

COAGULATION FLOCCULATION

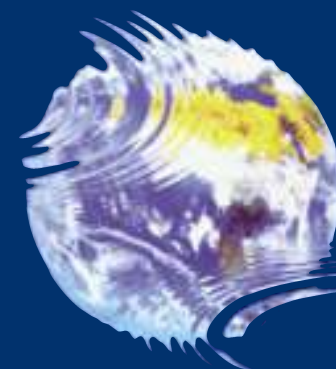


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There are many wastewater treatment processes in operation around the world. The most commonly used is the *physico-chemical process* that employs coagulants and flocculants.

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1 Overview of coagulation and flocculation

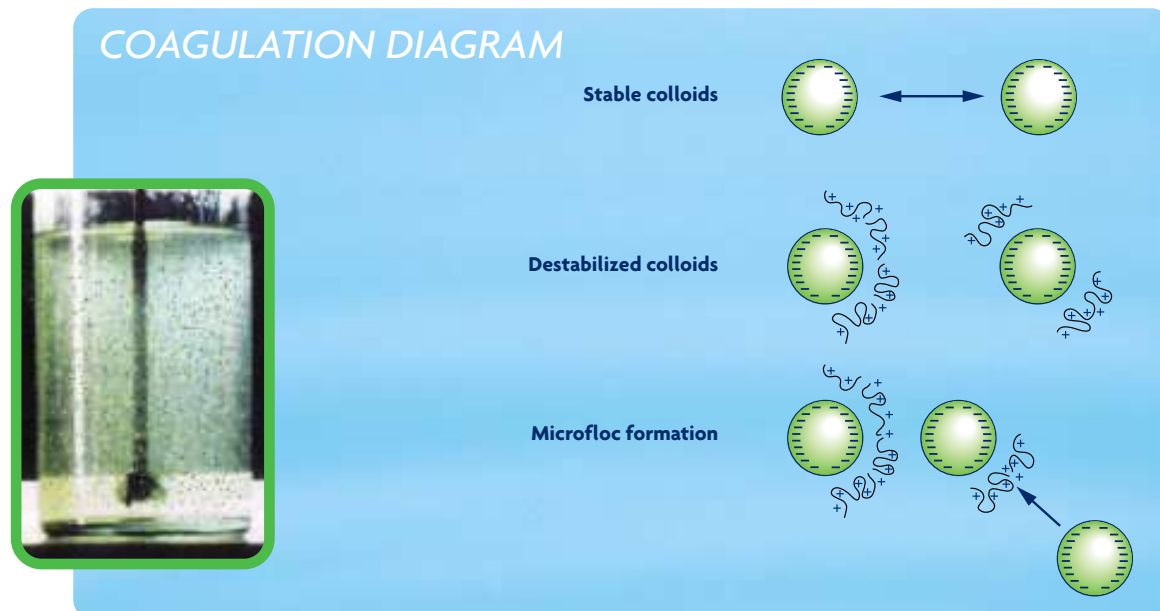
Coagulation and flocculation are two very distinctive parts of the physico-chemical treatment of wastewater.

1.1. Coagulation:

Coagulation is the step where colloidal particles (similar to spheres of a diameter of less than 1 micrometer) are destabilized.

1.1.1. Basic principle of coagulation:

Coagulation comes from the latin word « coagulare » which means « to agglomerate ». In water treatment, coagulation is the result of the addition of chemical reagents to water suspensions where the dispersed colloidal particles are assembled in larger aggregates called flocs or microflocs.



Coagulation is an intermediary step, but it is essential to the physico-chemical treatment process of water and wastewater. This is the first step in the elimination of colloidal particles and its main function is to destabilize the particles. This destabilization is essentially the neutralization of the electrical charge present on the surface of the particle thus facilitating the agglomeration of the colloids.

1.1.2. Colloidal particles:

Colloids are insoluble particles suspended in water. Their small size (less than 1 micron) makes the particles extremely stable. They can have different origins :

- **Mineral:** silt, clays, silica, hydroxydes and metallic salts...
- **Organic:** humic and fulvic acids, color, surfactants...

Note :

Micro-organisms such as bacteria, plankton, algae, viruses are also considered as colloids.

1.1.3. Coagulation mechanism:

The stability and consequently the instability of suspended particles is a factor of different attraction and repulsion forces :

- Van der Waals forces
- Electrostatic forces
- Universal attraction
- Brownian motion

Coagulation is both a physical and a chemical process. The reactions between particles and coagulant will allow the formation of aggregates and their subsequent sedimentation. **Cationic coagulants neutralize the negative charge of colloids** and form a spongy mass called microflocs.

The coagulation mechanism can be summarised in two steps :

1- Charge neutralization : this corresponds to the lowering of the electrical charges that have a repulsion effect on the colloids.

2- Agregation of the particles.

1.1.4. Coagulants:

There are two major coagulant types in use today:

a - Mineral coagulants:

These are mainly based on **Iron salts** (FeCl_3 , $\text{Fe}(\text{SO}_4)_2$, ...) or **Aluminium salts** (PAC, Alum, ...).

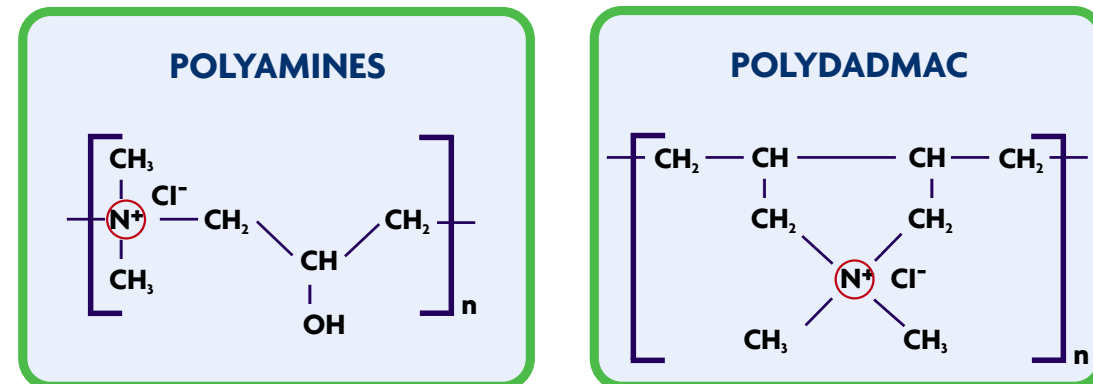
They are the most frequently used coagulants.

The cationic charge is brought by the metallic ions, **Fe^{3+}** or **Al^{3+}** that will form Iron hydroxydes $\text{Fe}(\text{OH})_3$ or Aluminium hydroxydes $\text{Al}(\text{OH})_3$ on contact with water.

The main advantages of such coagulants are their universal range of application and low price.

b - Organic coagulants:

The cationic charge is brought by a quaternary ammonium function fixed on a long polymer chain.



Four main organic coagulant families are present on the market today :

- **Polyamines** (FLOQUAT™ FL 17, FLOQUAT™ FL 28 P2,)
- **Polydadmac** (FLOQUAT™ FL 45 C, FLOQUAT™ FL 45 CLV, ...)
- **Dicyandiamide resins** (FLOQUAT™ DEC 50,...)
- **Melamine-formaldehyde resins** (FLOQUAT™ FL 42, FLOQUAT™ FL 61)

The main advantages are a lower dosage and a lower volume of sludge produced (no hydroxydes). Also these coagulants do not affect the pH or the Titration for Hardness (TH).

c - Blends of mineral and organic coagulants:

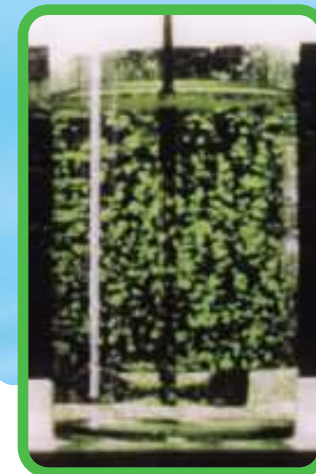
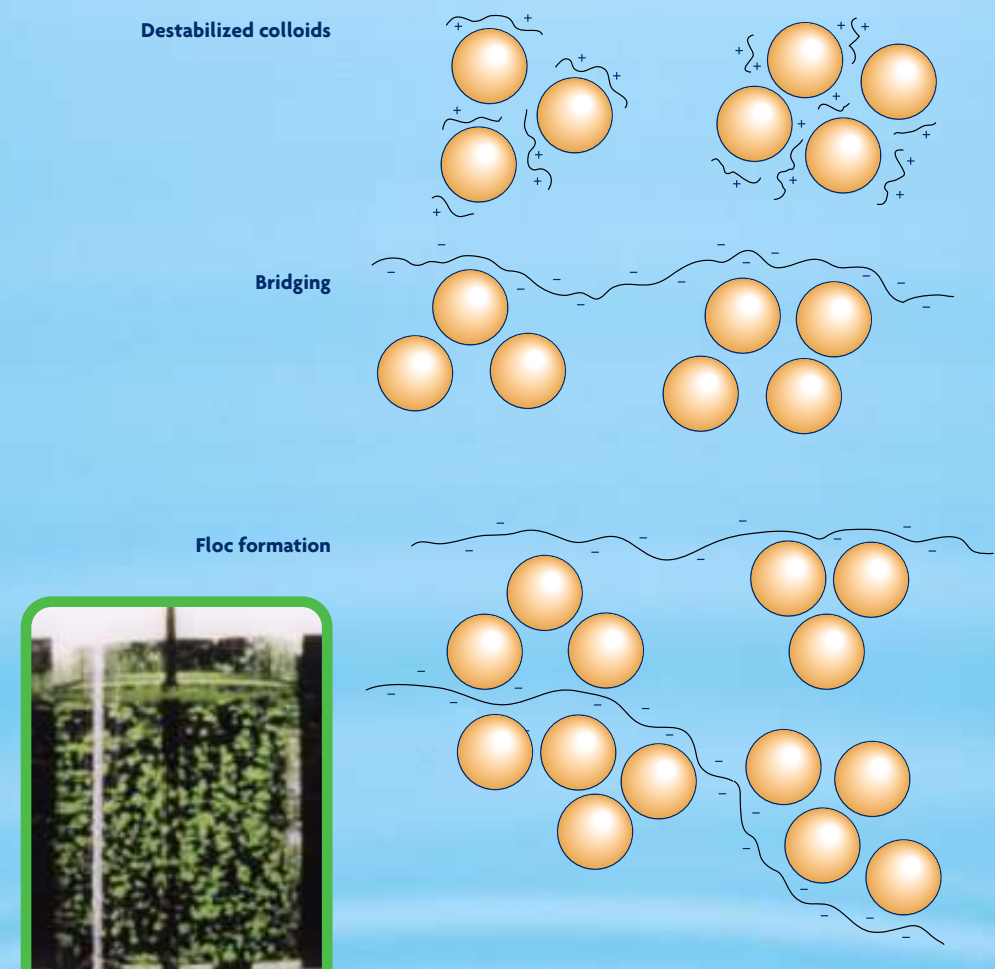
These blends bring, in a single commercial product, the advantages of both organic and mineral coagulants. The most frequent mineral coagulant used in these blends is PAC.

1.2. Flocculation:

Flocculation is the step where destabilized colloidal particles (or the particles formed during the coagulation step) are assembled into aggregates.

1.2.1. Basic principle of flocculation:

The flocculation step can only operate on a water/wastewater where the particles are **already destabilized**. It is the logical step following coagulation.

DIAGRAM OF FLOCCULATION

1.2.2. Destabilized particles:

The origin of destabilized particles is various and depends mainly on the origin of the water to be treated. They can come from an initial coagulation step.

The **charge** (+ or -) brought by the flocculant will be selected according to the nature of destabilized particles in the water. In general the selection follows the pattern below :

- Anionic flocculant (-) for **mineral** particles
- Cationic flocculant (+) for **organic** particles

1.2.3. Flocculation mechanism:

Flocculants, with their very high molecular weights (long monomer chain) and their charge content, fix the destabilized particles and aggregates along the polymer chain. There follows, during the **flocculation step**, an **increase in the size of the particles** present in the water phase resulting in the formation of **flocs**.

The type of bonds between the destabilized particles and the flocculant are mainly **ionic bonds** and **hydrogen bonds**.

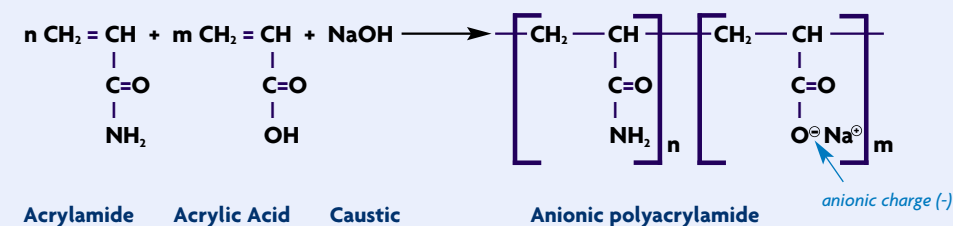
1.2.4. Flocculants:

Amongst the 800 different flocculants of the FLOPAM™ Range, two main categories of flocculants can be distinguished:

1 - Anionic and Non-Ionic flocculants that bring negative (-) charges to the media.

ANIONIC AND NON-IONIC POLYACRYLAMIDES

Copolymers of acrylamide and acrylic acid



Note : if $m = 0$, the polyacrylamide is non-ionic

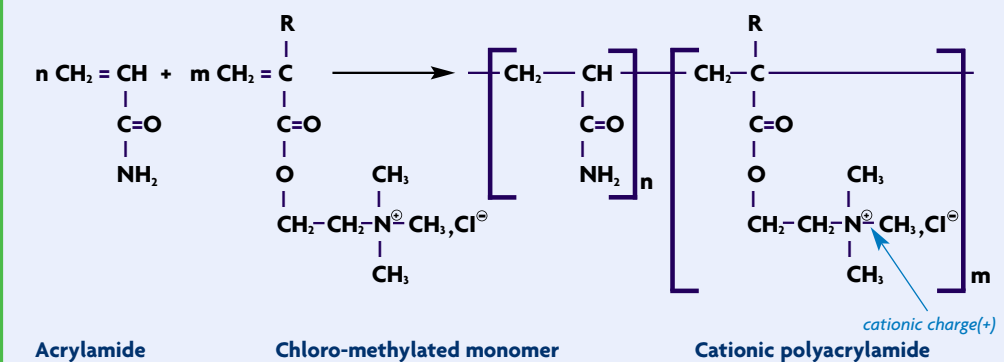
Different commercial forms are available :

- Solid form : FLOPAM™ AN 900 Series
- Emulsion form : FLOPAM™ EM 3 Series

2 - Cationic flocculants that bring positive (+) charges to the media.

CATIONIC POLYACRYLAMIDES

Copolymers of acrylamide and a chloro-methylated monomer



Note : if $R = H \longrightarrow$ ADAM (dimethylaminoethyle acrylate)
if $R = \text{CH}_3 \longrightarrow$ MADAM (dimethylaminoethyle methacrylate)

Different commercial forms exist :

- Solid form : FLOPAM™ FO 4000 Series
- Emulsion form : FLOPAM™ EM 4 Series

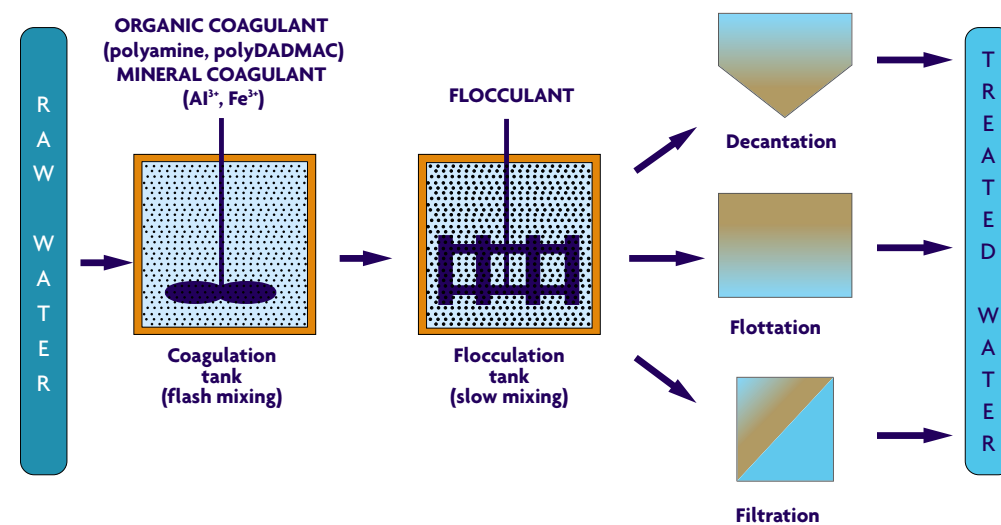


2 Physico-chemical water treatment processes

These processes are characterized by:

- The use of **chemical** reagents to destabilize and increase the size of the particles that form the pollution.
- Followed by a **physical** separation of the solids from the liquid phase. This separation is usually achieved by decantation, flotation or filtration.

2.1. General diagram of a physico-chemical process:



The common reagents are : mineral and/or organic coagulants, flocculation additives (activated silica, talcum, activated carbon,...), anionic or cationic flocculants and pH control reagents such as acids or bases.

Certain heavy metal chelating agents can also be added during the coagulation step.

2.2. Water treatment equipment:

2.2.1. Coagulation and flocculation tanks:

This step in the process, where colloids and/or destabilized particles react with the reagents, takes place in basins or tanks of many shapes and sizes. They are sometimes included in the settling tank.

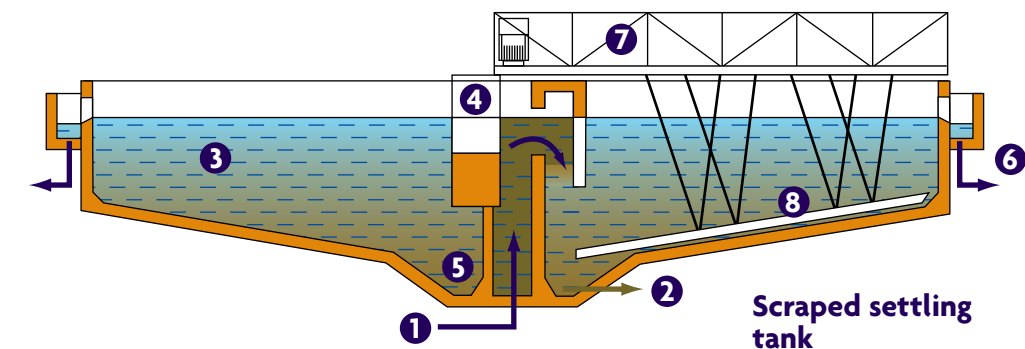
Certain rules must be followed:

- The **volume** of the basin is function of the input flow.
- The **injection points** of each reagent are determined in relation to the reagent's characteristics. For example, a coagulant will always be injected before a flocculant.
- The **stirring devices** (size and speed) will be selected according to the reagents used. Stirring must be high during the coagulation step (flash mixing with a recommended speed gradient around $1000s^{-1}$) and lower for flocculation (speed gradient around $100s^{-1}$).

2.2.2. Settling tanks:

There are different types of settling tanks. They must allow the separation of the solids from the water phase by **settling**. Their design is based on a **settling speed of the particles**. The most common are:

- **Scraped settling tank**: The inflow is in the centre and the overflow of the treated water is all around the peripheral chute. A scraping system prevents the accumulation of the sludge on the slopes of the tank and pushes it towards the underflow extraction.

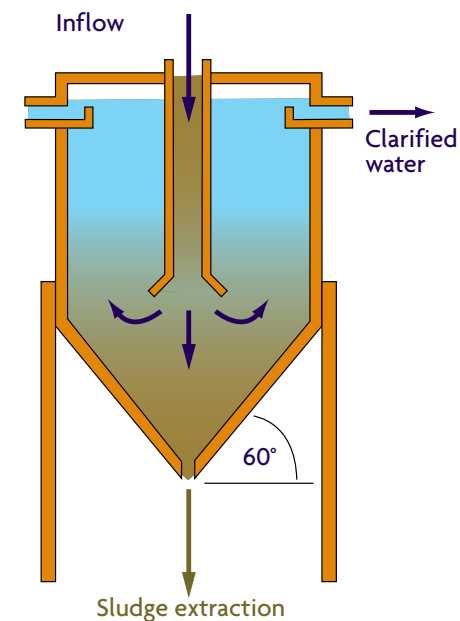


- 1 Inflow (wastewater)
- 2 Underflow (sludge)
- 3 Settling zone
- 4 Effluent distribution

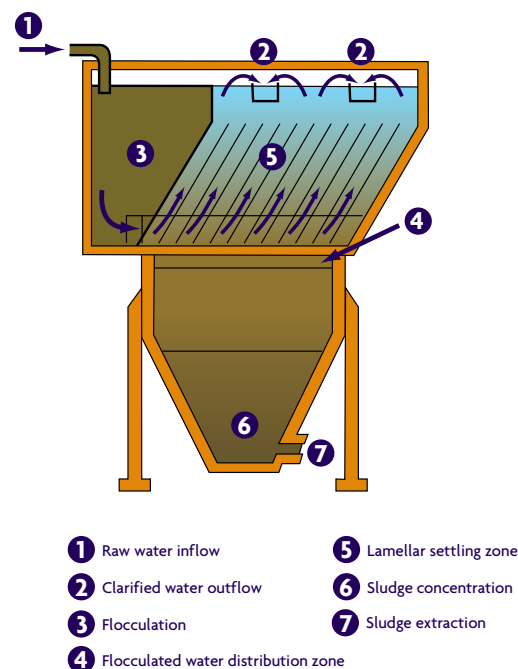
- 5 Sludge pit
- 6 Clarified water chute
- 7 Rotating bridge
- 8 Sludge scraper

● **Conical cylinder settling tank** (vertical flow): In such settling tank, there are no scraping systems and it is the slope of the cone that guides the sludge towards the extraction point. The inflow is in the centre and the overflow of the treated water is all around the peripheral chute.

Conical cylinder settling tank

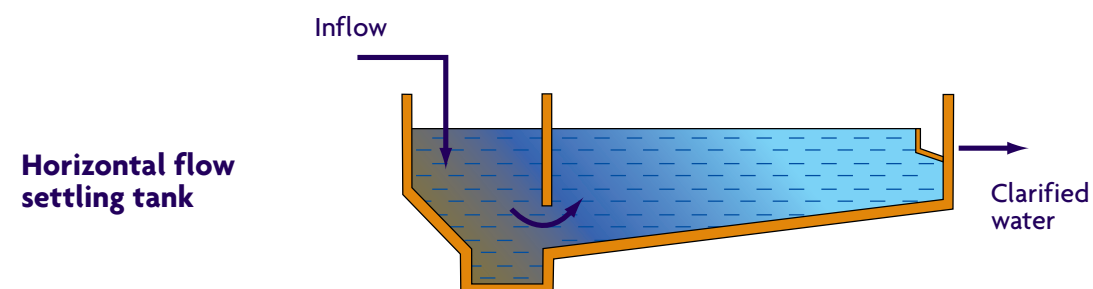


Lamellae settling tank



● **Lamellae settling tank**: These are composed of piled elementary settling tank whose individual horizontal surfaces are added up. Slanted slats allow the sludge to be gravity fed to the bottom of the settling tank.

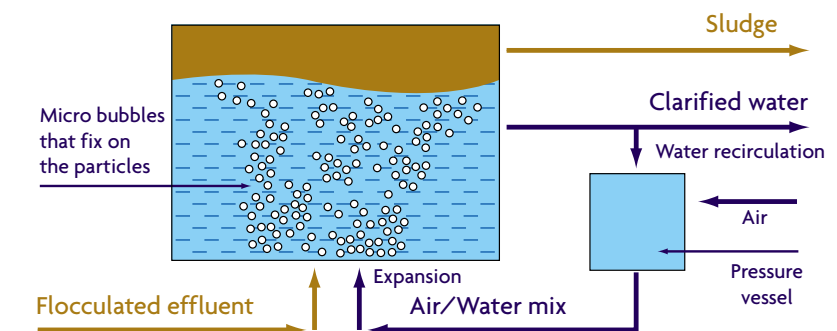
● **Horizontal flow settling tank**: Also called longitudinal settling tank, they are characterized by the horizontal flow of the water to be treated.



2.2.3. Flotation units:

Contrary to settling tanks, the solid/liquid separation is done by **floating solids to the surface**. The flotation can be natural (when the density of the particles is lower than 1) or assisted (by fixing micro-bubbles to the particles). The sludge extraction will be done at the surface of the unit.

Dissolved Air Flotation unit (D.A.F.)



In order to assist flotation, the creation of micro-bubbles is done by pressurizing the water to be treated (Direct Flotation) , or by injecting auxiliary water that has been previously saturated under a few bars pressure (Indirect Flotation).

2.2.4. Filters:

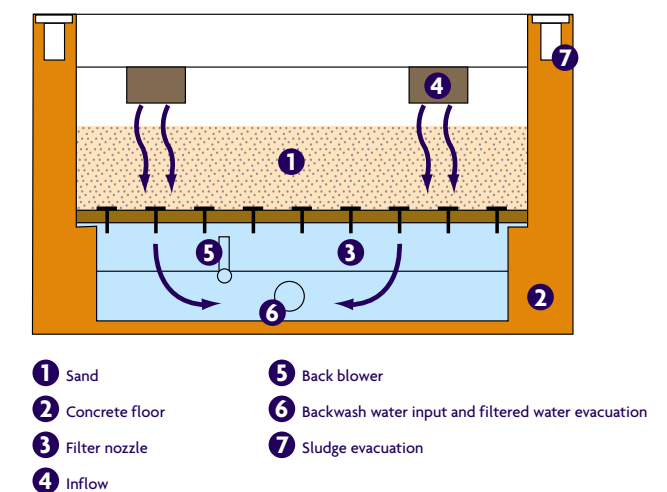
Filtration is the process of flowing a solid-liquid blend through a porous media in order to retain the solids and let the liquid through.

Filtration is a technology that is well adapted to low concentration effluents or as a finishing step.

The most common filters are :

- Sand filters.
- Belt filters or sock filters.
- Rolling paper filters.
- Suction filters (Disk or Plate)
- Ultrafiltration/Membranes.

Sand filter



2.3. Parameters influencing the product selection:

Several parameters must be taken into account when pre-selecting the coagulants and the flocculants in the laboratory as well as in the final industrial selection.

2.3.1. The effluent characteristics:

- pH
- Dry matter content (g/l)
- Ionic demand
- Mineral/organic ratio
- ...

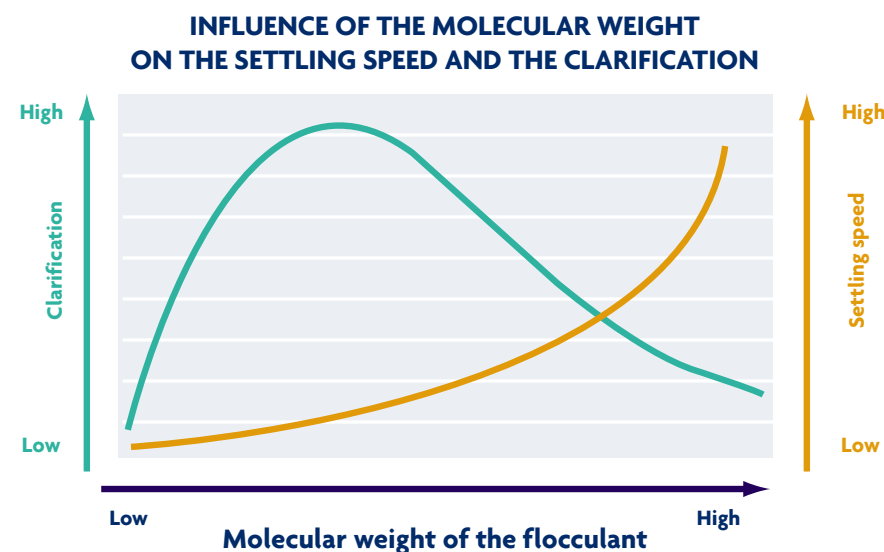
2.3.2. The working conditions:

- Flash mixing capability
- Injection points
- Mixing conditions
- Contact time
- Settling time
- ...

2.3.3. The results to be achieved:

- Suspended solids
- Turbidity
- Color
- COD

As well as the settling speed required :



3 Laboratory tests

Laboratory testing is essential. Considering the very wide range of products available (more than 800), laboratory tests are designed to:

- Select the best adapted product(s) to be tested industrially.
- Provide an estimate of the performance achieved : Suspended Solids, COD, Turbidity...
- Give an estimation of the dosages required.
- Optimise the industrial operating conditions : Injection Points, Stirring...

Note : Laboratory tests are not exact enough to extrapolate accurate industrial performance.

3.1. Sampling:

3.1.1. Sampling of the water to be treated:

Before any laboratory test, a representative sample of the effluent must be taken. In order to complete the appropriate tests a good knowledge of the process involved is necessary:

- Water quality (pH, SS, DS, Color, Turbidity, COD,...)
- Average and peak flows
- Quality variations
- Equipment used
- Future investments in process and/or equipment.

3.1.2. Sampling of the polymers:

It is not necessary to test all the available products, a primary screening will do.

- For **coagulants**, a sample from each family can be tested: polyamines (FLOQUAT™ FL 17), polyadmac (FLOQUAT™ FL 45 C), dicyandiamide resin (FLOQUAT™ DEC 50), metallic salt (PAC).
- For **flocculants**, select the ionic charge by testing a range of products with the same molecular weight: FLOPAM™ AN 900 SH Series for the anionic powders and FLOPAM™ FO 4000 SH for cationic powders.

3.2. Laboratory equipment:

The most common apparatus used to test physico-chemical processes is the jar-test. It allows a strict control on the stirring of several beakers at the same time (generally 6) and permits the comparison of the efficiency of several products or of the different dosages for the same product.

The small equipment necessary is: syringes, pipettes,... and a stop watch to measure the mixing times.



Automatic jar-test



Manual jar-test

Note : See the brochure «Preparation of Organic Polymers» for the methods of coagulant and flocculant dissolution.

3.3. Test procedures:

The aim of this section is not to impose a testing procedure but to **describe the key elements** that are essential and common to all the existing procedures. Any laboratory testing procedure has the purpose of representing the industrial conditions encountered and catering for the wishes of the operations manager. Follows these criteria, each test will be specific.

● **The injection of reagents:** after preparing the different solutions of reagents to be compared, their injection must be simultaneous and at pre-determined dosages.



● **The mixing of the reagent in the effluent:** after injection, a mixing phase is necessary to distribute the reagent throughout the effluent. These mixing phases may vary in time and in speed. For example :
For a coagulant : 250 rpm for 2 mn then 40 rpm for 15 mn.
For a flocculant : 250 rpm for 10 s then 40 rpm for 5 mn.

● **Flocs Settling** : Once the flocs are formed, the settling phase starts with an average time of 20 mn for coagulants and 10 mn for flocculants.



3.4. Parameters to follow and interpretation of results:

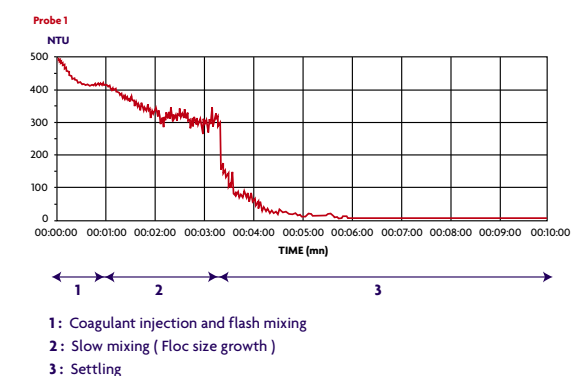
The main parameters to control during lab tests are :

- Reaction time
- Size of flocs
- Settling time
- Clarification
- Mixing
- Floc strength

These parameters can be controlled visually or with equipment such as the 6-probe turbidimeter developed by SNF to measure continuously the turbidity of a jar-test trial.



All these data are plotted in order to analyse the results.



4 Industrial trials

Industrial trials should be able to **confirm the lab results** obtained.

4.1. Setting up a trial:

During the trial period, the quality and flow of the effluent must be as close to average as possible. The making up of the reagents must be thorough. The concentration of the reagents, the injection points,... must be selected based on the lab results.

4.2. Parameters to follow and interpretation of results:

The main parameters to follow depend on the results targeted. Nevertheless the most frequents are:

- Reagent flow (l/h, kg/h, ...)
- Effluent flow (m³/h)
- Concentration of the effluent (g/l)
- Injection point
- Clarification
- Thickening

To analyse these results, it is useful to compile all the data in a spreadsheet in order to calculate the reagent consumption rates per volume treated and by dry matter weight.

5 Troubleshooting

5.1. In the lab:

Unexpected results in the lab may be due to:

- **A bad blending of the reagent:** the high viscosity of organic flocculants may make it difficult to mix them in.
- **An overdosing:** At certain dosages, the ionic charges (+) or (-) that are induced in the effluent are too high and will have a repulsion effect on the particles.

5.2. In the field:

When a reagent dosage problem occurs, it is very important to check each and everyone of the points.

WATER TREATMENT DOSAGE

