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**OPTIMIZATION OF COAGULANT AND COAGULANT AID IN
WASTEWATER TREATMENT**

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ABSTRACT

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<p>With the expanding urbanization, more municipal wastewater is produced by citizens, which requires more efficient wastewater treatment to meet the demand of stringent legislation.</p> <p>This thesis aimed to enhance the functions of coagulation and flocculation in the wastewater treatment process, which can lead to the optimal dosing of chemical reagent and the lower chemical residual in the post-treated wastewater. The project was approached by reviewing relevant literature and conducting experiments. The literature showed the current approach of the coagulation and flocculation in the wastewater treatment as well as their functional principles. In the experiment part, the parameters of turbidity and the residual of the chemical reagent were measured. During the procedures, Jar Test was implemented, and the optimal dose of the coagulant and the best operational pH were determined. Other factors such as the mixing intensity, mixing time were discussed in this thesis.</p>		

<p>Key words Coagulation, Flocculation, Jar test, Turbidity, Municipal Wastewater.</p>

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CONCEPT DEFINITIONS

BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
TS	Total solid
TSS	Total suspended solid
TVS	Total volatile solid
NOM	Nature organic matter
WWTP	Wastewater treatment plant
EDL	Electric double layer
RPM	Rotations per minute
AAS	Atomic absorption spectroscopy

ABSTRACT
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CONCEPT DEFINITIONS
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1 INTRODUCTION

Water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such. It is one of the most important resources for humans and other creatures on the planet. There is no doubt that life originates from the water. As we all know that approximately 71% of the earth's surface is covered with the water, which seems to show the evidence that we have plenty of water to meet the demand of water. But the truth is that fresh water is limited for human.

With the development of economy and technology, urbanization speeds up all around the world, which causes that high demand of the fresh water as well as the large amount of wastewater produced by the households and industrial plants. Nowadays, a lot of countries are becoming more conscious about the wastewater treatment issues than ever before because countless environmental incidents show that it is time to solve the problems between humans and environment, which aims to reach a sustainable and harmonious environment.

WWTP is an essential part of municipal facility. Every day, wastewater plant receives wastewater produced by citizens through the sewage and it purifies the raw wastewater so that it could be finally discharged into the rivers, lakes or seas.

In recent years, it is inevitable that city authorities need to handle the larger amount of wastewater due to the growing population and meet the stringent legislation under a limited budget. Within the wastewater plant, excluding the cost of labor, maintenance and equipment, the chemical reagent forms the main part of the budget.

There are mainly several kinds of the chemical reagents used in the wastewater plant such as acid or base for the pH adjustment, coagulant for the coagulation, flocculant for the flocculation, chlorine or chlorine dioxide for the disinfection. Due to the high cost of the chemical reagents, it is significant to optimize the usage of the chemical reagents. Not only the municipal wastewater treatment plants but also the industrial plants currently seek ways to reduce cost by either implementing the cost-efficient chemical reagents or adapting the new application of the chemical reagents.

Currently, the coagulant used in the Hopeakivenlahti WWTP is PIX-105(mainly Ferric sulfide). In this work:

1. The optimal dosing condition of the coagulant can be determined
2. Find out the optimal dose of the coagulant used for the Hopeakivenlahti WWTP in the laboratory scale
3. Determine how other factors influence the result of coagulation such as: the coagulation mixing intensity, flocculation mixing intensity and flocculation time.

The main approach implemented in this work is Jar Test. Jar test is regarded as a standard tool implemented to optimize the addition of the coagulant and flocculant in the potable water and wastewater treatment plant. There are many reasons of conducting the jar test. The result can be utilized to evaluate the influences of the changes in the chemical dosages and points of applicant; choose alternative coagulants; vary mixing intensity and times; add polymeric coagulant aids; or other water quality parameters of concern.

The research process can be divided into two parts which are the literature review as well as laboratory experiments. For the literature review, several topics related to the wastewater treatment will be presented such as the overlook of the wastewater plant, main configurations within the wastewater plant, coagulation and flocculation process and so on. For the experiments, a method of Jar Test will be conducted firstly to find out the optimal dosing condition of coagulant for the Hopeakivenlahti WWTP, in which the turbidity and the iron residue are the main parameters. Then based on the results from the Jar Test, the influences of the coagulation mixing intensity, flocculation mixing intensity and flocculation time will be found out.

During this research, because of the limited time, only some influencing factors regarding the coagulation process in the WWTP were discussed. And due to the limited resource of experimental apparatus, turbidity and the coagulant residue were regarded as main parameters instead of the concentration of the soluble reactive phosphorus which should be highly concerned. It needs to be aware of that how important is coagulation to phosphorus removal. Last but not the least, this research is in the laboratory scale, which needs to be scaled up to pilot scale and then eventually to the factory scale before implementation.

2 LITERATURE REVIEW

In this chapter, literature related to the wastewater is reviewed in detail. The definition of wastewater and the categories of the wastewater such as domestic wastewater and industrial wastewater are introduced. The main facilities of the wastewater treatment plant are briefly presented including the coagulation and flocculation processes.

2.1 Wastewater

Wastewater is a complicated mixture that contains both inorganic and organic material. In the Cambridge dictionary, wastewater is defined as water that is not clean because it has already been used in homes, business, factories, etc. In the broadest sense wastewater can be divided into three categories which are domestic or sanitary wastewater, industrial wastewater and the combination of both domestic and industrial wastewater. But nowadays it is unusual that municipal WWTP receives and treats the wastewater produced by the industrial plants because of the high cost charged by the municipal wastewater treatment plant, which leads most of the industrial factories either build their own wastewater treatment or pretreat the wastewater before discharging it into the local authority sewer. (Gray 2010, 403.)

2.1.1 Industrial wastewater

The term of industrial wastewater can be defined as following: The water or liquid carries waste from an industrial process. These wastes may result from any process or activity of industry, manufacture, trade or business, from the development of any natural resource, or from animal operations such as feedlots, poultry houses, or dairies. The term includes contaminated storm water and leachate from solid waste facilities (Washington State Department of Health 2012). Even though the amount of the water consumed by the industrial factories is less than agriculture and domestic, it contains highly polluting substance once it releases complicated pollutants. Much significant emphasis is given to the prevention of the industrial pollution by many countries nowadays. Industrial wastewater can be classified basing on biodegradability and dissolved solids. Figure 1 shows the classification of the industrial wastewater. (Gray 2010, 403.)

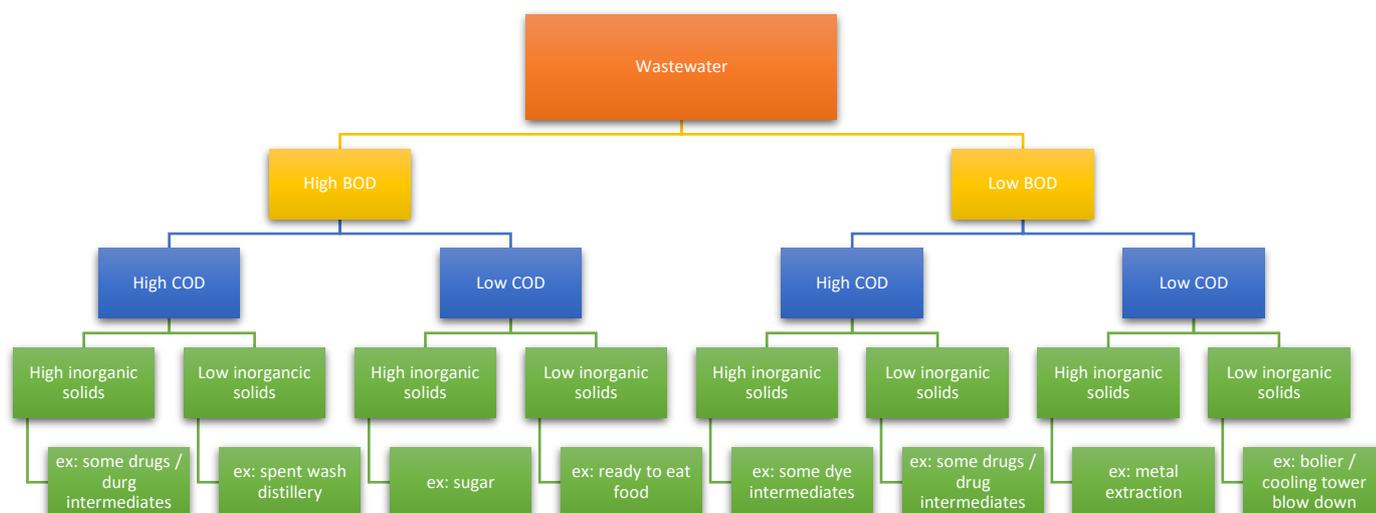


FIGURE 1. Industrial wastewater classification (adapted from Chandrappa & Diganta 2014)

Figure 2 show the classification of dissolved solids on biodegradability. The distillery, dye, electroplating, electropolishing, pharmaceutical, sugar and surface coating industries discharge effluents which contain a lot dissolved solid. Some factories such as pharmaceutical manufacture, dye can produce different kind of pollutants which varies from day to day because these sectors want to meet the demand within the market. (Chandrappa & Diganta 2014) The source of the chemical contamination in the industrial wastewater varies from factory to factory. Table 1 lists the sources of the chemicals from different industries.

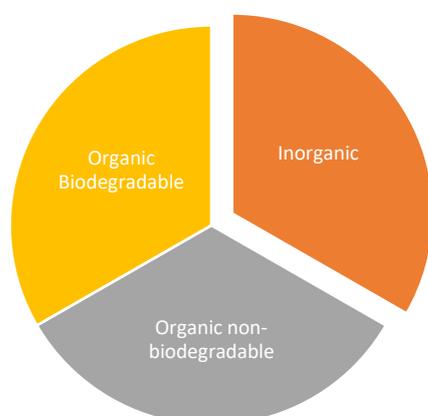


FIGURE 2. Classification of dissolved solids based on biodegradability (adapted from Chandrappa & Diganta 2014)

TABLE 1. Source of chemicals from various industries (adapted from Chandrappa & Diganta et al. 2014)

Number	Chemical	Industry
1.	Acetic acid	Acetate rayon
2.	Acids	Acid manufacturing, chemical manufacturing involving acids, mine, textiles manufacture, plating
3.	Alcohol	Breweries, distilleries
4.	Alkaline	Wool scouring, cotton/straw kiering
5.	Ammonia	Coke/gas and chemical manufacturing
6.	Arsenic	Sheep dipping
7.	Cadmium	Plating
8.	Chromium	Alum anodizing, chrome tanning, plating
9.	Chlorine	Health care establishments, leaching powder
10.	Chloride	Fish processing, pickling
11.	Citric acid	Citrus fruit processing and soft drinks
12.	Copper	Copper pickling, copper plating
13.	Cyanides	Gas manufacturing, metal cleaning, plating, steel hardening, electropolishing
14.	Fats, oils, grease	Wool scouring, laundries, textile industry, food industries using oil/grease, vehicle servicing, petroleum
15.	Fluorides	Scrubbing of flue glass, gases, etching
16.	Formaldehyde	Synthetic penicillin and resins manufacture
17.	Free chlorine	Textile bleaching, paper mills, laundry
18.	Gold	Plating
19.	Hydrocarbons	Rubber factories, petrochemical
20.	Hydrogen sulfide	Petrochemical
21.	Lead	Plating
22.	Iron	Iron and steel

Continue

TABLE 1. (continues)

Number	Chemical	Industry
23.	Mercaptans	Oil refining, pulp
24.	Nickel	Plating
25.	Nitro compounds	Chemical works and explosives
26.	Organic acids	Fermentation plants and distilleries
27.	Pesticides	Pesticide manufacturing
28.	Phenols	Gas and coke manufacturing, chemical plants
29.	Phosphate	Soap and detergent
30.	Radioactive material	Atomic power station, radioactive processing industry
31.	Silver	Plating
32.	Sodium	Fish processing, pickling
33.	Starch	Food processing, textile industries
34.	Sugars	Breweries, dairies, sweet industry, confectionaries, fruit juice, soft drink, sugar, jaggary
35.	Sulfides	Textile industry, tanneries, gas manufacture
36.	Tannic acid	Tanning, sawmills
37.	Tartaric acid	Wine, leather, chemical manufacture, dyeing
38.	Tin	Electroplating
39.	Zinc	Zinc plating, rubber process, galvanizing

2.1.2 Domestic wastewater

In this section, the definition, characteristics of the domestic wastewater and the methods of measuring the degree of the domestic wastewater will be described briefly. According to the Finnish decree, domestic wastewater means wastewater originating from water closets of dwellings, offices, business premises and other facilities, and from kitchens, washing facilities and similar facilities and equipment, and wastewater with similar properties and composition originating from milk stores at dairy farms or resulting from other business operations. (Finnish Ministry of the Environment 2003/542.)

2.1.3 Characteristics of the domestic wastewater

The colour of the wastewater can indicate the age of the wastewater because fresh wastewater is grey. After a certain time, the colour turns into dark and eventually to black due to rotten substance in the wastewater. The smell of the wastewater varies from time to time especially when the wastewater becomes dark because the organic matter is decomposed. The acidity also varies from time to time because the fresh wastewater has around neutral pH value. When putrefaction happens and the acidic gases are released, the pH value of the wastewater declines. In the wastewater, dissolved, undissolved and suspended particles only account 0.1% and the rest is water. About 50% of the particles in the wastewater is organic substance. Those organic substances have a large part which are microscopic living organisms. (Arash 2016, 6-8.)

2.1.4 Contaminants in wastewater

Wastewater contains a lot of microorganisms such as helminths, parasitic protozoa, bacteria, and viruses. Helminths are often known as parasitic worms. Protozoa are single-celled eukaryotes that are heterotrophic and usually larger than bacteria in size. Some protozoa are mobile by flagella, pseudopods or cilia, while others are immobile. Bacteria are single cell of prokaryotes which are shed by the human population in the sewer shed. Virus are very small infectious matter that needs a host cell to replicate and there are different viruses which infect almost all kind of organism including animals, plants and even bacteria. (National Academy Press 2011, 55-58.)

A variety of inorganic substances show their trace in the domestic wastewater, such as metals, nutrients, oxyhalides and salts. While the organic fraction is composed primarily of proteins, carbohydrates and fats, which reflect the diet of the community served by the treatment system. The carbohydrates have a general formula $(C_6H_{10}O_5)_n$. Glucose, sucrose and lactose are the most common sugars in the sewage, which represent a high portion of the BOD. The proteins in the wastewater can be decomposed into carbon, hydrogen, sulphur, nitrogen, oxygen and many other trace elements. (Gray 2010, 404-405.)

Phosphorus is found in the sewage in the form of orthophosphates, polyphosphate or as part of an organic complex. In the treatment of sewage, the amount of the phosphorus in the form of orthophosphate will account for 80% because of the decomposition of the polyphosphates and organic phosphorus. Fats is a term that can be used interchangeably with grease and lipids. Fats include all the fats, oils and waxes

associated with food. Because of the stability of the fats, the forms of the fats presenting in the sewage usually are palmitic, oleic and stearic. These fats can contribute a significant BOD of wastewater (40-100 mg/l). Nitrogen (N) exists in different forms in the sewage such as organic nitrogen, ammonia and oxidized nitrogen (nitrate and nitrite). (Gray 2010, 404-405.)

2.1.5 Wastewater plant

In this section, the basic units of the wastewater treatment will be introduced briefly. The following summarization is based on the book named *Water Technology-An Introduction for Environmental Scientists and Engineers*. (Gray 2010, 425-446.) According to the currently executed European Urban Waste Water Treatment Directive (91/271/EEC), the towns with a population equivalent excess of 2000 need to implement the secondary treatment when discharging the wastewater to the estuaries.

Wastewater treatment can be divided into two main processes which are the physical unit processes as well as chemical unit processes. The treatment is the separation of suspended, settleable and soluble substrate from the water by various sorption processes to form the large particles to be removed from the wastewater by settlement. Different treatment of wastewater has different kind of combination of unit which is usually decided by the nature of the wastewater itself. (Gray 2010, 425-446.)

2.1.6 Main processes of treatment

During the Preliminary Treatment, the Screens process is used to remove larger solids that may cause blockage of pipework or damage to pumps such as floating solids, wood, paper and so on. The mineral aggregate (sand and gravel) and other substance, such as glass, metal and dense plastic fragments are removed by the Grit Separation. (Gray 2010.)

In the Primary Treatment, also regarding as primary sedimentation, a sedimentation tank is constructed to remove the settleable solids or particles at a certain velocity by function of gravity. This process can reduce the BOD by 30-40% and the suspended solids concentration by 40-70%. The processes of coagulation and flocculation will be presented in the later chapter. (Gray 2010.)

Biological treatment is a significant sector of domestic wastewater plant, where the wastewater is mixed or exposed to a dense microbial organism under aerobic environment. And the Secondary treatment will separate the dense microbial biomass from the purified wastewater. (Gray 2010.)

The tertiary treatment is set when the secondary treatment can't meet the requirements. Filtration, disinfection processes are usually implemented. Chlorination of effluents is common accepted in the USA, while ozonation or ultraviolet is widely used in Europe because it has less impact on the environment. (Gray 2010.)

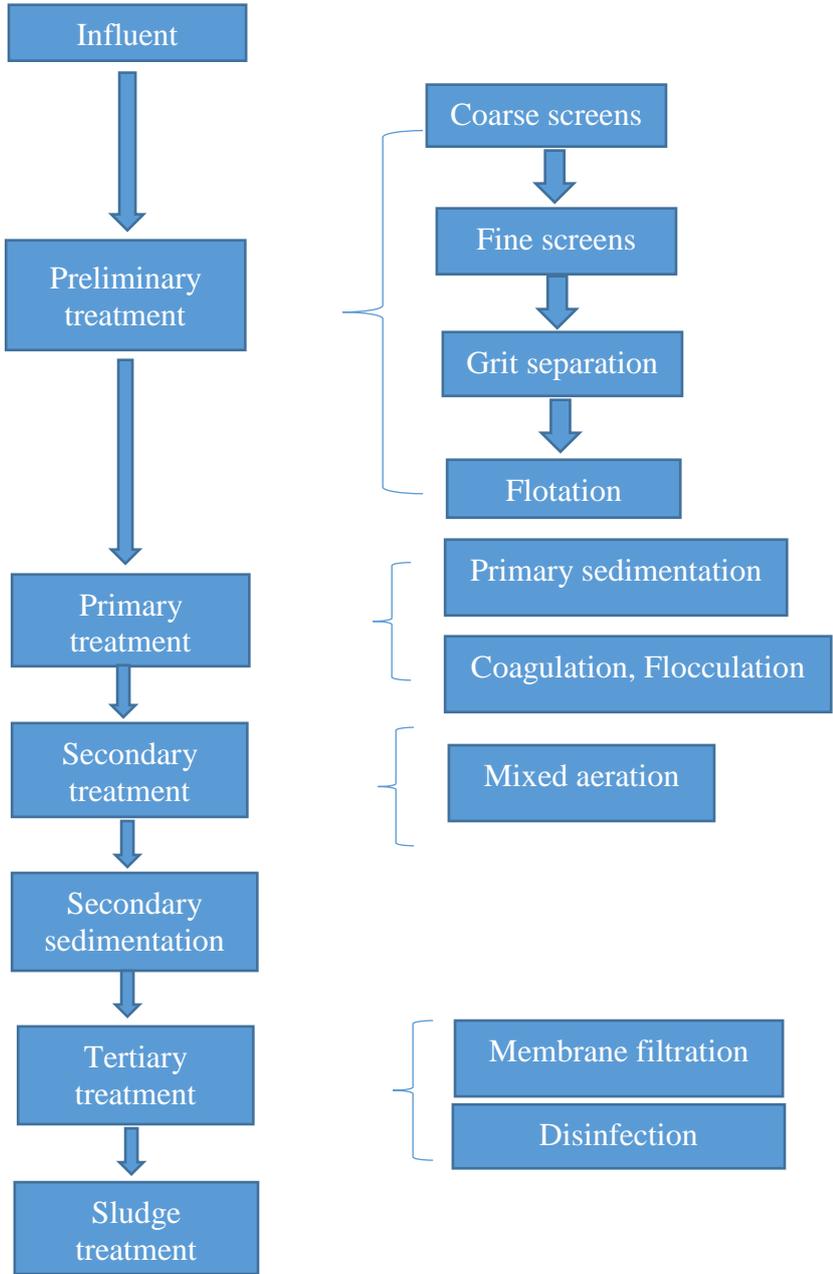


FIGURE 3. Basic flowchart of wastewater treatment plant (adapted from Gray 2010)

2.2 Turbidity of wastewater

Turbidity is the measure of the clarity of a liquid. It is contributed by both suspended solids and colloidal material in water. Most of the turbidity in surface water is due to the erosion of colloidal substances like clay, silt, rock fragments, microbes and so on. The units of measurements are the Jackson Turbidity Unit (JTU), the Formazine Turbidity Unit (FTU) and the Nephelometry Turbidity Unit (NTU). The procedures/instruments for measuring each of these units vary considerably. (Chandrappa 2014.)

The turbidity is mostly created by the suspended solid in water. Suspended solid means any substance suspended in water qualifies as a suspended solid. It is determined by filtration followed by weighing of filter paper after drying and subtracting the weight of the filter paper. It is represented as mg/l. The suspended solids are characteristics of surface water bodies and wastewater from domestic as well as industrial/trade effluents. (Chandrappa 2014.)

2.3 Coagulation and flocculation

Hopeakivenlahti WWTP has the processes of coagulation and flocculation. The coagulant PIX-105 is introduced into the following processes such as pretreatment, after primary sedimentation, flotation. And the coagulant aid is only added into the flotation process. (adapted from Sydänmetsä 2018.) The figure 4 shows the basic flowchart of dosing the chemical reagents.

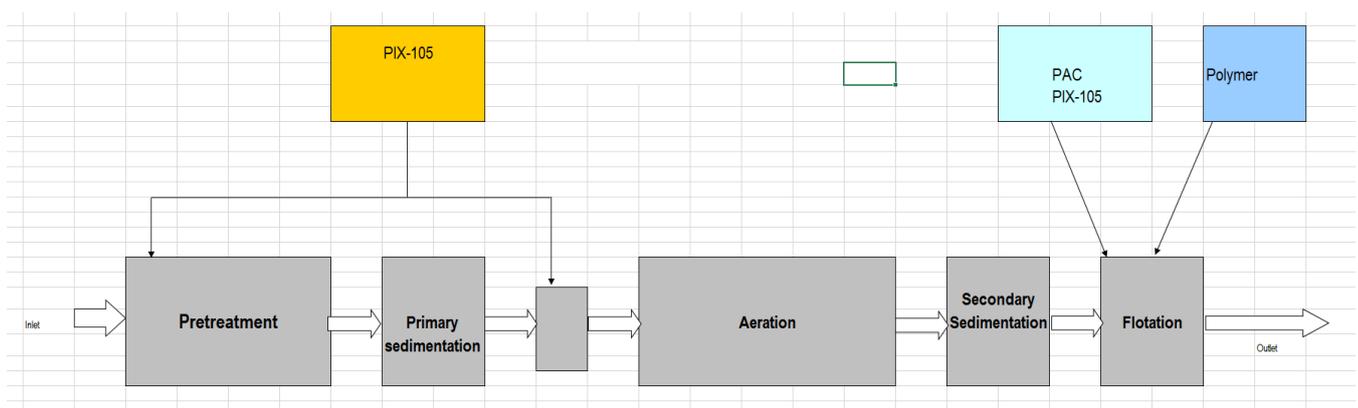


FIGURE 4. Flowchart of coagulant dosing and coagulant aid in Hopeakivenlahti WWTP (adapted from Sydänmetsä 2018)

Coagulation is one of the chemical processes to remove turbidity and color producing material that is mostly colloidal particles (1 to 200 millimicrons, μ) such as bacteria, organic and inorganic matters, algae and clay particles. (Lee & Lin 2007, 1.375.) Flocculation is the aggregation of destabilized particles and sedimentation substances formed by the addition of coagulants into a larger particle known as 'floc'. The most common method which is implemented to reduce the particulate substance and a portion of the dissolved NOM from the surface water is by sedimentation and/or filtration following the conditioning of the water by coagulation and flocculation. (R Rhodes & John 2012, 140.) Figure 5 shows the conventional treatment process of flow diagram which implements the coagulation.

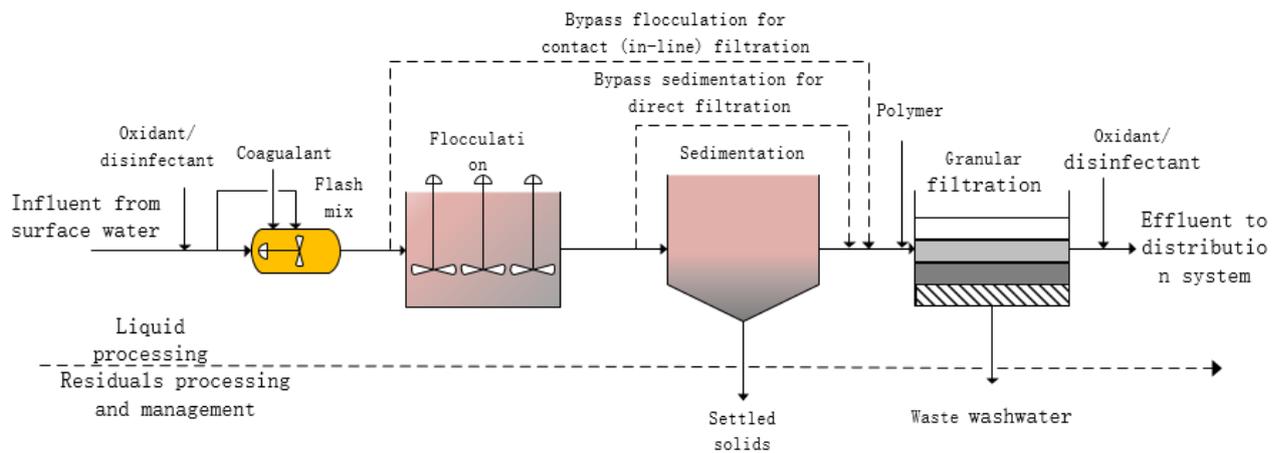


FIGURE 5. Typical wastewater process employing coagulation with conventional treatment, direct filtration or contact filtration (adapted from Trussell & John 2012)

2.4 Stability of particles in water

The Brownian motion is when mobile particles are immersed in an ambient medium, the particles undergo an incessant and irregular motion. Stability is one of the characteristics of Brownian motion. The motion can persist if the particles remain suspended in the liquid. (Robert 2008, 46) Particles in the wastewater can be categorized as hydrophobic (water repelling) and hydrophilic (water attracting). The fine particles in water have surface charge, which result to relative stability, causing a long period of detention of the particles suspended in water. There are four common kind of origination of the particle surface charge: Isomorphous Replacement (Crystal Imperfections), Structural Imperfections, Preferential Adsorption of Specific Ions and Ionization of Inorganic Surface Functional Groups. (Robert 2008, 46)

In the water, particles always have a negative surface. Figure 6 shows that a fixed adsorption layer will form when a layer of cations binds tightly to the surface of a negatively charged particle. This adsorbed layer of cations, stick to the surface of particle by adsorption forces and electrostatic, is about 0,5nm thick and is known as the Helmholtz layer (interchangeably with Stern layer). (Trussell & John 2012, 145.)

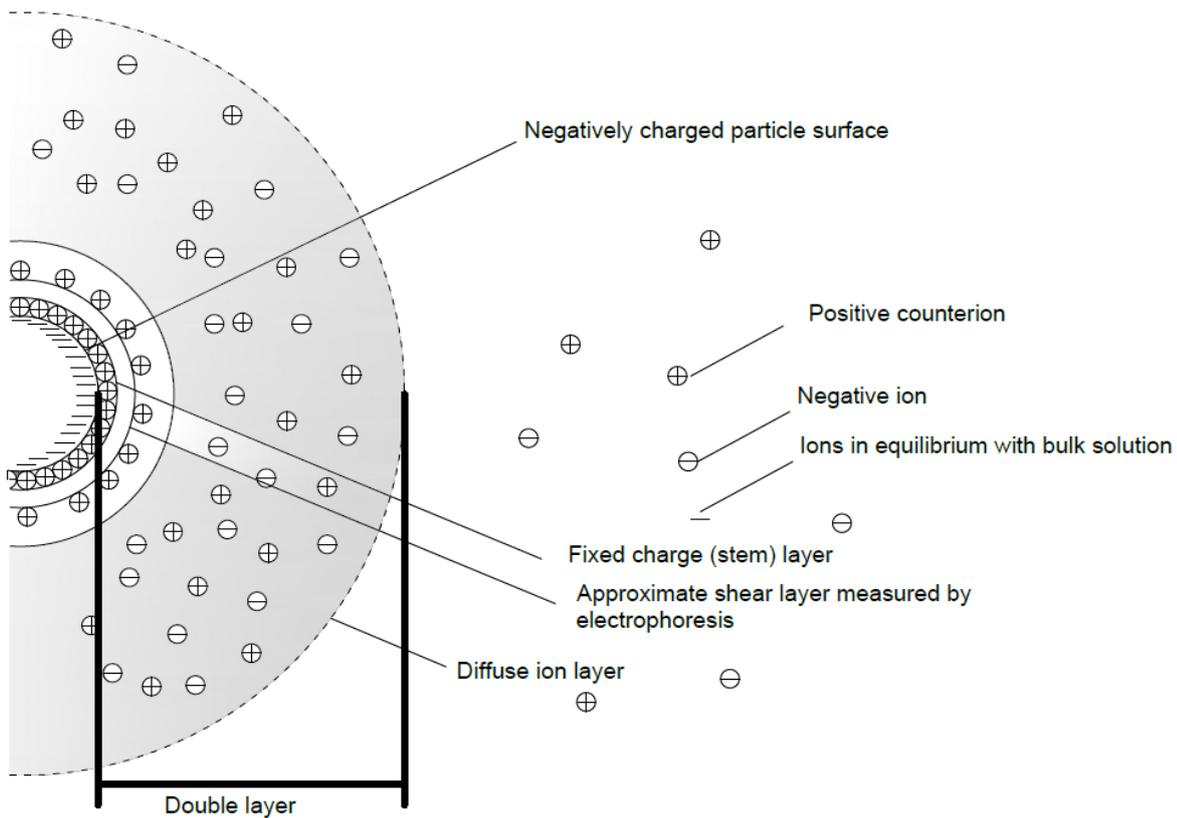


FIGURE 6. Structure of the electrical double layer (adapted from Trussell & John 2012, 145)

The layer of anions and cations which extends from the Helmholtz layer to the bulk solution where the charge is zero and electroneutrality is satisfied is known as the diffuse layer. Both adsorbed and diffuse layer are regarded as the electric double layer (EDL), which can reach up to 30 nm wide in the solution depending on the solution characteristics. (Trussell & John 2012, 145.)

The stability of particles in natural waters depends on a balance between the repulsive electrostatic force of the particle and the attractive forces known as the van der Waals forces. Van der Waals attractive forces are strong enough to overcome electrostatic repulsion but they are not able to do so because the EDL and electrostatic extend further than do the van der Waals forces in the solution. To destabilize particles, the energy of the electrostatic repulsion needs to be overcome. (Trussell & John 2012, 145.)

2.5 Principles of coagulation and flocculation

There are four main mechanisms regarding the principles of coagulation: compression of the electric double layer, adsorption and charge neutralization, adsorption and inter-particle bridging and enmeshment in a precipitate which is also known as “sweep flocculation”. Through adsorption of oppositely charged ions or polymer, particles can be destabilized. Positively charged hydrolyzed metal salts, prehydrolyzed metal salts and cationic organic polymers can be utilized to destabilize particles by neutralizing the charge on the particle surface. If the charge is neutralized in surface of particle, then the EDL will disappear and van der Waals force can easily make particles to stick together. Polymer chains adsorb on particle surfaces at one or more sites along the chain with a result of coulombic (charge-charge) interactions, dipole interaction, hydrogen bonding and van der Waals forces of attraction. After dosing enough aluminum or iron, they will form insoluble sedimentation and particles become entrapped in the amorphous precipitates. (Trussell & John 2012, 149.)

Flocculation includes the following mechanisms: small particles experience random Brownian motion due to collisions with fluid molecules resulting in particle-particle collisions; particles collisions happens because of the velocity gradients created by stirring water containing particles; These two interactions are also known as microscale and macroscale flocculation. (Trussell & John 2012, 165.)

Generally, the interval between coagulation and flocculation is very instant, almost at the same time during the wastewater treatment. The coagulation-flocculation can be classified into three stages: (a) drug dispersion and its interaction with particles (defined as mixing effect); (b) coagulation effect; (c) flocculation. (Hanhui, Xiaoqi & Xuehui 2004.) Figure 7 shows the physical models of coagulation-flocculation process.

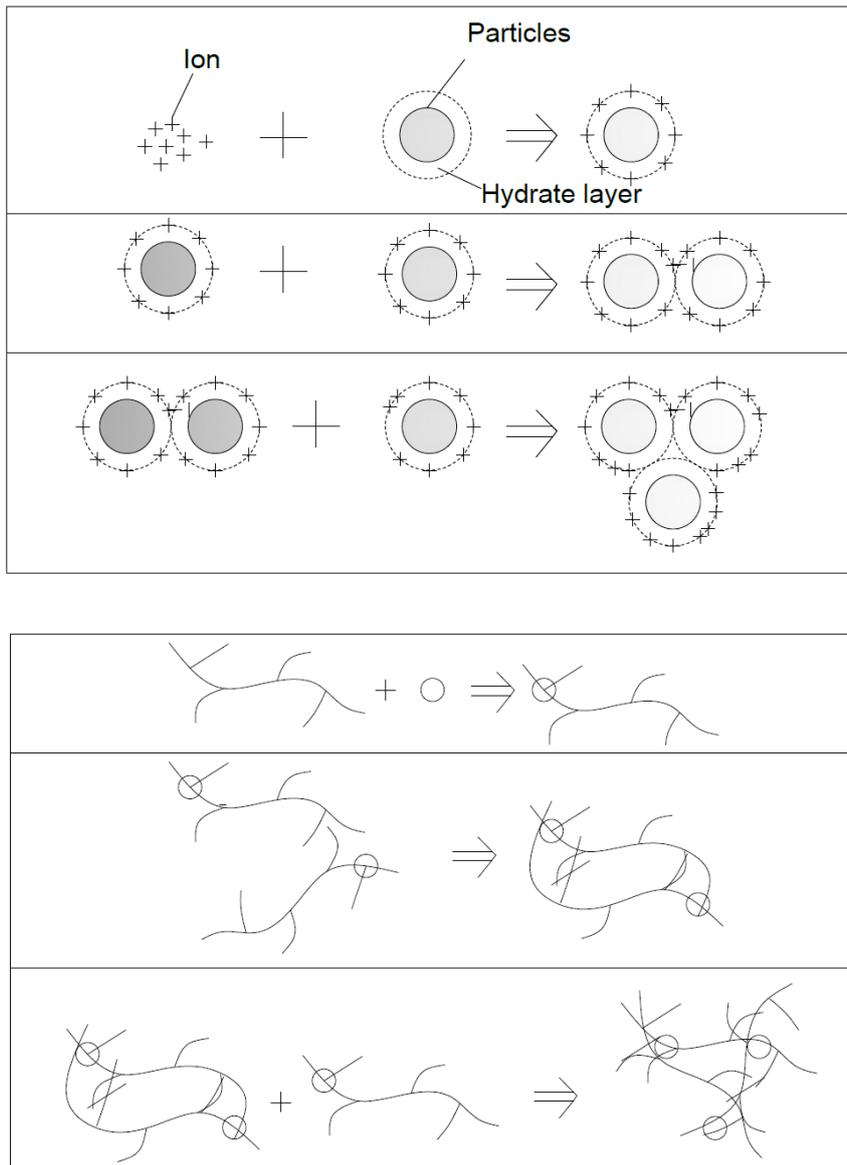


FIGURE 7. Physical models of coagulation-flocculation process (adapted from Hanhui, Xiaoqi & Xuehui 2004)

2.6 Coagulant and flocculant

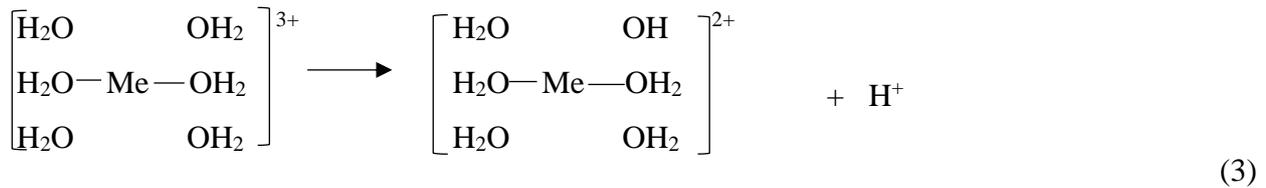
Basically, the coagulant used widely in wastewater treatment plant are chloride or sulfide salts or aluminum and ferric ions and prehydrolyzed salts of these metals while flocculant can be classified into natural and synthetic kinds. (Trussell & John 2012.) In this part, the kinds of coagulant and flocculant are introduced briefly and their functional mechanism are mentioned.

2.6.1 Coagulant

The common used inorganic coagulants in the wastewater plant are chloride or sulfide salts of aluminum, ferric ions and prehydrolyzed salts of these metals. These metal cations are readily available in both dry and liquid form. Aluminum sulfate or “alum” is favored by a lot of WWTP, which is solid in hydrated form as $\text{Al}_2(\text{SO}_4)_3 \cdot \chi \text{H}_2\text{O}$, where χ is normally about 14. When aluminum or ferric ions are introduced into wastewater, a certain number of sequential reactions happen. Firstly, the salt of Al(III) and Fe(III) will dissociate to produce trivalent Al^{3+} and Fe^{3+} ions, as shown below: (Trussell & John 2012.)



The ions of Fe^{3+} and Al^{3+} then hydrate to form the aquometal complexes $\text{Al}(\text{H}_2\text{O})_6^{3+}$ and $\text{Fe}(\text{H}_2\text{O})_6^{3+}$, as presented in the left side of the equation (3)



Then a variety of soluble mononuclear $\text{Al}(\text{H}_2\text{O})_5(\text{OH})^{2+}$, $\text{Al}(\text{H}_2\text{O})_4(\text{OH})_2^+$, $\text{Al}(\text{H}_2\text{O})_3(\text{OH})_3^0$ and polynuclear $\text{Al}_{18}(\text{OH})_{20}^{4+}$, $(\text{Al}_8(\text{OH})_{20} \cdot 28\text{H}_2\text{O})^{4+}$ form in the water. Similarly, iron forms a variety of soluble species, such as mononuclear $\text{Fe}(\text{H}_2\text{O})_5(\text{OH})^{2+}$ and $\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2^+$. These polynuclear and mononuclear species can interact with the particles in the water, depending on the characteristics of substances in the wastewater. (Trussell & John 2012)

The solubility of the different iron [Fe(III)] and alum [Al(III)] are illustrated in Figure 8. Figure 8 shows that the ferric species are more insoluble than aluminum species and are also insoluble in a wider pH range. Ferric ion is the good choice for the destabilization. (Trussell & John 2012)

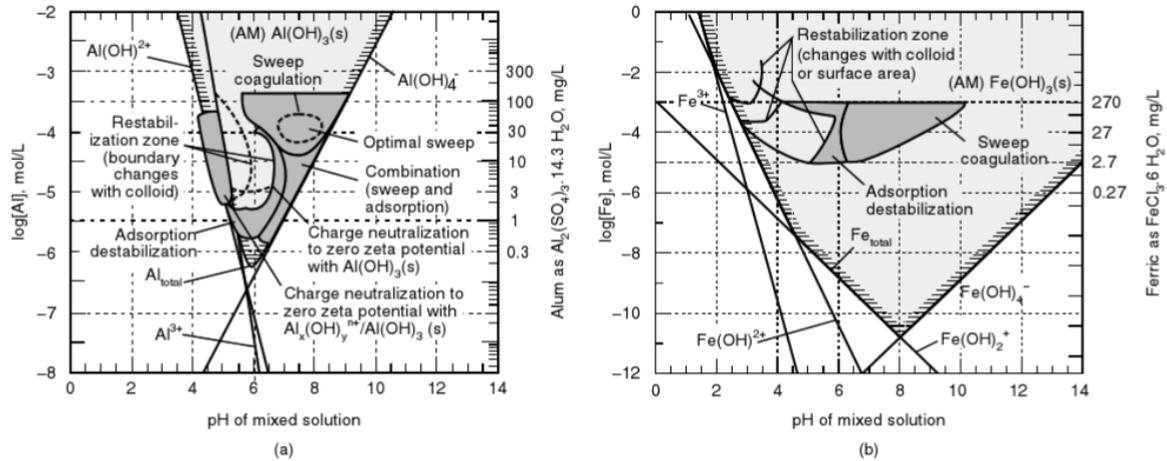
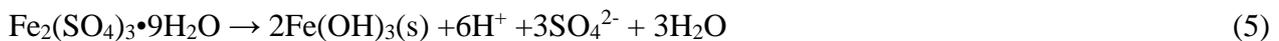
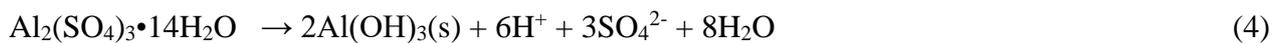


FIGURE 8. Solubility diagram for (a) Al(III) and (b) Fe(III) at 25°C (adapted from Trussell & John et al. 2012,152.)

When the alum or ferric sulfate is added into the wastewater, the overall precipitation reactions are as follows:



2.6.2 Flocculant

The basic aim of water and wastewater treatment is to make slowly aggregating suspension become a quick aggregating suspension. (Olufemo 2004,11.) Flocculant, interchangeably with coagulant aid, is a substance that is used in conjunction with a primary coagulant, to enhance coagulation. Flocculant can be classified into natural and synthetic kinds. Further, coagulant aid can be categorized as cationic, anionic, or nonionic polymers and of low, medium, or high molecular weight. (Olufemo 2004.)

Nowadays, the synthetic organic polymers play a significant role in the wastewater treatment. (AWWA Staff 2010, 36.) Because the synthetic organic polymers are much cheaper than those made from natural sources. Synthetic organic polymers are made either by homopolymerization of the monomer or by copolymerization of two monomers. Further, the polymer synthesis can be controlled to produce polymers of different size (molecular weight), charge groups, number of charge groups per polymer chain (charge density), and varying structure (linear or branched). Table show the principal synthetic organic polymers used for water treatment. (John 2012, 575.)

TABLE 2. Typical organic coagulant aids used in the water treatment (adapted from John 2012, 575.)

Type	Charge	Molecular Weight, g/mole	Common Applications	Typical Examples	Other Examples
Anionic	Negative	10^4 - 10^7	Coagulant aid, filter aid, flocculant aid, sludge conditioning	Hydrolyzed polyacrylamides	Hydrolyzed polyacrylamides, polyacrylates, polyacrylic acid, polystyrene, sulfonate
Cationic	Positive	10^4 - 10^6	Primary coagulant, turbidity and color removal	Epichlorohydrin dimethylamine	Aminomethyl polyacrylamide, polyalkylene, polyamines, polyethylenimine
			Sludge condition	Polydiallyldimethyl ammonium chloride (poly-DADMAC)	Polydimethyl aminomethyl polyacrylamide, polyvinylbenzyl, trimethyl ammonium chloride
Nonionic	Neutral	10^5 - 10^7	Coagulant aid, filter aid, filter conditioning	Polyacrylamides	Polyacrylamides, polyethylene oxide
Others	Variable	Variable	-	Sodium alginate	Alginic acid, dextran, guar gum, starch derivatives

2.7 Jar test

For over 50 years, the jar test has been the standard tool implemented to optimize the addition of coagulants and flocculants used in the wastewater and drinking water treatment industry. (Ebeling, Sibrell,

ogden & Summerflt 2003, 28) The jar test is evaluated as a valuable tool by water industry for realistically simulating coagulation, flocculation, and sedimentation at a full-scale treatment plant. The jar test may be done for many different reasons. By conducting the test, result can be utilized to evaluate the influences of the changes in chemical dosages and points of application; choose alternative coagulants; vary mixing intensity and times; add polymeric coagulant aids; implement alternative preoxidation strategies; and change the overflow rates on the removal of particles, NOM, or other water quality parameters of concern. It is significant that the condition of the jar test accurately simulates the full-scale plant conditions. There are several key parameters shown as following:

Effective retention times in the rapid mix and flocculation basins

Velocity gradient/mixing intensity in the rapid mix and flocculation basins

Surface loading rate of the sedimentation basin

Real retention time in basins if jar testing is being done to evaluate time-dependent reactions for which full-scale reaction time influences results. (Ebeling, Sibrell, ogden & Summerflt 2003.)

If a successful jar test is performed, there is usually a need to empirically tweak the parameters to make the jar test result corresponding to the full-scale results. There is a common result of the limitations of the jar test in matching the physical characteristics of the treatment process. Even the jar tests are performed to assist full-scale plant optimization, they may also be conducted to meet certain regulatory requirements. Under the Stage 1 Disinfectants and Disinfection By-products Rule (D/DBPR) (1998), jar testing may be conducted as part of the “enhanced coagulation” requirements. (AWWA Staff 2010, 17-18.)

2.7.1 Parameters concerned in Jar Test

The velocity gradient, G , refers to the intensity of mixing, with units of s^{-1} (seconds to the power of minus 1). The velocity gradient is calculated by using the energy dissipation rate in the fluid, or it can be interpolated from calibration curves. It should be noted that the velocity gradient varies significantly with water temperature (because of viscosity is associated with temperature) independent of the mixing device speed. So, it is better to simulate the temperature in the jar testing’s condition which is the same as plant water’s temperature. (AWWA Staff 2010, 18)

Initial mixing or rapid mix is the process which happens when the coagulant is added into the wastewater. It is better to conduct the rapid mix's condition which match the full-scale conditions as much as possible. The typical mixing intensities for a well-designed flash mix tank range from 700 to 1,000 s^{-1} , and for a typical jar test, 30-60 seconds of retention time is used, with high paddle speeds of 100-300 rpm. It should be noted that during the determination of the optimal initial mixing intensity, the other basic parameters should be conducted first such as, the preferable chemical coagulant dose, pH and alkalinity. (AWWA Staff 2010, 18-19.)

Flocculation's retention time and G values should correspond to those in the WWTP when conducting the jar testing. After dosing the coagulant and flash mixing, the coagulant aid is introduced into the flocculation basin where the typical retention times ranges from 15 to 30 minutes are conducted, while the mixing intensities vary from 10 to 40 s^{-1} . It should be noticed that the flocculation intensity should not be too low or too high, because too light intensity can't contribute to form big flocs while too high intensity will break the floc into small particles again. (AWWA Staff 2010, 19.)

Sedimentation time is considered carefully to optimize the floc development and settleability. The settling velocity of floc must be higher than the surface loading rate of the clarification basin, otherwise the floc won't settle. (AWWA Staff 2010, 19-20). The points of chemical applications are one of the popular topics in the jar testing. If the purpose of the jar test is to optimize the conditions for an existing full - scale plant, chemical reagents need to be added in the same order as in the plant. Alternatively, the same reagents can be added in a different order or at different times aiming to enhance the quality of water produced. (AWWA Staff 2010, 20)

2.7.2 Configuration of Jar Test

Jar test equipment consists of jars to contain the water, the impeller, the mechanism to drive the impeller and lab equipment to analyze the results. Figure 9 shows the typical jars used in the jar testing. Usually the jars are 2-L square beakers. (AWWA Staff et al, 2010, 25.)



FIGURE 9. Jar test unit (adapted from AWWA Staff et al, 2010, 25.)

3 EXPERIMENT

Experiments are mainly based on the theory of Jar test. But because of the limitation of the equipment, a similar equipment was built to replace the standard jar test equipment. The main parameters are turbidity and the coagulant residual (iron concentration). The experiment can be divided into six parts as following.

1. Characteristics of the raw wastewater
2. Optimal operation condition of coagulant
3. Effect of initial mixing intensity (flash mixing)
4. Effect of flocculation mixing intensity
5. Effect of flocculation mixing time

The data collected from these five experiments will be presented and analyzed in the results and discussion chapter.

3.1 Basic chemical reagents and source of wastewater

The coagulant used in the experiment was obtained from the Hopeakivenlahti WWTP. The coagulant is ferric sulfate solution (PIX-105) which is manufactured by Kemira. The technical data sheet of the PIX-105 can be found in the appendix. The coagulant aids used in the experiment was obtained from the Hopeakivenlahti WWTP as well. The coagulant aid is kind of polymer whose model is LC2218 manufactured by Finland Cleartech company. The analytical base and acid used in the experiment were sodium hydroxide and hydrogen chloride. All the experimental wastewater was obtained from the Hopeakivenlahti WWTP. For different experiment, the sampling sites were different. Details of sampling will be described latter.

3.2 Main equipment

The rotational stirring machine and the paddle were used in the experiment. The paddle was washed by the distilled water before it was used in the experiment. The turbidity meter was calibrated every time before it was used. Figure 10 shows the model of the stirrer and turbidity meter.



FIGURE 10. Rotational stirrer(left), paddle (middle) and Turbidity meter (right)

All of samples which were needed to be analyzed by atomic absorption spectroscopy (AAS) in the experiment were filtrated by the 0.45 μm filter disk. The AAS analyzer used in the determination of iron concentration is PerkinElmer AAnalyst 200.



FIGURE 11. Syringe and filter disk (left) and AAS analyzer (right)

3.3 Basic calculation

The density of the coagulant and coagulant aid is $1.55 \pm 0.05 \text{ g/cm}^3$ and $1100\text{-}1200 \text{ kg/m}^3$. Because the dosing of the chemical was according to the volume. The volume of coagulant and coagulant aid was calculated by equation (1).

$$v = \frac{m}{\rho} \quad (1)$$

During the experiment, the pH of the raw wastewater sometimes needed to be adjusted to preferable value, which was achieved by adding either sodium hydroxide or hydrogen chlorine into the raw wastewater. The following calculation steps were performed during the experiment. For adding the hydrogen chlorine, the volume of the acid was obtained by the following equation (2). For adding the sodium hydroxide, the volume of the base was obtained by the following equation (3).

$$v = \frac{x \times (10^{-y} - 10^{-z})}{10^{-z} - M} \quad (2)$$

v: volume of hydrogen chlorine, L

x: volume of raw wastewater, L

y: pH of the raw wastewater

z: desire pH of wastewater

M: molarity of hydrogen chlorine, mole/L

$$v = \frac{x \times (10^{-y} - 10^{-z})}{10^{-z} + M} \quad (3)$$

v: volume of sodium hydroxide, L

x: volume of raw wastewater, L

y: pH of the raw wastewater

z: desire pH of wastewater

M: molarity of sodium hydroxide, mole/L

3.4 Basic characteristic of raw wastewater

In this experiment, characteristics of raw wastewater were determined, such as the temperature, pH, turbidity, total solid, total volatile solid and total suspended solid. The following procedures are mainly based on the Standard Methods for the Examination of Water and Wastewater. (APHA & AWWA 1999, 2540.)

Four samples were taken from four different sites within the wastewater treatment processes. In the APPENDIX 1, the four sites are marked with number. Sample 1 is the wastewater after the screening process and before the sand removal process. Sample 2 was taken after the primary sedimentation. Sample 3 was taken between the aeration pool and the secondary sedimentation. Sample 4 was taken in the secondary sedimentation. All the four samples were placed separately in four 500 ml beakers marked with number. Then the thermometer and the electric pH meter were used to determine the temperature and pH. For every samples, they were shaken evenly before being analyzed by the turbidity meter for the turbidity value. All the glassware and instruments were pretreated before determining the total solids (TS), total volatile solids (TVS), total suspended solids (TSS). The determined steps are the same for the four different samples.

TS was determined by the following steps. 50 ml wastewater was pipetted into the marked evaporating dish for each sample. Then four evaporating dishes were put into the drying oven for 1 hour at 105°C. The dishes cooled down in the desiccator to balance temperature and the weigh was measured by the analytical scale. The repeating cycle of drying, cool, desiccating and weighing were conducted until the weight change was less than 0,5 mg. The residue produced from the TS was ignited to constant weight in a muffle furnace at a temperature of 550 °C. The constant weight was used to calculate the TVS.

TSS measuring was conducted by the following steps. The crucibles were weighed and marked with number before filtration. The filtering apparatus was assembled and 100 ml of the wastewater from four samples were filter separately. All the marked crucibles were placed into the oven for 1 h at 105°C. The processes of weighing are the same as TS determination.

3.5 Optimal dose and dosing conditions of coagulant

In this set of experiment, the optimal dose of the coagulant and pH were determined by the mean of jar test. There are three steps for this determination. The turbidity and the coagulant residual (iron concentration) were measured as for the parameters. Except the dose of the coagulant and the pH, the temperature, dose of coagulant aid was kept the same as the Hopeakivenlahti WWTP because this is regarded as the optimal dose in the Hopeakivenlahti wastewater treatment plant. The dose of coagulant aid used in the Hopeakivenlahti WWTP is 10 g/m^3 (Sydänmetsä 2018).

3.5.1 Optimal dose of coagulant

Currently, the dose of the coagulant used in the Hopeakivenlahti WWTP is 200 g/m^3 . As for the sample, it was taken in the first site (after the screening process shown in the APPENDIX 1). Figure 12 shows the exterior of raw wastewater. Firstly, pH, conductivity, temperature and turbidity of the raw wastewater were measured. During this experiment, the variable parameter is the dose of coagulant.



FIGURE 12. Raw wastewater from the first sampling site.

Table 2 shows that the beakers were numbered from 0 to 6. The volume of the wastewater used in the experiment was 500 ml. As shown in the last paragraph, the dose of coagulant aid used in the Hopeakivenlahti WWTP was 200 g/m³ which is converted to 4,35 microliters by equation (1). The different volume of coagulant used during the experiment are shown in the table as well.

TABLE 2. Determination of optimal coagulant dose

Number	0	1	2	3	4	5	6
Sample volume (ml)	500						
Coagulant aid (µl)	4,35						
Coagulant dose (g/m ³)	0	100	150	200	250	300	350
Coagulant dose (µl)	0	6,45	9,67	12,90	16,12	19,35	22,57

Because there is only one rotational stirrer, all the samples were treated one by one. Firstly, the sample was put under the stirrer and the stirrer was operated at 100 rpm. The coagulant was added first according to the Table 2, starting the timer at the same time. After 1 minute, the coagulant aid was dosed and the stirrer was operated in 20 rpm for 15 minutes. Then beaker was moved out from the stirrer, waiting for another 15 minutes for settling. Figure 13 shows the coagulation and flocculation process.



FIGURE 13. Coagulation (left) and flocculation (right)

The 40 ml pipette was used to move 40 ml supernatant of the sample into a glass vial for the turbidity determination. The filtration apparatus was set up to filtrate the sample by 0,45 µm membrane and filtrate

was collected for the ion concentration determination. The ion concentration was analyzed by the AAS. From the APPENDIX 2, the calibration of the iron concentration and the method used in the determination are shown. After collecting the data, two simple curves were drawn which shows the turbidity against coagulant dose and the ion concentration against the coagulant dose. These curves will be shown in the results and discussion chapter.

3.5.2 Optimal dosing pH

The second step aimed to determine the optimal dosing pH. The pH of the raw wastewater was altered by adding either acid or alkali. Then the jar tests were repeated using the optimal coagulant dose determined in the first set of the tests. Table 4 shows the pH, volume of sample, coagulant and coagulant aid used in this set of jar test. The optimal coagulant aid is 100 g/cm³ which was obtained by analyzing the curve made in the first step. Details about the optimal coagulant aid can be found in the RESULTS AND DISCUSSION chapter.

TABLE 4. Determination of optimal pH

Number of the sample	0	1	2	3	4	5	6
pH	2.99	3.5	4.5	5	5.5	6	6.5
Coagulant dose (g/m³)	0	100					
Coagulant dose (μl)	0	6.45					
Coagulant aid (μl)	0	4,35					
Sample volume (ml)	500						

After conditioning the pH of the raw samples, the coagulant was added first and under initial mixing of 100 rpm for 1 minute. While coagulant aid was added, the mixing intensity was switched to 20 rpm for 15 minutes. Then beaker was moved out from the stirrer, waiting another 15 minutes for settling.

The 40 ml pipette was used to move 40 ml supernatant of the sample into a glass vial for the turbidity determination. The filtration apparatus was set up to filtrate the sample by 0,45 μm membrane and filtrate was collected for the ion concentration determination. The ion concentration was analyzed by the AAS.

From the APPENDIX 2, the calibration of the iron concentration and the method used in the determination are shown. After collecting the data, two simple curves were drawn which show the turbidity against pH and the iron concentration against the pH. These curves will be shown in the results and discussion chapter.

3.5.3 Re-determination of the optimal coagulant dose

The test was repeated by using raw wastewater but this time wastewater was corrected to the optimal pH and tested at various coagulant doses again (Gray 2010). The optimal pH is 4.5 which was obtained by analyzing the curve made in the second step. Details about the optimal pH can be found in the results and discussion chapter. Table 5 shows the parameters concerned in the experiment.

TABLE 5. Re-determination of the optimal coagulant dose

Number	0	1	2	3	4	5	6
Coagulant dose (g/m³)	0	50	100	150	200	250	300
Coagulant dose(μl)	0	3.225	6,45	9,675	12,9	16,125	19.35
Sample volume (ml)	500						
pH	4.5						
Coagulant aid (μl)	4,35						

The initial mixing intensity was 100 rpm for 1 minute and the flocculation mixing intensity was 20 rpm for 15 minutes. Then another 15 minutes were for the floc settling. The supernatant was taken for the turbidity determination. The filtrate of the treated samples was analyzed by AAS for the iron concentration determination. When the data was collected, two curves were drawn which shows the turbidity against the coagulant dose and the iron concentration against coagulant dose. From the curves, the optimal dose of coagulant can be found at the pH of 4,5. These curves will be shown in the results and discussion chapter.

3.6 Effect of initial mixing intensity

From the “Optimal dose and dosing conditions of coagulant” section, the optimal dose of coagulant and the dosing pH were found and used to determine the effect of initial mixing intensity. In part of experiment, the pH of the raw sample was adjusted to the optimal value first. The equipment was prepared for another set of jar testing. During the experiment, the variable value was the intensity of initial mixing intensity. Table 6 shows the parameters concerned in this experiment.

TABLE 6. Effect of initial mixing intensity

Number	0	1	2	3	4
Mixing intensity(rpm)	0	50	100	140	170
pH	4,5				
Wastewater volume (ml)	500				
Coagulant dose(μ l)	6,45				
Coagulant aid (μ l)	4,35				

For the first sample, after dosing the coagulant, the initial mixing intensity was set at 50 rpm for 1 minute. Then the flocculation mixing intensity was at 20 rpm for 15 minutes after dosing the coagulant aid. Another 15 minutes was for the settling of floc. Supernatant was collected for the turbidity determination. The treated sample was filtrated by 0,45 μ m membrane for the determination of iron concentration by AAS. Except varying the initial mixing intensity, the other operational processes were kept as the same as the treatment of first sample. Finally, the two curves which show the turbidity against the initial mixing intensity and iron concentration against initial mixing intensity were illustrated. These curves will be shown in the results and discussion chapter.

3.7 Effect of flocculation mixing intensity

The optimal dose of coagulant and the dosing pH obtained from the “Optimal dose and dosing conditions of coagulant” part was used to determine the effect of flocculation mixing intensity as well. The pH of

the raw sample was adjusted to the optimal value first. The equipment was set for another group of jar test. The only variable parameter is the intensity of the flocculation mixing. Table 7 shows the parameters concerned in this experiment.

TABLE 7. Effect of flocculation mixing intensity

Number	0	1	2	3	4	5	6
Flocculation intensity(rpm)	0	5	10	15	20	25	30
pH	4.5						
Sample volume (ml)	500						
Coagulant dose(μl)	6.45						
Coagulant aid (μl)	4,35						

As for the first sample, the initial mixing intensity was 100 rpm for 1 minute after dosing the coagulant. When the dosing of the coagulant aid was done, the flocculation mixing intensity was set at 5 rpm, for 15 minutes. Then another 15 minutes was for the static settling of flocs. After settling, the supernatant was taken for determination of turbidity and filtration was conducted for the determination of iron concentration. The following samples were operated the same as first sample but in different flocculation mixing intensity. When the data was collected, two curves which are both the turbidity and iron concentration against the flocculation mixing intensity were drafted separately. These curves will be shown in the results and discussion chapter.

3.8 Effect of flocculation mixing time

The optimal dose of coagulant and the dosing pH obtained from the “Optimal dose and dosing conditions of coagulant” part was used to determine the effect of flocculation mixing time. Firstly, the pH of the raw sample was adjusted to the optimal value. The jar test equipment was implemented for another new series of experiments. The only variable parameter is the mixing time of flocculation. Table 8 shows the parameters concerned during this experiment.

TABLE 8. Effect of flocculation mixing time

Number	0	1	2	3	4	5
Flocculation time(minute)	0	5	10	15	20	30
pH	4.5					
Sample volume(ml)	500					
Coagulant dose(μl)	6.45					
Coagulant aid (μl)	4,35					

As for the first sample, when dosing of the coagulant was finished, the initial mixing intensity was set at 100 rpm for 1 minute. Then after the coagulant aid was added, the flocculation mixing intensity was operated at 20 rpm for 5 minutes. Another 15 minutes was for the settling of flocs. Finally, the supernatant was taken for the turbidity analysis and the treated sample was filtrated to determine the iron concentration by AAS. The other samples were treated in the same way but in different flocculation time. When the data was collected, two curves which are both turbidity and iron concentration against the flocculation time were drawn. These curves will be shown in the results and discussion chapter.

4 RESULTS AND DISCUSSION

In this chapter, the experimental data from the whole work are shown. The data are shown in both table and graph form. From the graphs, the optimal dose and dosing condition of coagulant, effect of mixing intensity and mixing time are found during different step within the experiment. There is also explicit discussion in every step within the experiment.

4.1 Basic characteristic of raw wastewater

Table 9 shows the basic characteristics of the wastewater in different position of the wastewater treatment. As the table shows, the pH doesn't change too much from sample 1 to sample 2 because there is only screening process and sedimentation process during the two sample. From the table, the NTU doesn't change too much from sample 1 to sample 2 but it rises to 36 in sample because aeration process increases the turbidity. Finally, the turbidity decreases to 0.84 because of the coagulation and flocculation processes.

TABLE 9. Characteristics of wastewater

	Sample 1	Sample 2	Sample 3	Sample 4
Temperature(°C)	16	16.5	16.5	16.5
pH	7.73	7.39	6.97	6.81
Turbidity(NTU)	5.9	6.4	36	0.84
Total solid(g)	0.0387	0.0312	0.0882	0.0225
Total volatile solid(g)	0.0136	0.0107	0.0566	0.0076
Total suspended solid(g)	0.0019	0.0001	0.0618	0.0000

4.2 Optimal dose and dosing condition of coagulant

In this part, three sets of experiment were conducted to find the optimal dose and dosing condition of coagulant. The first step was to determine the optimal dose of coagulant. The second step was to determine the optimal dosing pH basing on the optimal dose of coagulant determined from the first step. At the last step, the optimal dose of coagulant was to be redetermined under the optimal dosing pH value collected from the second step.

4.2.1 Optimal dose of coagulant

The figure 14 shows the treated wastewater in this experiment. As the figure shows, there was obvious sedimentation in the treated wastewater, which means the function of coagulant is critical in the wastewater treatment. The results of the turbidity and iron concentration are shown in the table 10. Graph 1 shows the curves: turbidity and iron concentration against coagulant dose.



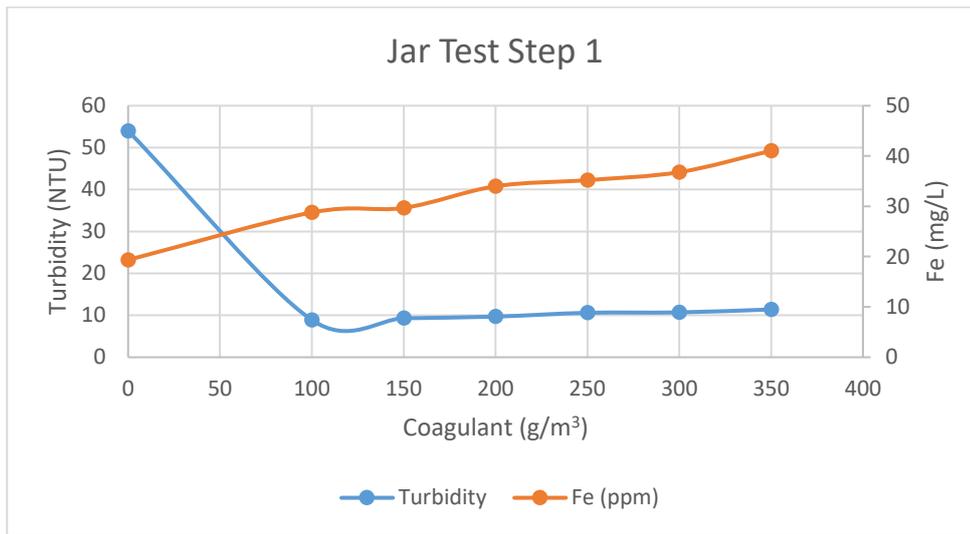
FIGURE 14. Treated wastewater

As for the blue curve, the turbidity falls dramatically when 100 g/m³ of coagulant is used. With the increasing of coagulant dose, the turbidity doesn't change too much, and it stays around 10 NTU. As for the orange curve, the iron concentration increases steadily while the dose of the coagulant increases. The iron concentration of raw wastewater is high because raw wastewater hadn't been treated with any other processes.

TABLE 10. Optimal dose of coagulant

Number	0	1	2	3	4	5	6
Coagulant dose(ppm)	0	100	150	200	250	300	350
Turbidity (NTU)	54	8,9	9,3	9,7	10,6	10,7	11,4
Fe (ppm)	19,35	28,78	29,69	33,99	35,21	36,79	41,04

In this case, the optimal coagulant dose seems to be the point where the two curves intersect, where the coagulant dose is around 50 g/m^3 . But it needs to be noticed that the nature of the raw wastewater varies too much from time to time, indicating that a buffer needs to be placed to the dose of coagulant. The optimal coagulant dose is set at 100 g/m^3 , which even leads to a higher iron concentration than the dose of 50 g/m^3 but the other processes in the treatment will decrease the iron concentration eventually.



GRAPH 1. Optimal dose of coagulant

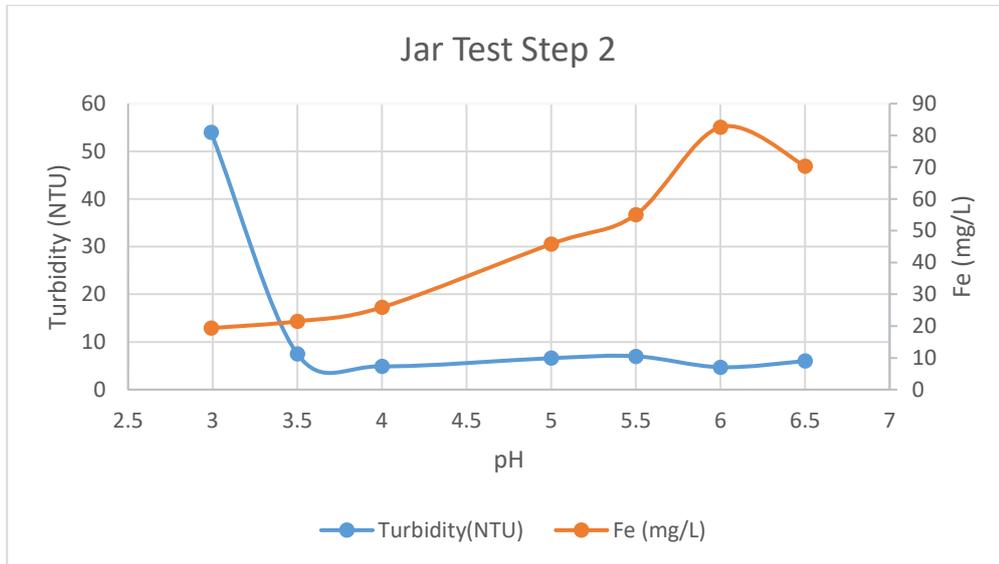
4.2.2 Optimal dosing pH

Table 11 shows the result of turbidity and iron concentration in the second step of determining optimal dosing pH. The curves which turbidity and iron concentration against the pH are shown in the graph 16. From graph 2, the turbidity falls dramatically and the concentration of the iron increase while the pH value increases. Information was obtained from the manufacturer about the optimal dosing pH for the PIX-105, which ranges from 5,5 to 7,5. (detail shown in the APPENDIX 4)

TBALE 11. Optimal dosing pH

Number	0	1	2	3	4	5	6
Coagulant dose (g/m ³)	100						
pH	2,99	3,5	4	5	5,5	6	6,5
Turbidity(NTU)	54	7,5	4,9	6,6	7	4,7	6
Fe (mg/L)	19,35	21,48	25,89	45,84	55,06	82,61	70,36

As the graph 2 shows, the iron concentration increases dramatically during the pH between 4 and 6. Regardless of the turbidity, the iron concentration become the main problem when optimal pH value is searched for. The value of pH 4,5 was chosen as the optimal pH in this case, which can satisfy the turbidity requirement and buffer of processing unpredictable nature of the wastewater.



GRAPH 2. Optimal dosing pH

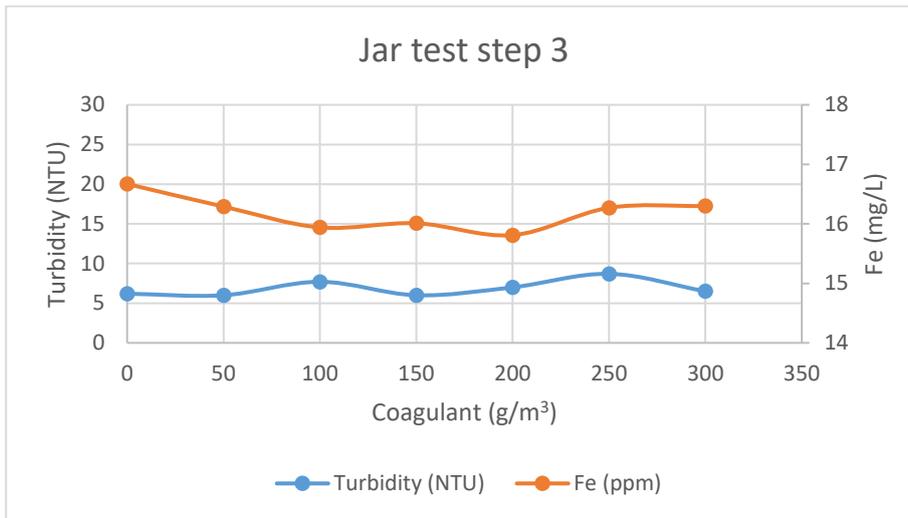
4.2.3 Re-determination of the optimal dose of coagulant

The first step of determining optimal coagulant dose was repeated but the samples were pre-treated to the optimal pH 4,5 which was determined by the secondary step. The table12 shows the original data collected from the experiment. Graph shows the curves which both turbidity value and iron concentration against volume of coagulant.

TABLE 12. Re-determination of the optimal dose of coagulant

Number	0	1	2	3	4	5	6
pH	4.5						
Coagulant dose(ppm)	0	50	100	150	200	250	300
Turbidity (NTU)	6.2	6	7.7	6	7	8.7	6.5
Fe residue(ppm)	16.67	16.29	15.94	16.01	15.81	16.27	16.3

The graph 3 shows that the turbidity doesn't change too much because the wastewater used in this experiment was so clean compared to the last experiment. But the optimal coagulant dose can be determined from the iron left in the treated wastewater. The iron concentration reaches relatively low position in the range of 100 to 200 g/m^3 . The 100 g/m^3 was chosen as the final optimal coagulant dose in this case. The optimal coagulant dose 100 g/m^3 and pH at 4,5 were determined, which would be used in the next three sets of experiments.



GRAPH 3. Re-determination of the optimal dose of coagulant

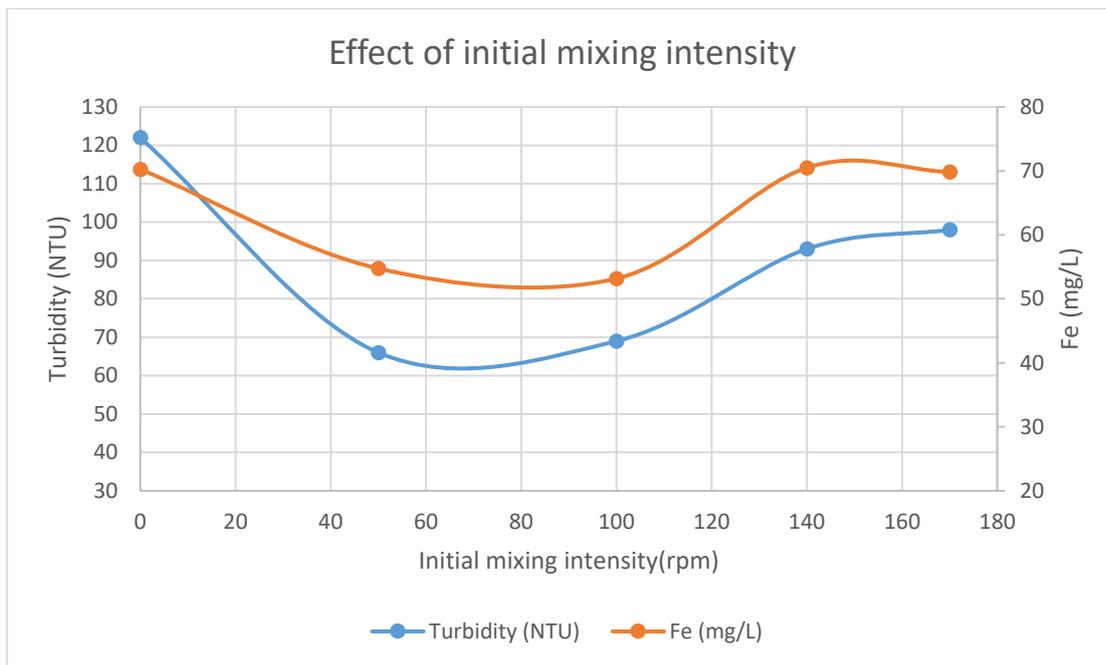
4.3 Effect of the initial mixing intensity

This experiment explored the effect in the initial mixing intensity under the optimal dose of coagulant and dosing pH. Table 13 shows the original data collected from this set of experiment. And graph 4 shows the curves which both turbidity value and iron concentration against initial mixing intensity. The optimal intimal mixing intensity of coagulation can be found in the graph 4.

TABLE 13. Effect of the initial mixing intensity

Number	0	1	2	3	4
pH	4.5				
Coagulant dose (g/m^3)	100				
Mixing intensity(rpm)	0	50	100	140	170
Turbidity (NTU)	122	66	69	93	98
Fe (mg/L)	70.257	54.75	53.17	70.5	69.83

The graph 4 explicitly shows the turbidity values don't fluctuate too much during the range which is between 50 rpm and 100 rpm. But when the intensity increases, the turbidity rapidly increases. As for the iron concentration in the wastewater, the concentration moves steadily during the range from 50 rpm to 100 rpm. But the iron concentration starts to rise quickly after the 100 rpm and stronger intensity are used. The ideal initial mixing intensity ranges from 50 rpm to 100 rpm. But the reasons why both turbidity and iron concentration go up still need to be concerned because as shown in the literature review chapter, the higher flash mixing speed can help to neutralize the charges in the surface of particles, leading to the destabilization of the particles.



GRAPH 4. Effect of the initial mixing intensity

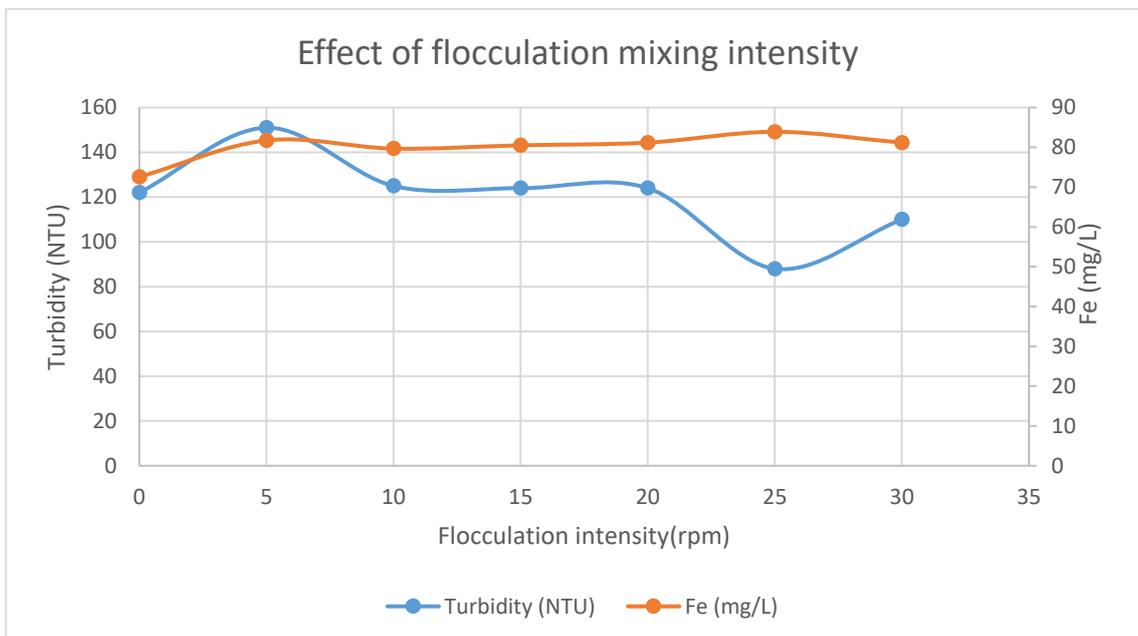
4.4 Effect of the flocculation mixing intensity

This experiment explored the effect in the flocculation mixing intensity under the optimal dose and dosing pH which was determined from the experiment of “Optimal dose and dosing condition of coagulant”. Table 14 shows the original data collected from the experiment. Graph 5 shows the curves which turbidity value and iron concentration against flocculation mixing intensity.

TABLE 14. Effect of the flocculation mixing intensity

Number	0	1	2	3	4	5	6
pH	4.5						
Coagulant dose (g/m ³)	100						
Flocculation intensity(rpm)	0	5	10	15	20	25	30
Turbidity (NTU)	122	151	125	124	124	88	110
Fe (mg/L)	72.57	81.75	79.68	80.51	81.19	83.91	81.18

The result shows that the concentration of the iron doesn't change too much with the increase of the flocculation mixing intensity. As for the turbidity curve, when the intensity is too low, the turbidity even turns high, which probably indicates the floc forming during the flocculation period. And the flocs are not big enough and could neither turn back to smaller suspended solid nor settle down. Eventually, these bigger suspended flocs increase the turbidity. The turbidity goes down in the range from 10 rpm to 25 rpm but the turbidity increases again when the intensity exceeds 25 rpm.



GRAPH 5. Effect of flocculation mixing intensity

The reason why the turbidity increases after 25 rpm is the speed of the paddle is so high that paddle breaks those flocs into pieces again. As Figure 16 shows, the small piece of flocs suspended in water. From the discussion above, the ideal flocculation mixing intensity should range from 10 rpm to 25 rpm for this kind of wastewater.

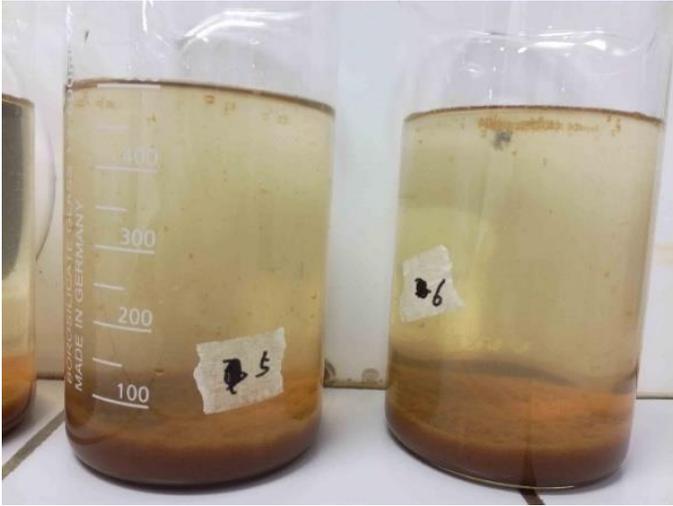


FIGURE 15. Small pieces of flocs suspended in water

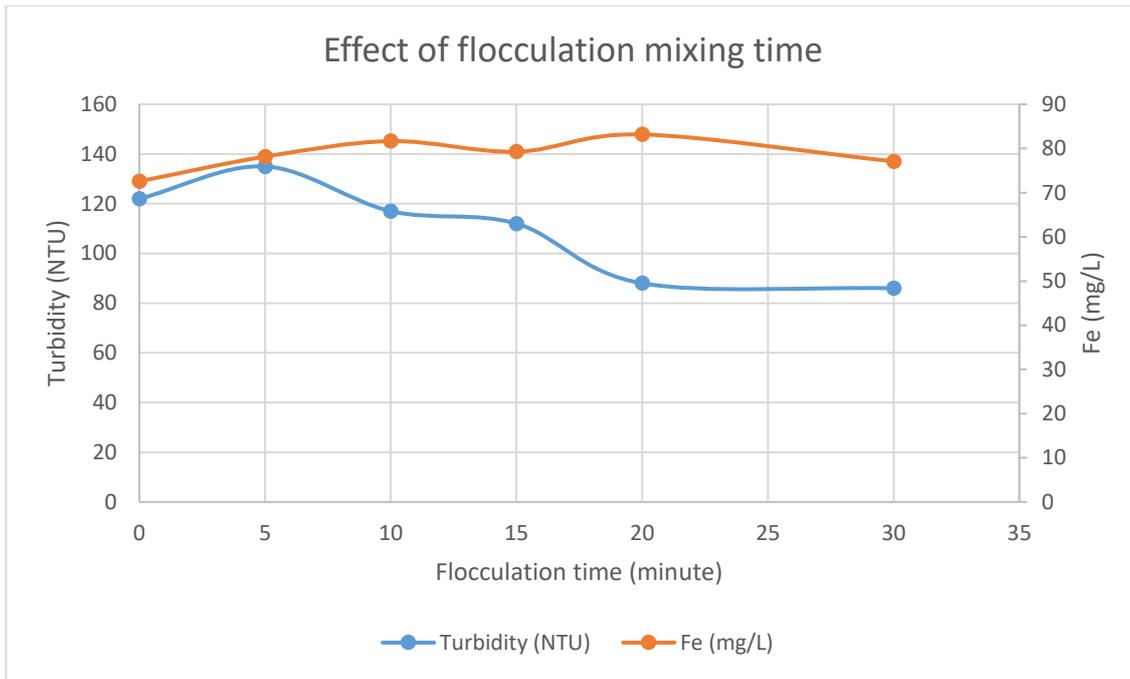
4.5 Effect of the flocculation mixing time

This experiment explored the effect of the flocculation mixing time under the optimal dose and dosing pH which was determined from the experiment of “Optimal dose and dosing condition of coagulant”. Table 15 shows the original data collected from the experiment and graph 6 shows curves which both turbidity value and iron concentration against flocculation time.

TABLE 15. Effect of the flocculation mixing time

Number	0	1	2	3	4	5
Flocculation time(mi-nute)	0	5	10	15	20	30
Turbidity (NTU)	122	135	117	112	88	86
Fe (mg/L)	72.57	78.16	81.67	79.27	83.17	77.09

The curve of iron concentration shows that the scale-up of the flocculation time doesn't contribute too much in decreasing the iron concentration. As for the turbidity, under the flocculation of 20 rpm, the turbidity goes up firstly during 0 to 5 minutes because lack of flocculation time leads to less flocs settling down. When the flocculation time is increased, the turbidity starts to drop and eventually become steady regardless of the time. Then the ideal flocculation time is around 20 minutes in this case.



GRAPH 6. Effect of the flocculation mixing time

5 CONCLUSIONS

Jar test is a useful tool for optimizing the utility of chemical reagents and the functions of the mechanism of wastewater processes. As for the highly consumed coagulant which is one of the most important chemical reagents in wastewater treatment plant, it is necessary to optimize the implementation of the coagulant, which can meet the stringent legislation and save money.

This thesis shows that there are a lot of factors which can influence the coagulation and flocculation. Only chemical reagent dose, dosing pH, initial mixing intensity, flocculation mixing intensity and flocculation time were discussed. The turbidity and coagulant residual of wastewater are concerned in this paper. But some other parameters such as the phosphorus and nitrogen removal which have significant effect to the quality of effluent wastewater were undiscussed. Especially phosphorus residue, this is the main parameter controlled strictly in all the wastewater plants.

This work presents the basic ideal of the jar test. The result of this test can be used in the future as basis for the further development and upscaling. Further, some factors can be determined such as the coagulation mixing time, the dose of the coagulant aid (flocculant), the shape of the mixing paddle, the shape of the mixing tank and so on. It should be noticed that the characteristics of the wastewater vary a lot in different regions. Even in the same city, the nature of wastewater changes a lot within one day.

This kind of experiment can be set as the routine process in a certain period. But in the future, if cost-efficient analytical machines were invented for the determination of the fresh wastewater characteristics, wastewater plant can adjust the whole treatment according to the nature of wastewater.

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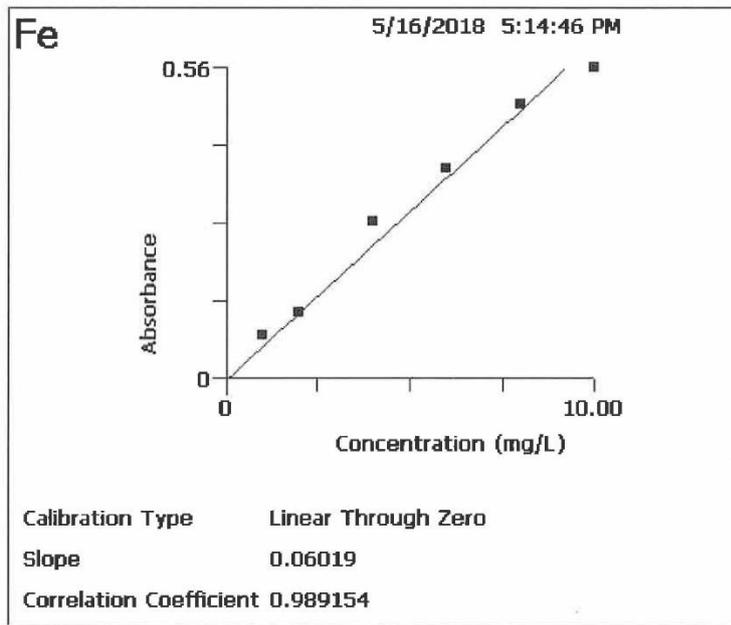
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Method 5/16/2018 5:08:21 PM
 Name:
 Description:

Lamp
 Element: Fe
 Wavelength (nm): 248.33
 Slit: 1.8/1.35
 Signal: Atomic Absorption

Flame
 Oxidant: Air
 Oxidant Flow (L/min): 10.00
 Acetylene Flow (L/min): 2.50

Parameters
 Integration Time (sec): 1.0
 Replicates: 3
 Read Delay (sec): 5
 Print: Method
 Sample Handling: Manual Data Display
 Calibration Equation: Linear Through Zero
 Units: mg/L
 Standard Concentrations:
 1 : 1.000
 2 : 2.000
 3 : 4.000
 4 : 6.000
 5 : 8.000
 6 : 10.000

KemiraWhere water
meets chemistry™**Technical Data Sheet**

2014-01-01

KEMIRA PIX-105

Ferric Sulfate Solution

KEMIRA PIX-105, ferric sulfate, is an effective coagulant in liquid form based on trivalent iron (Fe^{3+}). KEMIRA PIX-105 functions well for both process and wastewater treatment and can be used for color, phosphate and heavy metal removal. KEMIRA PIX-105 can also be used for hydrogen sulfide and sludge conditioning applications.

Product specification Pori plant

Appearance	Dark brown liquid
Iron (Fe_{tot})	$11,7 \pm 0,5 \%$
Iron (Fe^{2+})	$<0,5 \%$
Density (20°C)	$1,55 \pm 0,05 \text{ g/cm}^3$

Typical analysis

Active substance	Approx. 2,1 mol/kg
Sulfate (SO_4^{2-})	$32 \pm 2 \%$
Water insoluble	$<0,2 \%$
Viscosity (20°C)	$25 \pm 5 \text{ mPas}$
pH (20°C)	<1
Start of crystallization	-20°C

Dosing

Dosing by diaphragm metering pumps of non-corrosive material is suitable. KEMIRA PIX-105 could be dosed without dilution.

Storage

Storage tanks and piping should be constructed of suitable non-corrosive material such as fiberglass or cross-linked polyethylene. KEMIRA PIX-105 is highly corrosive and contact with metal equipment must be avoided. KEMIRA PIX-105

has a recommended shelf life of 6 months. As with any chemical, it is recommended to clean the storage tank every year. The first delivery of any product should be made into a clean storage facility to ensure optimum performance and storage.

If outside storage, tank and piping should be insulated and heat-traced.

Safe handling

The handling of any chemical requires care. Anyone responsible for using or handling KEMIRA PIX-105 should familiarise themselves with the full safety precautions outlined in our Safety Data Sheet.

Delivery

Transport by road: UN 3264, CORROSIVE LIQUID, ACIDIC, INORGANIC, N.O.S. (ferric sulfate), class 8, PG III, (E)

Please check our Safety Data Sheet for other means of transportation.

Kemira makes this information available as an accommodation to its customers and it is intended to be solely a guide in customer's evaluation of the products. You must test our products, to determine if they are suitable for your intended uses and applications, as well as from the health, safety and environmental standpoint. You must also instruct employees, agents, contractors, customers or any third party which may be exposed to the products about all applicable precautions. All information and technical assistance is given without warranty or guarantee and is subject to change without notice. You assume full liability and responsibility for compliance with all information and precautions, and with all laws and statutes, ordinances and regulations of any governmental authority applicable to the processing, transportation, delivery, unloading, discharge, storage, handling, sale and use of each product. Nothing herein shall be construed as a recommendation to use any product in conflict with patents covering any material or its use.

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FI-00101 Helsinki
FinlandTel +358 10 8611
www.kemira.com

Iron coagulants – Kemira PIX-105

- ❑ Chemical composition is ferric sulphate, $\text{Fe}_2(\text{SO}_4)_3$
- ❑ Coagulant for municipal and industrial wastewater treatment
- ❑ Fe^{3+} =11,2%
- ❑ Coagulation pH in
 - pre-precipitation 6,0-7,5
 - P-removal, post-precipitation 5,5-7,0
- ❑ Suitable also for water soluble metals removal like As, Pb, Ni, Cr, Cu
- ❑ Free acid can be adjusted between (-1-7%)