Université de Ghardaia- Ageria
Faculty of Science and Technology
Department of Hydraulics and Civil Engineering

Bachelor's Degree in Hydraulics

Water Treatment and Purification Course

Course Handout

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Foreword

This *document provides a comprehensive study on water treatment and purification, focusing on processes related to both drinking water and wastewater. It is tailored for third-year hydraulics students to equip them with essential knowledge and understanding of water treatment methods. This material is intended to guide students through various stages of water purification, giving them the theoretical and practical tools they'll need in their future careers.*

The reason for delving into this subject is rooted in the increasing global demand for clean water and the environmental challenges caused by pollution and the shrinking availability of freshwater. As future engineers and specialists, it's crucial that students are prepared to manage and develop systems that ensure water is used sustainably and protected.

The main goal of this course is to familiarize students with techniques to treat water to meet safety and consumption standards, as well as to ensure the safe disposal of wastewater. It aims to help students develop the skills needed to address complex water treatment challenges by exploring both traditional and advanced methods.

Creating this document wasn't without its challenges, especially in presenting intricate chemical and biological processes in a way that's both clear and understandable. Striking a balance between theoretical knowledge and practical applications was key to making this material engaging and educational.

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Associate professor at the
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Abbreviations

AOB: Ammonia-Oxidizing Bacteria

BOD: Biochemical Oxygen Demand

BOD$_5$ (DBO$_5$): Biological Oxygen Demand over 5 days

C: Concentration

COD: Chemical Oxygen Demand

COT: Total Organic Carbon (from the French term "Carbone Organique Total")

CT: Concentration of disinfectant multiplied by contact time

DBPs: Disinfection By-Products

DO: Dissolved Oxygen

EH: Equivalent Inhabitant (Equivalent Habitant)

EPA: Environmental Protection Agency

GAC: Granular Activated Carbon

HAAs: Haloacetic Acids

MF: Microfiltration

MO: Organic Matter (from the French term "Matières Organiques")

NF: Nanofiltration

NH_4^+: Ammonium (Ammonia in water)

NO_2^-: Nitrite

NOB: Nitrite-Oxidizing Bacteria

NOM: Natural Organic Matter

NTK: Total Kjeldahl Nitrogen

PAC: Powdered Activated Carbon

PAOs: Phosphorus-Accumulating Organisms

Pt: Total Phosphorus

RO: Reverse Osmosis

SS: Suspended Solids (from the French term "Matières en Suspension")

TDS: Total Dissolved Solids

THMs: Trihalomethanes

TSS: Total Suspended Solids

UF: Ultrafiltration

USEPA: United States Environmental Protection Agency

UV: Ultraviolet

VSS: Volatile Suspended Solids (Suspended Volatile Matter)

WHO: World Health Organization

Annotations

Q - Flow rate (m^3/s)

S - Surface area or section (m^2)

L - Length of the filter bed or channel (m)

v - Velocity of water (m/s)

V - Volume (m^3)

H - Height or depth of water column/tank (m)

d - Diameter of particles or pipes (m)

g - Acceleration due to gravity (m/s^2)

ρ_s - Density of the particle (kg/m^3)

ρ_l - Density of the fluid/liquid (kg/m^3)

μ - Dynamic viscosity of the fluid (Pa·s)

ε - Porosity of the filter medium

CD - Drag coefficient (dimensionless)

Ap - Projected surface area of the particle (m^2)

N - Number of particles

τ - Retention time (days or seconds, depending on context)

Vasc - Ascension velocity of particles (m/s)

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Part 1
Water Treatment

Chapter 1

Generalities and Standard

1.1. Water supplies

1.1.1. Key figures about water on Earth

Water is one of the most abundant substances on our planet. Seen from space, Earth appears predominantly blue due to its vast oceans, which cover nearly three-quarters of its surface (71%). The total volume of water on Earth is approximately 1.4 billion km³, existing in liquid, solid, or gaseous forms. However, 97% of this water is found in the oceans and is salty, making it unsuitable for human consumption without desalination

1.1.2. Distribution of water on the Earth's surface

The remaining freshwater (3% of the water on Earth) concerns:

- Mountain glaciers and the ice sheets of Greenland and Antarctica (nearly 2%) and is therefore unavailable
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- Groundwater (less than 1%)
- Surface freshwater (rivers, frozen soils, swamps, and freshwater lakes 0.03%)
- Atmosphere (0.001%)
- Living beings (0.0001%)

Thus, just 0.3% of the planet's water volume is available for human use, or 4 million km³. Its distribution on the Earth's surface is uneven, leading to disparities between countries, and its scarcity is immediately felt by all. The amount of water on Earth has remained unchanged for more than 3.5 billion years. It is neither lost nor created, it just transforms.

1.1.3. The water cycle

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1. Mountain glaciers and the ice sheets of Greenland and Antarctica (nearly 2%) and is therefore unavailable
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4. Atmosphere (0.001%)
5. **Living beings (0.0001%)**

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1.2. Water quality

During its natural cycle (precipitation, transport, infiltration, evaporation, etc.), water enriches itself with elements it carries, in dissolved form or as tiny solid particles.

On a global scale, the phenomena of evaporation and condensation of water are essential elements of energy transfer in the atmosphere, which determine the distribution of climates.

1.2.1. Precipitation and Climate

Some concepts:

The term "**precipitation"** encompasses all ice crystals or water droplets that, having undergone processes of condensation and aggregation within clouds, have become too heavy to remain suspended in the atmosphere and fall to the ground.

Evapotranspiration corresponds to the total amount of water transferred from the soil to the atmosphere through evaporation at the soil surface and through plant transpiration. It varies throughout the year.

The concept of **effective rainfall**, often used to characterize precipitation, corresponds to precipitation reduced by evapotranspiration. It represents the water available for streamflow and groundwater recharge.

- When rainfall exceeds evapotranspiration, reserves can replenish.
- When precipitation is less than evapotranspiration, there is a water deficit.

1.2.2. Characteristics of Drinking Water

Drinking water, also known as potable water, can come in two forms: tap water and mineral water. All drinking water must meet the same quality standards, with the exception of natural mineral waters, which may have specific characteristics.

1.2.3. Quality Standards for Water Intended for Consumption

Standards cover:

1.2.3.1. Microbiological quality

Water must be free from harmful microorganisms, including parasites, viruses, bacteria, and pathogens. Contaminated water can cause severe health issues, such as gastroenteritis, which is a leading cause of death among children worldwide.

Table 1. Microbiological Parameters (Algerian Standards from the Ministry of Water Resources, since March 22, 2011)

Parameters	**Units**	**Limit Values**
Escherichia Coli	count /100ml	0
Enterococci	count /100ml	0
Sulfite-reducing bacteria including spores	count /20ml	0

Approximately 6 million children worldwide die each year from complications related to gastroenteritis.

1.2.3.2. Chemical quality

Chemical contaminants in water, aside from essential minerals, are strictly regulated. These substances are often categorized as "undesirable" or "toxic" and are monitored in trace amounts (parts per million per liter). Standards are based on safe levels for daily consumption over a lifetime

Table 2. Parameters with Guideline Values (Algerian Standards from the Ministry of Water Resources, since March 22, 2011)

Parameter group	Parameters	Units	Guideline Values
Physicochemical parameters related to the natural structure of water	pH	pH unit	≥ 6.5 and ≤ 9.5
	Conductivity	µS/cm at 20°C	2800
	Temperature	°C	25
	Hardness	mg/L as $CaCO_3$	200
	Alkalinity	mg/L as $CaCO_3$	500
	Calcium	mg/L as $CaCO_3$	200
	Chlorides	mg/L	500
	Potassium	mg/L	12
	Dry residue	mg/L	1500
	Sodium	mg/L	200
	Sulfates	mg/L	400
Organoleptic parameters	Color	mg/L Platinum	15
	Turbidity	NTU	5
	Odor at 12°C	Dilution factor	4
	Taste at 25°C	Dilution factor	4

1.2.3.3. Desirable criteria

These criteria are either translated by maximum or minimum values beyond which water presents disadvantages, or by optimal values. (See table 2)

- Temperature: optimal between 9 and 12°C.
- Turbidity (fine solid matter in suspension)
- Color (due to colloids in suspension)

1.2.3.4. Organoleptic parameters

High-quality drinking water should be clear, odorless, and have a pleasant taste. However, water that does not fully meet these aesthetic criteria is not necessarily harmful to health (see table 2).

1.3. Water Uses and Their Requirements

In urban environments, water serves primarily as a vital element for physiological needs, then as a means of washing, as a solvent for various domestic and public needs, and finally as a waste remover.

When assessing water needs in urban centers, it's important to clearly distinguish between domestic needs, pertaining to individuals, and public needs, corresponding to societal life. Due to distribution conditions, all supplied water is potable, although certain domestic and public needs may not require water of such high quality.

1.3.1. Domestic Water

In addition to direct domestic needs (100 liters per person per day), there are additional needs of at least 200 liters per person per day, totaling 300 liters per person per day, or approximately 110 cubic meters per inhabitant per year. These needs are largely exceeded in large urban areas and are distributed into three equal parts: households, commercial establishments and other collective users, and municipal services (domestic and public needs thus range from 400 to 900 liters per person per day).

These waters are only distributed after treatment, and three factors determine the choice of treatment:

- **Quantity**: The source must cover the demand under all circumstances.

- **Quality**: The quality of the raw water available must be compatible with current legislation.

- **Economy**: The investment and operating costs of the treatment process relative to each available resource are decisive when making a decision.

It should be noted that the establishments distributing drinking water are responsible for ensuring the conformity of these waters to standards until they reach the consumer.

1.3.2. Industrial Waters

Industries have diverse water quality and quantity needs, depending on their processes. Examples include:

- **Cooling:** Used in power plants and manufacturing, requiring large volumes but with less stringent quality standards.
- **Process water:** Used in food production, pharmaceuticals, and electronics, requiring high-purity water.

Industries often source water from various sources, including rivers, lakes, and groundwater, and must treat it to meet specific needs.

1.3.3. Agricultural Water

1.3.3.1. Green Water

The water that is contained in the soil and available to plants (60% of total precipitation would constitute green water).

1.3.3.2. Blue Water

It refers to the consumption of surface water and groundwater.

1.3.3.3. Grey Water

It is the volume of freshwater required to dilute pollutants to a sufficient extent so that the water quality meets current standards.

The agricultural sector is by far the largest consumer of freshwater. In Asia and Africa, between 85 and 90% of all freshwater is used for agriculture. With the decrease in water supplies observed over several decades, farmers, especially in continental regions, are becoming interested in using wastewater.

Thus, quality standards for water intended for irrigation have been established in order to:

- Protect the public and agricultural workers.

- Protect consumers of agricultural products.

- Protect surface and groundwater resources and soils.

- Protect irrigation equipment.

- Maintain acceptable yields.

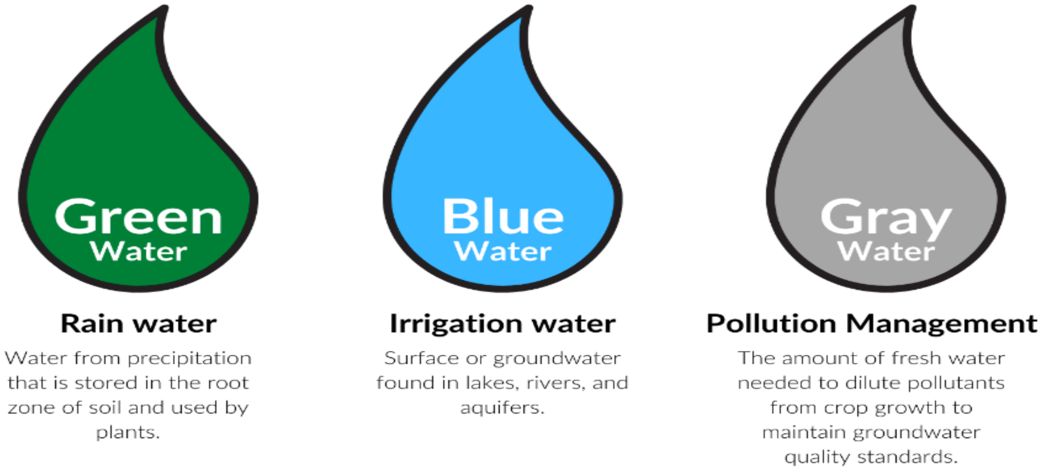


Figure 1. Types of Water used in agriculture

1.4. Typical Diagram of a Water Treatment Plant

A standard water treatment plant includes several key stages (Figure 2):

A. **Intake**: Raw water is collected from sources like rivers, lakes, or groundwater.
B. **Screening:** Large debris and particles are removed.
C. **Coagulation and Flocculation:** Chemicals are added to bind small particles into larger clumps (flocs).
D. **Sedimentation:** Flocs settle at the bottom of a sedimentation tank.
E. **Filtration:** Water passes through filters (sand, gravel, activated carbon) to remove remaining impurities.
F. **Disinfection:** Chlorine, ozone, or UV light is used to kill pathogens.
G. **Storage:** Treated water is stored in reservoirs or tanks before distribution.
H. **Distribution:** Water is pumped through pipelines to homes, businesses, and industries.

This process ensures that the water supplied meets health and safety standards.

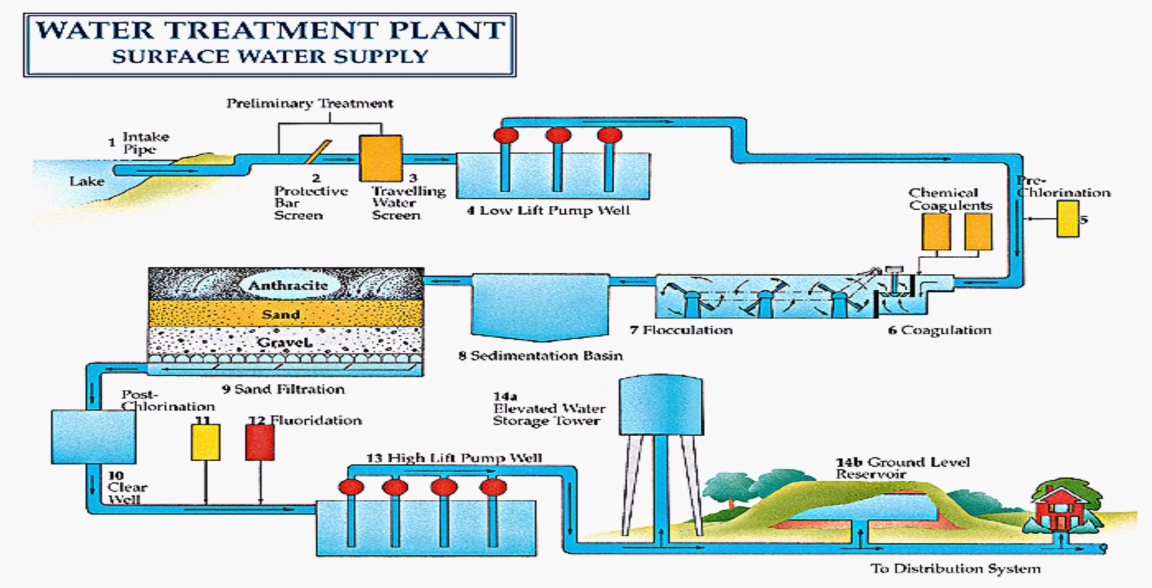


Figure 2. Typical Diagram of a Water Treatment Plant

Chapter 2

Water Pretreatment

2.1. Catchment

Initially, water is caught from surface or groundwater sources and conveyed through pipelines to the water treatment plant

- Raw water must undergo pretreatment before actual treatment.
- It is intended to extract from the raw water the largest quantity of elements whose nature or dimensions would be a hindrance for subsequent treatments.

2.2. Coarse screening

As soon as it is taken, the water passes through grids to stop coarse elements (floating objects and large waste such as branches and stones).

The screening installation consists of a channel, a grid, a screen cleaner, and a bin for waste.

- Different types of screening are defined according to the spacing of the bars:
    - Fine screening < 10 mm
    - Medium screening 10-30 mm
    - Pre-screening 30-100 mm

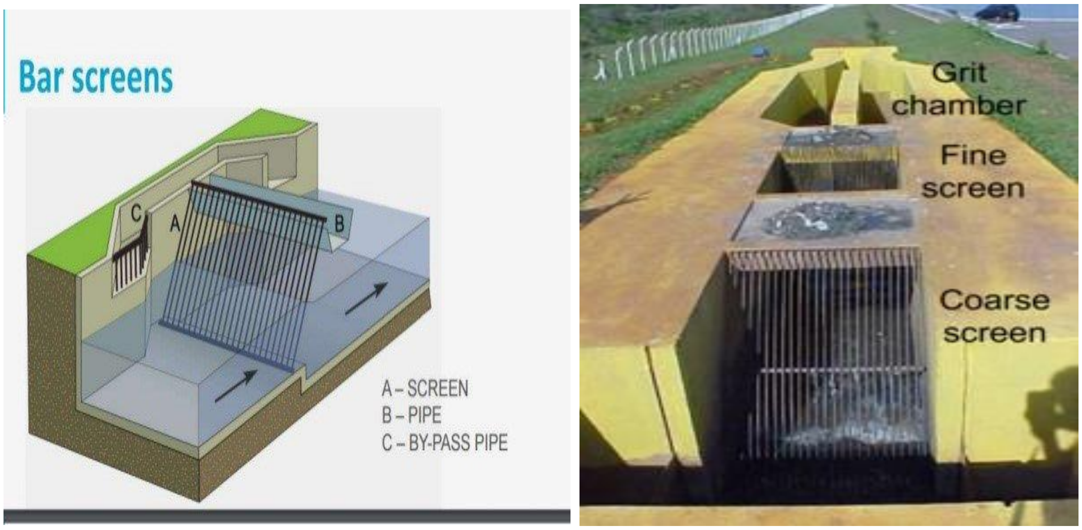


Figure 3. Coarse screening

Several screenings can be associated in series. Screens are generally installed upstream of retention basins and upstream of in-line treatment facilities (sand traps, oil separators, etc.), especially in urban areas where waste is abundant in the collected water. When heavily loaded raw water, rapid clogging can cause overflow.

2.2.1. Dimensioning

A grid generates a hydraulic head loss (m), such that: $i(m) = D_s.\left(\frac{e}{E}\right)^{\frac{4}{3}}.\frac{v^2}{2g}$

Where:

Ds: shape coefficient of circular bars = 1.8; oblong = 1.7

e: thickness of the bars (m)

E: free space between the bars (m), (spacing)

v: average arrival speed of the water

The grid crossing speed must not be less than 0.6 m/s in order to obtain the application of materials on the grid and to avoid sand deposits.

The speed must oscillate between 0.8 and 0.9 m/s and remain less than 1.2 m/s at peak flow.

2.2.1.1. Calculation of the grid width:

2.2.1.1.1. Immersed Surface

$$s = \frac{Q_{pic}}{v.\theta.C}$$

With: *v:* permitted velocity for the considered flow rate Q

C: clogging coefficient

θ: free passage coefficient = E / [E + e]

The clogging coefficient varies from 0.10 to 0.30 for a manual grid and from 0.40 to 0.50 for an automatic grid. The lower this coefficient, the greater the grid surface area. The amount of screening residue can vary depending on the time of year and the area considered within the same municipality.

2.2.1.1.2. Grid Width

$$L = \frac{s}{L_0}$$

With L : grid width

S: the immersed surface

L₀: the wetted width $L_0 = \frac{\tau}{\sin \alpha}$ τ: Maximum Draft α: inclination angle of the bar screen

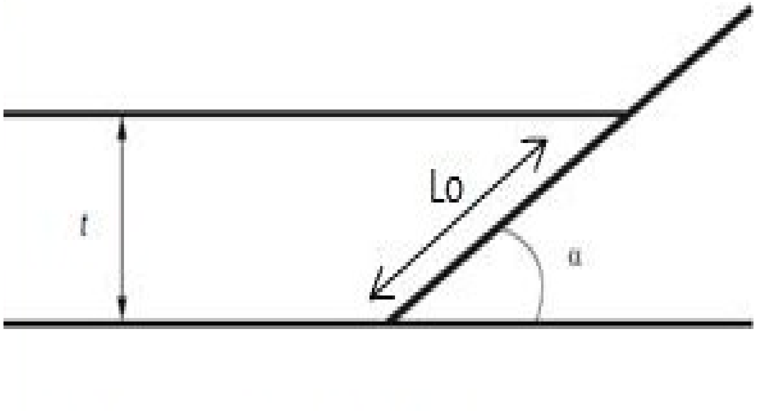


Figure 4. Vertical Cross-Section of the Bar Screen

2.2.2. Types of bar screens

Manual grids require frequent hand cleaning to ensure they remain effective and free of debris. This regular maintenance can be labor-intensive and time-consuming. In contrast, **mechanical grids** are designed with automated cleaning devices that reduce the need for manual intervention, providing a more efficient and reliable solution for maintaining grid functionality.

There are several types of grids available to suit different needs and applications. Straight screens with upstream cleaning involve the cleaning mechanism positioned upstream of the grid, which helps to capture and remove debris before it passes through. Straight screens with downstream cleaning, on the other hand, have the cleaning mechanism located downstream, allowing debris to be cleared after it has passed through the grid. Oscillating screens, or screens with an oscillating head, use a back-and-forth motion to dislodge and remove debris, providing a dynamic cleaning method that can be particularly effective in certain conditions. These various designs ensure that there is a suitable grid solution for a wide range of water catchment and treatment scenarios.

2.2.3. Maintenance

Depends on the type of screen chosen:

- Manual grid screen requires frequent and regular maintenance (removal of debris), so very constraining.

- Mechanical grid screen requires less frequent but always regular maintenance consisting of the removal of waste and a functional check (estimated frequency of once a month).
- It is difficult to set a frequency for removing waste because it depends on the amount of debris collected and therefore on the supply basin.

2.2.4. Efficiency

The efficiency of screening depends on 3 factors:

- the position of the device in relation to the rest of the network,
- the water passage speed in the structure (which conditions clogging),
- The frequency of maintenance.

2.3. Micro-sieving

Micro-sieving is a more refined filtration process, using cloth or porous membranes to capture organic and mineral particles, as well as plankton larger than the micro-sieve's openings. However, micro-sieving doesn't address issues caused by extremely fine particles or dissolved substances, which means that turbidity and water color may still be present..

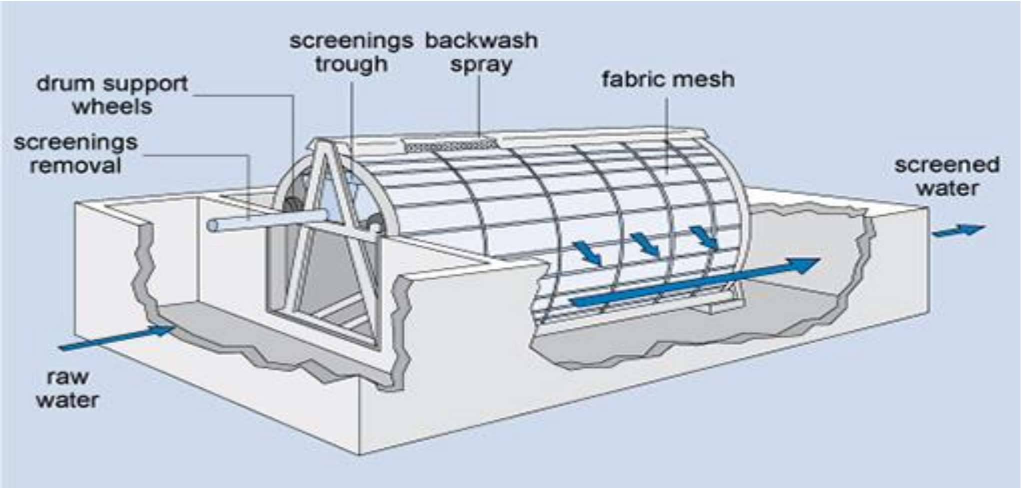


Figure 5. Drum screen lined with filtering fabric mesh

2.4. Sand trap

The purpose of this device is to trap the solid particles carried by the water and the suspended solids with a particle size between 200 and 500 µm: sands, gravels, etc. By retaining the sands associated with pollutants, the sand trap contributes to the protection of the receiving environment.

It also allows:

- The deterioration of downstream structures (wear of mechanical parts),
- The reduction of the flow capacity of the collectors.
- The installation of a sand trap will reduce the operating difficulties of the networks and the quantity of sand discharged into the environment.

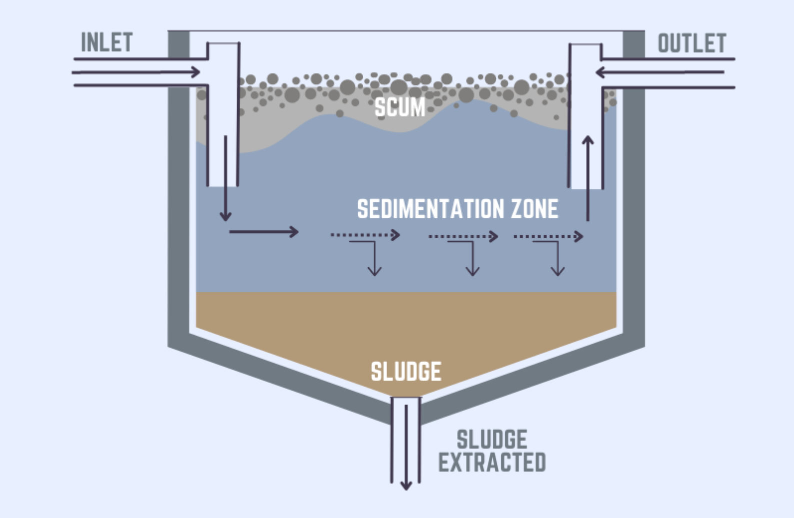


Figure 6. Sedimentation in Water Treatment

2.4.1. Principle

Structure consisting of a deep chamber, this device has been designed to stop the densest mineral particles, essentially sands and gravels but also debris and metal.

Gravitational separation is carried out by limiting the horizontal speed of the fluids which must be less than the settling speed of the mineral particles.

The sand trap thus ensures the sorting of dense and light particles:

- by retaining at the bottom of the sand trap chamber the mineral particles with a dry density ≈ 1.8;
- by leaving in suspension the organic matter with a density ≈ 1.2

2.4.2. Location

The installation of a sand trap in a separate stormwater network is recommended:

- downstream when the network is long and has a low slope (against sedimentation and obstruction),

- at the outlet upstream of certain treatment facilities whose operation could be disturbed.

2.4.3. Dimensioning

1. The sand trap must be designed so that the water speed inside the structure is between 0.2 and 0.4 m/s.
2. The design of the sand trap is done according to the choice of the size of the particles to be eliminated (0.2 mm) and their percentage to be eliminated (80 to 95%).
3. The widening of the collector section allows a reduction in the water speed and also regulation (useful for other downstream structures).

2.4.4. Types of sand traps

2.4.4.1. Classic sand traps

- The speed inside these structures varies according to the flow.
- These are the most elementary channel (or corridor) structures.
- The installation of two parallel channels allows the second channel to be put into service when the sand is extracted from the first.

2.4.4.2. Sand traps with constant speed

- In order to obtain a constant speed in the sand traps, the submerged section must vary in the same way as the flow.
- Sand traps with variable section
- Sand traps with parabolic section

2.4.4.3. Other Types of Grit Chambers Used Mainly for Wastewater Treatment

2.4.4.3.1. Aerated Grit Chambers

Operation: These chambers introduce air to create a spiral flow, which helps in separating heavier particles (like sand) from lighter organic matter

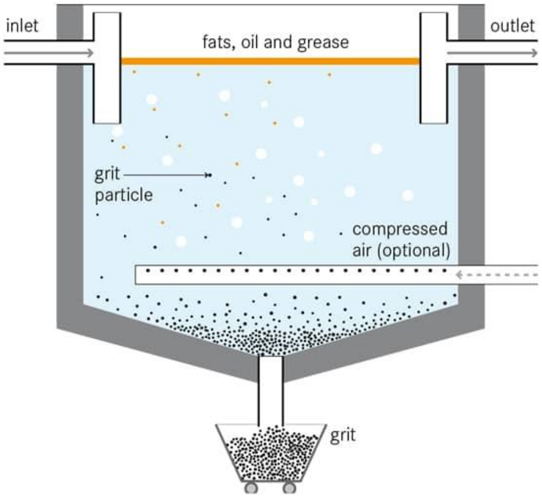


Figure 7. Aerated Grit Chamber

Advantages:

- Enhanced removal efficiency for fine particles.
- Reduces the organic content in the grit, which can minimize odor issues.

Disadvantages:

- Requires additional equipment for aeration, leading to higher operational cost
- More complex maintenance due to the presence of aeration systems.

2.4.4.3.2. Circular and Conical Grit Chambers (Hydrocyclones):

Operation: These grit chambers use centrifugal force to separate grit particles from the water. The circular motion causes heavier particles to settle at the bottom while lighter particles remain suspended.

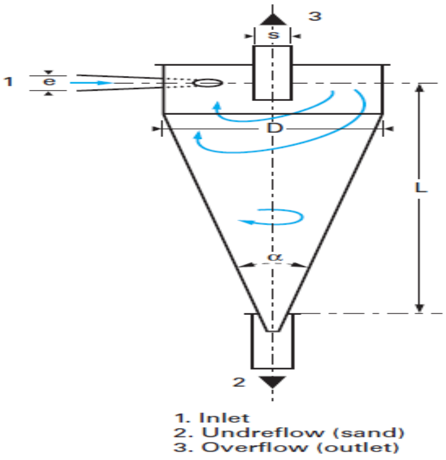


Figure 8. Hydrocyclone

Advantages:

- Efficient in grit removal, especially in a compact space.
- Low energy requirements as compared to aerated systems

Disadvantages:

- May require frequent cleaning to prevent clogging.
- Limited in handling large volumes of water.

4.4.3.3. Piston or Tangential Grit Chambers:

Operation: Water enters the chamber tangentially, creating a spiral flow that facilitates grit settlement. Piston-type chambers use a mechanical piston to assist in the grit separation process.

Advantages:

- Can handle variable flow rates.
- High efficiency in grit removal.

Disadvantages:

- Mechanical components may require frequent maintenance.
- Initial installation costs can be high.

2.4.5. Advantages and Disadvantages of Grit Chambers

Maintenance:

- Regular dredging is required to remove accumulated grit from the structure.

- Sand removal is crucial for maintaining the overall performance and efficiency of the grit chamber.

Challenge:

Setting a standard frequency for sand removal is difficult. The frequency depends on several factors, including the source of the collected water and the geographical location of the pollution control devices. For instance, areas with higher levels of sand or silt in the water may require more frequent maintenance.

Advantages:

- Efficient in removing grit, which protects downstream equipment from abrasion and clogging.

- Improves the overall efficiency of wastewater treatment plants by reducing the load on other treatment processes.

Disadvantages:

- Grit chambers can be costly to install and maintain, especially in large-scale operations.
- They require regular monitoring and maintenance to ensure continuous and effective operation

2.4.6. Fluid/solid separation

- Sand particles can be eliminated either by making them rise to the surface or by letting them descend to the bottom, depending on the chosen separation mechanism.
- Elimination at the bottom (sedimentation): Some sand traps are designed to allow sand particles to settle at the bottom of the structure by sedimentation.
- Elimination at the top (rising): Other sand traps are designed to encourage the rise of sand particles to the surface. This can be achieved by adjusting the water flow design or using mechanisms such as inclined lamellae that encourage the rise of particles.

The sizing calculation is performed as follows:

-**Surface**: $S = \frac{Q}{v_{asc}}$

-**Volume**: $V = \tau \times Q$

-**Height**: $H = \frac{v}{s}$

Where: S: Surface area (m^2), Q: Flow rate (m^3/s), V_{asc}: Ascension velocity of particles (m/s) (determined in the laboratory), V: Volume (m^3), τ: Retention time (days)

- Width of the grit chamber: $\boldsymbol{B} = \frac{Q}{H\,.v_t}$

-Length of the grit chamber: $\boldsymbol{L} > \frac{Q}{B.v_S}$

V_t: Maximum translation velocity in the grit chamber, **H**: Height, **V_s**: Settling velocity

Settling velocity $V_S = \frac{g(\rho_S - \rho_l)d^2}{18\mu}$

Where d: diameter of the particle, ρ_s: density of the particle, ρ_l: density of the fluid, g : acceleration due to gravity, μ: dynamic viscosity of the fluid.

Chapter 3

Clarification Treatment

3.1. Coagulation-Flocculation

Turbidity is an optical property describing how water scatters or absorbs light, affecting its clarity and color. Turbidity results from suspended particles, such as silt, clay, organic matter, and microorganisms, which prevent light from passing through the water, making it appear cloudy.

These suspended particles are often referred to as colloidal particles, which are extremely small, typically ranging in size from 0.1 to 10 micrometers (µm) in diameter. Due to their minuscule size, these particles do not settle easily and remain dispersed throughout the water column, contributing to the overall turbidity.

The three categories of impurities targeted for removal in water treatment are:

1. **Suspended Matter:** Includes sand, silt, plankton, and other particulate materials.
2. **Colloidal Materials:** Fine clays, bacteria, and macromolecules.
3. **Dissolved Materials:** Organic matter, salts, gases, and other dissolved substances.

These impurities are removed through the processes of coagulation and flocculation, which involve adding specific chemicals to the water.

Figure 9. water coagulation

If coagulation and flocculation are not performed correctly, the following issues may arise:

1. Insufficient Settling: If the floc particles produced are too small or too light, they may not settle effectively. As a result, when the water reaches the filters, it may contain a high concentration of floc particles. This can quickly clog the filters, necessitating frequent cleaning.

2. Filter Fouling: Fragile floc particles may break into smaller pieces, which can pass through the filters and compromise the quality of the treated water.

Properly managing coagulation and flocculation processes ensures the effective removal of impurities and maintains the efficiency and longevity of the filtration system.

3.2. Origin of Suspended Particles

Suspended particles in surface water originate from various sources, including:

1. **Land Erosion**: Erosion of soil and sediment from land surfaces, caused by wind, water, and other natural processes, contributes significantly to suspended particles in surface water. When rainfall or runoff occurs, it can wash away soil, sand, and silt into rivers, lakes, and reservoirs, leading to increased turbidity.
2. **Dissolution of Mineral Substances:** The weathering and dissolution of mineral substances from rocks and soil also contribute to suspended particles. As minerals break down, they can release fine particles and sediment into surface waters, adding to the turbidity.
3. **Decomposition of Organic Substances:** The breakdown of organic matter, such as plant material, dead aquatic organisms, and animal waste, produces smaller particles that become suspended in the water. As microorganisms decompose these substances, they release organic debris into the water, which can affect its clarity and quality.
4. **Sewage Spills:** In addition to natural sources, human activities contribute to suspended particles through sewage spills. Domestic, industrial, and agricultural waste can introduce a range of particles into surface waters. These spills often include organic matter, chemicals, and other contaminants, exacerbating turbidity and potentially harming aquatic ecosystems and water quality.

3.2.1. Particle Size in Suspension

Particles in suspension can be classified based on their size:

1. **Particles Greater than 1 µm**: These particles, which include both organic and inorganic materials, are relatively larger and can be more easily deposited from the water. They tend to settle out more readily compared to smaller particles.

2. **Particles Less than 1 µm:** These are classified as colloidal particles and have a much slower rate of settling. Specifically:

   a) **Mineral Matter:** Particles with high density (approximately 2.65 g/cm³) and very small diameters (less than or equal to 0.001 mm) settle very slowly and are not effectively removed by conventional settling methods.
   b) **Organic Matter:** These particles typically have a lower density and settle even more slowly than mineral particles, making them more challenging to remove through standard sedimentation processes.

3.2.2. Affinity of Colloidal Particles for Water

Colloidal particles can be classified based on their affinity for water as either hydrophilic or hydrophobic:

a) **Hydrophilic Particles:** These particles are attracted to water molecules and tend to dissolve or interact favorably with water. Their hydrophilic nature means they readily interact with and are stabilized by the aqueous environment. Typically, hydrophilic particles are organic matter, such as proteins, carbohydrates, and some types of colloidal organic substances.
b) **Hydrophobic Particles:** These particles repel water or are repelled by it, often described as "water-repellent." In this context, a hydrophobic group refers to a part of a molecule that exhibits a similar repulsive behavior towards water. Hydrophobic particles do not mix well with water and tend to aggregate or clump together in aqueous solutions. Generally, hydrophobic particles are inorganic materials, such as certain minerals and metal oxides. Hydrophobic particles do not mix well with water and often aggregate or clump together in aqueous solutions.

In reality, very few particles are exclusively hydrophobic or hydrophilic. Most particles exhibit a range of behaviors and can be classified as having varying degrees of hydrophilicity or hydrophobicity. Many particles are partially hydrated, showing a spectrum of interactions with water depending on their surface properties and environmental conditions.

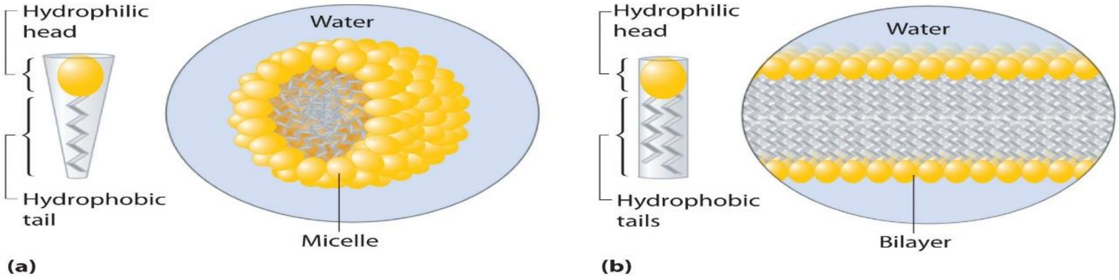


Figure 10. Affinity of Colloidal Particles for Water

3.2.3. Electric Charges and the Double Layer

Colloidal particles in raw water typically carry a negative surface charge. This charge arises due to various factors, such as the ionization of surface groups, adsorption of anions, or other surface interactions. The presence of this negative charge affects how colloidal particles interact with each other and with their surrounding environment, particularly in processes like coagulation and flocculation.

To neutralize this negative charge, positive ions (also known as counter-ions) are attracted to the colloid's surface. These counter-ions may naturally occur in the raw water, or they can be introduced intentionally during water treatment. The arrangement of these counter-ions around the colloidal particles is crucial for stabilizing or destabilizing the colloids, which in turn influences the effectiveness of water treatment processes.

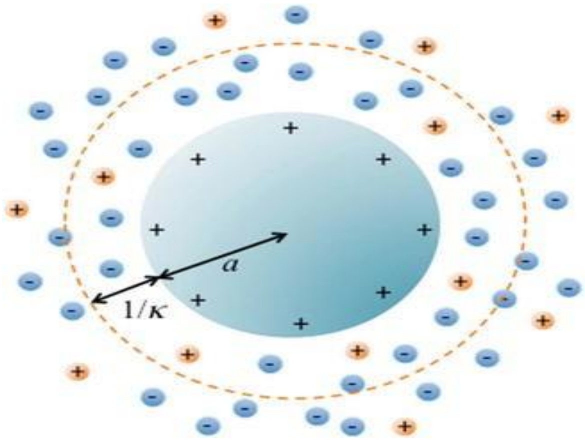


Figure 10. Electrical Double Layers

Several theories have been developed to describe how these counter-ions interact with the charged colloidal surface:

a) Helmholtz Theory

The Helmholtz theory is one of the earliest models to describe the interaction between charged surfaces and counter-ions. According to this theory, the positive ions form a uniform, tightly bound layer around the negatively charged colloid. This **fixed layer** of counter-ions neutralizes the surface charge, effectively preventing further repulsion between colloidal particles. While this model helps to explain charge neutralization, it is somewhat idealized because it assumes a perfectly uniform distribution of ions, which may not always be the case in real systems.

b) Gouy-Chapman Theory

The Gouy-Chapman theory provides a more realistic view by considering the thermal motion of ions in the solution. According to this theory, the positive ions do not form a tightly bound layer but are instead distributed more loosely around the colloid, creating a diffuse layer. The density of counter-ions is highest near the colloid’s surface and gradually decreases with distance. Neutrality is not achieved immediately at the colloid’s surface but rather at some distance away, where the concentration of positive and negative charges balances out. This diffuse layer accounts for the dynamic nature of ion distribution in the surrounding solution.

c) Stern Theory

The Stern theory combines elements of both the Helmholtz and Gouy-Chapman theories to provide a more comprehensive explanation. According to this theory, a double layer is formed around the colloid:

-**The inner layer** (often referred to as the Stern layer) consists of positive ions that are more strongly adsorbed and adhere closely to the colloid’s surface. These ions are less mobile and form a fixed layer similar to what is described in the Helmholtz theory.

- Beyond this fixed layer, there is **a diffuse layer** of positive ions that extends into the bulk of the surrounding liquid. This layer is more loosely bound and corresponds to the distribution described by the Gouy-Chapman theory. The combination of these two layers creates the overall **electric double layer** around the colloid.

Understanding these theories is essential for grasping how colloidal stability is controlled during water treatment. The application of coagulants, for instance, introduces additional positive ions to compress the diffuse layer or neutralize the surface charge entirely, leading to the aggregation of colloidal particles into larger flocs that can be more easily removed. This knowledge underpins many of the processes used in water purification, wastewater treatment, and even industrial applications where the manipulation of colloidal systems is required.

3.3. Coagulation

Coagulation is a critical process in water treatment that involves the destabilization of colloidal dispersions to facilitate the agglomeration of suspended particles into larger entities known as micro-flocs. This process is essential for improving the efficiency of subsequent treatment steps like sedimentation and filtration. In addition to agglomerating particles, coagulation also involves the precipitation of dissolved substances.

The primary goal of coagulation is to neutralize the charges on colloidal particles, thereby reducing the repulsive forces that keep them suspended in water. By destabilizing these particles, they can more easily coalesce into larger aggregates, which are more readily removed from the water. This is achieved through the rapid injection and dispersion of chemical reagents, known as coagulants, which play a crucial role in this process.

3.3.1. Coagulants Used

The main coagulants used in water treatment are typically polycationic mineral electrolytes. These substances are highly effective in neutralizing the charges on colloidal particles and promoting the formation of flocs. Among the most commonly used coagulants are aluminum and iron salts, which have been traditionally believed to function by releasing (Al^{+3}) and (Fe^{+3}) ions into the water. These ions were thought to neutralize the negative surface charges on colloids, thus encouraging coagulation.

However, recent studies have shown that the coagulation mechanisms are more complex than simple charge neutralization. The hydrolysis products of aluminum and iron salts, such as hydroxides, are more effective coagulants than the ions themselves. When these salts are added to water, they react with the water's alkalinity to form insoluble hydroxides like ($Al(OH)_3$) and ($Fe(OH)_3$), which precipitate out of solution. These hydroxides not only neutralize the colloidal particles but also create a "sweep floc" that helps to capture and settle other impurities.

Aluminum Salt Reaction (Aluminum Sulfate Example):

$Al_2(SO_4)_3 + 6\ HCO_3^- + 6\ H_2O \rightarrow 2\ Al(OH)3\downarrow + 6\ CO_2 + 3SO_4^{-2}$

Iron Salt Reaction (Ferric Chloride Example):

$FeCl_3 + 3\ HCO_3 - + 3\ H_2O \rightarrow Fe(OH)_3\downarrow + 3\ CO_2 + 3\ Cl^-$

3.3.2. Commonly Used Coagulants Include

1) **Aluminum Sulfate** ($Al_2(SO_4))_3 \cdot 14H_2O$) often referred to as alum, this is one of the most widely used coagulants in water treatment. It is effective in a broad pH range and is commonly used for the clarification of drinking water.
2) **Sodium Aluminate** ($NaAlO_2$)) - This coagulant is particularly useful in water with low alkalinity as it can increase the pH of the water while also providing the necessary aluminum ions for coagulation.
3) **Aluminum Chloride** ($AlCl_3$) this is another aluminum-based coagulant that is highly soluble and effective in neutralizing negatively charged colloids.
4) **Ferric Chloride** ($FeCl_3$) a commonly used iron-based coagulant, ferric chloride is particularly effective in wastewater treatment and industrial applications due to its strong coagulating properties.
5) **Ferric Sulfate** ($Fe_2)(SO_4))_3$this iron salt is used similarly to ferric chloride and is effective over a wide range of pH conditions.
6) **Ferrous Sulfate** ($FeSO_4$) - Although less commonly used than ferric salts, ferrous sulfate can be an effective coagulant, particularly in the treatment of wastewater with high organic content.

7) **Copper Sulfate** ($CuSO_4$) - While primarily used as an algicide, copper sulfate can also function as a coagulant in certain water treatment processes.
8) **Polyelectrolytes** these are synthetic organic polymers that can function as coagulants or coagulant aids. Polyelectrolytes can be either cationic, anionic, or nonionic, and they work by bridging and binding colloidal particles together, enhancing floc formation.

The choice of coagulant depends on the specific characteristics of the water being treated, including its pH, alkalinity, turbidity, and the presence of other dissolved substances. The effectiveness of coagulation is crucial for the overall efficiency of water treatment processes, ensuring the removal of impurities and the production of clean, safe drinking water.

3.4. Flocculation

Flocculation encompasses all the transport mechanisms that facilitate the movement of destabilized particles, leading to their collision and subsequent aggregation into larger flocs. These flocs are then easier to settle and remove from the water during the treatment process. The efficiency of flocculation is primarily influenced by two factors: the rate of particle collisions and the effectiveness of these collisions in forming stable aggregates.

The collision rate between particles is influenced by factors such as the turbulence in the water, the concentration of particles, and the mixing intensity. In water treatment, controlled agitation is typically used to enhance the frequency of collisions, promoting the formation of flocs.

Even if particles collide frequently, flocculation will only be effective if these collisions lead to the successful aggregation of particles. This depends on the surface properties of the particles, including the presence of coagulants or flocculants that can help bind them together.

Flocculation is a crucial step following coagulation, where coagulants have already neutralized the charges on particles, reducing the repulsive forces that keep them suspended. During flocculation, the destabilized particles are brought into contact with each other, and through gentle mixing, they collide and stick together, forming larger and heavier aggregates.

These larger flocs are more likely to settle out of suspension under gravity during the sedimentation phase, or they can be more effectively filtered out of the water in subsequent treatment steps. The effectiveness of flocculation directly impacts the overall efficiency of water treatment, as poor floc formation can lead to inadequate removal of impurities, resulting in water that is not sufficiently clarified.

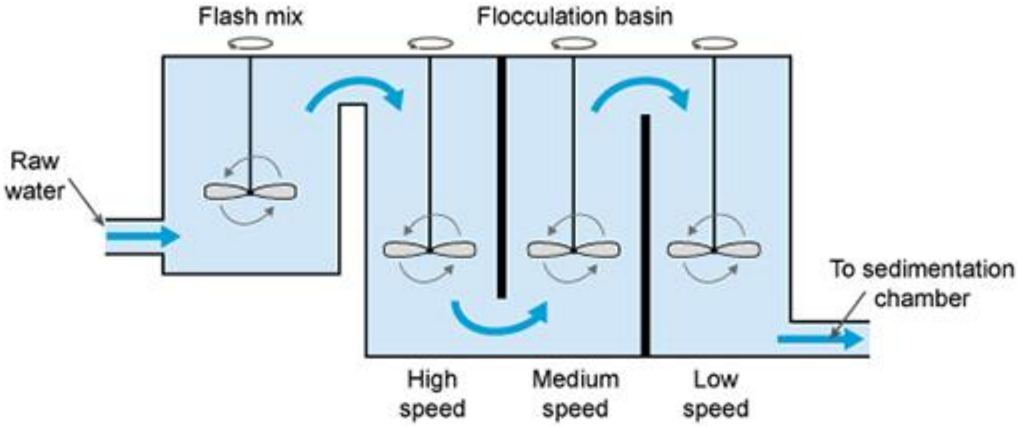


Figure 11. floculation chamber

3.4.1. Calculating the Volume of a Flocculator

The effectiveness of coagulation is directly related to the probability of contact between particles, which is why the fluid is agitated during the process. Agitation promotes the collision and subsequent aggregation of particles, leading to the formation of larger flocs that can be more easily removed from the water.

According to the Smoluchowski equation, which models the kinetics of particle aggregation, and for a target of reducing pollution by 50%, the required volume of the flocculator can be calculated based on the desired level of particle interaction and the specific conditions of the water treatment process.

After integrating the previous equation, we obtain the time necessary for the concentration of suspended particles to be reduced by half using the following relation:

$$\frac{dN}{dt} = -\frac{2}{3} G\, d_{pr}^{3} N^{2}$$

With: $\frac{dN}{dt}$ Collision rate between particles, G: Speed gradient, N: Number of particles, d_{pc}: Particle diameter.

Fine particles are therefore much more numerous than coarse particles, and generally 1µm < d_{pc} < 3µm.

This relation helps in determining the time required to achieve a 50% reduction in the concentration of suspended particles, which is crucial for effective water treatment.

After integrating the previous equation, we obtain the time necessary for the concentration of suspended particles to be reduced by half using the following relation:

$$\tau = \frac{3}{2G d_{pc}^{3}} \frac{1}{N_0}$$

N_0: Total concentration of suspended particles at time (t = 0) number of particles per cubic meter m^3.

This equation helps in determining the necessary parameters such as the rate of particle collisions, the concentration of particles, and the time needed to achieve the desired reduction in pollution. By optimizing these variables, the design of the flocculator can be tailored to ensure efficient coagulation and flocculation, leading to effective water treatment.

3.4.1.1. Variation of the Speed Gradient (G) Depending on Particle Diameter

In flocculation, the speed gradient (G) is an important factor that varies depending on the particle diameter. The recommended stirring speeds for effective flocculation typically range between 20 and 30 s^{-1}. This range is optimal for promoting the aggregation of particles into larger flocs without causing them to break apart.

The appropriate speed gradient ensures that the particles have sufficient energy to collide and stick together, forming stable flocs that can be more easily removed in subsequent treatment processes.

3.4.1.2. Calculating Power Requirements in a Classic Flocculator

In a classic flocculator, agitation is achieved by a set of blades aligned parallel to the axis of rotation, with these blades rotating at a constant speed. The power required from these blades to achieve a desired speed gradient can be calculated using the following equation:

$$P = \frac{1}{2} C_d A \rho v^3$$

With: P transmitted power (W), C_d = drag coefficient (1.8 for flat blades), A blade surface area (m^2), ρ liquid density (kg/m^3), v = relative speed of the blade compared to the liquid speed, approximately $\approx 0.75 \times \ blade\ speed\ (m/s)$

3.4.2. Principle of Coagulant Dosage

To determine the appropriate dosages for effective coagulation and flocculation, the "**Jar Test"** is commonly used. The Jar Test procedure involves preparing a series of beakers with water to be treated, including a control sample. First, the optimal pH for a given coagulant is determined by adjusting the pH of each beaker to different values, adding the same concentration of coagulant, and stirring the beakers at varying speeds to promote floc formation and sedimentation. After allowing the flocs to settle, the optimal coagulant concentration is determined by repeating the test at the ideal pH while using different coagulant dosages. The effectiveness is assessed by measuring the residual turbidity in each beaker.

Figure 12. Jar test

3.5. Decanting (settling)

Decantation, or settling, is a fundamental physical process used in water treatment and other applications to separate solid particles from liquids. This process relies on the natural tendency of particles with a density greater than that of water to settle out of suspension under the influence of gravity.

The process begins when a mixture of solids and liquids is allowed to rest in a basin or settling tank. Over time, the heavier solid particles begin to descend toward the bottom of the basin, while the lighter liquid remains above. This separation is known as solid/liquid separation and is driven by gravity.

The effectiveness of decantation depends on several key factors:

1. **Reduction of Horizontal Velocity**: The process is most effective when the horizontal flow speed of the water is reduced. This reduction ensures that the vertical settling speed of the particles is greater than the horizontal movement of the water. When this condition is met, particles have a higher chance of overcoming the resistance of the fluid and settling at the bottom of the basin.
2. **Sedimentation of Particles**: As particles settle, they accumulate in a designated collection zone at the basin's bottom, known as a sediment trap. This accumulation forms a layer of sediment, which must be periodically removed to maintain the efficiency of the decantation process.
3. **Extraction of Decanted Water:** The liquid that remains at the surface, now clearer and with fewer suspended solids, is called decanted water. This water is typically collected and may undergo further treatment depending on the application.

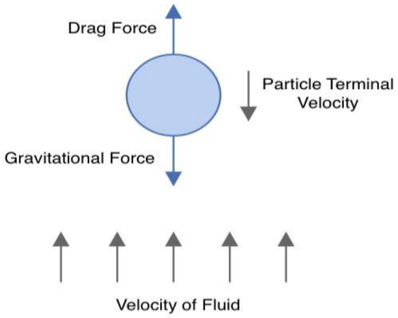


Figure 13. Terminal Velocity of Particles for Gravity Separation

3.5.1. Forces Acting on Particles

In the decantation process, each particle in the liquid is subject to two primary forces:

1. **Gravity:** Gravity acts as the driving force, pulling particles downward toward the bottom of the basin. This force enables the particles to separate from the liquid by falling due to their greater density.
2. **Friction Forces**:As particles move through the liquid, they encounter frictional resistance from the fluid. These forces work against gravity, slowing the particle's descent. The interplay between gravity and friction determines the rate at which particles settle.

3.5.2. Key Factors Influencing Sedimentation

Several factors influence the efficiency of sedimentation during the decantation process:

1. **Density Difference**: The greater the difference in density between the solid particles and the liquid, the more effectively the particles will settle. Heavier particles tend to fall more quickly.
2. **Particle Size:** Larger particles generally settle faster than smaller ones due to their greater mass and reduced susceptibility to frictional forces. However, for very fine particles (a few microns in size), sedimentation becomes challenging as their small mass leads to a slower settling velocity.
3. **Viscosity of the Fluid**: The viscosity, or thickness, of the liquid also plays a crucial role. Higher viscosity fluids offer greater resistance to the movement of particles, reducing their settling speed. In contrast, lower viscosity fluids allow particles to settle more readily.

3.5.3. The Balance of Forces in Particle Settling

When a particle is suspended in water, it is subjected to two primary forces:

1. **Driving Force**: This force is the result of gravity, reduced by the buoyant force (Archimedes' thrust). The gravitational force acts downward, pulling the particle toward the bottom of the basin. It is the driving force that causes the particle to settle.

2. **Resisting Force**: This force opposes the movement of the particle and is a result of fluid drag. The fluid drag is a combination of the viscous and inertial forces exerted by the fluid on the particle.

The interaction between these forces determines the settling velocity of the particle:

1. **Gravitational Force (G):** This is the driving element that propels the particle downward. It is calculated as the difference between the gravitational force acting on the particle and the buoyant force exerted by the fluid.
2. **Drag Force (R):** As the particle moves through the fluid, it experiences resistance, known as drag force. This resistance is described by Newton's law and is influenced by the viscosity of the fluid and the particle's speed.

3.5.4. Key Equations

a) **Fall Speed of the Particle**: The balance of forces acting on a particle moving relative to a fluid determines its fall speed. The fall speed is the velocity at which the downward gravitational force is balanced by the upward drag force.

$I(= ma) = -R + G - P = 0$-

Where: I The inertial force acting on the particle, R The flow resistance force or drag force, G The gravitational force on the particle, P The pushing force of the liquid on the particle.

b) **Flow Resistance Force**: The flow resistance force (R) is generally described by Newton’s equation, which includes:

$R = C_D A_P \frac{\rho_l v^2}{2}$

A_p is the projected surface area of the particle in the direction of the current.

The drag coefficient (CD) depends on the Reynolds number, which varies with the type of flow around the particle (laminar or turbulent).

The Reynolds number itself is a dimensionless quantity that describes the relative importance of inertial versus viscous forces in the fluid $Re = \frac{du}{\eta} = \frac{\rho du}{\mu}$

Where: η kinematic viscosity (m2/s) μ dynamic viscosity (Pa.s)

c) limit fall speed

The interplay between these forces determines the particle's settling velocity (V). When the forces are balanced, the particle reaches a limit fall speed (V_{lim}), where it continues to settle at a constant velocity without further acceleration.

3.5.4.1. Laminar Regime (Stokes' Law):

In the laminar regime, where the flow around the particle is smooth, the drag force is proportional to the velocity of the particle. Stokes' Law applies, and the settling velocity is given by: $v_{lim} = \frac{g(\rho_{s-}\rho_l)d^2}{18\mu}$

Where:

ρ_p= Density of the particle

ρl= Density of the fluid

g = Acceleration due to gravity

d = diameter of the particle

µ= **D**ynamic viscosity of the fluid

3.5.4.2. Intermediate Regime (Allen's Law):

In the intermediate regime, the flow is neither fully laminar nor fully turbulent. The drag force increases more rapidly with velocity, and the settling velocity is determined by a more complex relationship, often described by Allen's law:

$$v_{lim} = \alpha \frac{(\rho_{s-}\rho_l)^{2/3}}{\rho_l\sqrt{v}} d$$

3.5.4.3. Turbulent Regime (Newton-Rittinger Law)

In the turbulent regime, where the flow around the particle is chaotic, the drag force is proportional to the square of the velocity. The settling velocity is described by the Newton-Rittinger law:

$$v_{lim} = \alpha\sqrt{\frac{(\rho_{s-}\rho_l)d}{\rho_l}}$$

3.5.4.4. Troubled fall Correction for Viscosity:

The viscosity of the fluid is also a crucial factor in determining the resisting force. In troubled fall conditions, viscosity may vary due to changes in temperature or the presence of suspended solids or dissolved gases. The viscosity correction is particularly important in non-Newtonian fluids, where the relationship between shear stress and shear rate is nonlinear. The corrected viscosity equation takes into account the fraction of liquid which represents the proportion of liquid influencing the viscosity:

$\rho_l^* = (1-x)\rho_s + x\rho_l$.......1 $\rho_s - \rho_l^* = x(\rho_s - \rho_l)$.........2 $\mu^* = \mu\frac{10^{1,82}(1-x)}{x}$.......3

After correction, the fall speed in “Troubled fall” becomes

$$v_{lim} = \frac{g\,x^2(\rho_{s-}\rho_l)d^2}{18\ 10^{1.82}\mu(1-x)}$$

3.5.4.5. The Settling Tanks

In general, the design and sizing of settling tanks involve determining two main parameters:

1. **Surface Area of the Decanter:** The surface area must be large enough to accommodate low settling velocities. The larger the decanter surface, the better it can handle weaker decantation speeds.
2. **Depth of the Basin:** The depth determines the residence time of the suspension in the tank. This time must be sufficient to allow the formation of sludge at the bottom of the tank.

3.5.5. Types of Decanters

There are two main types of decanters:

3.5.5.1. Simple Decanter

Simple decanters are characterized by a settling surface equal to the base area of the tank. The most basic decanter consists of a parallelepiped tank with an inlet zone and two outlet zones (one for overflow and the other for sludge removal). There are two types of simple decanters:

3.5.5.1.1. Horizontal Flow Decanters

In horizontal flow decanters, the design ensures that particles have enough time to reach the bottom before the water exits the structure. The main characteristics of a horizontal decanter include:

- **Flow Rate (Q):** The rate at which water flows through the tank.
- **Surface Area (S):** The surface area of the decanter.
- **Height (h):** The height between the open water surface and the sludge zone.

The retention time in the decanter is defined by the relationship between these parameters. A suspended particle entering the decanter settles at a constant velocity (V_0). The decantation process is complete when the particle reaches the base, with a fall duration equal toh/V_0. Particles will only settle if the retention time t>h/V_0or even $V_0 > \frac{Q}{S}$.

The term $Q/S$is known as the **Hazen velocity**.

Theoretically, the efficiency of a horizontal decanter depends only on its Hazen velocity and not on its height or retention time. Generally, this velocity ranges between 0.5 and 1.5 m/h. However, particles in the flocculated water entering the decanter vary in size. As they travel through the structure, smaller particles may aggregate through coalescence, increasing in size and settling rate over time. This causes a curvilinear trajectory, meaning decantation efficiency also depends on the retention time.

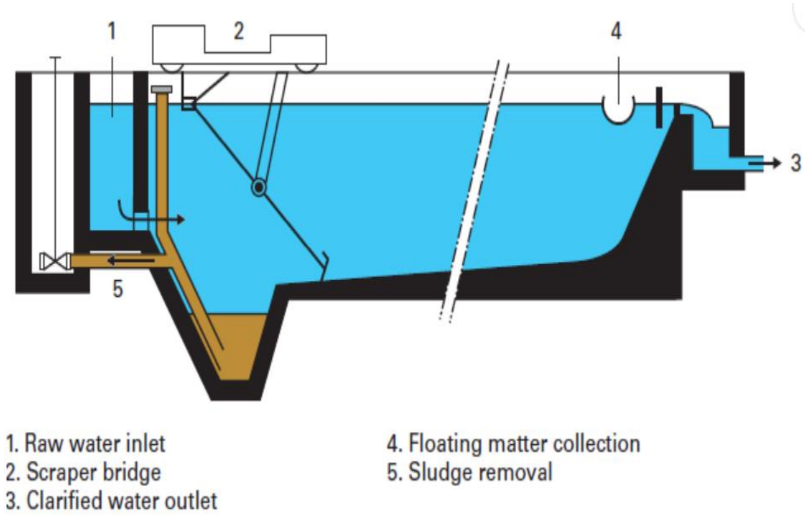


Figure 14. Horizontal Flow Decanters

There are two types of particles:

1. **Grainy Particles:** These particles settle independently with a constant fall speed.
2. **Flocculated Particles:** These have variable sizes and fall speeds. At low concentrations, the fall speed increases as the flocs grow larger through encounters with other particles, a process known as **diffuse settling**.

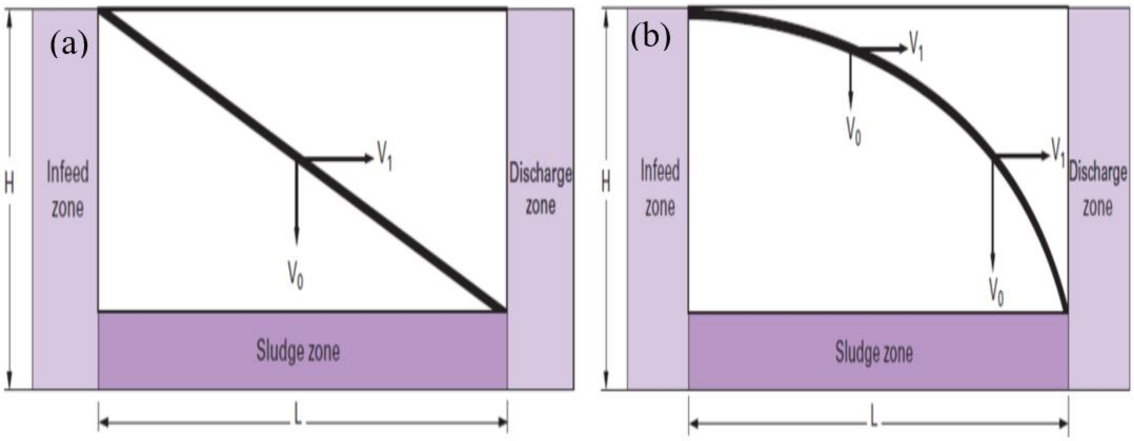


Figure 15. Schematic diagram of a horizontal flow sedimentation application (a: granular particles) (b: flocculated particles)

3.5.5.1.2. Vertical Flow Decanters

In vertical flow decanters, water flows in a vertical path, and the fall speed of particles is opposed by a force resulting from the combined effects of fluid friction and the rising velocity of the water.

All vertical decanters utilize a **sludge veil** due to this balance of speeds, regardless of whether a flocculator is used. The sludge veil plays a crucial role, acting as a filter for smaller flocs. Within the sludge veil, coalescence occurs, where particles combine to form larger aggregates. Vertical decanters typically have a conical or pyramid shape, which facilitates easier control of the sludge veil.

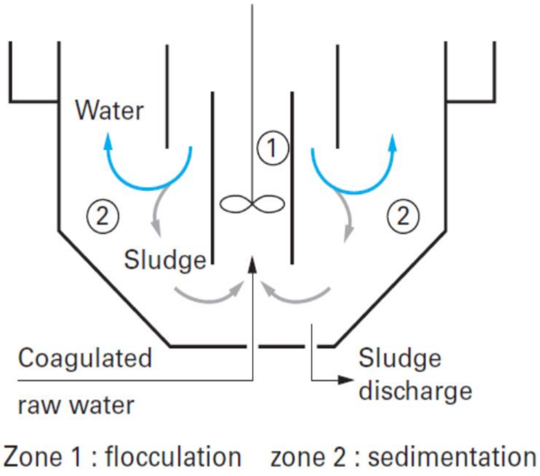


Figure 16. Vertical Flow Decanters

Vertical decanters can be classified into the following categories:

1. **Static Decanters:** These rely solely on gravity for particle settling.
2. **Sludge Circulation Decanters:** These incorporate mechanisms to enhance the circulation of sludge.
3. **Sludge Bed Decanters:** These feature a bed of sludge that aids in the settling process.

3.5.5.2. Cylindrical Decanters

Cylindrical decanters are characterized by a fixed mechanism support bridge attached to the edge of a cylindrical tank. The drive unit, mounted in the center of the support, powers a scraping mechanism consisting of a vertical shaft and two arms equipped with scrapers. These scrapers help collect and remove settled sludge from the bottom of the tank.

Cylindrical decanters are often used in situations where continuous sludge removal is necessary, and they are designed to maintain efficient sedimentation while minimizing the disturbance to the settled sludge.

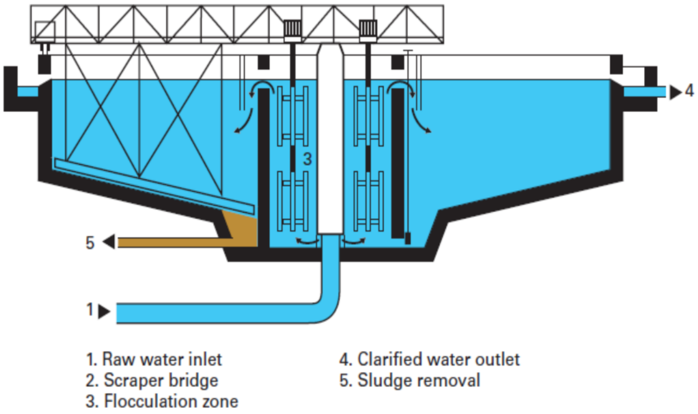


Figure 17. Cylindrical Decanters

3.5.5.3. *Lamellar Decanter*

Lamellar decantation operates on the principle that, according to Hazen's law, the retention of a grainy particle in free decantation is independent of the height of the structure. This allows for a significant increase in the surface area available for decantation by stacking multiple water/sludge separation cells vertically within the structure.

Lamellar decanters typically include a series of lamellae, which multiply the useful settling surface while reducing the floor space required compared to a classic horizontal flow decantation basin.

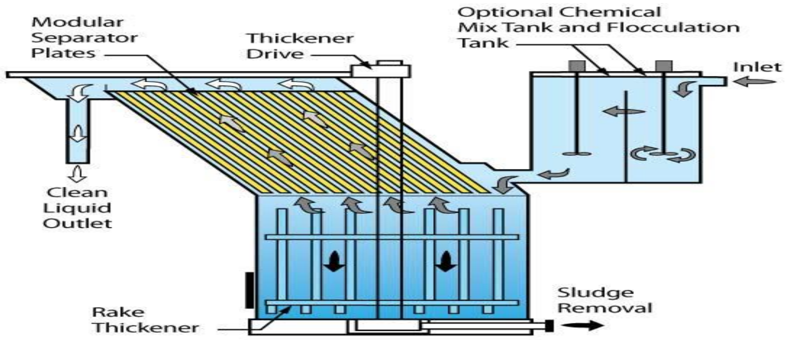


Figure 18. Lamellar Decanter

3.5.5.3.1. Design and Structure

In theory, the capacity of a decanter can be increased indefinitely by reducing the height between the levels. However, in practice, a sufficient distance must be maintained between each layer to allow for the accumulation of a certain amount of sludge. Generally, the height between each layer is approximately 5 cm.

There are many models of lamellar (or lamella) decanters available, including:

1. **Flat Plates**: Simple, flat surfaces.
2. **Corrugated Plates**: Textured surfaces for enhanced flow.
3. **Tubes**: Round, square, or hexagonal modules.

3.5.5.3.2. Implementation

To ensure the gravity-driven evacuation of settled sludge, the lamellae are inclined at an angle θ relative to the horizontal. The diagram below illustrates this principle for a network of parallel plates and shows the equivalent settling surface area on the ground.

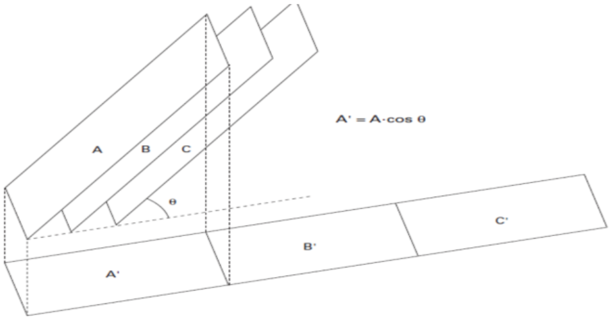


Figure 19. Lamellar plate sedimentation: cumulative effect of the unit surface areas

The characteristic equations of the lamellar decanter are as follows:

$$s_{tp} = \frac{Q}{v_H} \quad s_{tp} = n.L_p.l_p.cos\theta$$

Where S_{TP}: total projected surface area (which is the ground projection of the settling surface area).

l_p: width of the lamellae.

L_p: length of the lamellae.

n: total number of lamellae in the lamellar settling stage.

θ: inclination of the plates.

The **Hazen velocity** is calculated based on the projected surface area of all the lamellar elements: $v_h = \frac{Q}{n\, S_L COS\theta}$

$$S_L = l_P \times L_p$$

Where:

- $S_L$is the elementary surface area of each lamella.

3.5.5.3.3. Types of Lamellar Settling

Three types of lamellar settling configurations are possible:

1. **Counter-Current Flow**: In this configuration, water and sludge flow in opposite directions (water flows upwards at speed V_0 while sludge flows downwards). Upon entering the system, the path of a particle is the resultant of $V_0$and its settling speed u.
2. **Cross-Current Flow**: Here, water and sludge flow perpendicular to each other, with water moving horizontally and sludge descending from top to bottom.
3. **Co-Current Flow**: In this configuration, water and sludge flow in the same direction, both moving from top to bottom.

3.5.5.3.4. Choosing the Type of Lamellar Bundles

The effectiveness of a lamellar system is influenced by several parameters:

1. **Hydraulics**: The shape of the lamellae must facilitate the transition from a turbulent flow regime (at the lamellae inlet) to a laminar flow (within the lamellae). It's important to avoid support systems that use spacers, as they can disrupt flow and settling.
2. **Distribution of Water in the Decantation Cell**: Each cell must receive an equal flow to prevent overspeeding, which can degrade decantation efficiency.
3. **Slat Spacing**: The spacing must be sufficient to prevent clogging by settled sludge and to allow for easy cleaning, if necessary.

3.6. Filtration

Filtration is a separation process that involves passing a solid-liquid mixture through a porous medium, also known as a filter. The filter's primary function is to retain solid particles while allowing the liquid (referred to as the filtrate) to pass through. This process is fundamental in water treatment, as it helps remove suspended solids, contaminants, and other impurities from water to make it safe for consumption and use.

3.6.1. Filter Material

Various filter materials are used depending on the type of filter:

- **Fiber Fabrics and Metal Mesh**: Made from carbon fiber fabrics, metal mesh, or porous stones with very fine interstices. These materials retain solids on the surface and are rarely used for treating large quantities of water.
- **Free Granules**: These do not adhere to each other and are insoluble, meaning they are not affected by the filtered liquid or the solids that settle on them.
- **Glass Bead Filter Media:** Used for filtration processes that occur either on the surface or in depth, depending on the granulometric characteristics of the filter material, and the size and cohesion of the suspended solids. Sand, anthracite, and ilmenite are commonly used in water treatment plants.

3.6.2. Different Types of Filtration

3.6.2.1. Surface Filtration

In surface filtration, a filter medium with a pore size smaller than the particles in the suspension is selected, typically less than 50 micrometers (µm). This process effectively removes larger particles from a liquid but can result in rapid clogging of the filter. The accumulation of particles on the filter surface requires frequent cleaning and occasional stoppage of the filtration process to maintain efficiency.

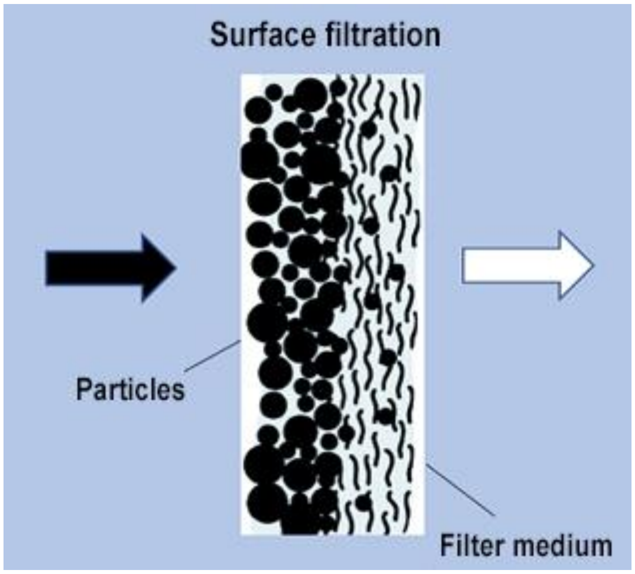


Figure 20. Surface filtration

3.6.2.2. Depth Filtration

Depth filtration involves directing the flow of the suspension parallel to the filter medium's surface. This method applies a shear rate to prevent particles from settling in the pores of the filter. It is considered a relatively coarse filtration method, usually performed using a thin support material like metal or plastic fabric or filter elements with regular orifices. Depth filtration is particularly effective for clarifying water and removing larger suspended solids.

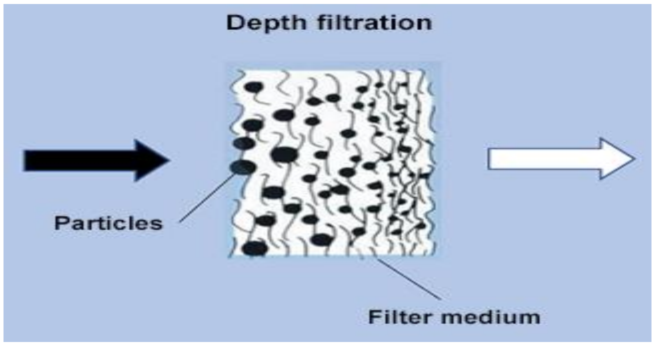


Figure 20. Depth filtration

3.6.2.3. Average Filtration

Average filtration combines elements of both surface and depth filtration. In this method, the filter medium retains particles of varying sizes throughout its structure, not just on the surface. This approach allows for a balance between retaining larger particles on the surface while smaller particles are trapped deeper within the medium. It provides moderate filtration efficiency and is less prone to clogging than surface filtration, requiring less frequent cleaning and maintenance**.**

3.6.2.4. Cross-Flow Filtration

Cross-flow filtration involves the suspension flowing parallel to the filter membrane. This method is characterized by a high shear rate along the filter surface, which helps prevent the accumulation of particles that would otherwise clog the filter. The continual flow of liquid across the surface washes away debris and maintains filter efficiency. This method is commonly used in applications where maintaining a continuous filtration process is crucial, such as in the separation of proteins or in microfiltration and ultrafiltration processes.

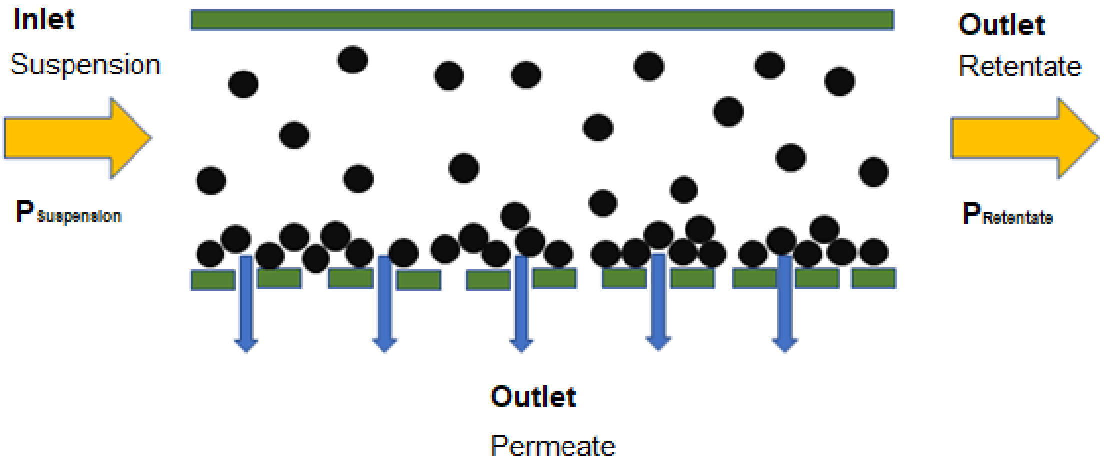


Figure 21. Cross-Flow Filtration

3.6.2.5. Cake Filtration

Cake filtration occurs when particles accumulate on the surface of the filter medium, forming a layer or "cake." As the cake layer builds up, it acts as an additional filter, trapping even finer particles. This process is particularly effective for suspensions with high solid content. However, as the cake layer thickens, it increases resistance to flow, requiring periodic removal to maintain filtration rates. Cake filtration is often used in industrial applications, such as wastewater treatment, where solid-liquid separation is needed.

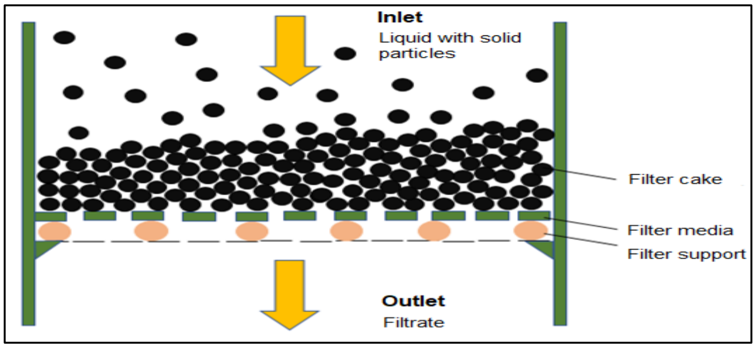


Figure 22. Cake filtration

3.6.3. Filtration Mechanisms

Filtration processes rely on three main mechanisms that act sequentially: capture, fixation, and detachment. The effectiveness of each mechanism depends on the characteristics of the particles to be retained and the type of filter material used.

3.6.3.1.1. Capture Mechanisms

a) Mechanical Screening:

This process involves the retention of particles that are larger than the openings in the filter mesh or larger than the spaces between already-deposited particles, which themselves can form a secondary filter layer. Mechanical screening is most effective for removing larger particles that are physically unable to pass through the filter due to size exclusion.

b) Retention in Intergranular Spaces:

Even if a particle is smaller than the filter pores, it can still be captured due to the tortuous path it takes through the filter bed. The particle may encounter areas of lower velocity and make contact with the filter material. These contacts, along with the intricate pathways, increase the chances of the particle being captured, even if it could theoretically pass through larger pores.

3.6.3.1.2. Fixation Mechanisms

The attachment of particles to the surface of the filter material is primarily influenced by the flow velocity and various forces. Lower flow velocities enhance the likelihood of particles adhering to the filter media. The fixation of particles is governed by:

a) Physical Forces:

These include mechanical interlocking (jamming) and cohesion, where particles are held in place by physical barriers or by the accumulation of other particles around them.

b) Adsorption Forces:

These are mainly Van der Waals forces, which weak electrical interactions are occurring between molecules with a dipole moment. These forces cause particles to adhere to the surface of the filter material at a molecular level, even when the physical forces are not strong enough to retain them alone.

3.6.3.1.3. Detachment Mechanisms

Detachment occurs when particles that were previously fixed to the filter material are released. This can happen due to several factors:

a) **Increased Flow Rate**: As the filtration progresses and particles accumulate, the flow rate between the particles and the walls of the filter material increases. This can exert sufficient force to dislodge particles that were loosely attached.
b) **Reduction in Particle Retention Space:** As more particles are deposited, the available space between the filter media becomes reduced, causing a higher velocity in the remaining pathways. This increased velocity can lead to the partial detachment of previously captured particles, which can then be carried deeper into the filter material. This phenomenon is known as the progression of the "filtration front."
c) **Breakthrough or "Puncture":** This occurs when detached particles move through the filter and end up in the filtrate. This usually indicates that the filter media is no longer effectively capturing particles, either due to clogging or wear.

3.6.4. Sand Filtration

Sand filtration is a common method used in the treatment of drinking water to remove suspended solids, turbidity, and microorganisms. There are two main types of sand filtration used in water treatment:

3.6.4.1. Rapid Sand Filtration

Rapid sand filtration is the most commonly used method in water treatment plants. It involves passing water through a sand bed at high filtration rates, typically between 2 to 20 meters per hour (m/h). This method is favored for its high efficiency and capacity to process large volumes of water quickly.

Advantages:

- High filtration rate allows for the treatment of large volumes of water.

- Requires less space compared to slow sand filters, making it suitable for urban and industrial applications.

- Effective in removing suspended solids and turbidity quickly.

- The filter can be cleaned relatively easily through backwashing, which involves reversing the flow of water to dislodge and remove accumulated particles.

Disadvantages:

- Requires regular maintenance and backwashing to prevent clogging and maintain efficiency.
- Not as effective at removing bacteria and viruses unless used in conjunction with other treatment processes like coagulation and disinfection.

3.6.4.2. Slow Sand Filtration

Slow sand filtration is a simpler filtration method in terms of construction and operation, with a filtration rate typically ranging from 0.5 to 15 meters per day (m/d). Water passes slowly through a bed of sand, allowing for the gradual removal of particles, microorganisms, and organic matter.

Advantages:

- Simple to construct and operate with minimal mechanical components.
- Highly effective in removing pathogens, including bacteria, viruses, and protozoa, due to the biological layer that forms on the top layer of the sand, known as the "schmutzdecke."
- Low operational costs since it does not require chemical coagulation or frequent backwashing.
- Provides long-term and sustainable filtration, particularly suitable for rural areas and communities with limited resources.

Disadvantages:

- Requires large land areas, making it less suitable for densely populated or space-limited regions.
- Slower filtration rate compared to rapid sand filtration, limiting the volume of water that can be treated.

- The filter bed requires periodic removal and replacement of the top layer of sand to maintain filtration efficiency.

3.6.5. Characteristics of Filter Materials

The performance of sand filters depends on the characteristics of the filter media used. The main characteristics of filter materials include:

3.6.5.1. Effective Diameter (DE or D10) or Effective Size (ES)

The effective diameter, or D10, is the grain size at which 10% of the material is finer by weight. It determines the filter's ability to capture smaller particles; smaller effective sizes capture finer particles but may increase the risk of clogging.

3.6.5.2. Uniformity Coefficient (UC)

The uniformity coefficient is the ratio of D60 (the grain size at which 60% of the material is finer) to D10. It indicates the range of grain sizes present in the filter media. A lower UC means the grains are more uniform in size, leading to more consistent filtration performance.

3.6.5.3. Relative Density

Relative density (specific gravity) is the density of the filter material relative to water. It affects how the filter media settles and resists fluid flow and is critical for stability during filtration and backwashing processes.

3.6.5.4. Dry Unit Mass (Maximum and Minimum)

Dry unit mass refers to the weight of the filter material per unit volume in its dry state. This property influences the amount of material needed for the filter bed and impacts the bed's ability to retain particles.

3.6.5.5. Porosity (Maximum and Minimum)

Porosity is the measure of the void spaces in the filter media and is expressed as a percentage of the total volume. High porosity means more space for water to flow through and potentially greater particle retention capacity. The maximum porosity indicates the highest void space in loosely packed media, while the minimum represents the densest packing.

3.6.6. Basic Equations for Sand Filtration

The flow of water through a filter bed and the associated pressure loss can be described by several equations:

3.6.6.1. Darcy's Equation for Instantaneous Flow Rate (Q)

Darcy’s law describes the flow of a fluid through a porous medium. The flow rate Q is proportional to the pressure drop ΔP, the cross-sectional area ω, and inversely proportional to the viscosity μ of the fluid: $Q = \frac{\Delta P . \omega}{\mu \, L}$

Where: L Length or thickness of the filter bed (m), ω Filtration surface area (m^2), μ Dynamic viscosity of the fluid (Pa·s), ΔP: Pressure drop across the filter (Pa)

3.6.6.2. Kozeny-Carman Equation

This equation refines Darcy’s law by incorporating the specific surface area of the filter grains and the porosity of the filter bed:

$$\Delta p = \frac{150. \ (1-\varepsilon)^2 \, .\mu \, .L. \ u}{d_p^2 \ \varepsilon^3}$$

Where: ε Porosity of the filter medium, L Depth of the filter bed, u Superficial fluid velocity, Δp Equivalent pore diameter, μ Viscosity of the fluid

3.6.6.3. Ergun Equation

The Ergun equation is a more generalized form that applies to both laminar and turbulent flow conditions within packed beds. It combines Darcy's law for low velocities with a term accounting for kinetic energy loss at higher velocities:

$$\Delta p = \frac{150. \ (1-\varepsilon)^2 \, . \mu \, .L. \ u}{d_p^2 \ \varepsilon^3} + \frac{1.75. \ (1-\varepsilon) \quad .\rho \, .L. \ u^2}{d_p \ \varepsilon^3}$$

Where: ρ Density of the fluid

The second term represents the pressure loss due to kinetic energy, which becomes significant at higher flow rates.

3.6.6.4. Pressure Loss in Sand Filtration

During filtration, water loses energy as it flows through the granular filter bed due to friction, known as pressure loss.

1. **At Low Speeds (Laminar Flow):** Pressure loss is governed by Darcy's law, which states that the pressure drop ΔP is directly proportional to the fluid's velocity, viscosity, and bed height, and inversely proportional to the medium's permeability.
2. **At Higher Speeds (Turbulent Flow):** As the flow rate increases, the flow can become transient or fully turbulent, necessitating the use of the Ergun equation to account for both viscous and inertial effects.

3.6.7. Technical Considerations for Granular Material Filters

When dealing with different types of granular material filters, two technical considerations are crucial:

Terms of Service: The operational parameters that define how the filter will function during its use.

Internal Washing Arrangements: The mechanisms and processes used to clean the filter material to ensure continued effectiveness and efficiency.

3.6.7.1. Cycles of Operation

Almost all granular material filters operate in cycles. These cycles involve a filtration period, where the water is filtered through the granular medium, followed by a cleaning phase called backwashing. During backwashing, water is flushed through the filter in the opposite direction to remove accumulated impurities and rejuvenate the filter medium.

3.6.7.2. Returning to Service

After backwashing, when the filter is put back into service, it is critical to avoid excessive flow from the freshly cleaned filter. This helps prevent a sudden release of any remaining impurities and maintains the integrity of the filtration system. Proper control measures must be in place to regulate the flow when reintroducing a cleaned filter to the filtration process.

3.6.7.3. Choice of Filtration Mode

The selection between different filtration types, such as support filtration or granular bed filtration, depends on several factors:

1. **Characteristics of the Liquid**: This includes the type of liquid to be filtered, the nature of its impurities, and how these characteristics might change over time.
2. **Quality of the Filtrate:** The desired quality of the filtered water and any allowable tolerances play a significant role in choosing the appropriate filtration method.
3. **Installation Conditions:** The specific conditions at the installation site, such as space availability, climate, and infrastructure, must be considered.
4. **Washing Capabilities:** The ability to wash the filter efficiently and economically is just as crucial as achieving optimal filtration quality. This includes assessing the ease and effectiveness of backwashing the filter medium to remove trapped impurities.

3.6.8. Rapid Sand Filtration

Rapid sand filtration is the most common type of filtration used for treating drinking water due to its efficiency and practicality.

1. **Mechanism:** The filter material, typically sand, is held in place by gravity, and water flows from top to bottom through the sand layer. Over time, as the sand traps impurities, the filter becomes clogged.
2. **Cleaning Process:** Once the filter medium is clogged, the system undergoes backwashing. During this process, water flow is reversed, causing the sand bed to expand and the trapped impurities, which are less dense than the sand grains, to be flushed out and removed through washing chutes.

3.6.8.1. Configurations of Rapid Sand Filters

Rapid sand filters are widely used in water treatment due to their efficiency in removing suspended particles from water. They can be installed in two main configurations based on the operating mechanism and the specific requirements of the water treatment facility:

3.6.8.1.1. Open Systems

Open systems, also known as gravity filters, operate under gravity flow, meaning that the water flows downward through the filter media due to the force of gravity. The characteristics of open systems are:

Flow Rates: These filters typically operate at flow rates ranging from 1 to 20 meters per hour (m/h), depending on the specific design and requirements of the water treatment plant. The flow rate is controlled by the head of water above the filter media and the resistance of the filter bed.

Operation and Maintenance: Open systems are simpler to operate and maintain compared to closed systems. The water level above the filter bed provides a visual indication of the filter's status, and any changes in water clarity can be quickly observed.

Applications: These filters are commonly used in municipal water treatment plants for drinking water purification, where the focus is on removing suspended solids and turbidity. They are particularly suitable for large-scale operations due to their simplicity and ease of maintenance.

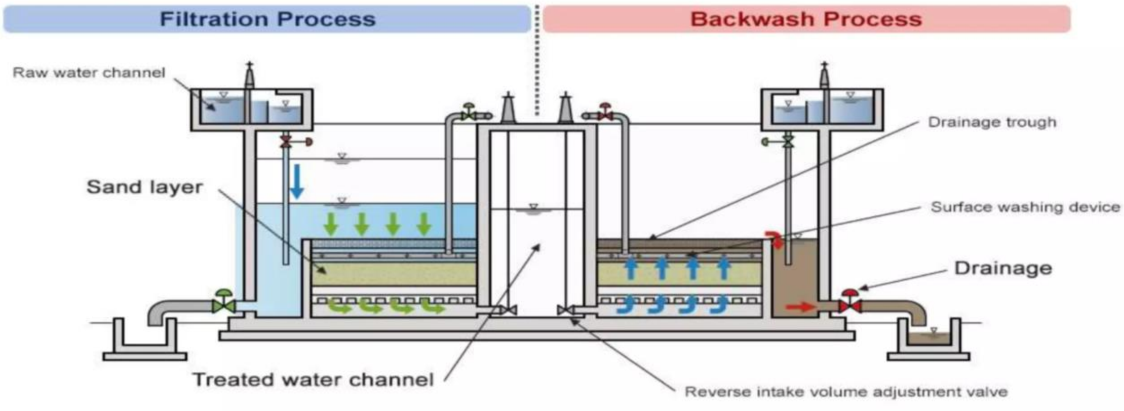


Figure 23. Rapid sand filtration open system

3.6.8.1.2. Closed Systems

Closed systems, or pressurized filters, operate under pressure, with the water being forced through the filter media under a higher pressure than that found in gravity systems. The characteristics of closed systems are:

Flow Rates: Closed systems are capable of functioning at higher flow rates, typically ranging from 4 to 50 cubic meters per hour per square meter ($m^3/h/m^2$). The increased pressure allows for a higher filtration rate, making these systems suitable for facilities with limited space but high water demand.

Operation and Maintenance: These systems are enclosed, which prevents contamination from external sources and reduces the risk of biological growth in the filter media. However, they are more complex to operate and maintain, requiring pressure gauges and automatic controls to monitor and adjust the pressure and flow rates.

Applications: Closed systems are often used in industrial applications or in situations where space is limited, such as in small water treatment plants, portable units, or shipboard systems. The pressurized nature of the system allows for more compact designs and higher efficiency in removing smaller particles and contaminants.

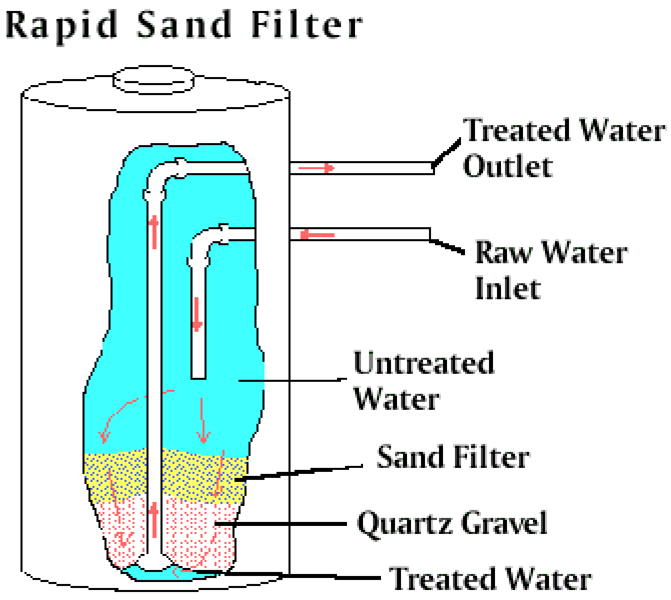


Figure 24. Rapid sand filtration closed system

3.6.8.2. Components of a Rapid Sand Filter

The main elements of a rapid sand filter include:

1. **Filter Bottom:** This structure separates the filter medium from the filtered water. It must be strong enough to support the weight of the filter medium (sand and gravel) and the water above it, while also ensuring even distribution and collection of the wash water and filtered water.
2. **Support Gravel:** Positioned immediately above the filter bottom, the support gravel serves two primary purposes:

- To retain the sand from the filter medium.
- To improve the distribution of backwash water across the filter.
- The thickness and grain size of the support gravel layer depend on the characteristics of both the filter bottom and the filter medium.

3. **Filter Medium:** The filter medium, typically sand or anthracite, is the primary material that traps impurities. For single-layer sand filters:

- Filter Layer: The filter layer is typically 60 to 90 cm thick, consisting of sand with an effective grain diameter ranging from 0.35 to 0.50 mm and a uniformity coefficient between 1.3 and 1.7.
- Surface Load: The maximum allowable surface load is about 5 m/h for single-layer sand filters.

3.6.8.3. Issues in Older Installations

In water treatment facilities with rapid sand filter installations that are around 30 years old or older, several issues commonly arise due to the wear and aging of materials. These problems can compromise the efficiency and safety of the filtration process, necessitating careful monitoring and maintenance. Here are some of the typical issues found in older installations:

3.6.8.3.1. Damage to Filter Bottoms

The filter bottom, also known as the underdrain system, is a critical component of rapid sand filters. It supports the filter media and facilitates the collection of filtered water and the distribution of backwash water. In older installations, the filter bottom can suffer from several types of damage:

- **Lifting of Slabs During Backwashing**: The slabs that make up the filter bottom may begin to lift during the backwashing process. This occurs because of repeated stress and pressure fluctuations as water is forced upwards to clean the filter media. Over time, this lifting can cause structural weaknesses.
- **Cracks and Structural Failures**: The stress from repeated lifting and settling can lead to cracks in the filter bottom. These cracks compromise the integrity of the filter structure and can lead to more severe failures, such as breakage of the slabs or leakage of water and filter media.
- **Nozzle Failures**: The nozzles in the filter bottom, which are essential for distributing water evenly during both filtration and backwashing, can fail due to cracks or shifts in the slabs. Nozzle failures can lead to uneven distribution of backwash water, reducing cleaning efficiency and potentially leading to uneven filter media compaction.

3.6.8.3.2. Damaged Support Gravel

Support gravel, positioned immediately above the filter bottom, plays a crucial role in ensuring the stability of the filter media and in distributing water flow uniformly. Over time, the support gravel can experience several problems:

- **Degradation and Wear**: The support gravel can break down over time due to constant friction and the chemical composition of the water passing through it. This degradation reduces the effectiveness of the gravel in supporting the sand filter media and in ensuring uniform flow distribution.
- **Shifting and Settlement**: Over the years, the gravel can shift or settle unevenly, which disrupts the distribution of water across the filter. This can lead to channeling, where water flows more freely through certain areas of the filter media,

bypassing large portions of the filter bed. Channeling reduces the effectiveness of filtration and can result in poorer water quality.

- **Impact on Water Distribution and Sand Retention**: The degradation or movement of the support gravel affects its ability to retain the sand layer above it. If the gravel does not effectively hold the sand in place, finer sand particles can be lost during backwashing, decreasing the filter's efficiency and requiring more frequent replacement or replenishment of the filter media.

3.6.8.4. Importance of Regular Maintenance and Upgrades

Addressing these issues in older installations is crucial to maintaining the effectiveness and longevity of the filtration system. Regular inspections, maintenance, and timely upgrades are essential. Here are some strategies to manage and mitigate these issues:

- **Regular Inspections**: Conduct regular inspections of the filter bottom and support gravel to identify early signs of damage, such as lifting slabs, cracks, or uneven gravel distribution.
- **Repair and Reinforcement**: When damage is detected, repairs should be made promptly. This might include replacing cracked slabs, reinforcing the filter bottom, or repairing or replacing damaged nozzles.
- **Replacing Support Gravel**: If the support gravel is degraded or has shifted significantly, it may need to be replaced or re-leveled to ensure proper function.
- **Upgrading to Modern Materials**: Consider upgrading to more durable materials that are better suited to withstand the stresses of filtration and backwashing processes over the long term. Modern materials can offer enhanced performance and longer service life.

Chapter 4

Additional Treatments

4.1. Disinfection

Disinfection is the final step in the treatment of drinking water before it is distributed to consumers. This process is crucial for eliminating pathogenic microorganisms, such as viruses and bacteria, which can be harmful to human health. However, it is important to note that disinfection is not the same as sterilization, which involves the complete destruction of all microorganisms present in an environment. Disinfection aims to reduce the number of harmful organisms to a safe level.

There are two primary methods of disinfection:

1. **Chemical Disinfection**: This involves adding chemical agents with germicidal properties, such as chlorine or ozone, to the water.
2. **Physical Disinfection**: This method uses physical means, such as ultraviolet (UV) radiation, to inactivate or destroy microorganisms.

4.1.1. Key Effects of Disinfection

Water disinfection involves two main effects of a disinfectant:

4.1.1.1. Bactericidal Effect

This is the ability of a disinfectant to destroy microorganisms at the time of treatment. It ensures that pathogens are killed or inactivated in the treated water before it is released into the distribution network.

4.1.1.2. Residual Effect

This refers to the continued effectiveness of the disinfectant within the water distribution system. It helps maintain the microbiological quality of the water up to the consumer's tap by:

- Providing a **bacteriostatic effect**, which inhibits the growth of any surviving bacteria.
- Providing a **bactericidal effect** against low-level, occasional contamination that might occur within the distribution network. This effect also prevents the

development of microorganisms that might resist treatment or reproduce in the system.

4.1.2. Conditions for Effective Disinfection

For disinfection to be effective, it must be performed on water that meets certain quality criteria:

1. **Low Suspended Solids**: The water should have a suspended matter content of less than 1 mg/L. Suspended solids can protect microorganisms by shielding them from the disinfectant.
2. **Low Organic Matter**: The concentrations of organic matter (OM), total organic carbon (TOC), and other oxidizable substances like COD (Chemical Oxygen Demand) should be minimal. High levels of these substances consume disinfectants, requiring higher doses and making it harder to maintain an adequate residual disinfectant level. This can also lead to the formation of harmful disinfection by-products (DBPs).

*Additionally, it is important to balance the reduction of potential DBPs, such as trihalomethanes (THMs), with the need to maintain effective disinfection.

4.1.3. Application Conditions for Different Disinfectants

Effective disinfection with chemical agents (oxidants) depends on achieving the right balance of disinfectant concentration (C) and contact time (T), known as the CT value. This value varies based on:

- The type of microorganism being targeted.
- The disinfectant being used.
- Environmental factors like water temperature and pH.

$$C(mg.l^{-1})T(min) = CT((mg.l^{-1}.min)$$

4.1.3.1. Factors Affecting CT Value

1. **Microorganisms Involved**: Different microorganisms have varying levels of resistance to disinfectants. For example, some viruses and bacteria can be more

resistant to chlorine than others. Protozoan cysts, such as those of *Cryptosporidium*, are particularly resistant to many common disinfectants. The CT value must be adjusted accordingly to ensure effective inactivation of the target microorganisms.

2. **Type of Disinfectant**: The effectiveness of a disinfectant also depends on its chemical properties and its ability to penetrate and destroy microorganisms. For instance, chlorine, chloramine, ozone, and ultraviolet (UV) light each have different mechanisms of action and varying levels of efficacy depending on the microorganism. Therefore, the CT value required to achieve a specific level of inactivation will differ for each disinfectant.
3. **Temperature**: The temperature of the water affects the disinfection process because chemical reactions generally occur faster at higher temperatures. A higher temperature can enhance the disinfectant's ability to kill or inactivate microorganisms, potentially lowering the CT value needed for effective disinfection. Conversely, lower temperatures might require a higher CT value to achieve the same level of disinfection.

4.1.3.2. Chick-Watson Model of Disinfection Kinetics

The **Chick-Watson model** is a widely used mathematical model that describes the inactivation of microorganisms by disinfectants. According to this model, the rate of microorganism inactivation (dN/dt) by an oxidant can be expressed as:

$$\frac{dN}{dt} = -kC^n$$

Where: **N** is the number of microorganisms present at a given time, **C** is the concentration of the disinfectant, **k** is the lethality coefficient, which indicates the effectiveness of the disinfectant against a specific microorganism. This coefficient depends on temperature and follows the Arrhenius equation, **n** is the order of the reaction, indicating how the disinfection rate depends on the concentration of the disinfectant.

The CT concept, introduced by the United States Environmental Protection Agency (USEPA), is based on the law established by Chick and Watson, which states that the rate of microorganism inactivation depends on both the concentration of the disinfectant and the time it remains in contact with the microorganisms.

The general form of this kinetic law for germ inactivation is:

$$\log\left(\frac{N}{N_0}\right) = -kCT$$

Where: N is the number of microorganisms at time T, N_0 is the initial number of microorganisms, K is the inactivation rate constant, which varies depending on the species and conditions.

Disinfection is considered effective when a sufficient residual disinfectant concentration is maintained for a designated period.

4.1.3.3. Arrhenius Equation and Temperature Dependence

The lethality coefficient, **k**, changes with temperature according to the Arrhenius equation:

$$k = A.\exp\left(-\frac{E}{R.T}\right)$$

Where: **A** is the Arrhenius constant (frequency factor), which represents the frequency of collisions that result in a reaction, **E** is the activation energy required for the disinfection reaction to occur, **R** is the universal gas constant, **T** is the absolute temperature in Kelvin (K).

As temperature increases, the value of k increases, which means the reaction rate of microorganism inactivation becomes faster. Thus, higher temperatures can reduce the necessary CT value to achieve effective disinfection.

4.1.3.4. Reaction Order (n)

The **order of the reaction** (n) represents how sensitive the inactivation rate is to changes in the disinfectant concentration. For many disinfectants, such as chlorine, the reaction is often considered to be first-order (n = 1), meaning the rate of microorganism inactivation is directly proportional to the concentration of the disinfectant. However, the order can vary depending on the disinfectant and the microorganisms present.

4.1.4. Types of Disinfectants

1. **Chlorine**: Chlorine is the most widely used disinfectant for water treatment. It can be applied in several forms, including chlorine gas, sodium hypochlorite, and calcium hypochlorite. While effective, chlorine can react with organic matter in water to form potentially harmful by-products like THMs.

2. **Ozone**: Ozone is a powerful oxidant used in some water treatment processes. It reacts quickly with microorganisms, often requiring a shorter contact time (CT value) than chlorine. The effectiveness of ozonation depends on factors like pH, temperature, and the presence of other oxidizable compounds.

3. **Ultraviolet (UV) Radiation**: UV disinfection uses UV light to inactivate microorganisms by damaging their DNA. It is effective against a broad range of pathogens, including protozoan cysts, and does not produce chemical by-products. The effectiveness of UV disinfection depends on factors such as UV dose, water clarity, and flow rate.

4. **Copper/Silver Ionization**: This method involves releasing copper and silver ions into the water. The ions bind to the negatively charged cell walls of microorganisms, disrupting their function and killing them. It is less commonly used compared to chemical and UV methods.

4.1.4.1. Types of Disinfectants Used in Water Treatment

Disinfection is a critical step in ensuring safe drinking water by eliminating or inactivating pathogenic microorganisms. Several types of disinfectants are used in water treatment, each with its own advantages and limitations. The choice of disinfectant depends on various factors, including the type of microorganisms present, water chemistry, treatment goals, and regulatory standards.

4.1.4.1.1. Chlorine

Chlorine is the most widely used disinfectant in water treatment due to its effectiveness, availability, and cost-efficiency. Chlorine can be applied in several forms, including:

- **Chlorine Gas (Cl_2)**: Chlorine gas is a potent disinfectant and oxidant. It is typically stored in pressurized containers and dissolved in water to produce hypochlorous acid (HOCl), the active disinfecting agent. Chlorine gas is highly effective at low concentrations and works well in a variety of water conditions.

- **Sodium Hypochlorite (NaOCl)**: Commonly known as liquid bleach, sodium hypochlorite is an aqueous solution of chlorine that is easier to handle than chlorine gas. It is often used in smaller water treatment systems or where gas handling poses safety concerns.

- **Calcium Hypochlorite ($Ca(OCl)_2$)**: This solid form of chlorine is typically available as granules, pellets, or tablets. It is used in situations where storage and handling of liquid or gas chlorine are not feasible, such as in small-scale or emergency water treatment applications.

a) Advantages

- Chlorine is highly effective against a wide range of bacteria, viruses, and protozoa.

- It provides a **residual effect**—a small concentration of chlorine remains in the water throughout the distribution system, offering ongoing protection against microbial contamination.

b) Disadvantages

- **Formation of Disinfection By-Products (DBPs)**: Chlorine reacts with natural organic matter (NOM) in water to form potentially harmful by-products, such as trihalomethanes (THMs) and haloacetic acids (HAAs), which are regulated due to their health risks, including cancer.

- **Effectiveness Varies with Water Quality**: Chlorine's efficacy can be reduced by high levels of turbidity or the presence of ammonia, which can form less effective chloramines.

4.1.4.1.2. Ozone (O_3)

Ozone is a strong oxidant and a highly effective disinfectant used in some water treatment processes. Ozone gas is generated on-site by passing oxygen through a high-voltage electric discharge or UV light.

a) Mechanism of Action

Ozone disinfects by breaking down the cell walls of microorganisms and disrupting their metabolic processes, leading to cell lysis and death.

b) Advantages

- **High Oxidation Potential**: Ozone is more potent than chlorine and can inactivate a broad spectrum of microorganisms, including viruses and protozoan cysts, such as *Cryptosporidium* and *Giardia*.
- **Shorter Contact Time (CT Value)**: Due to its strong oxidative properties, ozone often requires shorter contact times to achieve effective disinfection compared to chlorine.
- **Reduced By-Products**: Unlike chlorine, ozone does not produce THMs or HAAs. However, it can form other by-products like bromate, especially in bromide-containing waters.

c) Disadvantages

- **No Residual Disinfectant**: Ozone decomposes rapidly in water, leaving no residual disinfectant to protect against recontamination in the distribution system. This often necessitates a secondary disinfectant, such as chlorine, to maintain residual protection.
- **Complexity and Cost**: Ozone generation equipment is complex and expensive, requiring high energy consumption and regular maintenance.

4.1.4.1.3. Ultraviolet (UV) Radiation

UV Disinfection utilizes ultraviolet light, typically in the range of 200 to 280 nanometers (nm), to inactivate microorganisms by damaging their nucleic acids (DNA and RNA).

a) Mechanism of Action:

UV light penetrates microbial cells and disrupts their DNA, preventing replication and rendering them non-infectious.

b) Advantages:

- **Effective Against a Wide Range of Pathogens**: UV radiation can inactivate bacteria, viruses, and protozoa, including chlorine-resistant organisms like *Cryptosporidium* and *Giardia* cysts.
- **No Chemical Residues or By-Products**: UV treatment does not involve chemicals, so there are no concerns about chemical residues or harmful disinfection by-products (DBPs).
- **Fast Treatment**: The process is instantaneous, requiring only a few seconds of exposure, making it highly efficient.

c) Disadvantages:

- **No Residual Protection**: Like ozone, UV disinfection does not provide a residual disinfectant in the water. This can leave the treated water vulnerable to recontamination post-treatment, particularly in the distribution system.
- **Effectiveness Dependent on Water Clarity**: UV effectiveness is reduced in turbid or colored water, as particles can shield microorganisms from UV light. Pre-treatment may be required to remove turbidity and ensure adequate UV penetration.

Table 3. Comparison of Disinfection Methods for Water Treatment

Parameter	Chlorine Gas	On-Site Hypochlorite (OSHG)	Commercial Hypo	On-Site Chlorine (OSCG)	Chlorine Dioxide	Ozone	UV
Maintains a Residual	Yes	Yes	Yes	Yes	Yes	No	No
Effectiveness	High	High	High	High	High	High	Medium
Affected by High pH	Yes	Yes	Yes	Yes	No	Yes	N/A

Chemical Stability	High	Medium	Medium	Medium	Medium	Medium	N/A
Safety Concerns	High	Medium	High	Medium	High	Medium	Low
Reacts with Ammonia	Yes	Yes	Yes	Yes	No	No	No
THM Formation	Yes[1]	Yes[1]	Yes[1]	Yes[1]	No	No	No
Bromate Formation	Possible[2]	Possible[2]	Possible[2]	Possible[2]	No	Possible[2]	No
Chlorite Formation	No	No	No	No	Possible	No	No
Chlorate Formation	Negligible	Possible	Possible	Possible	Low	Negligible	No

Notes:

- If organic precursors are present
- If bromine is present in water
- If bromine is present in water or salt/brine

4.2. Adsorption and Ion Exchange:

Adsorption and ion exchange are advanced techniques frequently utilized in water treatment to eliminate various contaminants from drinking water. Adsorption operates by adhering dissolved substances onto the surface of solid materials, with activated carbon being the most commonly employed medium. This method is notably effective for removing organic compounds, such as pesticides, herbicides, and volatile organic chemicals, as well as certain inorganic substances, including chlorine and heavy metals. In contrast, ion exchange involves substituting undesirable ions present in the water with more favorable ions through the use of a medium, typically resin beads. This process is particularly effective in the removal of hardness ions such as calcium and magnesium, heavy metals, and nitrates, ensuring the production of water that meets stringent quality standards.

4.3. Iron and Manganese Removal (Deferrization and Demanganization)

The processes of iron removal (deferrization) and manganese removal (demanganization) are essential for the purification of drinking water, particularly when these metals are present in groundwater sources. The presence of iron and manganese can lead to staining, unpleasant taste, and operational challenges within water distribution systems. Removal techniques typically involve oxidation followed by filtration. Oxidizing agents such as chlorine, ozone, or potassium permanganate are employed to convert soluble iron and manganese into insoluble forms, which are subsequently filtered out. Specialized filter media, such as greensand, can enhance the efficiency of this process by combining oxidation and adsorption, resulting in more effective removal of these contaminants.

4.4. Decarbonation (Softening)

Decarbonation, often referred to as softening, is a treatment process aimed at reducing water hardness by eliminating bicarbonate hardness, primarily caused by calcium and magnesium bicarbonates. This is achieved by the addition of lime (calcium hydroxide) or soda ash (sodium carbonate) to the water, which leads to the precipitation of calcium and magnesium as carbonates, facilitating their removal through filtration. Decarbonation is particularly valuable in regions where water hardness is prevalent, as it helps prevent scaling in pipes and appliances, thereby extending their operational lifespan and efficiency.

4.5. Defluoridation

Defluoridation is the process of reducing the fluoride concentration in drinking water to safe levels. While fluoride is beneficial in small amounts for dental health, excessive levels can result in dental and skeletal fluorosis, posing significant health risks. Various methods can be employed for defluoridation, including adsorption using activated alumina or bone char, ion exchange, and reverse osmosis. The selection of the appropriate method depends on factors such as the initial fluoride concentration, water chemistry, and the desired level of fluoride removal to ensure safe consumption.

Part 2

Water purification

Chapter I

Pollution Parameters and Discharge Standards

1.1. Types of Wastewater

1.1.1. Domestic Wastewater

1) **Household Water (Gray Water)**: This type of wastewater comes from everyday household activities such as bathing, cooking, laundry, and cleaning. It generally contains fewer pathogens compared to black water but has high levels of organic pollutants like soaps, detergents, food particles, fats, oils, and grease. Gray water can often be recycled or treated for non-potable uses, such as irrigation or flushing toilets, depending on local regulations and treatment capabilities.
2) **Waste Water (Black Water)**: This is wastewater from toilets that includes human excreta and is heavily laden with pathogens, nitrogenous compounds (such as urea and ammonia), and other organic materials. Because of the high risk of contamination with fecal germs, black water requires careful handling and treatment to prevent the spread of diseases.

1.1.2. Rainwater (Stormwater Runoff)

Rainwater initially falls clean but picks up various pollutants as it flows over different surfaces. When rainwater hits urban areas, it can mix with pollutants like industrial emissions, oil, grease, heavy metals (from car tires and brake pads), pesticides, and other chemicals that have settled on roads and rooftops.

During heavy rainfall or storms, the volume of stormwater can surge, causing what is known as a “first flush” effect. This is when the initial runoff from a storm contains a high concentration of pollutants that have accumulated on surfaces since the last rain event. If not properly managed, stormwater can lead to significant pollution of rivers, lakes, and coastal waters, negatively affecting aquatic life and water quality.

1.1.3. Industrial Wastewater

Industrial wastewater is highly variable depending on the type of industry and its processes. For example, a textile factory may release dyes, chemicals, and solvents, while a food processing plant might discharge organic matter, oils, and fats.

Types of Contaminants: This wastewater can include not only organic matter and nutrients (like nitrogen and phosphorus) but also toxic substances such as heavy metals (e.g., mercury, lead, and cadmium), solvents, acids, bases, pesticides, and organic micro pollutants (e.g., PCBs, PAHs). These substances can be highly toxic to both aquatic life and humans, necessitating specific treatments to neutralize or remove them.

Treatment Complexity: The diversity and concentration of contaminants in industrial wastewater often require specialized treatment processes, such as chemical precipitation, adsorption, advanced oxidation processes, or membrane filtration, to ensure safe discharge into the environment.

1.2. Urban Sanitation Network

The urban sanitation network is crucial for managing wastewater to protect public health, maintain environmental quality, and ensure sustainable urban living. Different configurations of these networks are designed to handle various types of wastewater efficiently.

1.2.1. Separate Network

1. **Description**: This system uses two distinct pipelines—one dedicated to collecting domestic and industrial wastewater (sewage) and another for collecting stormwater (rainwater).
2. **Benefits**

- **Reduced Contamination Risk**: By keeping sewage and stormwater separate, the network reduces the risk of untreated wastewater overflowing into natural water bodies during heavy rain.
- **Targeted Treatment**: It allows for more targeted treatment of wastewater. Sewage can be directed to treatment plants where it undergoes biological, chemical, or physical processes to remove contaminants, while stormwater can be treated separately to remove pollutants picked up from urban surfaces.

3. **Challenges:**

Infrastructure Costs: Building and maintaining two separate pipeline systems can be expensive and requires more space, which may not be available in densely populated urban areas.

1.2.2. Unitary Network

1. **Description**: This system collects both sewage and stormwater in a single pipeline. It is common in older cities where space and resources were limited during the network's initial construction.
2. **Benefits**:

Lower Initial Costs: A single network requires less infrastructure compared to separate systems, making it less expensive to build.

Simplified Maintenance: Only one set of pipes needs to be maintained.

3. **Challenges**:

Overflow Risk: During heavy rainfall, the combined volume of sewage and stormwater can exceed the capacity of the system, causing overflow events. This can result in the discharge of untreated or partially treated wastewater into nearby water bodies, posing a risk to public health and the environment.

Pollution Control: The mixed nature of the water makes it harder to treat, especially when dealing with contaminants from stormwater that might not be typically handled in a sewage treatment plant.

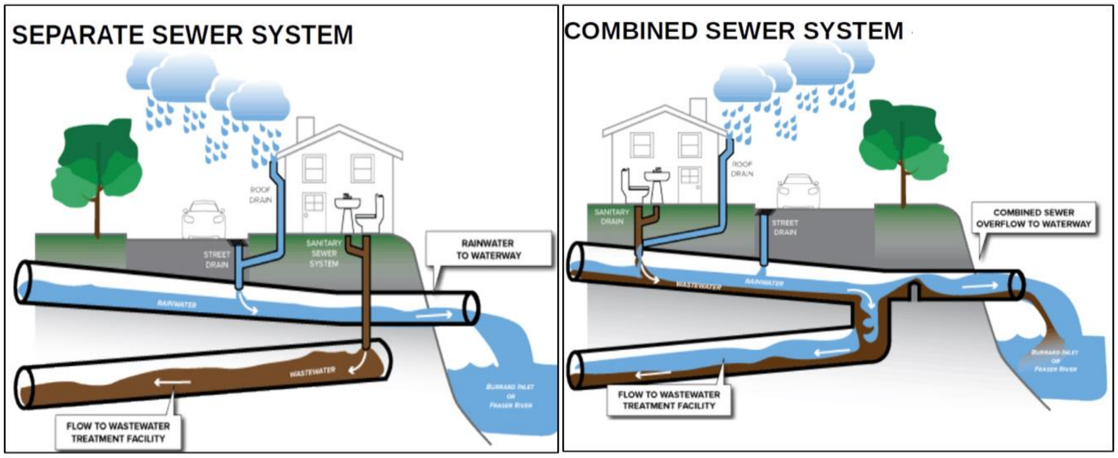


Figure 25. Sewerage System Types

1.2.3. Pseudo-Separative System

1. **Description**: This hybrid system aims to provide some benefits of separation without the full infrastructure requirements. It divides stormwater into two categories:

a) **Road Surface Water**: This water is collected through gutters, ditches, and storm drains specifically designed to handle runoff from streets. It is usually treated separately from sewage.

b) **Roof Water**: Rainwater that falls on roofs is directed into the sewer system and mixes with domestic wastewater.

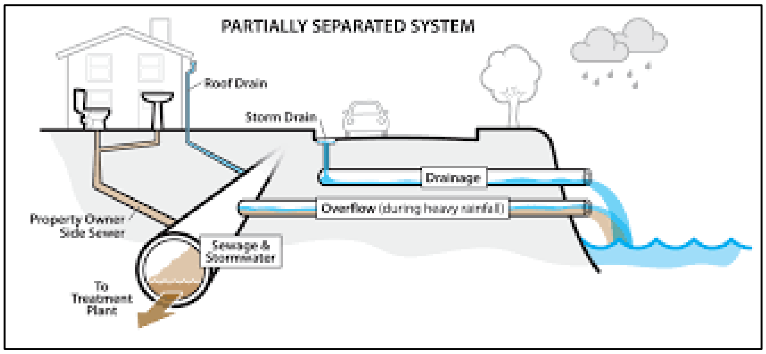


Figure 26. Pseudo-Separate System

2. **Benefits**:

Cost-Effective: This approach minimizes the need for new infrastructure by utilizing existing sewer connections for roof water, reducing costs.

Improved Stormwater Management: By separately managing road surface runoff, the system can better address pollutants specific to urban runoff (like oils, metals, and tire residues).

3. **Challenges**:

Partial Separation: While this system helps manage some stormwater pollutants, roof water still mixes with sewage, which can complicate treatment processes and increase the load on sewage treatment plants during heavy rains.

1.2.4. Overflow Outlet

An **overflow outlet**, often referred to as a **storm overflow**, is a structure within the wastewater management system designed to handle excess water flow during periods of heavy rainfall or storm events. When the volume of wastewater and stormwater combined exceeds the capacity of the sewer system or treatment plant, the overflow outlet allows a portion of the effluent to be directly discharged into the natural environment. This prevents sewer backups and flooding but can lead to temporary increases in pollution levels in receiving water bodies.

1.3. Parameters of Wastewater Pollution

Understanding the parameters of wastewater pollution is crucial for effective wastewater treatment and environmental protection. These parameters help in assessing the quality of wastewater and the efficiency of treatment processes. Common parameters include Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Suspended Volatile Solids (SVS), Total Kjeldahl Nitrogen (TKN), and Total Phosphorus (TP).

1.3.1. Chemical Oxygen Demand (COD)

Definition: COD measures the total amount of oxygen required to chemically oxidize both organic and inorganic substances in water. It reflects the overall level of pollutants that can be chemically oxidized.

Measurement: COD is typically determined by adding a strong oxidizing agent to the water sample in a hot acidic solution and measuring the amount of oxidant consumed. The result indicates the total pollution load in terms of oxygen required for oxidation, expressed in milligrams per liter (mg/L).

Importance: COD is a critical parameter because it provides a quick measure of the potential impact of wastewater on the environment, especially in terms of the oxygen depletion it could cause in receiving waters.

1.3.2. Biochemical Oxygen Demand (BOD)

Definition: BOD measures the amount of dissolved oxygen needed by aerobic biological organisms to break down organic material in water over a specified period. The most common measurement is BOD5, which represents the amount of oxygen consumed in five days.

Measurement: BOD is measured using the OxiTop method or other respirometric methods, which involve sealing a water sample in a container and measuring the oxygen depletion over five days.

Ultimate BOD: For a more comprehensive assessment, the ultimate BOD (often referred to as BOD ultimate or BODu) can be measured over 21 days, which includes the oxidation of organic matter and endogenous respiration of microorganisms. This provides a more complete picture of the total organic pollution.

Importance: BOD is a crucial parameter for assessing the degree of organic pollution in wastewater and its potential impact on the oxygen levels of natural water bodies.

1.3.3. Suspended Volatile Solids (SVS)

Definition: SVS represents the organic (biodegradable) fraction of suspended solids in wastewater. It gives an indication of the potential for biological treatment processes.

Measurement: SVS is determined by filtering a water sample to collect suspended solids, drying the filter residue, and then igniting it at 550°C. The difference in mass before and after ignition gives the SVS value, expressed in mg/L or as a percentage of total suspended solids (TSS).

Importance: SVS is an important parameter for evaluating the efficiency of biological treatment processes and understanding the nature of suspended matter in wastewater.

1.3.4. Total Kjeldahl Nitrogen (TKN)

Definition: TKN is the sum of organic nitrogen and ammonia nitrogen in a water sample. It represents the total nitrogen available in forms that can potentially be converted into other nitrogen species during treatment processes.

Measurement: TKN is measured by digesting the sample with a strong acid and catalyst, which converts all organic nitrogen to ammonium. The concentration of ammonium is then measured to determine the TKN value, expressed in mg/L.

Importance: TKN is used to assess the nitrogen load in wastewater, which is crucial for understanding its impact on nitrogen cycles and for designing treatment processes that manage nitrogen levels, such as nitrification and denitrification.

1.3.5. Ammonia and Nitrites

Definition: These two forms of nitrogen are common in wastewater. Ammonia is a product of organic nitrogen breakdown, while nitrites are an intermediate form in the nitrification process.

Measurement: Ammonia and nitrites are measured separately, often using colorimetric methods or ion-selective electrodes.

Importance: Monitoring ammonia and nitrite levels is essential for controlling the biological processes in wastewater treatment plants, especially in the nitrification and denitrification stages.

1.3.6. Total Phosphorus (TP)

Definition: TP represents the total amount of phosphorus in the form of both organic and inorganic phosphates. It is a key nutrient that can contribute to eutrophication in receiving water bodies.

Measurement: TP is measured by digesting the sample to convert all forms of phosphorus into orthophosphate, which is then measured using colorimetric methods.

Sources and Importance: Phosphorus in wastewater comes from detergents, fertilizers, and organic matter decomposition. Managing phosphorus levels is critical to prevent eutrophication, which can lead to algal blooms and hypoxic conditions in water bodies.

1.4. Characteristic Parameters of Effluents to be treated

When designing and operating wastewater treatment plants, it is essential to understand various parameters that characterize the effluents. These parameters help in determining the required capacity and treatment processes to effectively manage wastewater. The main parameters include flow rate, concentration, load, hydraulic head, organic load, purification efficiency, mass load, volumetric load, and equivalent inhabitant.

1.4.1. Flow Rate (Q)

Definition: The flow rate represents the volume of effluent passing through the treatment system per unit of time. It is typically expressed in cubic meters per day (m³/d), cubic meters per hour (m³/h), or liters per second (l/s).

Average Hourly Flow Rate in Dry Weather: This is the average flow rate received by the treatment plant during dry weather conditions, when there is minimal stormwater infiltration into the sewer system. $Q_{mh} = \frac{Q_{day}}{24}$

Dry Weather Hourly Peak Flow: The maximum flow rate that the plant receives during dry weather. This peak flow rate is critical for designing the hydraulic capacity of the treatment plant to handle surges without overflow or bypassing. $Q_{pts} = Q_{mh} \times C_P$

$$\begin{cases} C_P = 1{,}5 + \dfrac{2{,}5}{\sqrt{Q_{mh}}} \ if\ Q_{mh} \geq 2{,}8\,\dfrac{l}{s} \\ cp = 3 \qquad\qquad if\ \ Q_{mh} < 2{,}8\,\dfrac{l}{s} \end{cases}$$

1.4.2. Concentration (C)

Definition: Concentration refers to the mass of pollutants per unit volume of effluent, usually expressed in milligrams per liter (mg/L) or grams per liter (g/L). It provides information about the quality of the effluent, indicating how polluted the wastewater is with specific contaminants.

Significance: High concentrations of pollutants require more intensive treatment processes to remove contaminants to acceptable levels before discharge.

1.4.3. Load (F)

Definition: Load, also known as "charge," is the total amount of pollutants entering the treatment plant per unit of time. It is calculated as the product of the flow rate (Q) and the concentration (C), typically expressed in kilograms per day (kg/d).

Formula: $F=Q\times C$

Importance: Load indicates the total pollution burden the plant must handle, guiding the sizing and design of treatment processes.

1.4.4. Hydraulic Head of the Station

Definition: The hydraulic head of the station is the ratio of the actual flow rate received to the nominal hydraulic capacity of the treatment plant. It is expressed as a percentage of the plant's designed capacity.

Significance: This parameter helps assess whether the plant is operating within its design limits or if there is a risk of hydraulic overload, which could affect treatment efficiency and lead to bypassing untreated wastewater.

1.4.5. Organic Load of the Station

Definition: The organic load of the station is the ratio of the actual organic pollution load received to the plant's nominal capacity, typically expressed as a percentage. It is usually measured in terms of Biochemical Oxygen Demand (BOD5).

Significance: This measure helps in evaluating the biological treatment processes and determining if they are adequately sized to handle the organic load without compromising treatment efficiency.

1.4.6. Purification Efficiency of the Station

Definition: Purification efficiency is the proportion of pollution that is removed during the treatment process compared to the amount of pollution entering the plant. It defines the overall performance and effectiveness of the treatment plant.

Importance: High purification efficiency indicates that the plant is effectively removing pollutants, thus protecting downstream water bodies.

1.4.7. Mass Load (Cm)

Definition: The mass load is the ratio of the BOD5 load received to the amount of sludge present in the aeration basin. It is a critical parameter for understanding the biological balance within the treatment process. $C_m = \frac{BOD_{5\,load\ recived}}{Kg\ MVS\ (aeration\ basin\ )}$

Significance: This parameter helps in assessing the microbial activity and the effectiveness of the biological treatment process. Maintaining an appropriate mass load is crucial for optimizing the degradation of organic matter and preventing process imbalances.

1.4.8. Volumetric Load (Cv)

Definition: Volumetric load is the ratio of the BOD5 load received to the volume of the aeration basin. It provides an estimate of the capacity of the aeration basin to handle the organic load. $C_m = \frac{BOD_{5\,load\ recived}}{m^{\,3}(aeration\ basin\ )}$

Significance: This measure helps in designing and optimizing the size of the aeration basin to ensure adequate treatment capacity and avoid overloading, which can reduce treatment efficiency.

1.4.9. Equivalent Inhabitant (EH)

Definition: The equivalent inhabitant (EH) is a theoretical concept that represents the average pollution load generated by one person per day. It is used to standardize the measure of pollutant loads from various sources, including households, industries, and commercial activities.

Standard Pollution Loads per EH:

180 liters of effluent per day

90 grams of Suspended Solids (SS)

60 grams of BOD5

135 grams of Chemical Oxygen Demand (COD)

9.9 grams of total nitrogen

2 grams of total phosphorus

Importance: EH is used to calculate the total pollutant load from a community or industrial facility in terms of the equivalent number of people, facilitating the design and comparison of wastewater treatment systems based on standardized pollution loads.

These parameters are fundamental for the design, operation, and monitoring of wastewater treatment plants. Understanding and correctly applying them ensures efficient treatment processes, compliance with regulatory standards, and the protection of public health and the environment.

1.5. Analysis of the Parameters of the Effluent to be Treated

To effectively design and operate a wastewater treatment plant, it is crucial to have accurate data on the characteristics of the effluents that will be processed. The analysis of these effluent parameters provides essential information on the quality and quantity of pollutants that need to be removed. This data is obtained through comprehensive measurement campaigns that involve continuous sampling over a 24-hour period.

1.5.1. Continuous 24-Hour Sampling Campaigns

Purpose: The purpose of continuous sampling over a 24-hour period is to obtain a representative profile of the effluent characteristics under varying conditions. This includes both dry and rainy weather conditions, as the composition and flow rates of wastewater can significantly differ between these scenarios.

Methodology:

1. **Continuous Sampling**: Samples are collected continuously over a 24-hour period. This approach ensures that the data reflects all fluctuations in effluent quality and flow rates that occur throughout the day. For example, flow rates and pollutant concentrations may vary during peak household usage times (morning and evening) and lower usage times (midday and night).

2. **Flow-Proportional Sampling**: To ensure accuracy, the volume of each sample taken is proportional to the instantaneous flow rate of the effluent. This means that larger volumes of samples are collected when the flow rate is high, and smaller volumes are collected when the flow rate is low. This technique provides a more accurate representation of the average pollutant load over the sampling period.

3. **Weather Considerations**: Effluent characteristics are measured under both dry weather and rainy weather conditions:

    - **Dry Weather**: Sampling in dry weather provides data on the baseline conditions of the wastewater, which typically includes domestic and industrial effluent without the influence of stormwater runoff.

    - **Rainy Weather**: During rainy weather, stormwater can enter the sewage system, diluting the wastewater and potentially introducing additional pollutants like oils, heavy metals, and other debris from urban runoff. Sampling during these conditions helps in understanding the impact of stormwater on the effluent composition.

4. **24-Hour Composite Sample**: All the samples collected during the 24-hour period are combined into a single composite sample. This composite is then refrigerated to preserve its integrity until analysis. By using a composite sample, the analysis captures the average concentration of pollutants over the entire day rather than a

single point in time, providing a comprehensive overview of the effluent's characteristics.

1.5.2. Analysis and Interpretation of Results

The data obtained from these measurement campaigns are critical for defining the "identity" or "singular morphology" of the effluent. This means understanding the specific characteristics of the effluent, including:

- **Concentration of Pollutants**: Measuring concentrations of key pollutants such as Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), nutrients (like nitrogen and phosphorus), and toxic substances (like heavy metals and organic micropollutants).
- **Variability**: Understanding how these concentrations change over time and under different weather conditions.
- **Flow Rates**: Determining the average and peak flow rates that the treatment plant will need to handle.

1.5.3. Importance of Accurate Effluent Characterization:

1. **Design and Sizing**: Accurate characterization of the effluent allows engineers to properly design and size the various treatment units within the plant (such as primary clarifiers, aeration basins, and filtration systems).
2. **Operational Efficiency**: Understanding the effluent's composition helps in optimizing treatment processes for maximum efficiency, ensuring compliance with regulatory standards, and minimizing operational costs.
3. **Environmental Protection**: Proper analysis and treatment of effluents are crucial for protecting receiving water bodies from pollution, ensuring that treated water is safe for discharge into the environment

Chapter II

Pretreatment Processes

2.1. Overview of Wastewater Treatment Processes

Wastewater treatment processes are selected based on the nature, degree of pollution, and treatment objectives for a specific wastewater treatment plant. These processes can be either **physicochemical, biological**, or a combination of both, designed to achieve efficient wastewater treatment.

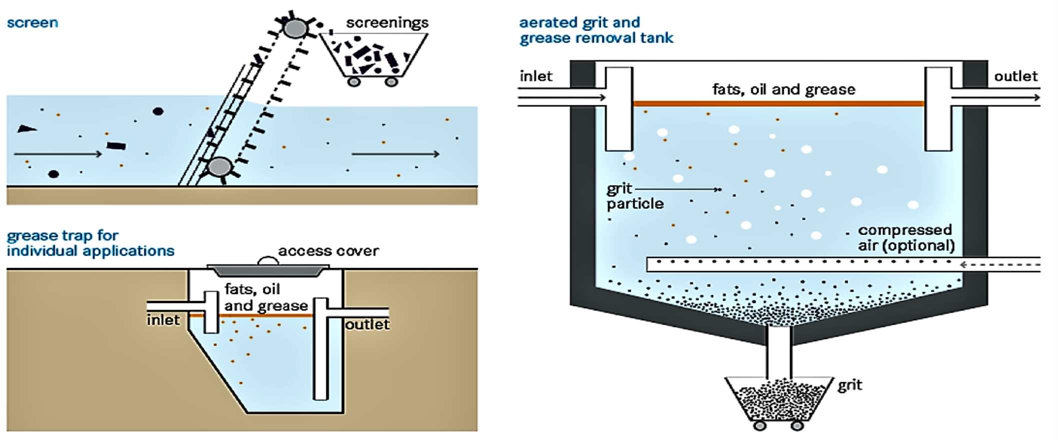


Figure 27. Pretreatment Processes

2.2. Pretreatment of Wastewater

Pretreatment is the first stage of wastewater treatment, focusing on removing large solids and debris that could obstruct or damage subsequent treatment processes. The main pretreatment stages include:

2.2.1. Screening

Screening is the process of removing solid waste, such as paper and plastics, from the incoming wastewater. A mechanical rake periodically clears these solids from the screens, after which the collected debris is discarded. Screening ensures that large items do not interfere with downstream treatment processes.

2.2.2. Sand Removal and De-oiling

This process is designed to separate:

- **Oils and Greases:** These are removed by flotation to prevent them from causing operational issues such as clogging pipes, decreasing oxygenation efficiency, or causing acidification in anaerobic digesters.
- **Solid Particles:** Sand traps help capture suspended solids in wastewater that range in size from 0.2 to 2 mm and have a dry density of approximately 1.8. Removing sand and grit is critical to avoid the abrasion of mechanical equipment and inefficiencies in the biological treatment stages.

Sand removal can be carried out in two main ways:

a) Desanding Alone

This process aims to remove 90% of particles larger than 0.2 mm in diameter. Recommended design values for desanding include: $surface = \frac{Q_{pts}\left({m^3}/{h}\right)}{50\left({m}/{h}\right)}$

- **Average dry weather flow:** Particle ascent velocity (Vasc) = 25 m/h, Dwell time (Ts) = 6 minutes.
- **Peak dry weather flow:** Vasc = 38 m/h, Ts = 4 minutes.

b) Combined Sand Removal and De-oiling

When sand removal and de-oiling occur in the same facility, the recommended hydraulic load values are:

- **Average dry weather flow:** Vasc = 6 to 10 m/h, Ts = 15 to 20 minutes.
- **Peak dry weather flow:** Vasc = 10 to 15 m/h, Ts = 10 to 15 minutes.

$$1{,}25\ m \leq \frac{volume\ (m^3)}{surface\ (m^2)} \leq 2{,}5\ m$$

Chapter III

Primary Treatments

3.1. Overview of primary Treatments

Primary treatments in wastewater treatment plants are essential for removing suspended solids and other pollutants through physical processes, sometimes enhanced with the addition of chemicals. These processes typically involve sedimentation (decantation) and may include the use of chemical reagents to improve the separation of solids from the liquid phase.

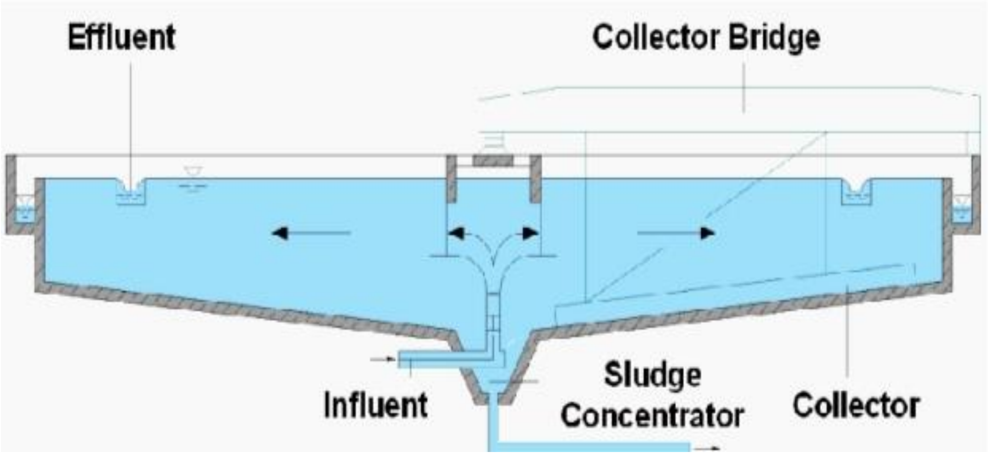


Figure 28. Primary settling basin

3.2. Sedimentation Processes

Sedimentation (or decantation) is the process where solid particles suspended in wastewater settle at the bottom of a tank due to gravity. This step is designed to reduce the concentration of suspended solids before the wastewater moves to more advanced treatment stages.

a) Process Overview

The wastewater is slowed down in large tanks, allowing the heavier particles (like sand, grit, and organic debris) to settle. The settled solids form a sludge layer at the bottom of the tank, while the cleaner water, or effluent, flows out of the tank for further treatment.

b) Purpose

Reduction of Total Suspended Solids (TSS): Sedimentation helps in removing solids that contribute to the overall pollution load.

Preparation for Secondary Treatment: The clarified water has fewer solids, which makes biological treatment in secondary stages more efficient.

3.3. Sedimentation with Chemical Reagents

In some cases, simple sedimentation may not be sufficient to achieve the desired level of solids removal. Chemical reagents can be introduced to enhance the process. This is known as chemical-assisted sedimentation or coagulation-flocculation.

a) Chemical Reagents Used:

Coagulants: Chemicals like aluminum sulfate (alum) or ferric chloride are added to the wastewater. These coagulants neutralize the charge of suspended particles, causing them to clump together into larger aggregates.

Flocculants: Flocculants are substances that promote the clumping of particles into "flocs," making them easier to remove. Polymers are commonly used for this purpose.

b) Process Overview:

Coagulation: Initially, the coagulant is mixed into the wastewater, destabilizing the fine particles and promoting their aggregation.

Flocculation: After coagulation, flocculants are added to help form larger flocs. These larger particles settle more rapidly during the sedimentation process.

Sedimentation: Once the flocs have formed, they settle to the bottom of the tank more effectively than without chemical assistance, producing a clearer effluent.

c) Benefits:

Improved Efficiency: Adding chemicals accelerates the settling process and increases the removal of smaller particles.

Enhanced Removal of Contaminants: Chemical reagents can improve the removal of organic matter, phosphorus, and other pollutants that are difficult to remove through physical processes alone.

Reduction in Biological Oxygen Demand (BOD): Sedimentation with reagents can decrease BOD levels, lowering the organic load on subsequent biological treatment steps.

3.4. Key Considerations in Primary Treatment

Sludge Production: Both physical and chemical sedimentation processes produce sludge that must be managed and treated. The type and quantity of sludge will vary depending on whether chemical reagents are used.

Optimization of Chemical Dosing: The amount of chemicals added to the system must be carefully controlled to ensure efficiency without excessive costs or side effects, such as increased sludge production.

Chapter IV

Secondary Treatments

4.1. Biological Purification

The main objective of biological treatment, also known as secondary treatment, is to eliminate as much biodegradable and non-settleable pollutants as possible from wastewater. This technique relies on the activity of bacteria present in the water. It involves bringing the organic matter contained in the wastewater into contact with an active bacterial mass in the presence of oxygen.

The bacterial mass feeds on the organic matter, which contains elements like hydrogen (H), carbon (C), nitrogen (N), oxygen (O), and phosphorus (P), and consumes it for two purposes:

- **Anabolism**: Extracting energy and elements necessary for their growth and development.
- **Catabolism:** Synthesizing new living cells.

This process replicates, in controlled conditions, a natural phenomenon that would typically occur in rivers. At the end of the biological treatment process, the bacteria form a substance known as "sludge", which needs to be separated from the purified water. The byproducts of this degradation process are primarily carbon dioxide (CO_2), biomass (the active mass of microorganisms), and purified water.

The overall equation of this process can be summarized as:

Wastewater + Biomass + O_2 → Purified Water + Biomass + CO_2

4.2. Types of Biological Purification

Biological purification can be carried out through two methods, either by using free culture or fixed culture processes.

4.2.1. Biological Purification with Fixed Culture

In this method, the bacterial culture (referred to as "fixed culture" or "biofilm") is attached to a supporting material. This biofilm is formed when bacteria adhere to the surface of a medium, creating a layer where the treatment occurs.

Fixed biomass systems have a significantly higher purification potential compared to free biomass systems. This is because the selection of species and their concentration in the biological reactor occur naturally by attachment to the support medium. This results in a higher concentration of active biomass compared to what is developed in the activated sludge, for the same reactor volume.

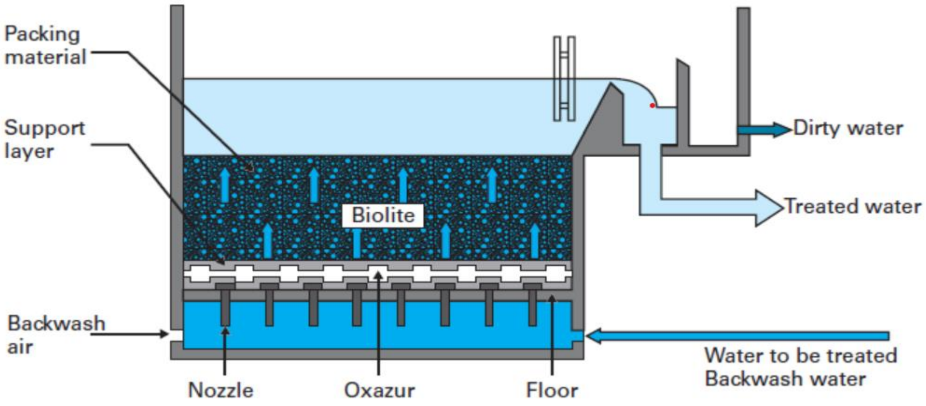


Figure 29. Aerated Biofor (biological filters)

4.2.2. Biological Purification with Free Culture

This technology is widely used in urban areas with populations of more than 5,000 inhabitants and in certain industrial activities. In this process, microorganisms are present in a free-floating state, typically at a concentration of several grams per liter. These microorganisms are kept in suspension and are supplied with oxygen either through mixing or by aeration.

The wastewater is continuously supplied to the system, and the residence time of the wastewater in the biological reactor can range from several hours to a few days, depending on the system design and treatment requirements.

There are two main free-culture biological purification processes:

Activated Sludge Process: This is the most common method used in municipal wastewater treatment plants. The bacteria, suspended in the water, consume organic matter, forming flocs that eventually settle as sludge.

Lagooning: In this process, wastewater is treated in large, shallow ponds where biological activity breaks down the pollutants over an extended period.

4.3. Biological Purification by Activated Sludge Process

The activated sludge process is a widely used and sustainable method for wastewater treatment. It offers a technical and economic balance that ensures satisfactory purification of effluents. The system relies on the cultivation of bacterial flocs in a controlled environment, ensuring proper agitation to prevent sedimentation, while providing oxygen to foster bacterial growth and interaction with pollutants. Below is an expanded and organized explanation of the process.

4.3.1. Principle of Activated Sludge Process

In this process, bacterial flocs are developed in an aeration basin where wastewater is introduced. The primary purpose of this basin is to maintain bacterial activity through two key conditions:

- Continuous agitation prevents the floc from settling.
- Oxygenation, which facilitates bacterial respiration and substrate interaction.

The aeration basin may follow a primary clarifier and is always followed by a secondary clarifier. The latter is responsible for separating solids from liquids. A portion of the sludge collected from this system is recycled back to the aeration basin to keep bacterial concentrations steady. The remaining excess sludge is directed for further treatment.

4.3.2. The Aeration Basin and Clarifier

Aeration Basin: This is the primary reactor where microorganisms degrade organic pollutants. Agitation and oxygen are provided to sustain bacterial activity.

Secondary Clarifier (Clarification): This unit allows the separation of treated effluent from the sludge. The sludge that settles at the bottom is scraped and recycled back into the system.

Part of the sludge is returned to maintain constant microbial activity in the aeration basin, while excess sludge is sent for further treatment.

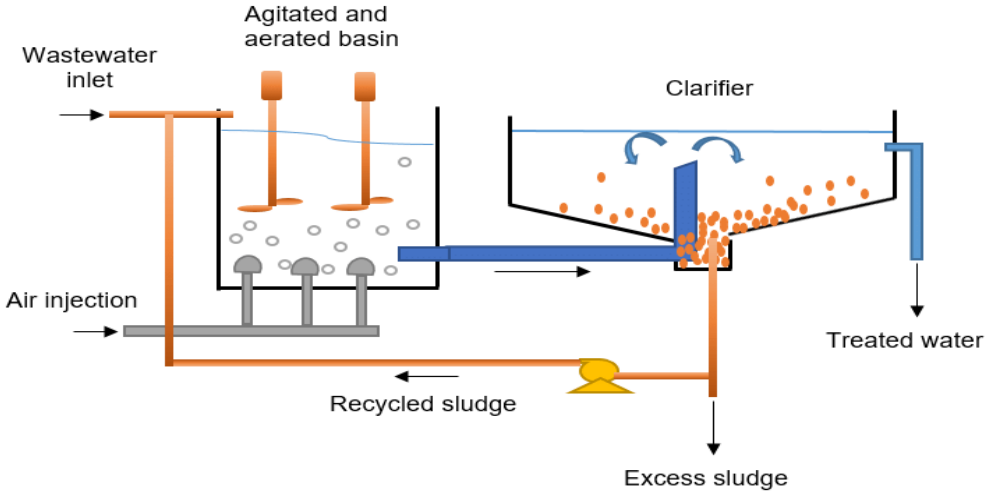


Figure 30. The activated sludge process

4.3.3. Biological Phase of Purification

a) Pollutant Removal by Microorganisms

Pollutants in the wastewater are broken down through biological oxidation. This is carried out by an aerated microfauna composed mainly of chemoorganotrophic bacteria, with protozoa and metazoans also playing a role.

b) Key Factors for Optimal Microbial Activity

- **Microbial Concentration:** A concentration of 2 to 5 g/L of microorganisms is maintained through biomass recycling, allowing for a constant rate of microbial growth.
- **Air Supply:** Oxygen is supplied to mix the biomass and prevent sedimentation of microorganisms in the basin.
- **Organic Load:** The system functions optimally when the effluent's COD/BOD5 ratio is less than 3, indicating high biodegradability.
- **Nutrient Balance:** The ideal carbon/nitrogen/phosphorus (C/N/P) ratio for wastewater is 100/5/1, ensuring proper microbial growth and treatment efficiency.

4.3.4. Structure of Activated Sludge

Activated sludge consists of bacterial flocs made up of clusters of bacteria embedded in an organic matrix. In wastewater, these bacteria face nutrient limitations and secrete extracellular polymers composed primarily of polysaccharides (complex sugars).

a) **Functions of the Polymers:**

- **Adhesion:** Bacteria adhere to one another, preventing their dispersion.
- **Nutrient Adsorption:** The polymers help retain and adsorb essential nutrients (such as BOD5 and oxygen) from the wastewater, concentrating them around the bacterial cells.

b) **Microbial Community:**

Protozoa and Metazoans: These organisms inhabit the floc, taking advantage of the nutrient-rich environment created by the bacteria. This relationship fosters the development of a diverse and efficient microfaunal ecosystem within the sludge.

4.3.5. How Activated Sludge Works

The activated sludge system functions much like a food chain. Bacteria serve as the primary producers, breaking down organic matter in proportion to the organic load in the wastewater. Other microorganisms establish predatory or competitive relationships, contributing to the stability of the ecosystem.

Key Mechanisms:

- **Bacterial Mineralization:** Organic matter is mineralized by bacteria.
- **Biomass Regulation:** Predation and competition among microorganisms help control bacterial population and maintain consistent biomass levels.
- **Clarification of Interstitial Liquid**: The process promotes the clarification of the liquid between the bacterial flocs.

4.3.6. Classification of Activated Sludge Systems

Activated sludge systems are classified based on the load applied to the reactor, typically in terms of mass and volumetric loads. These classifications help define the operational characteristics and efficiency of the system. Below is a detailed classification based on the mass load (Cm) and volumetric load (Cv).

a) **Mass Load (Cm)**

The mass load is the ratio of the amount of pollution applied per day (measured in kg of BOD5/day) to the mass of the purifying material (total dry matter) in the reactor. This factor indicates how much organic pollution the biomass is expected to treat, relative to its mass.

b) Volumetric Load (Cv)

The volumetric load is the ratio of the pollution applied per day (measured in kg of BOD5/day) to the total volume of the reactor (in cubic meters, m^3). This load measures the amount of organic pollution applied to the reactor per unit volume, reflecting the system's efficiency based on space utilization.

4.3.7. Types of Activated Sludge Systems by Load

a) Conventional Procedures

- **Mass Load**: Between **0.2 and 0.5 kg BOD5/kg MEST/day**
- **Volumetric Load**: Between **0.6 and 1.5 kg BOD5/m³/day**

These systems are the most commonly used in practice. They offer a balanced load distribution, which ensures stable performance and effluent quality. Conventional systems are often found in municipal wastewater treatment plants.

b) High Load Procedures

- **Mass Load**: Between **0.5 and 2.5 kg BOD5/kg MEST/day**
- **Volumetric Load**: Between **1.5 and 5 kg BOD5/m³/day**

These systems operate with a higher organic load, making them suitable for wastewater with a higher concentration of pollutants. They require a shorter retention time and higher aeration rates to ensure the rapid breakdown of organic matter.

c) Low Load Processes

- **Mass Load**: Between **0.07 and 0.2 kg BOD5/kg MEST/day**
- **Volumetric Load**: Between **0.35 and 0.6 kg BOD5/m³/day**

Low load systems operate under a lower organic load, resulting in slower biomass growth. These systems are more stable and are typically used when effluent quality is critical, such as for sensitive discharge environments.

d) Very Low Load Processes

- **Mass Load**: Less than **0.07 kg BOD5/kg MEST/day**
- **Volumetric Load**: Less than **0.35 kg BOD5/m³/day**

These systems are designed for wastewater with very low pollutant concentrations. They typically require longer retention times, and their use is often seen in specialized applications, such as the treatment of lightly polluted industrial or domestic wastewater.

4.3.8. Oxygen Requirements for Bacteria

The amount of oxygen required by the bacteria in an activated sludge system is based on the needs for both cellular synthesis and endogenous respiration (the respiration of cells not involved in active pollutant breakdown). The theoretical oxygen requirement can be expressed using the equation:

$$\boldsymbol{qO_2 = a'Le + b'Xa \left({}^{kg}/_{d} \right)}$$

Where:

- **a' [kg/kg BOD5]** is the constant for oxygen consumption during cellular synthesis.
- **b' [kg/kg MVS/day]** is the constant for endogenous respiration.
- **Le [kg BOD5/day]** represents the amount of pollution to be eliminated.
- **Xa [kg MVS]** is the amount of volatile suspended solids in the basin.

This equation helps in calculating the oxygen demand of the system, which is critical for aeration system design and efficiency.

4.3.9. Sizing an Aeration Basin

a) Horizontal Surface Area of the Basin

The volume of the aeration basin is calculated using the following equation:

$$V = \frac{L_0}{CV} (m^3)$$

Where:

- L_0 [kg BOD5/day] represents the quantity of pollution entering the basin, specifically the biochemical oxygen demand over 5 days (BOD5).
- CV is the rate constant representing the degradation of organic matter, which depends on the operational conditions of the basin.

b) Horizontal Surface Area of the Basin

The horizontal surface area (S) of the basin is determined by its geometry and depth. Typically, the depth h of an aeration basin ranges between 3 and 5 meters, ensuring optimal oxygen transfer and mixing of the wastewater.

$$S = \frac{V}{h}(m^2)$$

Where:

- h is the depth of the basin ($3 \leq h \leq 5$ m).
- V is the volume of the basin, as calculated earlier.

c) Basin Width Calculation

To calculate the width (L) of the basin, the Tabasaran relation can be used. This empirical formula relates the width, length, and hydraulic load of the basin, ensuring an efficient design for aeration and wastewater treatment. The exact form of the Tabasaran relation depends on specific design parameters, such as flow rate and pollutant concentration.

4.3.10. Important Parameters in Activated Sludge Systems

a) Sludge Concentration in the Basin

The concentration of sludge in the aeration basin is a key factor influencing treatment efficiency. It is controlled by recycling part of the sludge back to the basin, while excess sludge is directed for further treatment. $X_a = \frac{L_0}{Cm}(kg)$

b) Sludge Retention Time (SRT)

The sludge retention time is the average time the sludge remains in the aeration basin. This is an important design and operational parameter, as it affects the overall biomass growth and system performance. Systems with longer sludge retention times tend to promote the development of a more diverse microbial community, improving pollutant removal efficiency. $[X_a] = \frac{X_a}{V}\left({}^{kg}/_{m^3}\right)$

c) Hydraulic Retention Time (HRT)

The hydraulic retention time represents the length of time wastewater remains in the reactor. For peak flow conditions, particularly in dry weather, the retention time is crucial for ensuring the complete breakdown of organic pollutants before the treated water exits the system.$T_s = \frac{V}{Q_{pts}}$

4.4. Lagooning in Wastewater Treatment

Lagooning is a natural and simple method of wastewater treatment that utilizes natural or artificial ponds as a receiving environment for effluents. This system involves a series of shallow retention basins where water flows slowly by gravity, allowing for the natural biological processes to treat the wastewater. A lagoon system consists of multiple basins, often arranged in a sequence. In each basin, a stagnant layer of water provides an environment where a unique ecosystem of microorganisms, algae, and plants evolves. The main processes involved in lagooning include:

- **Settling of suspended solids**
- **Biological degradation** of organic matter
- **Natural purification** through interaction between bacteria, algae, and plants

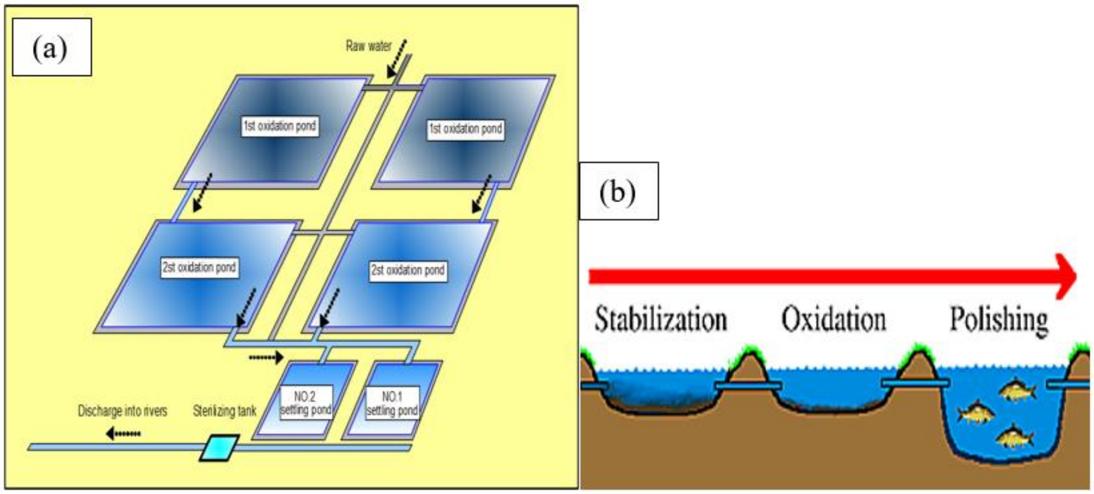


Figure 31. Wastewater Treatment by Lagooning: Artificial Basin (a) and Natural Basin (b)

4.4.1. Microphyte Pond (Algal Pond)

a) Role of Microorganisms and Algae

In the **microphyte pond**, bacteria and microscopic algae play crucial roles in the breakdown and assimilation of organic pollutants:

- **Bacteria** break down soluble organic matter, transforming it into simpler compounds such as water, carbon dioxide, nitrates, and phosphates.
- **Algae**, in turn, assimilate these mineral compounds through photosynthesis, a process that uses sunlight to produce energy and biomass while releasing oxygen into the water.

This oxygen produced by algae is vital for the aerobic bacteria in the pond, enabling them to continue their role in organic matter degradation.

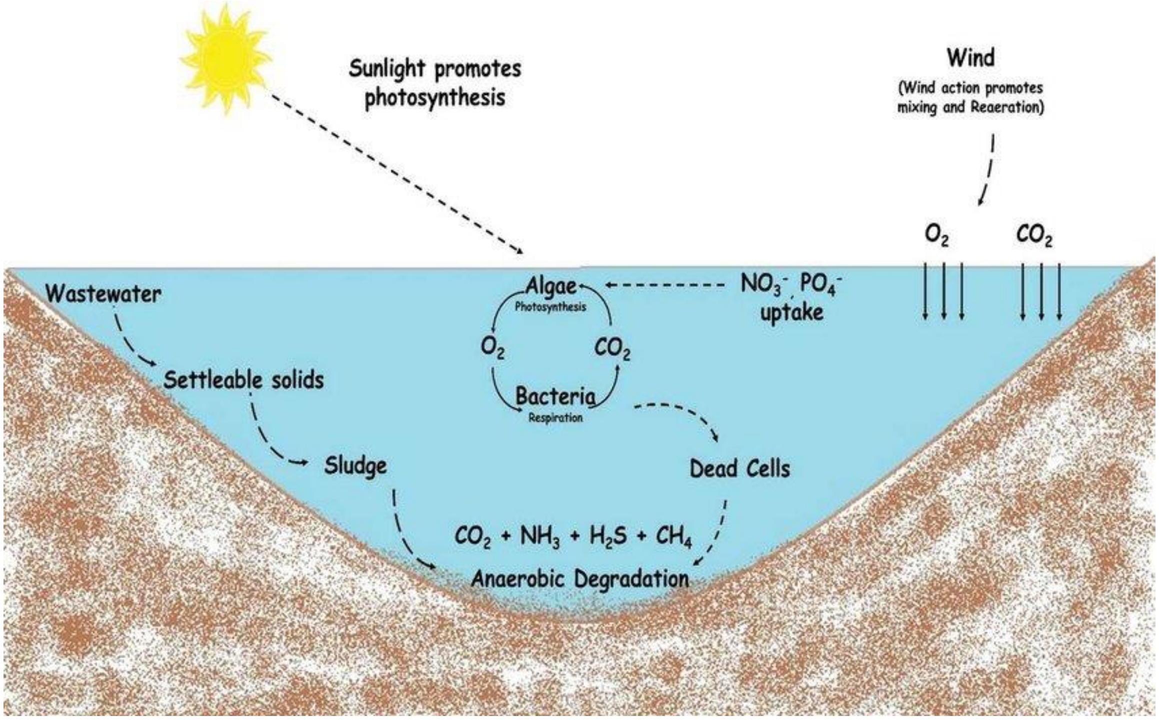


Figure 32. Phycoremediation mechanism of oxidation ponds for removal of nutrients from wastewater.

b) Photosynthesis and Biomass Production

Photosynthesis in the microphyte pond leads to the production of biomass, trapping organic and inorganic compounds that are in excess in the water. This biomass not only contributes to water purification but also aids in maintaining a balanced ecosystem within the pond.

c) Retention Time and Pond Characteristics

The water typically remains in the microphyte pond for about **50 days**. To achieve effective treatment, the ponds must be:

- **Wide** to provide enough surface area for photosynthesis and bacterial activity.
- **Shallow** to ensure proper light penetration, which is essential for algal growth.

4.4.2. Macrophyte Pond (Plant-Based Pond)

a) Characteristics and Plant Species

The macrophyte pond is characterized by the presence of larger, visible plants. These include:

- **Submerged or emerged plants** such as reeds, bulrushes, rushes, sedges, duckweed, and water hyacinths.
- The plants may be either rooted or floating on the water surface.

The macrophyte pond generally has a **smaller surface area** and is **less deep** (0.6 to 0.8 meters) compared to microphyte ponds. It handles water with a lower pollutant load, often after partial treatment in the preceding microphyte pond.

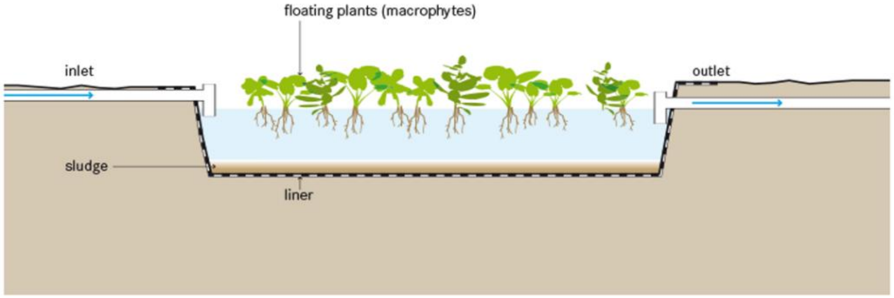


Figure 33. Floating Plant Pond

b) Role of Macrophytes

Macrophytes play an essential role in wastewater treatment by:

- Providing **oxygen** through their roots, which supports bacterial growth.
- Assisting in the **filtration and absorption** of nutrients and pollutants.
- Creating **habitats** for a diverse range of organisms that further contribute to the purification process.

4.4.3. Types of Lagoons

There are two main types of lagoons based on their treatment processes and oxygen availability:

a) Natural Lagoons

Natural lagoons are shallow ponds, typically ranging from 0.8 to 1 meter in depth, designed for the treatment of wastewater. These lagoons can operate under either facultative anaerobic conditions, where both aerobic and anaerobic processes take place, or under aerobic conditions, which require a continuous supply of oxygen. Depending on their design and purpose, natural lagoons can receive either raw effluents directly or pre-treated wastewater that has undergone initial treatment. The choice between aerobic or anaerobic processes, as well as the type of effluent, is determined by the specific treatment goals and local environmental conditions.

b) Aerated Lagoons

Aerated lagoons are advanced wastewater treatment systems where oxygen is introduced through surface aerators or mechanical blowers to maintain aerobic conditions for bacteria. By ensuring higher levels of dissolved oxygen, these lagoons enhance the biological processes, allowing for faster and more efficient breakdown of organic pollutants. This continuous oxygen supply boosts microbial activity, leading to more effective wastewater purification.

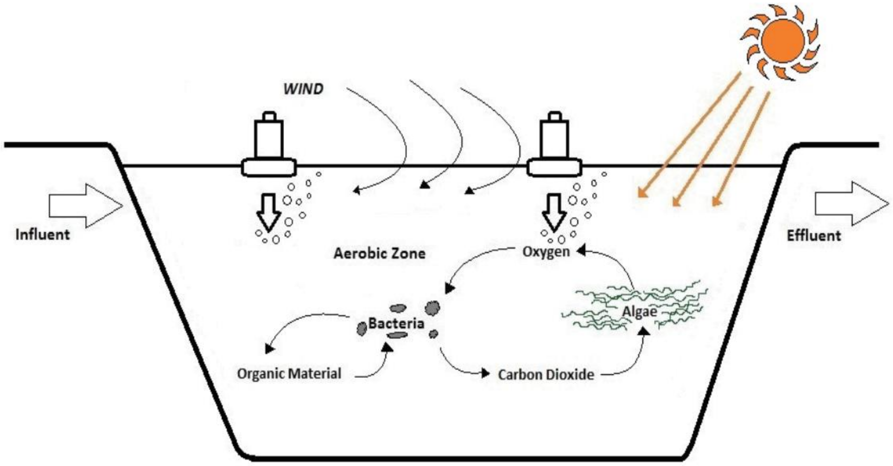


Figure 34. Aerated lagoon

4.4.4. Purification Process in Lagooning

In both natural and aerated lagoon systems, the purification process is primarily biological. Bacteria, algae, and plants work together to:

- **Degrade organic matter**
- **Convert pollutants** into simpler, less harmful substances
- **Absorb nutrients** and excess minerals

The combination of sunlight, oxygen, and biological activity within the lagoons leads to the natural treatment of wastewater, making lagooning an effective and environmentally friendly method for wastewater management, particularly in rural and less industrialized areas.

4.5. Clarification Process in Wastewater Treatment

Clarification is the final step of biological treatment in which the treated effluent is directed to a clarifier, also known as a secondary decanter. In this stage, the water is separated from the sludge through a process of sedimentation. The clarified water can then be discharged into the natural environment, while the sludge is either returned to the aeration basin or treated further for disposal or reuse.

4.5.1. Clarifier Design and Operation

For optimal results, clarifiers are often circular structures with a steeply inclined bottom (at least 50° to the horizontal). This design facilitates the efficient settling of solids:

- Clarified water is drawn off from the top and discharged.
- Sludge settles to the bottom, where part of it is returned to the aeration basin to maintain a sufficient mass of microorganisms for continued biological activity.
- The remaining sludge is dried and either sent to landfill, incinerated, or recycled in agriculture as a nutrient source.

4.5.2. Sizing a Clarifier

Proper sizing of the clarifier is essential, and it should be done before the biological reactor since the clarifier helps regulate the distribution of the sludge mass in the reactor. The mass of sludge in the reactor is determined by the concentration of suspended solids (MES), which should not exceed certain levels. The mechanical quality of the sludge is characterized by its Mohlman Index (IM).

1. **Mohlman Index (IM)**

The **Mohlman Index** indicates the volume occupied by 1 gram of sludge after a specific decantation period:

- For **activated sludge**, this is measured after 30 minutes.

- For sludge from a **bacterial bed**, it is measured after 2 hours.

This index is a critical parameter for determining the settling capacity of the sludge. It is calculated by dividing the volume of sludge in milliliters (ml) by the suspended solids content in grams per liter (g/L). The higher the IM, the more difficult it is for sludge to settle. $IM = \frac{V_{d\,(ml/l)}}{SS\,(g/l)} \left(ml/g\right)$

- **Practical Measurement of the Mohlman Index**

In practice, the Mohlman Index is determined by:

1. **Measuring the volume of settleable matter (SM)** in 30 minutes (for activated sludge) and expressing it as a volume concentration (V_d) in ml/L.
2. **Measuring the suspended solids (SS) content** by drying at 105°C and expressing it as a mass concentration in mg/L.

Once the IM is known, the maximum upward velocity for the clarifier is calculated to ensure efficient sludge separation. For a SS concentration of 30 mg/L in the treated effluent, specific values for upward velocity are used. If a SS concentration of 20 mg/L is required, these values are multiplied by 0.66 to maintain proper sedimentation.

$$S = \frac{Q_{pts(}{}^{m^3}/_{h)}}{v_{asc}({}^{m}/_{h})}$$

Table 4. Relationship between Mohlman Index (IM) and Maximum Upward Velocity in Clarification (Vasc)

IM (ml/g)	75	100	125	150	175	200	250	300	400	500
Vasc (m/h)	1.4	1.3	1.2	1.1	1.0	0.9	0.85	0.8	0.7	0.6

2. Clarifier Recycling

To maintain a constant concentration of sludge in the aeration basin, sludge recycling from the clarifier is necessary. The recycling rate can range from 15% to 100% of the effluent flow rate, depending on system requirements. $R = \frac{100 \times [X_a]}{\frac{1200}{I_m} - [X_a]}$

The concentration of sludge in the recycling flow (Xm) is calculated empirically based on:

$$X_m = \frac{1{,}2 \times 10^3}{I_m}$$

- **[Xa]**, the concentration of sludge in the aeration basin (Kg/m³)
- **IM**, the Mohlman Index

Chapter V

Advanced Treatment Processes

5.1. Nitrification and Denitrification

Nitrification and denitrification are two key biological processes used for removing nitrogen from wastewater, which is crucial in preventing environmental problems like eutrophication. Let's break it down:

1) **Nitrification:** This is an aerobic (oxygen-requiring) process where ammonia (NH_3) is converted into nitrate (NO_3^-) in two steps. First, ammonia-oxidizing bacteria (AOB) change ammonia into nitrite (NO_2^-). Then, nitrite-oxidizing bacteria (NOB) convert this nitrite into nitrate. The whole process needs a well-oxygenated environment and plays a vital role in wastewater treatment because nitrates are far less toxic than ammonia.
2) **Denitrification:** In contrast, this is an anaerobic process, meaning it happens in environments with little to no oxygen. Denitrifying bacteria take nitrate (NO_3^-) and convert it into nitrogen gas (N_2), which is harmless and just gets released into the atmosphere. This step is particularly important for getting rid of nitrates in wastewater, especially when treated water is released into sensitive ecosystems that require low nitrogen levels.

Together, nitrification and denitrification ensure that nitrogen levels in treated wastewater are kept in check, protecting water bodies from nutrient overloads that can lead to harmful algal blooms and oxygen depletion.

5.2. Physico-Chemical Removal of Ammonia

When biological treatments aren’t quite enough to handle ammonia, we turn to some physico-chemical methods. These methods are especially useful in industrial wastewater scenarios. Here's how they work:

- **Air Stripping**: By raising the pH and increasing the air-to-water contact, ammonia is converted into a gas and stripped from the water. The gaseous ammonia is then captured and treated separately.

- **Ion Exchange:** This involves passing water through a resin bed, where ammonia ions are swapped with other ions (usually sodium). It's quite effective for lower concentrations of ammonia but does require occasional resin regeneration.
- **Chemical Precipitation:** Adding reagents like magnesium and phosphate causes ammonia to form magnesium ammonium phosphate (struvite), which can then be filtered out. This approach is particularly helpful when dealing with high ammonia concentrations.

These physico-chemical techniques often complement biological treatments, providing that extra step needed to manage ammonia levels.

5.3. Disinfection

Disinfection is a crucial step in ensuring that the treated wastewater is safe for release into the environment or for reuse. Even after biological treatment and clarification, water can still harbor pathogens (bacteria, viruses, protozoa) that can pose health risks.

- **Chlorination**: The most common disinfection method, where chlorine is added to the water to kill microorganisms. Chlorination is effective but may produce harmful byproducts (such as trihalomethanes) if not carefully controlled.
- **Ultraviolet (UV) Radiation**: This is a physical disinfection method where water is exposed to UV light, which penetrates microorganisms and disrupts their DNA, preventing them from reproducing. UV disinfection has the advantage of not producing harmful byproducts, but it requires clear water and continuous maintenance of UV lamps.
- **Ozonation: Ozone (O3)** is a powerful oxidant that can destroy pathogens effectively. It is often used in advanced wastewater treatment plants because of its strong disinfection power and its ability to break down organic contaminants. However, it requires careful handling due to the reactivity of ozone.

Disinfection ensures that pathogens are removed or inactivated, making the treated effluent safe for disposal into water bodies or for reuse in irrigation or industrial processes.

5.4. Phosphorus Removal (Dephosphoration)

Phosphorus can be quite a problem when it comes to water quality, as it contributes to eutrophication, causing excessive plant and algae growth in water bodies. There are two main ways to remove it:

- **Chemical Precipitation**: Adding chemicals like aluminum sulfate (alum), ferric chloride, or lime reacts with phosphorus, forming insoluble compounds that can be settled out as sludge. It’s an effective method but tends to increase sludge production.
- **Biological Phosphorus Removal**: Here, phosphorus-accumulating organisms (PAOs) are encouraged to take up excess phosphorus from wastewater. This approach is more eco-friendly since it minimizes chemical use.

By removing phosphorus, we help prevent nutrient overload in water bodies, protecting aquatic ecosystems.

5.5. Filtration

Filtration is a vital physical process used to remove remaining suspended solids and particles from treated wastewater. It’s often the final step before disinfection:

- **Sand Filtration:** As the most common method, water passes through layers of sand, trapping suspended solids. It’s effective but requires regular maintenance and backwashing to keep it functioning properly.
- **Membrane Filtration:** This includes microfiltration and ultrafiltration. The membranes have very fine pores that filter out particles and microorganisms. While more effective than sand filtration, it is more expensive and requires advanced technology.

Filtration ensures that the treated water is clear and free from particles, making it ready for further disinfection or reuse.

5.6. Adsorption on Activated Carbon

Activated carbon is a highly porous material that’s excellent for adsorbing organic contaminants, trace pollutants, and certain heavy metals:

- **Granular Activated Carbon (GAC):** Typically used in larger systems, water flows through a bed of carbon granules, which adsorb impurities. GAC is great for removing residual chemicals, odors, and colors.
- **Powdered Activated Carbon (PAC):** This form is added directly to the water, where it adsorbs pollutants before being filtered out. It's often used for temporary applications or specific pollution events.

Activated carbon adsorption is particularly useful when we need to achieve very high water quality, especially during the final treatment stag

References

1. Ali, Adnan Sirage. *Wastewater Treatment Manual*. May 2019, Conference Presentation. DOI: 10.13140/RG.2.2.11548.13445.
2. Ali, Adnan Sirage. *Introduction to Drinking Water Treatment*., May 2019.
3. CHEREMISINOFF, Paul N. *Handbook of water and wastewater treatment technology*. Routledge, 2019.
4. CRITTENDEN, John C., TRUSSELL, R. Rhodes, HAND, David W., et al. MWH's *water treatment: principles and design*. John Wiley & Sons, 2012.
5. HOWE, Kerry J., HAND, David W., CRITTENDEN, John C., et al. *Principles of water treatment.* John Wiley & Sons, 2012.
6. KOUADIO, Adolphe. *Water Treatment Course*. Omni Chimie et Services Industriels de Côte d'Ivoire SARL.
7. MANAHAN, Stanley E. *Environmental chemistry*. CRC press, 2022.
8. METCALF & EDDY, ABU-ORF, Mohammad, BOWDEN, Gregory, et al. *Wastewater engineering: treatment and resource recovery*. McGraw Hill Education, 2014.
9. NEMEROW, NELSON LEONARD. WATER, *WASTEWATER, SOIL AND GROUNDWATER TREATMENT AND REMEDIATION*. (NO TITLE), 2009.
10. Observatoire Régional de l'Environnement Poitou-Charentes. *Water Quality for Drinking Water Supply in Poitou-Charentes*. Dernière mise à jour : 2015, http://www.environnement-poitou-charentes.org/La-qualite-de-l-eau-pour-l.html.
11. POST, G. B., ATHERHOLT, T. B., ET COHN, P. D. *WATER QUALITY AND TREATMENT: A HANDBOOK ON DRINKING WATER*. HEALTH AND AESTHETIC ASPECTS OF DRINKING WATER, 6TH EDN. MCGRAW-HILL, NEW YORK, 2011, P. 2.1-2.100.
12. QASIM, Syed R. *Wastewater treatment plants: planning, design, and operation*. Routledge, 2017.

13. SPELLMAN, FRANK R. *HANDBOOK OF WATER AND WASTEWATER TREATMENT PLANT OPERATIONS*. CRC PRESS, 2008.
14. SUEZ. Water Handbook [online]. 2024 [accessed 23 September 2024]. Available from: https://www.suezwaterhandbook.com/
15. THÉVENOT, Daniel, et Gilles VARRAULT. *Wastewater Treatment*. LEESU, Université Paris-Est Créteil, ENPC, ENGREF, 2016 (UMR-MA 102).
16. Water Environment Federation (WEF). Water Environment Federation [online]. 2024 [accessed 12 august 2024]. Available from: https://www.wef.org/
17. World Health Organization (WHO). Water, Sanitation, and Hygiene (WASH) [online]. 2024 [accessed 9 July 2023]. Available from: https://www.who.int/water_sanitation_health/en/

Part 3

Exercises

Tutorials

7.1. Tutorial 1

Exercise 01

Water exhibits the following characteristics:

Conductivity of 350 µS/cm, turbidity of 4 FTU, pH of 7.8, and a BOD_5 of 0.5 mg/l O_2.

1. Determine the type of water based on the mentioned characteristics.
2. Calculate the COD as well as the amount of organic matter present in this water.

Given:

A. Conductivity measures water's ability to conduct electricity between two electrodes.

1 Siemens (S) = 10^3 millisiemens (ms) = 10^6 microsiemens (µS)

Conductivity (χ)	**Water Type**
χ = 0.005 µS/cm	Deionized water
10 < χ < 80 µS/cm	Rainwater
30 < χ < 100 µS/cm	Slightly mineralized water, granitic domain
300 < χ < 500 µS/cm	Moderately mineralized water, carbonate rock domain (karst)
500 < χ < 1000 µS/cm	Highly mineralized water, brackish or saline water
χ > 30000 µS/cm	Seawater

i. PH (Hydrogen Potential) measures the concentration of H+ ions in water.

pH	**Description**
pH < 5	- Strong acidity, pH of Coca-Cola = 3, pH of orange juice = 5 - Presence of mineral or organic acid in natural waters
pH = 7	Neutral pH
7 < pH < 8	Approximate neutrality, majority of surface waters
5.5 < pH < 8	Groundwater
pH > 8	Alkalinity

B. Turbidity is used to specify visual information about the color of water.

1 NTU (Nephelometric Turbidity Unit) = 1 JTU (Jackson TU) = 1 FTU (Formazin TU).

NTU Value	Description
NTU < 5	Colorless water
5 < NTU < 30	Slightly colored water
NTU > 50	Colored water
NTU > 200	Surface water "African"

C. BOD (Biochemical Oxygen Demand) expresses the amount of oxygen needed for the degradation of biodegradable organic matter in water through the growth of microorganisms.

Situation	BOD_5, in mg/L of O_2
Pure and fresh natural water	< 1
Slightly polluted river	1 < c < 3
Sewer	100 < c < 400
Effluent from treatment plant	20 c < 40

*COD (Chemical Oxygen Demand) expresses the amount of oxygen needed to oxidize organic matter (biodegradable or not) in water using an oxidizing agent: potassium dichromate.

Generally, BOD_5 (Biochemical Oxygen Demand over 5 days) is approximately equal to 0.8 times the COD (Chemical Oxygen Demand). The following empirical relationship relates BOD_5, COD, and the organic matter in the sample (OM):

$OM = (2 * BOD_5 + COD) / 3$

7.2. Tutorial 2

Exercise 1

The characteristics of our bar screen are as follows (in accordance with typical design values for mechanical bar screens

E	20 mm
e	15 mm
D	1,8 (Circular) 1,7 oblique
C	0,5
V (combined sewer system)	1,2 m/s
V (separate sewer system)	0,6 m/s
Q	0,15 m3/s
τ	0,4 m
α	60 °

- Calculate the head loss generated by the passage of water through the bar screen, consider the submerged surface area and the width of the bar screen.

Exercise 2

We set an ascending velocity of sand particles at 14 m/h, the flow to be treated is 2000 m3 per day, and we have a hydraulic retention time of 30 minutes.

- Determine the characteristics of a cylindrical grit chamber

Exercise 3

A grit chamber is designed to handle a flow rate of 76 L/s. The particles have a diameter of 0.06 mm and a relative density of 2.5. What should be the surface area of this grit chamber?

Exercise 4

So, considering our solution consists of spherical particles with a diameter d_{pc}=2µm, and the concentration of particles per cubic meter of water is N0=1,06 10^{12}.

a. Calculate the volume of the flocculator to treat a flow rate of 10 l/s.
b. Determine the power transmitted by a blade (l=0.6 m, h=0.2m), which is moving at a speed of 1.5 m/s.

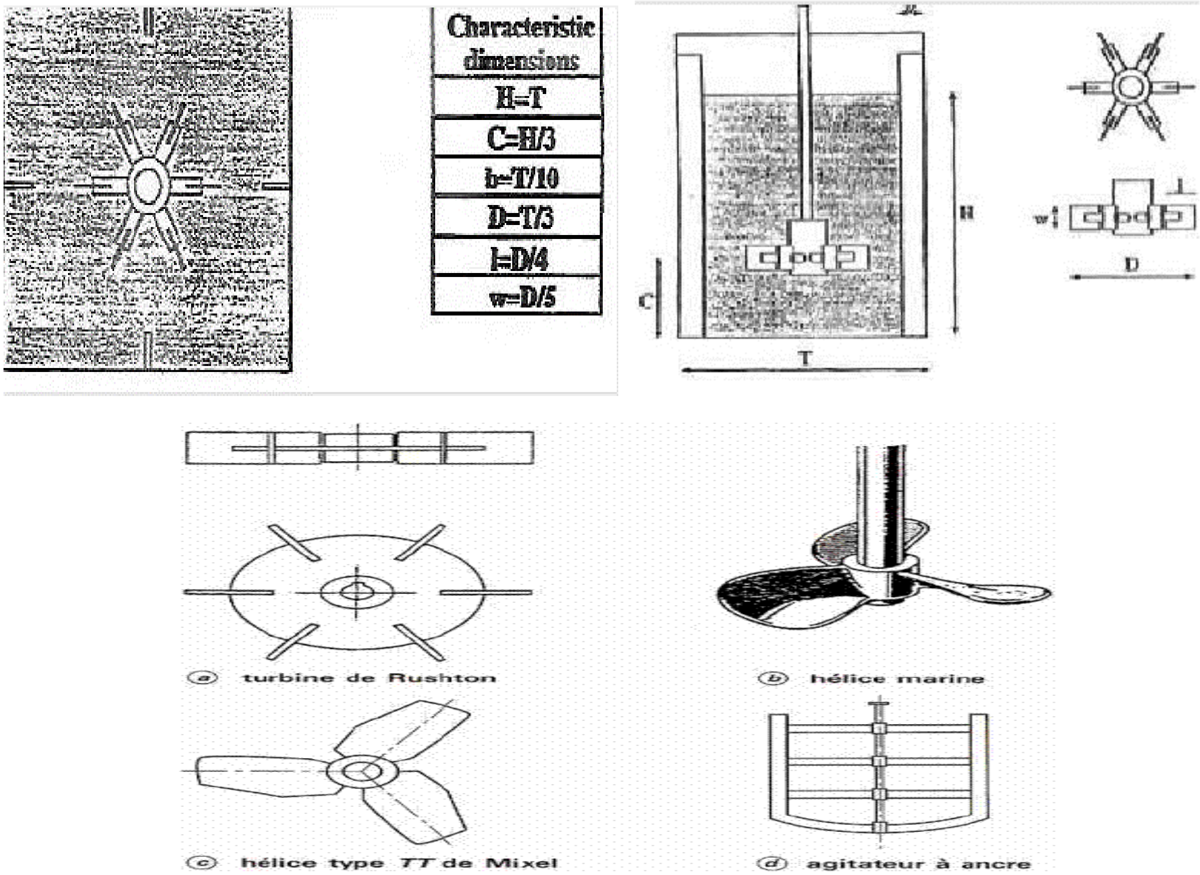
Exercise 5

The volume of a flocculator is 327 m3, its height (H) is 7 m, and it treats a flow rate of 15 m^3/s.

a. Calculate the water velocity.

b. Calculate the different characteristics of the flocculator, considering that its geometry is that of a standard reactor stirred by a Rushton turbine.

c. Calculate the power transmitted by the flat blade for a speed of 1.9 m/s and a velocity gradient of 27 s^{-1}



Characteristic dimensions
H=T
C=H/3
b=T/10
D=T/3
l=D/4
w=D/5

Figure 1. The standard geometry of a reactor stirred by a Rushton turbine (M. Rossini et al., 1999)

Exercise 6

Calculate the sedimentation velocity of a particle with a diameter d=10 micrometers, a volumetric mass ρ_s=1700 kg/m^3, submerged in a fluid with a volumetric mass ρ_L=1000 kg/m^3, and viscosity μ=10^{-3}Pa.s.

- Determine the surface area of the settler for a flow rate of 15 l/s.

Exercise 7

We consider a rectangular section settler, where h=1m, l=4m, and L=10m. A suspension containing particles with diameters ranging from 1 to 100 microns is fed at a rate of5 m3.h-1 at the surface of the basin, at one of its ends. The liquid flow is considered to be uniform across the entire vertical section of the basin. Clarified liquid exits by overflow at the other end of the basin.

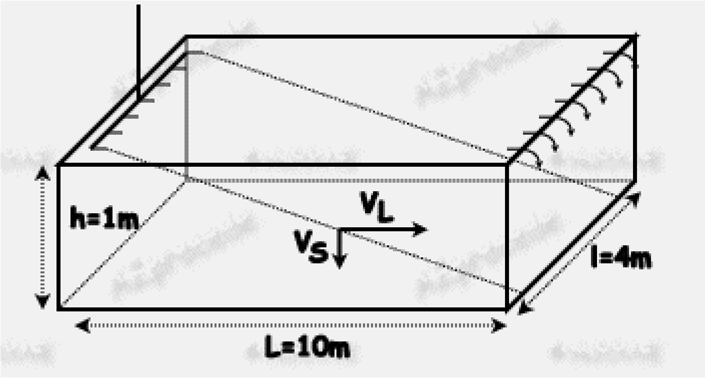


Figure 2. The geometry of the settler.

a) Calculate the flow section, volume of the solution in the apparatus, average residence time, and horizontal velocity V_1 of the liquid.

b) Determine the sedimentation velocity V_0 required for a particle to reach the bottom of the basin directly below the overflow, using the horizontal motion relationship, where the horizontal distance traveled is 10 m, and

c) Calculate the minimum diameter of particles that will settle in this basin, and the Reynolds number for these particles. (**Data:** Particle density 1.7, **ρ**L=1000 kg.m-3 and μ=10-3Pa.s, g= 9, 81 m)

Exercise 8

We consider a lamellar settler, where the width of a lamella lp= 5 m, the length of a lamella Lp 5 m, the inclination of the plates is 60°, with a flow rate to be treated of 1 m^3/s, and a Hazen velocity of 0.2875 mm/s.

a) Calculate the total projected surface area.

b) Calculate the total number of lamellae and the flow rate between the lamellae.

Exercise 9

Calculate the Reynolds number of the pores corresponding to a flow velocity of 2.5 m/h through a cake formed by grains with an equivalent diameter of 25 mm.

Density and viscosity of the liquid: $\rho = 103\ kg/m^3$; $\mu = 10^{-3}$ Pa•s,

Porosity of the cake: $\varepsilon = 0.5$.

Exercise 10

A suspension with a concentration of $s = 10^{-2}$ kg of solid/kg of suspension is filtered under a constant pressure $\Delta P = 2$ bars. The resulting cake has a moisture ratio of m = 1.40 and a specific resistance of $\alpha = 4.15\times10^8$ m/kg. The resistance of the filter medium is Rs $= 1.3\times10^8\ m^{-1}$.

- Calculate the instantaneous flow rate per m^2 of filter area corresponding to the production of V m^3 of filtrate per m^2 of filtering surface.

Numerical application: V = 0, 1, 2, 3, 4 m^3. The viscosity and density of the filtrate are respectively: $\eta = 10^{-3}$ Pa•s; $\rho_1 = 103\ kg/m^3$.

Exercise 11

Required chlorine concentration: 2 mg/L

Flow rate of the installation: 500 m^3/h

We need to calculate the total amount of chlorine to add to maintain a concentration of 2 mg/L.

7.3. Tutorial 3

Exercise

In order to design a wastewater treatment plant for an urban population with a water allocation of 76 L/person/day, you are required to:

1. Calculate the flow rates for the population in 2054 (daily flow, average hourly flow, and peak flow).
2. Calculate the pollution load at the inlet of the plant.
3. Design the necessary structures for an activated sludge treatment plant.

Given:

Parameter	Value
Population (2054)	10,000 inhabitants
Allocation (N)	25 L/person/day
Coefficient of Return (R)	0.8
BOD5	1250 mg/L
COD	? mg/L
TSS (Total Suspended Solids)	30 mg/L

Formulas and calculations:

1. **Flow rates :**

Number of inhabitants in the future

N: future population

N_0: current population

$$N = N_0 * \left(1 + \frac{T}{100}\right)^d$$

T: growth rate

d : projected period

Daily flow rate:

The total daily flow rate is defined by: $Q_J = D * N * R$

Average hourly flow rate:

The average hourly flow is given by the relation: $Q_{mh} = \frac{Q_{day}}{24}$

Peak flow rate: $Q_{pts} = Q_{mh} \times C_P$

By definition, the peak flow rate is defined by the relation:

$$\begin{cases} C_P = 1{,}5 + \dfrac{2{,}5}{\sqrt{Q_{mh}}} \; if \; Q_{mh} \geq 2{,}8\dfrac{l}{s} \\ cp = 3 \qquad\qquad if \;\; Q_{mh} < 2{,}8\dfrac{l}{s} \end{cases}$$

2. Calculation of Pollution Loads

The daily pollution loads are:

- TSS (kg/day) = Q_n (m^3/day) x [TSS mg/L] x 10^{-3}
- BOD5 (kg/day) = Q_n (m^3/day) x [BOD5 mg/L] x 10^{-3}

3. Pretreatment

3.1. Screening

A. Design Criteria

Consider a mechanical screen (circular bars) with the following characteristics:

- Velocity through the screen: **v = 0.8 m/s**
- Inclination angle: **θ = 70°**
- Spacing between bars: **E = 25 mm**
- Circular bars with diameter: **b = 10 mm**
- Width of the screen: **L = 1 m**
- Gravitational acceleration: **g = 9.81 m/s²**

B. Sizing

- The submerged surface area of the screen is given by the formula: $S = \frac{Q_{pic}}{v.\theta.C}$

- **Q**: Maximum flow rate through the screen
- **V**: Flow velocity through the screen
- **Θ**: Free passage coefficient, given by the relation: = E / [E + e]
- **C**: The clogging coefficient varies from 0.10 to 0.30 for a manual grid and from 0.40 to 0.50 for an automatic grid.
- The relation gives the height of the screen: H=S/ L

3.2. Grit Removal

A. Design Criteria:

The grit chamber removes 80% of the mineral matter in the wastewater. Mineral matter represents about 20% of the suspended solids (TSS), and the remaining 80% are volatile suspended solids (VSS).

B. Sizing

- **Volume of the Grit Chamber** is given by: $\boldsymbol{V = Q_{Pic} * T_S}$
- **T_s**: Settling time, adopted as **5 minutes**
- **Diameter of the Grit Chamber** : $D = \sqrt{4 * \frac{V}{\pi H}}$The height is taken h=3
- **Volumetric Flow Rate of Injected Air** $\boldsymbol{Q_{AIR} = Q_{Pic} * V}$ **V**: Volume of air to inject, adopted as **1.25 m³/m³**

C. Design Calculation:

Quantity of removed solids:

The grit chamber removes 80% of the mineral matter in the wastewater. Mineral matter represents 20% of the suspended solids (TSS), and the remaining 80% are volatile suspended solids (VSS).

- Total mineral matter = TSS * 20% = TMM (kg/day)
- Mineral matter removed by the grit chamber = 80% * TMM = TMM^e (kg/day)
- Remaining mineral matter = TMM - TMM^e = TMMr (kg/day)
- TSS exiting the grit chamber = TSS * 80% + TMMr = TSS_s

3. Primary Treatment

A. Sedimentation Tank Design Criteria:

- Overflow rate (τ) = 2 m³/h/m²
- Retention time (Tr) = 1.5h
- The primary clarifier removes 35% of BOD5 and 95% of mineral matter.

B. Sizing

- **Surface of the Settling Tank** is given by the relation: $S = \frac{Q_{Pic}}{\tau}$
- **Volume of the Settling Tank** $V = Q_P * T_r$
- **Diameter of the Settling Tank** $D = \sqrt{4 * \frac{S}{\pi}}$

C. Pollution Load Calculation:

The primary clarifier removes 35% of BOD5 and 95% of mineral matter:

- BOD5 load = BOD5 load kg/day
- Remaining mineral matter = TMMr (kg/day)
- BOD5 load removed = BOD5 load * 35% = $BOD5^e$ (kg/day)

- Mineral matter removed = TMMr * 95% = TMM^e (kg/day)
- **Sludge Volume per Day** The total quantity of sludge produced (BT) in the clarifier is:

BT = $BOD5^e$ + TMM (removed) $MES = \frac{B_T}{Q_j}$

4. **Secondary Treatment Works**

A. **Aeration Tank Design Criteria:**

We will assume that the activated sludge treatment will be medium-load.

- A mass load of $0.2 < Cm < 0.5$ kg BOD5 / kg VSS/day
- A volumetric load of $0.6 < Cv < 1.5$ kg BOD5 / m^3/day
- Length/width ratio = 1.5, with a tank height between 3 and 5 meters.
- The BOD5 concentration at the outlet must be less than 30 mg/L (WHO discharge standards).

B. **Pollution Loads for BOD5:**

The pollution load at the inlet of the aeration tank will be:

- (L_0) BOD5 = total BOD5 load – BOD5 removed in the primary clarifier
- The BOD5 concentration at the inlet is S_0.$S_0 = \frac{L_0}{Q_j}$
- The BOD5 concentration at the outlet must meet WHO discharge standards of 30 mg/L, so the outlet load is $L_s = S_s * Qj$.
- The BOD5 removed load is: $L_e = L_0 - L_s$.
- **Removal Efficiency:** :$R = \frac{L_0 - L_S}{L_0} 100$
- **Tank Volume:** is derived from the volumetric load C_v:

$$C_v = \frac{BOD_5 \; load \; at \; the \; inlet \left({kg}/{j} \right)}{volume \; of \; the \; tank \; (m^3)}$$

- Cv = 1.2 kg BOD5 / m^3/day
- V = tank volume $V = \frac{L_0}{CV}$
- **Sludge Mass in the Tank:**

  The total sludge mass in the tank is derived from the mass load:

$$C_m = \frac{BOD_5 \; load \; at \; the \; inlet \left({kg}/{j} \right)}{sludge \; mass \; VSS \; (kg)}$$

- Cm = 0.4 kg BOD5 / kg VSS/day
- The BOD_5 load at the inlet of the aeration tank is 1384.39 kg/day
- Xa: total sludge mass in the tank = $Xa = L_0/Cm$

- The sludge concentration in the tank is: $[X_a] = \frac{X_a}{V}\left({kg}/{m^3}\right)$

C. Sizing of the Aeration Basin

To properly design the aeration basin, the following calculations are considered:

- **Horizontal Surface Area** (**S**) is calculated using the formula: $S = \frac{V}{H}$
- **Basin Width** The width of the basin (**l**) is calculated as: $\boldsymbol{l} = \sqrt{\frac{\boldsymbol{S}}{\mathbf{1,5}}}$
- **Basin Length** The length of the basin (**L**) is determined as: $\boldsymbol{L} = \mathbf{1,5} * \boldsymbol{l}$
- **Residence Time** The residence time is: $T_s = \frac{V}{Q_{pts}}$
- **Oxygen Requirements (Kg/day):**

$$\boldsymbol{qO_2 = a'Le + b'Xa\left({kg}/{d}\right)}$$

- **a' [kg/kg BOD5]** is the constant for oxygen consumption during cellular synthesis.
- **b' [kg/kg MVS/day]** is the constant for endogenous respiration.
- **Le [kg BOD5/day]** represents the amount of pollution to be eliminated.
- **Xa [kg VSS]** is the amount of volatile suspended solids in the basin.

type of Treatment	**a'**	**b'**
Low load	0.65	0.065
Medium load	0.60	0.08
High load	0.55	0.12

Table 1: Values of a' and b' based on the type of activated sludge treatment

5. Clarifier

A. Sizing of the Clarifier

Since the clarifier will treat the same flow rate as the primary settling tank, its dimensions will be similar. The following steps outline the design process:

- **Useful Surface Area of the Clarifier** $S = \frac{Q_P\left({m^3}/{h}\right)}{v_{asc}\left({m}/{h}\right)}(m^2)$ **V**$_{\mathbf{asc}}$: Surface loading rate (m/day), adopted as **1.2 m/day**
- **Volume of the Clarifier** $\boldsymbol{V = s * h\ (m^3)}$ **h**: Depth of the clarifier, adopted as **3 m**

- **Retention time** $\boldsymbol{t_s = \frac{V}{Q_P}}$
- **Excess Sludge Concentration:** $X_m = \frac{1,2\times10^3}{I_m}$

  IM: volume occupied by one gram of sludge (ml/g), without dilution (Im = 115)

- **Sludge Recycle Rate (R%):** $R = \frac{100\times[X_a]}{\frac{1200}{I_m}-[X_a]}$

  [Xa]: sludge concentration in the tank

- **The recycled sludge flow rate** in the tank is given by:$Q_r = \frac{(R*Q_J)}{100}$