Section 1:Water treatment

Introduction

Water is essential for life

It covers 71% of the earth's surface and makes up 65% of our bodies. Everyone wants clean water to drink, for recreation, and just to enjoy looking at. If water becomes polluted, it loses its value to us economically and esthetically, and can become a threat to our health and to the fish living in it and the wildlife that depends on it.

Water functions in life

- Important component in food
- Universal solvent (salt, vitamins, sugar, gases, pigment)
- Capable of ionizing (H_3O^+, OH^-)
- Affects the texture
- Chemical reactions (hydrolysis of protein to amino acids)
- Stabilizing the colloids (by hydration)
- Necessary for micro-organisms growth

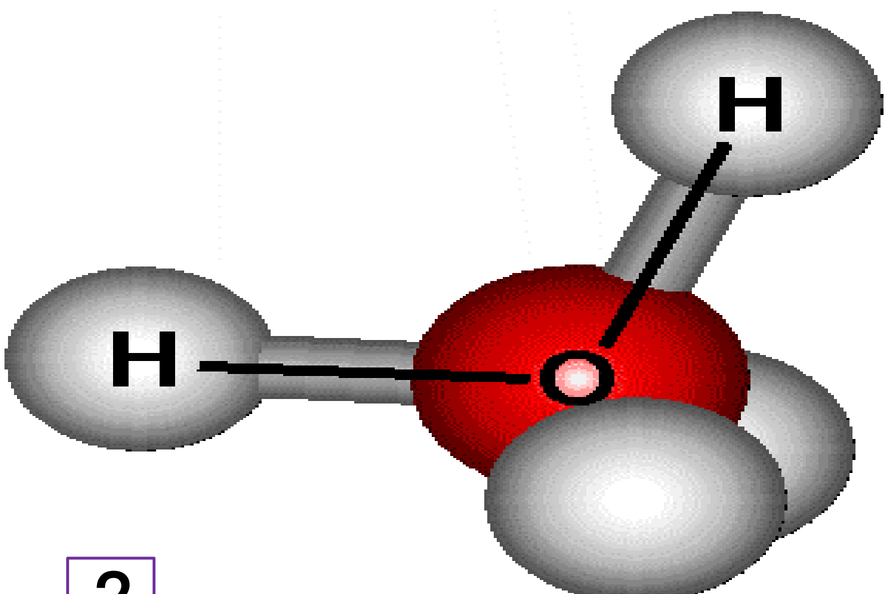
Molecular Structure of Water

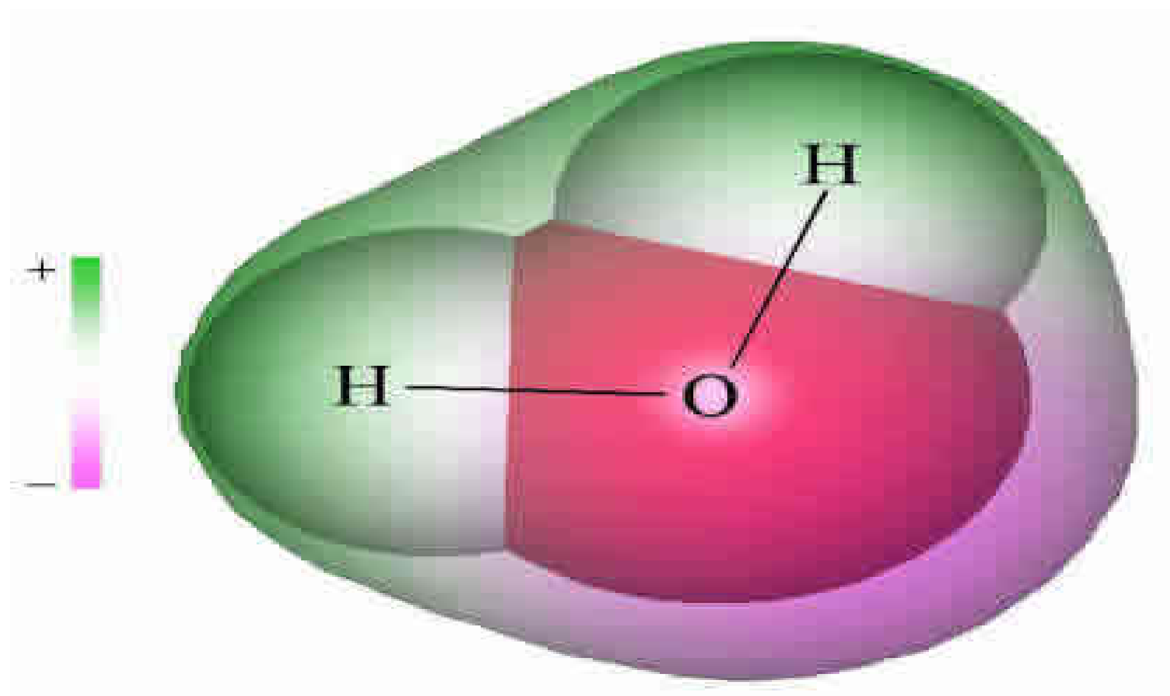
The molecular formula of water is expressed as H_2O.

water molecular has four electrical charges of two positive and two negative

Because of the water molecule structure, a water molecule has four arms making hydrogen bond.

These dipole moment and hydrogen bond of water give very unique properties to water comparing with the other organic and inorganic substances.





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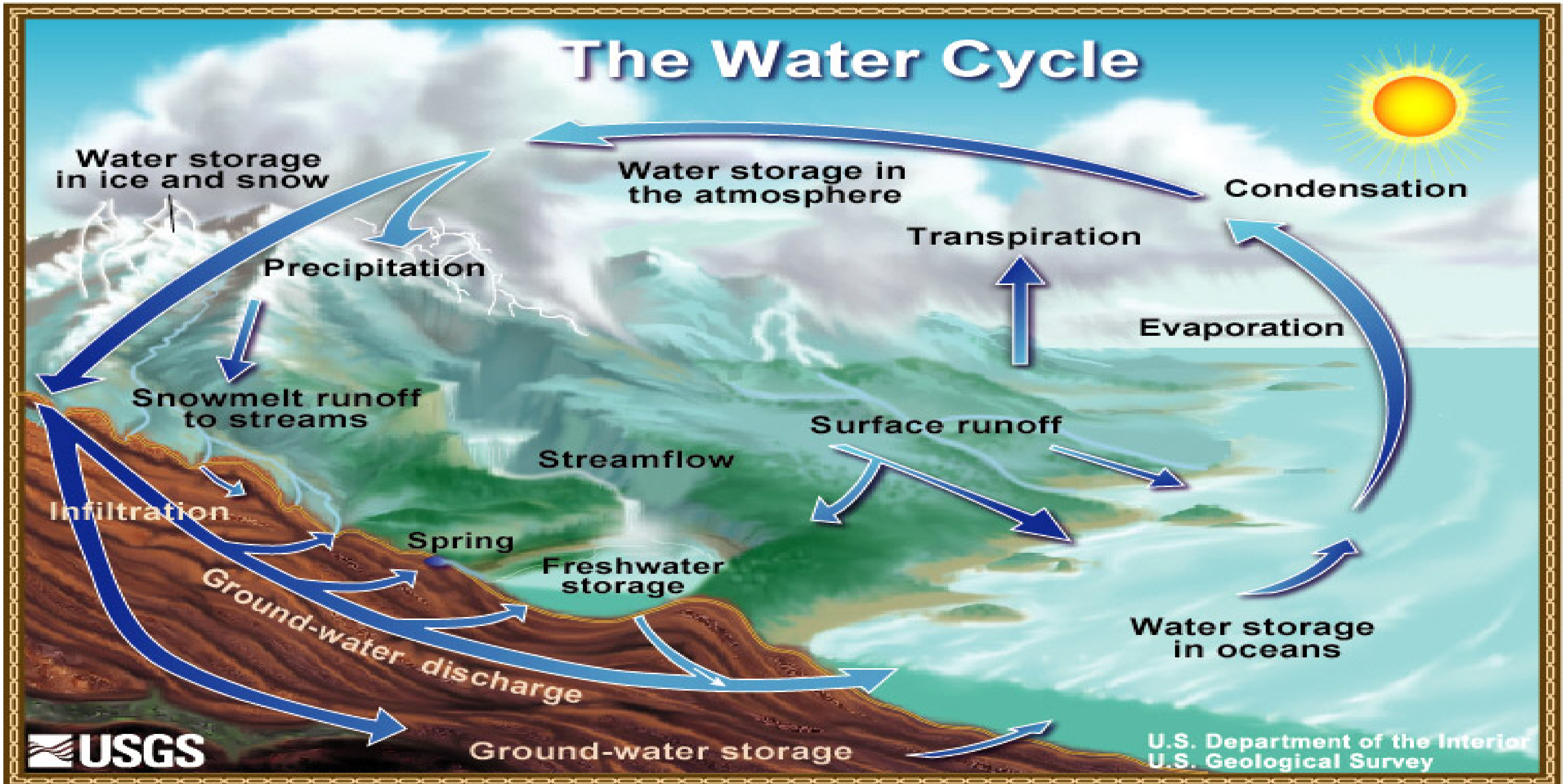
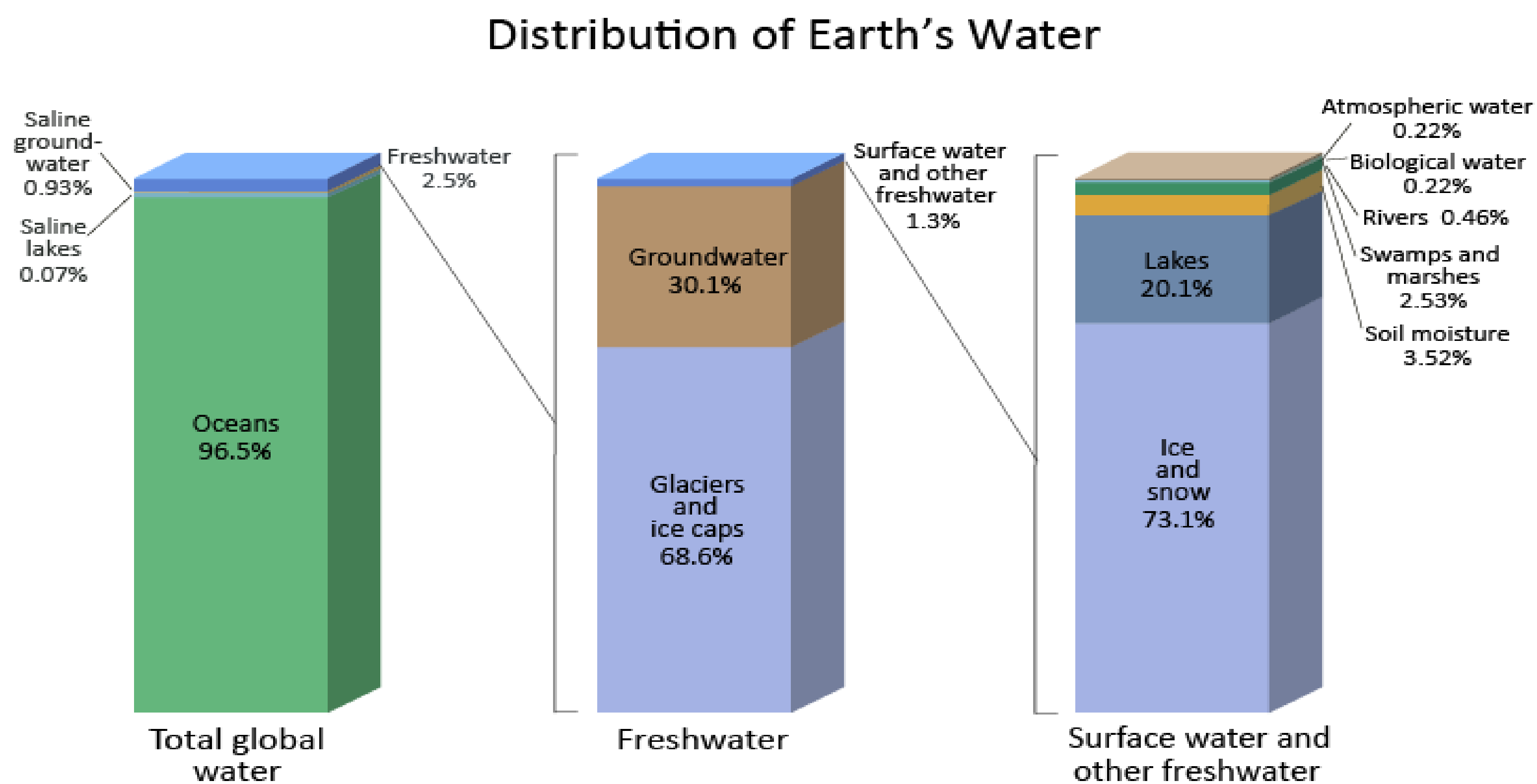
Water or Hydrologic cycle

Describes the continuous movement of water on, above and below the surface of the Earth.



Global water distribution

The world's total water supply of about 332.5 million cubic miles of water, over 96 percent is saline. And, of the total fresh water, over 68 percent is locked up in ice and glaciers. Another 30 percent of fresh water is in the ground. Fresh surface- water sources such as rivers and lakes. Rivers and lakes are the sources of most of the water people use everyday.



Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources.

Water Treatment Overview

Treatment systems are installed for two reasons: to remove those things that can cause disease and those things that create nuisances. The basic goal is to protect public health. However, the broader goal is to provide potable water that is safe to drink, pleasant in appearance, pleasant in taste and odor, and cost-effective to produce.

Reasons for Water Treatment

The two main reasons for treating water are

1) to remove those contaminants that are harmful to health and

2) to remove contaminants that make the water look, taste, or smell bad.

Aesthetic Contaminants

Aesthetic contaminants affect the appearance, taste, or **odor** of the water. Most are not directly harmful to human health, but their presence may lead to problems that can indirectly result in health concerns. Aesthetic contaminants include cloudiness or **turbidity**, iron and manganese, **color**, the rotten egg odor caused by **hydrogen sulfide gas**, and **hardness**, to name a few.

Health-related Contaminants

Contaminants that can affect human health can be naturally occurring, man-made, or a result of the treatment process itself. Health-related contaminants can be further subdivided into those contaminants that can cause sickness or illness at very low levels or low exposures, the so-called **acute contaminants**, or those that can cause sickness or illness only after prolonged exposure to the contaminant in drinking water, called **chronic contaminants**. Health-related contaminants include pathogenic microorganisms; inorganic materials such as lead, arsenic, nitrate and nitrite; and disinfection byproducts that can be formed during chlorination.

Some of the more common contaminants encountered in water treatment

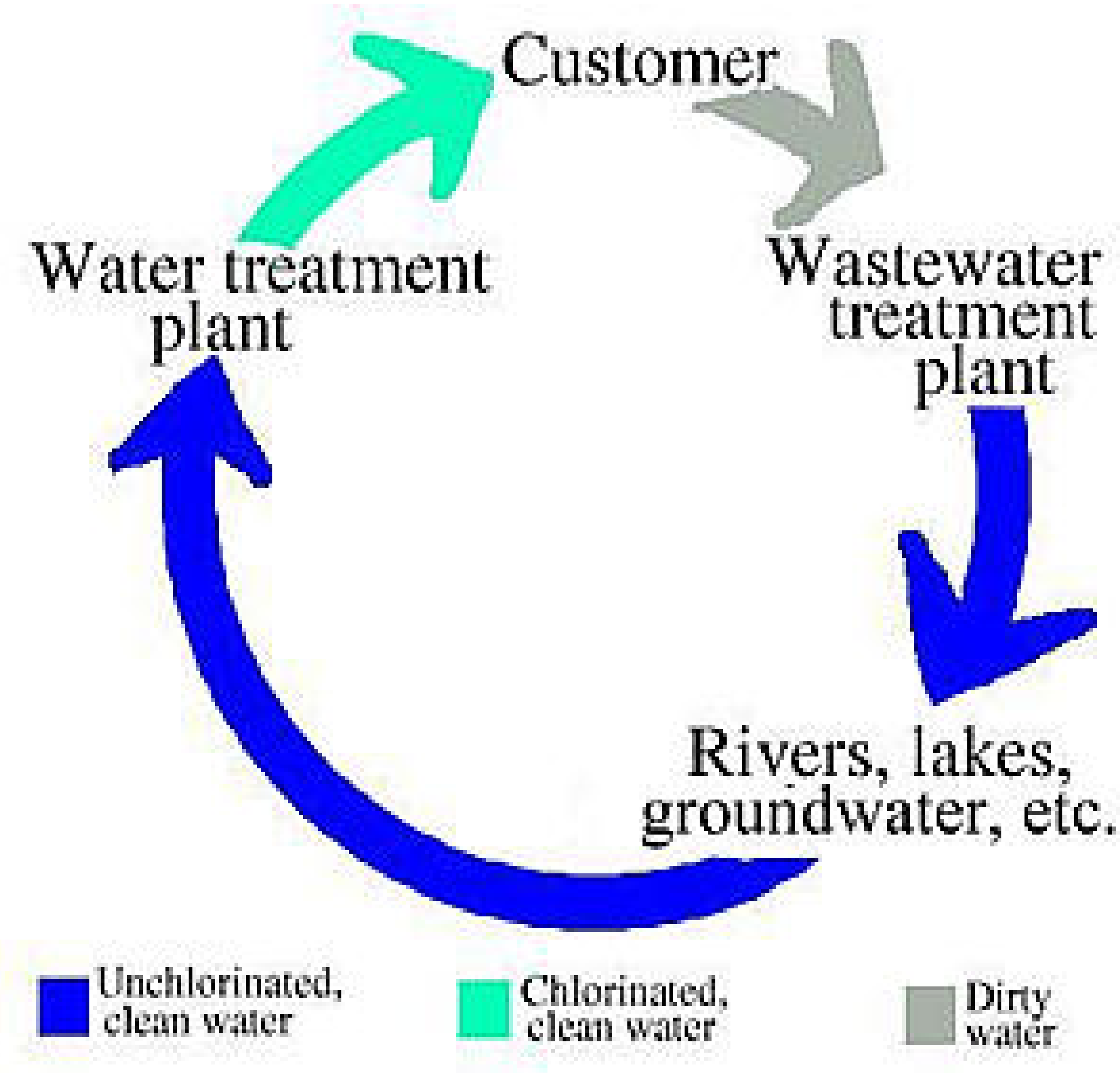
Contaminant	Affects	Source	Common Treatment Options
Giardia	Health	Organism	Filtration/Disinfection
Cryptosporidium	Health	Organism	Filtration
Viruses	Health	Organism	Filtration/Disinfection
TTHM	Health	Disinfection Byproduct	Filtration/Adsorption/Disinfectant Selection
HAA5	Health	Disinfection Byproduct	Filtration/Adsorption/Disinfectant Selection
Arsenic	Health	Mineral	Co-precipitation/Adsorption
Lead	Health	Mineral/Corrosion	Corrosion Control
Copper	Health	Mineral/Corrosion	Corrosion Control
Nitrate	Health	Nitrogen	Ion Exchange/Reverse Osmosis
Manganese	Health/Aesthetic	Mineral	Oxidation/Filtration/Adsorption
Iron	Health/Aesthetic	Mineral	Oxidation/Filtration
Turbidity	Health/Aesthetic	Particle Matter	Filtration
Color	Aesthetic	Minerals or Organics	Oxidation/Filtration/Adsorption
Odor	Aesthetic	Hydrogen Sulfide	Oxidation/Aeration
Hardness	Aesthetic	Minerals	Ion Exchange/Reverse Osmosis

<u>Basic Water Treatment Unit Processes</u>

Water treatment requires chemical, physical, and sometimes biological processes to remove contaminants.

The chemical processes involved in potable water treatment include **oxidation**, **coagulation** and **disinfection**. The physical processes include **flocculation**, **sedimentation**, **filtration**, **adsorption**, and **disinfection using ultraviolet light**. The types of processes that are required and the order in which they are used depend on the types and concentrations of contaminants that must be removed. Examples of this include oxidation, followed by filtration or sedimentation, followed by filtration. In the first example, the oxidation process causes the dissolved contaminants to form a **precipitate**, which is then removed by filtration. In the second example, sedimentation removes most of the solids by gravity and reduces the solids loading on the down stream filtration process.

Over view of the waste water treatment



Sources of Wastewater

You can classify wastewater as domestic, industrial, or storm, according to its origin.

- Domestic sources include water used for normal activity in homes, businesses and institutions. Domestic wastewater is readily treatable.

- The character of industrial wastewater depends on the type of industry using the water. Some industrial wastewaters can be treated the same as domestic wastes without difficulty. Others may contain toxic substances or high percentages of organic materials or solids which make treatment difficult.

- Storm water often goes to a treatment plant, although it is usually low in pollutants. Great amounts of storm water can interfere with treatment efficiency in two ways: Storm water may cause too much dilution of the wastewater. At the same time, it may cause hydraulic overloading of the plant. In most cases, wastewater systems now call for separate storm sewers.

Basic Water Quality Parameters

- pH
- Electrical conductivity (EC)
- Salinity
- Turbidity
- Dissolved oxygen (DO)
- Biochemical oxygen demand (BOD)
- Temperature

- Carbon Dioxide
- Solids
- Akalinity and hardness

pH

- Measures hydrogen ion concentration
- Negative log of hydrogen ion concentration
- Ranges from 0 to 14 std. units

- It reflects the acidity or alkalinity of a solution.

Note: Toxic metals less available in water at pH 6 to 8.

Conductivity

Electrical conductivity is the measure of the ability of water to conduct an electric current and depends upon the number of ions or charged particles in the water, and is measured by passing a current between two electrodes that are placed into a sample of water. The unit of measurement for electrical conductivity is expressed in either micro Siemens per centimetre (µS/cm) or milli Siemens per centimetre (mS/cm).

Electrical conductivity determinations are useful in aquatic studies because they provide a direct measurement of dissolved ionic matter in the water. *Low values* are characteristic of *high-quality, low-nutrient* water. High values of conductance can be indicative of salinity problems (*low quality, high nutrient)*

Salinity

In measuring the salinity of water, we consider the concentration of salt dissolved in the water. These are the classes of salinity we use for water:

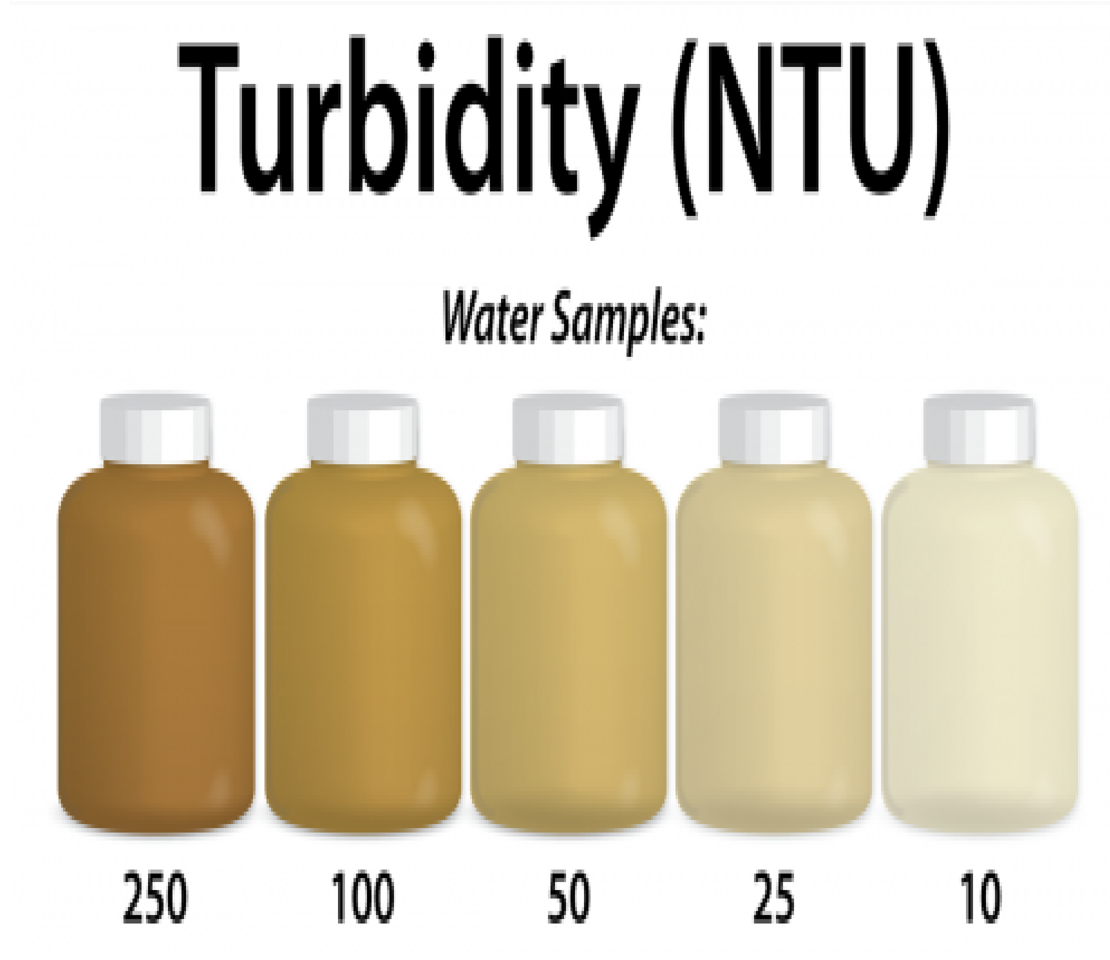
Type of Water	Dissolved salt content (mg/l)
Fresh water	< 1,000 mg/l
Brackish water	1,000 - 3,000 mg/l
Moderately saline water	3,000 - 10,000 mg/l
Highly saline water	10,000 - 35,000 mg/l
Sea water	> 35,000 mg/l

Dissolved Oxygen(DO)

- Amount of gaseous oxygen (O_2) dissolved in water
- Oxygen gets into water by diffusion from the surrounding air, by aeration, and through photosynthesis

Turbidity

- turbidity: the cloudy or muddy appearance of a naturally clear liquid caused by the suspension of particulate matter. It is commonly recorded in nephelometric turbidity units (NTUs).



Temperature

The solubility of dissolved oxygen decreases with increasing water temperature, high water temperatures limit the availability of dissolved oxygen for aquatic life. In addition, water temperature regulates various biochemical reaction rates that influence water quality.

Biochemical oxygen demand (BOD)

is the amount of oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period.

BOD $\uparrow$ DO $\downarrow$

Carbon Dioxide

- Carbon dioxide is a highly soluble in water.
- Concentration in pure water: 0.54 mg/L at 20° C.
- Groundwater concentrations range from 0-100 mg/L.

•The concentration of Carbon dioxide in surface water depends On the rate of respiration, photosynthesis and gas exchange with atmosphere

Exposure to high carbon dioxide concentrations reduces respiration efficiency.

Solids

<u>Three categories:</u>

- settleable
- suspended
- fine or dissolved solids

Alkalinity

(Acid neutralizing capacity of water)

Formula	Common Name	Equivalent Weight
$NaOH$	sodium hydroxide	40
Na_2CO_3	sodium carbonate	53
$NaHCO_3$	sodium bicarbonate	83
$CaCO_3$	Calcium Carbonate	50
CaO	slaked lime	28
$Ca(OH)_2$	hydrated lime	37

Hardness

Water Classified as:

soft (0-75 mg/L)

moderately hard (75 – 150 mg/L)

hard (150-300 mg/L)

very hard (> 300 mg/L)

Standards that are set by the United States Environmental Protection Agency (EPA) for drinking water quality.

Maximum contaminant level (MCL):

The" maximum allowed" is the highest level of contaminant that is allowed in drinking water.

Maximum Contaminant Level Goal (MCLG)

The "goal " is the level of a contaminant in drinking water, below which there is no know or expected risk to health.

MCLs are set as close to the MCLGs as feasible using the best available treatment technology

Nephlometric Turbidity Unit (NTU):

Is a measure of the clarity of water. Turbidity in excess of five NTU is just noticeable for person

Maximum Residual Disinfectant level (MRDL):

The highest level of a disinfectant allowed in drinking water.

Maximum Residual Disinfectant Goal (MRDLG)

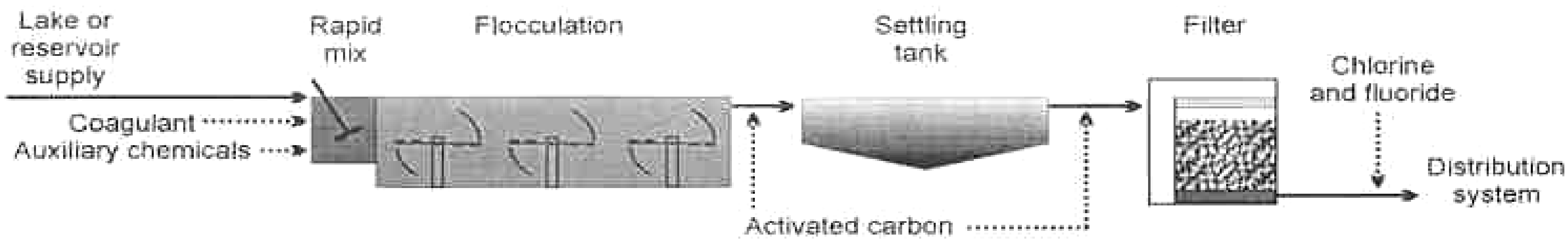
The level of a drinking water disinfectant, below which there is no known or expected risk to health

Water classification by source Ground-vs. Surface Water

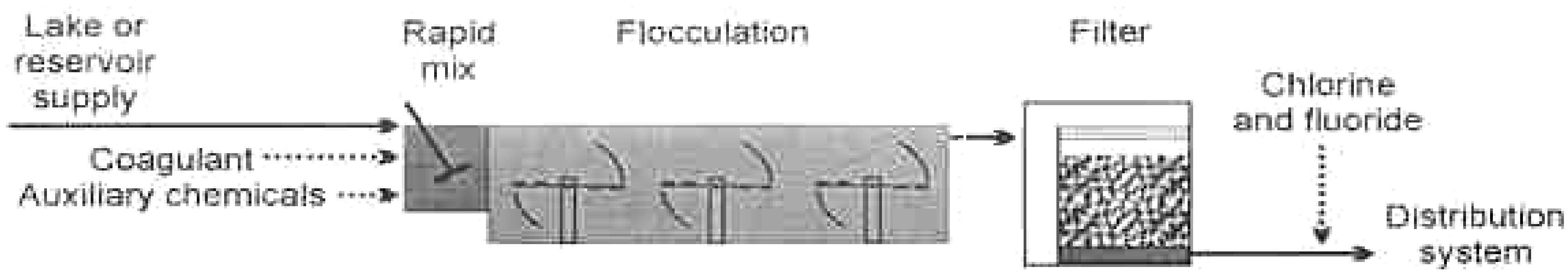
Surface water	Groundwater
variable composition	constant composition
low mineral content	high mineral content
high turbidity	low turbidity
colored	low color
D.O. present	low or no D.O.
low hardness	high hardness
Fe, Mn may present, usually as organic complexes.	high Fe, Mn

Surface Water Treatment

Conventional Treatment



Direct Filtration



Coagulation and Flocculation

Coagulation

Most organic and inorganic material suspended in water and not dissolved will settle out if given enough time. However, the main materials that contribute to color and turbidity are either dissolved or too small to settle. The basic problem comes from material that is less than one micrometer (0.001 mm) in size, called colloidal material.

Organic material that will pass through a 0.45 micrometer membrane filter is considered to be dissolved. These materials include humic and fulvic acids that can cause color in water and are measured as **organic carbon**.

Total organic carbon (TOC) includes the materials that are both larger and smaller than 0.45 micrometers in size.

Dissolved organic carbon (DOC) is the fraction of organic material that is smaller than 0.45 micrometers. These acids carry a negative charge.

Coagulants

There are two opposing forces that impact the removal of colloidal material:

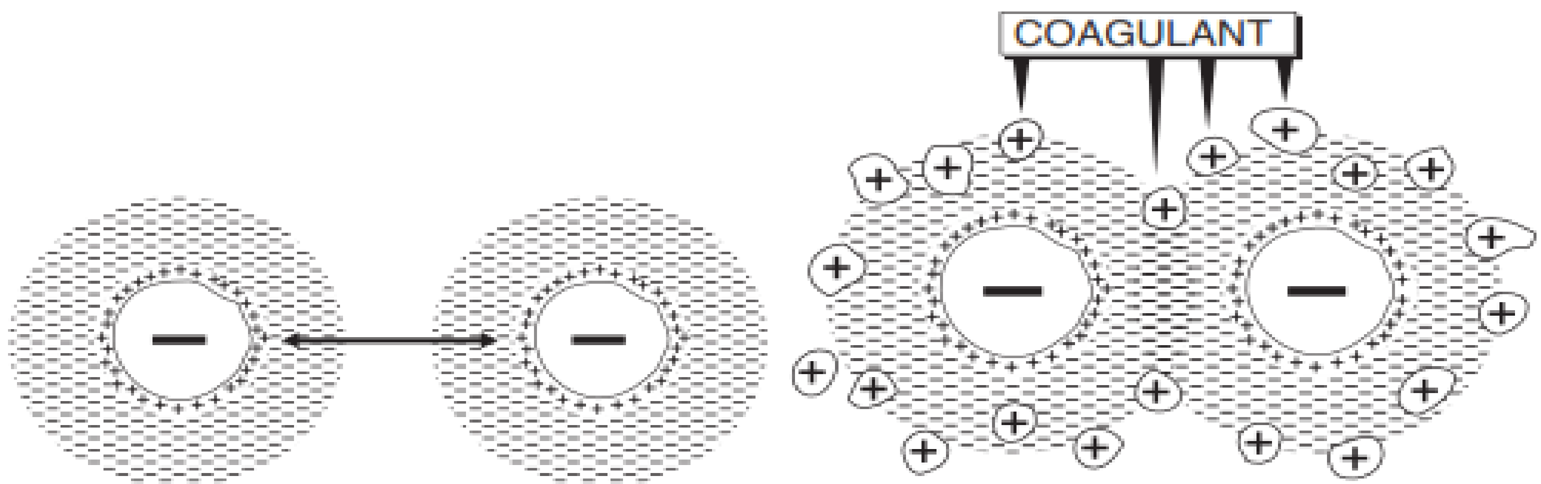
- Stability factors – Stability factors are those factors that help to keep colloids dispersed.

- Instability factors – Instability factors are those factors that contribute to the natural removal of colloids.

The process of decreasing the stability of the colloids in water is called coagulation. Coagulation results from adding salts of iron, aluminum, or cationic polymer to the water. Some common coagulants include the following:

- Aluminum Sulfate (Alum[29]) $Al_2(SO_4)_3 \cdot 18H_20$
- Sodium Aluminate – $NaAlO_2$
- Ferric Sulfate – $Fe_2(SO_4)_3 \cdot 9H_20$
- Ferrous Sulfate – $FeSO_4 \cdot 7H_20$
- Ferric Chloride – $FeCl_3$
- Polyaluminum Chloride (PAC)
- Cationic Polymers

The addition of metal salts or polymers to water containing negatively charged contaminants may result in a process called coagulation. The simplest coagulation process to explain occurs between alum and water. When alum is placed in water, a chemical reaction occurs that produces positive charged aluminum ions. The positively charged aluminum ions then become attached to the surface of the negatively charged colloid. The overall result is the reduction of the negative surface charges and the subsequent formation of agglomerate (floc). This destabilizing factor is the major contribution that coagulation makes to the removal of turbidity, color, and microorganisms.



Hydrophobic particles

Hydrophobic particles after coagulation

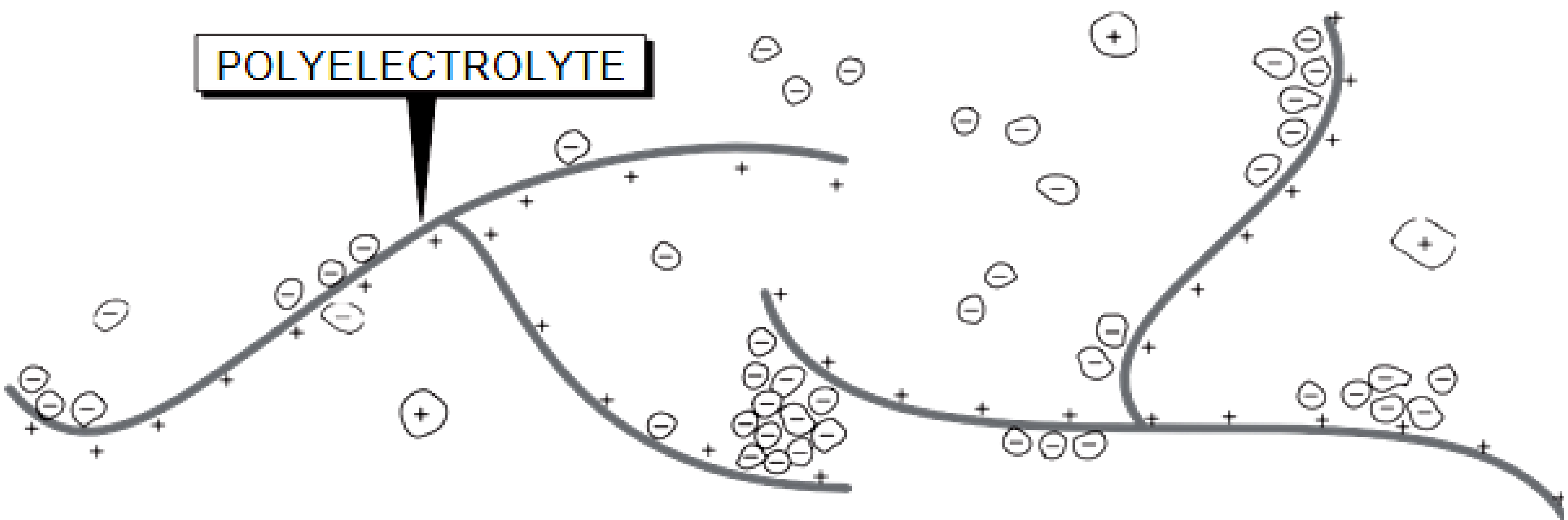
There are a number of factors that influence the coagulation process. Four of the most important are **pH, turbidity, temperature**, and **alkalinity**. The degree to which these factors influence coagulation depends upon the type of coagulant used. When metal salts are used as the primary coagulant, these factors can have a significant affect on the performance of the chemical in removing contaminants. The performance of cationic polymers, however, is less influenced by these factors.

Polyelectrolytes, or polymers, as they are commonly called, can be used as a primary coagulant or as an aid to coagulation when metal salts are used. Polymers are long string-like (chain) molecules with charges placed along the string. There are three common types of polymers:

Positively charged **polymeric** substances called **cationic** polymers,

Negatively charged polymeric substances called **anionic** polymers

Polymeric substances with no charge called **nonionic** polymers



Polyelectrolyte molecule

Flocculation

Flocculation is a physical process of slowly mixing the coagulated water to increase the probability of particle collision. This process forms the floc. Floc is a snowflake- looking material that is made up of the colloidal particles, microorganisms, and precipitate.

Adsorption

Organic and inorganic contaminants can be removed from water through the adsorption process. Adsorption of a substance involves its accumulation onto the surface of a solid called the adsorbent. Adsorbents can include stationary media, such as activated carbon, ion exchange resins, or metal oxides. Adsorbents can also include aluminum or ferric chloride floc that forms during coagulation. This floc can adsorb organics such as organic carbon and inorganics such as arsenic.

Organic Adsorption

Activated carbon can be used to remove hundreds of different types of organic contaminants. It can be injected into the water as a powder, or it can be placed in a vessel in granular form for the water to flow through it. The powdered form is known as powdered activated carbon (PAC) and the granular form is known as granular activated carbon (GAC). Greater process control and adsorptive capacities can be achieved with the GAC.

Inorganic Adsorption

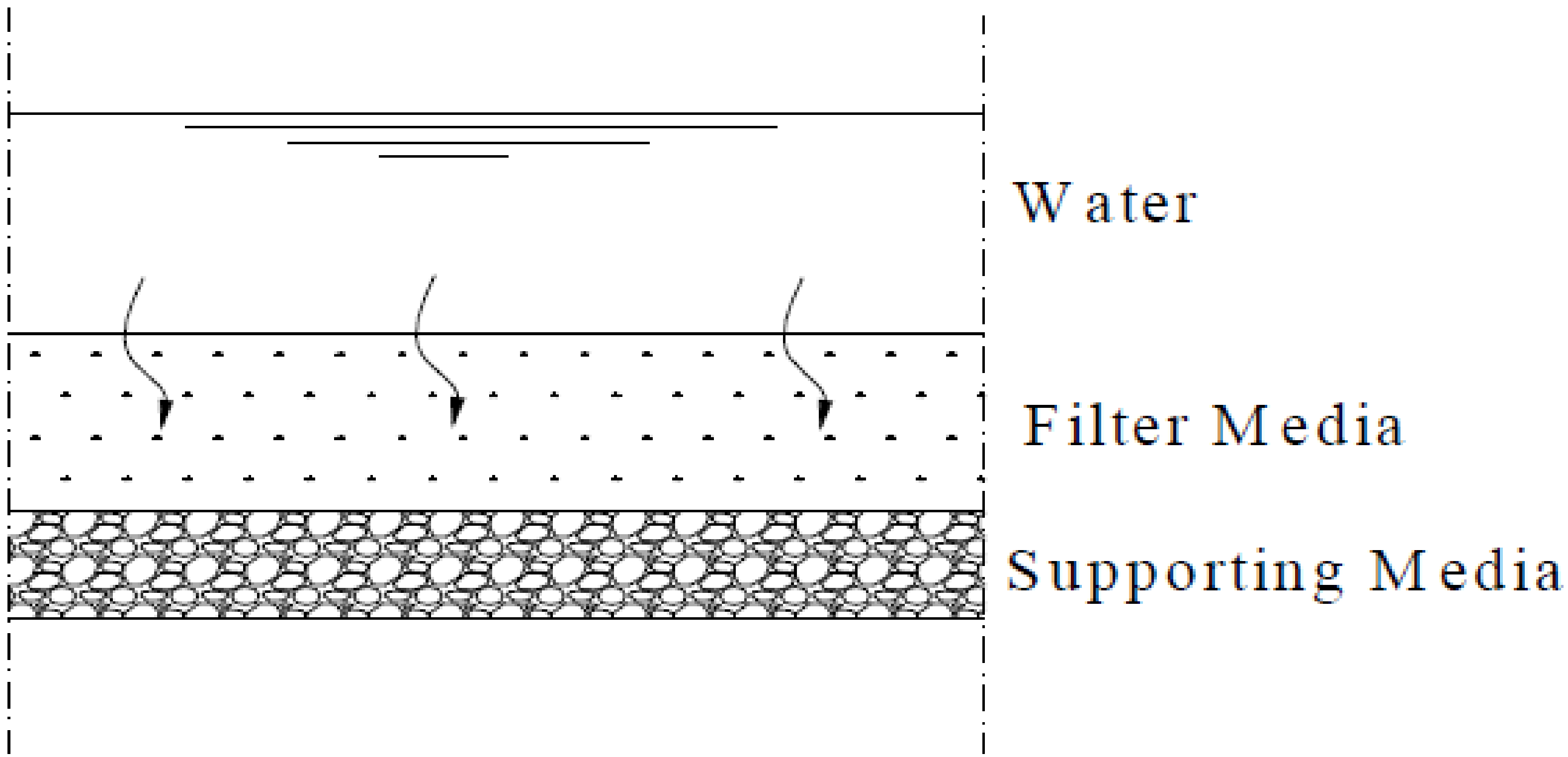
Some inorganic contaminants can be removed through the adsorption process as well. Adsorption can be on to the surface of a filter media or on to the surface of floc. Common adsorption media includes ferric oxide or activated alumina. Inorganic contaminants that can be removed by adsorption include arsenic, manganese, fluoride, as well as many others.

Settling

Sedimentation – A process that allows the flocculated or coagulated particles to settle by gravity in a sedimentation tank.

THEORY OF FILTRATION

Filtration is a physical process of separating suspended and colloidal particles from water by passing the water through a filter media.



A. Granular Media Filtration

Filter media can consist of silica sand, greensand, anthracite coal, activated carbon, and many other types of media. These media can be used by themselves as a single media filter or mixed to provide improved filtration characteristics. The two most common types of granular media filters include dual-media filters and tri-media (mixed media) filters. Dual-media filters consist of anthracite coal and silica sand; and tri-media filters have anthracite coal, silica sand and fine garnet.

B. Membrane Filtration

Membrane processes commonly used in water treatment include **membrane cartridge filtration** (MCF), **microfiltration** (MF), **ultrafiltration** (UF), **nanofiltration** (NF), and **reverse osmosis** (RO). The MCF process includes using **Bag Filters(**A membrane filter shaped like a bag) and **Cartridge Filters (**A membrane filter in the form of a cartridge) and is used to remove larger pathogens such as Giardia and Cryptosporidium.

The MF and UF processes are effective at removing turbidity, particles, and pathogens from water. The NF process provides a higher level of treatment than the MF/UF processes and has the added capability of removing dissolved organic contaminants. The RO process provides the highest level of treatment of the membrane processes and is also effective in removing salts from brackish water or seawater. Membrane processes are classified based on effective size range

Membrane Cartridge Filtration – Bag or cartridge filters capable of removing giardia and cryptosporidium.

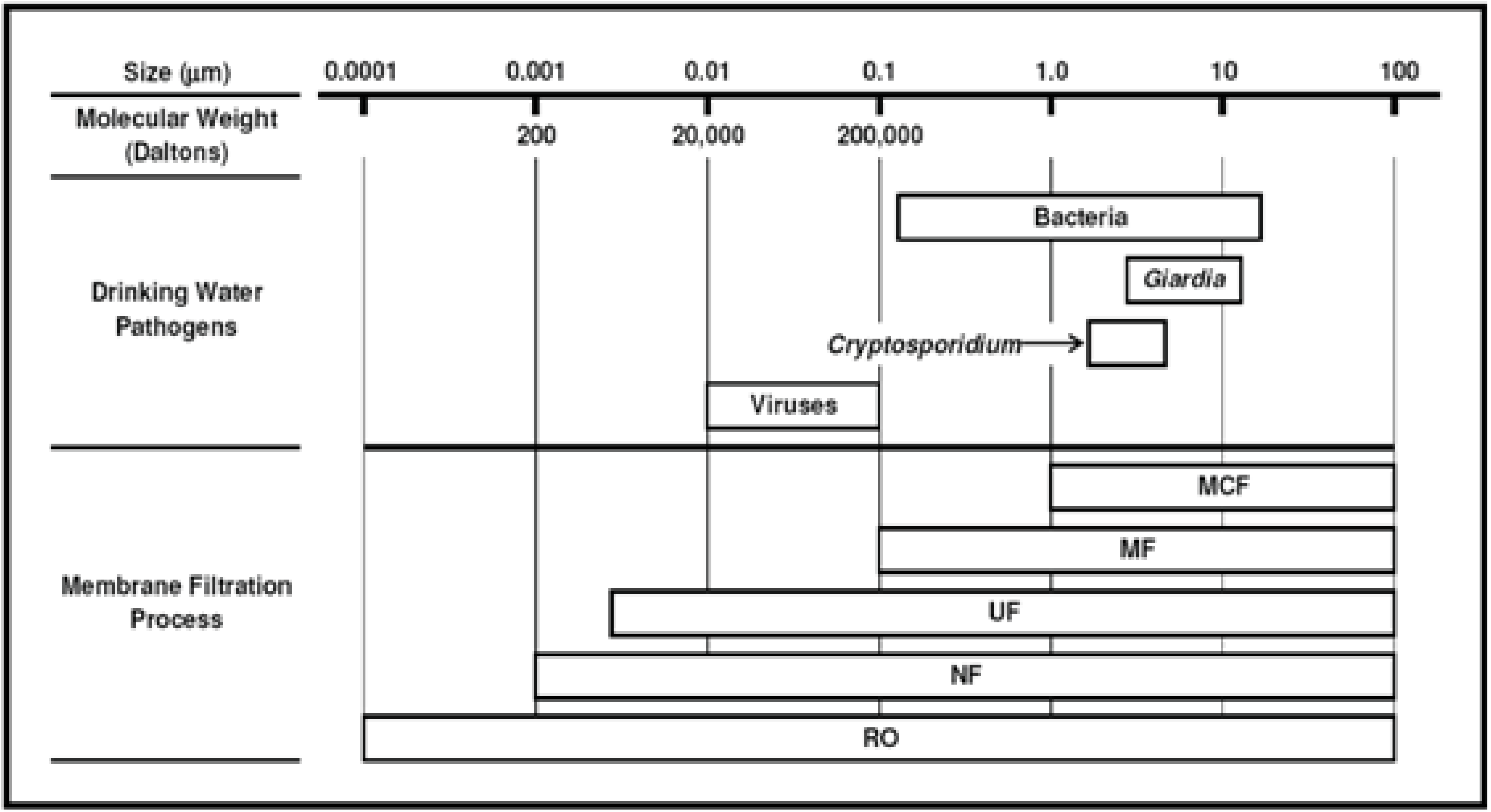
Microfiltration – Membrane filters capable of removing pathogenic organisms larger than 0.1 micrometers in size.

Ultrafiltration – Membrane filters capable of removing pathogenic organisms larger than 0.005 micrometers in size.

Nanofiltration – Membrane filters capable of removing pathogenic organisms and dissolved organic contaminants larger than 0.001 micrometers in size.

Reverse Osmosis – Membrane filters capable of removing pathogenic organisms, dissolved organic, and salts contaminants larger than 0.0001 micrometers in size.

The figure below, illustrates the ability of each type of membrane process to remove various drinking water pathogens and provides the filtration size range of each process.



Reverse Osmosis

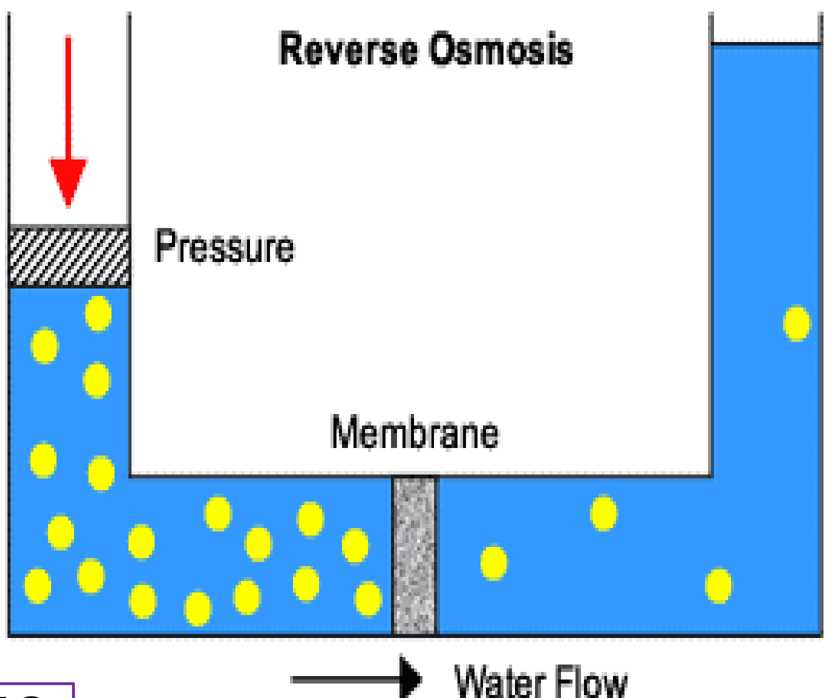
This unit used to remove TDS from water (90 % removal TDS).

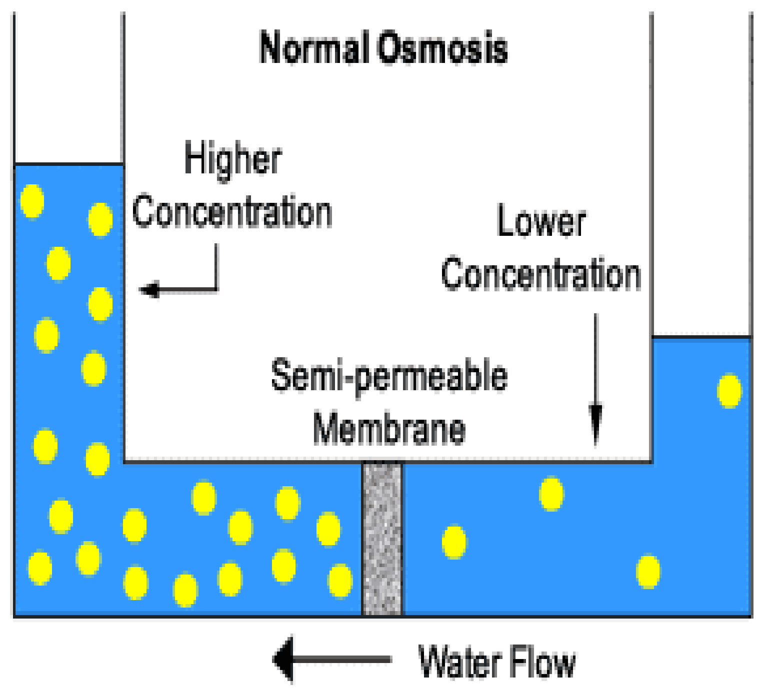
Osmosis

water flows from the side that has the lowest concentration to the side that has the highest concentration

Reverse Osmosis

Water flows from side that has the highest concentration to the side has the lowest concentration by applied pressure.





<u>Disinfection</u> :

Water is clear after the filtration step but is still contaminated by micro-organisms which must be killed by using disinfectant.

<u>Types of disinfection:</u>

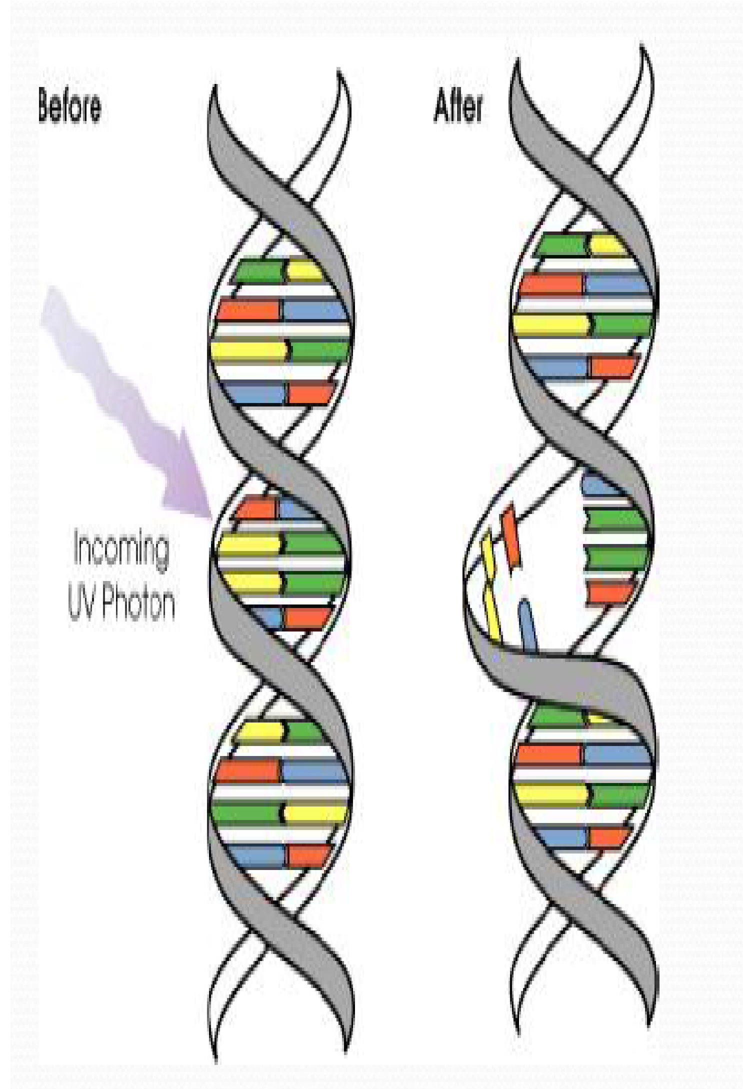
- Physical disinfection techniques include boiling and irradiation with ultraviolet light.
- Chemical disinfection techniques include adding chlorine, bromine, iodine, and ozone to water.

Physical disinfection (boiling):

- Boiling kills vegetative bacterial cells, but spores, viruses, and some protozoa may survive long periods of boiling.
- Boiling may also volatilize VOC’s.
- Boiling is an effective method for small batches of water during water emergencies.
- Boiling is prohibitively expensive for large quantities of water.

Physical disinfection (UV radiation):

- Ultraviolet radiation is an effective and relatively safe disinfection method, but is relatively expensive and not widely used.
- UV light disrupts DNA of microbial cells, preventing reproduction.
- Specific wavelengths, intensities, distances, flow rates, and retention times are required.



Chemical disinfection:

- Chemicals added to water for disinfection include chlorine, bromine, and iodine.
- Bromine is not recommended for drinking water disinfection, but may be used for pool water.
- Iodine is sometimes used for drinking water disinfection, but causes a bad aftertaste.

Chlorination:

Chlorination is employed primarily for microbial disinfection. However, chlorine also acts as an oxidant and can remove or assist in the removal of some chemicals –for example, oxidation of dissolved species (e.g., manganese(II)) to form insoluble products that can be removed by filtration; and oxidation of dissolved species to more easily removable forms (e.g., arsenite to arsenate).

Chlorine (and its compounds) is widely used because it is:
1- readily available as gas, liquid or powder.
2- cheap.
3- easy to apply (it is highly water soluble).
4- of harmless residual in solution which protects the distribution system.
5- Very toxic to most micro-organisms.

Disadvantages

1) It is a suffocating and irritant gas that requires careful handling.
2) It gives taste and odour problems.
* Chlorine can react with naturally occurring organic compounds found in the water supply to produce compounds known as disinfection byproducts (DBPs). The most common DBPs are trihalomethanes (THMs) which is carcinogenic.

Three types of chlorine residual :

- Free chlorine - which kills microorganisms most effectively.
- Combined chlorine - formed when free chlorine reacts with other chemicals in the water.
- Total chlorine - the sum of free and combined chlorine.

In the absence of ammonia (simple chlorination)

$Cl_2 + H_2O = HCl + HClO$ **(free residuals)**

-HClO, hypochlorous acid, is a more effective disinfectant.

In the presence of ammonia (chloramines treatment)

$Cl_2 + NH_3 \rightarrow NH_2Cl + HCl$ **monochloramine**

(Combined residuals)

$NH_2Cl + Cl_2 \rightarrow NHCl_2 + HCl$ **Dichloramine**

Ammonia may be present in water or added as solution NH_4OH or $(NH_4)_2SO_4$. Compared with free residuals, the combined residuals are more stable, give prolonged disinfection effect (useful in swimming pools) and cause less trouble with taste and odour. However, they have less effective disinfection.

<u>Dechlorination :</u> residual free chlorine can be reduced to harmless chlorides by activated carbon or chemical reducing agents(sulphur dioxide (SO_2) or sodium thiosulphate ($Na_2S_2O_3$))

$$C + 2Cl_2 + 2H_2O \rightarrow 4HCl + CO_2$$

$$\mathbf{SO_2 + Cl_2 + 2H_2O \rightarrow 2HCl + H_2SO_4}$$

Ozonation:

- Ozone (O_3) is an effective, relatively harmless disinfection method, but is expensive (and therefore less popular than chlorine).

- Ozone is a strong oxidant, that produces hydroxyl free radicals that react with organic and inorganic molecules in water to kill microbes.

Treatment for corrosion control

Corrosion is the partial dissolution of the materials constituting the treatment and supply systems, tanks, pipes, valves and pumps. Corrosion control is therefore an important aspect of the management of a drinking-water system for safety. Corrosion control involves many parameters, including the concentrations of calcium, bicarbonate, carbonate and dissolved oxygen, as well as pH. The detailed requirements differ depending on water quality and the materials used in the distribution system.

Examples

1. Iron

Iron is frequently used in water distribution systems, and its corrosion is of concern. water quality problems (e.g., “red water”) can arise as a result of excessive corrosion of iron pipes. The corrosion of iron is a complex process that involves the oxidation of the metal, normally by dissolved oxygen, ultimately to form a precipitate of iron(III).

Successful control of iron corrosion has been achieved by
•adjusting the pH to the range 6.8–7.3

•Silicates and polyphosphates are often described as “corrosion inhibitors,” they can complex dissolved iron (in the iron(II) state) and prevent its precipitation. These compounds may act by masking the effects of corrosion rather than by preventing it.

2. Lead

- Lead corrosion (plumbosolvency) is of particular concern. Lead piping is still common in old houses in some countries

- Plumbosolvency tends to be at a maximum in waters with a low pH and low alkalinity

- Treatment to reduce plumbosolvency usually involves pH adjustment. Increase pH to 8.0-8.5 after chlorination, and possibly to dose orthophosphate (act as corrosion inhibitor).

Iron, manganese, arsenic, carbon dioxide, and hydrogen sulfide are contaminants that commonly occur in groundwater and require some level of treatment for removal. Iron and manganese are found as naturally occurring **soluble** minerals in the soil.

Carbon dioxide and hydrogen sulfide are gases that can cause treatment problems or odor production respectively. Carbon dioxide gas tends to reduce pH. Hydrogen sulfide gas produces a strong rotten egg odor that can be detected at levels as low as 0.1 µg/L.

Arsenic is almost always a contaminant that is associated with groundwater. Arsenic can exist as either **arsenite** (As^{3+}) or **arsenate** (As^{5+}). Arsenite is difficult to remove using the adsorption process without first converting it to arsenate. Converting arsenite to arsenate can be accomplished through oxidation using chlorine or potassium permanganate. Once the arsenic is oxidized, it can then be removed by adsorption onto the surface of an iron floc or onto the surface of an iron oxide-coated filter media.

Iron & Manganese Removal from Groundwater

The two most common treatment methods are removal by oxidation/filtration and adsorbing onto ion exchange resins. Oxidation involves the introduction of an oxidizing agent which chemically reacts with the iron or manganese to form an insoluble particle which can then be physically filtered out.

Oxidation can be carried out one of the following methods:

- aeration - blowing/spraying air through the water
- addition of dissolved chemical oxidants - chlorine, chlorine dioxide and potassium permanganate ($KMnO_4$)

The use of ion exchange resins for the removal of iron and manganese has limited application due to the tendency of oxygen to react with the iron and manganese and therefore, increase the potential for plugging and buildup on the resin surface.

Softening

<u>*Objective:*</u> To remove hardness (Ca and Mg).

1. Lime Soda-Ash Method

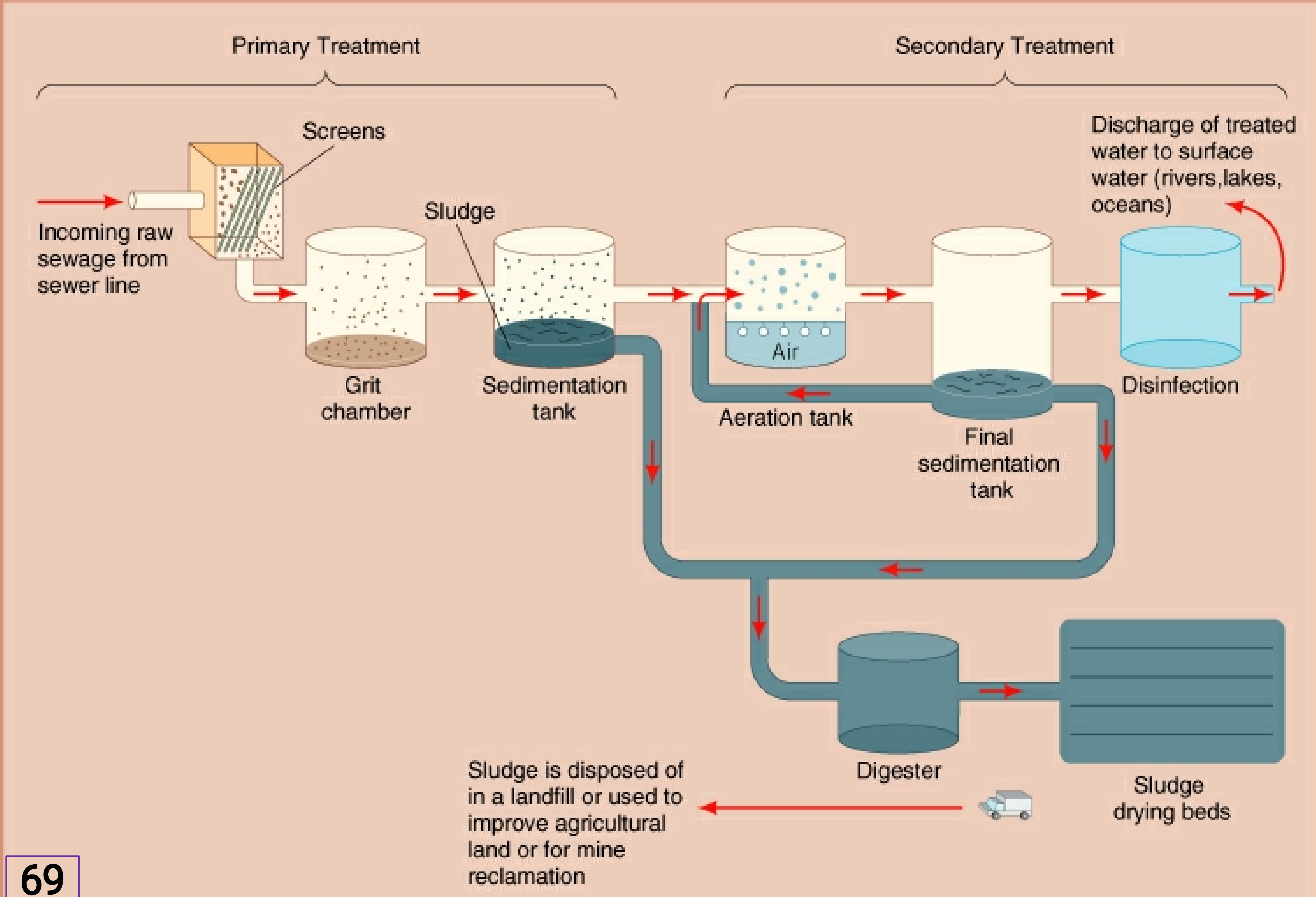
Most metals can be converted to insoluble compounds by chemical reactions between the agent and the dissolved metal ions.

$$Ca + CO_3 \longrightarrow CaCO_3$$

2. Ion Exchange

$$\underbrace{Ca^{2+}}_{\text{Ca hardness}} + \underbrace{Na_2R}_{\text{Resin}} \longrightarrow CaR + 2Na^+$$

Wastewater Treatment


Primary Treatment
Secondary Treatment
Screens
Incoming raw sewage from sewer line
Sludge
Grit chamber
Sedimentation tank
Air
Aeration tank
Final sedimentation tank
Disinfection
Discharge of treated water to surface water (rivers,lakes, oceans)
Digester
Sludge drying beds
Sludge is disposed of in a landfill or used to improve agricultural land or for mine reclamation

Wastewater Treatment

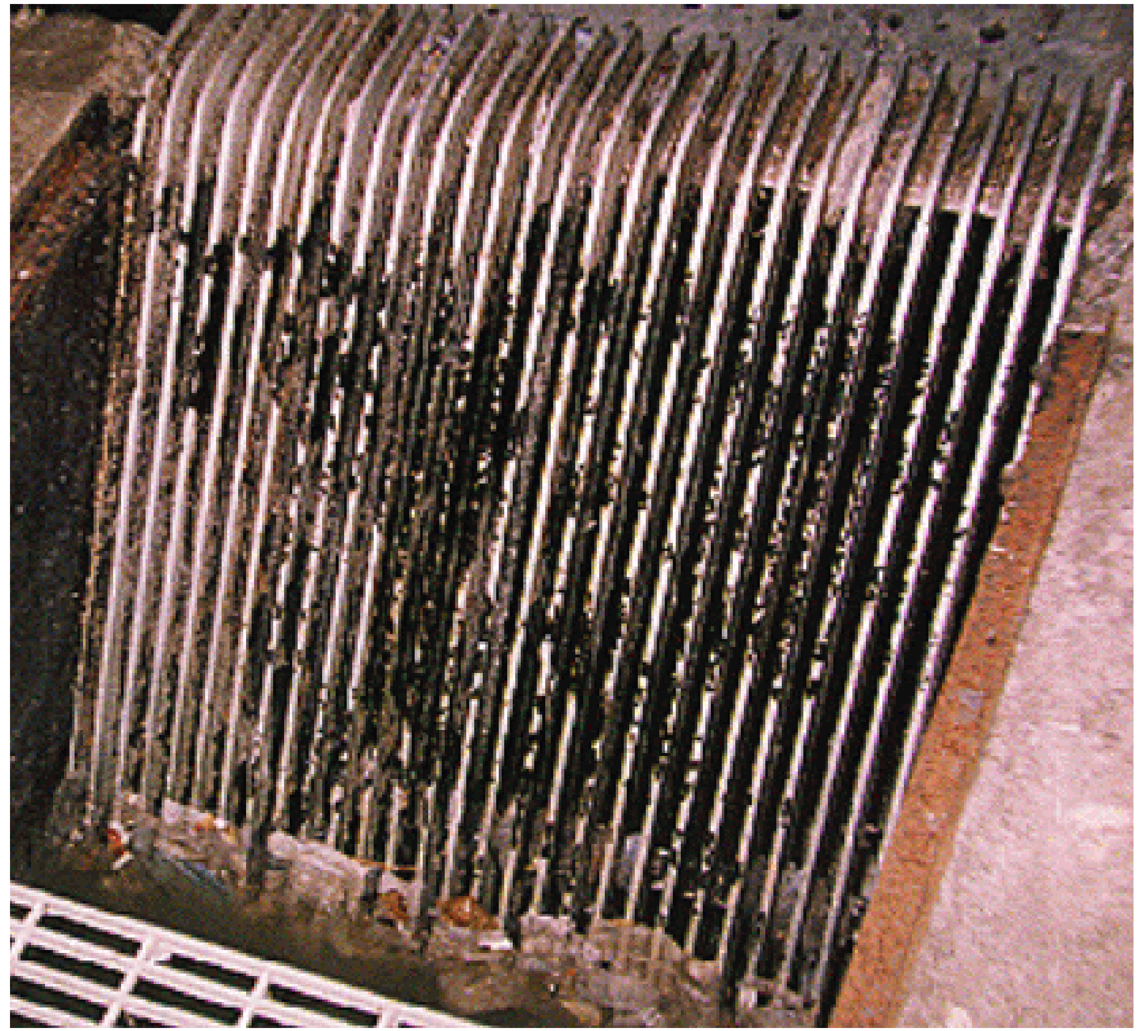
- Preliminary treatment
- Primary treatment
- Secondary treatment
- tertiary treatment

Types of treatment

- **Mechanical treatment**
  - Influx (Influent)
  - Removal of large objects
  - Removal of sand and grit
  - Primary Sedimentation
- **Biological treatment**
  - Trickling bed filter
  - Activated sludge
- **Chemical treatment**
  - Disinfection

Preliminary treatment

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



Grit chamber

removes rocks, gravel, broken glass, etc.

Grit chamber

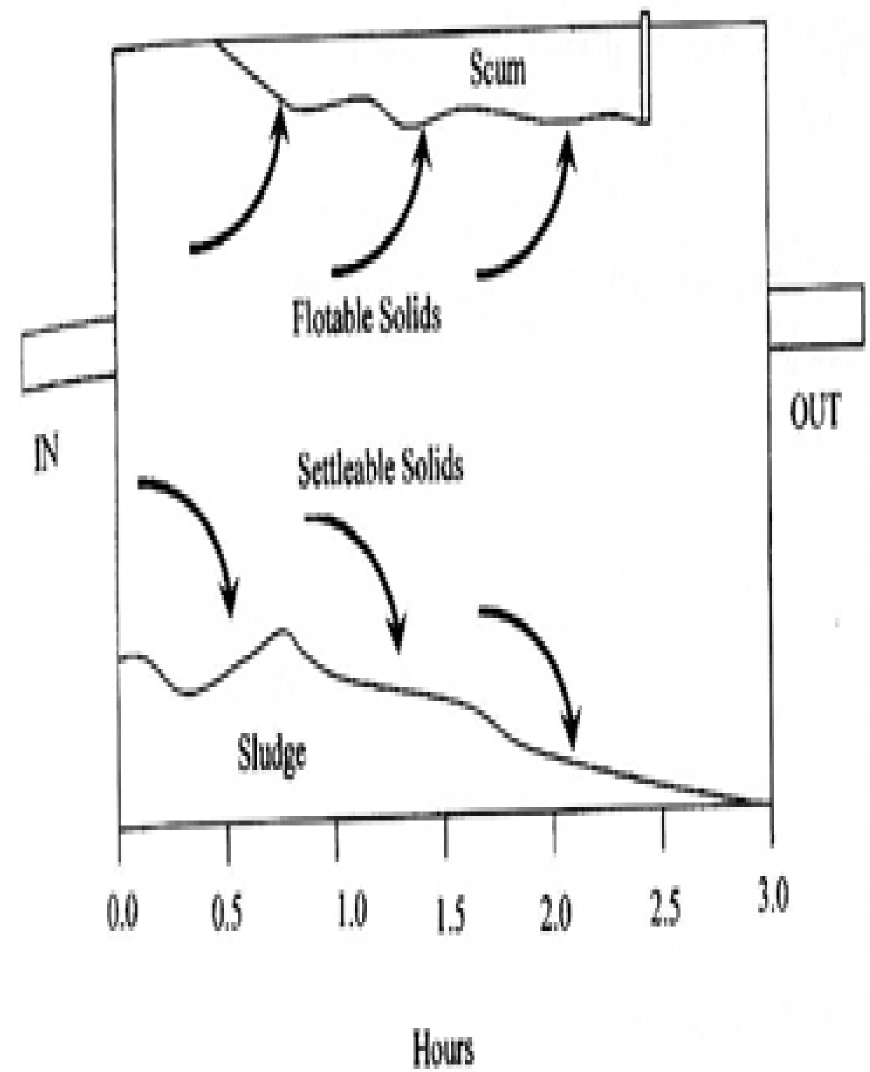
Primary treatment

- typical materials that are removed during primary treatment include
  - fats, oils, and greases
  - sand, gravels and rocks
  - larger settleable solids including human waste, and
  - floating materials

Primary treatment

- <u>Primary Sedimentation Tank</u>

settling tank (sedimentation tank or clarifier): a vessel in which solids settle out of water by gravity during wastewater or drinking water treatment processes.
Settled solids are removed as sludge, and floating solids are removed as scum. Wastewater leaves the sedimentation tank over an effluent weir to the next step of treatment. The efficiency or performance of the process is controlled by: detention time, temperature, tank design, and condition of the equipment.



Detention time is how much time the water spends in the sedimentation tank.

Detention time is inversely proportional to the incoming flow rate - as flow rate increases, the detention time decreases.

Mathematically, detention time is the volume of water in the tank divided by the flow rate through the tank.

$$\text{detention time} = \frac{\text{tank volume}}{\text{incoming water flow rate}}$$

Example

Calculate the detention time for a rectangular sedimentation tank with the following dimensions, length is 20m, width is 10m, depth is 4m, and the flow rate is 0.5m ^{3} per sec.

$$\text{detention time} = \frac{\text{tank volume}}{\text{incoming water flow rate}}$$

$$\text{detention time} = \frac{(20 \times 10 \times 4)}{0.5}$$

$$\text{detention time} = \frac{800}{0.5}$$

detention time = 1600 seconds

detention time = 26.7 minutes

Sewage sludge treatment

The sludges accumulated in a wastewater treatment process must be treated and disposed of in a safe and effective manner

3 different sludge treatments

- Aerobic digestion
- Anaerobic digestion
- composting

Aerobic digestion

- Bacterial process
- Need oxygen
- Consume organic matter
- Convert into carbon dioxide (CO_2)

Anaerobic digestion

- Bacterial process
- Do not require oxygen
- Consume organic matter
- Produce biogas (with the most useful component being as methane), which can be used in generators for electricity

Composting

Composting is also an aerobic process that involves mixing the sludge with sources of carbon such as sawdust, straw or wood chips. In the presence of oxygen, bacteria digest both the wastewater solids and the added carbon source and, in doing so, produce a large amount of heat

Sludge disposal

- Superheat sludge and convert into small granules that are rich in nitrogen
  - Sell it to local farmer as fertilizer
- Spread sludge cake on the field
- Save landfill space

Secondary treatment

- ❖ Secondary treatment is a biological process
- ❖ Utilizes bacteria and protozoa to metabolize organic matter in the wastewater
  - – Ex: human waste, food waste, soaps, detergent
- ❖ different approaches
  - – Fixed film system
  - – Suspended film system

Fixed Film Systems

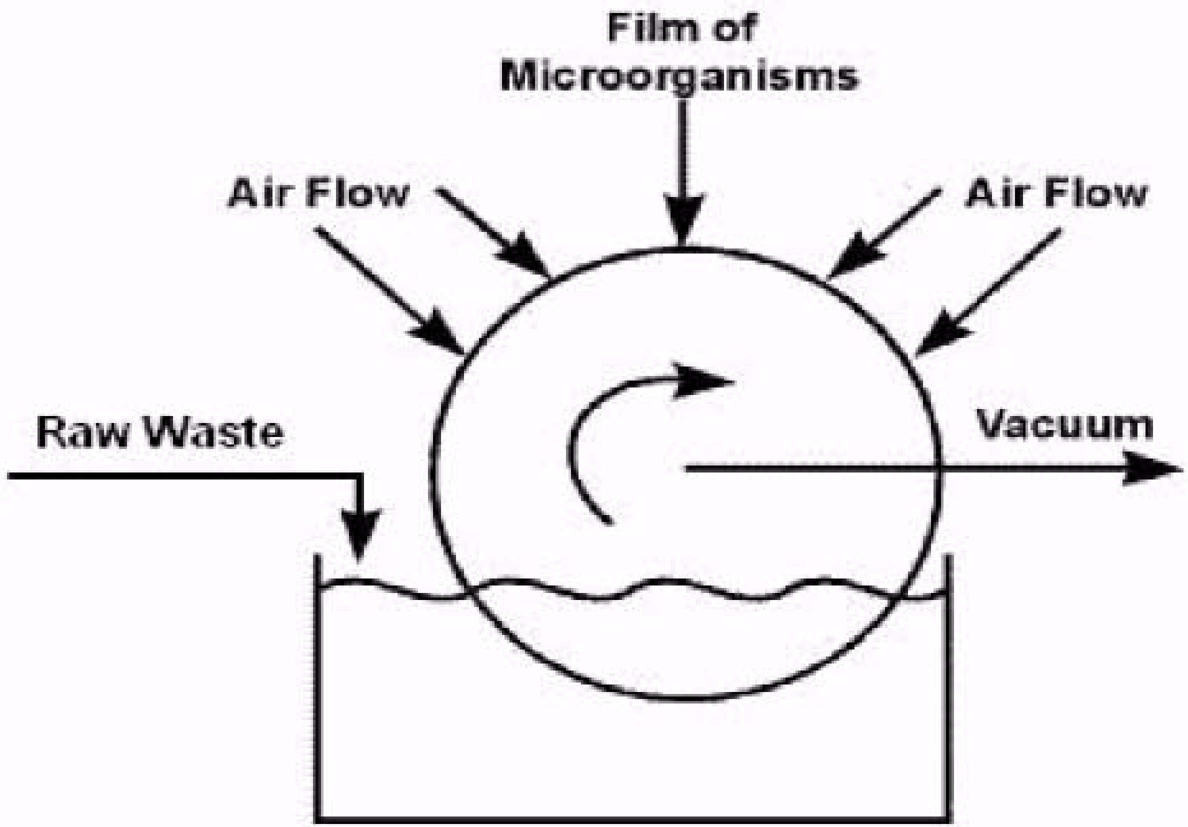
- grow microorganisms on substrates such as rocks, sand or plastic
- wastewater is spread over the substrate
- Ex: Trickling filters, rotating biological contactors

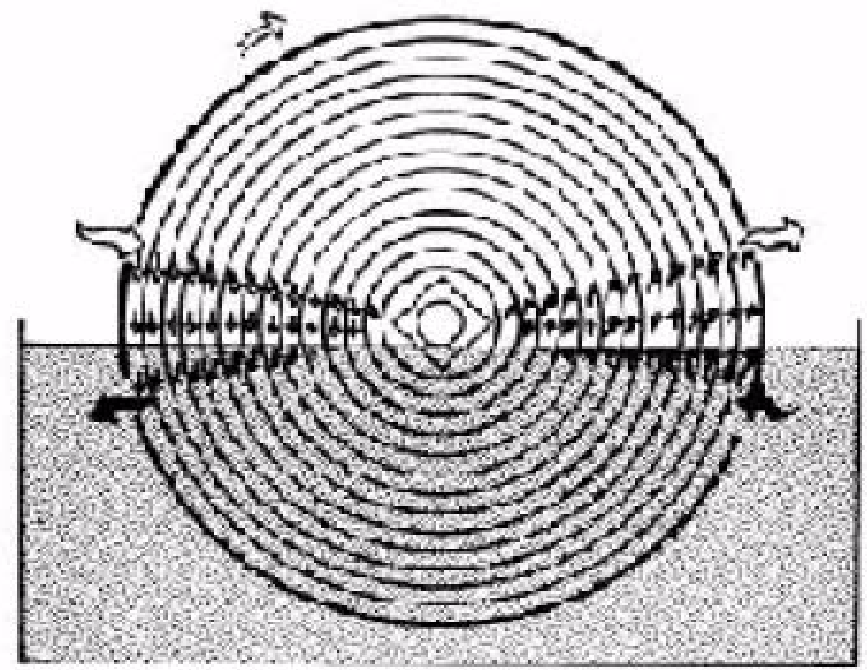
Trickling filters bed

- Spread wastewater over microorganism
- made of coke, limestone chips or specially fabricated plastic media

Rotating Biological Contactor (RBC)

- Consists of 2-4 m diameter disks
- Disks are covered with a biofilm.
- The disks are only partially submerged in wastewater.
- As the disk rotates the biofilm is exposed to the wastewater only part of the time.
- The shaft rotates about about 1-2 rpm (slowly).





Rotating biological contactor

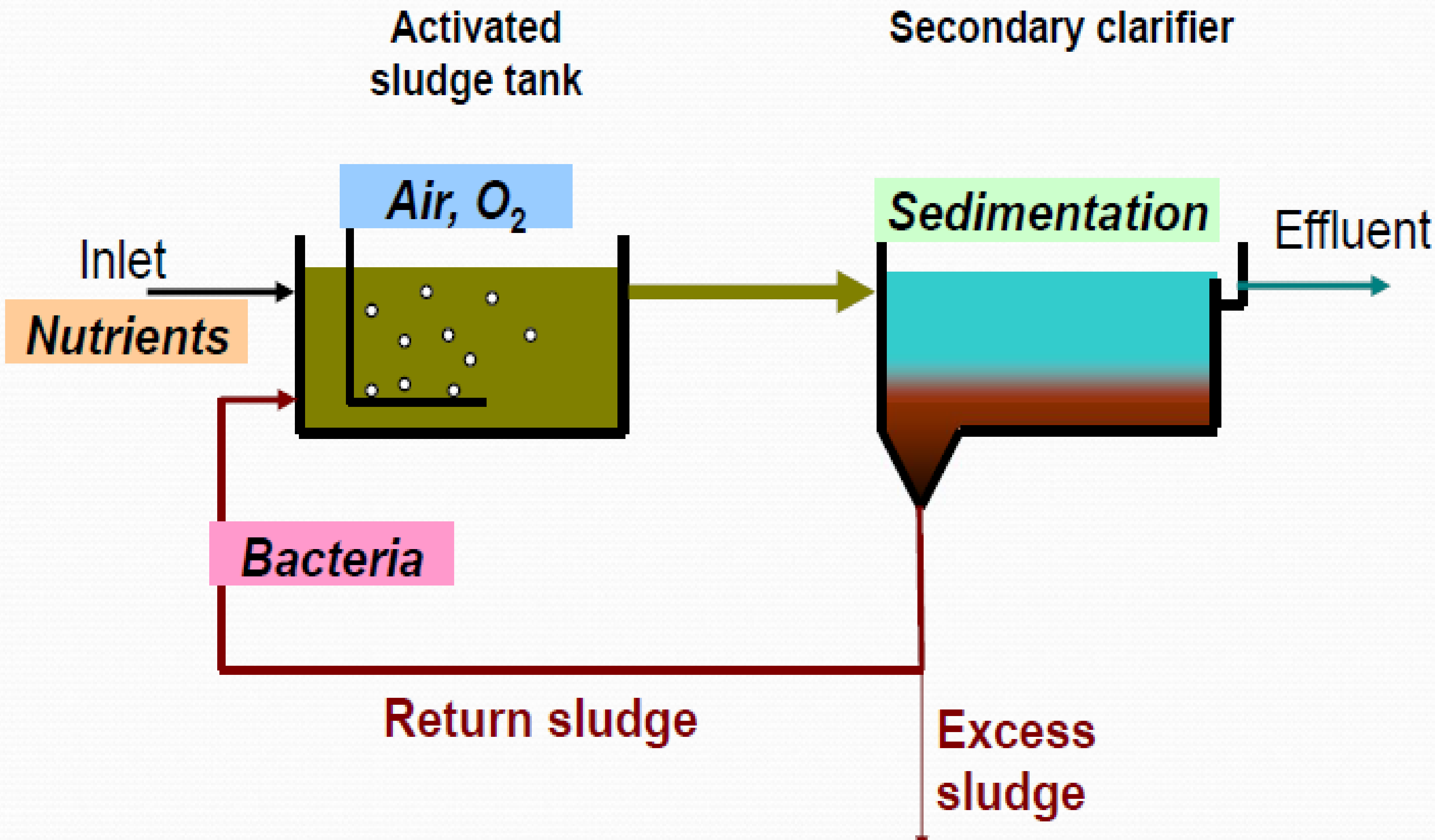
- Suspended Film Systems
  - stir and suspend microorganisms in wastewater
  - settled out as a sludge
  - pumped back into the incoming wastewater
  - Ex: Activated sludge process, Lagoon or ponds

Activated sludge

Activated sludge refers to a mass of microorganisms cultivated in the treatment process to break down organic matter into carbon dioxide, water, and other inorganic compounds.

Activated sludge process is a process for treating sewage and industrial waste water using air and a biological floc composed of bacteria and protozoans.

Activated sludge system



lagoons (oxidation ponds):

a wastewater treatment method that uses ponds to treat wastewater. Algae grow within the lagoons and utilize sunlight to produce oxygen, which is in turn used by microorganisms in the lagoon to break down organic material in the wastewater.

Tertiary or Advanced Waste Treatment

Provides contaminant removal beyond that achieved in primary (physical) or secondary (biological) treatment• It may include additional removal of organic matter or solids, reductions in the concentration of nutrients such as nitrogen and phosphorus or treatment of toxic substances Wastewater Treatment Plants

Nutrients Removal

Basic nutrients present in the domestic wastewater are

- Nitrogen (ammonia, nitrite, nitrate)
- Phosphorus
- Sulfate
- Other compounds of nitrogen & phosphorus

Problems associated with nutrients presence in wastewater are

- accelerate the eutrophication
- stimulate the growth of algae & rooted aquatic plants
- depleting D.O. concentration in receiving waters
- Toxicity towards aquatic life

Control and Removal of Nitrogen (Biologically):

- Removal of Nitrogen by Nitrification/Denitrification Processes:

$$NH_4^+ \xrightarrow{\text{aerobic}} NO_3^- \text{ (nitrification)}$$

$$NO_3^- \xrightarrow{\text{anoxic}} N_2 \text{ (denitrification)}$$

Nitrification is a two step aerobic process each step facilitated by a different type of bacteria

- $2\,NH_4^+ + 3\,O_2 \rightarrow 2\,NO_2^- + 2\,H_2O + 4\,H^+$ (Nitrosomonas)
- $2\,NO_2^- + O_2 \rightarrow 2\,NO_3^-$ (Nitrobacter, Nitrospira)

Phosphorus Removal

1. Chemical Precipitation

2. Enhanced Biological Uptake

Chemical Removal

$$M^{+3} + PO_4^{-3} \longrightarrow MPO_4 \downarrow$$

(M^{+3} = Metal in Solution)

PRECIPITATION

Metals used are Aluminum, Iron.
Ferric Chloride
Ferrous Chloride
Alum

2. Enhanced Biological Uptake

Phosphorus can be removed biologically in a process called enhanced biological phosphorus removal. In this process, specific bacteria, called polyphosphate-accumulating organisms (PAOs), are selectively enriched and accumulate large quantities of phosphorus within their cells (up to 20 percent of their mass). After separation from the treated water, these biosolids have a high fertilizer value.

Disinfection is different from sterilization

Sterilization

Is the complete destruction of all organisms found in water and which is usually expensive and unnecessary.

- Disinfection is the process of eliminating or reducing *harmful* microorganisms

Heavy metal

The term **heavy metal** refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations.

Industrial Wastewater

Heavy metals (as soluble ions) are common contaminants of industrial wastewaters. Because of their toxicity they are typically removed prior to wastewater discharge. The most common heavy metal contaminants are:

- Arsenic
- Barium
- Cadmium
- Chromium
- Copper
- Lead
- Mercury
- Nickel
- Selenium
- Silver
- Zinc

Precipitation of Heavy Metals

Heavy metals are typically precipitated from wastewater as:

- hydroxides
- sulfides or sometime sulfates
- carbonates

- Metal co-precipitation during flocculation with iron or aluminum salts is also possible for some metals (e.g., arsenic).

Precipitation of Heavy Metals as Hydroxides

• Precipitation by hydroxide formation is the most common heavy metal precipitation method. The precipitation typically follows the reaction:

$$M^{+n} + nOH^- \Leftrightarrow M(OH)_n$$

• The addition of caustic materials is used to raise the pH. The most common caustics are:

- sodium hydroxide ($NaOH$)
- calcium hydroxide ($Ca(OH)_2$; lime)

Precipitation of Heavy Metals as Sulfides

- Metal sulfides are typically very insoluble. Therefore metals can be precipitated by adding sulfide ions (S^{2-})

- Metal sulfides have much lower solubilities than the corresponding metal hydroxides, thus allowing lower residual metal concentrations in the treated wastewater.

- Hydrogen sulfide (H_2S) is a weak acid and dissociates in two steps according to:

$$H_2S \qquad H^+ + HS^-$$
$$HS^- \qquad H^+ + S^{-2}$$

- Sulfide precipitation is always conducted under alkaline conditions to promote sulfide ion formation.

- Evolution of H_2S is a potential hazard if the pH is not carefully maintained in the alkaline region.

Precipitation of Heavy Metals as Carbonates

- Some metals (lead, cadmium, nickel) form insoluble carbonates.

- Carbonate precipitation takes place only if carbonate ions (CO_3^{2-}) are present. Free carbonate ions are present only if the pH is high. A caustic is often added to raise the pH.

- High pH's also promote the precipitation of the metals as hydroxides. Hence, carbonate precipitation is often a co-precipitation.

Iron Co-Precipitation and Adsorption

- $2Fe^{+3} + 4H_2O \rightarrow Fe_2O_3 \bullet H_2O + 6H^+$

- $Fe_2O_3 \bullet H_2O$ has high binding capacity for heavy metals as well as for oxyanions of metals

- Depending on the pH, the oxide surface acts as an adsorbent for heavy metals and for oxyanions of metals

- Removes heavy metals (Cu^{2+}, Ni^{2+}, Zn^{2+}, Pb^{2+}, Cd^{2+}, etc) at pH > 7.5

- Removes Oxyanions of metals (As, Mo, Sb, V) at pH <7.5

Wastewater Pretreatment Prior to Metal Precipitation

- If the wastewater contains complexing agents that can keep the metals in solution and prevent them from precipitating, the complexing agent must be destroyed prior to metal precipitation.

- This is especially true for the case of cyanide salts because many heavy metals form strong complexes with cyanide.

- Oxidation is typically the most common method to destroy metal complexes.

- Oxidants such as chlorine, hypochlorite, and ozone are often used for this purpose.

- After the complexing agent is destroyed the metals are precipitated as usual.

Cyanide Removal Via Alkaline Chlorination

- **The first step is the conversion of cyanide (CN^-) to cyanate ion (OCN^-) in a two-reaction sequence at a pH above 10**

$$CN^- + H_2O + ClO^- \Leftrightarrow CNCl + 2OH^-$$

$$CNCl + ClO^- \Leftrightarrow OCN^- + Cl^- + H_2O$$

- **The second step is the oxidation of cyanate with hypochlorite at pH 8.5**

$$2OCN^- + 3ClO^- + H_2O \Leftrightarrow 2CO_2 + N_2 + 3Cl^- + 2OH^-$$

Arsenic in Industrial Wastewaters

Arsenic is present in the wastewaters of a number of industries producing:

- metallurgical products
- glassware and ceramic
- tannery products
- dye stuff
- pesticides
- synthetic chemicals
- petroleum refinery product

Precipitation of Arsenic from Industrial Wastewaters

Arsenic can be removed by precipitation as sulfide, through the addition of sodium sulfide or hydrogen sulfide to the wastewater. Arsenic can also be removed by coprecipitation when a $Fe(OH)_3$ floc is formed.

Barium in Industrial Wastewaters

Barium is present in the wastewaters of a number of industries producing:

- metallurgical products
- glassware and ceramic
- dye stuff
- explosives
- rubber products

- Barium can be removed by precipitation as sulfate, by adding any sulfate ion source

Cadmium in Industrial Wastewaters

Cadmium is present in the wastewaters of a number of industries producing:

- metallurgical products
- ceramics
- electroplated products
- photographic products
- pigments
- textiles
- synthetic chemicals

Precipitation of Cadmium from Industrial Wastewaters

- Cadmium can be removed by precipitation as hydroxide at pH ranging from 8 to 11
- Cadmium can be removed by precipitation as sulfide.
- Cadmium can also be removed by coprecipitation with $FeCl_3$ when a $Fe(OH)_3$ floc is formed.
- Cadmium can also be removed by precipitation as carbonate at pH between 7.5 and 8.5.

- *Cyanides interfere with any of these processes and must be removed prior to cadmium precipitation*

Chromium in Industrial Wastewaters

Chromium is present in the wastewaters of a number of industries producing:

- steel manufacturing
- chrome plated products
- tannery products
- dye stuff
- paints

Precipitation of Chromium from Industrial Wastewaters

Chromium is typically precipitated in two steps:

- hexavalent chromium (Cr^{+6}) is reduced to trivalent chromium (Cr^{+3}). Compounds such as $FeSO_4$, $Na_2S_2O_5$ (sodium bisulfite) or SO_2 (sulfur dioxide) are used as reducing agents. The reaction is conducted at low pH (< 3)

- trivalent chromium is precipitated as $Cr(OH)_3$. Lime is typically used for the precipitation reaction. The effluent concentration is 0.2 ppm at pH 7.5

Precipitation of Chromium from Industrial Wastewaters

The reactions involved in chromium precipitation are:

Reduction reaction (at pH < 3):

$$H_2Cr_2O_7 + 3SO_2 \rightarrow Cr_2(SO_4)_3 + H_2O$$

or

$$H_2Cr_2O_7 + 6FeSO_4 + H_2SO_4 \rightarrow$$
$$Cr_2(SO_4)_3 + 3Fe_2(SO_4)_3 + 7H_2O$$

Precipitation reaction (at pH of 8 to 9):

$$Cr_2(SO_4)_3 + 3Ca(OH)_2 \rightarrow 2Cr(OH)_3 \downarrow + 3CaSO_4$$

Copper in Industrial Wastewaters

Copper is present in the wastewaters of a number of industries producing:

- Chemicals using copper salts
- Chemicals using copper catalyst
- Metal processing products
- Metal plated products

Precipitation of Copper from Industrial Wastewaters

- Copper can be removed by precipitation as hydroxide at pH ranging from 9 to 10.3
- Copper can be removed by precipitation as sulfide at pH 8.5.
- The presence of cyanide or ammonia may interfere with copper precipitation. In such a case activated carbon can be used to remove copper cyanide

Lead in Industrial Wastewaters

Lead is present in the wastewaters of a number of industries producing:

batteries
pigments
printing products

Precipitation of Lead from Industrial Wastewaters

- Lead can be removed by precipitation as hydroxide (at pH 11.5.
- Lead can be removed by precipitation as sulfide at pH 7.5 to 8.5
- Lead can also be removed by precipitation as carbonate. The pH required in this case is between 7.5 and 8.5.

Mercury in Industrial Wastewaters

Mercury is present in the wastewaters of a number of industries producing:

- chlor-alkali
- explosive
- electronic products
- pesticides
- petrochemical products

Precipitation of Mercury from Industrial Wastewaters

Mercury can be removed by precipitation as sulfide, through the addition of sodium sulfide or hydrogen sulfide to the wastewater. Mercury can be removed by co-precipitation
with alum. Mercury can be removed by co-precipitation with $FeCl_3$ when a $Fe(OH)_3$ floc is formed.

Nickel in Industrial Wastewaters

Nickel is present in the wastewaters of a number of industries producing:

- Metal products (e.g., aircrafts)
- Steel
- Chemicals

Precipitation of Nickel from Industrial Wastewaters

- Nickel can be removed by precipitation as hydroxide at pH ranging from 10 to 11
- Nickel can be also be removed by precipitation as sulfate or carbonate
- The presence of cyanide may interfere with nickel precipitation