

FS-PRI-001

TECHNOLOGY FACT SHEETS
FOR EFFLUENT TREATMENT PLANTS
ON TEXTILE INDUSTRY

COAGULATION-FLOCCULATION

SERIES: PRIMARY TREATMENTS

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COAGULATION-FLOCCULATION (FS-PRI-001)

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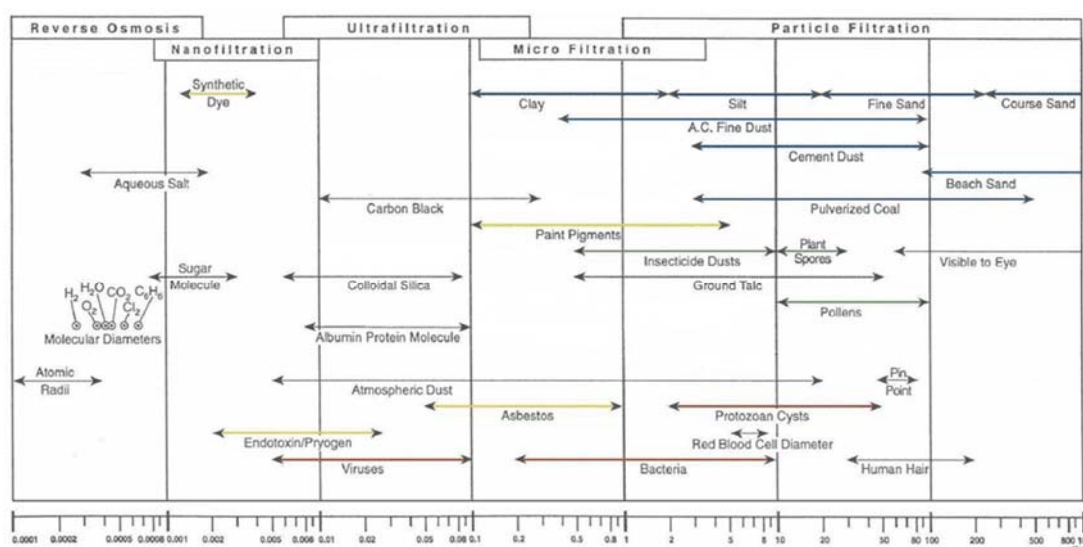


1.- INTRODUCTION

The total solids content of natural or residual water is one of the most important physical parameters. The total solids are composed by floating materials, suspended solids, colloidal dispersion and dissolved solids.

The total solids, or dry residue, can be categorized into suspended solids and filterable solids. The filterable solids fraction comprises colloidal and dissolved substances.

The colloid fraction consists of particles with a diameter ranging from 10^{-3} to $1\ \mu\text{m}$. Dissolved solids comprise organic and inorganic substances together with ions that are dissolved in water.



**Figure 1.- Particle size in microns (adaptation of Water Quality Association source material;
<https://omegamanjournal.wordpress.com/page/4/>).**

Solids with sizes greater than $0.2\ \text{mm}$ ($200\ \mu\text{m}$) are often referred as sands. Silt, clay, bacteria, etc., is retained by filtering the water as its size is greater than $0.1\ \mu\text{m}$.

Colloidal fraction cannot be removed by sedimentation. Turbidity and color are often associated with colloidal particles. Focusing this particle sizes, surface properties and electrical charges are more important than the relative weight of the particle in water phase.

The colloidal particles have surface charges generating electrostatic repulsive forces between one another and avoiding the possibility to agglomerate forming flocs, what could facilitate sedimentation. These charges are generally negative. A colloidal suspension can be almost infinite time without sedimentation.

When the surface of a particle has electric charge, some ions of opposite charge can get attached to the surface and are held there by electrostatic and van der Waals forces. Around this stationary ion layer other (non-compact) diffused layer exists, due to thermal agitation impediment.

If wastewater with colloidal matter is driven through an electric direct current, the electrically charged particles will be attracted among one or another electrode according to the sign of their charge.

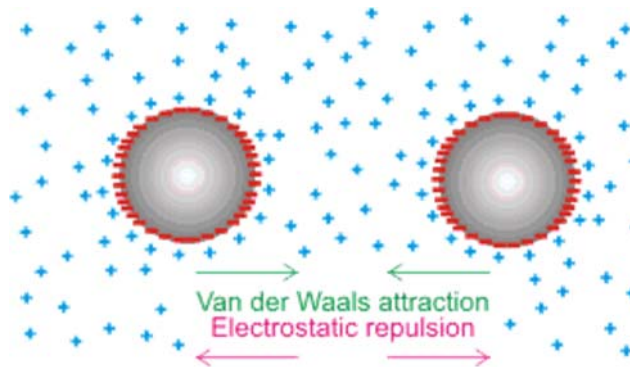


Figure 2.- Forces involving suspended solids aggregation.

Colloidal particles are considered as partially ionized on their surface and capable to move under the action of an electric field. About the electro-kinetic effects, it is stated that there is a ionic double layer on the colloid-liquid interphase, with the following ideal structure:

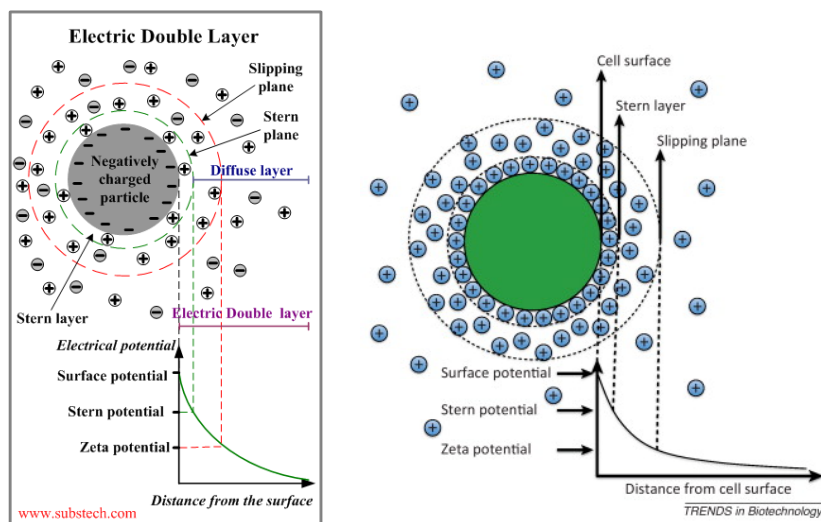


Figure 3.- Electrical double layer model.

References agree on a double layer model, where one layer is adhered to the wall, while the other is moved under the action of the electric field, with an electrokinetic kind of electrical potential difference (Zeta) between surfaces separating the fixed/mobile interface inside the liquid. There is also a thermodynamic potential, E , equal to the potential difference between the wall and the bulk liquid. The zeta potential depends on both the E and the double layer thickness, whose value determines the magnitude of the electrostatic repulsion forces between particles, and thus, its probability of adhesion. Zeta potential measuring is normally obtained using an equipment called Zetameter.

The Z potential value varies depending on the nature of the components inside the solution.

In order to remove colloids from the bulk water it is necessary to conduct particles aggregation into larger flocs, easier to settle. It is normally needed to introduce a product in water capable to;

- Neutralize the charge of the colloids (remove Z potential).
- Form aggregates of particles.

The process that achieves the above objectives is the so called COAGULATION - FLOCCULATION.

The main goal of coagulation – flocculation processes is electric charges neutralization on colloids and emulsions present on wastewater, followed by particles rearrangement, so that it could be feasible a further separation either by settling or floatation processes. It is remarkable that in coagulation-flocculation process, there is no pollutant extraction, but an adaptation of certain particles to be easily separated by other processes installed downstream (SAIZ-SASTRE, 2007)

2.- COAGULATION-FLOCCULATION PROCESSES

2.1.- Coagulation and flocculation phenomena

Coagulation is known as the process of destabilization of colloids. Properties that made them stay in suspension are removed. The basic mechanism of destabilization is removing the electrical charge. With this purpose, coagulation chemical reagents are used.

The time required for the reagent to cause coagulation is less than 1 second. It is very important that the reagent is rapidly mixed with all water, but reaching a good mix can take from 30 seconds to 3 minutes. Mixing techniques with high energy application are normally used to achieve high yields in the mixture.

Once destabilized the interest is focused on that these particles settle. Its size is still not optimal to do so in short periods of time and need to get bigger; this is achieved by the flocculation process.

In flocculation process, aggregation of destabilized colloid particles is achieved (although it is not necessary that were ex-colloid). Aggregation is facilitated if the particles are getting contacted and if there is something to create links between them, maintaining this contact. The first is accomplished by mixing and the second by addition of flocculants. The bonding process is slow and units take contact times ranging from 10 to 30 minutes.

It is necessary to achieve a proper flocculants and water mixing, but if it is mixed with too much energy already formed flocs can break, so mixing and flocculation process should be slow.

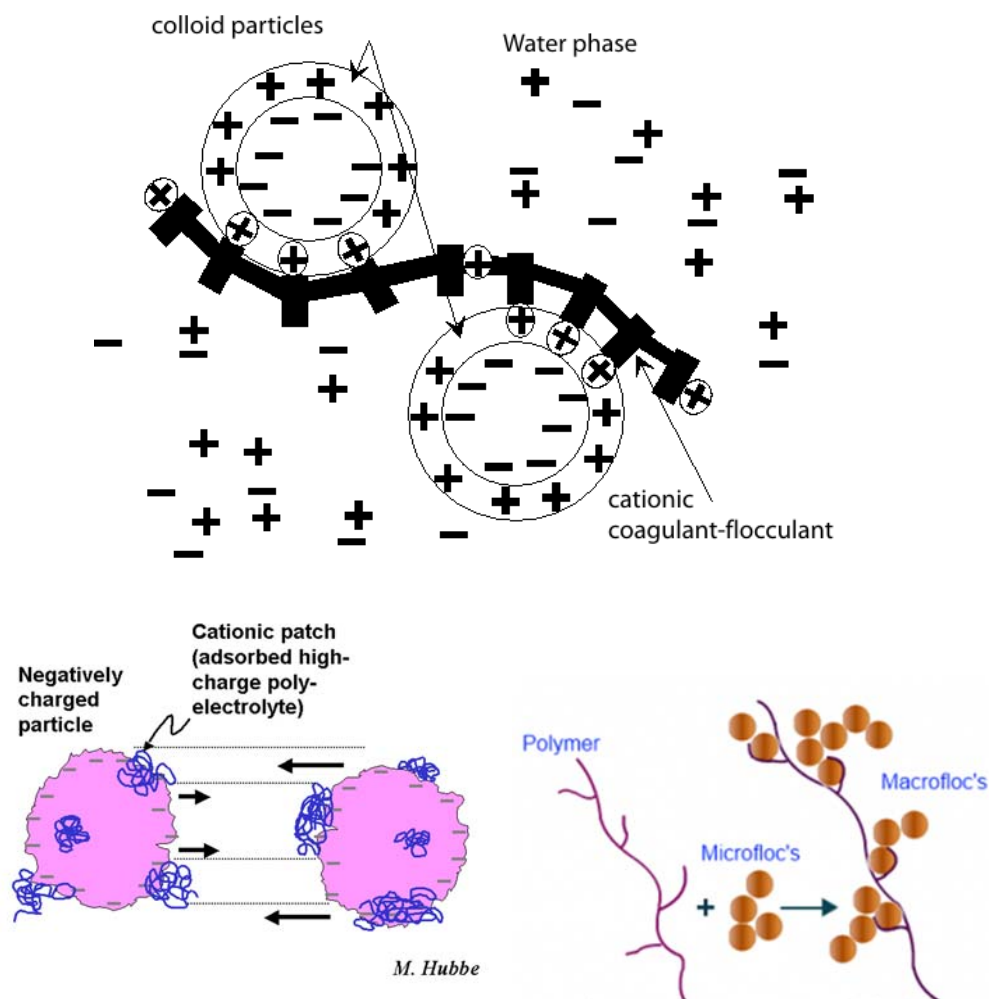


Figure 4.- Coagulation and flocculation reagents operation diagram.

In order to remove dissolved solids, PRECIPITATION process is employed. By adding chemicals dissolved salts are converted to insoluble salts. It is not the same as sedimentation or decantation after flocculation.

2.2.- Chemical reagents

Different chemicals are used, and they are grouped under the name of coagulants and/or flocculants and coadjuvants.

2.2.1.- Coagulants

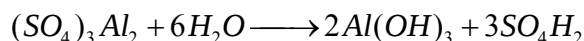
Destabilization of a colloid is caused by adding an electrolyte with the opposite electrical charge of the colloidal particles. The effect is greatly increased when the number of charges carried by the polyelectrolyte is large. The better the coagulant works, the higher is its valence.

Frequently coagulants:

- **Aluminum sulphate** $(\text{SO}_4)_3\text{Al}_2$; on market is in granular or liquid form.
- **Ferric chloride**: FeCl_3 , used in wastewater, but less in drinking water treatments because it gives color to water. It is commonly found in liquid form at concentrations 37% - 47%
- **Ferrous and ferric sulphate**: $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ and $(\text{SO}_4)_2\text{Fe}_2 \cdot 3\text{H}_2\text{O}$; are supplied in solid form.
- **Polymers**: Few applications on coagulation. Its use is widespread in flocculation.
- **Polyaluminum chloride (PAC)** is currently widely used. It improves the properties of the aluminum sulfate, $\text{Cl}_{3n-m}(\text{OH})_m\text{Al}_n$.

When a metal salt (primarily iron or aluminum) is added to water a series of hydrolysis reactions arise. A set of complex substances are formed with multivalent charges, which are responsible for the coagulation process. Most frequently used reagents are metal salts of cations with high ionic strength. The greater the charge on the cation and the smaller ionic radius, the better is the performance of the operation.

When Al^{3+} (in sulphate form) is added as a coagulant a small part of these trivalent ions are directed to neutralize the negative charges of the colloid, while simultaneously, the majority react with water to form insoluble hydroxide according to the reaction:



Neutralized colloids are trapped by the insoluble hydroxide by an independent mechanism and facilitates their sedimentation.

The acid formed in the above reaction reacts with the bicarbonate alkalinity, which is normally present, without actually requiring neutralization with lime.

Ferric sulphate reacts similarly. The selection of the most appropriate reagent will depend on the results of coagulation assays performed previously. The pH is a critical factor in the coagulation-flocculation process. There is always a range of pH in which a specific coagulant works better (Rigola, 1989).

2.2.2.- Flocculants

Particles formed during the coagulation process can still be of a small size or with a low density, having settling difficulties. Particle sizes can be increased with chemicals addition of high molecular weight, which are water-soluble. By electrolytic dissociation in water, they give multiple ionic forms, capable to act as links between coagulated particles.

Among the different types of flocculants can be cited:

- **Polymers**: Frequently used in the flocculation process. Polymers are organic and inorganic compounds with a high molecular weight; they form long chains and can be electrically charged (polyelectrolytes); there are also anionic (-) and cationic (+) polymers. Cationic are most commonly used because natural colloids are anionic; non-ionic polymers have other applications in water treatment. They can become toxic and its use is limited in drinking water. Depending on their origin, polyelectrolytes are divided into two main categories: naturally, such as starch, cellulose and alginates, etc., or synthetic, consisting of simple monomers which are polymerized to form chains of very high molecular weight.



- **Activated silica:** The activated silica is formed by a solution of polysilicic acid (H_2SiO_3)₄ obtained from silicic acid process. It is not very stable, so it must be prepared "in situ". Until the recent development of polyelectrolytes, it was considered the best flocculant in association with aluminum salts. It is still frequently used in drinking water and frequently applied in dilutions of 0.5% to 1%.

2.2.3.- Adjuvants

Adjuvants main function is to improve the performance of coagulants and flocculants. Adjuvants can have several objectives

a) pH correction: Each coagulant has an optimum working pH. As an example, aluminum sulfate tends to acidify treated water, worsening coagulation conditions, which are better in neutral pH. Bases or alkaline salts (lime, sodium hydroxide, sodium carbonate, etc.) are added to water in order to adjust the pH level.

b) Oxidation of compounds: It is believed that coagulation-flocculation process improves if some organic compounds (that can interfere with the process) are removed by oxidation. For this purpose, Chlorine, Potassium Permanganate, Ozone and other reactives can be used as oxidants.

c) Add weight to particles: So called gravimetric agents are used. They are applied in waters with low initial turbidity. It seeks to improve sedimentation rates. Activated carbon in powder, lime, clays, or polymers can be used. The addition of other products such, as bentonite, increases the particle density and the overall weight of the suspension providing, at the same time, a large area for the adsorption of organic compounds. Something similar occurs when active carbon powder is added to the treatment. The dose of clay can be between 10 and 50 mg/L.

The activated silica and polymers may also be considered as processing aids in the coagulation and flocculation.

2.3.- Reagents management

Reactants may be in liquid or solid form. The solids, in turn, can be in granular or powder form. Reactives in powder form and liquids are those with higher management problems. In handling the reagents must distinguish three stages: storage, preparation and dosage.

2.3.1.- Storage

Storage facilities depend on the format of the reagent. The basic typology consists of silos, bags or tanks.

Silos are used for the storage of solid reagents. They must have arm filters and vibratory systems to avoid the "silo effect" that prevents the descent of the material through the hopper.

The bags are common in small facilities and for reagents used in low doses. It is recommended not to stack substances exceeding 1.5 meters in height. This data may provide an insight into the necessary warehouse surface that a particular installation may need

Deposits, generally of cylindrical shape, are made of non-corrosive materials (plastics, polyester resin and glass fiber, etc.) and may be with vertical or horizontal axis.

The treatment plant should have a range of reagent use between 15 and 20 days considering the maximum dose and peak flows.

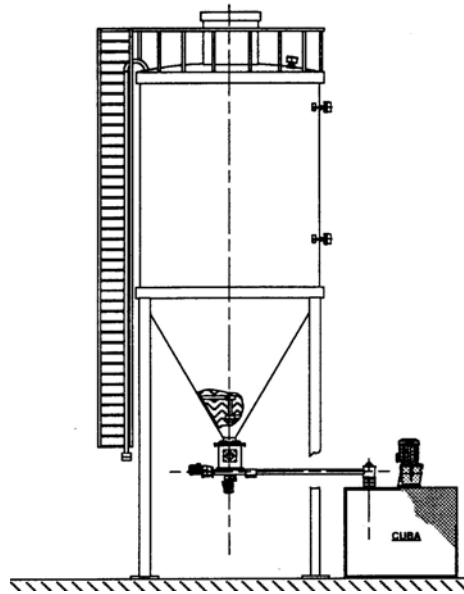


Figure 5.- Silo with incorporated arm dosing system.

2.3.2.- Preparation and dosage

Some chemicals are supplied with a high purity or with no adequate presentation to make a right mixing and dosage. Reagent preparations, suspensions or solutions are performed prior to dosing step. These preparations are made in similar tanks to those of coagulation (with a little volume and mixers). Dosing pumps extract the reagents from these deposits.

Dosages are usually expressed in milligrams of reagent per liter of water to be treated. Dosage optimization of the reagents minimizes the cost. The optimal dose is determined by tests called "jar test", involving a series of coagulation and flocculation essays with different reagent doses. The results can be expressed graphically and optimum operating conditions are obtained from them.

The usual reagent dry addition system consists in a hopper that can be supplemented by a volumetric or a gravimetric system. Volumetric pumps may include a paddle or a screw drive. The dosage is usually controlled by the rotational speed. Gravimetric system usually comprises a conveyor belt connected to a weighing system. These systems typically supply the preparation depots.

Preparation tanks are generally duplicated because they work normally in discontinuous form. The volume of the working solution should allow a minimum of 24 to 48 hours. In addition, it must have a feed capacity of at least twice the maximum consumption. It is normal to have a reserve of 100% if only we have one equipment (1 + 1) and 50% if you have 2 or more equipments (2+1, 4+2). It should also have hourly transportation capacity (pumps + pipelines) higher than 1/8 of the maximum daily consumption.

When using liquid reactives, it is also common the use of a preparation tank, from which dosage is performed. Dosing pumps can be of membrane, piston, solenoid or peristaltic types. Centrifugal pumps require supplementary flow measurement as a spinner or a float.

2.3.3.- Chemicals use

Table 1.- Reactives summary for coagulation-flocculation process.

PRODUCT	AVAILABLE		WORK SOLUTION	DOSAGE	Optimum	COMMENTS
	FORM	PERCENT				
ALUMINUM SULPHATE $\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$	granules liquid	~100% Liquid 50%	~10%	< 35-45 mg/L	5.8 a 7.4	
FERRIC CHLORIDE $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$	Solid (crystal or anhydrous)	37%-47%	.	< 25-35 mg/L	3.5 a 6.5 y > 8.5	Due to its corrosive and hygroscopic nature, it is necessary to maintain it on safe and well-sealed containers. Ferric hydroxide forms a brownish and gelatinous floc. Ferric chloride tends to provide water with a straw yellow color, so it is not recommended for use in drinking water neither in supply no in recycled water.
FERROUS SULPHATE $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	solid	90%-94%		< 50 mg/L	3.5 a 6.5 and > 8.5	It is a solid readily soluble in water and its efficiency is similar to that of FeCl_3 . The use of one coagulant or another depends on the anions annexed to Fe^{3+} , that means, on the preference between sulphates or chlorures level rise on the treated water.
FERRIC SULPHATE $\text{Fe}_2(\text{SO}_4)_3 \cdot 3\text{H}_2\text{O}$				<25 mg/L	3.5 a 7 and > 9.0	
POLYMERS	powder liquid	100%	1%	C: <5 mg/L F: <0.5 mg/L		
ALUMINUM POLYCHLORIDE $\text{Cl}_{3n-m}(\text{OH})_m\text{Al}_n$				15-100 mg/L		
LIME $\text{Ca}(\text{OH})_2$	powder 0.5 Kg/L	85%-99%	slurry 10%	pH correction 0.39 mg/mg alum. 40 % dosage sulph. Fe^{+3} 26 % dosage sulph. Fe^{+2}		
ACTIVE CARBON	powder grain	100%	suspension	<25 mg/L		

C: coagulation F: flocculation



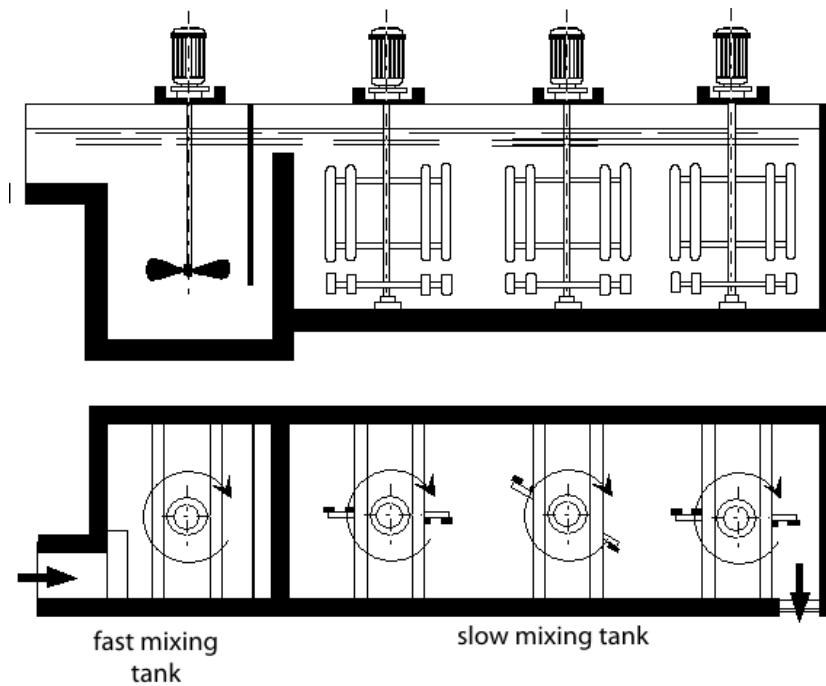


Figure 6.- Coagulation-flocculation mixing facility.

Another slow mixing system involves the use of long channels or labyrinth deposits. They are common in chlorination processes.

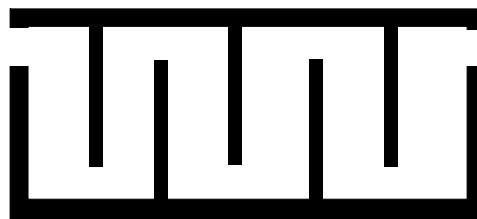


Figure 7.- Deposit with slow labyrinth mixing system. Plain view.

2.4.- Design parameters

In all coagulation-flocculation process, it is necessary to conduct laboratory tests in order to determine:

- Most suitable chemicals.
- Coagulant dose.
- Flocculant dose.
- Optimum pH
- Coagulation and flocculation times (hydraulic retention times).
- Sedimentation rate.
- Sludge production volume.
- Raw and treated water quality.

Hydraulic retention times in coagulation and flocculation reactors are the two main design parameters.

3.2 Design Criteria

Table 1 Summary of design values for lamellar/tubular decantation.

Parameter	Values
Coagulation HRT (minutes)	2 – 3
Flocculation HRT (minutes)	20 – 30

This calculation must be performed for the average and maximum flow rate, where applied design values are those indicated above.

3.- SPECIFIC TECHNICAL CONSIDERATIONS

Attention to the safe storage and handling of different reagents.

Aspects to take into account in the geometric sizing:

- The mixing for coagulation can be accomplished by mechanical agitators or by air injection to form medium or coarse bubbles. In the latter case the required air is about 1 to 1.5 m³ air/m³.h
- In the final equipment sizing should consider a margin for the spatters (40/50 cm).
- If a cylindrical section coagulator is adopted, it is necessary to install circuit breakers, to lessen the effect of the vortex created by the stirrer, which would lead to an energy loss by water entrainment. These circuit breakers are normally installed in a total number of three or four, and their width ranges between 5 and 10% of the tank diameter.
- It should be noted that, in the coagulation process, secondary type precipitation may occur; corresponding to compounds present in the wastewater, such as phosphates, carbonates, etc. This effect can lead to precipitation of corresponding insoluble compounds, carrying some additional reagent consumption and increasing theoretically expected sludge production
- In the case of using lime as a neutralizing agent, being a solid-liquid type reaction, hydraulic retention times should arise, as the reaction rate is considerably lower.
- Agitation in the flocculation deposit can be carried out by low-speed stirrers or by air injection through medium-bubble diffusers. In the latter case the required air is about 0.5 to 0.75 m³ air/ m³ h.
- In the case of mechanical stirring, it is important to have a speed control in the flocculation process in order to adjust the speed according to the type of formed floc.
- Inlet and outlet should be located at opposite positions.
- Both coagulator and flocculator, are usually oversized on a range of 15 - 20% of the theoretical volume obtained by calculation.
- Monitoring of the chemical feed system to detect clogging of the lines and maintenance of the mixers tanks is very important.
- Appropriate mixing energy is an important part of optimization of the chemical dose. Excess dosing with coagulant to compensate for inefficient mixing is not only uneconomical in terms of the chemical usage, but also expensive in terms of sludge production.
- Most drive failure are caused when the unit is started at the top rotational speed. O&M manuals should note that the mixers should be started at low speed to avoid very high torque force and high power requirement.

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ANNEX 1

ESTIMATION OF AREA REQUIREMENTS

AREA REQUIREMENTS FOR THE IMPLEMENTATION OF COAGULATION-FLOCCULATION PROCESS

HYDRAULIC RETENTION TIME		
Range	Coagulation 2 a 5 min Flocculation 20-30 min	
Adopted value	Total time 25 minutes	Total time 40 minutes
CAUDAL (m3/h)	AREA REQUIMEMENT (m ²) (2 m water depth)	
5	1	2
10	2	3
20	4	7
30	6	10
40	8	13
50	10	17
60	13	20
70	15	23
80	17	27
90	19	30
100	21	33



ANNEX 2

GRAPHIC DESCRIPTION OF PROCESS UNITS

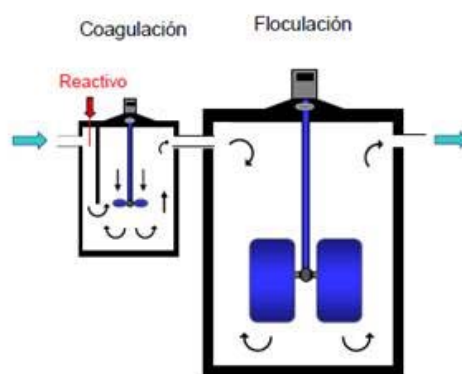


Figure 1
Basic sketch of a coagulation-flocculation system.

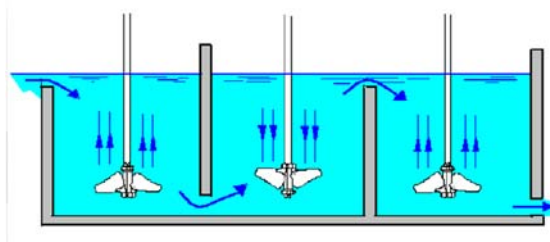


Figure 2
Sketch of flow directions in a flocculation chamber. Mixing systems have decreasing agitation speeds.



Figure 3
Stations for polymer preparation (manual and continuous flow (Ultromat®)).



Figure 4
Engines for mixing in coagulation tanks.



Figure 5
Mixing system and coagulation by hydraulic jump.

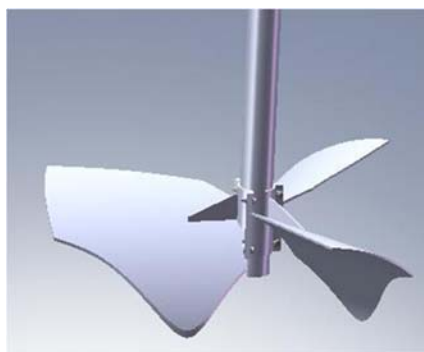


Figure 6
Flocculation propellers of slim profile.



Figure 7
Flocculation stirring paddles.



Figure 8
Paddles for slow agitation in a flocculation chamber with horizontal axis. (WesTech)..



Figure 9
Plates for slow agitation in flocculation chamber with horizontal axis. (WesTech).



Figure 10
In-pipe Coagulation-flocculation system.



Figure 11
Flocculation chamber and lamella separator.



Figure 12
Reagents preparation and dosing system.



Figure 13
Membrane Metering Pumps.



Figure 14
Solenoid pump installed on the dosing tank.



Figure 15
Reagent storage tanks: horizontal and vertical axis.