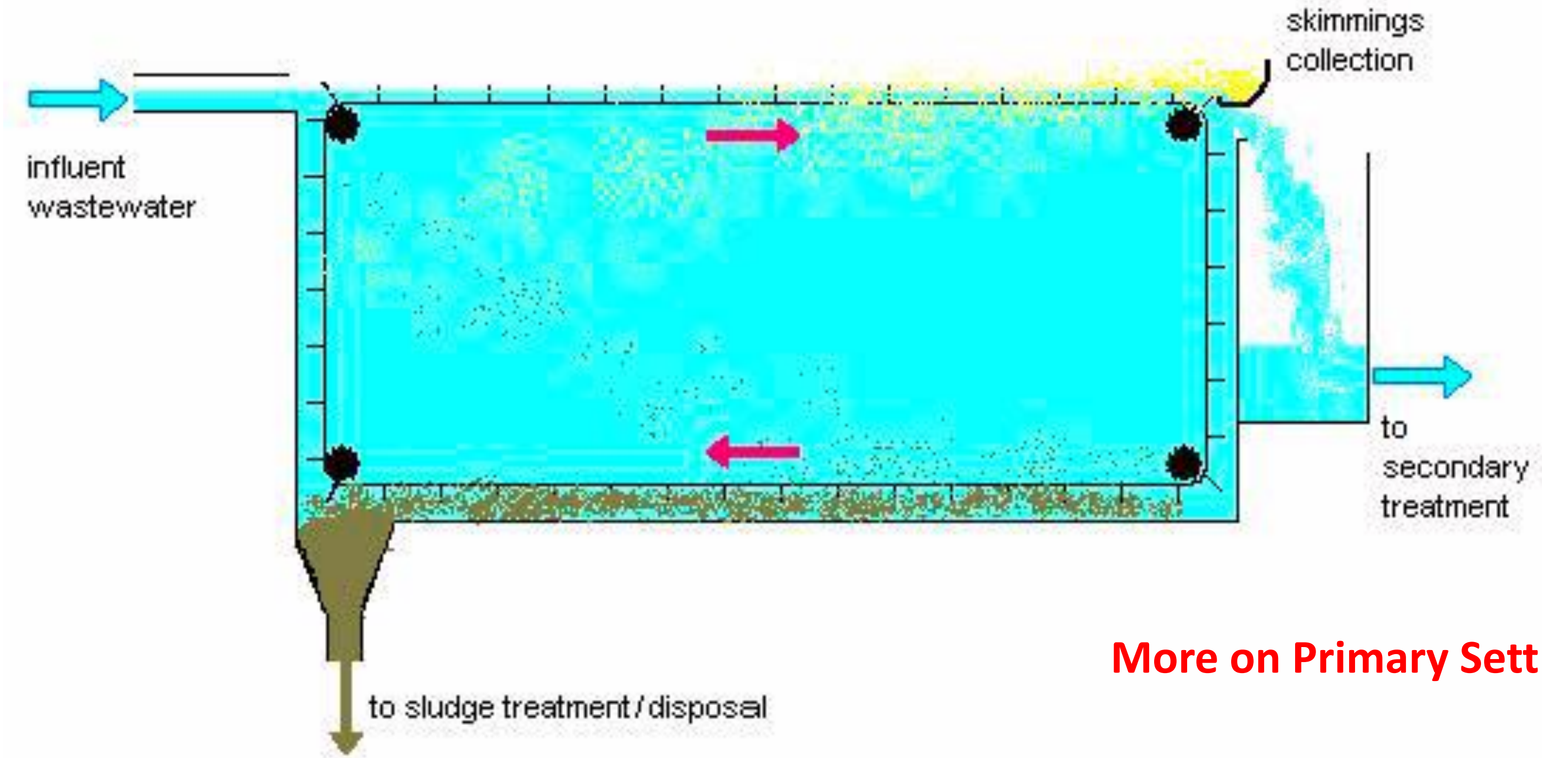


- **Measurement and sampling at the inlet structure**
  - a flow meter continuously records the volume of water entering the treatment plant
  - water samples are taken for determination of suspended solids and B.O.D.



Primary Treatment (settling/sedimentation) – removes 50-60% of suspended solids and 30-35% raw sewage BOD. The raw water is considerably clarified. The sludge is removed from the tank bottom and further treated before disposal. May be used for generation of biogas.

Primary Treatment



More on Primary Settling Tank

❖Secondary Treatment

❖Secondary treatment is a biological process

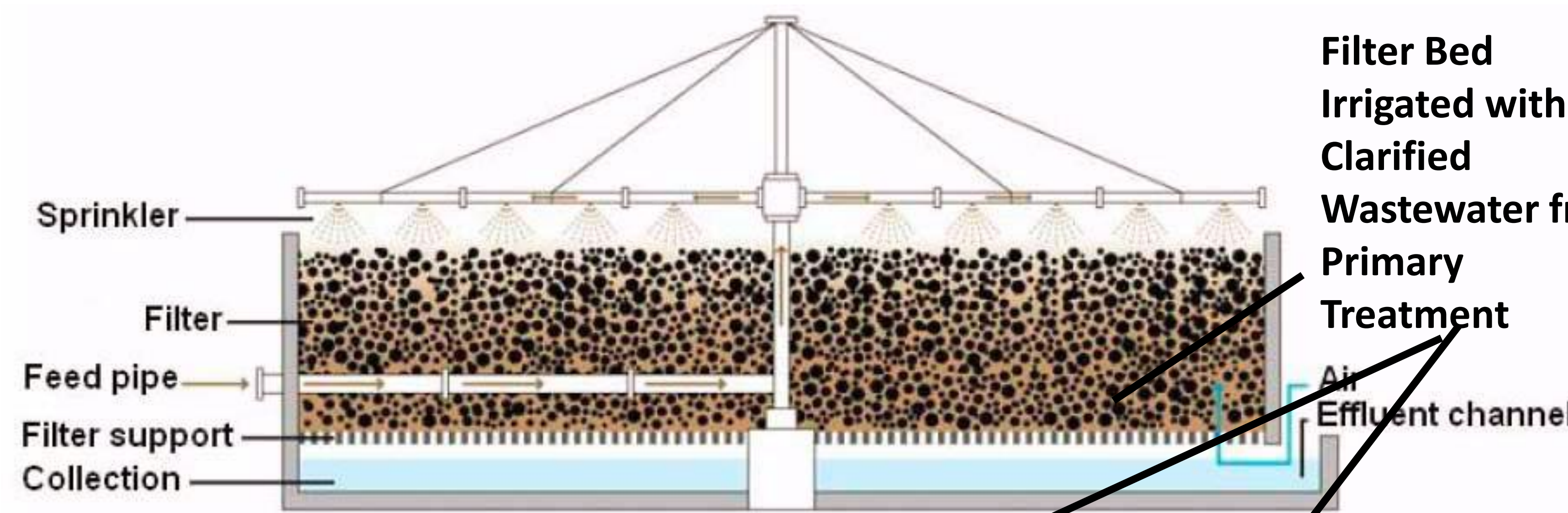
❖Utilizes bacteria and algae to metabolize organic matter in the wastewater. The organic matters (we measure it in terms of BOD and COD) are used by the bacteria for its growth (i.e. multiplication) and survival. Oxygen is supplied by aeration of the water from the primary sedimentation tank. There are different types of aeration techniques.

❖Removal of BOD may be dome in different types of equipment. Here we will discuss a few. The bacteria/algae may be present in the aeration vessel or tank either supported on a surface (attached growth) or suspended in the water (suspended growth)

❖The Trickling Filter is a device that relies on attached growth. The activated sludge is a suspended growth technique. Air is supplied

❖The **Trickling Filter** construction and operation are shown in next a few slides.

Trickling Filter of Different Types

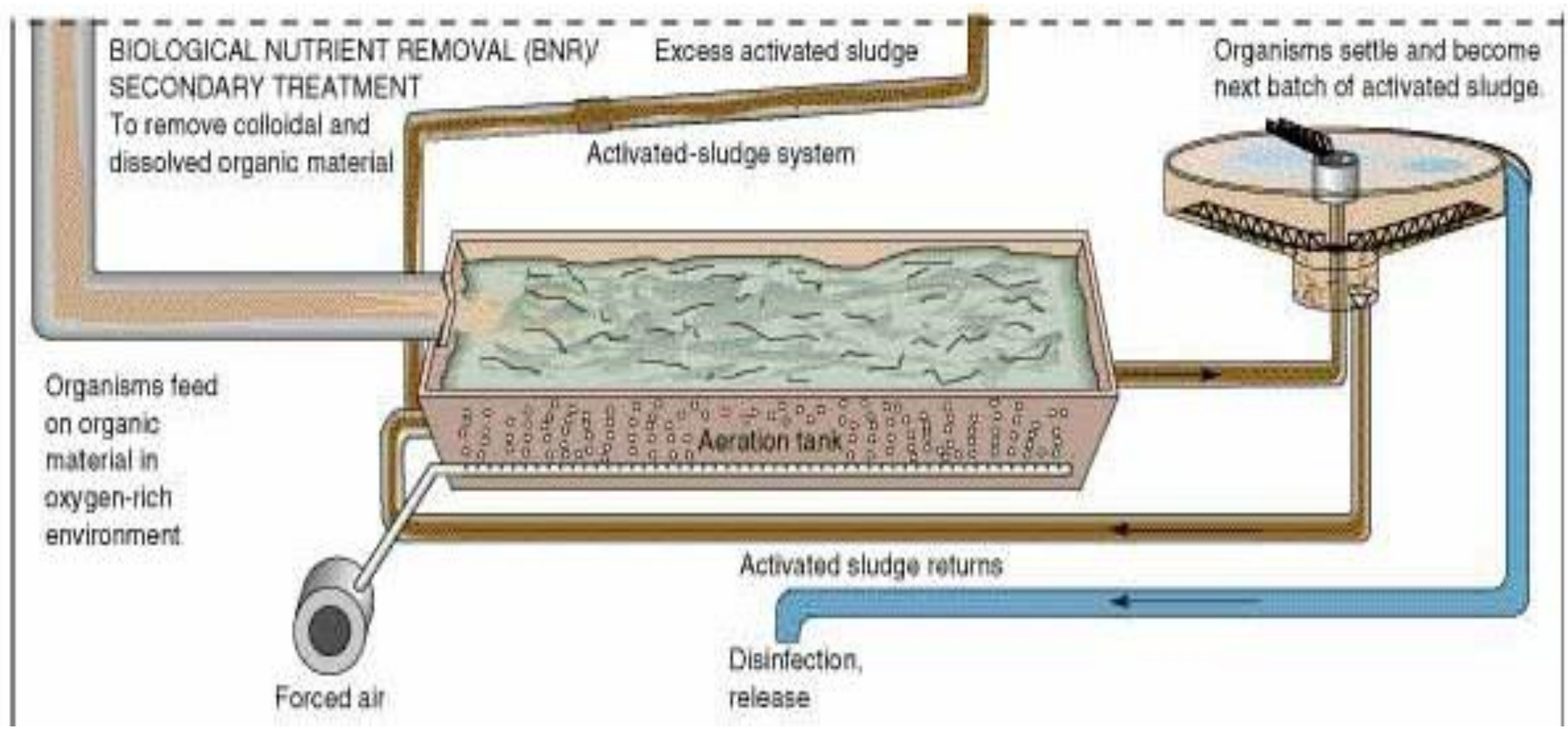


Filter Bed Irrigated with Clarified Wastewater from Primary Treatment

Water from the primary treatment is irrigated at the top of the packing and air flows through the bed by natural draft or by a blower. The bed (about 3 m depth) may be made by stone chips or plastic balls (much lighter) on which the bacteria grows (it is called attached growth). A part of the treated water may be recirculated if necessary.

Secondary Treatment : Activated Sludge

This is the common technique of removing organics and some other contaminants such as ammonia compounds by biological method. The equipment consists of multi-chamber bioreactor in which mostly aerobic microbes consume BOD for their survival and growth. The low-BOD water along with suspended biomass flows to a secondary settling take where the biomass is separated. A part of this sludge is recycled to the aeration tank to supplement the biomass there (this is why it is called activated sludge) and the rest is dewatered and further used as a manure after stabilization or for making biogas.



Wastewater Treatment

- The final clarifiers remove additional sludge and further reduce suspended solids and B.O.D.
- A sand bed is often used as a filter.

Determination of Biochemical Oxygen Demand, BOD

A known volume of sample has its initial dissolved oxygen content recorded.

After a five day incubation period at 20°C, the sample is removed from the incubator and the final dissolved oxygen content is taken.

The BOD value is calculated from the depletion and the amount of sample used. This called 5-day BOD

If the incubation period is 3-days, we call it 3-day BOD

If the BOD is high, the sample is diluted with oxygenated water. The dissolved oxygen may be measured by iodometry.

BOD Removal rate Constant

Here we develop a simple equation to determine the rate constant for microbial degradation of BOD in a sample of water by estimating the dissolved oxygen concentration over a period of time. It is assumed that BOD degradation is a first order process . It *L* is the BOD of water at time *t*, its removal rate may be expressed as

$$-\frac{dL}{dt} = k_d L; \qquad k_d = \text{first order degradation rate constant}; \qquad (1)$$

$$\text{Initial Conditiom, I.C.:} \quad t = 0, \quad L = L_o \quad \Rightarrow \quad L = L_o e^{-k_d t} \qquad (2)$$

If the BOD value is measured at different times, a plot of ln(L/L_o) against time (t) will give a straight line of slope k_d ; L_o = ultimate BOD.

Example: In a BOD test, 75 ml of river water is taken in a 300 ml BOD bottle and diluted with oxygenated distilled water at 20ºC. The initial DO in the bottle is 8.8 mg/L and that after 5-day incubation at 20oC drops down to 3.3 mg/L. If the BOD degradation rate constant is 0.23 day^{-1}, calculate the ultimate BOD and BOD3.

Solution: The river water sample has been diluted by a factor of 300/75 = 4

BOD consumed = $D_o - D_5$ = 8.8 – 3.3 = 5.5 mg/l

$$\Rightarrow \quad L = L_o e^{-(k_d t)} \qquad \Rightarrow \quad L_5 = L_o e^{-(5k_d)}$$

$$L_o - L_5 = L_o - L_o e^{-(5k_d)} = L_o\left(1 - e^{-(5k_d)}\right) = 5.3 mg/l; \quad k_d = 0.23\, day^{-1}$$

$$\Rightarrow \quad L_o(1 - 0.31) = 5.3 \quad \Rightarrow \quad L_o = 17.4 \text{ mg/l} = \text{ultimate BOD}$$

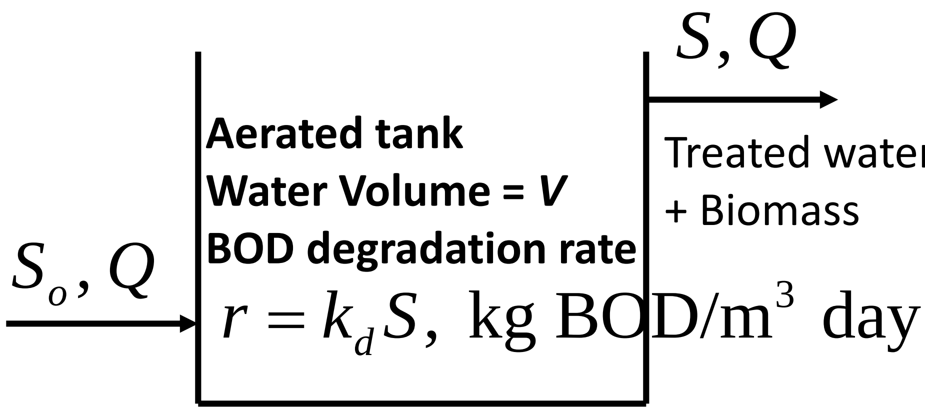
3-day BOD, BOD_3 is determined by putting L_o = 8.8 and k_d = 0.094 in Eq (2)., i.e. L = 6.64 mg/L
Taking the dilution factor of 4 into consideration, BOD_3 of the river water = (6.64)(4) = 26.5 mg/L

Example: Wastewater Treatment in a Well-mixed aerator without recycle of cells

An industrial wastewater stream generated at a rate of 500 m3/day enters the activated sludge chamber at an influent BOD of 300 mg/l. The BOD has to be reduced to 30 mg/l in order to comply with the regulatory provisions. A bench scale study indicates that the first order rate constant for BOD degradation is 0.7 day^{-1}. determine the size of the aerated activated sludge unit. The operating conditions are the same as in the lab experiment.

Solution: The tank volume can be calculated by making a mass balance of rates of input, Output and degradation of BOD in the tank.
Assume steady state of operation. At "Steady State" there is no accumulation of anything in the tank.

Q **= water flow rate = 500m3/day;** S_o **= BOD in the influent water = 300 mg/l;** ***S*** **= BOD in the effluent from the tank = 30 mg/l;** k_d **= first order BOD degradation rate constant = 0.7/day.**



Steady State BOD mass balance equation:

$$QS_o - QS = V \cdot r = Vk_d S$$

$$\Rightarrow V = \frac{Q(S_o - S)}{k_d S} = \frac{500(300-30)}{(0.7)(30)} = \underline{6430\text{m}^3}.; \quad \text{Residence time} = \frac{V}{Q} = \frac{6430 \text{ m}^3}{500 \text{ m}^3/day} = \underline{13 \text{ days}}$$

Growth of Pure Culture

Growth of microbes depends upon Food and nutrients, pH, temperature and other factors.

If some microbes is added to a limited volume of the medium containing food with supply of oxygen in a batch system and if we plot the microbe concentration X = number of cells per unit volume against time, we get the following type of curve that typically shows four phases of the growth curve..

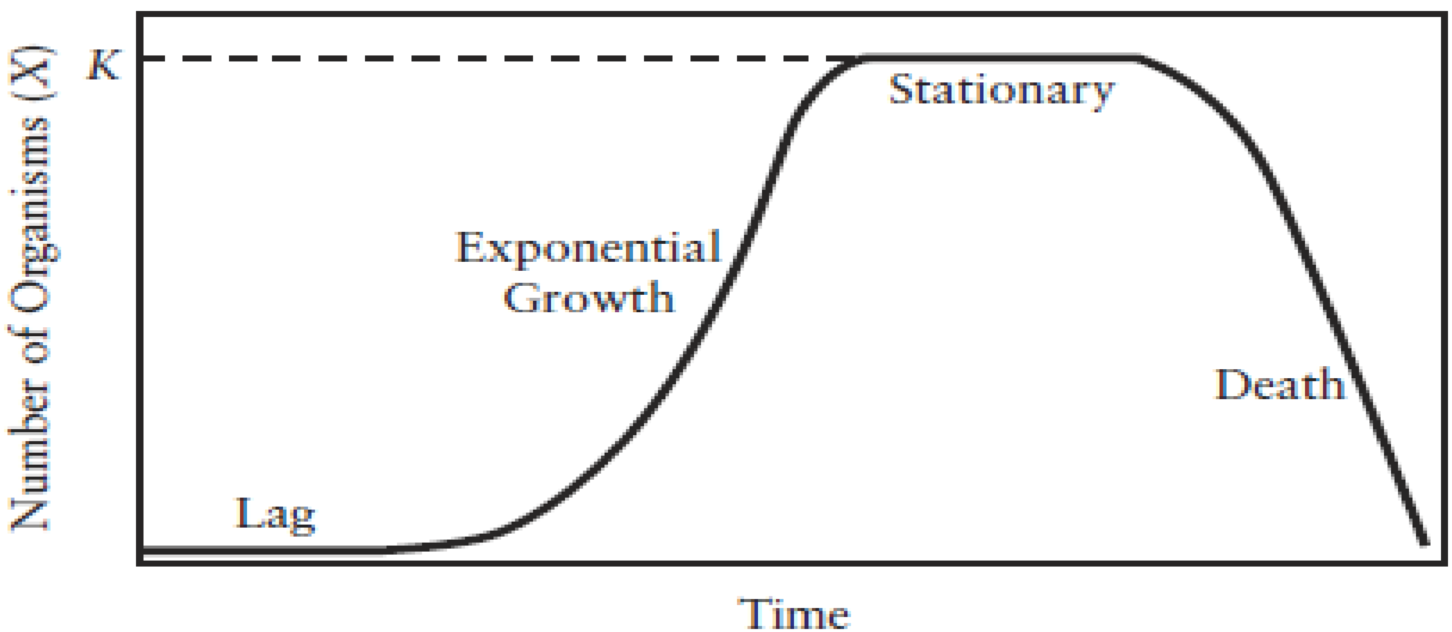


Fig. Microbial growth curve in a batch system

(i) Lag Phase: The microbes adjust or acclimatize with the medium; slow or no growth.

(ii) Exponential Growth Phase: The microbe population grows exponentially.

(iii) Stationary Phase: The cell concentration remains stationary because of limited food supply, waste accumulation; growth stops.

(iv) Death Phase: the bacterial population declines because of dearth of food supply, waste accumulation. Some of the dead cell may be the source of food to the survivors. But, on the whole, the population declines.

The rate of growth in the exponential phase is expressed as a first order process based on experimental data.

$$\frac{dX}{dt} = \mu X = \bar{\mu}\frac{SX}{K_s + S}; \quad \bar{\mu} = \text{maximum growth rate when } S >> K_s \qquad \textbf{(3)}$$

$S =$ substrate (food for the microbes) concentration, expressed in terms of BOD

$K_s =$ Half saturation constant, an experimentally measured parameter

For a large substrate conbentration, $S >> K_s, \quad \mu = \bar{\mu}$

Equation (3) is called Monod Equation for cell growth

A part of the substrate consumed goes for supplying energy for survival of the cells

The other part is utilized for generation of new cell mass.

$$\text{Rate of consumption of substrate} = r_s = -\frac{dS}{dt}$$

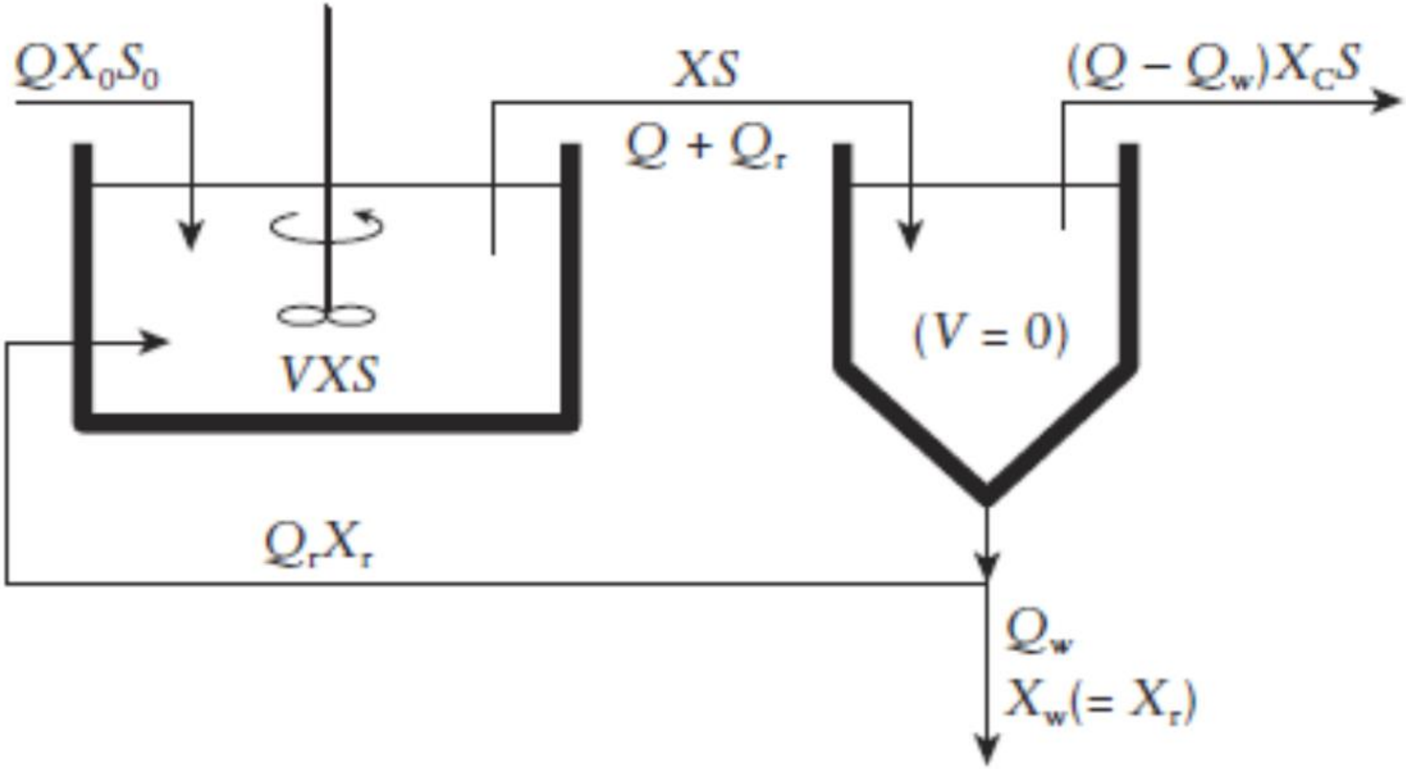
$$\text{Rate of generation of cells} = r_X = \frac{dX}{dt} = \bar{\mu}\frac{S\,X}{K_s + S}$$

If we define Y = mass of microbes produced per unit mass of the food (or BOD), then

$$-Y\frac{dS}{dt} = \frac{dX}{dt} = \text{ rate of cell growth per unit volume of the medium.}$$

$$\Rightarrow \quad -\frac{dS}{dt} = \frac{1}{Y}\frac{dX}{dt} = \frac{1}{Y}\left(\frac{\bar{\mu}S}{K_s + S}\right)X \qquad \textbf{(4)}$$

Now consider a continuous bioreactor (secondary or aerated tank) with partial cell recycle as shown in the sketch.



Notations: Q = rate of inflow of the wastewater; S_o, X_o = inlet substrate and cell conc.

Q_w = Sludge removal rate from the system; X_w = cell or biomass concentration in the outgoing sludge

Q_r = rate of recycle of activated sludge; X_r = cell concentration in the recycle.

$(Q - Q_w)$ = rate of withdrawal of treated effluent at substrate concentration S and cell concentration X_C.

V = volume of the aeration tank

In this connection the mean cell retention time in the aerated tank (ϑ_c) is important It is defined as

$\bar{t} =$ average resudence time of the liquid in the tank V/Q

Now we make a mass balance of the substrate over the system

$$\begin{bmatrix} \text{Rate of} \\ \text{ACCUMULATION} \end{bmatrix} = [\text{Rate IN}] - [\text{Rate OUT}] + \begin{bmatrix} \text{Rate of} \\ \text{substrate} \\ \text{PRODUCTION} \end{bmatrix} - \begin{bmatrix} \text{Rate of} \\ \text{substrate} \\ \text{CONSUMPTION} \end{bmatrix}$$

$$\Rightarrow \quad -V\frac{dS}{dt} = QS_o - QS - V.\frac{\mu X}{Y} \qquad \textbf{(5)}$$

If the cell concentration is X, rate of cell growth in V volume = $V\mu X$

Corresponding rate of substrate consumption = $\dfrac{V\mu X}{Y}$

At steady state, ***dS/dt*** **= 0**

$$\Rightarrow \quad Q(S_o - S) = \frac{V\mu X}{Y} \quad \Rightarrow \quad (S_o - S) = \frac{(V/Q)\mu X}{Y} = \frac{\mu X\,\bar{t}}{Y};$$

$\bar{t}$ = average resudence time of the liquid in the tank V/Q

$$\Rightarrow \quad (S_o - S) = \frac{X\,\bar{t}}{Y}\,\frac{\bar{\mu}S}{K_s + S} \qquad \textbf{(6)}$$

The values of the parameters $\bar{\mu}, K_s$ *and* Y are to be determined experimentally.

Then the above equation can be used to determine the volume of the aeration tank for a given wastewater flow and substrate concentration (which id expressed in terms of BOD)

A Few Basic Parameters related to the Activated Sludge Process

Mixed Liquor Suspended Solids (MLSS) – It is simply the mass of suspended solids in mg/L of the liquid in the aerated tank.

Mixed Liquor Volatile Suspended Solids (MLVSS) – It is simply the amount of suspended biomass mg/L of the liquid in the aerated tank.

Method of measurement: A volume of liquid with cells in suspension is filtered using a glass fiber filter. The filter with the solid is dried in an air oven at 10-105oC and the dry weight is noted. The filter with dry solid is burned in a furnace at 550oC for half an hour and the filter with the ash is weighed again.

Initial weight of the filter = w_1
Weight of filter with dry solids = w_2
Weight of filter with ash = w_3
Volume of water filtered = 1 liter

$$\text{MLSS} = \left(w_2 - w_1\right) mg/L; \qquad \text{MLVSS} = \left(w_2 - w_3\right) mg/L$$

$$\text{Sludge Volume Index (SVI, mL/gm)} = \frac{\text{Settled Sludge Volume, ml/L}}{\text{Suspended Solid Conc, mg/L}} \times \frac{1000\ \text{mg}}{\text{g}} \qquad \textbf{(7)}$$

Representative values of the parameters: MLSS -2000-5000 g/L ; MLVSS - 0.7-0.9 times MLSS ; SVI - 100-200 mL/mg

$$\text{Hydraulic Retention Time, } \tau = \frac{\text{volume of liquid in the aerated tank}}{\text{Rate of Flow of Liquid}} = \frac{V}{Q} \qquad \textbf{(8)}$$

$$\text{Mean Cell Residence Time, } \theta_c = \frac{\text{Mass of cells in the aerated tank}}{\text{Mass of cells removed or 'wasted' per unit time}}$$

$$\text{If there is no recycle of cells (see slide...), } \theta_c = \frac{VX}{QX} = \frac{V}{Q}$$

In such a case, Hydraulic Retention Time = Mean Cell Residence Time, $\tau = \theta_{\mathrm{c}}$

If there is cell recycle (Activated Sludge process),

$$\theta_c = \frac{VX}{V r_x} = \frac{X}{\bar{\mu} XS/(K_s + S)} \quad \Rightarrow \quad \theta_c = \frac{VX}{V r_x} = \frac{(K_s + S)}{\bar{\mu} S}$$

If there is recycle of cells (i.e., activated sludge process), consider the sketch in slide... (we assume that there are no cells in the clear water leaving the tank, X_c = 0).
Also, at steady state, mass of cells wasted = mass of cells growing **(9)**

Problem An activated sludge system operates at a flow rate (Q) of 400 m^3/day with an incoming BOD (S_0) of 300 mg/L. Through pilot plant work, the kinetic constants for this system are determined to be $Y = 0.5$ kg SS/kg BOD, $K_S = 200$ mg/L, $\hat{\mu} = 2$ day^{-1}.

A solids concentration of 4000 mg/L in the aeration tank is considered appropriate. A treatment system must be designed that will produce an effluent BOD of 30 mg/L (90% removal). Determine

a. the volume of the aeration tank
b. the sludge age (or mean cell residence time, MCRT)

Solution (The mixed-liquor suspended solids concentration is usually limited by the ability to keep an aeration tank mixed and to transfer sufficient oxygen to the microorganisms. A reasonable value for the solids under aeration would be $X = 4000$ mg/L as stated in the problem.)

a. The volume of a basin is typically calculated from the hydraulic retention time (HRT), which is currently unknown. Therefore, we need another equation to calculate HRT. Because we know the kinetic constants, we can use Equation 11.15

$$S_0 - S = \frac{\hat{\mu} S X \bar{t}}{Y(K_S + S)}$$

$$\bar{t} = \frac{Y(S_0 - S)(K_S + S)}{\hat{\mu} S X}$$

$$= \frac{(0.5\ \text{kg/kg})(300\ \text{mg/L} - 30\ \text{mg/L})(200\ \text{mg/L} + 30\ \text{mg/L})}{(2\ \text{day}^{-1})(30\ \text{mg/L})(4000\ \text{mg/L})}$$

$$= 0.129\ \text{day} = 3.1\ \text{hr}$$

The volume of the tank is then (Equation 11.5) $V = \bar{t}Q = (0.129\ \text{d})(400\ \text{m}^3/\text{day}) = 51.6\ \text{m}^3 \cong 52\ \text{m}^3$.

Sludge residence time, $\theta_c = \dfrac{(K_s + S)}{\bar{\mu} S}\ {}_{4000\ mg/L} = \dfrac{200\ \text{mg/L} + 30\ \text{mg/L}}{(2\ \text{day}^{-1})(30\ \text{mg/L})} = 3.8\ \text{day}$

Calculate the sludge wasted per day

Cells wasted per day = Cells produced per day in the tank

$$= V.r_X = V.\bar{\mu}.\frac{X.S}{K_s + S} \quad [\text{ see Eq ( )}] \quad = \left(52\ m^3\right)(2\ day^{-1})\frac{(4000\ mg/L)(30\ mg/L)}{4000\ mg/L + 30\ mg/L}$$

$$= \quad 54\ \text{kg/day}$$

The cell concentration in the tank is the Mixed Liquor Volatile Suspended Solids (MLSS) = 4000 mg/L. It is usually maintained at 2500 to 6000 mg/l

Stabilization and Disposal of Sludge

- -- the sludge undergoes lime stabilization (pH is often raised by addition of lime) to kill potential pathogens

-- the stabilized sludge is land applied by injection into agricultural fields

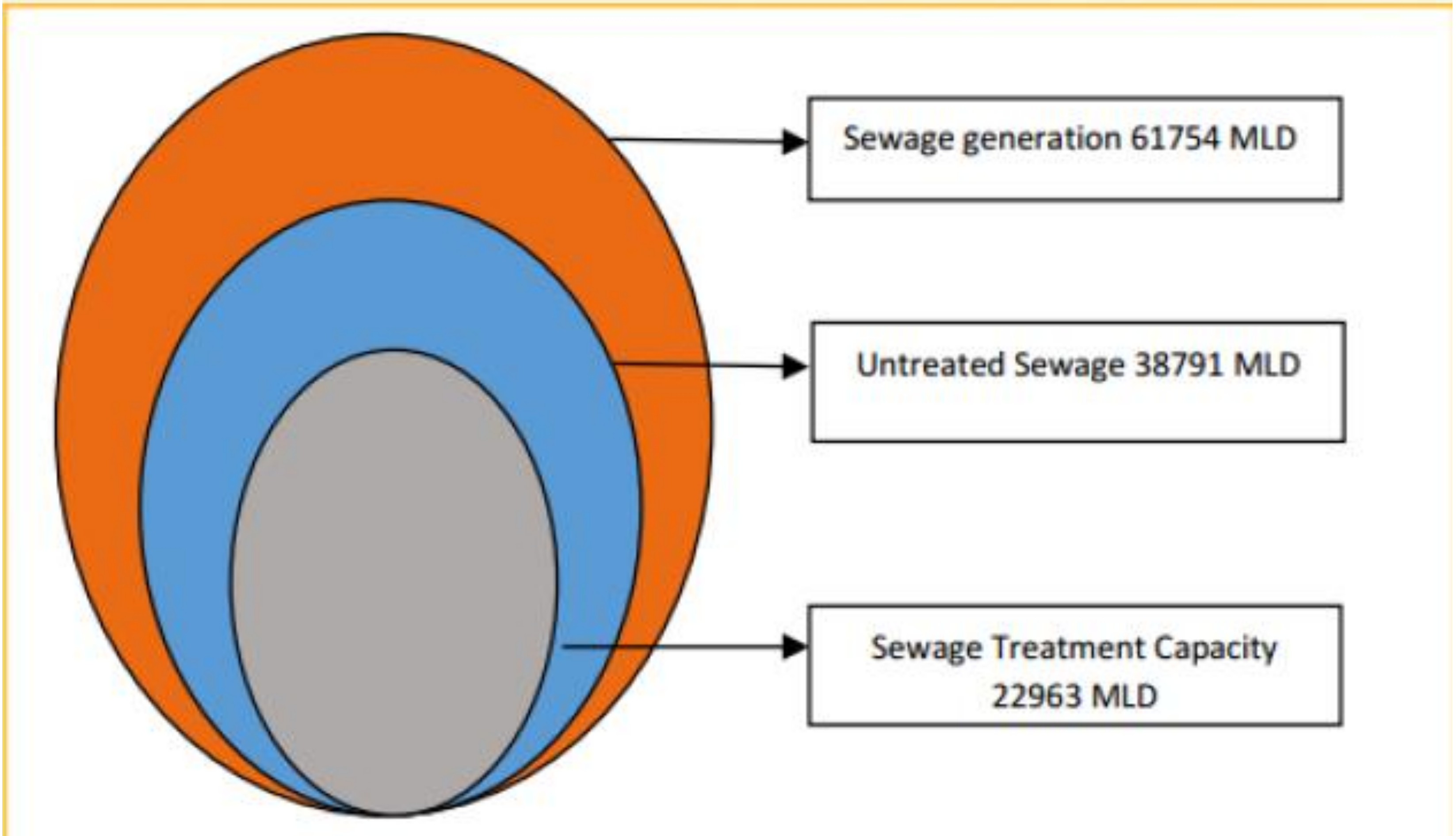
Tertiary Treatment

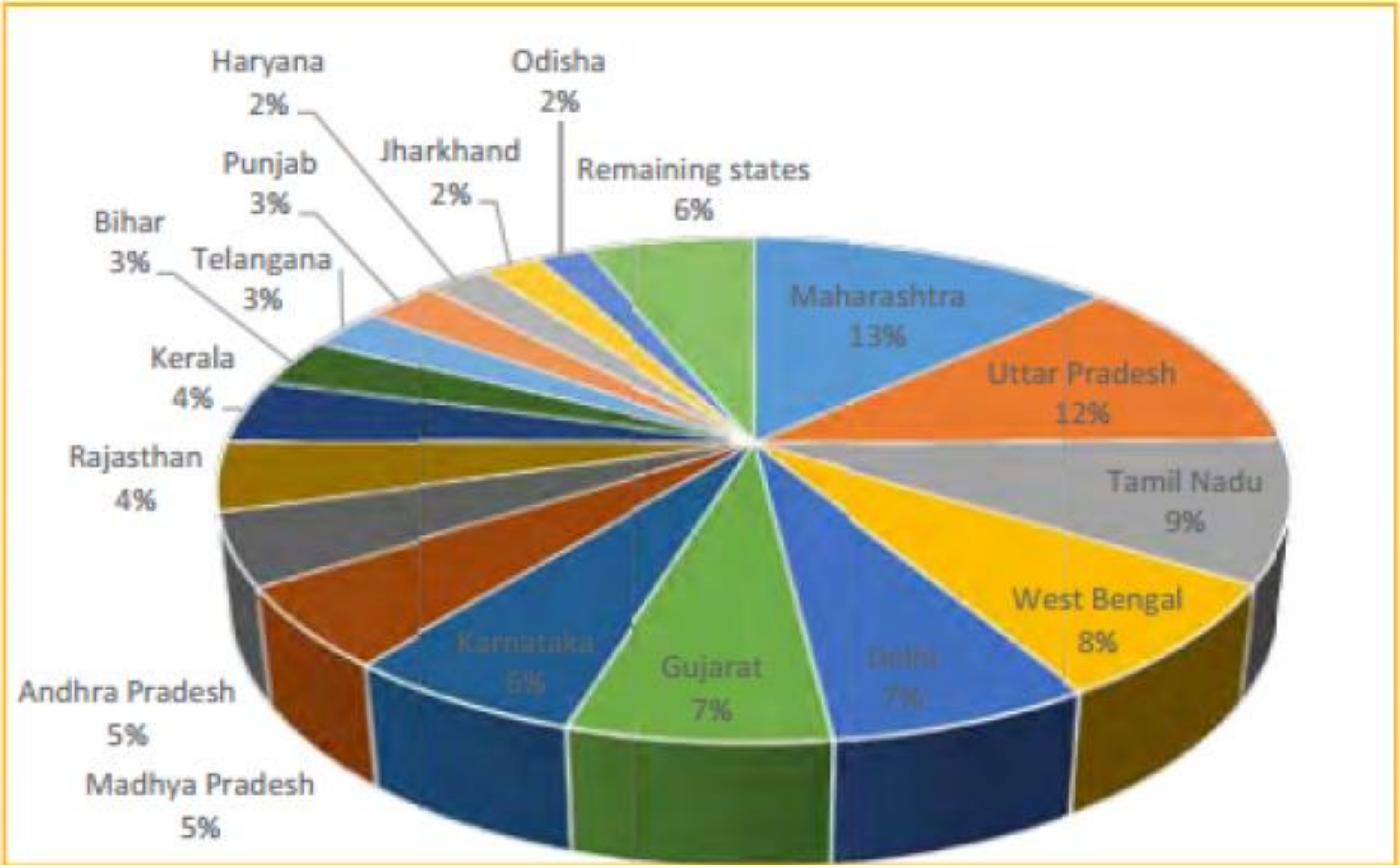
Tertiary Treatment removes certain contaminants that do not biodegrade but are required to be removed to maintain the desired quality of treated water before disposal. The substances removed are phosphorus (removed by ferric alumn), nitrogen (denitrifying bacteria), ammonia (by stripping), certain organics 9by adsorption) and also by membrane filtration.

Exercise Problem: An activated sludge system is to treat 4000 m3/day of wastewater from the primary clarifier at an influent BOD (S_o) = 300 mg/l that has to be reduced to 30 mg/l. The parameters have been determined by a pilot plant experiment - Y = 0.5 kg cell/kg BOD, Ks = 200 mg/l and $\bar{\mu}$ = 2 / day. Calculate the volume of the aeration tank if the MLSS = 4500 mg/l

Wastewater Treatment and Reuse – the Indian Scenario

Sewage Generation and Treatment



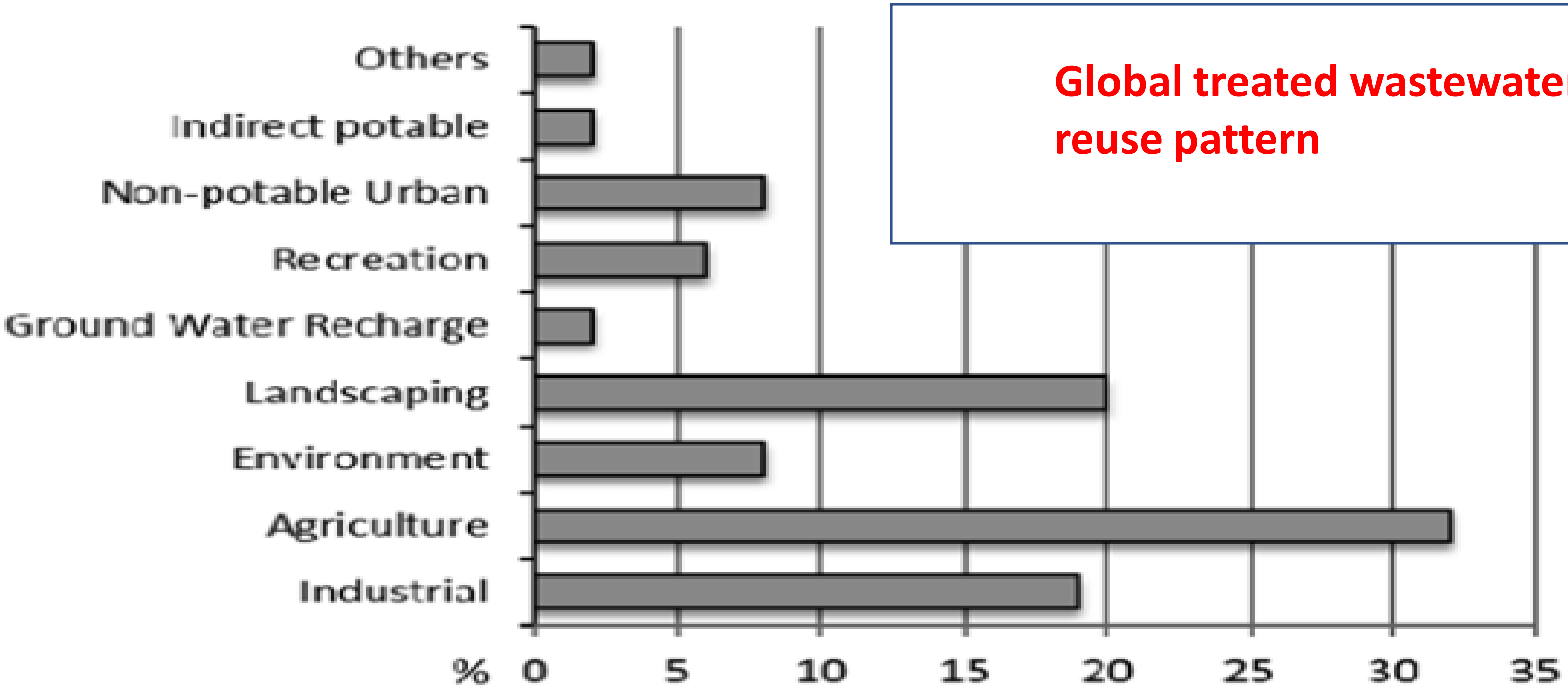


Statewise Sewage Genaration

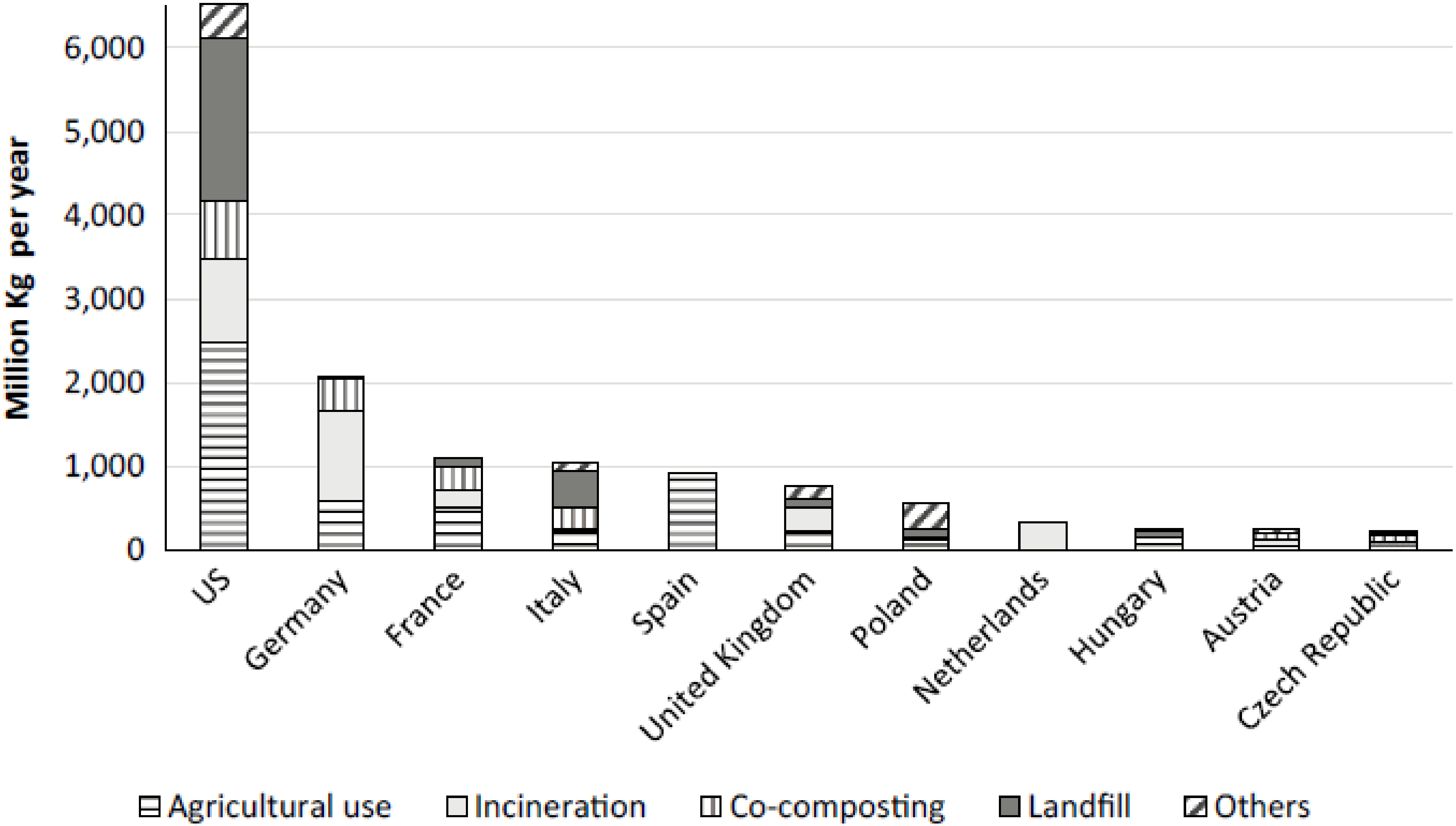
Resource Potential of Globally Produced Wastewater

Strength of wastewater	N (Tg/yr)	P (Tg/yr)	C (Tg/yr)
Weak	6.6	1.3	26.4
Medium	13.2	2.6	52.8
Strong	28.1	5.0	95.7

Note: *Tg* Teragram $= 10^9$ kg



Global treated wastewater reuse pattern



Sewage Sludge utilization pattern in selected countries