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Waste Water Treatment
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Self-Learning Material
(SEM 1)

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PREFACE

This book is a comprehensive exploration of wastewater treatment technologies, practices, and principles, designed to serve as a valuable resource for engineers, scientists, policymakers, and students working in the field of environmental engineering and water management. It provides a thorough overview of the key processes, challenges, and innovations in wastewater treatment, with a focus on both conventional and emerging technologies.

In order to maintain natural ecosystems, preserve public health, and save water supplies for future generations, wastewater treatment is a crucial part of contemporary environmental engineering. There has never been a higher need for efficient wastewater treatment solutions as the world's population grows and becomes more urbanized.

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UNIT: 1

CHARACTERISTICS OF WATER

Learning Objectives

- Understand the characteristics of water
- Analyze the Physical Properties of water
- Explore International Standards of drinking water

Structure

Water is a fundamental component of life on Earth, and its characteristics and sources are varied from place to place and essential for different ecosystems, human consumption and industrialprocesses.

1.1 Physical Properties of water

State: Water exists in three states that are solid (ice), liquid (water) and gas (vapor).

Density: Water has a maximum density at 4°C (39°F), which is why ice floats on water.

Boiling and Melting Points: Boiling point of **water** is 100°C (212°F), and melting point is 0°C (32°F) understand atmospheric pressure condition.

Color and Clarity: While natural water can have different color and clarity due to dissolved minerals, organic matter and contaminants, pure water is colorless, odorless and tasteless.

1.2 Chemical Properties

Molecular Structure: Water (H_2O) consists of two H-atoms which are covalently bonded to one O-atom, producing a polar molecule with a slight positive charge on the H-atom and a slight negative charge on the O-atom.

Solvent Abilities: Water is known as the "universal solvent" because it can dissolve manysubstances,whichis crucialfor biologicalprocessesandchemical reactions.

pH Level: Pure water has a neutral pH of 7, but natural water sources can vary in pH due to the presence of dissolved substances.

1.3 Biological Importance

Hydration and Nutrient Transport: Water is essential for hydration and is a medium for transporting nutrients and waste in biological organisms.

Temperature Regulation: Water helps regulate temperature in living organisms and environments due to its high specific heat capacity.

1.4 Sources of Water

Surface Water:

Rivers and Streams: These are flowing bodies of water that originate from precipitation, melting ice, or springs.

Lakes and Ponds: Standing bodies of freshwater that can be natural or artificial.
Oceans and Seas: Large bodies of salt water covering about 71% of the Earth's surface, crucial for climate regulation and marine life.

Groundwater:

Aquifers: Underground layers of water-bearing rock or sediment that store and transmit water. They are accessed through wells and springs.

Wells: Man-made structures drilled to extract water from aquifers.

Atmospheric Water:

Precipitation: Water that originates from atmospheric moisture and falls to the Earth's surface as rain, snow, sleet, or hail.

Fog and Dew: Condensed water vapor that forms on surfaces and can be a source of water in certain environments.

***Desalinated Water*:**

Desalination Plants: Facilities that convert sea water or brackish water into freshwater by removing salts and minerals, using processes such as reverse osmosis or distillation.

Recycled Water:

Wastewater Treatment: The process of treating and purifying waste water from domestic, industrial, and agricultural sources so it can be reused for various purposes, including irrigation and industrial processes.

1.5 International Standards of drinking water

International standards for drinking water are established to ensure that water is safe for human consumption and free from harmful contaminants. These standards are set by various organizations, with the World Health Organization (WHO) being the primary authority providing guidelines globally. Other organizations like the United States Environmental Protection Agency (EPA), the European Union (EU), and national health agencies also contribute to setting these standards.

1.5.1 Key Organizations and Their Standards

World Health Organization (WHO):

Guidelines for Drinking-water Quality: WHO publishes comprehensive guidelines that set the benchmark for safe drinking water world wide. These guidelines cover microbial, chemical, and radiological aspects of water quality.

Microbial Parameters: Emphasize the absence of pathogens (e.g., bacteria, viruses, and protozoa). Key indicators include *Escherichia coli* (*E.coli*) and coliform bacteria.

Chemical Parameters: Set limits for chemicals that may pose health risks, such as arsenic, fluoride, lead, nitrates, and pesticides.

Radiological Parameters: Provide guidance on acceptable levels of radioactive substances like radon and uranium.

Aesthetic Parameters: Address taste, odor, color, and turbidity to ensure water is not only safe but also pleasant to drink.

1.5.2 United States Environmental Protection Agency(EPA):

*National Primary Drinking Water Regulations (NPDWR):*In United states, the legally enforceable standards that apply to public water systems

Maximum Contaminant Levels (MCLs): The highest level of a contaminant permitted in drinking water.

*Maximum Contaminant Level Goals (MCLGs):*Non-enforceable health objectives that are set at levels where no known or anticipated health risks occur.

Treatment Techniques: Requirements for specific treatment methods to control certain contaminants.

1.5.3 EuropeanUnion(EU):

*Drinking Water Directive (DWD):*Sets standards for drinking water quality in EU member states.

Microbiological Parameters: Similar to WHO and EPA, focusing on pathogens like E.coli and enterococci.

Chemical Parameters: Includes limits for chemicals like lead, arsenic, and nitrates.

Indicator Parameters: Cover additional aspects such as pH, conductivity, and iron to ensure overall water quality.

1.5.4 Other National Standards:

Canada: Follows guidelines set by Health Canada ,similar to WHO and EPA standards.

Australia: Australian Drinking Water Guidelines (ADWG) adopted by Australia which are provided by the National Health and Medical Research Council (NHMRC).

Japan: Maintains its own set of drinking water quality standards enforced by the Ministry of Health, Labour and Welfare.

1.6 Common Parameters and Their Standards

Microbial Parameters:

E.coli: 0CFU/100mL (colony-forming units per 100 milliliters)-Indicates no presence is allowed.

*Total Coliforms:*Generally,0CFU/100mL-Some variations allow upto5% of samples to be positive in a month.

Chemical Parameters:

Arsenic: WHO and EPA: 10µg/L (micrograms per liter or parts per billion, ppb)

Lead: WHO and EPA : 10µg/L; EU: 10µg/L

Nitrates: WHO and EPA: 50mg/L (milligrams per liter or parts per million ppm)

Fluoride: WHO and EPA: 1.5mg/L ; variations exist based on climate and fluoride occurrence.

AestheticParameters:

Turbidity: WHO: ≤1NTU (Nephelometric Turbidity Units);EPA:≤0.3NTUin95%ofsamplesper month.

pH: WHO: 6.5-8.5; EPA and EU: 6.5-9.5

Taste and Odor: Should be acceptable to consumers and free from undesirable tastes and odors. Monitoring and Compliance

Regular Testing: Drinking water providers are required to regularly test water sources and supply systems to ensure compliance with these test standards.

Public Reporting: Results are often made available to the public to ensure transparency and maintain consumer confidence.

Treatment Requirements: Water treatment processes must be capable of reducing contaminants to levels that meet or exceed the standards set by regulatory bodies.

1.7 Water quality parameters: COD

Chemical Oxygen Demand (COD) is a critical water quality parameter that measures the amount of oxygen needed to oxidize organic & inorganic matter chemically in water. It is an important indicator of water pollution, particularly from organic pollutants, and helps in assessing the overall water quality.

Definition:

COD is the overall measurement of all chemicals which may be organic and inorganic present in water that can be oxidized. It may be expressed in milligrams of oxygen consumed per liter of solution (mg/L).

Importance:

Pollution Indicator: High COD values indicate a high level of pollution, which can harm aquatic life by depleting the oxygen available in the water.

Treatment Efficiency: Monitoring COD helps in evaluating the efficiency of waste water treatment processes.

Regulatory Compliance: Many environmental agencies set limits on COD levels to control pollution and protect water bodies.

1.7.1 Sources of COD

<u>*Organic Waste:*</u>

Domestic Sewage: Contains organic matter from food waste, human waste, and household chemicals.

Industrial Effluents: Industries like food processing, textiles, and pharmaceuticals discharge organic and inorganic pollutants.

Agricultural Runoff: Includes fertilizers, pesticides, and decayed plant material.

<u>*Inorganic Compounds*</u>:

Oxidizable Inorganics: Substances such as ammonia, nitrites, and sulfides can contribute to COD.

1.7.2 Measurement of COD

TestingMethod:

Closed Reflux Method: The most common method involves heating a water sample with a strong oxidizing agent (usually potassium dichromate) in an acidic solution. The sample is then titratedtodeterminethe amountof oxygen consumed.

Photometric Method: Involves measuring the absorbance of the sample after digestion using aspectrophotometer.

Procedure:

Sample Preparation: A known volume of water sample is mixed with a potassium dichromatesolutionand concentrated sulfuric acid.

Digestion: The mixture is heated for a specified period (typically 2 hours) at a high temperature(around150°C).

Titration or Photometric Analysis: After digestion, the amount of unreacted dichromate is measured to calculate the COD.

1.7.3 COD Standards and Regulations

WHO Guidelines:

WHO does not specify a direct guideline for COD in drinking water but focuses on maintaining overall water quality, emphasizing that treated drinking water should be free of harmful contaminants that can contribute to high COD levels.

EPAStandards:

The U.S. Environmental Protection Agency regulates COD in industrial effluents and waste water discharge rather than in drinking water. The permissible levels vary depending on the industry and the receiving water body.

EU Water Framework Directive:

Similar to the EPA, the EU sets limits for COD in industrial discharges and municipal wastewater. The standards are designed to protect the aquatic environment and ensure water quality.

Local Regulations:

Many countries have specific regulations for COD levels in wastewater to protect local water bodies and ensure the safety of aquatic life and human health.

1.7.4 COD in Different Water Bodies

Surface Water: Natural waters like rivers and lakes typically have low COD levels (2-10 mg/L) if unpolluted. Higher levels indicate pollution from organic or inorganic waste.

Wastewater: Untreated domestic sewage and industrial effluents can have COD values ranging from 200 to 20,000 mg/L or more. Treatment plants aim to reduce these levels significantly before discharge.

Drinking Water: While direct COD limits for drinking water are not common, low COD values (typically less than 5 mg/L) are expected in treated water to ensure safety and quality.

1.8 Water quality parameters: BOD

Biochemical Oxygen Demand (BOD) is a key parameter used to assess water quality, particularly in relation to organic pollution. It measures the amount of oxygen that microorganisms require to decompose organic matter in water over a specified period, typically five days at 20°C (BOD_5).

Definition: BOD represents the quantity of dissolved oxygen required by aerobic biological organisms to break down organic matter in a given water sample at a certain temperature over a specific time period.

Importance: Pollution Indicator: When BOD values are high; it means there are high levels of organic pollution, which can cause oxygen depletion in water bodies, which can adversely affect the aquatic life.

Wastewater Treatment: BOD is a critical parameter in designing and operating wastewater treatment plants.

Environmental Monitoring: Helps in assessing the impact of wastewater discharges on receiving waters.

1.8.1 Sources of BOD

Domestic Sewage: Organic matter from human waste, food scraps, detergents, and householdchemicals.

Industrial Effluents: Organic pollutants from industries such as food processing, paper mills, textile factories, and chemical plants.

Agricultural Runoff: Organic materials from manure, plant residues, and agrochemicals.

Natural Sources: Decaying plant and animal matter, as well as naturally occurring organic substances.

1.8.2 Measurement of BOD

Testing Method: Standard BOD Test (BOD_5): Measures the oxygen consumption by microorganisms over a five-day period at 20°C.

Procedure: Sample Collection: Water samples are collected in airtight BOD bottles to avoid oxygen contamination.

Incubation: The samples are incubated at 20° C for five days.

Dissolved Oxygen Measurement: The dissolved oxygen (DO) levels are measured at the start and end of the incubation period. The difference in DO levels gives the BOD value.

Equipment: BOD Bottles: Specially designed bottles that prevent air exchange.

DO Meteror Winkler Titration Method: Used to measure dissolved oxygen levels accurately.

1.8.3 BOD Standards and Regulations

WHO Guidelines: WHO does not set specific BOD limits for drinking water but emphasizes that treated water should have low organic pollution, which indirectly relates to low BOD levels.

EPA Standards: The U.S. Environmental Protection Agency sets limits for BOD in waste water discharges. Typical BOD limits for treated waste water are around 30mg/L for municipal treatment plants.

EU Water Framework Directive: The EU sets regulatory standards for BOD in effluents to protect water bodies, ensuring that BOD levels are kept within limits that prevent significant oxygen depletion.

Local Regulations: Various countries and regions have specific regulations for BOD levels in waste water to ensure the protection of local aquatic environments.

1.8.4 BOD in Different Water Bodies

Surface Water: Unpolluted rivers and lakes typically have low BOD values (1-8 mg/L). Higher values indicate organic pollution and potential oxygen depletion.

Wastewater: Raw sewage can have BOD values between 150-300mg/L, where as treated waste water should ideally have BOD values below 30 mg/L to be safely discharged into natural water bodies.

Drinking Water: Drinking water should have very low BOD values, ideally less than 1 mg/L, indicating minimal organic contamination and ensuring the water is safe for consumption.

1.9 Summary

Water possesses unique physical and chemical properties, making it vital for life on Earth. Its characteristics include being a universal solvent, exhibiting high heat capacity and surface tension, and having polar molecules. Water is sourced from natural and artificial sources, essential for biological processes, and subject to international standards to ensure safe drinking water for human consumption.

1.10Keywords:

- **Tasteless**: Lacking a distinct flavor.
- **Boiling point**: Temperature at which water changes from liquid to vapor.
- **Freezing point**: Temperature at which water changes from liquid to solid.
- **Precipitation**: Rain, snow, sleet, or hail falling from the atmosphere.

1.11 Self-Assessment questions

1. What property of water allows insects like water striders to walk on its surface?

   a) High heat capacity

   b) Low surface tension

   c) High specific gravity

   d) High surface tension

2. What property of water allows it to resist temperature changes?

   a) Low specific heat capacity

   b) High specific heat capacity

   c) Low heat of vaporization

   d) Low boiling point

3. Capillary action in plants is primarily driven by:

   a) Cohesive forces

   b) Adhesive forces

   c) Hydrophobic interactions

   d) None of the above

4. What property of water makes it an excellent solvent?

a) Low heat capacity

b) Polar molecule

c) High boiling point

d) None of the above

5. Water acts as an acid when it:

   a) Donates a proton

   b) Accepts a proton

   c) Releases hydroxide ions

   d) Forms hydrogen bonds

6. Which state of water is denser than its solid state?

   a) Liquid

   b) Solid

   c) Gas

   d) None of the above

7. Explain why water has a high heat capacity.
8. How does the structure of water molecules contribute to its polarity?
9. Name three natural sources of water.
10. What is the role of water in the human body?
11. Briefly explain the importance of international standards for drinking water quality.

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UNIT: 2
TREATMENT OF POTABLE WATER

Learning Objectives

- Understand the sources for water protection
- Analyze the various methods for treatment of water
- Discuss the sludge/ sewage treatment

Structure

The treatment of potable water, which involves a sequence of processes designed to remove contaminants and ensure that water is now safe for human consumption. The specific treatment methods can vary, which depends on the source of the water and the types of contaminants present in it. Some common steps involved in potable water treatment are:

2.1 Source Water Protection

Source Selection: Identifying and protecting sources of water, such as rivers, lakes, and aquifers, from contamination.

Watershed Management: Implementing practices to reduce pollution runoff and maintain the quality of the water source.

2.1.1 CoagulationandFlocculation

Coagulation: To neutralize the charge of suspended particles in water, chemicals (coagulants) like aluminum sulfate (alum) or ferric chloride can be added.

Flocculation: Gently mixing the water to form larger aggregates (flocs) from the smaller particles, making them easier to remove.

2.1.2 Sedimentation

Sedimentation Tanks: Allowing the water to sit in large tanks causes the flocs to settle to the bottom by gravity, which results in a significant reduction in suspended solids.

2.1.3 Filtration

Sand Filtration: Passing the water through sand filters to remove remaining suspended particles.Multi-layerfilterswithsand, gravel,andactivated carboncan also beused.

Membrane Filtration: Using microfiltration, ultrafiltration, or reverse osmosis membranes toremoveparticles, pathogens, and dissolvedsubstances.

2.1.4 Disinfection

Chlorination: Adding chlorine or chlorine compounds (e.g., sodium hypochlorite) to kill bacteria,viruses, and other pathogens. It's a widely used method due to its effectiveness and residual protection.

UV Disinfection: Using ultraviolet light to inactivate microorganisms. This method is effective but does not provide residual disinfection.

Ozonation: Using ozone gas to disinfect water. It is very effective but more complex and expensive compared to chlorination.

2.1.5 AdditionalTreatments

pH Adjustment: Adding chemicals like lime or sodium hydroxide to adjust the pH of the water to a desirable level, typically around7 to8.5, to prevent corrosion in the distribution system.

Fluoridation: Adding fluoride to the water to help prevent too the decay, based on local public health guidelines.

Softening: Removing hardness (calcium and magnesium) from the water using ion exchange or lime softening, if necessary.

2.1.6 Distribution System Maintenance

Pipe Integrity: Ensuring the distribution network is well-maintained to prevent contamination and leaks.

Residual Disinfection: Maintaining a residual level of disinfectant (e.g., chlorine) throughout the distribution system to prevent microbial growth.

Summary of Potable Water Treatment Processes

Source Water Protection: Protecting and managing the water source.

Coagulation and Flocculation: Adding coagulants and forming flocs.

Sedimentation: Allowing flocs to settle out.

Filtration: Removing particles through sand or membrane filters.

Disinfection: Killing pathogens using chlorine, UV light o rozone.

Additional Treatments: Adjusting pH, adding fluoride and softening water as needed.

Distribution System Maintenance: Ensuring the integrity of the water distribution network.

Considerations for Treatment

Source Water Quality: Treatment processes are tailored based on the specific contaminants present in the source water.

Regulatory Standards: Ensuring compliance with local and international drinking water quality standards, such as those set by the WHO, EPA and EU.

Public Health: Prioritizing the removal of harmful contaminants to protect public health.

2.2 Treatment of sewage waste water:

The treatment of sewage wastewater involves a series of processes designed to remove contaminants and produce an effluent that can be safely discharged into the environment or reused. The primary stages of sewage treatment are typically divided into primary, secondary, and tertiary treatment, each addressing different types of contaminants. Here’s a detailed overview:

2.2.1 PreliminaryTreatment

Screening: Removes large objects such as rags, sticks, and other debris that could damage equipment or obstruct flow.

Grit Removal: Removes sand, gravel and other heavy particles that can cause wear and tear on equipment.

2.2.2 PrimaryTreatment

Primary Sedimentation: Allowing wastewater to stand undisturbed in large tanks (sedimentation or settling tanks) so that heavy solids settle down as sludge, while lighter materials float to the surface and are skimmed off. This process removes a major portion of suspended solids and some organic matter also.

2.2.3 SecondaryTreatment

Biological Treatment: Microorganisms can be used to degrade organic matter in the waste water. Common methods used for this are as follows:

Activated Sludge Process: Air or oxygen is introduced into the waste water to encourage the growth of aerobic bacteria, which consume organic pollutants. The mixture is then allowed to settle,separatingthe biomass from thetreated water.

Trickling Filters: Wastewater is sprayed over a bed of stones or plastic media, on which biofilms of bacteria grow and degrade the organic matter.

Bio-towers: Similar to trickling filters but often taller and designed to maximize the contact between waste water and the biofilm.

Lagoons: Large, shallow ponds where wastewater is treated by a combination of microbial action, sunlight, and algae.

Secondary Sedimentation: Clarifiers are used to settle out the biomass (activated sludge) formed during biological treatment. This sludge is often recycled back into the biological treatment process to maintain microbial populations.

2.2.4 TertiaryTreatment(AdvancedTreatment)

Filtration: Removes remaining suspended solids. Methods include sand filtration, activated carbon filtration, and membrane filtration.

Disinfection: Kills remaining pathogens using chlorine, ultraviolet (UV) light, or ozone.

Nutrient Removal: Reduces levels of nitrogen and phosphorus to prevent eutrophication in receiving waters. Methods include:

Biological Nutrient Removal (BNR): Specific bacteria are used to remove nitrogen (via nitrification and denitrification) and phosphorus.
Chemical Precipitation: Adding chemicals such as alum or ferric chloride to precipitate and remove phosphorus.

Advanced Oxidation Processes: Uses chemical oxidants like ozone or hydrogen peroxide, often combined with UV light, to break down organic contaminants.

2.2.5 Sludge Treatment and Disposal

Thickening: Increases the solids content of the sludge by removing excess water.

Digestion: Microbial digestion of organic matter in the sludge under anaerobic o aerobic conditions to reduce volume and produce biogas.

Anaerobic Digestion: Sludge is broken down by bacteria in the absence of oxygen, producingbiogas(methane) that canbeused for energy.

Aerobic Digestion: Sludge is decomposed by bacteria in the presence of oxygen, generallyproducinglessbiogas.

Dewatering: Further reduces the water content of the digested sludge using centrifuges, belt filter presses or drying beds.

Disposalor Reuse: Treated sludge (biosolids) can be applied as fertilizer, used in land reclamation, or disposed of in landfills.

2.2.6 Effluent Discharge or Reuse

Discharge to Water Bodies: Treated effluent can be discharged to rivers, lakes, or oceans, following regulatory standards to protect the environment and public health.

Reuse: Treated wastewater can be reused for purposes such as agricultural irrigation, industrial processes, or groundwater recharge. Advanced treatment methods, including reverse osmosis and advanced oxidation, may be required to meet the stringent quality standards for reuse.

2.3 Summary of Sewage Waste water Treatment Processes

Preliminary Treatment: Screening and grit removal to protect equipment and remove large debris.

Primary Treatment: Sedimentation to eradicate suspended solids and organic matter.

Secondary Treatment: Biological methods to degrade organic matter and secondary sedimentation to separate biomass.

Tertiary Treatment: Advanced filtration, disinfection and nutrient removal to produce high-quality effluent.

Sludge Treatment: Thickening, digestion, and dewatering to manage and reduce sludge volume, with options for disposal or reuse.

Effluent Discharge or Reuse: Ensuring treated water meets regulatory standards for environmental discharge or reuse applications.

2.4 Summary

In the treatment of potable water, various processes are employed to ensure its safety and quality for human consumption. Filtration acts as an initial step, removing suspended solids and impurities by passing water through a porous medium. Biological treatment utilizes microorganisms to break down organic matter and pollutants, reducing their concentration in the water. Disinfection is crucial for killing or inactivating harmful pathogens, safeguarding public health. Coagulation and flocculation further improve water quality by promoting the aggregation and settling of suspended particles, enhancing the efficiency of filtration. Together, these processes work synergistically to produce clean, safe, and potable water, meeting the needs of communities while protecting public health and the environment.

2.5 Keywords:

Filtration: The process of passing water through a porous medium to remove suspended solids.

Biological Treatment: Microorganisms: A water treatment process that utilizes microorganisms like bacteria and fungi to degrade organic matter.

Disinfection: The process of killing or inactivating pathogenic microorganisms in water to make it safe.

Coagulation: The process of adding chemicals to water to neutralize the electrical charges on suspended particles, allowing them to come together and form larger clumps called flocs.

2.6 Self-Assessment questions

1. What is the primary purpose of filtration in the treatment of potable water?

   a) To add chemicals for disinfection

   b) To remove suspended solids and particles

   c) To increase the pH of water

   d) To improve taste and odor

2. Which process of water treatment involves the use of microorganisms to degrade organic matter?

   a) Filtration

   b) Disinfection

   c) Coagulation and flocculation

   d) Biological treatment

3. What is the main objective of disinfection in potable water treatment?

   a) To remove turbidity

   b) To neutralize pH

   c) To kill or inactivate pathogens

   d) To reduce hardness

4. Define filtration in the treatment of potable water.
5. What is meant by biological treatment using microorganisms?
6. Explain the significance of disinfection in the treatment of potable water.
7. Describe coagulation and flocculation in the context of potable water treatment.

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