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Programme: M.Sc., Environmental Science

Course Title:Water, Soil Pollution and management
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Unit-III

Wastewater Treatment

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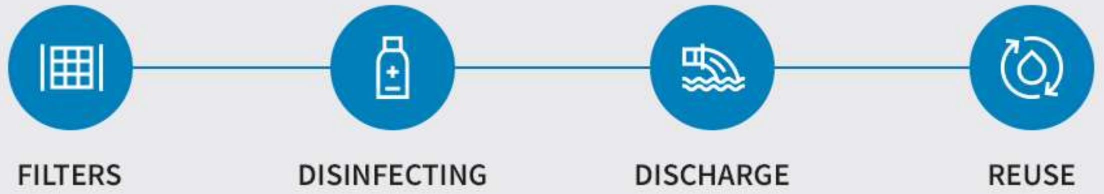
Tertiary treatment

- The purpose of tertiary treatment is to provide a final treatment stage to raise the effluent quality to the desired level.
- This advanced treatment can be accomplished by a variety of methods such as, filtration, reverse osmosis, and extending secondary biological treatment to further stabilize oxygen-demanding substances or remove nutrients.
- In various combinations, these processes can achieve any degree of pollution control desired.
- As wastewater is purified to higher and higher degrees by such advanced treatment processes, the treated effluent can then be reused for urban, landscape, and agricultural irrigation, industrial cooling and processing, recreational uses and water recharge, and even indirect and direct augmentation of drinking water supplies.

How Does Tertiary Wastewater Treatment Work?



Tertiary treatment

- Tertiary treatment involves a series of additional steps to further reduce organics, turbidity, N, P, metals and pathogens. This is for wastewater that may impact recreational areas, will be used for irrigation, or will be used for drinking water.

- Physicochemical process

  Coagulation

  Filtration

  Activated carbon adsorption of organics

  Disinfection

Coagulation

<u>Flocculation and Sedimentation</u>

- Synthetic organic polymers
- Alum (aluminum sulfate)
- Iron salts (ferric sulfate, ferric chloride)
- Slow mixing
- Reduces microorganisms (transfer to sludge)
  - Bacteria 90 %
  - Virus 60 %
  - Protozoa 90 %

Filtration

- Removal of flocculated matter
  - Organic matter
  - Microorganisms
  - Mineral colloids

Disinfection

- Most common is halogens: chlorine, chloramine, chlorine dioxide, bromine, or iodine
- Ozone is more expensive but does not leave toxic residuals
- Metals: copper and silver have been used for disinfection of swimming pool and hot tub water.
- Ultraviolet is also more expensive and does not leave toxic residuals.

Filtration

- Tertiary filtration components can contain a few different materials. Sand and activated carbon filters are common, and filters can also contain fine woven cloth. The filters also come in a few different types, including bag filters, drum filters and disc filters:
- Bag filters: Bag filters are ideal for wastewater treatment plants that need to reduce contaminants to a specific micron rating. They can be made of felt to serve as depth media or made from mesh to serve as surface media.

- Bag filters and housings come in various shapes and sizes, including single and multi-bag filters and plastic and metal housings, so they are useful across a range of treatment plants and equipment.
- Drum filters: A drum filter consists of a drum with a woven cloth filter around it. Gravity sends wastewater flowing into the filter via the central drum. Media mounted on the drum then separate the solid particles from the water, and the filtered water moves through the media and into the collection tank. Once the separation is complete, backwash cleans the media components to ensure their continual functioning.
- Disc filters: A disc filter consists of a central drum attached to multiple discs with cloth filters. Gravity pushes wastewater from the drum into the filters in an inside-out flow pattern. Then media mounted on each side of the discs separate solid particles from the liquid. Clean water flows into a collection tank, and backwash cleans the media once they become saturated with particles.
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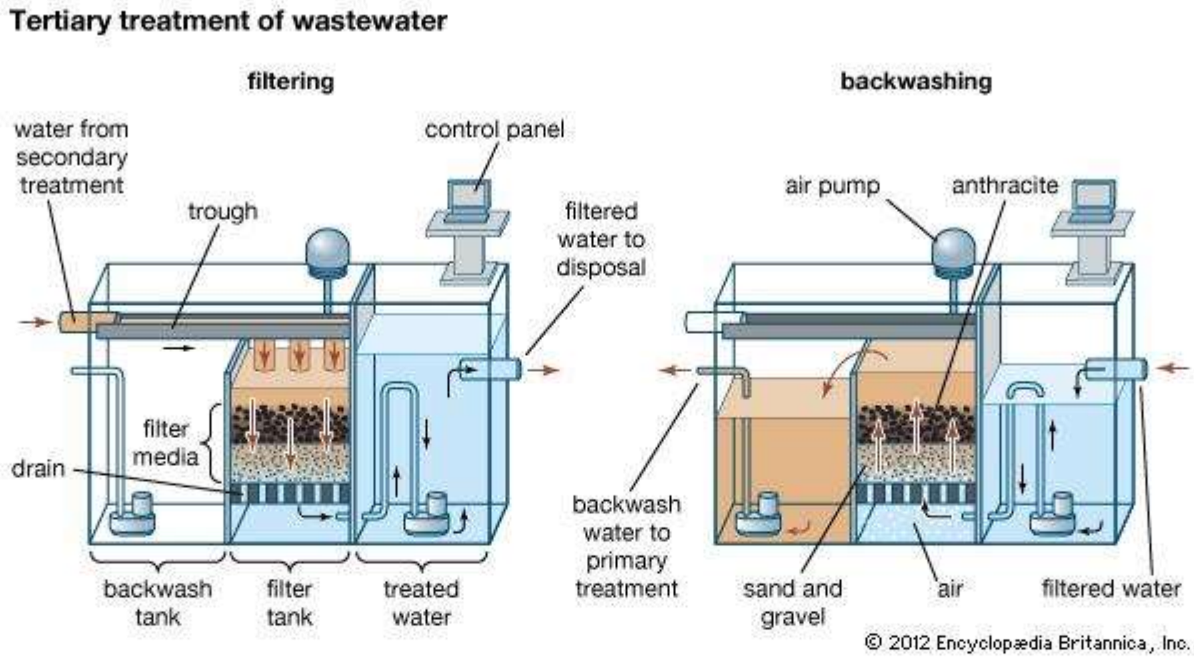
Sand Filtration

- A variety of filtration methods are available to ensure high quality water. Sand filtration, which consists of simply directing the flow of water through a sand bed, is used to remove residual suspended matter. Filtration over activated carbon results in the removal of the following types of contaminants: non-biodegradable organic compounds, adsorbable organic halogens, toxins, color compounds and dyestuffs, aromatic compounds including phenol and bis-phenol A (BPA), chlorinated/halogenated organic compounds, and pesticides.

- Although there are a number of different methods of membrane filtration, the most mature is pressure driven membrane filtration. This relies on a liquid being forced through a filter membrane with a high surface area. Membrane filtration is designed to remove bacteria, viruses, pathogens, metals, and suspended solids.



Tertiary treatment of wastewater
filtering
backwashing
water from secondary treatment
trough
control panel
filtered water to disposal
filter media
drain
backwash tank
filter tank
treated water
air pump
anthracite
backwash water to primary treatment
sand and gravel
air
filtered water
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Adsorption

- Adsorption is a wastewater purification technique for removing a wide range of compounds from industrial wastewater. Adsorption is most commonly implemented for the removal or low concentrations of non-degradable organic compounds from groundwater, drinking water preparation, process water or as tertiary cleansing after, for example, biological water purification.
- Adsorption takes place when molecules in a liquid bind themselves to the surface of a solid substance. Adsorbents have a very high internal surface area that permits adsorption.
- Active carbon is by far the most commonly used adsorbent and is particularly suited to the removal of apolar compounds.
- Other adsorbents are used for specific applications:

- Natural or synthetic zeolites (alumina-silicate-polymers)
  - Have a very homogenous pore distribution and polar bonding sites. Zeolites are a lot more selective than active carbon;
- Natural clay minerals
  - used for the adsorption of very polar organic and inorganic matter (ions);
- Silica gel and activated aluminium
  - Very polar adsorbents with large affinity for water – normally used to remove water from an apolar medium;
- Activated carbon can be made from wood, charcoal and coconut. Each type is characterised by a specific surface, grain size and pore diameter. Active carbon can be used in powder form, granular form or in impregnated form.
- In powder form, activated carbon is added to aerobic and anaerobic wastewater purification systems.

Ion exchange

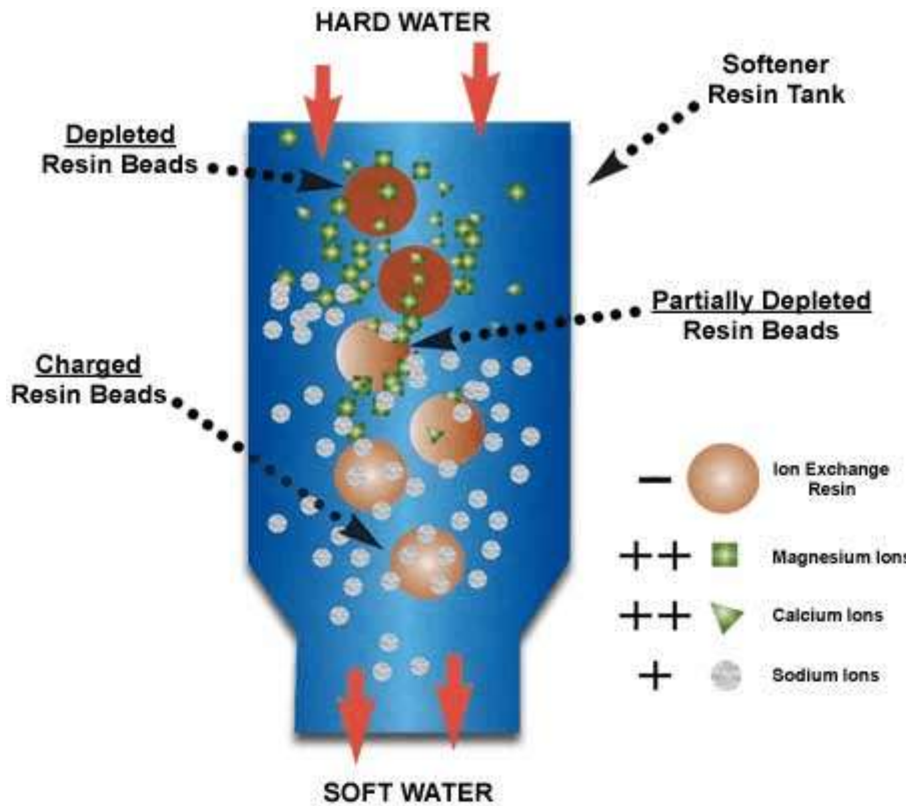
- Ion exchange is a common method used for wastewater treatment, particularly for removing dissolved ions from water. This process involves the exchange of ions between a solid (usually a resin) and a liquid (the wastewater). The resin consists of positively or negatively charged sites that attract ions of the opposite charge from the wastewater, effectively removing them from the water.
- Here's a basic explanation of the ion exchange process along with a simplified diagram:
- **Ion Exchange Resin**: The resin used in ion exchange is typically made of tiny beads or granules. These beads are usually made of a synthetic polymer material with functional groups that can attract and exchange ions.
- **Wastewater Inlet**: The wastewater containing dissolved ions enters the ion exchange system through an inlet.

- **Ion Exchange Columns**: The resin is packed into columns through which the wastewater flows. The columns are designed to provide maximum contact between the resin and the wastewater to facilitate ion exchange.
- **Ion Exchange Process**: As the wastewater flows through the columns, the resin attracts and captures ions of the opposite charge. For instance, if the resin has negatively charged sites, it will attract and capture positively charged ions (cations) from the wastewater, and vice versa. The captured ions replace ions of the opposite charge that were previously bound to the resin.
- **Clean Water Outlet**: The treated water, now depleted of the targeted ions, exits the ion exchange columns through an outlet. This water is now purified to a certain extent depending on the efficiency of the ion exchange process.
- **Regeneration**: Over time, the resin becomes saturated with captured ions and loses its effectiveness. To regenerate the resin and restore its ion exchange capacity, a regenerating solution is passed through the columns. This solution contains a high concentration of ions that are more strongly attracted to the resin than the ions captured from the wastewater. The captured ions are then displaced by the ions in the regenerating solution, and the resin is ready for another cycle of ion exchange.
- **Waste Regenerate Stream**: The waste regenerate stream, containing the displaced ions from the resin along with the regenerating solution, is collected separately for appropriate treatment or disposal.

example

- Let's consider an example of ion exchange in wastewater treatment focusing on the removal of heavy metal ions such as lead (Pb2+) and cadmium (Cd2+) from industrial wastewater.
- **Ion Exchange Resin Selection**: In this case, a resin with negatively charged functional groups is chosen because heavy metal ions typically carry a positive charge.
- **Wastewater Inlet**: Industrial wastewater containing heavy metal ions enters the ion exchange system through an inlet.
- **Ion Exchange Columns**: The resin, packed into columns, allows the wastewater to flow through. As the wastewater passes through the columns, the resin attracts and captures the positively charged heavy metal ions (Pb2+ and Cd2+).
- **Ion Exchange Process**: The resin exchanges its bound ions (usually sodium or hydrogen ions) for the heavy metal ions present in the wastewater.
- **Clean Water Outlet**: The treated water, now depleted of heavy metal ions, exits the ion exchange columns through an outlet. The water is now purified to a certain extent, suitable for discharge or further treatment.
- **Regeneration**: As the resin becomes saturated with heavy metal ions, it needs to be regenerated. A regenerating solution containing a high concentration of sodium or hydrogen ions is passed through the columns. These ions displace the heavy metal ions from the resin, releasing them into the regenerating solution. The resin is then ready for another cycle of ion exchange.
- **Waste Regenerate Stream**: The waste regenerate stream contains the displaced heavy metal ions along with the regenerating solution. This stream is collected separately for appropriate treatment or disposal, often requiring additional treatment steps to precipitate or otherwise immobilize the heavy metal ions for safe disposal.

Ion exchange resin



Ion exchange

- **Chitosan**: Chitosan is a derivative of chitin, which is a natural polymer found in the shells of crustaceans like shrimp and crab. Chitosan is known for its ability to bind with heavy metal ions and other contaminants in water through ion exchange and other mechanisms. Its amino groups can act as functional sites for ion exchange. Chitosan-based materials have been explored for various water treatment applications, including the removal of heavy metals, dyes, and organic pollutants.
- **Chitin**: Chitin itself may not be as commonly used for ion exchange as chitosan due to its lower solubility in water. However, chitin can still participate in ion exchange processes to some extent, especially when modified or combined with other materials. Chitin-based materials have been investigated for their potential in removing heavy metals and other contaminants from water, although they may require additional modifications to enhance their ion exchange properties.
- In summary, both chitosan and chitin have the potential to participate in ion exchange processes, particularly for the removal of heavy metals and other contaminants from water. Chitosan, in particular, is more widely studied and utilized in various water treatment applications due to its better solubility and functional groups conducive to ion exchange.

- Zeolites are crystalline aluminosilicates with a porous structure that allows them to selectively adsorb and exchange ions with surrounding solutions. Here's how zeolites function as ion exchangers:
- Structure: Zeolites have a unique crystalline structure with regularly spaced pores and channels. These pores and channels provide a large surface area and create an intricate network of voids capable of trapping and exchanging ions.
- Ion Exchange Capacity: The framework of zeolites contains cations (positively charged ions), such as sodium, potassium, or calcium ions, which can be exchanged with other ions in solution. This exchange capacity arises from the presence of exchangeable cations located within the pores of the zeolite structure.
- Selective Adsorption: Zeolites exhibit selective adsorption based on the size, charge, and affinity of ions. Different types of zeolites may have specific preferences for certain ions, allowing for targeted removal of contaminants from solution. This selectivity is advantageous in water treatment, where specific ions, such as heavy metals or ammonium, need to be removed.
- Regeneration: Zeolites can be regenerated by exchanging the adsorbed ions with a solution containing a higher concentration of desired ions. This process is commonly referred to as regeneration or recharging and allows for the reuse of zeolites over multiple cycles.
- Applications: Zeolites are utilized in various water treatment processes, including softening, desalination, heavy metal removal, and ammonium removal from wastewater. They are also used in soil remediation to remove contaminants and improve soil quality. Additionally, zeolites find applications in catalysis, gas separation, and purification processes in the chemical industry.

Nitrogen Removal

- Nitrogen removal from wastewater is a crucial aspect of wastewater treatment, as excess nitrogen compounds can cause eutrophication of water bodies, leading to harmful algal blooms and oxygen depletion. There are several methods employed for nitrogen removal, each suited to different wastewater characteristics and treatment goals. Here are some common methods:
- Biological Nitrogen Removal:
- Nitrification: This process involves the conversion of ammonia (NH_3) to nitrite (NO_2^-) and then to nitrate (NO_3^-) by autotrophic bacteria under aerobic conditions. This step is typically achieved in an aerated biological reactor.
- Denitrification: Denitrification is the biological process where nitrate (NO_3^-) is converted to nitrogen gas (N_2) under anaerobic conditions by heterotrophic bacteria. This step usually occurs in an anaerobic reactor or anoxic zone within the treatment system.
- *Thiobacillus denitrificans, Micrococcus denitrificans,* and some species of *Serratia, Pseudomonas,* and *Achromobacter* are implicated as denitrifiers. *Pseudomonas aeruginosa* can, under anaerobic conditions (as in swampy or water-logged soils), reduce the amount of fixed nitrogen (as fertilizer) by up to 50 percent.

Physical-Chemical Methods

- Ammonia Stripping: Ammonia stripping involves exposing wastewater to air, which allows the ammonia (NH3) to volatilize into the atmosphere. This method is effective for removing ammonia but requires additional treatment to capture and treat the ammonia-rich air.
- Ion Exchange: Ion exchange resins can be used to remove ammonium ions (NH4+) from wastewater by exchanging them with other ions, such as sodium or hydrogen, present on the resin.
- Membrane Processes: Membrane bioreactors (MBRs) or reverse osmosis (RO) systems can be used to concentrate and remove nitrogen compounds from wastewater by retaining them within the membrane system.

- Chemical Methods: Chemical Precipitation: Chemicals such as lime (calcium hydroxide) or ferric chloride can be added to wastewater to precipitate ammonium ions (NH4+) as solid compounds, which can then be separated from the liquid phase.
- Biological Aerated Filters (BAFs): BAFs utilize a combination of biological and physical processes to remove nitrogen. Wastewater passes through a filter media where attached bacteria facilitate nitrification and denitrification processes.
- Constructed Wetlands: Constructed Wetlands: Natural or engineered wetlands can be used for nitrogen removal through a combination of biological, physical, and chemical processes, including plant uptake, microbial activity, and sedimentation.

Phosphorus removal

- Phosphorus removal from wastewater is crucial because excessive phosphorus discharge can lead to eutrophication, algal blooms, and oxygen depletion in aquatic ecosystems. Various methods are employed for phosphorus removal, depending on the characteristics of the wastewater and treatment objectives. Here are some common methods:
- **Chemical Precipitation**:
  - **Coagulation and Flocculation**: Chemicals such as aluminum or iron salts (e.g., alum or ferric chloride) are added to the wastewater to form insoluble precipitates with phosphorus compounds. Coagulants destabilize phosphorus particles, while flocculants aid in their aggregation, forming larger particles that settle out of the water.
  - **Lime Precipitation**: Lime (calcium hydroxide) can be used to raise the pH of wastewater, leading to the precipitation of insoluble calcium phosphate compounds. This process is particularly effective for removing orthophosphate, the most bioavailable form of phosphorus.

Biological Removal:

- Enhanced Biological Phosphorus Removal (EBPR): This process relies on specialized microorganisms called polyphosphate-accumulating organisms (PAOs) to take up and store phosphorus under anaerobic conditions. Phosphorus is then released and removed during subsequent aerobic conditions in a bioreactor. EBPR is commonly employed in activated sludge treatment systems.
- Phytoremediation: Certain aquatic plants, such as water hyacinth and duckweed, can absorb phosphorus from wastewater through their roots. Constructed wetlands or floating treatment wetlands can be used to facilitate this process.
- Numerous studies have identified *Bacillus spp., Pseudocystis spp. and Burkholderia* spp. in different types of soils (tea gardens, saline soil, soils with heavy metals, forest soil) and in crop rhizosphere soils, where they have a high relative abundance in the bacterial community as well as a strong phosphorus-solubilizing capacity .

- Adsorption:Adsorption onto Media: Adsorbent materials like activated carbon, zeolites, and iron-based materials can be used to adsorb phosphorus from wastewater. These materials have high surface areas and affinity for phosphorus ions, effectively removing them from the water.
- Biochar: Biochar, a form of charcoal produced from organic matter, has been studied for its ability to adsorb phosphorus from wastewater due to its porous structure and high surface area.
- Ion Exchange:Ion exchange resins can also be used for phosphorus removal by exchanging phosphate ions in the wastewater with other ions immobilized on the resin.
- Membrane Processes:Membrane filtration techniques, such as nanofiltration or reverse osmosis, can remove phosphorus compounds by retaining them within the membrane system.
- Chemical Oxidation/Reduction:
- Advanced oxidation processes (AOPs), such as ozonation or UV/H2O2 treatment, can oxidize phosphorus compounds to less soluble forms or convert them into compounds that are easier to remove through precipitation or filtration.

Membrane Process

- Membranes have been used in water and wastewater applications since the 1960's. However, initially membrane processes were felt to be too expensive for this field, and were only applied in niche applications or special circumstances.
- The rapid uptake of membranes since 2000 has led to a dramatic fall in costs, to the extent that membranes now often compete with conventional processes, while achieving much better quality standards.
- There are two classes of membrane process used in the water and wastewater field. The first category includes reverse osmosis (RO) and nanofiltration (NF). These membranes have a dense non porous separating layer cast onto a porous support, and are used for the removal of dissolved substances.

Nano filtration

- Nanofiltration is a membrane filtration-based method that uses membrane. Nanofiltration membranes have pore sizes from 1-10 nanometers, smaller than that used in microfiltration and ultrafiltration, but just larger than that in reverse osmosis.
- Membranes used are predominantly created from polymer thin films. Materials that are commonly used include polyethylene terephthalate. Pore dimensions are controlled by pH, temperature and time during development.
- Membranes made from polyethylene terephthalate and other similar materials.

Micro filtration

- Microfiltration usually serves as a pre-treatment for other separation processes such as ultrafiltration, and a post-treatment for granular media filtration. The typical particle size used for microfiltration ranges from about 0.05 to 10 μm under a operating pressure of <2 bar. In terms of approximate molecular weight these membranes can separate macromolecules of molecular weights generally >400 kDa.
- The filters used in the microfiltration process are specially designed to prevent particles such as, sediment, algae, protozoa or large bacteria from passing through a specially designed filter.
- More microscopic, atomic or ionic materials such as water (H2O), monovalent species such as Sodium (Na^+) or Chloride (Cl^-) ions, dissolved or natural organic matter, and small colloids and viruses will still be able to pass through the filter.

- MF processing is widely used in the food industry for applications such as wine, juice and beer clarification, for wastewater treatment, and plasma separation from blood for therapeutic and commercial uses.
- In biotechnology industries, MF concerns applications such as cell recycle and harvesting, separation of recombinant proteins from cell debris, and purification of process streams.

Ultra filtration

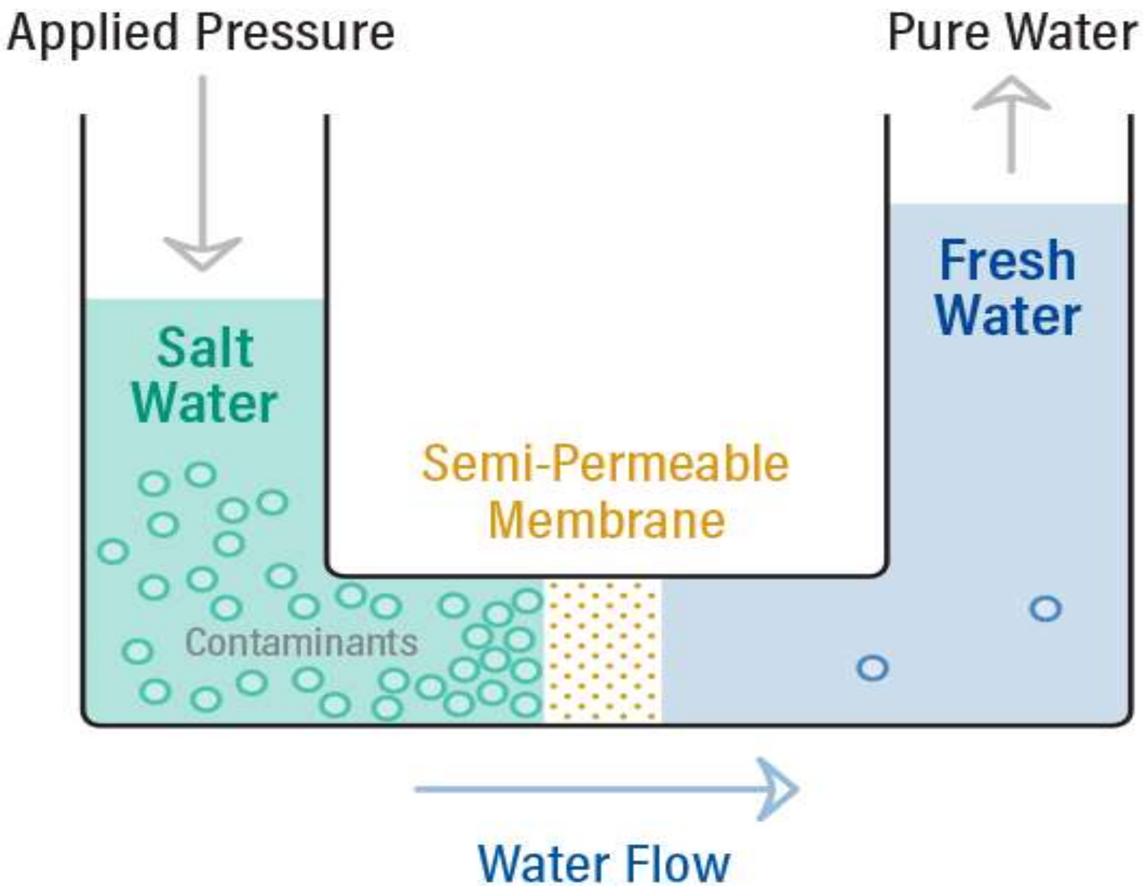
- Ultrafiltration can be used for the removal of particulates and macromolecules from raw water to produce potable water. It has been used to either replace existing secondary (coagulation, flocculation, sedimentation) and tertiary filtration (sand filtration and chlorination) systems employed in water treatment plants or as standalone systems in isolated regions with growing populations.
- When treating water with high suspended solids, UF is often integrated into the process, utilising primary (screening, flotation, filtration) and some secondary treatments as pre-treatment stages.

- UF processes are currently preferred over traditional treatment methods for the following reasons:
- No chemicals required (aside from cleaning)
- Constant product quality regardless of feed quality
- Compact plant size
- Capable of exceeding regulatory standards of water quality, achieving 90–100% pathogen removal

Reverse osmosis

- In the reverse osmosis process, pressure is used to force effluent through a membrane that retains contaminants on one side and allows the clean water to pass to the other side.
- Reverse osmosis is actually a type of membrane filtration called microfiltration because it is capable of removing much smaller particles including dissolved solids such as salt.
- Reverse osmosis can remove many types of dissolved and suspended species from water, including bacteria, and is used in both industrial processes and the production of potable water. The result is that the solute is retained on the pressurized side of the membrane and the pure solvent is allowed to pass to the other side.
- To be "selective", this membrane should not allow large molecules or ions through the pores (holes), but should allow smaller components of the solution (such as solvent molecules) to pass freely.
- This process is also effective at removing biological contaminants, metals, pharmaceuticals, pesticides, and endocrine disruptors.

Reverse Osmosis



- **If there are any disadvantages to reverse osmosis, they would have to include:**
- RO units use a lot of water. They recover only 5 to 15 percent of the water entering the system. The remainder is discharged as waste water. However, since the water is used for drinking and cooking only, the amount of wastewater can be small compared to other sources.
- Some systems have built-in monitors, but many do not. Therefore, leaks through the semipermeable membrane (or other problems) may go undetected.

Disinfection

- For all levels of wastewater treatment, the last step prior to discharge of the sewage effluent into a body of surface water is disinfection, which destroys any remaining pathogens in the effluent and protects public health.
- Disinfection is usually accomplished by mixing the effluent with chlorine gas or with liquid solutions of hypochlorite chemicals in a contact tank for at least 15 minutes.
- Because chlorine residuals in the effluent may have adverse effects on aquatic life, an additional chemical may be added to dechlorinate the effluent.
- UV radiation. which can disinfect without leaving any residual in the effluent, is becoming more competitive with chlorine as a wastewater disinfectant. Specific wavelengths have biocidal properties (~254 nm), for which Quartz, mercury-vapor lamps are used. Cleaning is required but it leaves no residues.
- Even **Ozone O3** is used to disinfect water . O_3 a gas, must be generated on-site and it is Bubbled into a basin *(or pipeline)* with treated effluent. No residual…ozone degrades to oxygen, O_2.

- Among other applications, hydrogen peroxide is used as a disinfectant. It is used to treat inflammation of the gums and to disinfect (drinking) water. It is also used to combat excessive microbial growth in water systems and cooling towers.
- In the United States, hydrogen peroxide is used more and more frequently to treat individual water supplies. It is used to prevent the formation of colors, tastes, corrosion and scaling by pollution degradation (iron, manganese, sulphates) and micro-organism degradation. Hydrogen peroxide reacts very fast. It will than disintegrate into hydrogen and water, without the formation of byproducts. This increases the amount of oxygen in water.
- The disinfection mechanism of hydrogen peroxide is based on the release of free oxygen radicals:
- $H2O2 \rightarrow H2O + O2$

The other product left after wastewater treatment is sludge

- Sludge is generated during primary and secondary treatment. Processing of sludge has three major goals:
  - Reduce water content
  - Reduce odors
  - Reduce pathogens
- Sludge treatment is the most costly operation of wastewater treatment
  - 7 million tons/day (USA)
- Primary sludge
  - 3 to 8% solids
- Secondary- 0.5 to 2% solids

Sludge Treatment Processes

Thickening (water removal)

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Digestion (pathogen inactivation and odor control)

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Conditioning (improved dewatering with alum and high temp, 175-230^{o} C)

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Dewatering (pathogen inactivation and odor control)

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Incineration (volume and weight reduction)

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Final disposal

Sludge stabilization

- Once the sludge is thickened, two options are available for further treatment of the concentrated sludge.
- It can be dewatered to a solid content of between 30-40% or it can undergo stabilization processes to reduce the organic materials in the sludge before going to the dewatering step.
- Coarse primary solids and secondary sludge (sometimes called biosolids) accumulated in a wastewater treatment process must be treated before disposal to ensure environmentally responsible and lawful outcome.
- Sludge is often inadvertently contaminated with toxic organic and inorganic compounds and is nutrient-rich.'
- Stabilization of sludge can be done chemically or biologically, though the latter is more common and effective. Lime stabilization is achieved when a sufficient amount of lime is added to the sludge to alter the value of pH to a high level (>11) that no microorganisms can survive.

- Biological stabilization utilizes biological (in many cases, microbiological) agents to reduce organic matters in the sludge, a process often termed digestion.
- There are a variety of digestion techniques, the purpose of which is to reduce, in addition to the amount of organic matter, the number of disease-causing microorganisms present in the solids.
- The most common treatment options include anaerobic digestion, aerobic digestion, vermistabilization, and composting.

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