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MUNICIPAL WASTEWATER TREATMENT TECHNOLOGIES

Wastewater treatment plant by Michal Jarmoluk from Pixabay licensed under CC0

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Municipal waste water (MWW) means waste water from residential settlements and services which originates predominantly from human metabolism and from household activities (**domestic waste water**) or a mixture of domestic waste water with waste water which is discharged from premises used for carrying on any trade or industry (**industrial waste water**) and/or runoff rain water.

Directive 2000/60/EC establishing a framework in the field of water policy

There are different types of collection systems. In urban areas, the most common one is the **combined collection system**. Therefore, MWW includes (1) domestic wastewater or sewage, (2) industrial wastewater, (3) storm water and (4) infiltration.

2.1. MUNICIPAL WASTEWATER TREATMENT

Municipal wastewater

- 99.9% H_2O
- <u>0.1% Pollutants</u> ← material to be removed
  - 70% Organic
    - 65% Proteins
    - 25% Carbohydrates
    - 10% Fats and oils
  - 30% Inorganic

MWW TREATMENT

The principal objective of MWW treatment is the production of a safe and aesthetically appealing water that is protective of public health and in compliance with water quality standards.

In Europe, traditional design of wastewater treatment plants are based on the **Urban Waste Treatment Directive 91/271/EEC** standard final effluent: **Biochemical Oxygen Demand (BOD)** of **20 $mg \cdot L^{-1}$** and **Suspended Solids (SS)** of **30 $mg \cdot L^{-1}$**.

Treatment of wastewater is a **sequential continuous process**, involving the following categories:

1. Pretreatment
2. Primary treatment
3. Secondary treatment
4. (Advanced or complementary treatment)

PRETREATMENT

Objective: Removal of large objects such as rags, sticks, floatables, grit, and grease that may cause operational problems.

Unit operations:

- Coarse solids removal
- Settleable solids, grit and sand removal
- Fats, oils and scum removal

Additional unit processes

- Homogenization
- Others: neutralization, addition of nutrients, de-absorption, pre-aeration and chemical oxidation and reduction

PRIMARY TREATMENT

Objective: Removal of the settleable Suspended Solids (**SS**) from the wastewater, which are separated as sludge (**primary sludge**).

Unit operations:

- Settling, clarification or primary sedimentation

For advanced primary treatment, chemicals (**coagulants**) are added to enhance the removal of SS and to a lesser extent, Dissolved Solids (DS).

Settling tanks can be designed with mechanisms for the completion of the removal of fats, oils and scum by flotation.

SECONDARY TREATMENT

Objective: Removal of biodegradable organic matter (**BOD**) in solution and in suspension by biological means.

Unit operations:

- Suspended-growth processes: activated sludge systems
- Attached-growth processes
- Stabilization lagoons or ponds

Biological processes are usually aerobic, thus, oxygen must be provided.

The resulting sludge is the **secondary sludge**.

ADVANCED TREATMENTS

Objective: Further treatment of a biologically treated effluent to enable the final effluent to comply with a standard more stringent that can be achieved by conventional treatments.

Unit operations:

- Nutrient removal
- Disinfection
- Adsorption
- Filtration

...

Residual organic matter in the sludge is putrescible and rapidly develops odors. Therefore, it is necessary to contain and treat it.

SLUDGE TREATMENT

Objective: Increase the concentration of solids and reduction of the fraction of biodegradable matter and the pathogen concentration, in order to reduce volume to be treated and/or disposed-of.

Unit operations:

- Thickening
- Stabilization
- Conditioning
- Dewatering

2.2. PRETREATMENT

2.2.1. Screening

Conventional wastewater collection systems transport sewage from homes or other sources by **gravity** flow through buried piping systems to a central treatment facility.

Properly designed and constructed gravity sewers provide some advantages. However, this implies the entry of **large solids** such as rocks, branches, paper, tree roots, rags,... to the treatment facility. These materials need to be removed because they can damage machinery or clog processes.

Screening consists in passing water through device with openings (gradually decreasing in size), to retain large solids

The first unit operation generally encountered in wastewater treatment plant is a **water well**. Then, in order to retain floating solids and partially submerged solids, wastewater is passed through a series of devices with different openings. Two types of screens (coarse and fine) are generally used.

- **Coarse screens** are composed of parallel bars or rods with clear openings: **10- 25 mm.** According to the method used to clean them, coarse screens are designated as either hand-cleaned or mechanically- or automatically-cleaned (operated normally based on the differential head loss through the screen or by a time clock).

- **Fine screens** or **sieves** are devices consisting of perforated plates, wedge-wire elements and wire cloth that have smaller openings: **1-2 mm**.

Screens used in a wastewater plant

2.2.2. Coarse solids reduction

As an alternative to coarse bar screens or fine screens, **comminutors** and **macerators** can be used. Coarse solids are cut up into smaller pieces for return to the flow stream for subsequent removal by downstream treatment operations. Macerators are particularly advantageous to eliminate the need to handle and dispose the screenings.

Macerator

"Kitchenaid-Whirlpool Dishwasher Mascerator Assembly" by Zenzoidman from Flickr licensed under CC BY-NC-SA 2.0

2.2.3. Grit and sand removal

Grit is comprised of heavy inorganic solids having a size and specific density of > 200 μm and 2.6 g·cm^{-3}, which could cause problems downstream.

In **grit channels**, grit is allowed to settle in under conditions of low flow velocity and then, it is scrapped mechanically from the bottom of the tank.

Grit channels

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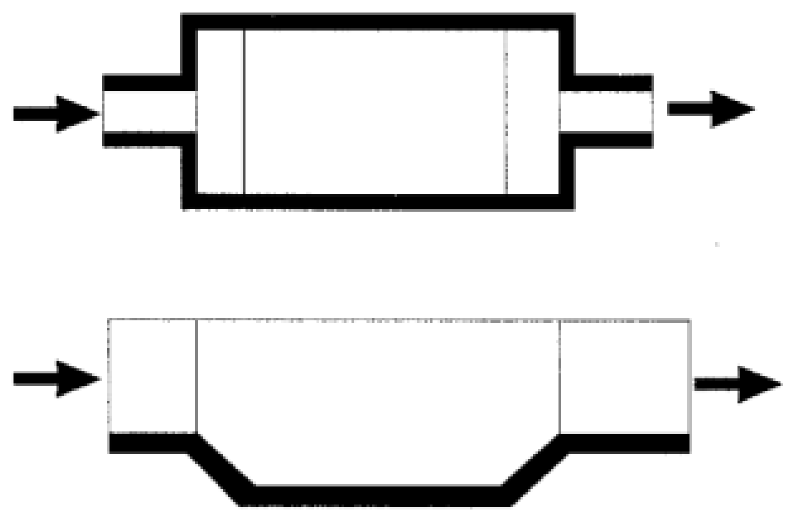
Grit chambers are provided to:

- Reduce formation of deposits in pipelines, channels and conduits
- Protect moving mechanical equipment from abrasion
- Prevent overloading of subsequent processes
- Reduce the frequency of tanks and digesters cleaning

Design of grit chambers is commonly based on **horizontal-flow configuration**.



Horizontal grit chambers

PRINCIPLES OF SETTLING

Settling of discrete, non-flocculating particles can be analyzed by means of the classic laws of sedimentation formed by Newton and Stokes. **Terminal settling velocity** (v_s) can be determined:

$$v_s = \sqrt{\frac{4}{3}\frac{g\ (\rho_s - \rho_w)d_p}{C_D\,\rho_w}}$$

v_s = terminal settling velocity [L·T^{-1}]
g = acceleration due to gravity [L·T^{-2}]
ρ_s = density of particle [M·L^{-3}]
ρ_w = density of water [M·L^{-3}]
d_p = diameter of the particle [L]
C_D = drag coefficient [=]

Drag coefficient depends on Reynolds' number (R_e)

$$R_e = \frac{d_p \, v_s \, \rho_w}{\mu} < 2 \qquad C_D = \frac{24}{Re}$$

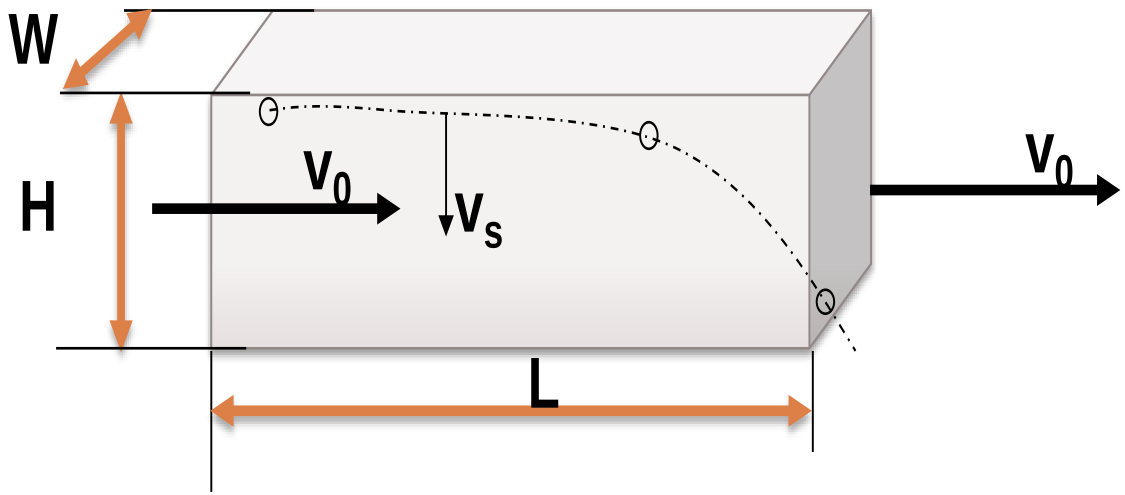
R_e = Reynolds number [=]
μ = dynamic viscosity [$M \cdot L^{-1} \cdot T^{-1}$]

Thus, terminal settling velocity of a spherical particle falling in the laminar flow of a viscous fluid under the force of gravity is:

Stokes' Law

$$v_s = \frac{g \; (\rho_s - \rho_w) {d_p}^2}{18\mu}$$

GRIT CHAMBER DESIGN PARAMETERS



Grit Chamber Design Parameters by E. Sáez de Cámara

Aim: determination of the length (*L*), width (*W*) and height (*H*) of the grit chamber.

Design criteria is based on the settling velocity (***v_s***) of the smallest grit particles (diameter ***d_p***) that should be removed with a 100 % efficiency. This velocity is known as the **critical velocity** (***v_c***)

It is assumed that the critical particle (d_p) enters at the top of the chamber. The velocity components of such a particle are v_o in the horizontal direction and v_s in the vertical direction.

The length of the channel and the time a unit volume of wastewater is in the channel should be such that all particles will settle to the bottom of the channel. Thus, the **critical velocity** (v_c) is:

$$v_c = \frac{H}{t_c}$$

H = height [L]

t_c = critical time [T]

Therefore,

$v_s < v_c$ particles will not be removed in the grit chamber

$v_s > v_c$ particles will be retained in the grit chamber

In order to retain d_p size particles in the grit chamber they must settle H in a t_c equal or lower than the **hydraulic residence time** (t_{RH}):

$$t_c \leq t_{HR}$$

$$t_c = \frac{H}{v_s}$$

$$t_{RH} = \frac{V}{Q} = \frac{L}{v_0}$$

Design velocity can be calculated:

$$v_c = \frac{H}{\left(\frac{V}{Q}\right)} = \frac{H\ Q}{V}$$

Q = flow rate [L·T^{-1}]

V= volume [L^3]

As the volume is the area multiplied by height, the critical particle settling velocity is:

$$v_c = \frac{H\,Q}{L\,W\,H} = \frac{Q}{L\,W} = \frac{Q}{A_c}$$

A_c = area of the top of the chamber [L^2]

According to this relationship, the slowest-settling particles, which could be expected to be removed in a grit chamber, would have a settling velocity of Q/A_c. This parameter is called **surface loading rate** (*SLR*) or **surface overflow rate.**

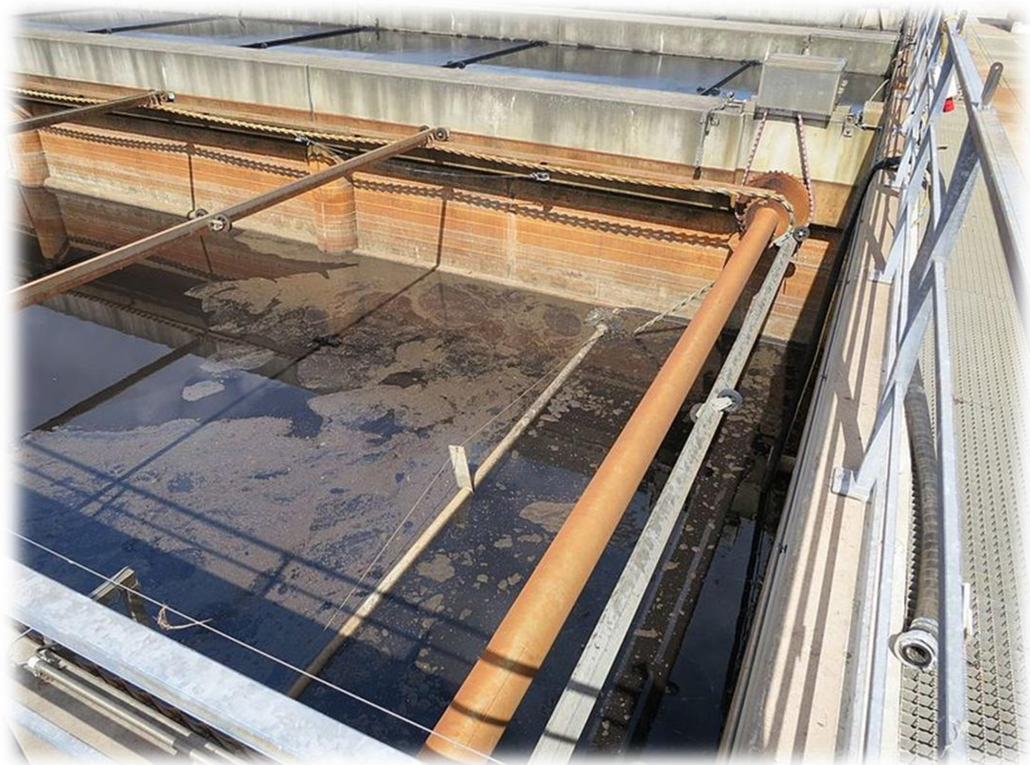
Grit chambers are designed to maintain a velocity ≈ **0.3-0.4 m·s^{-1}**. The length is usually **20-25 times** the height of the water level.

2.2.4. Oils and fats removal

Fats, oils, scum and other related constituents removal is a must for WW treatment plants because they can cause:

- Clogging of fine screens and sieves, resulting in increased operation and maintenance costs.
- Interference of biological treatment processes; as they tend to form an overnatant layer, they impede aeration
- This overnatant layer hampers settling too.

Removal is brought by introducing fine air bubbles into the WW in a grit channel. The buoyant force of these bubbles is great enough to cause the fat and oil particles to rise to the surface to form a scum.



Oils removal in a grit channel

“Bremen-Seehausen Kläranlage 01 Sandfang” by C. Löser from Wikimedia licensed under CC BY 3.0 DE

Skimmer blades push the **scum** across the surface of the tank to where it is discharged.

2.2.4. Homogenization

Homogenization is used to overcome operational problems caused by flow-rate, constituent and mass loading variations of WW emanating from combined sewer systems.

Large **storage tanks** are used to equalize flow and minimize variation in water quality.

Benefits: enhancement primary and biological treatments, chemical treatment, …

The best location for homogenization facilities is after pretreatment, ahead of primary settling.

2.3. PRIMARY TREATMENT

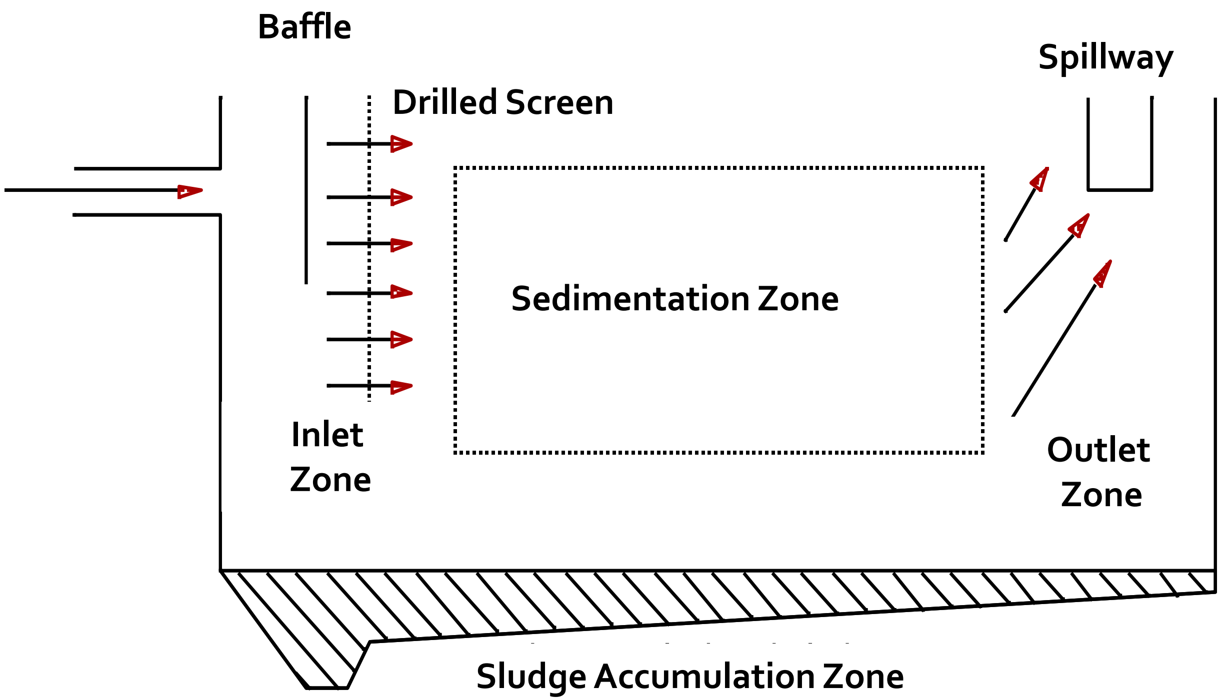
2.3.1. Primary sedimentation

Sedimentation is a treatment process in which the velocity of the wastewater is lowered below the v_s and the SS settle out the WW due to gravity. This process is also known as **clarification** or **settling**.

Types of settling tanks (or clarifiers or sedimentation tanks)

They can be **rectangular** or **circular**, with **horizontal flow**, **radial flow** or **up-flow.**

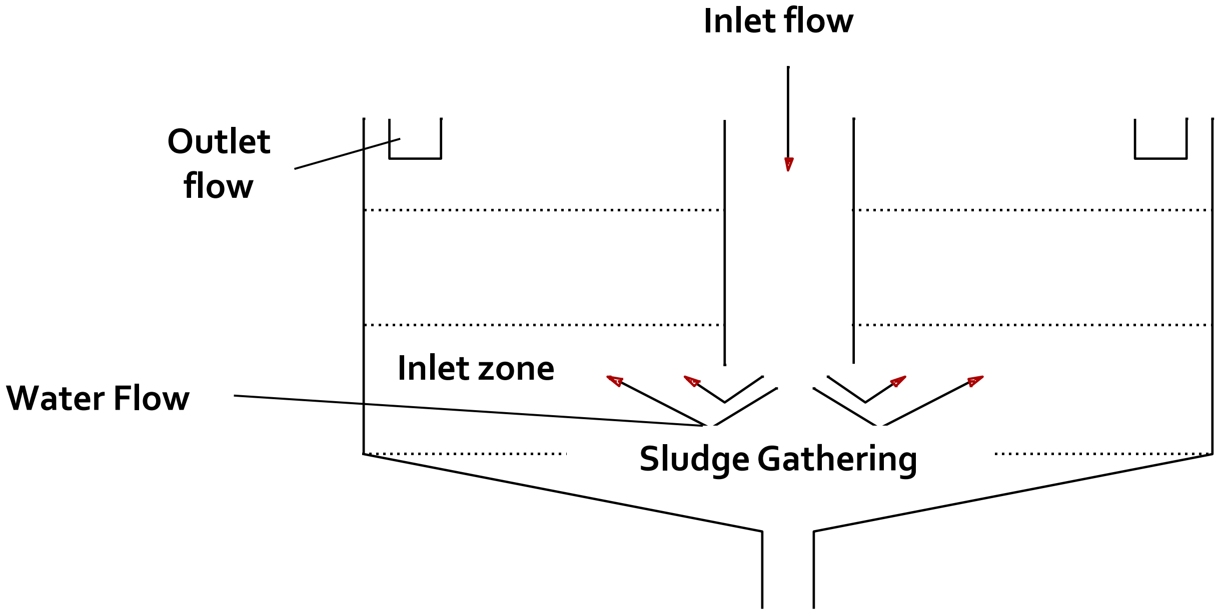
Rectangular tanks with **horizontal flow** are the simplest design. Sedimentation occurs as wastewater moves along the channel. The floor is sloped towards a sump where sludge is collected by a travelling bridge scrapper (*not shown in the figure*).



Functional zones within a horizontal settling tank

by E. Sáez de Cámara

In **circular tanks** with **radial flow** the wastewater is transported to the center of the tank, which is designed to distribute the flow equally in all directions. The floor slopes into a central sump where the sludge is gathered by a rotating scrapper. Settlement occurs as wastewater moves up and out.



Functional zones within a circular settling tank

by E. Sáez de Cámara

Rectangular settling tank

“Vorklärung - primary settling tank” by SuSanA Secretariat from Flickr licensed under CC BY 2.0

Circular settling tank

"Sedimentation tank" by MADe from Wikimedia licensed under CC BY 3.0

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THE DESIGN OF CIRCULAR SETTLING TANKS

Particles falling through the settling basin have two components of velocity: **settling velocity** (v_s) and **design velocity** (v_o). The path of the particle is given by the vector sum (v_r):

$$v_r = v_s - v_0$$

For design purposes, the critical particle in a circular settling tank is the one with smallest diameter d_p to be removed.

The time required for this particle to be carried horizontally across the settling zone (*D* or *H*) is:

$$t_d = \frac{H}{v_s}$$

$$v_s = v_0 \qquad v_r = 0$$

Therefore, in order to retain d_p size particles in a circular settling tank they must settle depth (*D* or *H*) in a critical time (t_c) lower than the hydraulic residence time.

$$v_c = \frac{Q}{L\,W} = \frac{Q}{A_c} = OR$$

Thus, the depth of the basin is not a factor in determining the size particle that can be removed completely in the settling zone.

The determining factor is the quantity Q/A_c, which is referred to as **hydraulic load rate**, **loading factor** or **overflow rate** (**OR**).

THE DESIGN OF RECTANGULAR SETTLING TANKS

They are designed just as grit chambers. The critical particle settling velocity is given by:

$$v_c = \frac{H\,Q}{L\,W\,H} = \frac{Q}{L\,W} = \frac{Q}{A_c} = OR$$

OR= hydraulic load rate or **overflow rate** $[L^3 \cdot L^{-2} \cdot T^{-1}]$ $(m^3 \cdot m^{-2} \cdot h^{-1})$

Efficiently designed and operated primary sedimentation remove from 50-60 % of SS and 40 % of BOD in 1.5 -2.5 hours

2.3.2. Complementary processes: coagulation-flocculation

Colloids are very small particles that do not settle out of water for a long time because of their small size (0.01 to 1 μm) and negative electrical charge.

Coagulation and flocculation

"Coagulation-flocculation process in a water treatment system" by US EPA from Wikipedia licensed under Public Domain

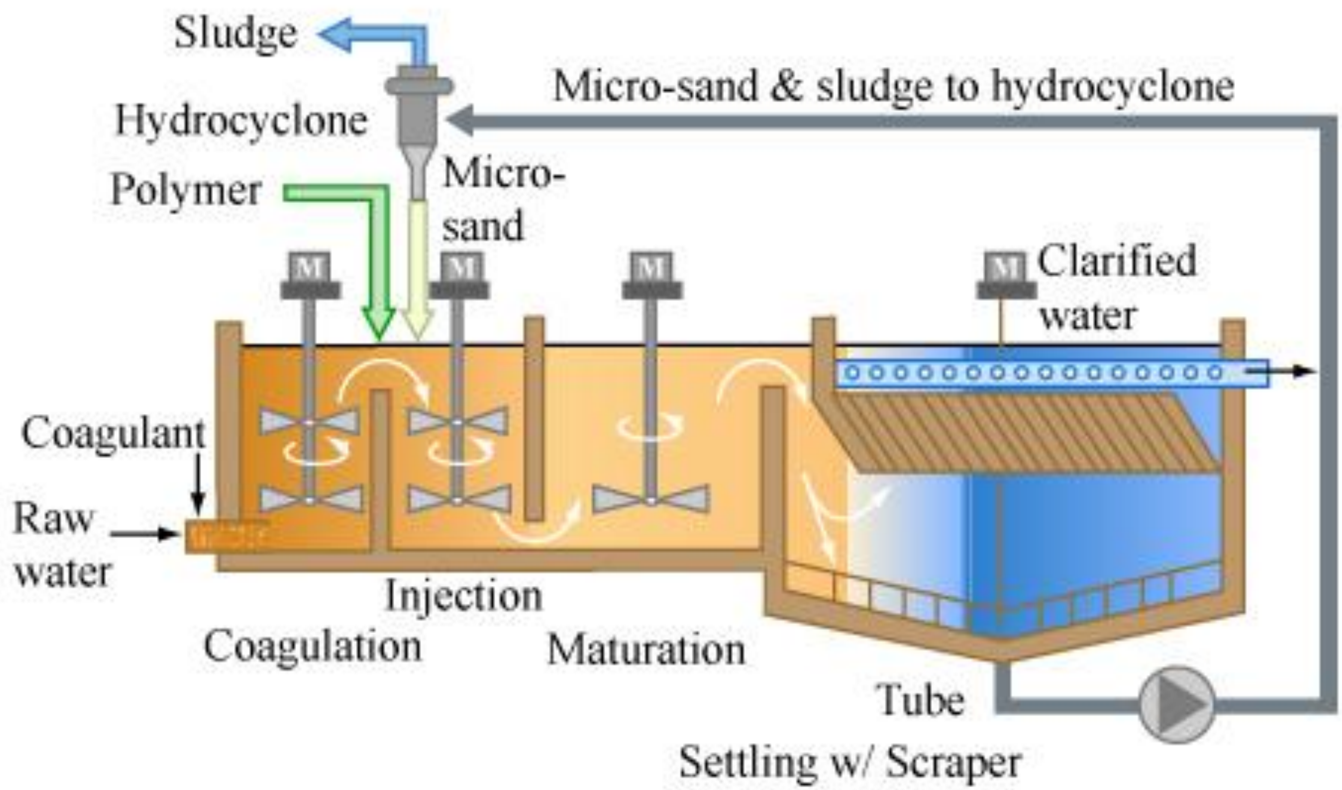
The unit process for colloids' removal is a three-step process:

- **Coagulation** involves addition of a chemical coagulants such as ferric chloride ($FeCl_3$) or aluminum sulfate ($Al_2(SO_4)_3$ for destabilizing colloids so that particles come close together. WW is mixed quickly (1 minute) and violently in small tanks.

- **Flocculation** is aggregation of particles that have been chemically destabilized by flocculent agents. They are typically organic polymers of high MW such as polyelectrolytes.

  The mixture is stirred gently in a tank (30-45 minutes) that allows *flocs* particles to grow.

- **Sedimentation.** Flocs are removed by gravity settling.



Coagulation and flocculation process

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2.4. SECONDARY TREATMENT

Secondary treatment consists in the transformation of biodegradable organic matter, both in solution and in suspension, into acceptable end products by taking advantage of biological processes.

Biological processes are classified into **aerobic** and **anaerobic**.

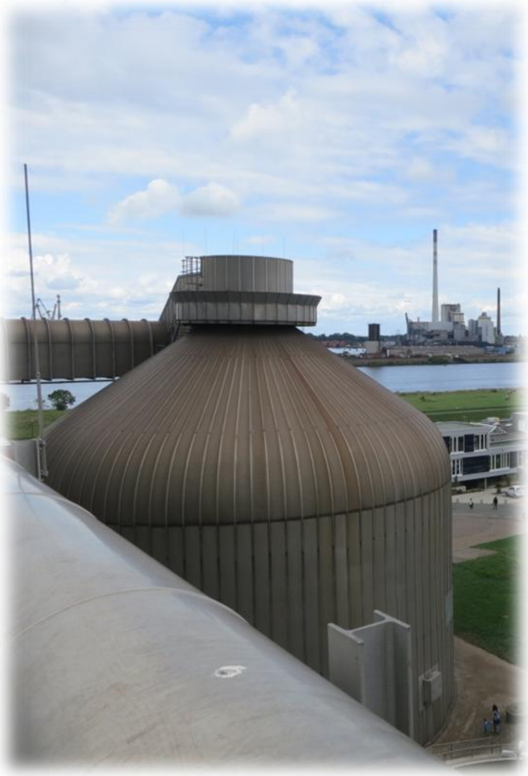
- Aerobic processes Without entry of air (O_2)

  For WW with low concentration of organic matter (OM).

  Application: Municipal WW

- Anaerobic processes With air (O_2)

  For WW with high [OM]. Application: Industrial WW



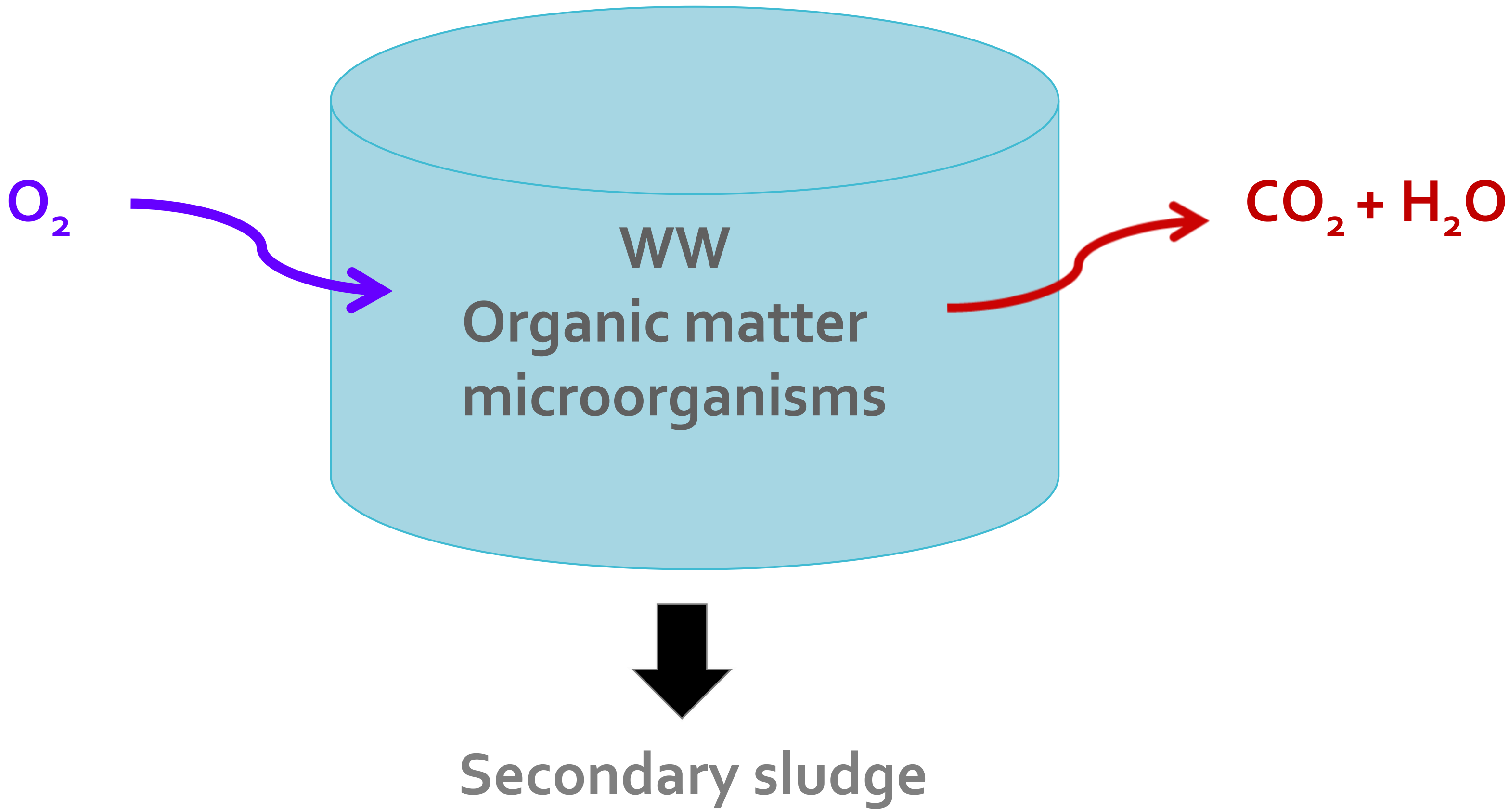
Anaerobic treatment

“Bremen-Seehausen Kläranlage 33 Faulbehälter und Schlammeindickung” by C. Löser from Wikimedia licensed under CC BY 3.0 DE

Aerobic treatment

“Bremen-Seehausen Kläranlage 06 Biologische Reinigung” by C. Löser from Wikimedia licensed under CC BY 3.0 DE

AEROBIC BIOLOGICAL PROCESSES



Aerobic Biological Process Diagram by E. Sáez de Cámara

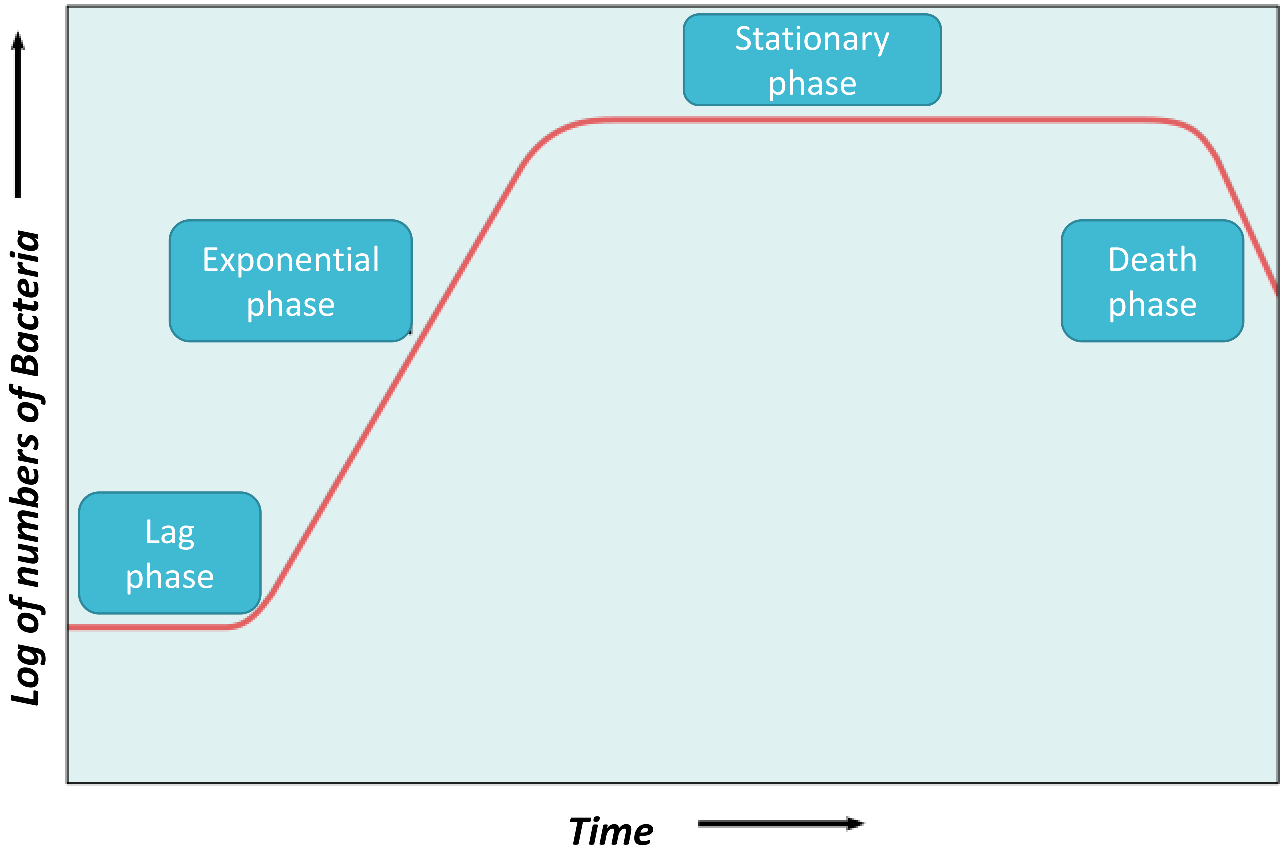
As substrate (OM) is consumed, four phases develop sequentially:

1. **Lag phase.** It is the time required for microorganisms to acclimate to their new environment and for synthesis of new enzymes that are necessary to metabolize the substrates.
2. **Exponential growth phase.** The number of microorganisms increases exponentially (**log phase**). Increase is only limited by the generation time, that is, the time interval required for the cells to divide.

But then, due to exhaustion of substrate accumulation of inhibitory compounds and/or exhaustion of space, the situation leads to

3. **Stationary phase.** The amount of growth is offset by the death of microorganisms.
4. **Death phase.** The number of viable microorganisms decreases exponentially.

Microbiological growth curve



Microbiological growth curve in a batch reactor

Adapted version of "Curva de crecimiento bacteriano" from Wikipedia licensed under Public Domain

AEROBIC BIOLOGICAL PROCESS INTENSIFICATION

Same processes which occur in natural waters are utilized in biological treatment systems to treat wastewater. Nevertheless, natural processes of self-purification are enhanced by:

1. **Concentration of microorganisms**. Two mechanisms:
    - Attached-growth processes
    - Suspended-growth processes

2. **Biomass activity**. Suitable environment (temperature, nutrients, O_2, ~~toxics~~,...) for the microorganisms within specific reactors.

3. **Good contact between biomass and substrate**. Contact for a sufficient period of time to allow removal of biodegradable organic matter.

Attached-growth processes

Microorganisms are attached to inert mediums such as rocks, gravel, metals, plastics,… composing a biofilm.

- Trickling filters
- Rotating Biological Contactors (RBC)

Suspended-growth processes

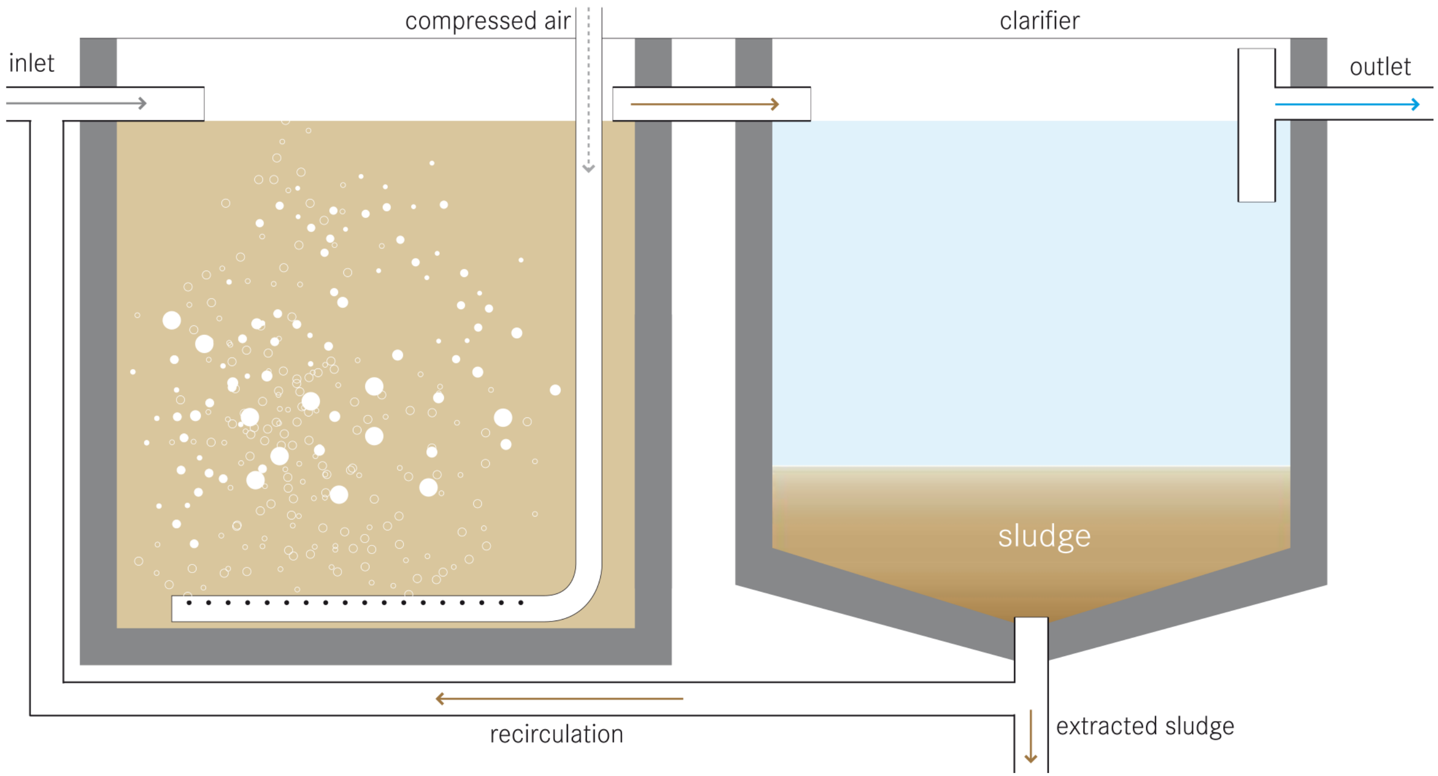
Microorganisms are maintained in suspension within the liquid by mixing methods.

- Activated sludge systems

Biological process

"Bremen-Seehausen Kläranlage 05 Biologische Reinigung" by C. Löser from Wikimedia licensed under CC BY 3.0 DE

2.4.1. Suspended-growth processes: Activated sludge systems



Activated sludge system

"Diagram of the activated sludge process used in wastewater treatment" by Swiss Federal Institute of Aquatic Science and Technology from Wikimedia licensed under CC BY 3.0

ACTIVATED SLUDGE SYSTEMS

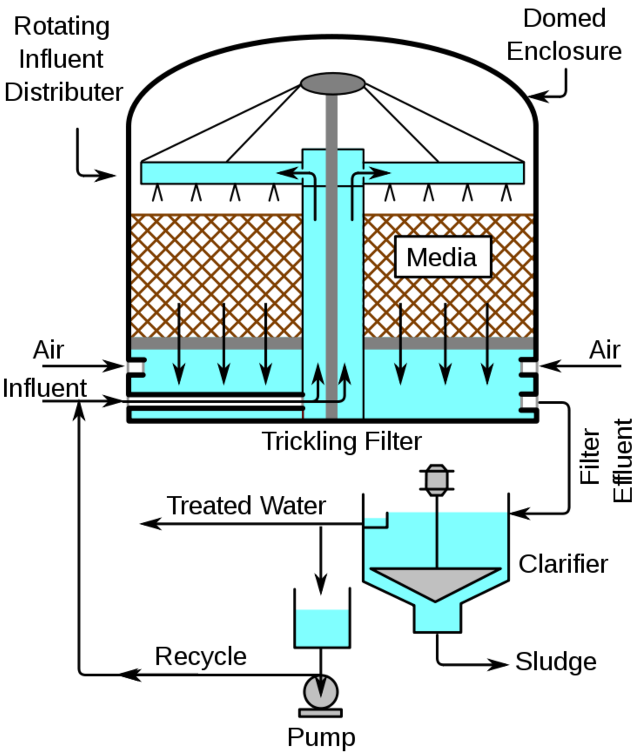
In the **aeration tank**, the activated sludge is mixed with the wastewater effluent to form **mixed liquor**. Activated microorganisms use the organic material as food producing CO_2, water and more viable microorganisms (biomass).

The mixed liquor then flows to a clarifier or **secondary settling tank** where microbiological suspension (**secondary sludge**) is settled and thickened.

Part of the settled biomass is **returned** back to the aeration tank to maintain a constant composition of microorganisms and to continue biodegradation of the influent organic material. This sludge is referred to as **return activated sludge** (RAS). Periodically, a portion of the settled solids is removed (**excess sludge**).

2.4.2. Attached-growth processes

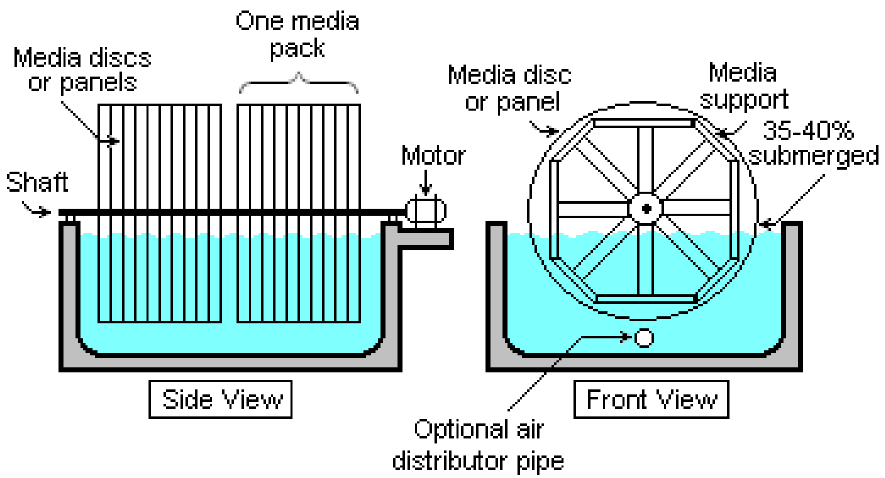
In **trickling filters** wastewater is sprayed over a packing material covered with microorganisms. Excess biomass sloughs from the attached-growth periodically and clarification is required to provide an effluent with an acceptable suspended solid concentration.



Trickling filter

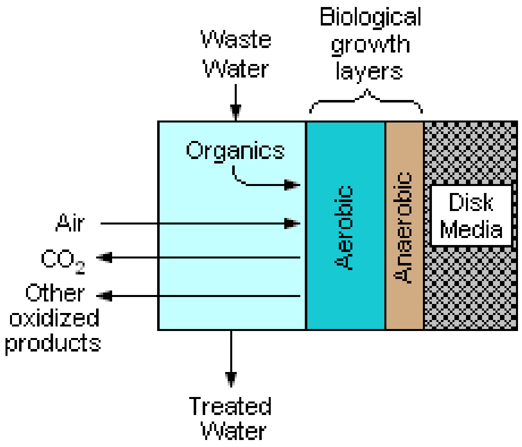
“Trickle Filter” by Mbeychok from Wikimedia licensed under Public Domain

Rotating Biological contactors (RBC) consist of a series of closely spaced circular disks, which accumulate thin layers of attached biomass, that are submerged in wastewater and rotated slowly through it.



RBC

“Rotating Biological Contactor” by Mbeychok from Wikimedia licensed under Public Domain



RBC Cross Section

“RBC Media Corss Section” by Mbeychok from Wikimedia licensed under Public Domain

2.4.3. Disinfection

After secondary treatment, wastewater may still contain large numbers of microorganisms (10^8-10^{10} microorganisms·100 mL^{-1}). Some of them may be pathogenic and may cause diseases if discharged to receiving waters.

Thus, disinfection process is carried out at the end of treatment. The most widely used disinfection process is **chlorination**.

Disinfection process

"Desinfección" by Landahlauts from Flickr licensed under CC BY-NC-SA 2.0

2.5. ADVANCED TREATMENT

Advanced wastewater treatment is the additional treatment needed to remove constituents remaining after conventional treatment.

Use of **highly treated wastewater effluents**, now discharged to the environment from MWW treatment plants, is receiving more attention as a reliable water resource. In many parts of the world, water reuse is already an important element in water resources planning and implementation. **Water reuse** consists on the use of treated water for a beneficial use.

Advanced treatment options are dependent upon the quality of the effluent from the secondary treatment and, the characteristics to be obtained after treatment to satisfy further use or disposal of treated water to the environment.

Pollutants removed by advanced treatments fall into three main categories:

- Nutrient removal, mainly nitrogen and phosphorous, to limit eutrophication of sensitive water bodies, by chemical or biological treatments.
- Removal of organic and inorganic colloidal and suspended solids by filtration.
- Disease causing microorganisms removal by disinfection.

2.5.1. Nutrient removal

2.5.1.1. Nitrogen removal

The need of nitrogen removal (NH_4^+) arises from the concerns over:

- Avoid dissolved oxygen consumption. Ammonia exerts BOD.
- Fish toxicity
- Unwanted algal and plant growths: eutrophication

It can removed by a biological treatment that consists of two steps:

1. **Nitrification**, where nitrifying microorganisms oxidize ammonium (NH_4^+) to the intermediate nitrite (NO_2^-) that is further converted to nitrate (NO_3^-).
2. **Denitrification**, where denitrifying microorganisms convert nitrate to nitrogen gas (N_2).

NITRIFICATION

It is carried out by nitrifying bacteria under aerobic conditions (O_2)

$$2\,NH_4^+ + 3\,O_2 \xrightarrow{Nitrosomonas} 2\,NO_2^- + 4\,H^+ + 2\,H_2O + energy$$

$$2\,NO_2^- + O_2 \xrightarrow{Nitrobacter} 2\,NO_3^- + energy$$

Nitrification can be accomplished in suspended-growth processes together with the carbonaceous BOD removal. However, nitrification requires more hydraulic residence time, more solids retention time as well as more aeration time.

4.57 g $O_2 \cdot g^{-1}$ NH_4^+ oxidized

vs

1.07 g $O_2 \cdot g^{-1}$ $C_6H_{12}O_6$ oxidized

DENITRIFICATION

It is carried out by nitrifying bacteria under anoxic conditions (**absence of free oxygen**)

$$NO_3^- \longrightarrow NO_2^- \longrightarrow NO \longrightarrow N_2O \longrightarrow N_2$$

There are two alternatives:

1. **Substrate driven denitrification** or **pre-denitrification**. The anoxic tank where denitrification occurs is followed by the aeration tank where nitrification occurs. Nitrate produced in the aeration tank is recycled back to the anoxic tank. Organic substrate in the influent WW provides carbon to denitrifyiers.
2. **Endogenous driven denitrification** or **post-denitrification**. An exogenous carbon source such as methanol or acetate is added to increase the rate of denitrification.

2.5.1.2. Phosphorous removal

The removal of phosphorous from wastewaters involves the incorporation of phosphate into solids and their subsequent removal.

CHEMICAL PRECIPITATION

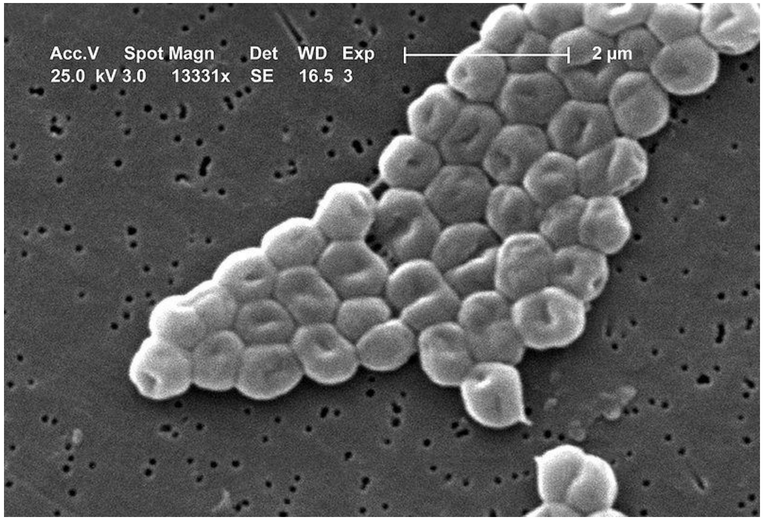
It is brought about by the addition of the salts of multivalent ions such as ferric chloride ($FeCl_3$) or sulfate ($Fe(SO_4)_3$) that form precipitates of insoluble phosphates.

$$FeCl_3 + PO_4^{3-} \leftrightarrow FePO_4 \downarrow + 3Cl^-$$

Precipitation of phosphorous from wastewater can occur in a number of different locations: (1) pre-precipitation, (2) co-precipitation or (3) post-precipitation.

BIOLOGICAL PHOSPHOROUS REMOVAL

Phosphorous is incorporated into **Phosphorous Accumulating Organisms'** (PAO) as polyphosphates (poly-P). Subsequently, accumulated phosphorous is removed from the process with the sludge stream.



Acinetobacter

"Acinetobacter baumannii" from Wikipedia licensed under Public Domain

2.5.2. Disinfection

Disinfection consists in adding oxidizing agents (such as chlorine, ozone or UV radiation) to inactivate pathogenic organisms in water.

2.5.2.1. Chlorination

Chlorine is supplied as a liquefied gas under high pressure in pressure vessels, and allowed to remain in contact with wastewater for a time (30 min -2 h).

$$Cl_2 + H_2O \leftrightarrow H^+ + Cl^- + HOCl$$

↓ (HOCl)

Free available chlorine
Effective killing bacteria

Objectives chlorination

- Disinfection
- BOD reduction
- Color and odor control

Disadvantages chlorination

- Chlorine reacts with the organic constituents in wastewater to produce **Trihalomethanes** (THM). These by-products are known to be carcinogenic and mutagenic.
- Highly corrosive and toxic

Advantages chlorination

- Residual disinfectant. Prevention of re-growth in the distribution system and water storage tanks.
- Effective against a wide spectrum of organisms
- More cost-effective than other methods

Chlorine tanks

“Cloración: Tanques de Cloro” by Landahlauts from Flickr licensed under CC BY-NC-SA 2.0

2.5.2.2. Ozonization

The use of ozone has increased and spread into several countries.

O_3 is produced dissociating O_2 by an energy source into O (then O+ O_2) → After generation, O_3 is pumped into a contact chamber where contacts water enough time (10-15 minutes) for disinfection

Ozone disinfection system

“Ozone System” by Lenore Edman from Flickr licensed under CC BY 2.0

Advantages ozonization

- More effective than chlorine
- No unwanted by-products
- Elevation of [DO]
- Odor control

Ozone disinfection

"Ozone Disinfection of the Water" by Lenore Edman from Flickr licensed under CC BY 2.0

Disadvantages ozonization

- No residual disinfectant effect
- Complex technology
- High costs due to capital costs and power requirements ($O_2 \rightarrow O_3$)

2.5.3. Adsorption by activated carbon

Adsorption is the process of accumulating substances that are in solution on a suitable interface.
Adsorbate is the substance that is transferred from a liquid-phase to the interface; whereas **adsorbent** is the solid-phase onto which the adsorbate accumulates.

Activated carbon (AC) is the most commonly used adsorbent

- ✓ Highly porous structure (700-1500 $g \cdot m^{-3}$)
- ✓ Broad spectrum adsorbent
- ✓ Affinity for certain constituents as complex organic compounds (↑ MW). Thus, it allows polishing after biological treatment.

Activated carbon is used either as a powder being added to water as slurry (**Powdered Activated Carbon**), or as granules which are housed in a filter or column through with water is passed (**Granular Activated Carbon**).

Powdered activated carbon

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2.5.4. Other processes

Filtration involves the separation of SS and colloids from a liquid.

In **membrane filtration** the range of particle sizes is extended to DS. The role of the membrane is to serve as a **selective barrier** that allows the passage of certain constituents found in the wastewater.

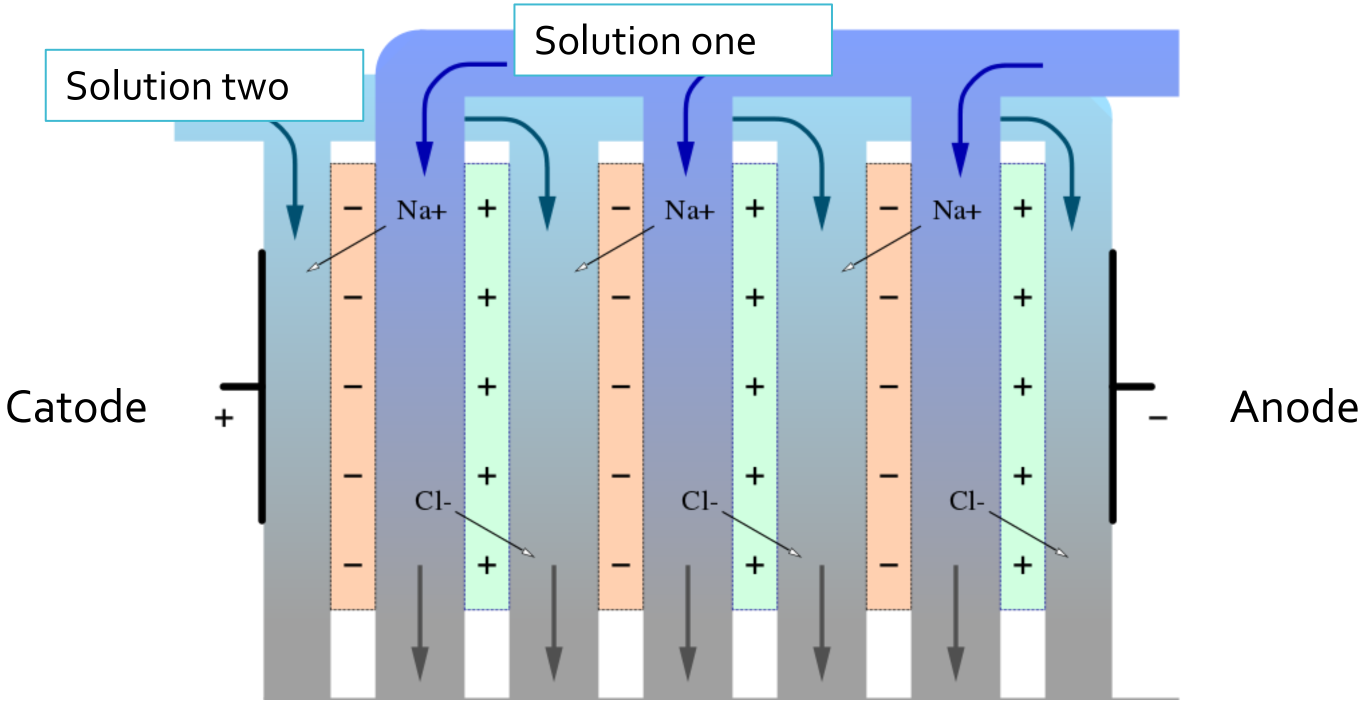
Membrane processes include:

- Microfiltration (MF)
- Ultrafiltration (UF)
- Nanofiltration (NF)
- Reverse osmosis (RO)
- Electrodyalisis (ED)

Membrane filtration can be classified in a number of different ways including the **driving force** and **separation mechanism:**

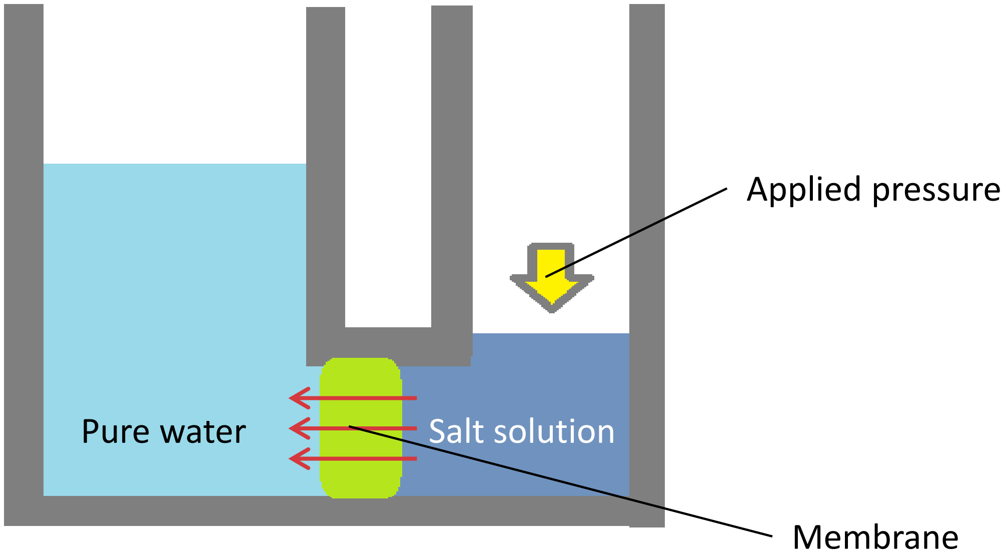
Membrane Process	Driving force	Separation mechanisms	Operating range (µm)
Microfiltration	Hydrostatic pressure difference	Sieve	0.08-2
Ultrafiltration		Sieve	0.005-0.2
Nanofiltration		Sieve diffusion+ exclusion	0.001-0.01
Reverse osmosis		Solution diffusion+ exclusion	0.0001-0.001
Electrodyalisis	Electromotive force	Ion exchange	-

Electrodialysis is used to transport salt ions from one solution through ion-exchange membranes to another solution under the influence of an applied electric potential difference.



Adapted version of "Osmosekraftwerk via umgekehrter Elektrodialyse" from Wikimedia licensed under Public Domain

Reverse osmosis (**RO**) is a technology that is used to remove dissolved constituents from water by pushing the water under pressure through a semi-permeable membrane potential difference.



Reverse Osmosis Diagram by E. De la Torre

RO is used primarily for desalinization.

Finally, removal of dissolved constituents can be accomplished by **chemical processes** as well. The principal ones are chemical precipitation, ion exchange and distillation.

Ion exchange is the reversible interchange of ions of the same charge between a solid ion-exchange medium and a solution.

The most widespread use of this ion exchange is **water softening**. In this process **Ca^{2+}** and **Mg^{2+}** cations in the water are exchanged by Na^{+} cations.

Cation anion ion exchange system

“Inside Treatment Building 891. Part of the Ion-Exchange Process Unit” by U.S. Department of Energy from Wikimedia licensed under Public Domain