Surface Water Treatment and Implementation of New Flotator System

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Bachelor’s Thesis

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SAVONIA UNIVERSITY OF APPLIED SCIENCES **THESIS**

Abstract

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Abstract

Nowadays surface water can be utilized in many ways, such as treated for drinking or other human consumption. But the humus present in surface water causes problems in water quality, both in household water production and distribution to consumers. The purpose of the surface water pilot plant is to clean surface water and produce household water for human consumption.

The final purposes of the thesis were to make it clear that how the system of the surface water treatment plant works and to find out what needs to be taken into account when introducing a new flotator system.

The thesis consists of four parts in general, introduction to the surface water treatment processes, the project on lab-scale tests, tests of the Savonia's surface water pilot plant and tests of the new flotator system. The purpose of the project was to find out the optimal variable parameters of chemical surface water treatment in lab-scale tests. The main equipment was Flocculator 2000, which has been designed for flocculation tests under laboratory conditions, and aims to simulate the stages of the process more effectively. Coagulation forms in beakers sized 800 ml by Flocculator 2000. After sedimentation, samples from the upper liquid were taken for analyses including pH, color, iron, turbidity and chemical oxygen demand (COD). In this case, the main variables were the pH level and the dosage of PIX, with other conditions under the same circumstances. Optimization was known when tests were done by changing the parameters and analyses were done by laboratory methods. The results showed that when the pH level was 4.5 and the concentration of PIX was 95 ml/m^3, it reached the optimum. The tests of the savonia's surface water pilot plant and new flotator system were based on the lab-scale tests. In the surface water pilot plant, different values of pH level and concentration of PIX were tested to determine if the values 4.5 and 95 were respectively the optimum. After some adjustments and analyses, the new flotator still needed further implementation.

The results indicated that when the pH level was 4.5 and concentration of PIX was 95ml/m^3, the surface water pilot plant treatment reached the optimum. When taken to field work, some improvements can be applied to the new flotator system. They are: 1) Expand the volume of new flocculation tank. 2) Connect one or two more flocculation tanks. 3) Slow down the rotation frequency of mixer to about 7 Hz in flocculation tank. 4) Turn the two inside walls of flocculation tank off.

Keywords

pH, PIX, COD, Flocculation, Flotation, Dispersion water, Optimization

CONTENTS

1 INTRODUCTION

The purpose of the thesis is to introduce the surface water treatment processes, especially flocculation and flotation, and to find the optimal parameters in plant treatment and to find the implementation of the new flotator system. The lab-scale project is to find out the optimal variable parameters of chemical surface water treatment. Its raw water source is surface water from the bottom of Lake Kallavesi and pumped by the University of Kuopio’s fish farm.

One of the main equipments in the thesis was Flocculator 2000, which has been designed for flocculation tests under laboratory conditions, and aims to simulate the stages of the process more effectively. This equipment has six control units, and each of them can be connected to an agitator. The control of six agitators is individual, which means six different tests can be run separately at the same time. Flocculation forms in beakers sized 800 ml by Flocculator 2000. After sedimentation, samples from the upper liquid are taken for analyses including pH, color, iron, turbidity and chemical oxygen demand (COD).

In this project, four agitators run with four corresponding 800 ml beakers at the same time in each test. The main variables are pH and PIX. PIX is the term for Ferric Sulfate, formula of which is $Fe_2(SO_4)_3$. PIX is a coagulant causing coagulation and flocculation. While changing the value of pH and the dosage of PIX, it keeps other parameters as constant conditions. Given the pH range from 4.0-5.5 and the dosage of PIX range from 80-120 ml/m^3 based on previous experiment estimation, four points of pH are 4.0, 4.5, 5.0, 5.5, and four points of PIX are 85, 95, 105, 115 in this project.

PIX and pH levels which gave the best results in the laboratory tests were then used in Savonia’s surface water treatment plant. Aim of this was to clear out the water quality after flotator and based on these values, try to start using new flotator which have different feeding of dispersion water compared to Savonia’s flotator. Samples for analyses both in Savonia’s pilot plant and new flotator system were all taken from the output after flotation process.

2 THEORY OF SURFACE WATER TREATMENT PRCESSES

2.1 Overview and introduction of the Savonia’s pilot plant

The purpose of surface water pilot plant is to clean surface water or groundwater and produce household water for human consumption. Humus residues and chemical residues in humus sedimentation are the main problems to be dealt with in surface water because the concentrations of them usually exceed the quality standards values. Humus in surface water can cause problems of water quality in both household water production and distribution to people, such as disinfection by-products, re-growth of microbes and harms on water taste and smell. On account of the risk to human health caused by the by-products of chlorine reactions, many waterworks in Finland have used safer methods instead of chlorine, such as chloramine disinfection, ozonation (an very expensive way) and UV radiation. In disinfection, a way to keep the balance between the control of treatment by-products and reaching the standards of water hygienic quality is necessary. To some extent, the need for disinfection can be reduced in surface water treatment pilot plant by more effective removal of nutrients which is necessary for microbes in the distribution work. (Kettunen, J., Utriainen, P. & Janhunen, M., 2014)

This surface water pilot plant (Figure 1) in Savonia University of Applied Sciences is for running chemical test drives, disinfection methods, teaching and testing measuring and monitoring devices. Its raw water is the same as that of project of lab-scale tests. The maximum production rate for water of the plant is about 3 m^3/h. In terms of technical steps, the process of the treatment plant can be divided into the following parts: adding of chemicals, rapid mixing, flocculation, flotation, rapid sand filtration, disinfection and post-chemicalization (pH control). The analytical tests were based on those of the lab-scale project.

Figure 1. The surface water pilot plant (Kettunen, J., Utriainen, P. & Janhunen, M., 2014)

2.2 Rapid mixing

Mixing is closely linked to agglomeration and flocculation. In the plant, rapid mixing is for adding chemicals, where mixing of coagulants and raw water and pH adjustment take place simultaneously. It is of importance for the flowing processes such as flocculation (in slow mixing step) and flotation. In this step, the pH level is adjusted and then maintained until the filtration step. There is a propeller mixer in the rapid mixing tank. From the past summarized experience, that higher the mixer speed, the better the mixing efficiency. The speed of the propeller mixer is maintained at approximately 1,200 rpm. PIX as a coagulant and lime (calcium hydroxide) as pH adjustment chemical are added into the rapid mixing tank. Microflocs begin to form from the rapid mixing step called agglomeration. At the next stage slow mixing, flocculation takes place, where lager flocs (macroflocs) form. The duration of rapid mixing is different from slow mixing (flocculation). Rapid mixing usually lasts for less than one minute, however, slow mixing lasts from a few minutes to half over an hour. (Kettunen et al. 2014)

2.3 Theory of coagulation and flocculation

In real life, most people mix coagulation with flocculaton. But actually they are two different processes when it comes to detail. Coagulation is the phenomenon of particle coagulation. Agglomeration and flocculation are collectively known as coagulation. Agglomeration refers to the process that addition of certain dissolved salts in the water make the suspended solids or colloidal particles adsorb and combined with each other forming larger particles, and then those precipitate in the water. Flocculation refers to the process by which the microparticles adhere to each other by the action of the adsorbent bridging bridge. The stabilized colloids are agglomerated together, which is called agglomeration. Coagulants are mainly used for the purification of drinking water and industrial waste water, special water quality treatment (such as oily waste water, printing and dyeing paper-making waste water, smelting sewage, including radioactive properties, containing Pb, Cr and other toxic heavy metals and F-containing sewage). It is very important to choose a suitable coagulant according to the technological conditions of the water treatment plant, the raw water quality and the water quality target after treatment. Both flocculation and flotation are the most important parts in the thesis, not only because these two processes are essential in whole treatment, but the samples in pilot plant and new flotator system were all taken from the output right after the flotation. Flotation process is connected to the flocculation process. So the adjustments and comparison are based on the two processes to find out the optimum and implementation.

2.3.1 Basic content of coagulation

Water turbid impurities are large and small, small suspended impurities settling very slow, or even close to not sink. The particles remain dispersed in water and cannot settle. After the coagulation process, the suspended impurities, destabilized colloidal particles, and pharmaceutical reactants are bonded to each other to become larger, visible, easy to sink filter flocs.

The coagulation process can be divided into several stages of rapid mixing, agglomeration and flocculation. When the chemical is put into the water, stirred vigorously, so that the two are evenly mixed in the twinkling of an eye. The chemical reaction and the stabilization of the colloid (called coagulation) are usually completed in a few seconds. And then through the appropriate strength of the mixing and turbulence in the flow, reaction products, colloidal aggregates and suspended impurities collide combine with each other forming one kind of strong and coarse floc, which is called flocculation. It usually takes 5 to 30 minutes or so to complete. (Tang, 1996)

There are many factors that affect the coagulation process. The main factors are: pH value, turbidity, temperature, chemical composition and stirring conditions and coagulant composition. The agitation test is still the most commonly used method of designing and managing the coagulation process. Through the mixing test can be determined: ① the type of chemical agents, dosage, dosing sequence and location; ② agglomeration and flocculation of the two stages of mixing strength and time; ③ pH test. In a group of beaker of the same size (also known as cup test), each beaker has a stirrer. The stirrer speed can be adjusted, but the whole group of agitator speed is the same. (Tang, 1996)

In the coagulation process, what mainly acts the role of colloidal stabilizer is called coagulant. The agent that makes the small suspended impurities and destabilized particles bond to each other forming floc is called coagulant. Coagulants are metal salts and polymers, the latter of which are mainly used as coagulants aids. ① Metal salts. Aluminum salts include alum, aluminum sulfate, sodium aluminate. Iron salts include ferric chloride, ferric sulfate, ferrous sulfate and the like. Metal salts are dissolved first after put into water, forming ions and then reacting with the alkaline ions in water to form precipitation. In the process of reaction, the high-valent metal ions help to promote the cohesion of particles. ② Polymer. There are natural polymers and synthetic polymers. Synthetic long chain structure of polymer molecular weight from tens of thousands to millions, divided into kation, anionic and non-ionic. The current use of polyacrylamide is more. (Qin, Zhang & Chen, 2004)

The coagulation equipment includes dosing, mixing and flocculating equipment. ① Dosing equipment. Coagulants can be directly put into the water as powder. The equipment used is called dry-type machine. But generally the coagulant is paired solution and then put into the water. The flow rate of the solution can be controlled by the orifice or weir of the head, or it can be controlled by a quantitative pump, so the dosage is easier to control than the dry dosing machine. ② Mixing equipment. Most use mechanical way to mix coagulant and raw water. Coagulant or its sulution is put into the water flow before going in the pump, and rapidly mixed by the pump impeller. Dedicated pool can as well be set up, equipped with a stirrer. The flow of water stays for around 1 minutes in the pool. ③ Flocculation pool, also known as reaction pool. The particles in the water flow flocculate in virtue of turbulence in the pool. The turbulence of the water flow can be achieved by increasing the flow of water or slow mechanical agitation.(Zheng, Peng, Huang & Liu, 2007)

2.3.2 Mechanism of coagulation

The mechanism of coagulation can be explained from four aspects. (1) Double layer compression mechanism: When put the electrolyte into the solution, the concentration of ions in the solution increases, the thickness of the diffusion layer is reduced. When the two particles are close to each other, due to the thickness of the diffusion layer decreases, ζ potential decreases, so their mutual rejection of the force is reduced, the particles can be quickly cohesion. (2) Mechanism of adsorption electrical neutralization: The adsorption of electrical and neutral means that the surface of the particles with a different amount of charge has a strong adsorption. This adsorption neutralizes its part of the charge, reducing the electrostatic repulsion, and thus it is easy to close with other particles and mutual adsorption. (Qin, Zhang & Chen, 2004) (3) Principle of adsorption bridge: Adsorption bridge role mainly refers to the adsorption of polymer substances and colloidal particles, but the colloidal particles and the plastic itself are not in direct contact, leaving the particles cohesion for large flocs. (4) Sediment trap mechanism: When metal salts or metal oxides and hydroxides are used as coagulants in amounts sufficient to rapidly form metal oxides or metal carbonate precipitates, the colloidal particles in the water can be used by catching these precipitates. When the precipitate is positively charged, the sedimentation rate may be accelerated by the presence of cations in the solution. (Zheng et al. 2007) In addition, the water particles themselves can be used as the core of these metal hydroxide precipitates. So the best dosage of coagulant is inversely proportional to the concentration of the substance to be removed, i.e., the more the colloidal particles are, the less the amount of metal coagulant is added.

2.3.3 Selection of coagulants

Since the hydrolyzate of the coagulant diffuses very slowly to the very adjacent part, the number of colloidal particles in the high turbidity water is very large. So the coagulant hydrolyzate is diffused at the very adjacent part and is contacted and caught by closer colloid particles. This coagulant is formed in some places locally concentrated high cloud hydrolyzate period, and in some places no. Coagulants local concentration of local alum grows rapidly. Alkaline aluminum chloride forms loose alum particles, encountering a strong shear force adsorption bridge cut. Then there has been a local reaction phenomenon. Pharmacy did not spread to the local colloidal particles have not yet stabilized, this part of the flocculation reaction is bound to imperfect. This is because they cannot keep up with the rate of detoxification of colloidal particles, on the other hand because the coagulant concentration area alum quickly unreasonably grow up, but also to non-stabilized colloidal particles lost reaction collision conditions. This led to the high turbidity sludge sedimentation performance is poor, water quality cannot guarantee water. According to the traditional process of construction of the water plant, in the large high turbidity are required to significantly reduce its processing capacity to ensure that the water quality, but also greatly saves the dosage. (Ma, Zhang, Yuan, Wang, Wang, Wang, 2005)

It is very important to choose a suitable coagulant according to the technological conditions of the water treatment plant, the raw water quality and the water quality target after treatment. The choice of coagulant species should follow the following general principles: (1) Coagulation effect is good. In the specific raw water quality, after treatment, water quality requirements and specific treatment conditions, you can get a satisfactory coagulation effect. (2) No toxic effects. When used for the treatment of drinking water, the choice of coagulants shall not contain harmful ingredients harmful to human health; when used in industrial production, the choice of coagulants shall not contain harmful ingredients. (3) Adequate supply. Should be selected from the use of coagulant sources and manufacturers to conduct research to understand whether the supply is sufficient, whether the long-term stable supply, product quality and so on. (4) Low cost. When a variety of coagulant varieties can be selected, should consider the price of pharmaceuticals, transportation costs and dosage, etc., to compare the economic analysis, to ensure that the premise of water treatment under the premise of reducing the use of cost. (Zhou, Lin, Xie & Tan, 2009)

Coagulants can be grouped into two categories. One is inorganic salts including aluminum salts (aluminum sulfate, potassium aluminum sulfate, potassium aluminate, etc.), iron salts (ferric chloride, ferrous sulfate, ferric sulfate, etc.) and magnesium carbonate. The other one is macromolecular substance including polyaluminium chloride, polyacrylamide and so on. In the treatment, the coagulant is added to the waste water to eliminate or reduce the mutual repulsion between the colloidal particles in the water, so that the colloidal particles in the water are easy to collide with each other and agglomerate to form larger particles or flocs, and then separated from the water. Factors affecting the coagulation effect are: water temperature, pH, turbidity, hardness and coagulant delivery volume.

2.3.4 Ferric Sulfate

Ferric Sulfate is an off-white powder or an orthogonal prism-crystalline flow of light yellow powder, sensitive to light and easy to moisture. It dissolves slowly in water, but dissolves faster in the water with trace amounts of ferrous sulfate. It is slightly soluble in ethanol, almost insoluble in acetone and ethyl acetate, and slowly hydrolyzed in aqueous solution. It is used as a mordant and as a coagulant for industrial waste water and also in pigments. Medicine uses ferric sulfate as astringent and hemostatic agent. A large amount of ferric sulfate can be obtained by reacting sulfuric acid, ferrous sulphate hot solution with an oxidizing agent such as nitric acid or hydrogen peroxide.

The valence of iron element in ferric sulfate is +3, so its aqueous solution is yellowish brown (tan). Ferric sulfate as a coagulant has lots of advantages. It is a new type, high quality and high efficiency iron salt inorganic polymer coagulant, having excellent coagulation performance and settling speed. Ferric sulfate’s purification on water is great. Treated water quality is good, and does not contain aluminum, chlorine, heavy metal ions and other harmful substances. There are no iron ions of the water phase transfer, also non-toxic, harmless, safe and reliable. It has good performance on reducing turbidity, decolorization, de-oiling, dehydration, sterilization, deodorization, algae removal, removal of water COD, BOD and heavy metal ions. Slightly polluted, low temperature and low turbidity of raw water purification treatment with ferric sulfate effect is remarkable, while high turbidity raw water purification effect is better. Ferric sulfate is dangerous, though. Immediately remove contaminated clothing and rinse with plenty of water for at least 15 minutes when touched on skin by ferric sulfate, and the go to hospital. If eyes rather than skin, immediately lift the eyelid and rinse thoroughly with plenty of water or saline for at least 15 minutes. Quickly get out from the scene to the fresh air to maintain airway patency if inhale some of it before sent to hospital. It ingest some, then rinse with plenty of water and drink some milk or eat some eggs.

2.4 Flocculation in the pilot plant

In the surface pilot plant, flocculation (Figure 2) takes place at the slow mixing stage after the rapid mixing step. The microflocs formed in the rapid mixing step grow into lager macriflocs in flocculation with the help of coagulant. Electrically charged humus particles or impurities repel each other. The coagulant added attaches to the surface of the particles, changing the particle charge and increasing the mass of particles. Under the circumstances of adjusted electric charge, the microflocs combine with each other forming bigger particles and precipitate. This kind of precipitation caused by chemical coagulants is generally called coagulation or flocculation. This process helps to treat organic matters, colloids and impurities in water.

After adding chemical substances (coagulants), the reactions produce particles in rapid mixing, which are first microflocs. These microflocs are very small, close to colloids, and cannot precipitate or coagulate effectively by themselves. When the particles present in water under the Brownian motion (thermal radiation), they grow bigger. But during growth, the Brownian motion slows down and then stops. From this point onwards, it needs external energy (i.e. machanical energy) to increase the size of particles, becoming macroflocs. The slow mixing stage creates turbulence by mixers, allowing microflocs to attach to each other and form settleable macroflocs. A good mixing process can affect many elements in the treatment, including reducing dosage of chemical, forming and more flocs and accelerating the formation. Good enough blending can reduce dosage of chlorine to minimum value when chlorine is used for disinfection.

In the slow mixing process, optimal circumferential velocity of mixing blades should be determined. If the velocity is not enough, the speed of formation and content of flocs cannot reach target levels. When the viscosity increases all the time, the performance of flocs formation gets worse. Then circumferential velocity can be increased to against the problem. But if the velocity is too high, exceeding the point, then the flocs formed before will break up or disintegrate rather than maintaining flocs. So it is important to find the balance of forces to keep the formation and maintenance of flocs at good levels. (Kettunen, Utriainen & Janjunen, 2014)

In the pilot plant, the slow mixing stage has three mixing tanks, gradually decreasing the speed of circumferential velocity. The rotation frequency is 80 Hz in the first tank, 55 Hz in the second tank and 30 Hz in the last tank. This way helps to get a much better treatment.

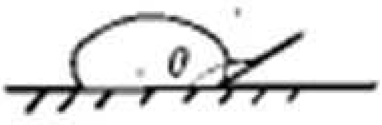
Figure 2. Flotation tanks

2.5 Flotation

Flotation is a process after flocculation, whereby microbubbles released from dispersion water adhere to suspended flocs and give a force to rise the flocs up to water surface. Flocs are light particles whose proportion is close to water. If the traditional precipitation method is used to treat the flocs, the effect must be poor. Especially in the winter low temperature conditions, due to coagulation and hydraulic conditions worse, the treatment effect is more difficult to guarantee. It is conceivable that it is bound to be less effective to make the flocs sink while the flocs themselves are hard to be precipitated. So it is better to make the best use artificially introduced into the water bubbles to adhere to the floc particles, thus greatly reducing the overall density of the flocs. By the rate of rising bubbles, flocs are forced to float up, in order to achieve rapid solid-liquid separation. In this sense, the emergence of air flotation technology is a revolution to gravity sedimentation, which opened up solid-liquid separation technology in new areas.

Air flotation utilizes the hydrophobicity of the particles in the water and allows the contaminants(flocs) in the water to be adsorbed on the bubbles by passing a certain size of air bubbles into the water tank. It causes the formation of water-gas-particles three -phase mixing system. The particles adhere to a large number of highly dispersed fine air bubbles, forming a state of flocs whose apparent density less than water and floating to the surface. Then the formed scum layer is scraped by scraper and drained off, in order to achieve solid-liquid separation process.

The surface of the suspended matter is hydrophilic or hydrophobic. Hydrophobic particles are easily attached to the surface of the bubble, which can be used by air flotation method. If the particles are easily wetted by water, the particles are said to be hydrophilic. If the particles are not easily wetted by water, it is hydrophobic. In the stationary state, when the gas, liquid and solid phases are in contact, the angle between the gas-liquid interface tension line and the solid-liquid interface tension line (including the liquid phase) is called the equilibrium contact angle and is denoted by θ. When the particles are completely wetted by water, θ = 0° , the particles can not adhere to the bubbles. When the particles are not wetted by water at all, θ = 180° , the power of adhesion between particles and bubbles is strong, so it is easy to use air flotation treatment. When θ > 90° , in a certain range, the particle surface hydrophobicity is dominant, easy for adhesion and stability, thereby suitable for air flotation. When θ < 90° , the particle surface is hydrophilic dominant, and adhesion is not stable. The particles that are adhered may fall off during the floating process. The greater the contact angle of the solid, the easier it is to adhere to the bubbles. However, for some systems, although it is beneficial for the adhesion of the solid to the bubble, the adhesion of the particles to the air bubbles is difficult due to the small adhesion force. Whether the particles of contaminants can be adhered and whether they are strongly adhered to bubbles are related to the hydrophobicity of the contaminants. Sometimes the hydrophobicity of flocs is weak and the efficiency is very low when treated with flotation. In order to increase the hydrophobicity of the suspended particles in the water and to improve the flotation effect, it is necessary to add chemicals to the water. The previous processes of adding coagulant and flocculation are beneficial for the flotation process. Coagulant makes colloids and other particles into flocs with a network structure, which is easy to trap bubbles, thereby improving the air flotation efficiency. (Mao, Zhang, Luo & Yan, 2008)



① θ > 90° , hydrophilicity

② θ < 90° , hydrophobicity

The flotation tank is the main equipment of the air flotation process. Its function is that when the dispersion water flows from the pressure reducing valve into the tank, the air dissolved in the dispersion water escapes in the form of tiny bubbles due to the pressure reduced to normal pressure. Bubbles adsorb emulsified oil and small suspended particles in the process of rising, floating to the surface to form scum layer, which is removed by scraper. The air flotation methods used in the treatment of waste water or surface water can be divided into three types: dissolved air flotation (DAF), diffused air flotation (DAF) and electrolyzed flotation. (Wang, Zheng, Ma, Ma, Liu, & Zhang, 2013).

Electrolyzed flotation is the electrolysis of water, then produces a lot of hydrogen bubbles in the cathode. The hydrogen bubble diameter is very small, only 20-100μm. Suspended particles in the water adhere to the hydrogen bubbles, with its floating, so as to achieve the purpose of purification of water. At the same time, the hydroxide formed by ionization on the anode acts as a coagulant to help the sludge or flocs in the water to float or sink. Diffused flotation uses the mechanical mixing force to crush the air mixed in the water into fine bubbles for flotation. According to the different methods of pulverizing bubbles, diffused flotation is divided into four types: water pump suction flotation, jet flotation, diffusion aeration flotation and impeller flotation. The advantage of diffused air flotation is simple equipment and easy to implement. But the air is crushed not enough, resulting in the formation of large bubble size, generally not less than 1000μm, so that in the certain situation of the amount of air, the bubble surface area is small. Due to the large diameter of the bubble, the quick movement and the short contact time between the bubbles and the to be removed particles, these factors make the diffused air flotation removal efficiency relatively low.

Dissolved air flotation (DAF) is a relatively more effective method of air flotation, which used in this surface water pilot plant. This method is to make the air dissolve into water under a certain pressure, achieving a supersaturated state. Then pressure in water is reduced to atmospheric pressure. At this time, the air dissolved in water escapes from the water in the form of small bubbles and proceeds the process of adhering to flocs. The water with air dissolved in is called dispersion water. Figure 3 and Figure 4 show the flotation tank and the dispersion water tank connected to flotation tank in the surface water pilot plant. The diameter of air bubbles should be about 20-100μm. The contact time between bubbles and water can be artificially controlled and the application of the method is more extensive. The particles adhere to a large number of highly dispersed fine air bubbles, forming a state of flocs whose apparent density less than water, and floating to the surface. Then the formed scum layer is scraped by scraper and drained off (Figure 5). According to the different pressure conditions when the bubbles escape from water, dissolved air flotation can be divided into: pressurized dissolved-air flotation and vacuum flotation two types (Alemayehu, 2017). In vacuum flotation, the air is dissolved in water under atmospheric pressure or positive pressure and escapes under negative pressure. The flotation tank is operated under negative pressure. The dissolved air pressure is lower than that of pressurized dissolved-air flotation and it consumes less energy. However, the structure of the flotation tank is complicated and the equipment is sealed. So the operation and maintenance are more difficult, and the application is not much. In pressurized dissolved-air flotation, air is dissolved in water under pressurized conditions, then the pressure is dropped to atmospheric pressure and the supersaturated air releases in the form of micro-bubbles. The advantages of pressurized dissolved-air flotation are high solubility of air in water, enough and uniformed provided micro-bubbles, small size of bubble (diameter 20-100μm) and simple flow of equipment.

Figure 3.Flotation tank in pilot plant

Figure 4.Dispersion water tank in pilot plant

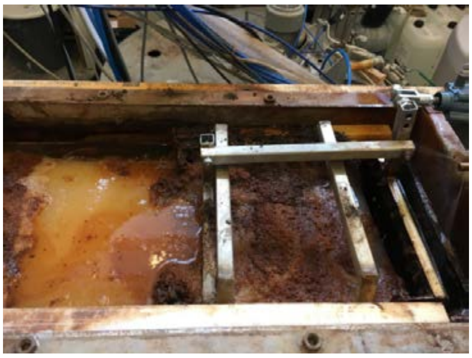
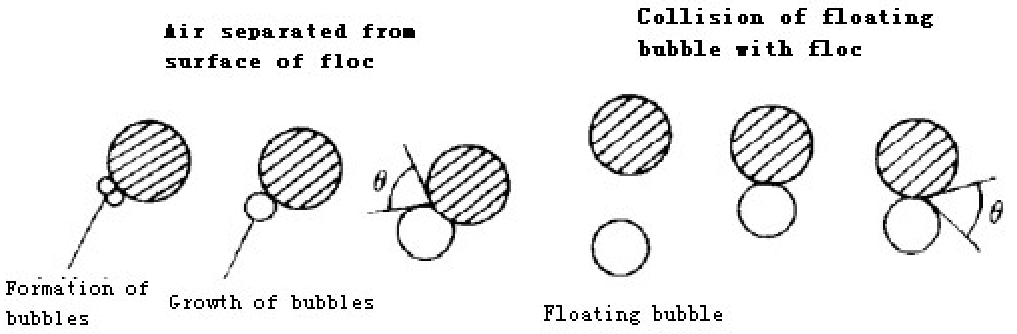


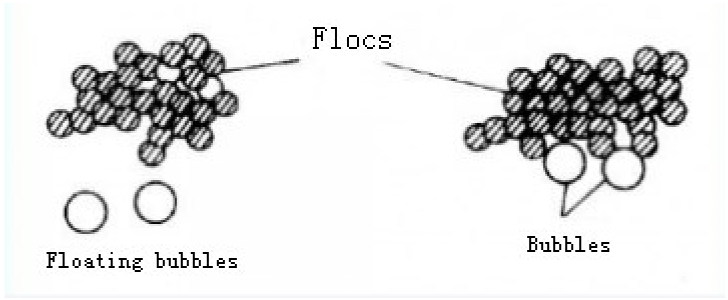
Figure 5. Scum layer

In the surface water pilot plant, an immersion pump feeds about 10% of the water coming from the flotation tank to the dispersion water container along with compressed air. This way is more energy efficient than some other methods such as the way of feeding all raw water into pressure tank. The needed capacity of equipment tank is also reduced greatly. Under the same energy consumption, the dissolved-air pressure can be greatly improved with the formation of bubbles smaller, more uniform and more fully available. Especially in the treatment using coagulant, it can make full use of coagulant, reducing the dosage and avoiding damage on flocs. (Shen, Shi, Lu & Liu, 2004)

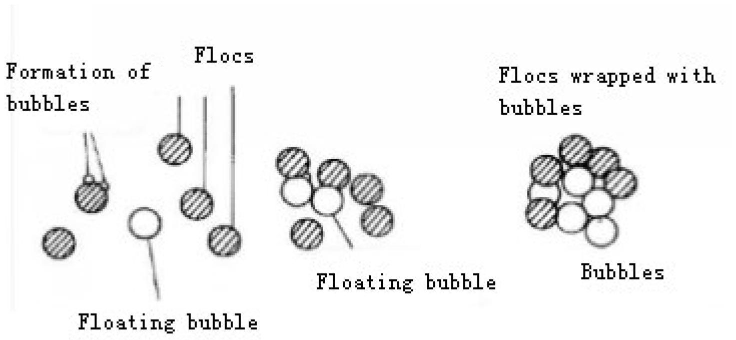
Air flotation can be divided into three phases: producing bubbles, adhesion between flocs and bubbles and flocs floating process. The formation of bubbles plays a decisive role. The ability to form stable and dispersed bubbles depends on the surface tension of the water. Since the formation of bubbles means increasing the area of the water vapor, the smaller the surface tension of water is, the more likely the formation of stable bubbles and the smaller the bubble diameter. To get smaller bubbles, the dissolved air pressure should be improved. In this way, not only increases the energy consumption, but also the requirements on the equipment are higher. So the pressure required to produce dispersion water is usually 3 to 5 bar, and it is around 5 bar in this pilot plant. The process of air flotation needs a large number of fine and uniform bubbles as a carrier, so the air float effect depends largely on the amount and saturability of air dissolved in the water, and also the dispersion and stability of the bubbles. The greater the amount of bubbles, the higher level of the dispersion, the more they have the chance of adhering to flocs. Bubble should have a certain degree of stability. Because of lack of protection of surface active substances, bubbles are unstable and easily broken. But it is difficult for transport and dehydration with bubbles which are too stable, so the appropriate stability time is several minutes. In the second phase, it is a necessary condition that flocs can adhere to bubbles to achieve the process of flotation and separation. Basic forms of attachment between flocs and bubbles are: a) adsorption of flocs and bubbles, b) bubbles jacking and c) entrapment of flocs and bubbles. The three forms show as following. (Li, Qin & Zhang, 2012)



a) Adsorption of flocs and bubbles



b) Bubbles jacking



c) Entrapment of flocs and bubbles

The third phase is the process where flocs with bubbles rise up to surface to be scraped. The flotation tank provides a certain volume and surface area, so that micro-bubbles and suspended particles in water are fully mixed, contacted and adhered, then the particles with bubbles are separated from water.

2.6 Rapid sand filter

In the surface water treatment, clarified water is fed from the bottom of the flotation tank to a filter by using an intermediate pump. The filter is used to remove excess flocs remaining in the water after flotation. The water penetrates the sand filter and the impurities are trapped in this layer. In filtration, the most important and appropriate parameter of water quality is turbidity. This plant uses a dual-bed filter, including an upper anthracite layer (2-4 mm) and a lower quartz sand layer (grain size 0.7-1.2 mm). Then sand filter is cleaned by backwashing with added compressed air every midnight. The backwash is automatical and the cleanout takes approximately 15 minutes.

2.7 Disinfection

The disinfection stage in the surface water pilot plant consists of UV radiation and chlorination. UV radiation is classified as a physical method and chlorination as a chemical method. The purpose of disinfection is to destroy the pathogenic micro-organisms in water such as viruses and bacteria. (Janhunen, 2017b)

2.8 Post chemicalization

Post-chemicalization is also known as pH control. To avoid the problems of corrosion and carbonate deposits in water, the water quality i.e. pH, alkalinity and hardness should be carefully adjusted and regulated by adding lime (calcium hydroxide) and carbon dioxide (CO_2). If lime does not efficient effect, lye (sodium hydroxide) is added. When pH adjustment goes too far, the automatically running lime dose is decreased.

3 LAB-SCALE PROJECT TEST

The main equipment in lab-scale project is Flocculator 2000, which has six control units, and each of them can be connected to an agitator. The control of six agitators is individual, which means six different tests can be run separately at the same time. Flocculation forms in beakers sized 800 ml by Flocculator 2000. After sedimentation, samples from the upper liquid are taken for analyses including pH, color, iron, turbidity and chemical oxygen demand(COD).

In this project, four agitators run with four corresponding 800 ml beakers at the same time in each test. The main variables are pH and PIX. PIX is the term for Ferric Sulfate, formula of which is $Fe_2(SO_4)_3$. PIX is a coagulant causing coagulation and flocculation. While changing the value of pH and the dosage of PIX, it keeps other parameters as constant conditions. Given the pH range from 4.0-5.5 and the dosage of PIX range from 80-120 ml/m^3 based on previous experiment estimation, four points of pH are 4.0, 4.5, 5.0, 5.5, and four points of PIX are 85, 95, 105, 115 in this project.

3.1 Operation with Flocculator 2000

3.1.1 Reagents&Apparatus

These are the reagents and apparatus needed in the lab-scale project.

1) Deionized water;

2) PIX, 10g/100ml;

3) Calcium hydroxide solution [$Ca(OH)_2$];

4) 800 ml beakers X 4;

5) Pipette;

6) pH meter.

3.1.2 Process of using flocculator 2000

Make sure the enclosed mains unit is connected to the wall socket and start Flocculator 2000 (figure 6). Then connect the control unit by connecting the power cable to the socket on the rear of the control unit. After this, agitators ought to be connected to the socket on the front of the control unit. In main menu, there are two options to do with, FLOCCULATION and RPM MENU.

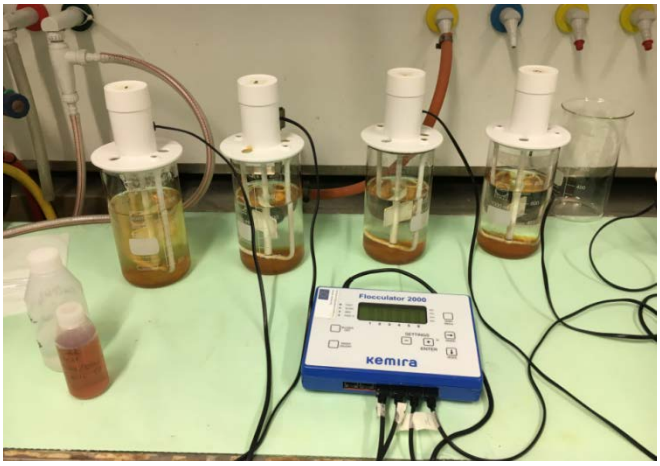


Figure 6. Flocculator 2000

In flocculation menu, the values can be altered by using the plus or minus buttons. Three main clarifications are fast, slow and sed. Fast means fast stirring time, ranging from 0-60 seconds. Slow means slow stirring time, ranging from 0-60 minutes. Sed means sedimentation time, ranging from 0-60 minutes. In this project, keep the fast stirring time as 60 seconds, the slow stirring time as 10 minutes and the sedimentation time as 30 minutes. Sometimes the needed values are too far from default values, so hold the buttons down for few seconds and values will increase or decrease automatically until release the buttons. Fast stirring, slow stirring and sedimentation are three connected processes. Slow stirring happens immediately after fast stirring done, while sedimentation is after the slow stirring. What has to be aware of is that values can be changed while in operation. It is important to keep careful not to press wrong buttons in operation since four tests run together. If values are changed during running process, it mostly means the test should restart because it can not be restored to what before.

RPM means rounds per minute, showing the speed of agitators. In RPM menu, there are two important clarifications, which are fast stirring rotation and slow stirring rotation corresponding to fast stirring and slow stirring in flocculation menu. In this project, set the rotation of fast stirring as 300 and that of slow stirring as 40. Operation is almost the same as that in flocculation menu. Flocculator will beep when each test finishes, then press buzzer off button to silence. (KEMIRA, 2006)

The project is conducted in two parts. Part 1 is that keep the dosage of PIX 100 ml/m^3, which is 1,26 ml in diluted PIX solution. First start from beaker 1 filled with 800 ml raw lake water. There are two holes on the top of each agitator for inserting pH meter and other purposes. Agitator should be away from pH meter to avoid collision when rotating, so pH meter should be placed in spare space. Add 1,26 ml PIX with pipette into beaker through one hole while put pH meter into the other hole during fast stirring process. PH scales go down soon after that, then add calcium hydroxide solution drop by drop to adjust pH scales to around 4,00. At the beginning, it is very easy to add more calcium hydroxide solution and the pH scales go far. After practice, it gets easier to keep that under control. When pH scales in beaker 1 come to around 4,00, leave it along and continue beaker 2. Similarly, add 1,26 ml PIX into beaker 2 and then adjust pH to around 4,50. After that, adjust pH to around 5,00 for beaker 3 and around 5,5 for beaker 4, while both dosage of PIX are the same 1,26 ml. Take samples from each beaker for analyses. Values of adjusted PIX and pH are shown as Table 1. in theoretical way.

Table 1. PIX and pH theoretically adjusted in part 1

Beaker	1	2	3	4
PIX(ml/m^3)	100	100	100	100
pH	4.00	4.50	5.00	5.50

Part 2 is related to part 1. Results from part 1 shows that when pH is around 4,50, treatment effect is the best. So in part 2, keep pH scales around 4,50 in each beaker and add four different dosage of PIX into corresponding beakers. The concentrations of PIX are 85 ml/m^3, 95 ml/m^3, 105 ml/m^3 and 115 ml/m^3, which in real volume of PIX are respectively 1,07 ml, 1,20 ml, 1,32 ml and 1,45 ml. Values of adjusted PIX and pH are shown as Table 2. in theoretical way. In both part, two samples are taken from each beaker to make sure the accuracy of results.

Table 2. PIX and pH theoretically adjusted in part 2

Beaker	1	2	3	4
PIX(ml/m^3)	85	95	105	115
pH	4.50	4.50	4.50	4.50

3.2 Analyses

3.2.1 Analysis of Chemical oxygen demand

COD (Chemical Oxygen Demand) is a chemical method to measure the amount of reducing substances that need to be oxidized in a water sample. In waste water, waste water treatment plant effluent and contaminated water, it is oxygen equivalent of substances (usually organic) which can be oxidized by strong oxidant. It is an important and faster method for the determination of organic pollutants in the study of river pollution and the nature of industrial waste water and the operation and management of waste water treatment plants, often expressed in symbolic COD. There are few methods measuring COD including dichromate method, potassium permanganate method, spectrophotometry, rapid digestion method and rapid digestion spectrophotometry. In this project, potassium permanganate method (COD_{Mn}) is the main way. COD_{Mn} means the chemical oxygen demand which is reached when the sample is oxidized with potassium permanganate. This analysis method is usually used for clean water and effluent waters, and the COD values of them are above 1 mg/L. It is not fitted for waters in which chloride is more than 300mg/L. (Savonia University of Applied Sciences, 2017)

The amount of oxidant consumed by the reducing substance in the 1 liter water sample under certain conditions is determined as the number of milligrams of oxygen required per liter of water to be oxidized, expressed in mg / L. It reflects the extent to which is contaminated by reductive material in water. The index is also one of the comprehensive indicators of the relative content of organic matter. Chemical oxygen demand is often used as an indicator of how much organic matter is present in the water. The greater the chemical oxygen demand, the more serious is the pollution of water contaminated by organic matter. In chemical oxygen demand determination, with the determination of water samples in the reduction of substances and the determination of different methods, the measured values are also different. Strictly speaking, chemical oxygen demand also includes the presence of inorganic substances in the water. In general, the amount of organic matter in the waste water is generally greater than the amount of organic matter in the waste water. Therefore, the total amount of organic matter in the waste water is generally represented by chemical oxygen demand.

COD_{Mn} analysis is the main method based on SFS 3036 for this project to get COD results. In this method, samples are digested with strong acid and known excess amount of oxidant for 20 minutes exactly. In the case, acid is 4 M sulfuric acid and the oxidant is potassium permanganate. Potassium permanganate oxidizes organic matters in the digestion process. After the step of digestion, iodometry is used for determining the excess amount of potassium permanganate with potassium iodide and sodium thiosulphate. First, potassium iodide is added into the sample and then starch is added as indicator during titration step while sodium thiosulphate is for titrating the sample in the end. When it comes to the point where the color vanishes completely, the amount of added sodium thiosulphate is equivalent to the amount of excess potassium permanganate which is left in the sample.

One mixed well sample of which the volume is 10 ml is transferred into a conical flask. In the project, two replicates of one sample are made. Some samples are 10 ml of original samples for each while some samples are diluted (5 ml of original sample + 5 ml of deionized water). After transfer, 0.5 ml of sulfuric acid (4 M) and 2.0 ml of potassium permanganate (0.01 mol/L) are added into sample. Sample (Figure 7) turns into purple after the addition of potassium permanganate. The next step is to make the flask covered with aluminium-foil paper and kept in a boiling water bath for 20 minutes. As soon as digestion has finished, cool the sample immediately to normal temperature or room temperature in cold water. Then Add 1 ml of potassium iodide (0.1 M) before adding five drops of starch solution. The color of sample turns yellow (Figure 8. Right) after addition of potassium iodide and turns dark blue (Figure 8. Left) after addition of starch solution. In the last stage, the sample is titrated (Figure 9) with sodium thiosulphate until dark blue color goes to light blue and disappears eventually. Two blank samples of 10 ml of deionized water are analyzed in the same way of the sample.

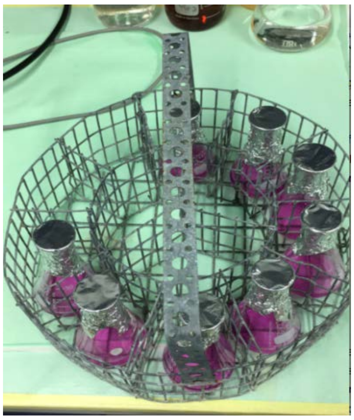


Figure 7.Samples before digestion *Figure 8. Samples after adding KI and after starch solution*

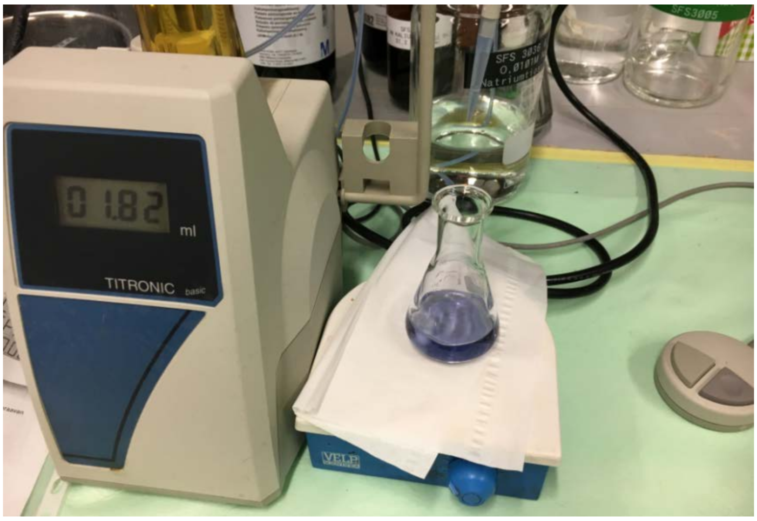


Figure 9. Titration with sodium thiosulphate

COD_{Mn} (mg/L) is calculated with the following formula:

$COD_{Mn} = (V_2 - V_1) * c_1 * 800 * f$, where,

V_1 = volume of sodium thiosulphate, which is used in titration of the sample, mL.

V_2 = volume of sodium thiosulphate, which is used in titration of the blank, mL.

c_1 = concentration of the sodium thiosulphate (mol/L).

800 = factor, half of the molar mass of the oxygen, which is changed to milligrams by dividing it with the volume of the sample (16/2) * (1000/10).

f = dilution factor, the volume of the diluted sample divided by the volume of the undiluted sample (in this project, f=1 when not diluted, f=2 when diluted).

3.2.2 Color

Color and iron are both measured with equipment DR 2800 Spectrophotometer. The spectrophotometer is a scientific instrument that divides the complicated component light into spectral lines.

Spectrophotometric method analyzes material quality and quantity by measuring absorbance or luminous intensity of the measured material at a specific wavelength or a certain range of wavelength. In the spectrophotometer, when the light of different wavelengths is continuously irradiated to a sample solution of a certain concentration, the absorption intensity corresponding to the different wavelengths can be obtained. The method of measuring a colorless matter with an ultraviolet light source is known as ultraviolet spectrophotometry. The method of determining a colored material with a visible light source is known as a visible light photometric method. Wavelength coverage of ultraviolet region is 200-400 nm while that of visible region is 400-760 nm.

According to Beer-Lambert Law: A=a*b*c, where, A=absorbance, a=absorptivity (related to the nature of the absorbed substance and the wavelength of the incident light), b=solution layer thickness (cm), c=solution concentration (g/dm^3). It can be seen from the above formula, when fix the solution layer thickness and the absorptivity, the absorbance A and the concentration of the solution are in a linear relationship.

The spectrophotometer uses a light source that can produce multiple wavelengths through a series of spectroscopic devices to produce light sources of a particular wavelength. After the light passes through the tested sample, part of the light is absorbed. Calculate the absorbance of the sample and convert it to the concentration of the sample.The absorbance of the sample is proportional to the concentration of the sample. The selective absorption wavelength of the material for light, and the corresponding absorption coefficient, are the physical constant of the substance. When the pure substance is known to be the absorption coefficient under certain conditions, the test substance can be formulated into the solution under the same conditions and the absorbance can be determined. Then the content of the substance in the test sample can be calculated. In the visible region, in addition to some substances to absorb light, many substances themselves do not absorb but can be added coloring reagent under certain conditions, or after processing to color and then measured, it is also known as colorimetric analysis. There are many factors that affect the color depth, and due to instruments with less purity of monochromatic light, standard or reference materials should be tested at the same time operation.

It is easy to measure the color of sample. The project uses 10-ml sample cells. These sample cells are matched in only one orientation. For this spectrophotometer, the 10-ml mark is placed to the left (toward the light filter). Besides, the fill marks are intended for measuring the approximate volume of the sample to be tested. They are not intended for measuring standard addition or sample dilution volumes because of the accuracy. Turn on the spectrophotometer, press Stored Programs. Then select the test 120 Color, 455nm. Fill a clean sample cell with 10 ml of sample and fill another clean sample cell with 10 ml of deionized water. After filling, wipe both cells to make sure they are clean. First, insert the deionized water sample into the cell holder with the fill mark facing left, and press Zero. Take the blank out and then place the sample into the cell holder with the fill mark facing left. The last step is to press Read and then results are out. The results are the color of samples.

3.2.3 Iron

Iron analysis process is similar to that of color analysis. FerroVer method (Iron, Total, Method 8008) is used in the project with FerroVer iron reagent powder pillow. First, select the test 265 Iron, FerroVer. Transfer 10 ml of sample into a clean square sample cell. All contents of one pack of FerroVer iron reagent powder pillow are added to the sample cell and then swirl it to mix for a while. If iron exists, an orange color will form. If too much iron is present in sample, then the color will be strong orange. From the color, it can be inferred if there is too much iron. The method can only measure samples of which the range of contained iron is from 0.02 to 3.00 mg/L. So when the color shows as strong orange or like blood red, it usually indicates that concentration of iron exceeds 3.00 mg/L. In the project, samples are diluted when there is too much iron. The way of dilution is to add 3 ml of sample with 7 ml of deionized water to sample cell. After the addition and swirl done, press TIMER>OK on screen and a three-minutes reaction period begins. It means waiting for 3 minutes before measuring. In the meanwhile, transfer 10 ml of sample into a second clean cell which is called blank. When the timer expires, wipe clean both of the sample cells and insert the blank one into the cell holder with the fill mark towards left. Press ZERO and the display shows 0.00 mg/L Fe. After zero, the other prepared sample is placed into the cell holder with the fill mark towards left. Press READ and results (Figure 10) can be seen in mg/L Fe on the screen. (Hach Company, 2007)

Figure 10. Iron analysis

3.2.4 Turbidity

Turbidity refers to the degree of obstruction in the presence of suspended solids in the water. Suspended matter in water is generally soil, sand, fine organic and inorganic matter, plankton, microbial and colloidal substances. The turbidity of water is not only related to the amount of suspended matter in water, but also to their size, shape and refraction coefficient. Suspended matter can make the water becomes turbid and showing a certain turbidity. Water quality analysis provides: the turbidity formed by 1 L water containing 1 mg SiO_2 is a standard unit of turbidity, referred to as 1 degree. Usually the higher the turbidity, the more turbid solution. Turbidity can be measured with a nephelometer. The nephelometer emits light through a sample and detects how much light is scattered by the particles in the water in a direction 90° from the incident light. This scattered light measurement method is called a scattering method and any real turbidity must be measured in this way. The nephelometer is suitable for both field and laboratory measurements and is also available for continuous monitoring throughout the day.

In this project, HACH 2100N IS turbidimeter (Figure 11) is used for measuring turbidity. It contains a tungsten-filament lamp and a 90° scatter detector. Some disturbances should be taken care of. Strongly colored waters can absorb light and that causes lower NTU (nephelometric turbidity unit) results. Besides, make sure that there are no air bubbles in the samples before measurement. Turbidity is preferably measured on the sampling day. Nephelometer should be calibrated in advance and be warmed up for at least 30 minutes before measuring.

First, take a clean and empty sample cell, then rinse it two times with the sample to be measured. After rinse, transfer the sample into sample cell to the line (about 30 ml) and put the cap on the sample cell promptly. Clean the sample cell with soft tissue to remove outside water and fingerprints. Few drops of silicone oil are used to smear the cell from the top to the bottom. Then use the oiling cloth to smear the oil equally on the surface of the sample cell. The excess oil is removed and make sure that the sample cell is almost dry. Put the sample cell upside down slowly and gently for a while to fully mix the sample. Make sure that there is no air bubbles in the sample cell during mixing. Align the triangle mark on the sample cell with the reference mark on the sample cell holder while inserting the sample cell into the sample holder. Then close the equipment cover and result is read when it is stable.

Figure 11. To measure turbidity

3.3 Results and discussions

The project was conducted in two parts. Part 1 is that keep the concentration of PIX 100 ml/m^3, which is 1.26 ml in diluted PIX solution. Four samples were run with Flocculator 2000 at the same time. Dosage of PIX was controlled constant as 1.26 ml while the pH scales were 3.95, 4.54, 5.03 and 5.53, respectively. This part is to find the optimal pH levels in treatment.**Table 3. Analyses in part 1**

Beaker	1	2	3	4
pH	3.95	4.54	5.03	5.53
PIX(ml/m^3)	100	100	100	100
COLOR(mg/L PtCo)	283	41	53	55
IRON(mg/L)	2.89	1.73	2.07	2.15
TURBIDITY(NTU)	16.9	1.33	2.03	3.22

In part 1, the results of analyses of color, iron and turbidity are in the table above (Table 3.). There was too much iron in sample 1. So the value of iron in above table is after the dilution, 3 ml of sample and 7 ml of deionized water. The original result should be 9.63. It can be seen easily from the table above that the sample in beaker 2, of which the pH scales were 4.54, performed the best.

For COD analyses, two deionized water samples (10 ml of each) were taken as blank, labeled as 0-1 and 0-2. Two samples were taken from beaker 1 and both diluted to 5 ml of sample with 5 ml of deionized water, labeled as 1-1 and 1-2. Two samples were taken from beaker 2, one not diluted (10 ml of sample), labeled as 2-1, and the other one diluted to 5 ml of sample with 5 ml of deionized water, labeled as 2-2. Two samples were taken from beaker 3, one not diluted (10 ml of sample), labeled as 3-1, and the other one diluted to 5 ml of sample with 5 ml of deionized water, labeled as 3-2. Two samples were taken from beaker 4, one not diluted (10 ml of sample), labeled as 4-1, and the other one diluted to 5 ml of sample with 5 ml of deionized water, labeled as 4-2.

As mentioned, COD_{Mn} (mg/L) is calculated with the following formula:

$COD_{Mn} = (V_2 - V_1) * c_1 * 800 * f$, where,

V_1 = volume of sodium thiosulphate, which is used in titration of the sample, mL.

V_2 = volume of sodium thiosulphate, which is used in titration of the blank, mL.

c_1 = concentration of the sodium thiosulphate (mol/L).

800 = factor, half of the molar mass of the oxygen, which is changed to milligrams by dividing it with the volume of the sample (16/2) * (1000/10).

f = dilution factor, the volume of the diluted sample divided by the volume of the undiluted sample (in this project, f=1 when not diluted, f=2 when diluted).

Table 4. Volumes of sodium thiosulphate in part 1

Sample	V_2 (ml)	V_2(average)	V_1 (ml)
0-1	2.16	2.155	-
0-2	2.15		-
1-1	-	-	1.75
1-2	-	-	1.73
2-1	-	-	1.82
2-2	-	-	1.99
3-1	-	-	1.75
3-2	-	-	1.95
4-1	-	-	1.66
4-2	-	-	1.91

In this part 1 calculation, V_2 is taken average as 2.155 ml, which was used in titration of the blank.

Take sample 1-1 for example:

COD(1-1) = $(V_2 - V_1) * c_1 * 800 * f = (2.155-1.75) * 0.01 * 800 * 2 = 6.48$ mg/L. Sample 1-1 was diluted, so f was 2.

Take sample 2-1 for example:

COD(2-1) = (V_2 - V_1) * c_1 * 800 * f = (2.155-1.82) * 0.01 * 800 * 1 = 2.68 mg/L. Sample 2-1 was not diluted, so f was 1.

Other samples were calculated in the same way. Results are in the table below (Table 5.).

Table 5. Results of $\mathrm{COD_{Mn}}$ in part 1

Sample	1-1	1-2	2-1	2-2	3-1	3-2	4-1	4-2
pH	3.95		4.54		5.03		5.53	
COD(mg/L)	6.48	6.80	2.68	2.64	3.24	3.28	3.96	3.92
COD(average)	6.64		2.66		3.26		3.94	

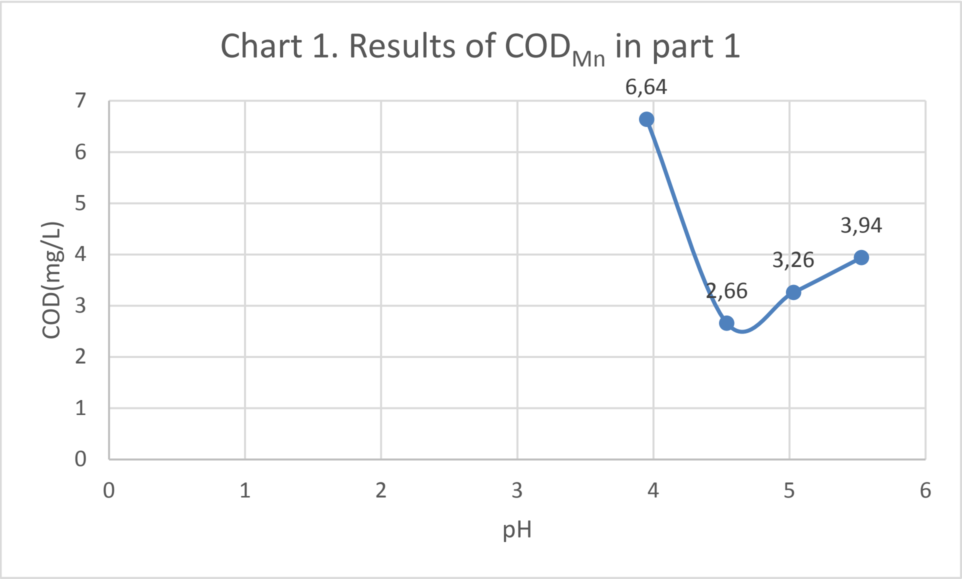


Chart 1. Results of $\mathrm{COD_{Mn}}$ in part 1

As shown in the chart above, values of COD goes down until the point around 4.5 and then goes up. It indicates that when the concentration of PIX keeps invariable as 100 ml/m^3, the optimization of pH is 4.5.

Part 2 is related to part 1. Results from part 1 shows that when pH is around 4.50, treatment effect is the best. So in part 2, keep pH scales around 4.50 in each beaker and add four different dosage of PIX into corresponding beakers. This part is to find out the optimal dosage of PIX in treatment.

Table 6. Analyses in part 2

Beaker	1	2	3	4
PIX(ml/m^3)	85	95	105	115
pH	4.49	4.50	4.51	4.56
COLOR(mg/L PtCo)	103	50	53	65
IRON(mg/L)	1.11	1.81	2.08	2.16
TURBIDITY(NTU)	3.47	1.84	1.99	2.87

In part 2, the results of analyses of color, iron and turbidity are in the table above (Table 6.). There was too much iron in sample 1. So the value of iron in above table is after the dilution, 3 ml of sample and 7 ml of deionized water. The original result should be 3.70. It can be seen easily from the table above that the sample in beaker 2, of which the concentration of PIX was 95 ml/m^3, performed the best.

For COD analyses in part 2, labels, dilution and calculation are the same as those in part 1.

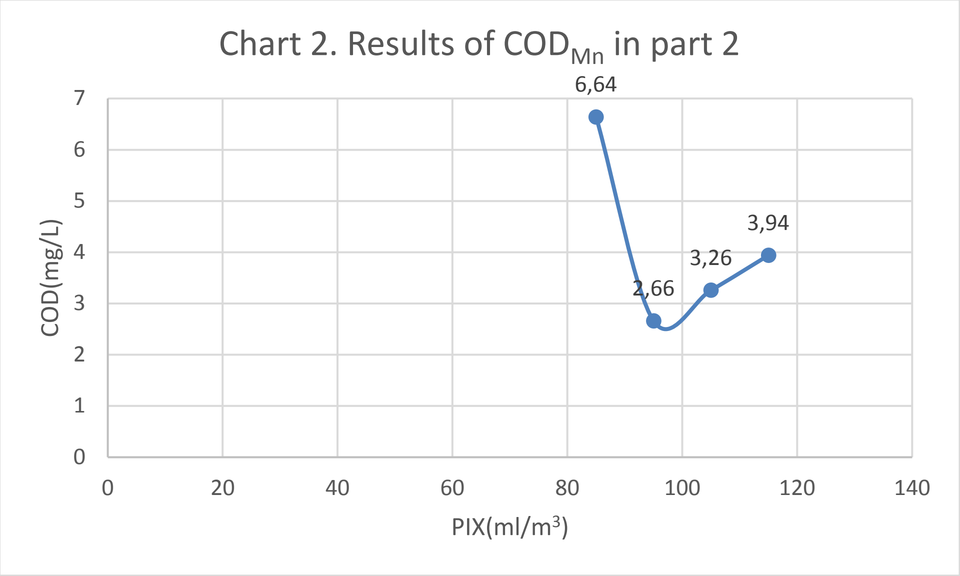
Table 7. Volumes of sodium thiosulphate in part 2

Sample	V_2 (ml)	V_2(average)	V_1 (ml)
0-1	2.31	2.295	-
0-2	2.28		-
1-1	-	-	2.03
1-2	-	-	2.01
2-1	-	-	1.95
2-2	-	-	2.12
3-1	-	-	1.88
3-2	-	-	2.09
4-1	-	-	1.80
4-2	-	-	2.04

In this part 2 calculation, V_2 is taken average as 2.295 ml, which was used in titration of the blank. Results are in the table below (Table 8.).

Table 8. Results of COD_{Mn} in part 2

Sample	1-1	1-2	2-1	2-2	3-1	3-2	4-1	4-2
pH	4.49		4.50		4.51		4.56	
PIX(ml/m^3)	85		95		105		115	
COD(mg/L)	6.48	6.80	2.68	2.64	3.24	3.28	3.96	3.92
COD (average)	6.64		2.66		3.26		3.94	



As shown in the chart above, values of COD goes down until the point around 95 and then goes up. It indicates that when the pH scales keep invariable as 4.50, the optimization of concentration of PIX is 95 ml/m^3.

Results of COD analyses are the main data to judge the quality of the treatment water. Combining both parts, it can be seen that when the pH level is 4.5 and concentration of PIX is 95 ml/m^3, the treatment reaches the optimization. From the analyses of color, iron and turbidity, although the differences not too much, the sample 2 in part 1 and the sample 2 in part 2 still performed the best. In summary, Optimization of chemical surface water treatment in this lab-scale test is that pH scales are 4.5 and concentration of PIX is 95 ml/m^3.

4 COMPARISON WATER QUALITY RESULTS FROM SAVONIA'S PILOT PLANT

4.1 Hypothetical values of parameters in analyses based on project

All samples were taken from the output after the flotation process. Analyses at the surface water treatment were conducted in two parts. Due to the results obtained from lab-scale project tests, the hypothetical optimal value of pH is 4.5 and value of concentration of PIX is 95 ml/m^3. Adjustments of the pH level and the PIX level can be easily done by setting values on the pilot plant operation interface and it runs automatically. In practice, pH value should be set a little higher than 4.5 such as around 5.0, so real pH level is around 4.5. Due to the operation of supplying PIX is pumping dose into water tank at a certain rate, values of PIX should time 1.2 to get the practical set value. For example, 95 times 1.2 to get 114, then the practical value is 114 ml/h. The analyses were to find out whether the values are optimal or not in fact.

Part 1 was divided into three small parts: part A (sample A), part B (sample B) and part C (sample C). Part 1 was to keep the pH at the level of 4.5 and change the dosage of PIX for each small part. Part 2 was also divided into three small parts: part D (sample D), part E (sample E) and part F (sample F). Part 2 was to keep the pH at the level of 5.0 and change the dosage of PIX for each small part. The pH levels and PIX levels are shown as Table 9 and Table 10 in a theoretical way.

Table 9. PIX and pH theoretically adjusted in part 1

Sample	A	B	C
PIX(ml/m^3)	80	95	110
pH	4.50	4.50	4.50

Table 10. PIX and pH theoretically adjusted in part 2

Sample	D	E	F
PIX(ml/m^3)	80	95	110
pH	5.00	5.00	5.00

For COD analyses, two deionized water samples (10 ml of each) were taken as blank for each analysis of sample, labeled as A-0-1 and A-0-2 in part A, as B-0-1 and B-0-2 in par B, as C-0-1 and C-0-2 in part C, as D-0-1 and D-0-2 in part D, as E-0-1 and E-0-2 in part E, as F-0-1 and F-0-2 in part F.

Two samples (10 ml of each) were taken from sample A and both not diluted, labeled as A-1-1 and A-1-2 in part A. Similarly, B-1-1 and B-1-2 in part B, C-1-1 and C-1-2 in part C, D-1-1 and D-1-2 in part D, E-1-1 and E-1-2 in part E, F-1-1 and F-1-2 in part F. Then factor f is 1.

Two samples were taken from sample A and both diluted to 5 ml of sample with 5 ml of deionized water, labeled as A-2-1 and A-2-2. Similarly, B-2-1 and B-2-2 in part B, C-2-1 and C-2-2 in part C, D-2-1 and D-2-2 in part D, E-2-1 and E-2-2 in part E, F-2-1 and F-2-2 in part F. Then factor f is 2.

Calculation process is in the same way as that of lab-scale project analysis.

4.2 Results and discussions

Methods of analyses and calculation were in the same way as those of the lab-scale project. Results are presented in part 1 and part 2.

Table 11. Analyses in part 1

Sample	A	B	C
pH	4.55	4.52	4.49
PIX(ml/m^3)	80	95	110
COLOR(mg/L PtCo)	23	18	134
IRON(mg/L)	1.32	1.18	1.74
TURBIDITY(NTU)	2.04	2.10	5.66
COD(mg/L)	2.54	2.28	4.56

In part 1, the results of analyses of color, iron and turbidity are in the table above (Table 11.). There was too much iron in sample C. So the value of iron in above table is after the dilution, 3 ml of sample and 7 ml of deionized water. The original result should be 5.80. It can be seen easily from the table above that the sample B performed the best in general.

In the calculation of COD analyses of this pilot plant, V_2 (volume of sodium thiosulphate, which is used in titration of the blank) and V_1 (volume of sodium thiosulphate, which is used in titration of the sample) are skipped in the thesis text. Results of COD analysis in part 1 are also presented in Table 11. It can be seen that sample B performed the best, where pH was 4.52 and the concentration of PIX was 95 ml/m^3.

Table 12. Analyses in part 2

Sample	D	E	F
pH	5.07	5.05	5.09
PIX(ml/m^3)	80	95	110
COLOR(mg/L PtCo)	80	27	59
IRON(mg/L)	2.69	1.21	2.27
TURBIDITY(NTU)	3.27	2.15	2.69
COD(mg/L)	4.20	2.44	3.40

In part 2, the results of analyses of color, iron and turbidity are in the table above (Table 12.). It can be seen easily from the table above that the sample E performed the best in general. Results of COD analysis in part 2 are presented in Table 12 as well. It can be seen that sample E performed the best, where pH was 5.05 and the concentration of PIX was 95 ml/m^3.

Synthesizing the results shown in Table 11 and Table 12 , sample B was the best performance, where the pH level was 4.52 and the concentration of PIX was 95 ml/m^3. This indicates that the results accord with the assumed optimal values. The values, which the pH level is 4.5 and concentration of PIX is 95 ml/m^3, could be used in further experiment or plant tests.

5 INTRODUCTION OF THE NEW FLOTATOR SYSTEM

5.1 Overview and introduction

In this thesis one of the main issues was to put a new flotator in to operation for the first time. The idea was to feed water into a new flotator from the Savonia's surface water treatment unit right after flocculation. Water supplied to the flotator flows via a connecting input pipe (Figure 17) and the incoming water is then immediately mixed with dispersion water. Due to the first use, some adjustment should be done before taking the flotator into operational use.

This new flotator is WISER Flotator WPF-1. The flotator (Figure 12) is for field work such as treating water in mine work. There are no processes after flotation for temporary such as disinfection and sand filtration. The main principle is the same as pilot plant flotation. In the tube there is a nozzle, which play the role of forming and producing micro bubbles. Micro bubbles released from dispersion water keep the flocs floating on the surface until the scraper removes them to the sludge exit. There is a bottom sludge removal valve for removing some solids which collects at the tank bottom. The dispersion water pump sucks both air and water and pressurizes the mixture. As not all air can dissolve in water, excess air or big bubbles are bled out of the water through a hosepipe to the tank to avoid disturbing the flotation. Water level is related to flow. So flow is better to be controlled in a reasonable range or some water may overflow to the sludge trough at higher flow conditions.

The dispersion water nozzle is for the formation and production of micro bubbles. Pressurized air and water from dispersion water pump (Figure 13) is supplied to the nozzle. Pressurized air is used to control the water pressure and it can release the pressure periodically. The pressurized water contains dissolved air, which is released to form micro bubbles when the pressure is reduced at the nozzle. The nozzle can keep the water pressure almost constant in a range of flows.

5.2 Operation and adjustment of the flotator

The main operation of new flotation is not very complex, but still some detail to be payed attention to in practice. First ensure that electricity and pressure air connections are plugged into the apparatus. Fill the apparatus with clean water. Open Valve 1 (V1, Figure 13) fully so water starts to flow.

In the pneumatic control cabinet there is the pressure regulator. Check that the regulator to the nozzle pressure is set to approximately 2-4 bar. Ensure than the air rotameter (I1, in the cabinet on the left, Figure 14) is open. Turn on electric power and push the main buttons. Start-up pump then the pump and the scraper timer start. Use the pressure regulator to adjust the air pressure to the nozzle so that water pressure in the piping system is between 7 to 7.5 bar. The value of pressure regulator is close to that of water pressure panel, but not same. Then make sure that the piping system is filled with water by ensuring that there is no visible air bubbles in the water rotameter (I2, Figure 15). Every time the whole system on, water should be clean for a while then to be treated water flows. (WISER, 2016)

Close V1 very slowly until the ball in air rotameter (I1) starts hopping around 1.5 l/min, which is easily overdone. V1 is fully open at the beginning, where piping system is filled with water. Rotate the V1 30-40 degrees, the values of air rotameter shows 1.5. As the angle increase, the greater the value of air rotameter, until air rotameter reads around 1.5 l/min. After that, the more the degrees, the smaller the value.

Water pressure decreases about 0.5 bar when air input is started. Then air rotameter increases a little from 1.5 l/min because of the reduced water pressure. So reduce air input to air rotameter by turning the adjusting screw to make the value around 1.5 l/min. Then water rotameter (I2) flow should be 12-15 l/min. I2 can also be adjusted by turning the screw on it. The air bleed valve (V3) is installed to the highest part of the pipeline connecting the dispersion water pump and the nozzle. Ensure that the valve(V3, Figure 16) is partially open to allow a small stream of mixture of excess air and water to be moved to tank. Until here, most important operations have been completed. (WISER, 2016)

Micro bubbles should be working now and a thin foam layer should be formed on the surface of the water. Then pressure of scraper should be adjusted to 3-4 bar and the velocity of working movement of scraper should be adjusted to 30-40 mm/s. When the flotation process needs to be stopped, the production of dispersion water still needs to be kept on going even though no water is flowing in for treatment.

Figure 12. New flotator

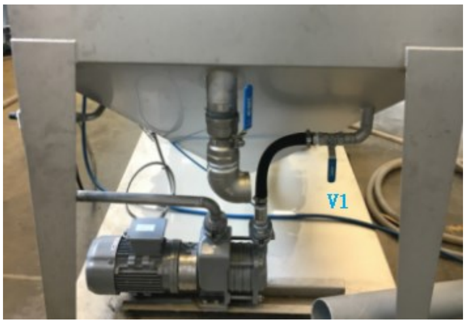


Figure 13. Dispersion water pump and V1

Figure 14. I1

Figure 15. Water rotameter (I2)

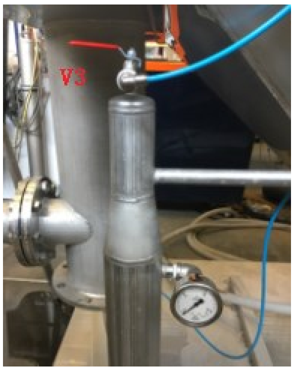


Figure 16. Valve 3

At the beginning after putting flotator in use first time, it was noted (by eyes and analyses) that flotation doesn't work as expected. Reason for that tried to find from the flotator's manual but the process didn't work with any adjustments. Then it was noticed that the hosepipe (Figure 17) connecting the new flotator and the Savonia’s flocculation tank was too narrow, so the treatment effect was not good at all because formed flocs were probably broken before taken into the flotator. It was also seen that in flocculation stage the flocs were formed as supposed. After this observation a big intake pipe (Figure 18) with a new flocculation tank (Figure 19) was installed to the flotator. After installing a new bigger pipe, it was noticed that the flotation process started to work better.

Analyses were conducted in four parts, original sample 1, original sample 2, original sample 3 and original sample 4. The pH level was always 4.5 and the concentration of PIX was always 95 ml/m^3. First the big mixer in the flocculation tank was set to 9 Hz and the system ran for a while. Then original sample 1 was taken from output of the new flotator into a container. Two samples were taken from this container, both diluted to 5 ml of sample with 5 ml of deionized water, labeled as 1-1 and 1-2. Blank samples are always labeled as 0-1 and 0-2.

System continued to run for about three hours after taking sample 1, and then sample 2 was taken. This is for checking the stability of the new system. Two samples were taken from original sample 2, both diluted to 5 ml of sample with 5 ml of deionized water, labeled as 2-1 and 2-2.

Keep the mixer in the flocculation tank off and the system running for over 8 hours, then take original sample 3. Two samples were taken from original sample 2, both diluted to 5 ml of sample with 5 ml of deionized water, labeled as 3-1 and 3-2.

There are three walls (Figure 20) inside the flocculation tank which can be turned on or off. All three inside walls were on before. Keep the mixer at 9 Hz with two of the three walls off. The system ran for over 8 hours and sample 4 was taken. Two samples were taken from original sample 4, both diluted to 5 ml of sample with 5 ml of deionized water, labeled as 4-1 and 4-2.

Figure 17. Previous hosepipe

Figure 18. Big in take pipe

Figure 19. New flocculation tank inside

Figure 20 New flocculation tank

5.3 Results and discussions

The results of analyses of color, iron and turbidity are in the table below(Table 13). There was too much iron in all samples. So iron analyses were conducted after the dilution, 3 ml of sample and 7 ml of deionized water. The final results are in the Table 13. Also included in Table 13, V_1 is the volume of sodium thiosulphate, which is used in titration of the sample. V_2 is the volume of sodium thiosulphate, which is used in titration of the blank.

Table 13. Analyses in treatment by new flotator

Sample	1-1	1-2	2-1	2-2	3-1	3-2	4-1	4-2
pH	4.5							
PIX(ml/m^3)	95							
COLOR(mg/L PtCo)	690		514		516		590	
IRON(mg/L)	20.70		15.90		17.70		18.20	
TURBIDITY(NTU)	24.3		18.9		20.1		20.8	
V_2 (ml)	1.90						1.92	
V_1 (ml)	-	1.03	-	1.20	-	1.25	1.27	1.26

As for the COD analyses, some results are not included in the calculation when they are obviously wrong for mistakes. Results are shown as Table 13 and Table 14..

Table 14. Results of COD_{Mn} of original sample 1-4

Sample	1-1	1-2	2-1	2-2	3-1	3-2	4-1	4-2
COD(mg/L)	-	13.92	-	11.20	-	10.4	10.40	10.56
COD(average)	13.92		11.20		10.40		10.48	

From the results of analyses of color, iron and turbidity in Table 13 it can be seen that original sample 2 performed best while original sample 3 followed. Original sample 2 performed better than original sample 1 because the system needs about 8 hours to stabilize. Original sample 2 was taken three hours after original sample 1, when the stabilizing time was over 8 hours. Results indicate that when the frequency of flocculation mixer was 9 Hz and all three walls were on, the system performed better.

From the results of analyses of chemical oxygen demand in Table 14, it can be seen that the performance of original sample 2, original sample 3 and original sample 4 is similar. But original sample 4 performed better than original sample 2, which indicates that when the frequency of mixer is 9 Hz, one of the inside walls of flocculation tank off is better then all three on. Original sample 3 performed a little better then original sample 4 indicates that when mixer is off, the system treatment is better. This is probably because the flocculation process has some problems. Flocculation should help improve the treatment by effectively flocculating impurities in water. So the mixer in the new flocculation tank could slow a little to avoid breaking the balance of formation and maintenance of flocs and more inside walls could be off to test the way of effecting flocs. There is also a balance between breaking flocs and forming flocs with the inside walls.

Besides, the new flotator tank is bigger than the Savonia’s flotator tank. So the flocculation process could perform better with a bigger flocculation tank in the new flotator system. In addition, the mixing speed of the flocculation in Savonia’s plant gradually decreases with the rotation frequency. So the new system could need one or two more flocculation tank to be connected to the new flotator. The rotation frequency of new mixers should also gradually decrease in the flocculation tanks in order.

6 CONCLUSIONS

The Savonia’s surface water pilot plant can treat water effectively. Results indicated that when pH level was 4.5 and concentration of PIX was $95ml/m^3$, the surface water pilot plant treatment reached the optimum. It could be used in further experiment or plant tests.

The Savonia’s pilot plant worked very well with the optimal pH level and the PIX level obtained from the lab-scale test. The new flotator were tested with same PIX and pH levels. However, the results were not even close to those in Savonia’s pilot plant. It is probably because problems in flocculation. Original plan was to use Savonia's flocculation tanks before the new flotator but connection pipe was too small and it broked the flok which has already formed in flocculation tanks. Then new flocculation tank were built with bigger connection pipe but still the results were not as espected.

Before taking the flotator in to the field work, there should be more time for testing the new flotator system. Some improvements could be applied to the new flotator system based on the analyses and the Savonia’s plant system. They are: 1) Expand the volume of new flocculation tank. 2) Connect one or two more flocculation tanks. The two ways should improve the new flotator system greatly. After both the improvements tested, there are two more suggestions if the new flotator system still cannot reach good enough treatment effect: 3) Slow down the rotation frequency of mixer to about 7 Hz in flocculation tank. 4) Turn the two inside walls of flocculation tank off.

7 REFERENCES

Alemayehu, Z. *Dissolved Air Flotation* [pdf] [accessed 7 April 2017]. Available from: https://www.ircwash.org/sites/default/files/259-72WA-1.pdf

Chinese Environmental Protection Agency. (2002). *Analysis Method for Monitoring Water and Waste(Fourth Edition).* Beijing: Environmental Science Press in China.

Gao, M., Gao, N., Zhou, J., Rong, W., Lu, N. & Yuan, J. (2014). *Comparison of pilot effect between sedimentation and dissolved air flocculation for the treatment of Taihu Lake water*. Journal of Harbin Institute of Technology. Shanghai: Tongji University.

Hach Company. (2007). *Iron, Total, Method 8008*. [PDF] [accessed 6 March 2017] DR 2800 Spectrophotometer Procedure Manual. Germany.

Hach Company. (2012). *2100N IS User Manual.* [PDF] [accessed 6 March 2017].

He, X., Liu, L. & Zhang, C. (2014). *Study on the Production Wastewater Treatment and Reuse of A Cellophane Flotation Mill*. Non-Metallic Mines. Yunnan: Kunming.

Huttunen, U. (2017). *Thesis new version. 27/05*. [email]. Recipient Hai Liu. Sent 28 May 2017. [accessed 28 May 2017].

Janhunen, M. (2017a). *Drinking water production using the surface water pilot plant: Equipment operation, water quality and measurements*. [web document]. Kuopio: Savonia University of Applied Sciences.

Janhunen, M. (2017b). *Household water production using the surface water pilot plant: Introduction to the surface water plant unit processes*. [web document]. Kuopio: Savonia University of Applied Sciences. Available from: http://moodle.savonia.fi/pluginfile.php?file=%2F514076%2Fmod_resource%2Fcontent%2F1%2FHouseHold%20water%20Exercise%201.pdf

KEMIRA. (2006) *Flocculator 2000 Instrction Manual.* [PDF] [accessed 6 March 2017].

Kettunen, J., Utriainen, P. & Janhunen, M. (2014). *Surface Water Pilot Plant Manual*. Kuopio: Savonia University of Applied Sciences.

Li, D., Qin, F. & Zhang, Y. (2012) *Effect of calcium and magnesium ions on Yunnan phosphate flotation and backwater treatment process.* Journal of Wuhan Institute of Technology.

Ma, F., Zhang, J., Yuan, L., Wang, W., Wang, Q. & Wang, A. (2005). *Flocculating Mechanism and Ingredient Analysis of Compound Bioflocculant*. ACTA Scientiae Circumstantiae, 25.

Mao, Y., Zhang, Y., Luo, S. & Yan, Y. (2008) *Advances in Flocculation Mechanism and Research of Water-treatment Flocculants*. Journal of Huazhong University of Science and Technology (Urban Science Edition), 25.

Matikka, V. (2017). *About the values*. [email]. Recipient Hai Liu. Sent 10 April 2017. [accessed 11 April 2017].

Matikka, V. (2017). *Final thesis*. [email] Recipient Hai Liu. Sent 24 May 2017. [accessed 24 May 2017].

Matikka, V. (2017). *Hai Liu VM comments*. [email] Recipient Hai Liu. Sent 19 April 2017. [accessed 20 April 2017].

Matikka, V. (2017). Meeting in school about new flotation system. [accessed 28 April 2017].

Matikka, V. (2017). *Structure of thesis*. [email] Recipient Hai Liu. Sent 2 February l 2017. [accessed 3 February 2017].

Qin, P., Zhang, T. & Chen, C. (2004). *Flocculating Mechanism of Microbial Flocculant MBFTR21*. Environmental Science, 25.

Rubio, J., Souza, M, L. & Smith, R, W. (2002). *Overview of flotation as a mastewater treatment technique.* Minerats Engineering.

Salehizadeh, H. & Shojaosadati, S A. (2001). *Extracellular Biopolymeric Flocculants Recent Trends and Biotechnology Importance*. Biotechnology Advances.

Savonia University of Applied Sciences. (2017) *DETERMINATION OF CHEMICAL OXYGEN DEMAND (CODMn-VALUE OR KMnO4–-NUMBER) IN WATER. OXIDATION WITH PERMANGANATE.* [electronic file] *Kuopio:* Savonia University of Applied Sciences. [accessed 6 March 2017].

Shen, Z., Shi, S., Lu, S. & Liu, H. (2004). *Development Survey of Flotation Equipments(Contd.1)*. Non-Ferrous Metallurgical Equipment. Beijing: Beijing General Research Institute of Mining and Metallurgy.

Shen, Z., Shi, S., Lu, S. & Liu, H. (2005a). *Development Survey of Flotation Equipments(Contd.2)*. Non-Ferrous Metallurgical Equipment. Beijing: Beijing General Research Institute of Mining and Metallurgy.

Shen, Z., Shi, S., Lu, S. & Liu, H. (2005b). *Development Survey of Flotation Equipments(Contd.3)*. Non-Ferrous Metallurgical Equipment. Beijing: Beijing General Research Institute of Mining and Metallurgy.

Tang X. (1996). *The Differences of Behavior and Coagulating Mechanism between Inorganic Polymer Flocculants and Traditional Coagulants*. Chemical Water and Wastewater Treatment VI.Spring-Verlag.

Tong, X. (2014). *Application of Air Flotation Technology in Water Treatment Process.* Oil-Gasfield Surface Engineering. Daqing: Daqing Oil Field Co.

Wang, X., Zheng, W., Ma, J., Ma, S., Liu, X. & Zhang, Q. (2013). *Performance of new flotation system based on high dissolved air content.* CIESC Journal.

WISER Environmental Technology. (2016). *Flotator WPF-1 Installation, operation and maintenance.* Helsinki: Malminkaari5.

Yuan Z., Zheng H., & Shu X. (2001). *Journal of Chongqing University(Natural Science Edition)*, 2001, 24.

Zheng, H. & Liu K. (2004). *Technology of Water Treatment.* [PDF] [accessed 10 March 2017].

Zheng, H. (2004) *Biological Flocculants and Flocculant Technologies*. Beijing: Chemical Industry Press.

Zheng, H., Peng, D., Huang, X. & Liu, H. (2007). *Study on the Spectrum of the Flocculent Conformation of Polymer Ferric Sulfate Flocculants.* Spectroscopy and Spectral Analysis.

Zheng, Q. (2016) *Modification of the micro-bubble whirling air flotation of industrial wastewater system on Mingzhu*. Industrial Water Treatment. Tianjing: CNOOC EnerTech-Safety & Environmental Protection Co.

Zhou, Q., Lin, T., Xie, L. & Tan, X. (2009) *Review of Mechanism of Bioflocculation and Settleability of Activated Sludge Bioflocs* , 37.

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