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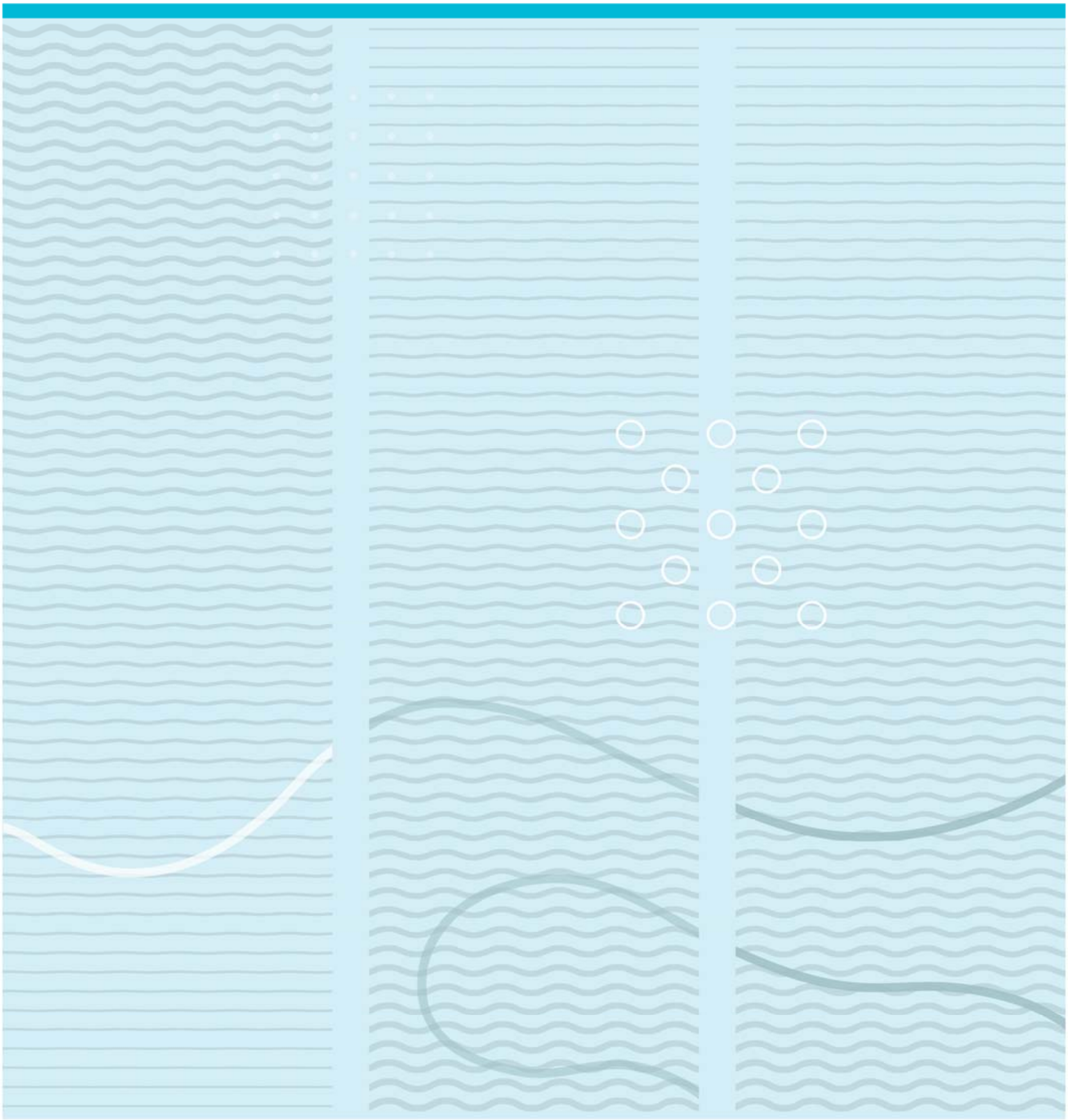
Ingrid Kiær Salmi

Optimization of potable water treatment by coagulation



University College of Southeast Norway
Faculty of Technology
Institute of PEM
PO Box 235
NO-3603 Kongsberg, Norway

http://www.usn.no

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Supervisor: Rune Bakke Sign.: . . . .

2nd supervisor: Hildegunn H. Haugen Sign.: . . . .

Censor: Øystein Svalheim Sign.: . . . .

External partner: Vestfold Vann IKS Sign.: . . . .

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Abstract:

Securing hygienic barriers and also removal of particles, natural organic matter and dissolved minerals are necessary factors in the treatment of surface water. The presence of natural organic matter has increased during the last years in Seierstad's water source Farris and there is a desire to remove organic matter more efficiently at an early stage in the process. The main objective of this thesis is to evaluate alternative coagulants and dosages in order to improve Seierstad's potable water treatment process. The evaluation regards cost and water quality. A Jar test and a pilot plant at Seierstad were used to perform experimental tests and to obtain water quality results. The parameters indicating the water quality are colour, turbidity, organic matter and residual aluminium. The polyaluminium chloride coagulants Ecoflock 91 and 96 seem to be suitable alternatives to the currently used coagulant PAX-16. These coagulants provide good results in terms of water quality and cost. Ecoflock and PAX-16 coagulants provide similar results for the quality parameters, but the content of organic matter is further reduced with Ecoflock. The calculated cost reduction associated with coagulants is 12 % lower with Ecoflock 91 than with PAX-16. In addition, the filtration cycle time is prolonged with Ecoflock 91, which could provide an even greater reduction of the cost. The Jar test results suggest that it could also be advantageous to cut coagulant dosage but this was not verified by the pilot tests, perhaps due to inadequate coagulant mixing in the pilot plant. It is therefore recommended to improve the pilot plant design to obtain appropriate mixing of coagulants with the raw water.

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Nomenclature

HSE	Health, Safety and Environment
NOM	Natural Organic Matter
NTU	Nephelometric Turbidity Unit
mH_2O	Meter water column
PACl	Polyaluminium Chloride
TOC	Total Organic Carbon
USN	University College of Southeast Norway
VV	Vestfold Vann IKS
WTP	Water Treatment Plant

Preface

This master's thesis is the final assignment of the study program Energy and Environmental Technology at University Collage of Southeast Norway (USN). The thesis equals 30 credits and has been written during the spring semester 2016. Vestfold Vann IKS (VV) has commissioned the thesis. Professor Rune Bakke and Hildegunn H. Haugen have been supervisors from USN.

Experiments have been carried out at VV's pilot plant at Seierstad water treatment plant. The laboratory at Seierstad has been used to analyse water samples.

I got the opportunity to work at VV's water treatment plant at Seierstad the summer in advance of the work with this thesis. During this time I got familiar with the water treatment process at VV and pilot plant at Seierstad. A part of the summer job was to prepare and facilitate the work pilot, as it had been out of operation for many years. In addition, we had a group project during the autumn semester. This project had the same scope as the thesis, but a deeper investigation has been made this time around. I have learned a lot about the subject water treatment.

I would like to thank the staff at Seierstad for assisting me during the pilot plant experiments. A special thank you to Ryan Mathisen, who has always been helpful whenever I had practical problems at the pilot. I would also like to thank my grandmother for letting me stay with her in Larvik while working at the pilot plant, and who also made sure I was properly fed during this period. Last but not least, I would like to thank my supervisors Rune and Hildegunn for input and guidance with this master's thesis.

Porsgrunn, June 2016

Ingrid Kiær Salmi

1 Introduction

Available potable water that satisfies quality requirements is a matter of high priority in our society. Treatment of potable water has been developed over thousands of years. The first standard from ancient Sanskrit and Greek writings 4000 B.C. stated that "*impure water should be purified by being boiled over a fire, or being heated in the sun, or by dipping a heated iron into it, or it may be purified by filtration through sand and coarse gravel and then allowed to cool*" (Crittenden & Montgomery Watson, 2005). The standards and regulations today are varied and depend on location.

In Norway, the potable water's chemical and physical quality is set by acts and regulations from the European regulation and Norwegian potable water regulation. The majority of water sources are surface water in Norway, such as lakes and rivers. The greatest challenges in treating surface water are regarding securing hygienic barriers, removal of particles, removal of natural organic matter and removal of dissolved minerals (Ødegaard, Norheim, & Norsk Vann, 2012).

1.1 Main objective

The main objective of this study is to evaluate measures to improve Seierstad's potable water treatment process. By using the pilot plant at Seierstad alternative coagulants and dosages are evaluated by:

- Quality parameters: turbidity, colour, organic matter and residual aluminium
- Performance under different pH ranges
- Filtration cycles – turbidity and pressure loss development
- Optimal coagulant dosage regarding cost-benefit

A Jar test is also conducted to see whether similar and/or useful experimental results as in the pilot plant can be obtained in a smaller scale. Through analysis of data retrieved from the experiments, the aim is to make a recommendation regarding coagulant, based on process performance and cost-benefit.

1.2 Structure of thesis

The first chapter introduces the theme water treatment and provides an overview of the main objectives in this thesis. The following chapter is a theory part describing water treatment as a whole, with a deeper focus on the coagulation process. An overview of the water treatment at Vestfold Vann, and the challenges related to this are presented in chapter 3. Chapter 4 describes the methods used while working with the experiments for this thesis. The results of the experiments performed are presented in chapter 5, followed by a discussion of the results in chapter 6. At the end, chapter 7 presents the conclusion.

2 Theory

There are more than sufficient water resources in Norway and 90 % of the potable water is from surface water. The challenges of surface water sources are often a high content of organic material (Casey, 1997). Natural organic matter (NOM) is defined as organic material, which is present in all water sources. According to Matilainen et.al. there has been an increase of the content of natural organic matter in several areas around the world over the past decades. A reason for this might be the climate changes causing more extreme weather conditions. Furthermore, an increase of NOM will have consequences in the process of treating potable water (Matilainen, Vepsäläinen, & Sillanpää, 2010). Norwegian potable water sources are typically low in turbidity, alkalinity and hardness, and usually high in colour due to natural organic matter (Leiknes, Ødegaard, & Myklebust, 2004). The theory part focuses mainly on natural organic matter in water, in addition to coagulation principles in combination with contact filtration.

2.1 Treatment need in surface water

To secure safe potable water, the treatment processes are dependent on location and water source. In Norway the main challenges related to treatment of potable water are: Removal or inactivation of pathogenic microorganisms as hygienic barriers, removal of particles, removal of natural organic matter, and removal of dissolved metals in water (Ødegaard et al., 2012, p. 136).

Large and deep lakes (like Farris) are usually little affected by contaminations. This is because of intake under a boundary called the “leap layer”, which works somewhat as a barrier against pollution. It is a boundary where a layer of warmer water is above a colder water layer. This is due to the difference in densities in the warm and cold water. During the summer when the water temperature increases, the density difference of the water in the upper layer and the heavier lower layer, results in very little mixing of the water. At a certain depth the temperature decreases rapidly, this is where the boundary leap layer exists. The water temperature reduces towards 4 °C. When the intake of the raw water is below this layer it will prevent pollution to penetrate from the outside, and to some extent act as a hygienically barrier. The ice has this function during the winter. However, when the circulation of the water in the spring and fall period begins, the protection barrier will break down (Ødegaard et al., 2012).

This makes lakes with a deep-water intake preferable, in a deep and large lake. An other advantage with this type of lake is the occurrence of self-cleaning. This is a consequence of long residence time in the water pool, which leads to stable and adequate water quality. With self-cleaning microbiological contamination will reduce, particulate matter will settle, and organic matter will slowly decompose or settle down so the water is often clear or without visible colour (Ødegaard et al., 2012).

In northern parts of the world, where soil and vegetation is frozen and defrosted frequently, the water is often yellowish brown due to content of organic matter. The natural organic matter in potable water was in Norway originally considered an aesthetic problem, due to the unflattering colour. Before the 1980's there were few treatment plants built for removal of organic matter. However, during the last 20-30 years the attention has been more focused on the hazardous by-products that occur with chlorination of water with high organic water (Matilainen et al., 2010).

There are a number of other problems related to natural organic matter in potable water and the potable water treatment process. The water quality reduces due to increase in colour value, and undesirable taste and odour. It will be necessary to use higher dosages of chemicals in the treatment process. A higher addition of chemicals will also lead to higher sludge volume and the production of harmful disinfection by-products. In addition, other disadvantages are biological growth in distribution systems, which leads to larger quantities of adsorbed organic pollutants and complex heavy metals (Sillanpää, 2014).

2.1.1 Particles and organic matter in water

Particles in water lead to unclear water and are usually measured by turbidity. The particles have different origins and include sludge particles, microbiological particles, and erosion and degradation particles. Sludge particles from discharges can be organic and non organic. Microbiological particles consist of viruses, bacteria, parasites, algae and similar. Clay and soil particles are examples of erosion and degradation products. Organic matter in water is a collective term on a number of individual organic substances. These substances are normally characterised in groups as: Natural organic matter (NOM), oxygen consuming substances and organic micro pollutions. There are different analysing methods to determine the content of organic matter in the water. This can be done by biochemical oxygen demand (BOD_5 and BOD_7), chemical oxygen demand (COD) and total organic carbon (TOC). The latter method measures the carbon in the water – which is proportional to the organic matter. High organic content in water is mainly from natural organic matter (NOM) in Norwegian water sources. NOM can have a natural origin or come from emissions from households, agriculture and industry (Ødegaard et al., 2012).

The amount of NOM in raw water has a significant effect for the water treatment. Hydrological and biogeochemical cycles of the environmental surroundings cause the quantity, nature and properties of NOM to vary. Furthermore, the amount of NOM may in addition vary seasonally, because of rainfalls, snowmelt, floods or draughts (Matilainen et al., 2010).

2.2 Removal of natural organic matter

The research related to NOM removal was until 1970's primarily concerning colour removal. Since then there has been several studies and research regarding removal of NOM most efficiently before addition of disinfection. NOM behaves in the same way as colloidal particles, and can thus be removed in the same manner (Ødegaard et al., 2012, p. 231). The most used treatment for removal of NOM worldwide is conventional coagulation/floc separation method. Flow schemes showing the different coagulation/flocculation processes are illustrated in Figure 2-1 (H. Ødegaard, 2010).

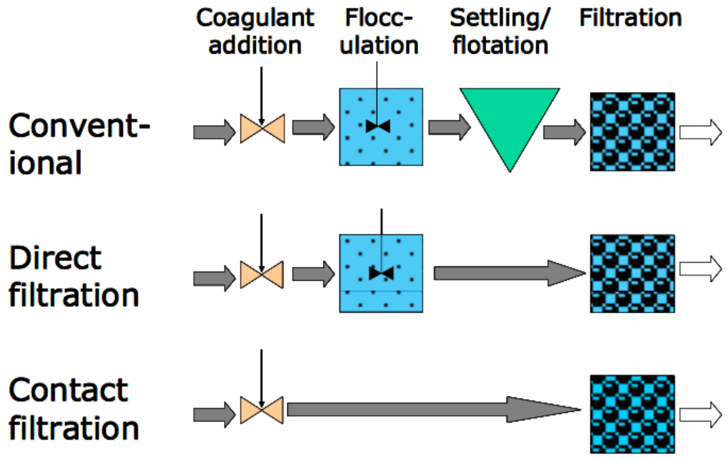

Figure 2-1: Flow schemes of different coagulation/flocculation processes (H. Ødegaard, 2010).

The conventional method is based on the addition of a coagulant, followed by a flocculation process, then followed by settling or flotation of the flocs, and filtration at the end. This method is used for water containing high turbidity. Direct filtration and contact filtration is a shorter version of the conventional. These are the most widely used in Norway as there is typically low turbidity content in Norwegian water. The direct filtration does not have a separated settling/flotation stage, and contact filtration consist of only addition of coagulant before the filtration.

The two most important operating parameters with coagulation of NOM are pH and dosage of coagulation chemicals. Sufficient removal of NOM can be achieved with optimal coagulation conditions, correct pH and dosage. This can be measured by a colour reduction of 80 – 90 %, 50 – 60 % TOC reduction and adequate content of residual coagulant in effluent, i.e. 0.1 – 0.15 mg/L (Al/Fe) (Ødegaard et al., 2012). Other techniques available for NOM removal besides coagulation/filtration are membrane (nano) filtration, oxidation/biofiltration and sorption process (H. Ødegaard, 2010).

2.3 Coagulation and flocculation principles

Small particles in the range of 0.01 – 1 μm, called colloids, will remained suspended because of their size and negative charge. These particulates or colloids stay stable and will not settle by gravity. A coagulation process can destabilize the colloids. This is done by adding a positive charged coagulant, normally salts of aluminium or iron. The metals will neutralize the negative charge of the particle. At the same time the metal ions reacts with the water and precipitate metal hydroxide, which the particulate can connect to. This coagulation process is done in a few seconds, and the particles will be combined into larger masses. These are still very small, typically 1 – 10 μm, but are now charge neutral. When the water at this point is mixed, the small masses will connect to larger flocs (100 – 1000 μm), this process is called flocculation. To separate the flocs in water treatment, the filtration processes is done by conventional, direct or contact filtration (Ødegaard et al., 2012). The overall coagulation process includes coagulation mechanisms and flocculation.

2.3.1 Coagulant types for NOM removal

Coagulants used in water treatment consist of salts of aluminium and ferric ions, and prehydrolyzed salts of these metals. The water type, characteristics of the coagulant, concentration and type of particulates, and NOM determines which coagulant to use (Crittenden & Montgomery Watson, 2005). The most frequently used coagulants are aluminium based, aluminium sulphate and prepolymerised aluminium/polyaluminium chloride (PACl – called PAX in Norwegian) (Ødegaard et al., 2012). Recommended dosages for removal of NOM with coagulation are listed in Table 2-1 together with the optimal pH range for the different chemicals. The suggested dosages and pH ranges are presented on the basis of a number of studies done by Eikebrokk (2010) taken with a water source of colour 30 mg/L (Pt) (Ødegaard et al., 2012, p. 232).

Table 2-1: Recommended pH and dosage of coagulant for NOM removal.

Coagulant	Optimal pH	Min. dosage mg/L (Al/Fe)
Aluminium sulphate	5.8 – 6.6	1.89
Ferric chloride	4.0 – 5.5	6
Polyaluminium chloride	5.7 – 6.7	1.62

To achieve an adequate coagulation the pH must be adjusted to the appropriate area. If the coagulant dosage is reduced, the pH area narrows down. According to another study done by Yan et al. (2008), optimal NOM removal was achieved at pH 5.5 – 6.5 with PACl. This is reasonably consistent with the recommendation of Eikebrokk. Matilainen et al. (2010) gives an overview of different coagulant types used in recent research studies for NOM removal, as well as associated advantages and disadvantages of the use of these. The advantages associated to sulphate and aluminium chloride are high colour removal, readily solvable, stable and easy to handle. These coagulation chemicals is said to be most effective in the pH range of 5 – 6.5. Among the disadvantages listed are high coagulant residuals in effluent water that also gets corrosive and resulting in high alkalinity consumption. In many studies ferric salts have been noted to have better NOM removal. The most effective pH range is suggested to be 4.5 – 6 for Ferric chloride and Ferric sulphate. Ferric salts are less temperature dependent than aluminium salts. Polyaluminium chloride is also less dependent on temperature changes compared with alum salts. In addition, the coagulant can operate in a wider pH range. PACl has lower alkalinity consumption. It also has better NOM removal capacity compared to aluminium sulphate. In addition it requires lower dosages and less sludge is produced. There is lower residual aluminium in the effluent water (Matilainen et al., 2010).

2.3.2 Coagulation mechanisms

The coagulation mechanisms to destabilize particulate matter are referred to as (1) compression of the electrical double layer, (2) adsorption and charge neutralization, (3) adsorption and interparticle bridging, and (4) “sweep floc”. Most of these mechanisms are related and occur simultaneously (Crittenden & Montgomery Watson, 2005, p. 664)

2.3.2.1 Electrical double layer

Colloidal particles with a negatively charged particle surface will remain stable in neutral water because of its surrounding positive counter-ions, causing electron neutrality. Figure 2-2 shows the electrical double layer structure.

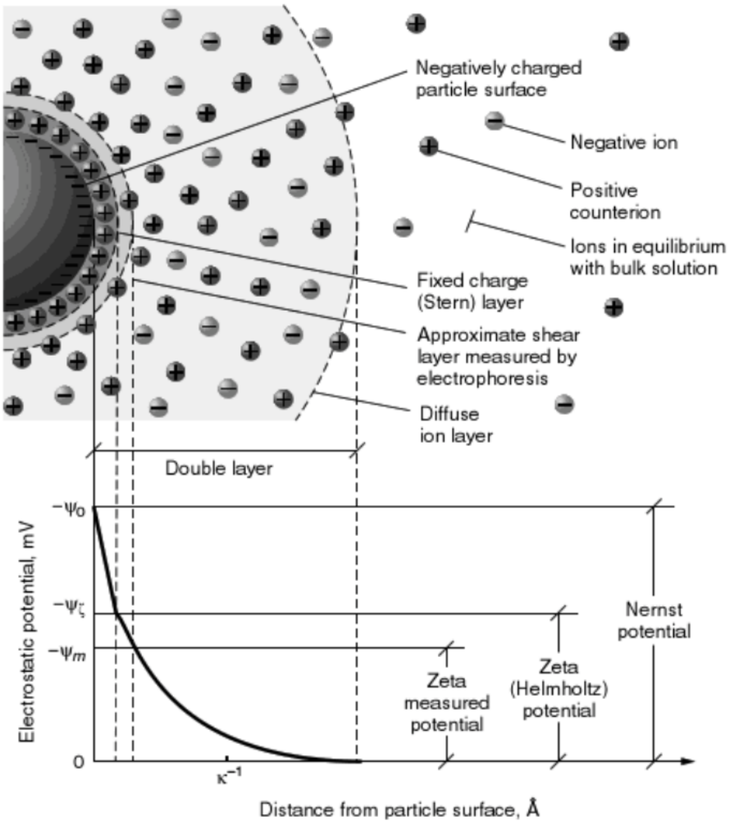

Figure 2-2: Schematic presentation of the electrical double layer (Crittenden & Montgomery Watson, 2005).

The electrical double layer consists of the adsorption (Stern) layer and the diffuse layer. The adsorption layer is where the cations are bound to the surface of the negatively charged particle. The diffusion layer is the layer of cations and anions that extents from the adsorption layer to the bulk solution. The ions move by diffusion, until the momentum of electric potential is eliminated. This occurs when stable condition if from of electric neutrality. The excess concentration of cations then extends to the bulk solution. The thickness of this double layer depends on the ionic strength in the bulk water. With increasing ionic strength, the thickness of the electrical double layer compromises dramatically. The colloids will approach each other when the thickness of the layers reduces. Adding positively charged metal ions would do this. The relation between repulsive electrostatic forces and attractive forces (van der Waals forces) keeps the colloids stable at pH neutral water. Van der Waals forces cause two colloids to approach as a consequence of magnetic and electronic resonance. These forces are proportional to the polarizability of the particle surfaces, and will not overcome electrostatic repulsion. However, when a coagulant is added the repulsive force will be reduced and allows rapid flocculation (Crittenden & Montgomery Watson, 2005).

2.3.2.2 Adsorption and charge neutralization

In the neutral pH range, colloids in natural water are mostly negatively charge. To destabilize the particles hydrolysed metal salts, pre-hydrolysed metal salts, and cationic organic polymers can be used for charge neutralization. The optimum coagulant dosage will increase proportionally to the surface area concentration to a certain point. It is generally when the particle surface is enclosed less than 50 per cent. The particles will be charge neutralized and flocculate when a sufficient dose of polymer has been adsorbed. If the added polymer gets too high, the charge will reverse and become stable in positive charge (Crittenden & Montgomery Watson, 2005).

2.3.2.3 Adsorption and interparticle bridging

Cationic organic polymers are often used in combination with inorganic ions to form particle bridges. Polymer bridging will occur when chains of polymer adsorb on particulate surfaces. The bridging phenomenon is presented schematically in Figure 2-3.

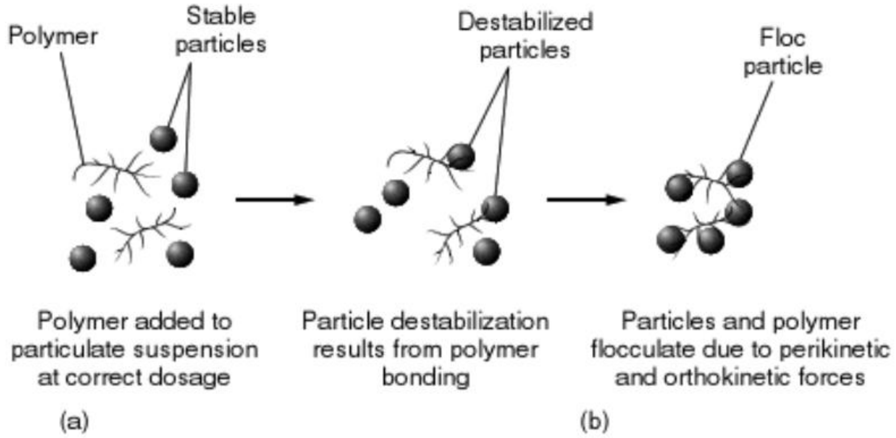

Figure 2-3: Coagulation by particle bridging.

When the correct dosage of polymer as shown in the figure (a), the stable particles will react with the polymer and form polymer bonding, and eventually form floc particles (b). The polymer bridging is sensitive to mixing and dosage of coagulant. If the dosage is too low or the mixing is not sufficient, the reaction will not occur. On the other hand, if the dosage is too high the particles will not flocculate and if the particles are mixed too intense, the bonds will break up (Crittenden & Montgomery Watson, 2005).

2.3.2.4 Sweep floc

Precipitates formed from aluminium and iron can entrain particulate matter in amorphous precipitates. This form of coagulation mechanism is known as precipitation and enmeshment, or sweep floc. The molecular actions leading to sweep floc has not been defined properly, but the procedure of iron and aluminium salts are described as: first ions are hydrolysed and polymerised, secondly hydrolysis products at the interface are adsorbed, and at the end charge neutralization occurs.

Different coagulation mechanisms and efficiency occurs when using Aluminium sulphate (alum) and Polyaluminium chloride (PACl). The latter are often more effective at removing natural organic matter in neutral pH water through charge neutralization and bridging. With alum, sweep flocculation occurs under most practical conditions. Bridging mechanisms and electrostatic patch are more important for PACl. Research focused specially on floc breakage and re-growth process shows that only limited re-growth of broken flocs occurs for alum and PACl. If a small amount of alum is added at the time of floc breakage the re-growth of flocs can be significantly improved (Yu, Gregory, Campos, & Graham, 2015).

2.3.3 Stoichiometry reaction of aluminium coagulants

The formation of hydroxide precipitates in reaction with aluminium is given by the stoichiometric reaction equation R2-1. The subscripts “am” in the equations R2.1 – R2.3 stands for amorphous solids.

$$Al^{3+} \cdot 3H_2O \leftrightarrows Al(OH)_3(am) \downarrow +3H^+ \quad \text{(R2-1)}$$

The hydrogen is released in the formation. It will then react with the alkalinity of the water given by equation R2-2 and give aluminium hydroxide.

$$Al_2(SO_4)_3 \cdot 14H_2O + 6(HCO_3{}^-) \rightarrow 2Al(OH)_3(am) \downarrow +3SO_4{}^{2-} + 14H_2O + 6CO_2 \quad \text{(R2-2)}$$

For water sources with natural low alkalinity, it is necessary to add supplementary alkalinity in the form of caustic soda, lime or soda ash. This is to obtain a sufficient pH buffering. The reaction for aluminium with lime, $Ca(OH)_2$, is given by the reaction equation R2-3 (Crittenden & Montgomery Watson, 2005, p. 678).

$$Al_2(SO_4)_3 \cdot 14H_2O + 3Ca(OH)_2 \rightarrow 2Al(OH)_3(am) \downarrow +3CaSO_4 + 14H_2O \quad \text{(R2-3)}$$

To increase the alkalinity at Seierstad WTP lime is added in the form of micronized marble.

2.3.4 Mixing of coagulant

Initial rapid mixing is required when the coagulant is added, and slow mixing is required for the flocculation process to occur. The coagulation mechanisms occur during the rapid mixing stage. When using inorganic coagulants, such as aluminium and iron salts or polymeric inorganic coagulants the main mechanisms that occur are adsorption and charge neutralization, and sweep floc. While for organic polymers the main mechanisms are interparticle bridging and charge neutralization and adsorption (Amirtharajah, Clark, Trussell, & Foundation, 1991). As the reaction with coagulants occurs within seconds, the mixing is crucial to get a sufficient distribution of the chemical. There are different types of mixers available for water treatment. Static mixers are utilized by obstacles in the flow, which will result in a sudden change in the velocity patterns in addition to momentum reversals. This can promote turbulence, by for example angled vanes in the water pipe, plates connected to the chemical nozzle. Other ways of improving the mixing can be done by propellers or turbines, high speed induction of chemical or by a pressurized water jet mixer (Tchobanoglous, Stensel, Tsuchihashi, Burton, 2014a, p. 332).

2.4 Filtration process in water treatment

The efficiency of the filtration process is dependent of two equally important sequences, the filtration and backwash process. Filters with dual media are advantageous compared to single media in terms of adapting a larger area of the filter bed. Because of the different densities of the medias, such as sand and anthracite, the filter settles in different layers after back flushing. In normal operation, the material to be removed is gradually filtered through the area so that the depth is better utilized. This makes it possible to maintain a longer filtration cycle before flushing (Ødegaard et al., 2012, p. 195).

Contact filtering is a method where the raw water is added a coagulant and flows directly to the filter, without any other types of separation. This is a common way of filtering when the particle concentration from the raw water is low (Ødegaard et al., 2012). At Seierstad the coagulant is added some distance before the filters, causing floc formation. When the polymer is added just prior to the filtration, these flocs compose into larger flocs. These will be captured in the filter medium. When the filter has been in operation for some time it needs to be cleansed from all the deposited material. The filter is then backwashed by water flowing upstream in the filter. The flow rate of the backwash water has to be sufficient enough for the filter bed to fluidize and the deposited material to be released, but not so high that the filter media will be carried away with the flush water. The optimal expansion of anthracite is approximately 25 % and 37 % for sand (Crittenden & Montgomery Watson, 2005).

Different aids and methods can be adapted to optimize the coagulation/filtration process. Jar tests can be used to find the optimum coagulant dosage. Pressure drop curves can be analysed to look at the development of pressure through the filter, and turbidity and pressure drop can be used to look at the filter cycle.

2.4.1 Filtration cycle time

The filtration time is determined by one of two factors: when the head loss over the filter or when the turbidity of the cleaned water is too high. Optimal operation would be to achieve both of these factors to occur simultaneously. Figure 2-4 shows the filtration cycle with the development over time of a) turbidity and b) head loss.

When the filter run starts the head loss increases steadily, until a certain time (t_{HL}) where the head loss reaches the available head. After a backwash of the filter the turbidity peaks in the beginning of a filter cycle; this period is called the ripening period. Then the turbidity stabilizes at a certain value and keeps steady in an effective filtration period until the turbidity reaches breakthrough (t_B). The turbidity then increases rapidly. This happens when the shearing forces in the water flow exceeds the strength of the bond formed between the filter and the matter being filtered. At this point, the material clogged in the filter will extricate continuously when new suspended material from the raw water enters the filter (Tchobanoglous, Stensel, Tsuchihashi, Burton, 2014b, p. 1133).

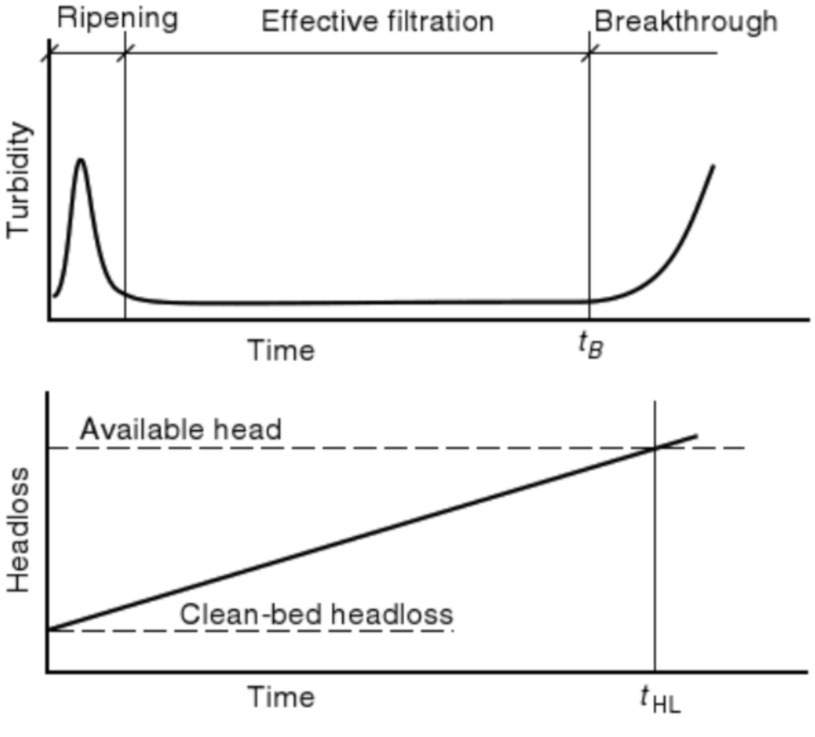

Figure 2-4: Filtration cycle of: (a) turbidity over time (b) head loss over time (Crittenden & Montgomery Watson, 2005).

2.4.2 Pressure drop curves

When the filter is in operation it restrains material and this cause a build up in pressure. If negative pressure occurs at inside the filter it might result in air binding. This is formation of gas bubbles in the filter, which can lead to release of the accumulated solids in the filter media into the effluent water. This can cause problems in filter operation. To investigate the development of pressure within the filter, pressure drop curves can be used. The principle is to use risers at various depths at the filter, to see the water heights at different times. This makes it possible to follow the progress of the pressure drop over time (Droste, 1997). Figure 2-5 shows a filter bed with pressure curves at different times during the filtration process. The static pressure, when there is no water flow, is marked as the 45° line in the figure. According to Darcy's law, once the water begins to flow through a clean filter the pressure will be a linear function of the height of the filter (Droste, 1997). As time passes, the filter curves will show the distribution of material hold back in the filter. The solid removal will be concentrated in the upper layers, and as a consequence of this the pressure drop will also be highest in this area.

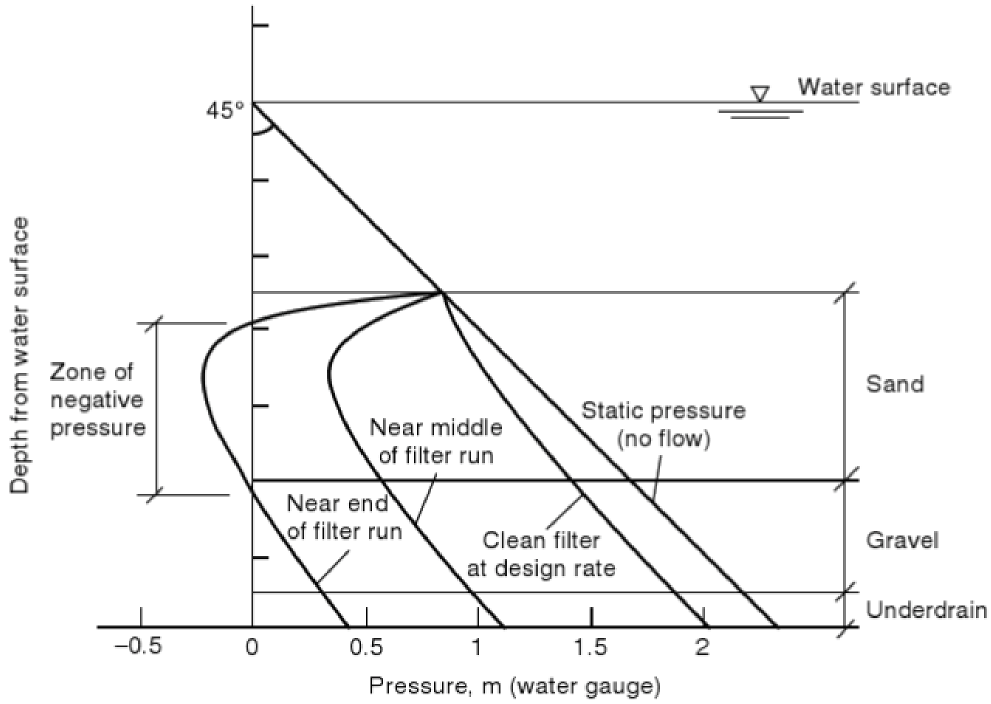

Figure 2-5: Pressure development in filter at different times (Crittenden & Montgomery Watson, 2005).

This is also seen in multimedia filters, but because of the different properties of the filter medias the pressure loss will develop slightly different. The concentration of deposited material at different times, is at the depth where the curves goes from the skewed lines to when it is linear with the clean filter line. The head loss after a certain period of time is the horizontal distance between the pressure curve and the clean filter curve.

3 Process description

This chapter presents a general description of the water treatment at Vestfold Vann IKS and Seierstad, including the water source Farris. Some of the challenges related to the potable water treatment are also presented.

3.1 Water treatment at Vestfold Vann IKS

Vestfold Vann IKS (VV) is an inter-municipal cooperation between ten municipalities in Vestfold County. There are two water treatment plants, Seierstad in Larvik city and Eidsfoss, which is located north of the county. VV produces and supplies approximately 24 million m^3 of potable water every year, to the municipals of roughly 160,000 residents. In the course of one year, the distribution of portable water is about 65 % from Eidsfoss and 35 % from Seierstad ("Vestfold Vann IKS," 2015). The water source at Eidsfoss is Eikeren, which is lake of 27.7 km^2. The treatment at Eidsfoss is done by filtration with marble gravel for carbonation, followed by disinfection by chlorination and ultra violet radiation. The quality of the potable water from Eidsfoss and the treatment method used at this place is satisfactory. The treatment plant at Seierstad receives water from Farris. The water treatment process at Seierstad is done by chemical coagulation and filtration for removal of suspended solids and colour. For carbonation liquid micronized marble is added. The disinfection is done by chlorination.

3.2 Farris as a potable water source

The 21.1 km^2 lake Farris is a water source for approximately 200,000 inhabitants, and is thus one of Norway's most important potable water lakes. The water treatment plants connected to this lake is "Vestfold Vann IKS", "Larvik og Omegn Vannverk" and Valleråsen potable water plant in Porsgrunn city. By testing various parameters, Farris is regularly checked for parameters such as pH, TOC, aluminium, turbidity and colour. Farris is in the best class as a potable water reservoir according to Norwegian classification system based on EU Water framework directive. A report from 2011 by NIVA (Norwegian institute for water research) states that the deep water in Farris shows a good water quality in terms of nutrients and bacteria, and it shows no signs of developing in any particular direction (Berge, 2011). Farris is a large and deep lake, which makes it possible to have a deep-water intake for the water treatment plants. Seierstad's water intake is located at 30 meters depth, under the leap layer that acts as a protective barrier against pollution.

3.2.1 Physical and chemical quality in Farris

Both the raw water and the treated from Seierstad water treatment plant (WTP), are checked for a number of physical and chemical parameters to ensure a good quality of the potable water. The water is continuously monitored by online measuring equipment. Some parameters are analysed at Vestfold Vann's laboratory and certain samples are sent to an external laboratory. Among the parameters being tested are pH, turbidity, alkalinity, colour, conductivity, aluminium, calcium, chlorine and organic matter (TOC). Typical values for the parameters are shown in Table 3-1. These values are based on the mean values collected in the time period 7.1.15 – 14.9.15. The raw water in Farris is characterized by having very low turbidity, hardness (calcium) and alkalinity, but high colour value. The table shows values within the limits set by the Norwegian Potable water Regulation for the treated water. The colour is reduced from 31 to 4 mg/L (Pt) during the treatment process. The turbidity, measuring the particles in the water, decreases during the treatment procedure. Other parameters decreasing are aluminium and TOC. It is a requirement to have two treatment processes acting as hygienically barriers in the water treatment. One of the barriers is chlorination at Seierstad, and this is why the chloride level increases through the process. Chemical coagulation serves as a secondary barrier. For this to be valid, the values of the different parameters have to be below an "indicator limit" set by the regulations. The indicator limits for the different parameters are shown in the table. Depending on how complete each of the hygienic barriers are, two or more treatment stages can act together as a barrier ("Veiledning til drikkevannsforskriften," 2011). In the report the indicator limits are referred to as recommended limits. In order to maintain the water as neutral as possible, the parameters pH, alkalinity and calcium are adjusted, as seen in the table, by adding micronized marble and lye. The pH increases from 6.4 to 7.3, alkalinity from 0.05 to 0.67 mmol/L, and calcium from 2.1 to 9 mg/L. This is also to prevent wear on the pipes and fittings on the water supply network ("Vestfold Vann IKS," 2015). The increased conductivity and alkalinity in the water through the treatment process may be due to the addition of calcium.

Table 3-1: Water quality parameters of raw and treated water, in addition to limits for the treated water ("Drikkevannsforskriften," 2001).

Parameter	**Unit**	**Treated water limit**	**Indicator/ Recommended limit**	**Raw water**	**Treated water**
pH		6.5 – 9.5		6.4	7.3
Turbidity	NTU	1	< 0.2	0.35	0.16
Colour	mg/L Pt	20	< 10	31	4
Conductivity	mS/m at 25°C	250		3.57	11.05
Aluminium	mg/L Al	0.2	< 0.15	0.132	0.036
Alkalinity	mmol/L	-		0.05	0.67
Calcium	mg/L	-		2.1	9
Chloride	mg/L Cl	200		3.9	9.3
TOC	mg/L C	5.0	< 3.0	6.2	3.1

In order to evaluate the water quality, the physical and chemical parameters that are in focus in this report are colour, turbidity, organic matter and residual aluminium. To compare water quality parameters from the main plant at Seierstad, data retrieved from Vestfold Vann's reporting system Gurusoft Report was used. By using Excel graphs the intention was to find correlations between parameters such as colour, turbidity and TOC with dates and seasonal changes.

The colour value of the water in Farris increased significantly during the 1990's; from 10 in 1993 to 35 mg/L (Pt) in 2002. The average of the colour has since that time been above the limit of 20 mg/L (Pt). Since 2012 it has been between at a minimum value of 28 and maximum value of 36 mg/L (Pt). An overview of average monthly values for colour from 2012 – 2015 is shown in Figure 3-1.

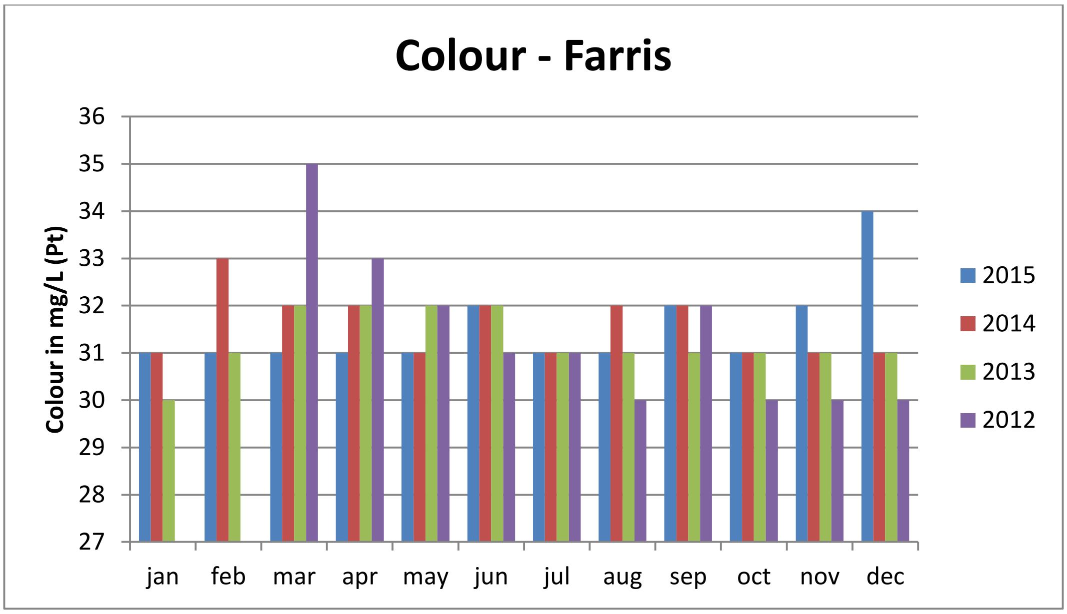

Figure 3-1: Colour value in lake Farris from 2012 – 2015.

The annual averages of colour values are: 31.5 in 2015, 31.6 in 2014, 31.3 in 2013 and 31.4 in 2012. The values do not differ much from year to year in this time period. Peaks in colour value due to spring and autumn circulations are not easily seen for all years in this graph. A year that stands out is 2012. The peak in March 2102 indicates the circulation in spring, followed by a decrease in the colour towards the summer. The colour value peaks again in September 2012, indicating the autumn circulation, followed by a stable period during the winter. Overall, the colour of the water in Farris is expected to continue to be at such high levels, or even higher. This is because of the climate changes with more extreme weather (Berge, 2011).

The organic matter, expressed as TOC, has increased during the years in Farris. The limit for the treated water, according to the potable water regulation, is 5.0 mg/L Carbon. It is recommended to have a value less than 3.0 mg/L (C) with coagulation as water treatment ("Veiledning til drikkevannsforskriften," 2011). The figures below show the organic matter in the both the raw and the treated water from Seierstad WTP in the time period 2010 to 2015. Figure 3-2 shows measured values of organic content, TOC, in the raw water entering the WTP at Seierstad. A linear trend line is added to show the development over the past five years.

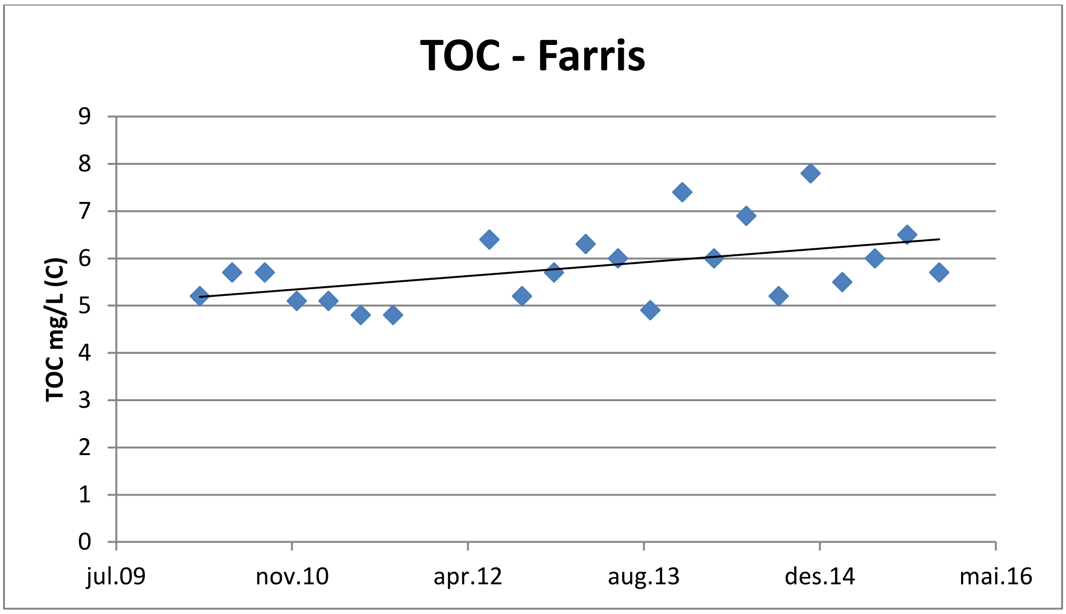

Figure 3-2: Organic matter in raw water treated at Seierstad water treatment plant.

The organic matter in the raw water has increased by an average of 25 %: from 5.2 mg/L (C) in March 2010 to 6.5 mg/L (C) in September 2015. The TOC in the raw water is reduced during the water treatment process, and the values for the treated water is presented in Figure 3-3.

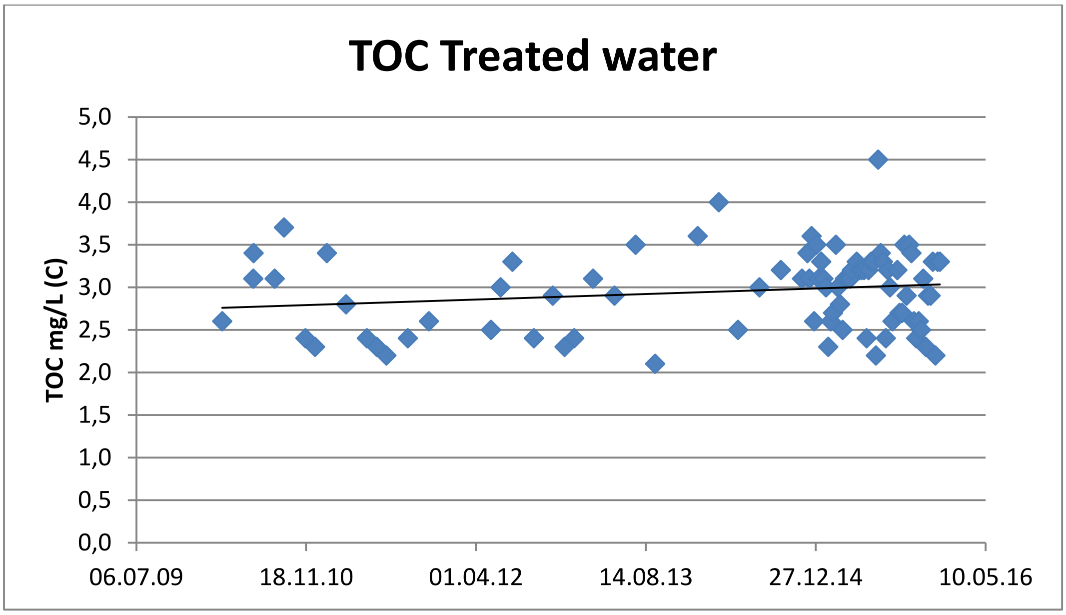

Figure 3-3: Organic matter in the treated water at Seierstad water treatment plant.

The trend line of the treated water also shows an increase of TOC over the past five years. In March 2010 the average value was 2.6 mg/L (C), and in August 2015 the average value was 3 mg/L (C). This is an increase of 15 %. Even though all the values are below the limit at 5 mg/L (C), the average value is above the recommended limit of 3 mg/L (C) the past year. Annual average values are respectively 2.9 in 2010, 2.6 in 2011, 2.7 in 2012, 2.8 in 2013, 3.2 in 2014, and 3.0 mg/L (C) in 2015. Vestfold Vann wants to investigate whether the use of another coagulant will decrease the TOC content in the treated water.

The mean value of aluminium in the treated water from Seierstad over the 5 last years is 38 µg/L (Al). The maximum value is 86 µg/L (Al). This is far below the recommended limit at 150 µg/L (Al). The measured turbidity in Farris is shown in Figure 3-4, along with an added sliding average trend line. The turbidity is generally low in Farris, and varies between a minimum of 0.24 and maximum of 0.62 NTU in 2015. The average value over the year is 0.38.

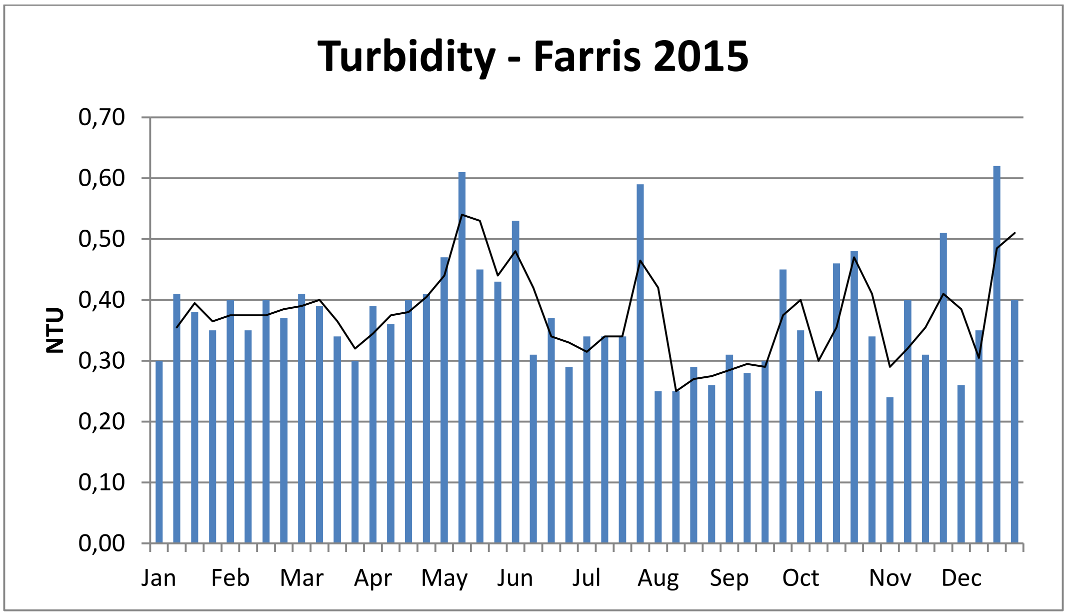

Figure 3-4: Turbidity in Farris over a year.

The turbidity is stable during the winter months until April. After this there is an increase in the turbidity, indicating the spring circulation. During the summer months the turbidity decreases again, except for one high turbidity value in July. This can be due to an incident like a heavy rainfall. The circulation is visible again in the autumn months from October to December, where the turbidity increases and is generally unstable.

3.3 Water treatment at Seierstad

The raw water from Farris is collected at a depth of 40 m. It enters the treatment plant by gravity fall through two pipes with a diameter of 1000 mm. The treatment process at Seierstad is shown in Figure 3-5, which also displays all the chemicals that are added in the process. A model with all the data regarding flow rates, measured parameters and chemical dosages is available in Appendix 2.

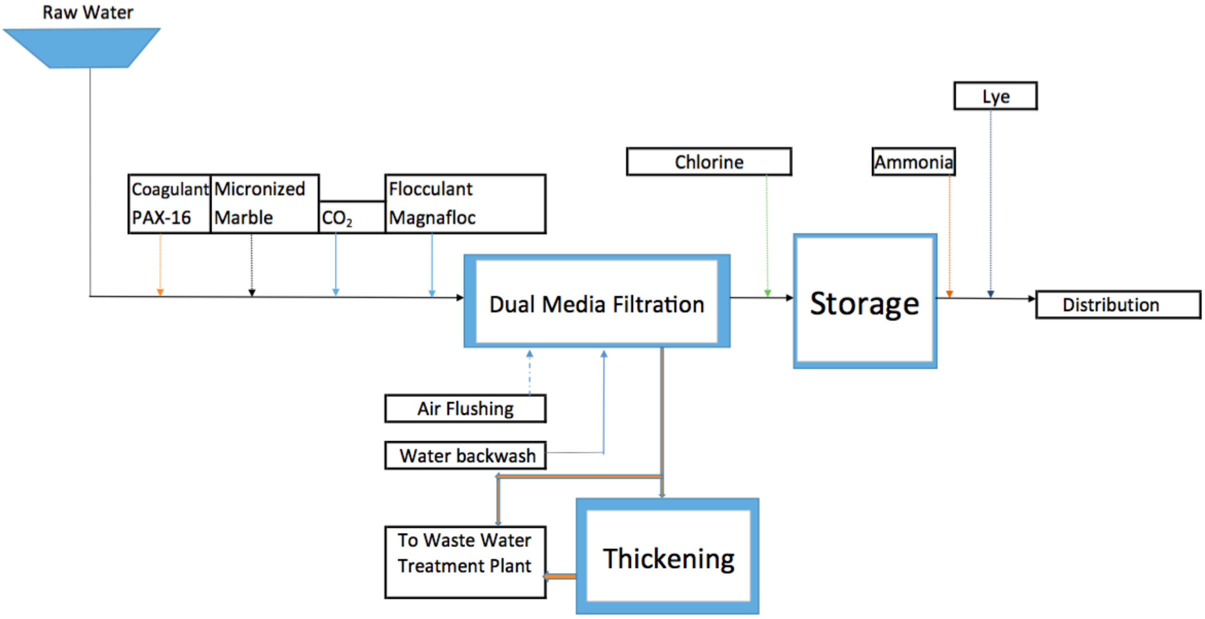

Figure 3-5: Water treatment process at Seierstad, from raw water to distribution towards the consumers.

The polyaluminium chloride named PAX-16 is used as a chemical coagulant, together with a polymer called Magnafloc. These chemicals are added together with micronized marble and carbon dioxide at the water treatment plant. Micronized marble and carbon dioxide are used for adjusting the optimal pH in order for the coagulation to occur. The water is filtered down stream. There are six dual media filters filled with sand and Filtralite[1]. Gravel is at the bottom for support, followed by a layer of sand and Filtralite at the top. Chlorine and ammonia are added towards the end of the process. Chlorine disinfects and the addition of ammonia forms chloramine. This is to prevent biological growth in the distribution network of pipes. In order to adjust the pH before distribution to the water pipe network, an amount of lye is added at the end of the process. After all these steps, the water is distributed out to the network and to the municipalities. VV has built a pilot plant at Seierstad to make it possible to do experiments on different methods of water treatment. The water treatment process is almost fully automated and is controlled by the software Citect, used both at the pilot and the main plant.

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[1] Expanded clay from crushed Leca.

The filtration time is based on experience at Seierstad. The filters are backwashed every 15 hours, and the duration of the backwashing depends on the quantity of water passing through the filter during the period. Typically there are 60 seconds of air flushing followed by 10 minutes of water flushing. The ripening period is set to 20 minutes.

A dosage of 1.7 mg /L (Al) is added to the raw water in the coagulation process. The major part of the aluminium is clogged in the filter that eventually is washed with the backwash water. The backwash water goes directly to the sludge treatment. The first period when the filter starts up again, called the ripening period, will still contain a high level of suspended solids. This water goes directly into the river Numedalslågen. In addition, the backwash water from the filters is discharged into the river after sludge treatment.

4 Methods

To investigate the effects of different coagulation chemicals, experiments at the pilot plant and Jar testing was carried out. All water samples were collected in plastic bottles and stored in a refrigerator at 4 °C. The laboratory at Seierstad was used to analyse turbidity and colour, and an external laboratory (VestfoldLAB) analysed the samples for colour, TOC and residual aluminium. To evaluate the cost related to the coagulation chemicals a brief cost estimation was done.

4.1 Seierstad pilot plant

The pilot plant at Seierstad intends to simulate the treatment procedure at the main plant, and is designed to conduct experiments on alternative treatment methods. The pilot is located in the building where the raw water enters. The pilot plant consists of a system of pipes, valves, sensors, pumps, vessels, a filter and a control system. The design of the pilot is presented in Figure 4-1.

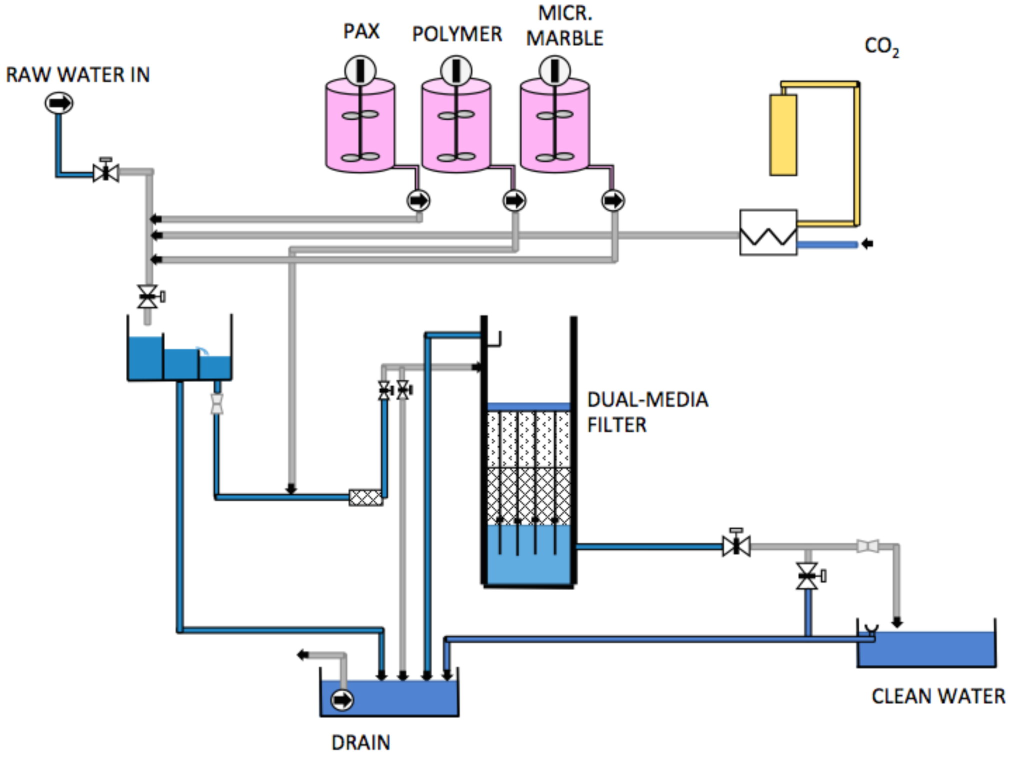


Figure 4-1: Process description of the pilot plant at Seierstad.

A branch from the main pipe of the raw water inlet provides a sub stream to the pilot plant. This is fed to the system by a frequency-controlled pump, where the water first ends up in a vessel. This vessel was previously used for measuring the water flow, until an electrical measuring device was added to the system.

Polyaluminium chloride, CO_2, and micronized marble are added before the vessel and polymer is added afterwards. All the chemicals are stored in plastic vessels and fed to the process by peristaltic pumps.

The water flows out of the measuring vessel into a cylindrical filter. A flow meter is mounted on this pipeline. The water runs down stream through the filter. A window, positioned longitudinally with the cylinder, makes the filter media visible. Several riser pipes are installed along different heights of the filter to follow the head loss development at different heights in the filter. Figure 4-2 shows the filter at the pilot plant. It is 4.2 m high, and has a diameter of 1 m. It is filled up with ¼ sand and ¾ Filtralite. In total there is 1.9 m^3 of filter media. At the end of the process the water flows into a clean water pool.

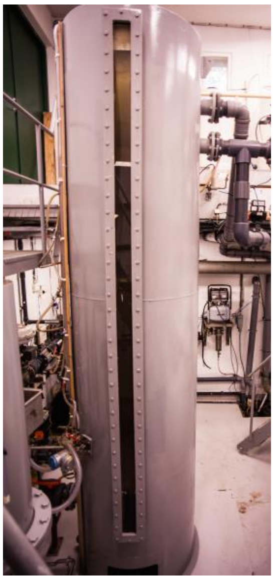


Figure 4-2: Filter in the pilot plant.

Both air and water are used for backwashing of the filter. A fan for air flushing is connected to the bottom of the filter, in addition to a pump supplying the flush water. Sampling of clean water is done after the filtering.

A sketch, shown in Figure 4-3, displays the heights of the filter with the different media layers, together with the heights of the mounted risers.

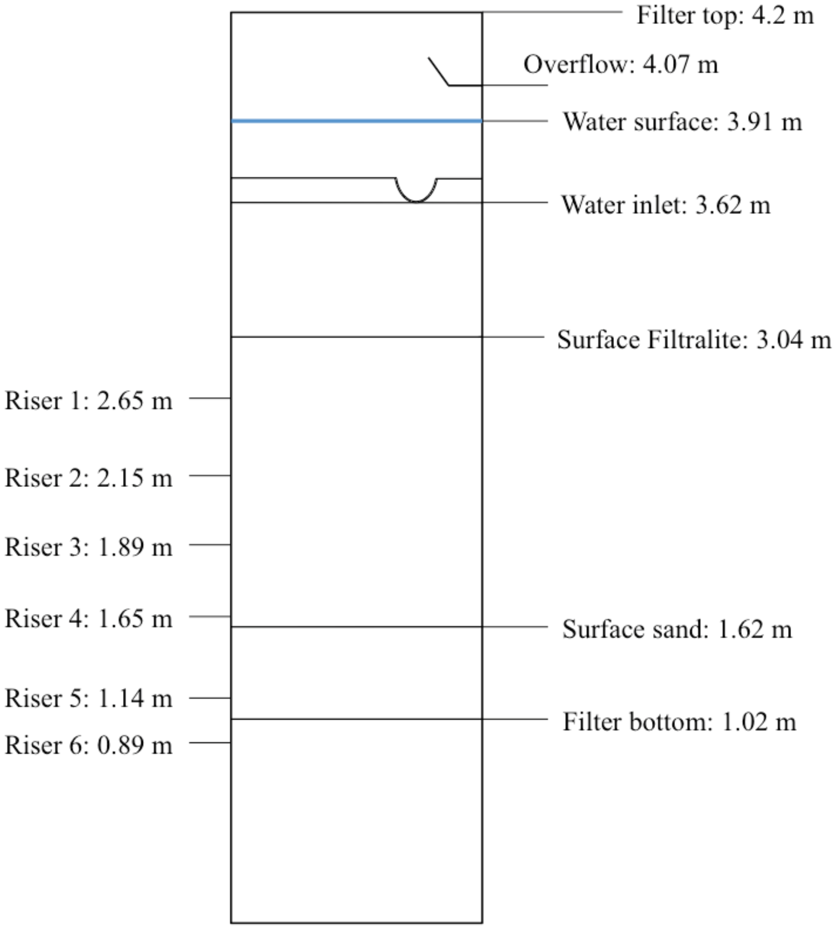


Figure 4-3: Sketch of the pilot plant filter.

In order to control and manage the process at the pilot plant, there are several online measuring and regulating equipment installed in the process. A flow meter is mounted before the water flows into the filter, and another is mounted just after the pump for the backwash of the filter. The effect of the pump supplying the raw water can be controlled from the software program Citect. 42 % of the maximum effect was used in the experiments, resulting in a water flow of 5 m^3/h. On the outflow of the filter there is a conductivity meter. A pH meter is connected to the water flow where the chemicals are supplied, and another one is put into the clean water pool. A turbidity meter is also positioned at this place. An ultrasound senor is connected at the top to measure the water level in the filter. A regulating valve, at the outflow of the filter, keeps the water at a constant level. The CO_2 flow is controlled manually by a rotameter, and the frequency-controlled chemical dosage pumps can be controlled manually. The backwash sequence of the filter is automated and can be controlled by either high turbidity, high head loss or by a set time period. All the valves are controlled pneumatic actuators, which are connected to an air compressor.

4.1.1 Operational problems at the pilot

Some operational problems occurred with different equipment during the pilot plant testing. This was regarding the filter and the connected risers, tubing of micronized marble, supply of CO_2 and a pump. The risers mounted at the filter contained some contaminations from the filter, causing resistance and clogging. To be able to measure the water pressure from the risers properly, the tubes had to be detached and flushed with water. The water level in the filter is reduced when the backwash procedure starts. This level is programmed by a set point in the software program Citect that has to be reached for the proceeding steps to initiate. At the beginning the set point was too low, so the following steps were not completed. When the level was adjusted to a higher set point, a small amount of filter material was flushed away with the water in the backwashing procedure. After some trial and error, the correct set point was achieved. On one occasion the micronized marble tubing got clogged. This resulted in lack of marble in the main flow. To solve this problem a part of the tube was replaced. The CO_2 supply was uneven when the cylinder was replaced. This resulted in a varying pH through this period, making it difficult to run tests. After a period of time the feed achieved stability again. The pump connected to the coagulant basin stopped running during one of the experiments where the pilot was set to run over night. Another basin and a pump were then applied for the rest of the experiments. The pump had to be calibrated and the tubing had to be mounted before the coagulant supply was up and running again.

4.2 Method for making a coagulation profile

The polyaluminium chloride coagulants of type PAX-16, Ecoflock 91 and Ecoflock 96 were used at the pilot plant to observe the ripening period and to make a coagulation profile for the raw water from Farris. In addition aluminium sulphate was tested with a Jar tester. In order to carry out the experiments at the pilot, varied type and dosage of coagulant chemicals were added, while the polymer and micronized marble were kept at a constant dosage. The CO_2 feed was varied to achieve different pH conditions. The experiments were run in series of 3 – 4 hours, until the values of the treated water showed stable results. The online turbidity meter and colour analysis were used as an indication for stable results. Water samples were taken every 30 minutes during this period. Samples of the raw water were taken in the beginning and at the end of all experiments in order to notice any possible fluctuations. The filter was backwashed at the end of each experiment. All the tests were done with a filter rate of 6.4 m/h. The stabilized results from the experiments were put together to form a coagulation profile for the different parameters: turbidity, colour, TOC and residual aluminium.

Pilot experiments were run over a longer period of time in order to see how long the filter held before it reached breakthrough. The experiments with different coagulants had a running time for 17 – 32 hours. This was also done to look at the pressure drop at different layers in the filter. The total differential pressure can be read by online measurement equipment at all times. A manual ruler was used to measure the pressure at different levels in the filter manually. The water pressure (mH_2O) was read by the height difference between the mounted riser on the filter, and the water surface inside the riser pipe. To monitor the development of the pressure drop as an indicator of the distribution of the deposited material, the pressure was read at different times through the filter run.

To make a coagulation profile of the different chemicals, the dosage of 1.7, 1.5 and 1.3 mg/L (Al) were tested in the pH area of 5.7 – 6.7. To enable the dosage pumps to deliver such small quantities the chemicals were diluted and the pumps were calibrated.

4.2.1 Dilution of chemicals

Chemical data available from the supplier was used to calculate the dilution of the chemicals giving the right concentration and the required setting percentage on the delivery pumps. By using Equation 4-1 the capacity setting percentage of the pump was calculated for all pumps. Detailed calculations are presented in Appendix 5.

$$Q \cdot C = q \cdot c \tag{4-1}$$

Where,

$Q = pump\ capacity\ of\ the\ raw\ water$

$C = target\ concentration\ of\ aluminium\ in\ raw\ water$

$q = capacity\ of\ the\ dosage\ pump$

$c = concentration\ of\ aluminium\ in\ dosage\ basin$

Data sheet for the chemicals used at the pilot plant are available in Appendix 4. For micronized marble the chemical data shows a concentration of 78 % and a specific weight 1900 g/L. The dilution of micronized marble is shown in Table 4-1.

Table 4-1: Dilution of Micronized marble.

Liters of water to liter of micr. marble (L)	**Total weight micr. marble + water (kg)**	**Volume micr. marble + water (L)**	**Spec. weight of the mixture (g/L)**	**Marble in mixture (g/L)**	**Calcium in mixture (g/L)**
0	1.9	1	1900	1.48	0.59
149	150.9	150	1006	19.76	7.90

The capacity setting percentage of the micronized marble pump was calculated to be 5.59 mL/s. The pump delivers 11.76 mL/s at 100 % capacity. The pump curve is linear and can be adjusted on a scale from 0 – 100 %. To get the correct dosage the pump was set to 29.6 %.

PAX-16 has aluminium content of 8.05 % and the specific weight of the chemical is 1335 g/L. The dilution of PAX-16 is shown in Table 4-2.

Table 4-2: Dilution of PAX-16.

Liters of water to liter of PAX-16 (L)	**Total weight PAX-16 + water (kg)**	**Volume PAX-16 + water (L)**	**Spec. weight of mixture (g/L)**	**Aluminium in mixture (g/L)**
0	1.34	1	1335	107.47
49	50.34	50	1006.7	2.15

The dosage pump delivers 1.47 mL/s at a frequency of 50 Hertz. The pump curve is linear and can be adjusted on a scale from 0 – 50 Hz. To get the correct dosage the pump was set to 37.4 Hz, which gives a pump flow of 1.10 mL/s.

Ecoflock 91 has 9.3 % aluminium concentration of and a specific weight of 1380 g/L. The dilution of Ecoflock 91 is shown in Table 4-3.

Table 4-3: Dilution of Ecoflock 91.

Liters of water to liter of Eco.91 (L)	**Total weight Eco.91 + water (kg)**	**Volume Eco.91 + water (L)**	**Spec. weight of the mixture (g/L)**	**Aluminium in mixture (g/L)**
0	1.38	1	1380	128.34
49	50.38	50	1007.6	2.57

The dosage pump delivers 1 mL/s at a frequency of 50 Hertz. The pump curve is linear and can be adjusted on a scale from 0 – 50 Hz. To get the correct dosage the pump was set to 46 Hz, giving a pump flow of 0.92 mL/s.

Ecoflock 96 has 9.6 % aluminium and a specific weight of 1380 g/L. The dilution of Ecoflock 96 is shown in Table 4-4.

Table 4-4: Dilution of Ecoflock 96.

Liters of water to liter of Eco.96 (L)	**Total weight Eco.96 + water (kg)**	**Volume Eco.96 + water (L)**	**Spec. weight of the mixture (g/L)**	**Aluminium in mixture (g/L)**
0	1.380	1	1380	132.48
49	50.38	50	1007.6	2.65

The dosage pump delivers 1 mL/s at a frequency of 50 Hertz. The pump curve is linear and can be adjusted on a scale from 0 – 50 Hz. To get the correct dosage the pump was set to 44.6 Hz, giving a pump flow of 0.89 mL/s.

To calculate the appropriate dilution and dosage of Magnaflock, the ratio of produced water and dosage on the main plant was used. The main plant uses 159 l/h of Magnaflock to 1 468 000 l/h raw water. The pilot uses 5004 l/h raw water. By using the ratio, the dosage then becomes:

$$x = \frac{159\frac{l}{h}}{1468000\frac{l}{h}} \cdot 5004\frac{l}{h} = 0.54\frac{l}{h}\,, \quad 0.54\frac{l}{h} \cdot \frac{1h}{3600\,s} \cdot \frac{1000\,ml}{l} = 0.15\frac{ml}{s}$$

The polymer was diluted by 1:10. This means the dosage pump has to deliver 1.5 mL/s. The dosage pump delivers 1.53 mL/s at 100 % capacity, to get the correct dosage the pump was set to 98 %.

4.3 Laboratory analysis at Seierstad and VestfoldLAB

Raw water and treated water has been analysed in terms of colour value, turbidity, TOC and residual aluminium. Water samples from the pilot and Jar test were analysed for turbidity and colour at the laboratory at Seierstad. The apparatus used for colour analysis is a spectrophotometer, delivered form Hach. The model type is DR 6000. The standardized method NS-EN ISO 7887 is programmed into the device.

To analyse the turbidity the turbidimeter model 2100B from Hach was used. The instrument is valid for compliance reporting and meets the design criteria of the United States Environmental Protection Agency (Method 180.1).

The methods used for analysis of colour, TOC and residual aluminium at VestfoldLAB are presented in Table 4-5.

Table 4-5: Analysis methods done at VestfoldLAB.

Analysis	Method	Uncertainty
Aluminium, graphite furnace	NS-EN ISO 15586	± 20 %
Total organic carbon	NS 1484	± 20 %
Colour	NS-EN ISO 7887	± 15 %

4.4 Jar test for coagulant dosage

The Jar test is performed to simulate the effectiveness of the different coagulants and dosages. The intention of the experiment was to see whether similar results could be obtained on a small laboratory scale, compared with the pilot plant experiments. The aim was to simulate the process at the main plant regarding mixing and retention time. Assuming turbulent flow, the fast mixing period is set to

60 seconds, followed by a slow mixing period. The retention time from where the coagulant is added to the filter is calculated to be 4 minutes.

The Jar tester from the company KEMIRA is called Flockulator 2000. The apparatus is shown in Figure 4-4 and consists of 6 beakers, each of 1000 mL. A stirring impeller ensures even mixing, where the velocity is programmed into a controller device.

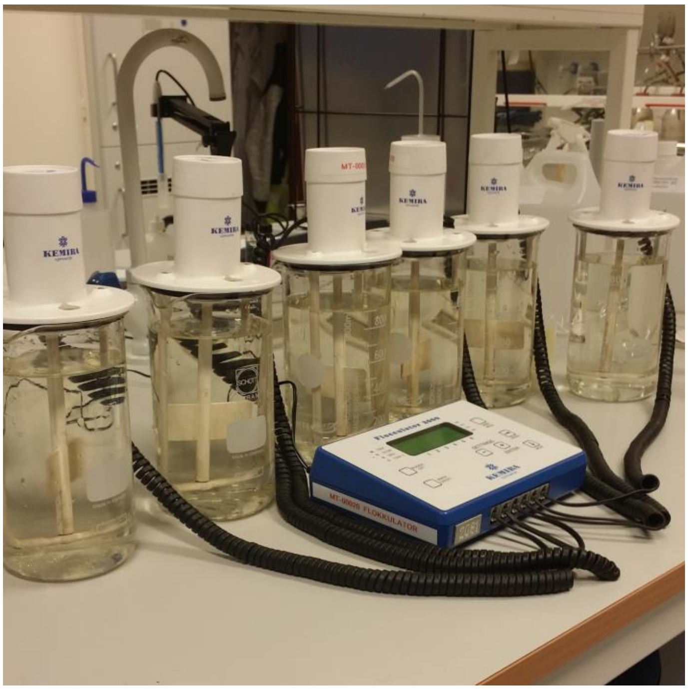


Figure 4-4: The Jar test apparatus.

Different factors like pH, mixing velocity, settling time and mixing time can influence the test. Initial rapid mixing ensures proper distribution of the coagulant and flocculant, followed by a slow mixing period to promote floc formation. At the end there is a settling period. This emulates the floc forming process in the water treatment plant for laboratory purposes, such as to determine the degree of treatment. The procedure is based on a method developed at USN.

4.4.1 Procedure of Jar test

Raw water from Farris was collected at Seierstad WTP, and tests were performed with the coagulants PAX-16, Ecoflock 91, Ecoflock 96 and Aluminium Sulphate. The tests performed, with dilution of chemicals and dosages, are showed in Table 4-6.

Table 4-6: Dilution of chemicals and dosages for the Jar test.

Test	Coagulant	Dilution (L)	Dosage (mg/L Al)	Pipette dosage (µL coagulant)
1.1	PAX-16	1:10	1.7	158
1.2	PAX-16	1:10	1.5	140
2.1	Ecoflock 91	1:10	1.7	137
2.2	Ecoflock 91	1:10	1.5	121
2.3	Ecoflock 91	1:10	1.3	105
2.4	Ecoflock 91	1:10	1.7	137
3.1	Ecoflock 96	1:10	1.7	128
3.2	Ecoflock 96	1:10	1.5	113
3.3	Ecoflock 96	1:10	1.3	98
3.4	Ecoflock 96	1:10	1.7	128

The aluminium sulphate was delivered in solid form and had to be dissolved in tap water by using a magnetic stirrer. 3 grams of aluminium sulphate was diluted into 1 litre of mixture. With an aluminium concentration of 9 %, the concentration of the stock solution was 0.27 g/L (Al). By adding 6.3 mL and 7mL of the solution, the target concentrations for the aluminium sulphates tests were 1.7 and 1.9 mg/L (Al).

The beakers were filled with 1000 mL of the raw water, and 60 seconds of rapid mixing at 400 rpm were initiated. After 5 seconds of mixing, the coagulant was added to the beaker by a pipette. A slow mixing period at 100 rpm for 3 minutes followed the rapid mixing. The polymer was added and mixed at 400 rpm for 60 seconds. After the addition of both chemicals, there was a slow mixing period at 100 rpm for 10 minutes. The Jar test concluded in a settling period of 30 minutes. When the settling time was finished the upper layer of 250 mL was collected by a pipette and stored in a plastic bottle. The sample was then brought to the laboratory at Seierstad to be analysed for turbidity and colour. The procedure was the same as for the samples from the pilot plant experiments.

4.5 Cost estimation of coagulants

In order to compare cost associated with the purchase of coagulants, price quotes from were requested the suppliers. The price quotes are referred to as estimated prices, and are attached in Appendix 6. The coagulant consumption at Seierstad in 2014 was used to calculate the cost, with a consumption of 230 ton PAX-16. The possible volume reduction of coagulants was calculated as the percentage reduction of the dosage. The cost calculation is limited to the costs of chemicals.

4.6 Health, Safety and Environment considerations

In advance of this master thesis a report was written in which the pilot plant was risk evaluated regards health, safety and environment (HSE). The aim of the report was to give an overview of measures and improvements in order to facilitate work at the pilot plant. The safety data sheets for the various chemicals were used as a basis for assessing risks and propose measures. The HSE report is available in Appendix 9. All the proposed measures were completed in advance of the work at the pilot plant.

5 Results

This chapter presents the results obtained from the experiments done at the pilot plant at Seierstad and Jar test. The coagulants PAX-16, Ecoflock 91, Ecoflock 96 are run in series of 3 – 4 hours at the pilot plant. In addition, each of the chemicals has been tested for a prolonged filter run of 17 – 32 hours. The raw water colour was stable throughout the experimental period with a colour value between 37 – 39 mg/L (Pt). As the online turbidity meter at the pilot does not display values above 1 NTU, the turbidity results above 1 NTU are marked as 1 NTU. At the end of this chapter a cost estimation of the chemicals is presented.

5.1 Coagulation tests with PAX-16

The coagulation with PAX-16 is tested with the dosage 1.7 mg/L (Al), which is the dosage used at the main plant. Afterwards the dosage was reduced to 1.5 and 1.3 mg/L (Al). Figure 5-1 to 5-5 show the development of turbidity and colour using PAX-16 as coagulant. The ripening period is indicated by the time spent for these parameters to stabilize. The pH is kept constant at various levels through each of the experiments. Figure 5-1 presents the turbidity results, indicating the ripening period, from the experiment with 1.7 mg/L (Al) PAX-16.

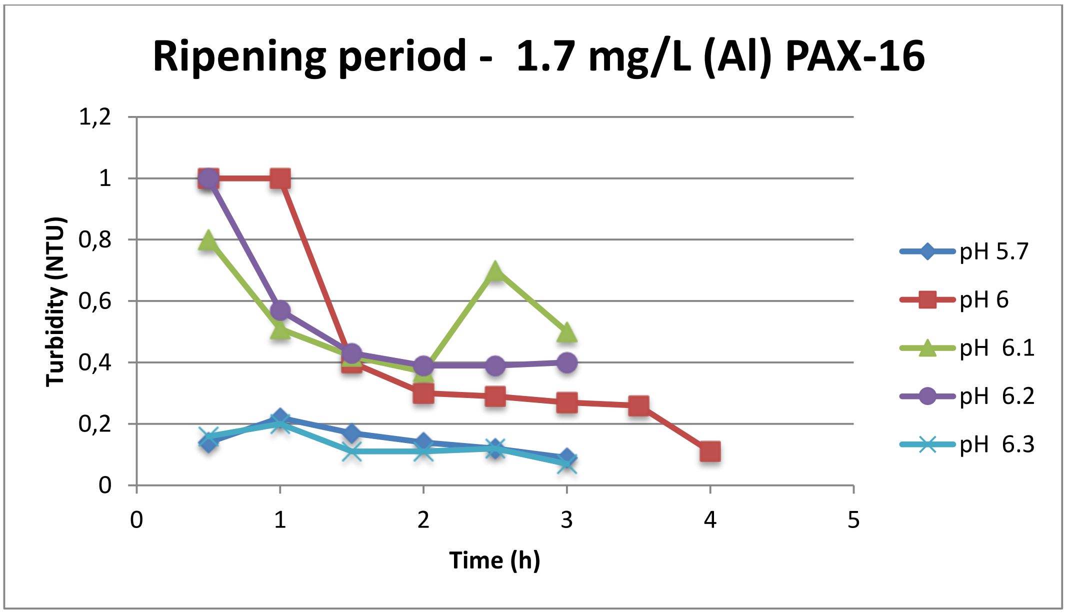


Figure 5-1: Ripening period indicated by turbidity development, with a dosage of 1.7 mg/L (Al) PAX-16 and different pH ranges.

The turbidity is plotted in the graph every half hour, starting at 0.5 h. The pH range 6, pH 6.1 and pH 6.2 all start out with a high turbidity level (0.8 – 1 NTU), followed by a gradually reduction and a stabilization after 1.5 – 2 hours. However, the turbidity development with the pH range 6.1 increases again after this period, and a peak in turbidity is seen after 2.5 hours. Using pH 5.7 and 6.3 the turbidity stays at a low level during the whole experiment, between 0.2 and 0.07 NTU. The turbidity has a small peak after 1 hour of operation for both of these pH ranges. The results of colour development are consistent with the turbidity development; this is shown in Figure 5-2. Also here, the pH ranges 5.7 and 6.3 stays at a low level of colour value throughout the experiments, with a colour value between 5 and 7 mg/L (Pt). The other pH ranges decreases from a high colour value, and stabilizes between 9 and 11 after 1.5 hours.

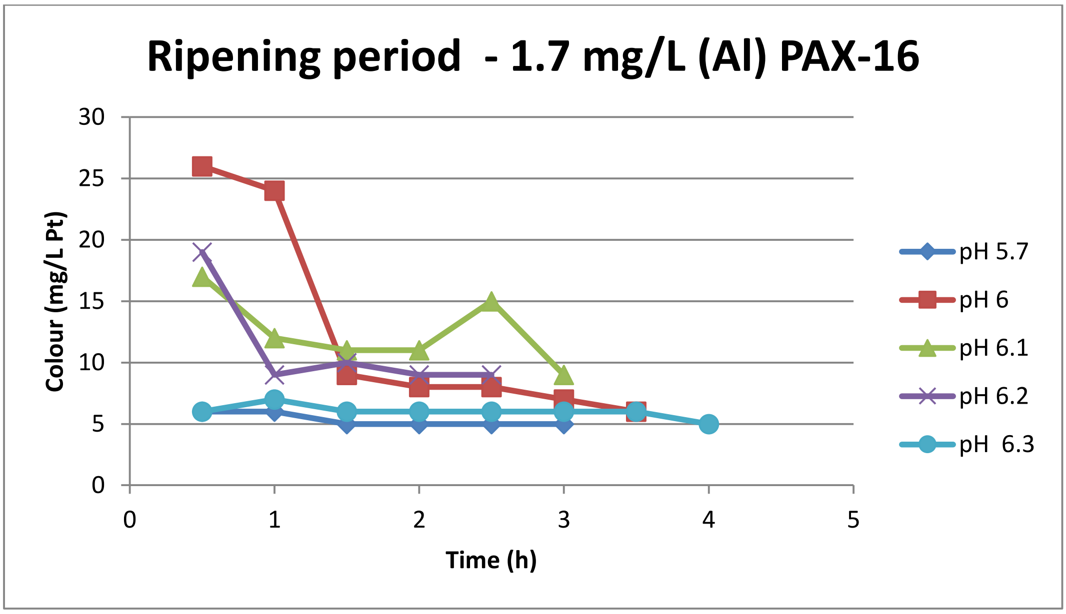


Figure 5-2: Ripening period indicated by colour development, with a dosage of 1.7 mg/L (Al) PAX-16 and different pH ranges.

A peak is also seen in colour for the pH 6.1. After 3 hours of operation the colour values stabilize between 5 and 9 mg/L (Pt) for all experiments. Overall the ripening period for the experiments with 1.7 mg/L (Al) PAX-16 is 1.5 – 2 hours.

The results obtained from experiments of 1.5 mg/L (Al) of PAX-16, show higher values of turbidity and colour than the experiments with 1.7 mg/L (Al). The turbidity during the ripening period with 1.5 mg/L (Al) of PAX-16 is shown in Figure 5-3. The turbidity in the experiment with pH 5.7/5.8 reduces from 0.7 NTU to a stable turbidity of approximately 0.4 NTU after 2 hours.

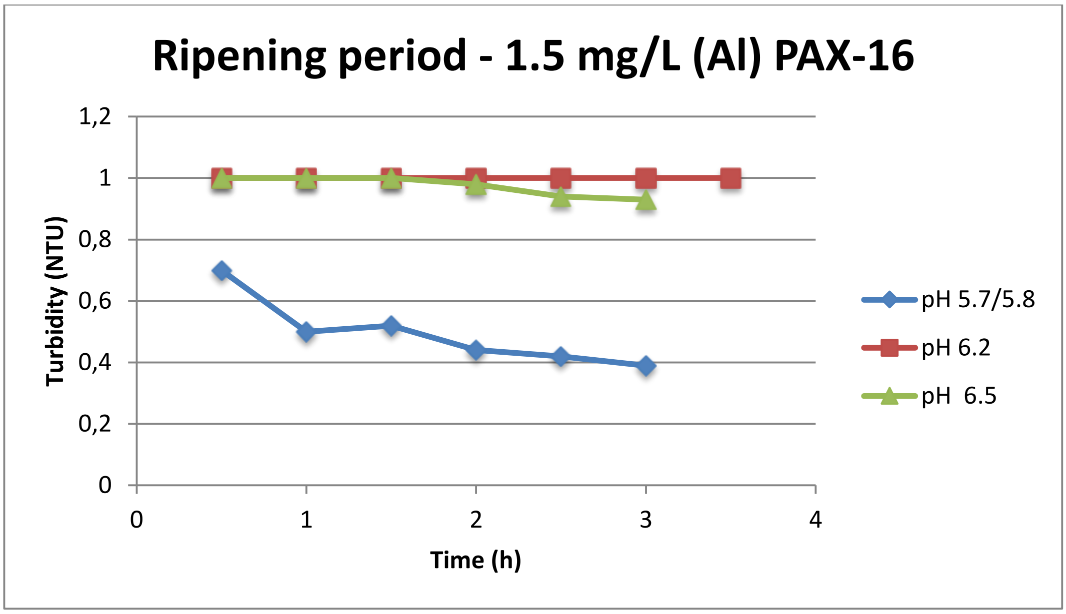


Figure 5-3: Ripening period indicated by turbidity development, with a dosage of 1.5 mg/L (Al) PAX-16 and different pH ranges.

The other two pH ranges of pH 6.3 and 6.5 remain at a high level in turbidity through the experiment. The experiment using pH 6.2 does not stabilize at a lower value than 1 NTU (or higher), as it is at this level during the whole experimental time. The pH range 6.5 reduces slightly from 1 NTU, and stabilizes at 0.94 NTU after 2.5 hours of operation. A similar result regarding colour is obtained, as shown in Figure 5-4. The figure shows the colour development with 1.5 mg/L (Al) PAX-16. The experiments with pH 6.2 and 6.5 does not decrease significantly in colour value throughout the experimental period. The colour is stable after 2.5 hours with a colour value higher than 20 mg/L (Pt). The experiment with a lower pH setting of 5.7/5.8 shows better reduction in colour value. For this pH range, the turbidity and colour seem to stabilize after 2 hours, indicating the ripening period. Though, the colour reduces even more after 3 hours.

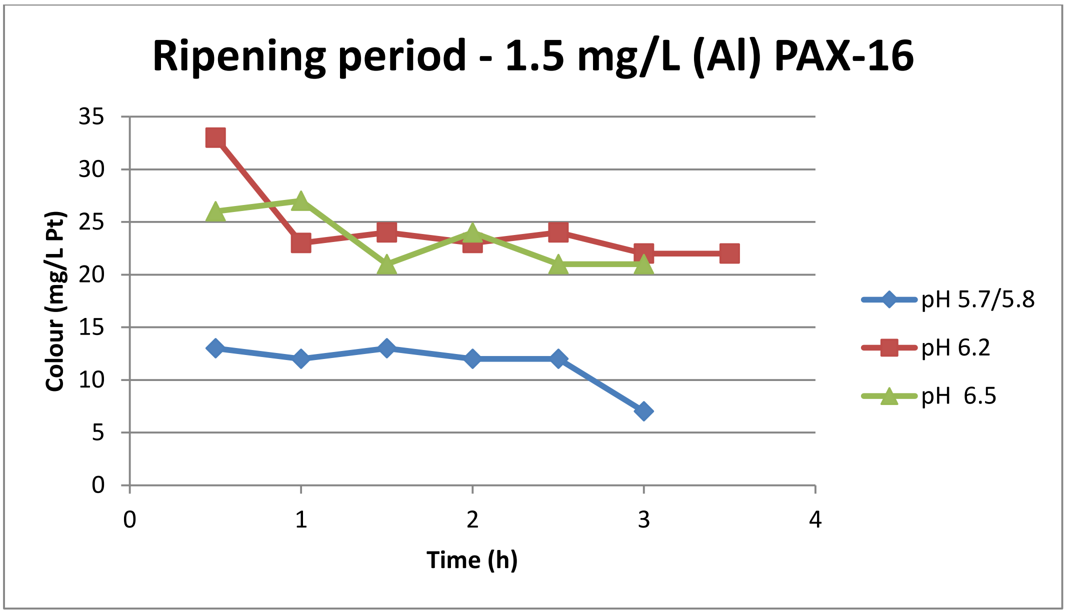


Figure 5-4: Ripening period indicated by colour development, with a dosage of 1.5 mg/L (Al) PAX-16 and different pH ranges.

The turbidity and colour provides higher results in turbidity and colour when the dosage is reduced further to 1.3 mg/L (Al). The development of both parameters is shown in Figure 5-5. The turbidity is displayed at the y-axis on the left hand side, and the colour value on the right y-axis. The pH is kept at a level of 6.5 during the experiment.

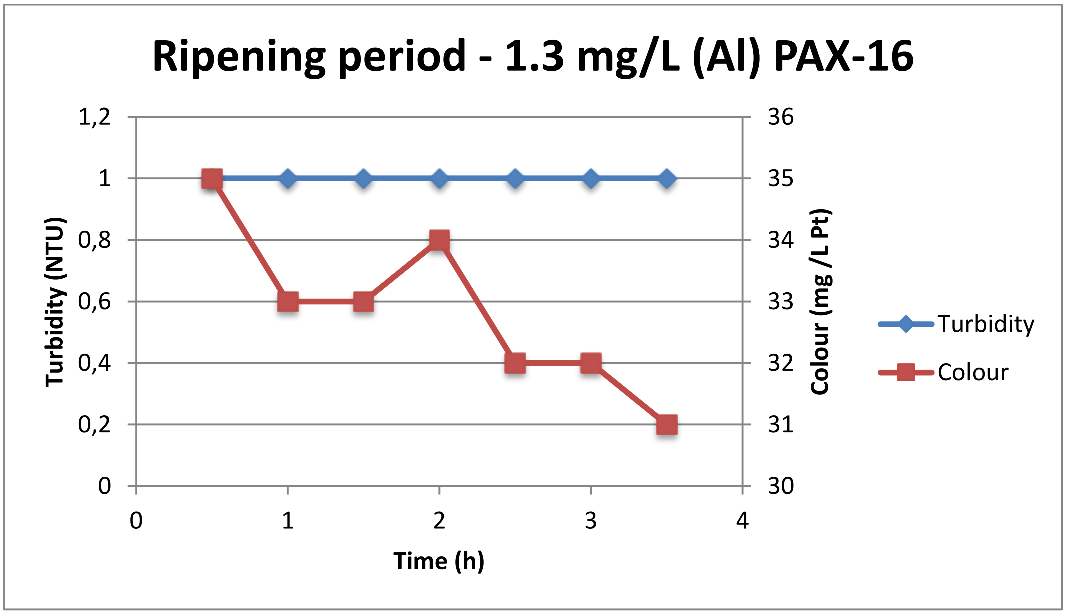


Figure 5-5: Ripening period indicated by colour and turbidity development. The pH is 6.5 with a dosage of 1.3 mg/L (Al) PAX-16.

The turbidity does not go below 1 NTU throughout the experimental period. The colour value is somewhat reduced during the experiment; from 35 mg/L (Pt) in the beginning, but is still high (31 mg/L Pt) after 3.5 hours.

5.1.1 Coagulation profile with PAX-16

Coagulation profiles are made to visualize the results from the pilot plant experiments, in relation to dosages, pH range and potable water regulation limits. By combining the results from different dosages, coagulation profiles regarding colour, turbidity, TOC and residual aluminium are presented in Figure 5-6 to 5.9. The plotted results are taken from stabile values of the different parameters, i.e. the last samples from each series of testing. The result from the different dosages is presented in relation to the coagulation pH displayed on the x-axis. The absolute limit and the recommended limit, which is set by the Norwegian potable water regulation, are displayed by horizontal lines in the graphs. Figure 5-6 shows a turbidity profile of the results obtained from experiments with PAX-16.

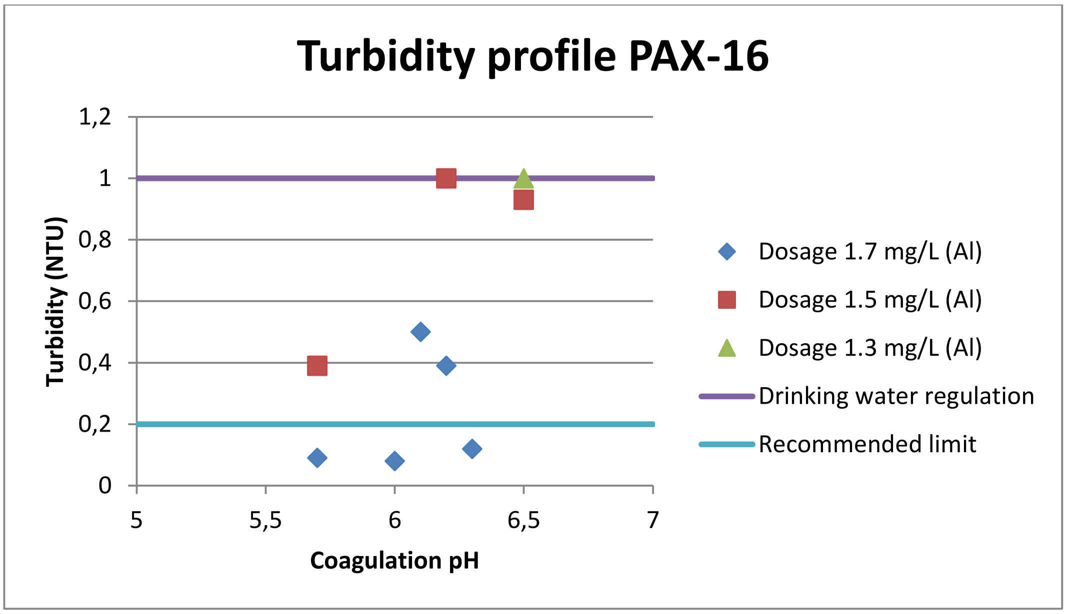


Figure 5-6: Turbidity at different pH ranges and dosages of PAX-16, including limits from potable water regulation.

According to the potable water regulation the limit of turbidity is 1 NTU, and the recommended limit is 0.2 NTU. The turbidity is below the potable water regulation limit of 1 NTU for all the experiments with a dosage of 1.7 mg/L (Al). However, the pH 6.1 and 6.2 are above the recommended limit. The lower dosages are all above the recommended limit. For the experiments with 1.5 mg/L (Al) the turbidity is 0.39 NTU at pH 5.7, and close to 1 NTU at a higher pH range. The dosage of 1.3

mg/L (Al) is at the potable water regulation limit of 1 NTU. The colour profile for experiments with PAX-16 is shown in Figure 5-7. The limit for colour value is 10 mg/L (Pt), and the recommended limit is 5 mg/L (Pt). The colour values are between 6 and 9 mg/L (Pt) with the dosage of 1.7 mg/L (Al). This is below the potable water regulation limit, but still above the recommended limit. The results for 1.5 mg/L (Al) are 12 mg/L (Pt) with pH 5.7 and 21 – 22 mg/L (Pt) at a higher pH level. As seen in the figure, the colour value is far above the limits for the lowest dosage of 1.3 mg/L (Al).

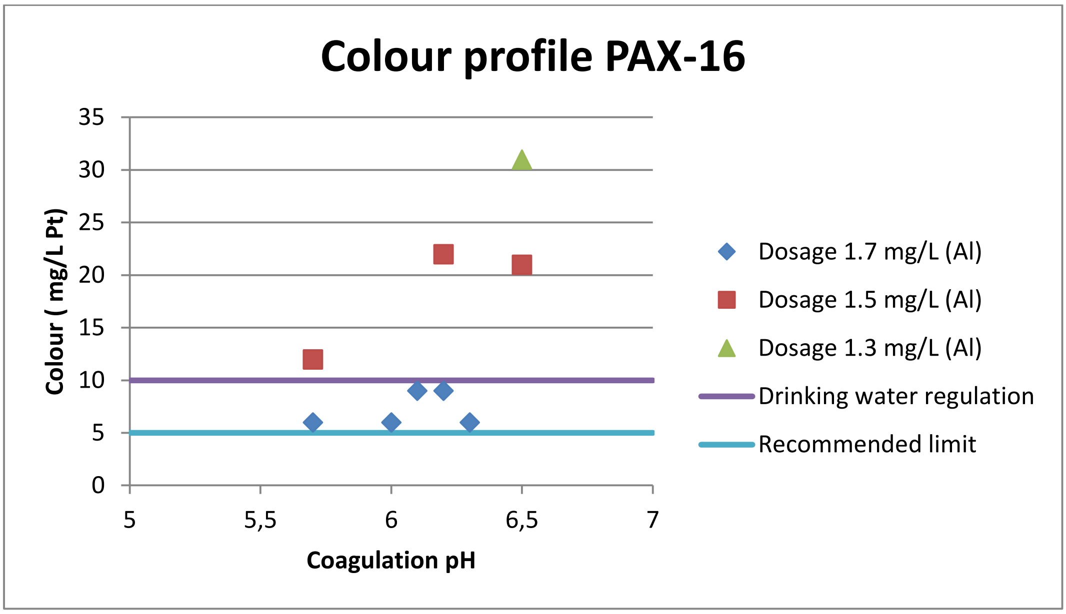


Figure 5-7: Colour value at different pH ranges and dosages of PAX-16, including limits from potable water regulation.

Organic matter is measured for total organic carbon (TOC), as the content of organic carbon is proportional to the organic matter. The TOC profile for PAX-16 is shown in Figure 5-8. The potable water limit for TOC is 5 mg/L (C) and the recommended limit is 3 mg/L (C). The TOC values are close to the recommended limit for the dosage of 1.7 mg/L (Al) at pH 5.7 and 6. At a higher pH range the TOC is between the indicator and potable water. For the dosage of 1.5 mg/L (Al) the TOC is close to the potable water regulation limit, and for the lowest dosage of 1.3 mg/L (Al) the TOC is above this limit.

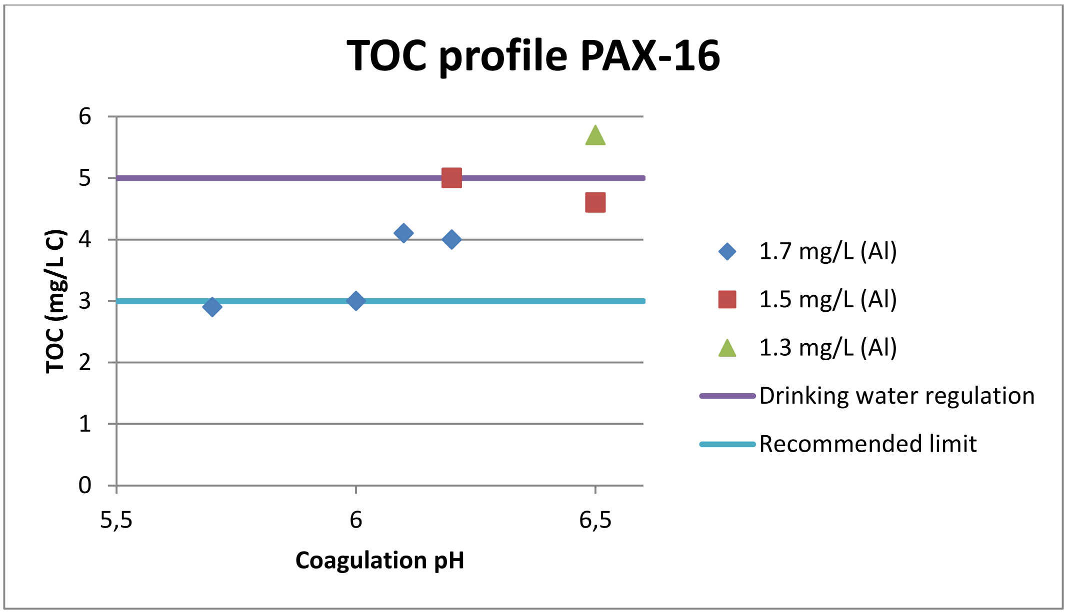


Figure 5-8: TOC at different pH ranges and dosages of PAX-16, including limits from potable water regulation.

The coagulation profile displaying the residual aluminium with experiment done with PAX-16 is shown in Figure 5-9. The limit for residual aluminium is 0.2 mg/L (Al), with a recommended limit at 0.15 mg/L (Al). The residual aluminium is below the recommended limit for all the experiments with a dosage of 1.7 mg/L (Al). With this coagulant dosage, the highest concentration of residual aluminium is 0.1 mg/L (Al) at pH 6.1 and 6.2. The residual aluminium is 0.17 mg/L (Al) with coagulant dosage 1.5 mg/L (Al), which is over the recommended limit. For the same dosage at higher pH levels the residual aluminium is above the potable water limit. The dosage of 1.3 mg/L (Al) has high residual aluminium with 0.6 mg/L (Al).

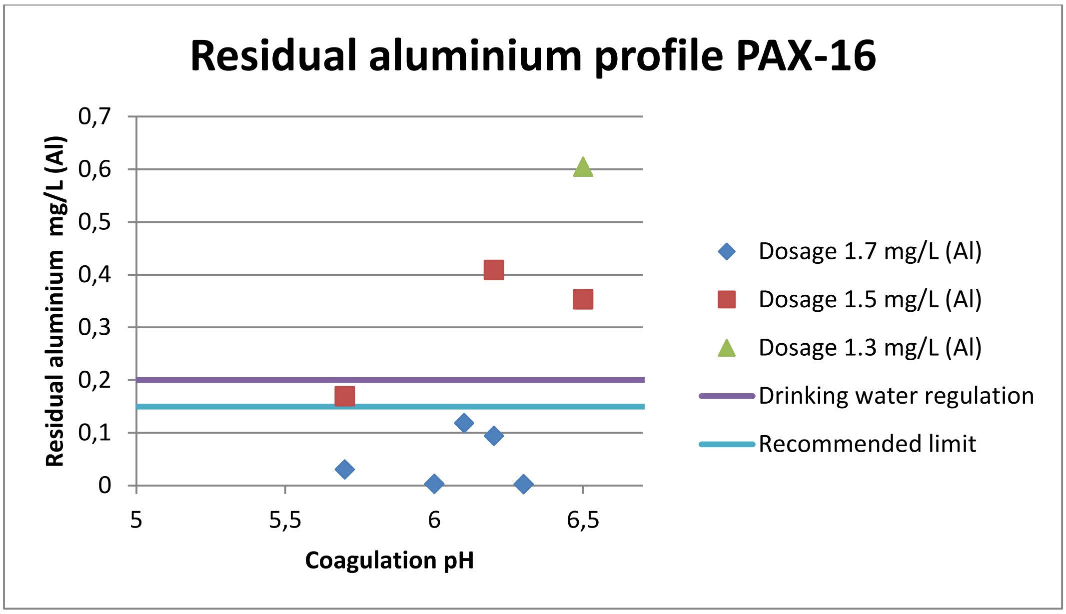


Figure 5-9: Residual aluminium at different pH ranges and dosages of PAX-16, including limits from potable water regulation.

5.1.2 Filter cycle time with PAX-16

By running the filter over time, the filter cycle time can be noted. The filter cycle time is determined by either high turbidity or high differential pressure. Figure 5-10 shows the development of turbidity and differential pressure in the filter over a longer period of time. The dosage is 1.7 mg/L (Al) PAX-16. The turbidity stabilizes around 0.5 NTU and keeps this level for the filter cycle time. After 17 hours of filter run the turbidity increases dramatically, implying “breakthrough”. The built up of differential pressure increases linearly with time, and is at 1.38 mH_2O when the filter reaches breakthrough. The available head in the filter is 2.6 meters, which means that 53 % of the available head is utilized.

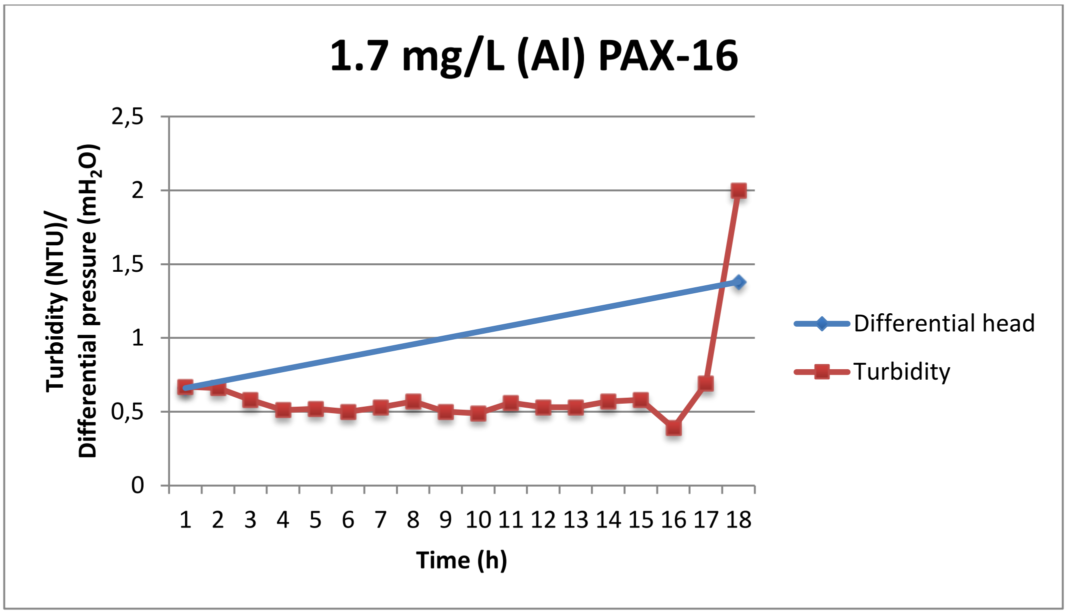


Figure 5-10: Filter cycle indicated by differential pressure and turbidity development with 1.7 mg/L (Al) PAX-16.

5.1.3 Filter head loss with PAX-16

Figure 5-11 shows the pressure development at different levels in the filter with PAX-16 used as a coagulant. The filter height is at the y-axis while the water pressure is at the x-axis. The upper horizontal line represents the water surface and the lower line represents the media border between sand and Filtralite. The diagonal straight line represents the static water pressure when there is no flow in the filter. The linear pressure curve next to the static pressure is form the beginning of a filter run when the filter is clean. The pressure is plotted after 15 and 17 hours and displayed in the graph. It can be seen that the greatest collection of clogged material is at the top of the filter, after filter run of 15 and 17 hours. The filter area from the water surface at 1.95 meter to the filter height 1.56 meter is most utilized. This is where the head loss is greatest per unit depth in the filter. The head loss increases in the different layers as the pressure curves move to the left. The head loss decreases slightly from 15 hours of filter run to 17 hours, which is just before the filter reaches breakthrough.

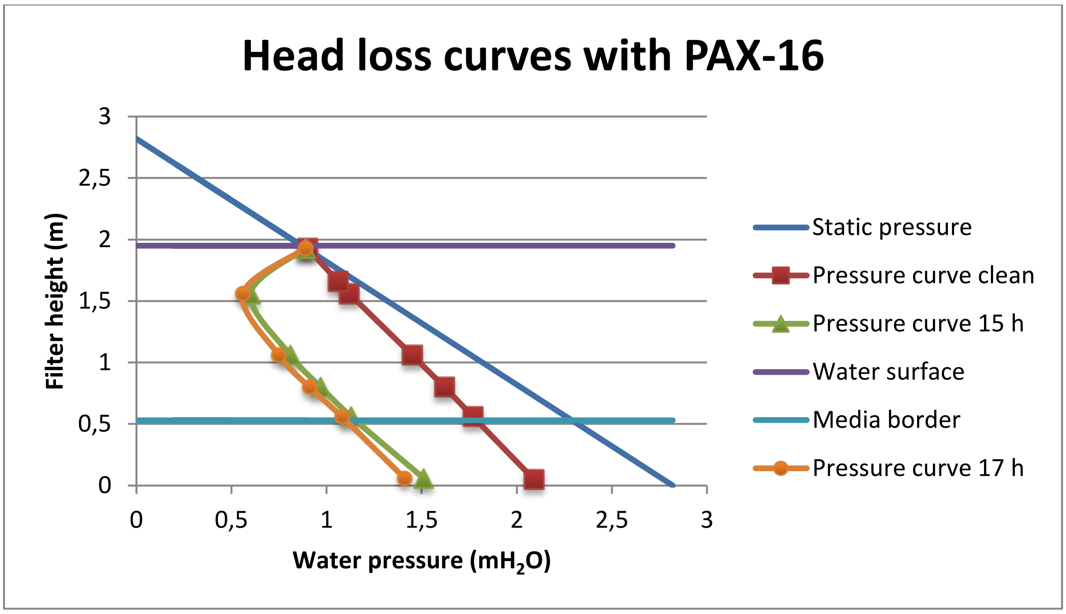


Figure 5-11: Water pressure development at different layers of the filter with PAX-16. Pressure curves for different times illustrate the head loss.

5.2 Coagulation tests with Ecoflock 91

The coagulation with Ecoflock 91 is tested with the dosage 1.7 mg/L (Al), which is the dosage used at the main plant. Afterwards the dosage was reduced to 1.5 mg/L (Al9. Figure 5-12 and Figure 5-13 show the development of colour and turbidity using Ecoflock 91 as coagulant. The ripening period is indicated by the time it takes for these parameters to stabilize. The pH is at different ranges with each of the filter runs. The turbidity, displayed in Figure 5-12, shows a fast decrease for all the pH ranges. The lowest turbidity can be seen with pH 6.1 and 6.3. The turbidity stabilizes below 0.2 NTU after 1.5 hours for both of these pH ranges. The decrease in turbidity is not as steep for the pH ranges 6.4 and 6.6, which stabilizes at a slightly higher level. The reduction in colour also happens quickly, as displayed in Figure 5-13. All the colour values are below 10 mg/L (Pt) after 1 hour of operation. The turbidity and colour development indicates a ripening period of 1 – 1.5 hours for all pH levels.

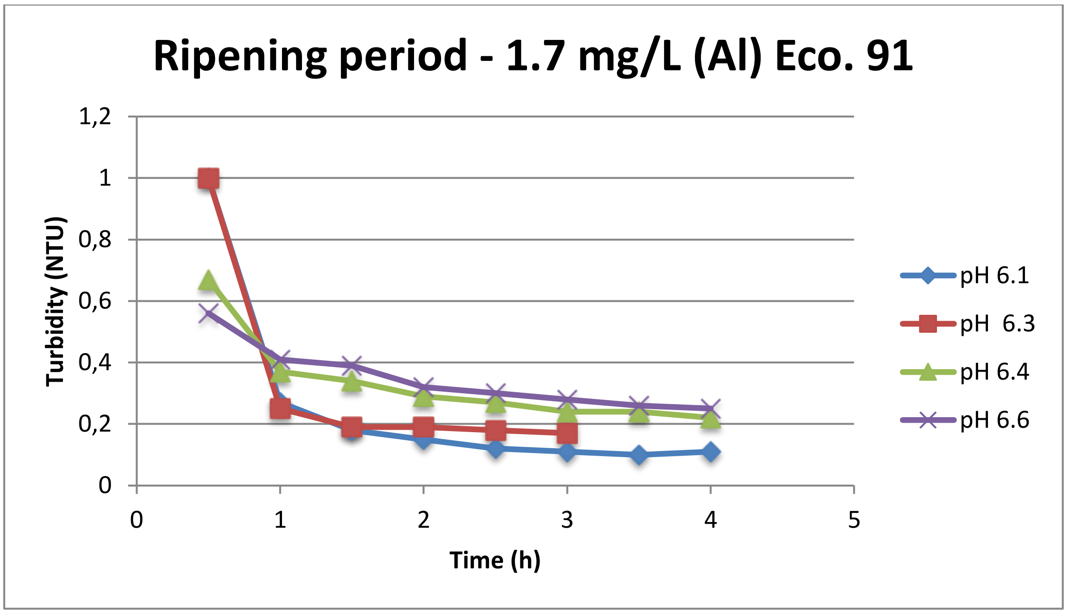


Figure 5-12: Ripening period indicated by turbidity development, with a dosage of 1.7 mg/L (Al) Ecoflock 91 and different pH ranges.

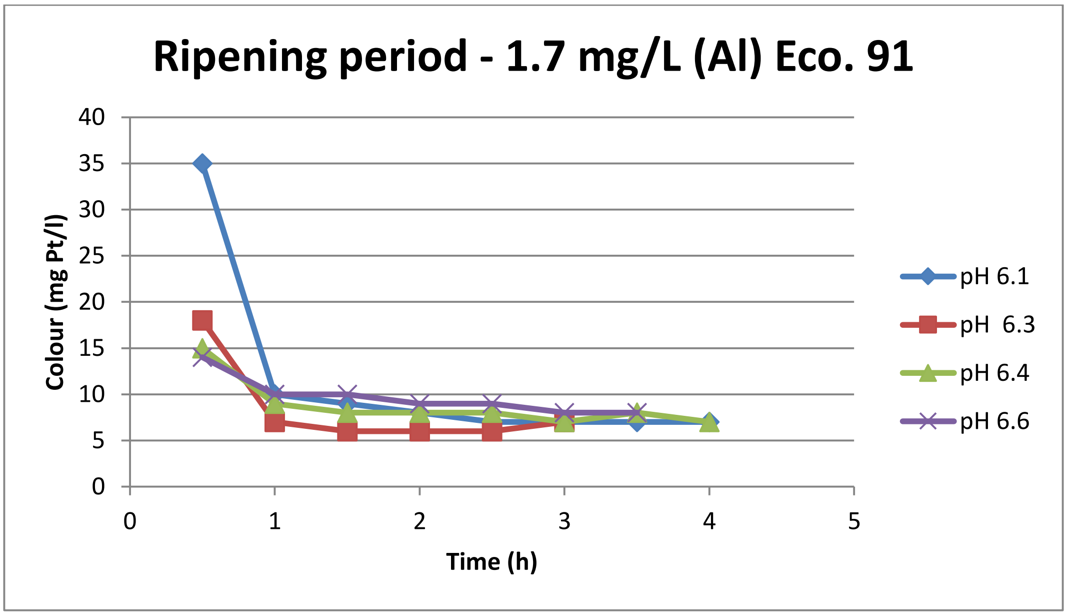


Figure 5-13: Ripening period indicated by colour development, with a dosage of 1.7 mg/L (Al) Ecoflock 91 and different pH ranges.

The development of turbidity and colour for a lower dosage of 1.5 mg/L (Al) Ecoflock 91 can be seen in Figure 5-14. The turbidity can be found on the y-axis on the left hand side, and the colour value on the right y-axis. The pH is kept at a level of 6.2 during the experiment. The turbidity stabilizes after 1.5 hours at 0.4 NTU. The colour has decreased to a value of 10 mg/L (Pt) when the first water sample is taken at 0.5 hours. After 2 hours the colour increases to 11 mg/L (Pt), before it decreases to a value of 9 mg/L (Pt). The ripening period is assumed to be around 1.5 hours according to the turbidity, disregarded the slightly unstable colour.

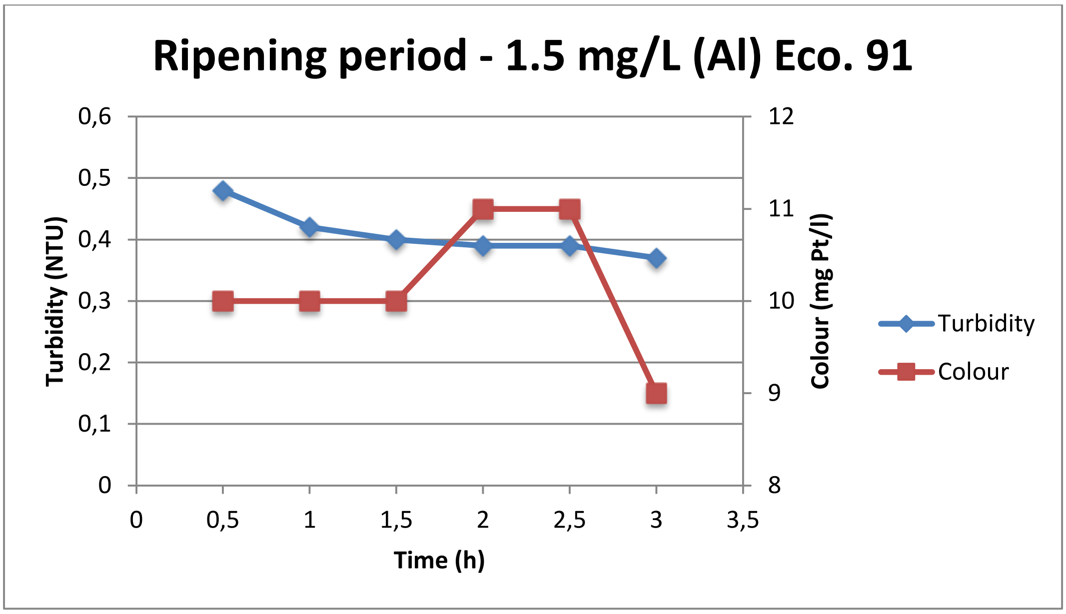


Figure 5-14: Ripening period indicated by colour and turbidity development. The pH is 6.2 with a dosage of 1.5 mg/L (Al) Ecoflock 91.

5.2.1 Coagulation profile with Ecoflock 91

By combining the results from experiments with Ecoflock 91, coagulation profiles regarding colour, turbidity, TOC and residual aluminium are presented in Figure 5-15 to 5-18. The plotted results are taken from the stabile values of the different parameters, at the end of all ripening periods. The result from dosages 1.7 and 1.5 mg/L (Al) is presented, in relation to the coagulation pH displayed on the x-axis. Figure 5-15 shows a turbidity profile of the results obtained from experiments with Ecoflock 91. Horizontal lines in the graphs displays the absolute limit and a recommended limit at a lower level. According to the potable water regulation the limit is at 1 NTU, and recommended limit is at 0.2 NTU. The turbidity is below the recommended limit for all the experiments using a dosage of 1.7 mg/L (Al), with one exception. The turbidity for this one is 0.33 NTU at a pH range 6.2. For the experiments with 1.5 mg/L (Al) the turbidity is above the recommended limit, with 0.32 NTU at pH 6.4.

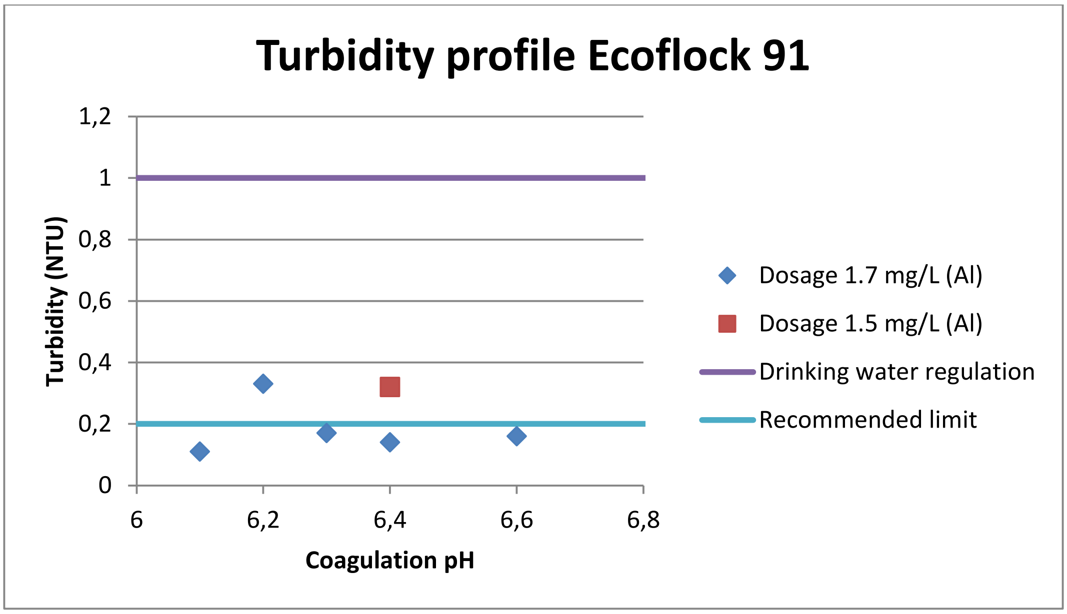


Figure 5-15: Turbidity at different pH ranges and dosages of Ecoflock 91, including limits from potable water regulation.

The colour profile for experiments with Ecoflock 91 is shown in Figure 5-16. The limit for colour is at 10 mg/L (Pt), and the recommended limit is 5 mg/L (Pt).

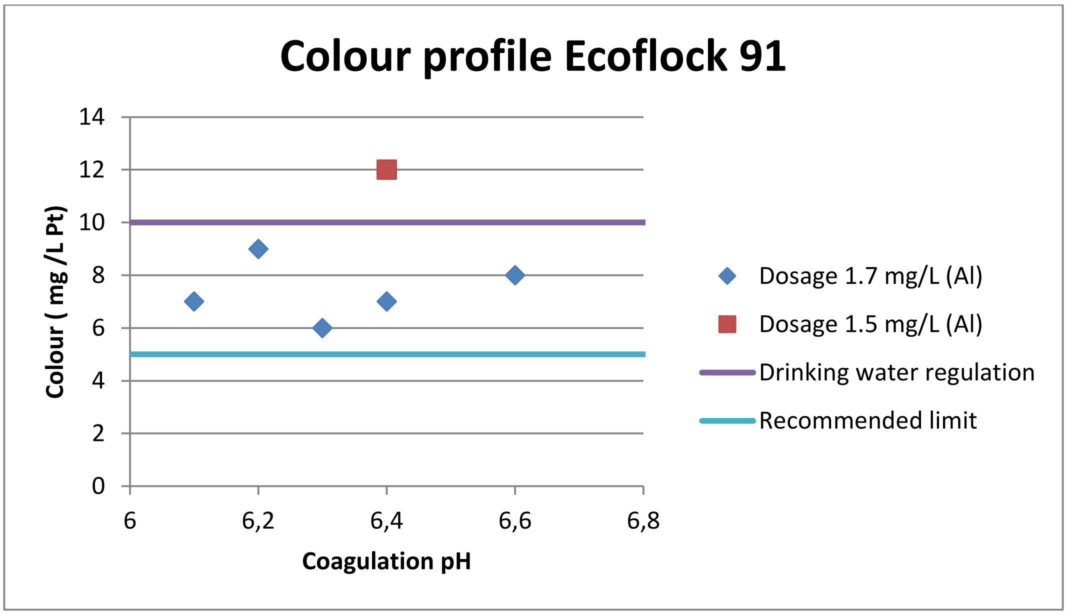


Figure 5-16: Colour value at different pH ranges and dosages of Ecoflock 91, including limits from potable water regulation.

The colour values are between 6 and 9 mg/L (Pt) and below the potable water regulation limit for all the experiments with the dosage of 1.7 mg/L (Al), but still above the recommended limit. The colour value for 1.5 mg/L (Al) is 12 mg/L (Pt) with pH 6.4. The TOC profile for Ecoflock 91 is shown in Figure 5-17, which indicates the organic matter. The potable water limit for TOC is 5 mg/L (C) and the recommended limit is 3 mg/L (C). The TOC values are close to the recommended limit for all pH ranges and dosages. The highest TOC can be seen at pH 6.4 where it is 3.4 mg/L (C) for dosage 1.5 mg/L (Al) and 3.3 mg/L (C) for dosage 1.7 mg/L (Al).

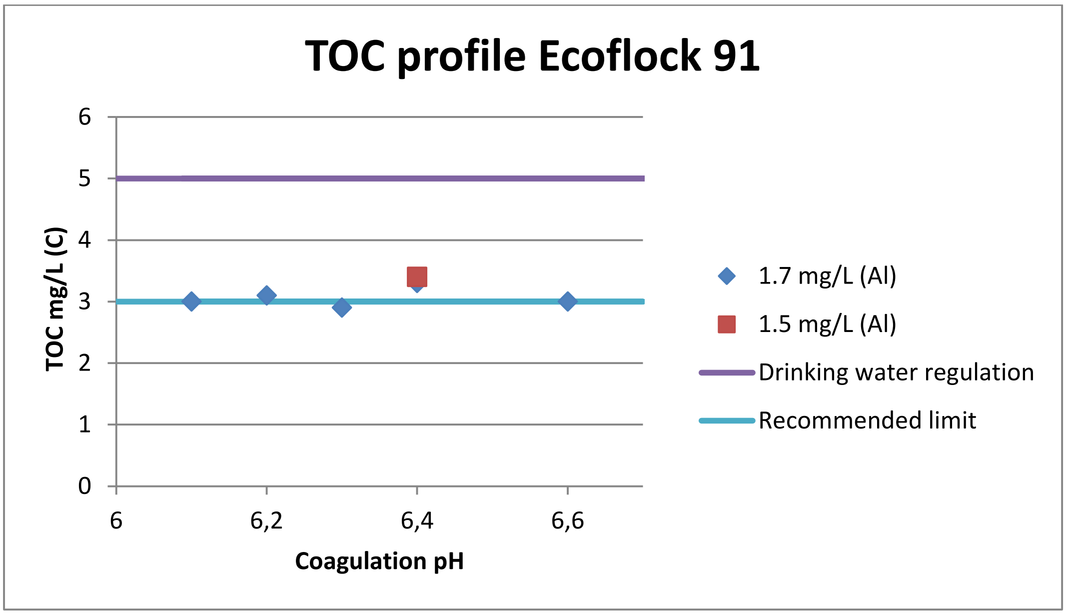


Figure 5-17: TOC at different pH ranges and dosages of Ecoflock 91, including limits from potable water regulation.

The coagulation profile displaying the residual aluminium with Ecoflock 91 is shown in Figure 5-18. The limit for residual aluminium is 0.2 mg/L (Al) and the recommended limit is 0.15 mg/L (Al). The residual aluminium is below the recommended limit for all the experiments with a dosage of 1.7 mg/L (Al). With a dosage of 1.5 mg/L (Al) the residual aluminium is above the potable water regulation limit.

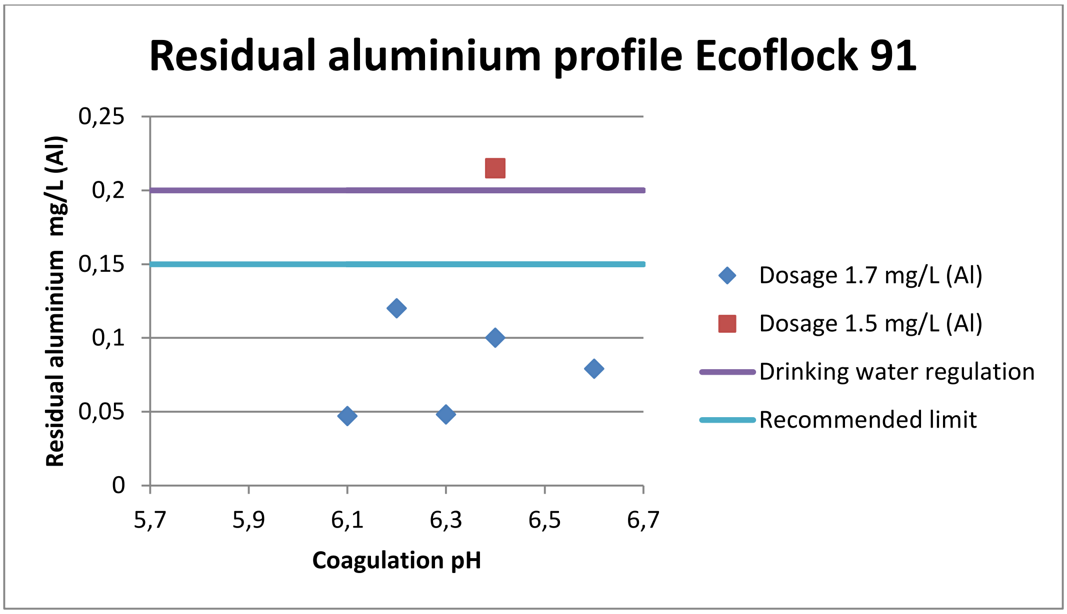


Figure 5-18: Residual aluminium at different pH ranges and different dosages of Ecoflock 91, including limits from potable water regulation.

5.2.2 Filter cycle time with Ecoflock 91

By running the filter over time, the filter cycle time can be noted. The filter cycle time is determined by either high turbidity or high differential pressure. Figure 5-19 shows the development of turbidity and differential pressure for a filter run with 1.7 mg/L (Al) Ecoflock 91.

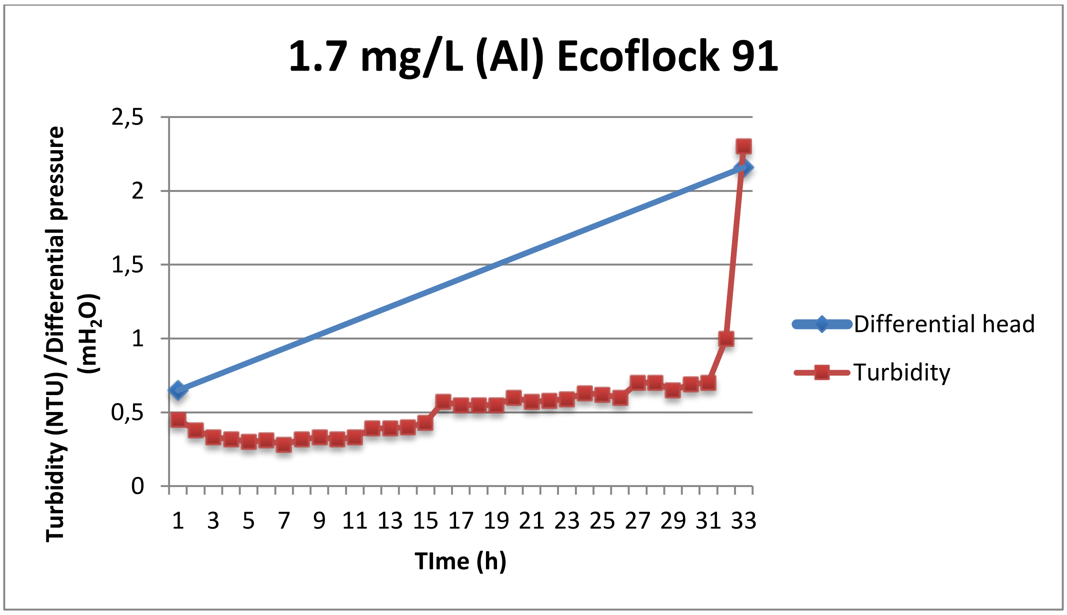


Figure 5-19: Differential pressure and turbidity development with 1.7 mg/L (Al) Ecoflock 91.

The turbidity stabilizes around 0.3 NTU for the first 12 hours, after this period the turbidity increases and remains at a higher level of 0.5 – 0.7 NTU. After 31 hours of filter run the turbidity increases dramatically, implying that the filter has reached "breakthrough". The built up of differential pressure increases linearly with time, and is at 2.16 mH_2O when the filter reaches breakthrough. The available head in the filter is 2.6 meters, which means that the 83 % of the available head is utilized.

5.2.3 Filter head loss with Ecoflock 91

Figure 5-20 shows the water pressure development at different layers in the filter at different times. The filter height is at the y-axis while the water pressure is at the x-axis. The upper horizontal line represents the water surface and the lower line represents the media border between sand and Filtralite. The straight diagonal line represents the static water pressure when there is no flow in the filter. The linear pressure curve next to the static pressure is form the beginning of a filter run when the filter is clean. The pressure is plotted after 9 and 25 hours and displayed in the graph. It can be seen that the filter greatest collection of clogged material is at the top of the filter, after filter run of 25 hours. The filter area from the water surface at 1.95 meter to the filter height 1.56 meter is most utilized. This is where the head loss is greatest per unit depth in the filter. The head loss at the different heights in the filter after 25 operational hours is the horizontal distance from the pressure curve 25 h, to the clean water pressure curve.

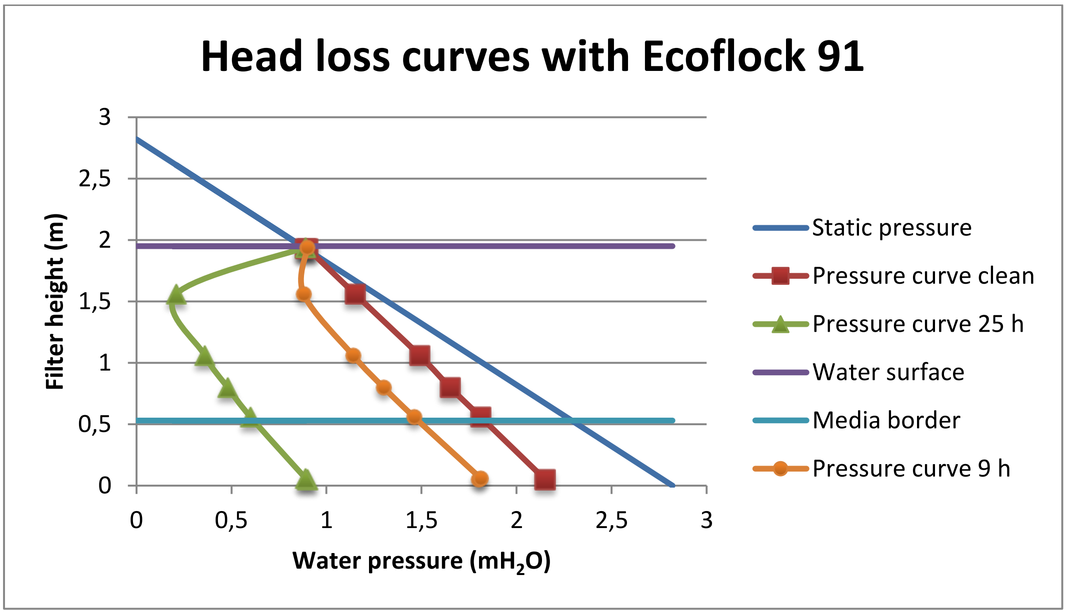


Figure 5-20: Water pressure development at different layers of the filter with Ecoflock 91. Pressure curves for different operational hours illustrate the head loss.

5.3 Coagulation test with Ecoflock 96

The coagulation is tested with 1.7 mg/L (Al) of Ecoflock 96. Figure 5-21 shows the ripening period indicated by turbidity and colour. The colour value can be found on the y-axis on the left hand side, and the turbidity on the right y-axis. The figure shows a significant reduction in both colour and turbidity after 1 hour. At this point the colour value is 8 mg/L (Pt) and turbidity is 0.28 NTU. After this, the values keep reducing with a decreasing effect during the experiment. The ripening period is assumed to be around 2 hours.

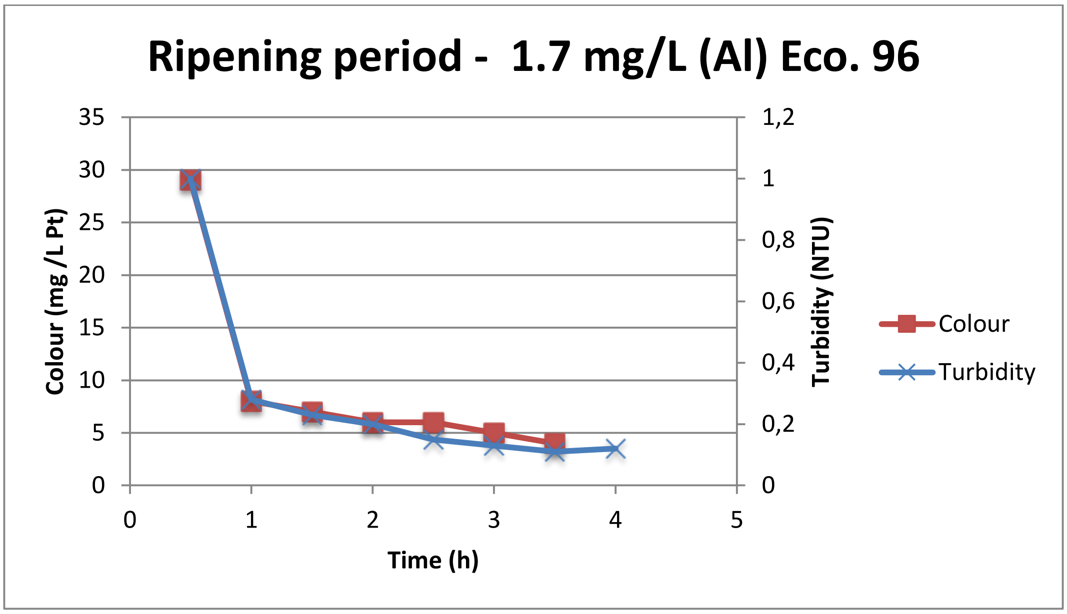


Figure 5-21: Ripening period indicated by colour and turbidity development, with a dosage of 1.7 mg/L (Al) Ecoflock 96.

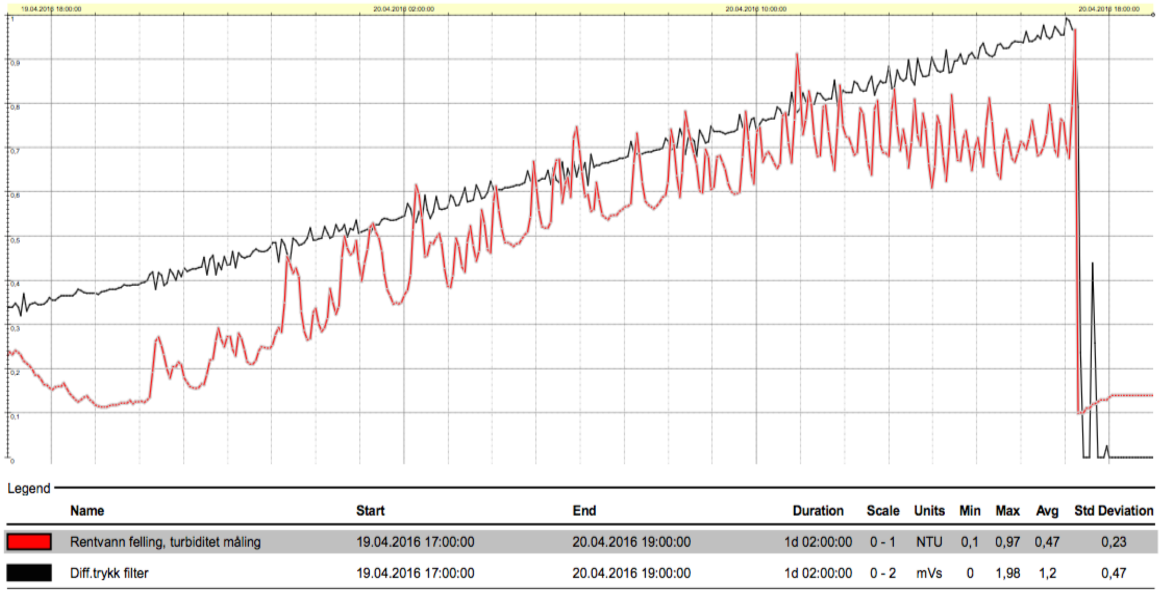
Table 5-1 shows the stable results of colour, turbidity, TOC and residual aluminium from the experiment with 1.7 mg/L (Al) Ecoflock 96 after 3.5 hours operation time. All the parameters are below the recommended limits from the Norwegian potable water regulation; The colour value of 4 mg/L (Pt) is below the 5 mg/L (Pt) recommended limit, the 0.11 NTU in turbidity is below the recommended limit at 0.2 NTU, residual aluminium with a value of 45 µg/l (Al) is below the recommended limit at 150 µg/l (Al) and 2.7 mg/L (C) is below the 3 mg/L (C) recommended limit for TOC.

Table 5-1: Laboratory results from experiment with 1.7 mg/L (Al) Ecoflock 96.

Colour mg/L (Pt)	**Turbidity (NTU)**	**TOC mg/L (C)**	**Residual aluminium µg/l (Al)**
4	0.11	2.7	45

5.3.1 Filter cycle time with Ecoflock 96

The developments of turbidity and differential pressure for a prolonged filter run using 1.7 mg/L (Al) Ecoflock 96 can be seen in Figure 5-22. The filter has been running for 1.5 hours before the values are shown in the graph. Turbidity from 0 – 1 NTU is displayed at the y-axis on the left hand side and differential pressure from 0 – 2 mH_2O on the other y-axis. The turbidity from the ripening period is shown previous in Figure 5-21. The turbidity stabilizes gradually below 0.2 NTU after 2 hours of filter run, and remains stable for further 2 hours. After this period the turbidity increases and is very unstable throughout the filter test. The differential pressure increases in the filter over the entire time. There are irregular peaks and troughs in the pressure; this seems to appear at the same time as the turbidity increases. The differential pressure is at 2 mH_2O after a filter run of 26 hours, the experiment was then terminated for practical reasons.



	Name	Start	End	Duration	Scale	Units	Min	Max	Avg	Std Deviation
🟥	Rentvann felling, turbiditet måling	19.04.2016 17:00:00	20.04.2016 19:00:00	1d 02:00:00	0 - 1	NTU	0,1	0,97	0,47	0,23
■	Diff.trykk filter	19.04.2016 17:00:00	20.04.2016 19:00:00	1d 02:00:00	0 - 2	mVs	0	1,98	1,2	0,47

Figure 5-22: Differential pressure and turbidity development with 1.7 mg/L (Al) Ecoflock 96.

5.3.2 Filter head loss with Ecoflock 96

Figure 5-23 shows the water pressure development at different layers in the filter at different times. The filter height is at the y-axis while the water pressure is at the x-axis. The upper horizontal line represents the water surface and the lower line represents the media border between sand and Filtralite. The straight diagonal line represents the static water pressure when there is no flow in the filter. The linear pressure curve next to the static pressure is form the beginning of a filter run when the filter is clean. The head loss is plotted after 5, 20 and 25.5 hours and displayed in the graph.

The filter area from the water surface at 1.95 meter to the filter height 1.56 meter is most utilized. This is where the head loss is greatest per unit depth in the filter. The head loss at the different heights in the filter after 25.5 operational hours is the horizontal distance from the pressure curve 25.5 h to the clean water pressure curve.

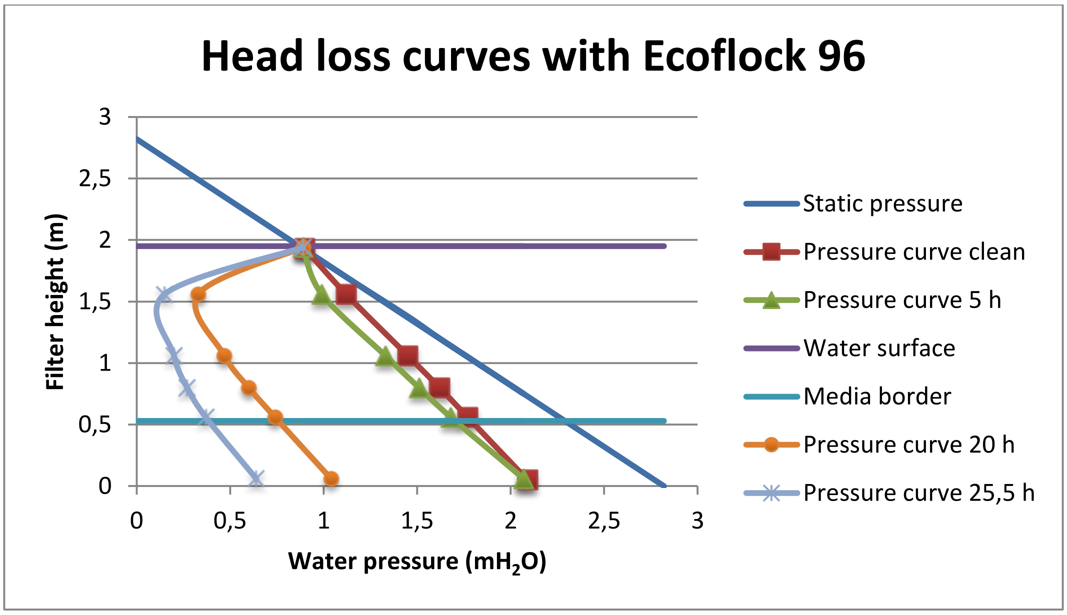


Figure 5-23: Water pressure development at different layers of the filter with Ecoflock 96. Pressure curves for different operational hours illustrate the head loss.

5.4 Coagulation experiment with Jar test

Coagulation experiments with the Jar test provide results regarding turbidity and colour of the coagulants PAX-16, Ecoflock 91, Ecoflock 96 and Aluminium sulphate. The obtained results are presented in Figure 5-24, where the different coagulants and dosages are marked on the x-axis. The turbidity is illustrated as bars, and the colour is marked as points.

The tests with PAX-16 show no reduction in colour or turbidity for the dosages 1.7 and 1.5 mg/L (Al). The colour values for both are 43 mg/L (Pt), and the turbidity is 2.6 and 2.7 NTU. The tests with aluminium sulphate provide identical results for both dosages of 1.7 and 1.9 mg/L (Al): 1.9 NTU in turbidity and 38 mg/L (Pt) in colour. Two parallels were made for the dosage 1.7 mg/L (Al) with both Ecoflock 91 and Ecoflock 96. All of these tests showed similar results with a turbidity of 1.9 NTU for three of them and 2.3 NTU for one. The colour value is 40 – 41 mg/L (Pt), and 44 mg/L (Pt) for the test with the highest turbidity. It can be seen in the figure that when the dosage is reduced to 1.5 mg/L (Al) the parameters reduces for the Ecoflock coagulants.

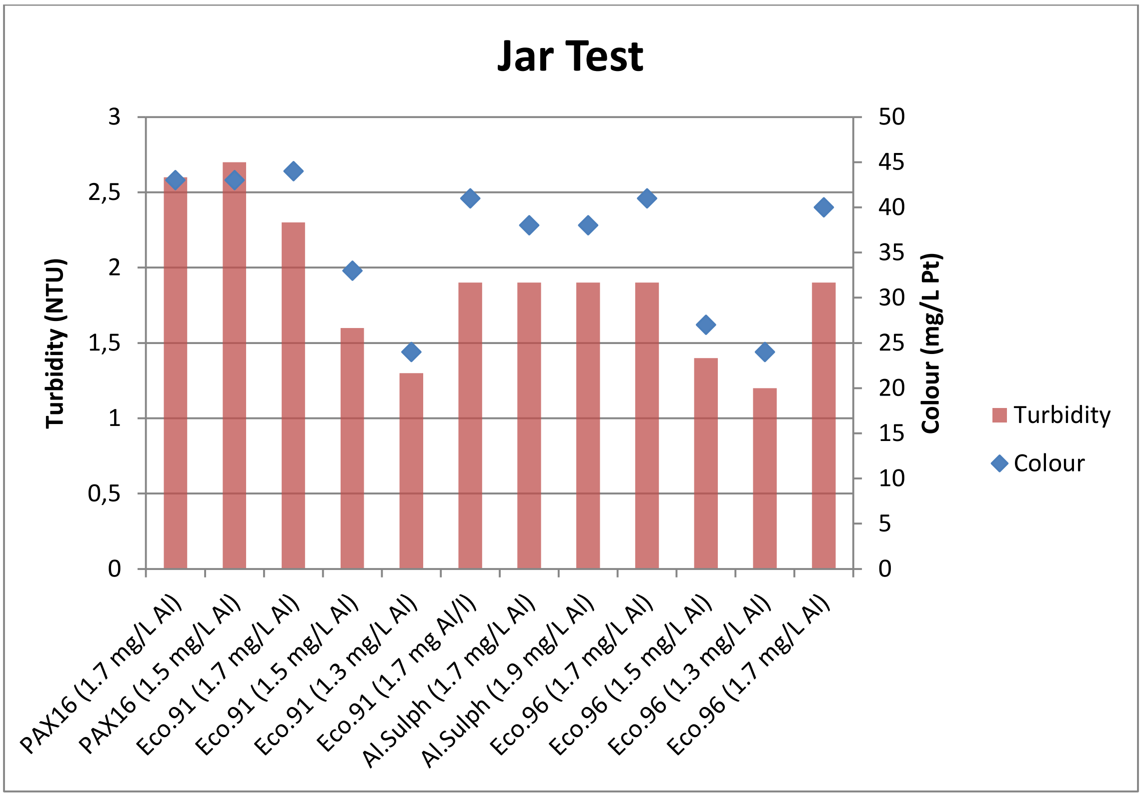


Figure 5-24: Turbidity and colour from coagulation experiment with a Jar test, using different coagulants and dosages.

Using Ecoflock 91 the colour is 33 mg/L (Pt) and turbidity is 1.6 NTU. With Ecoflock 96 the colour is 27 mg/L (Pt) and the turbidity is 1.4 NTU. It is also shown that the same applies when the dosage is reduced further, to 1.3 mg/L (Al). The colour values are then 24 mg/L (Pt) for both Ecoflock coagulants, and the turbidity is 1.2 – 1.3 mg/L (Al). Observation of floc formation was very difficult to see and capture on camera in this experiment. However, a small amount of flocs were observed in the Jar tests with the highest reduction in colour.

5.5 Cost estimation with different coagulants

Based on quotes from the suppliers a cost estimation is done in order to compare the cost associated with the different coagulants. The quotes are available in Appendix 6. The calculations below show that the estimated annual chemical costs range from 423 to 483 kNOK for the PACl coagulants, and that the chemical cost for aluminium sulphate is 999 kNOK.

The chemical company Kemira has estimated the price for PAX-16 delivered to Seierstad WTP in Larvik to 2100 NOK/ton. This is based on a cost estimate from November 2015. The annual consumption is assumed to be 230 ton, as it was at Seierstad WTP in 2014.

Cost of PAX-16 is then:

$$230\,\frac{ton}{year}\cdot 2100\,\frac{NOK}{ton} = 483\ 000\,\frac{NOK}{year}$$

The company Kemetyl has estimated the price of the Ecoflock coagulants to be 2200 – 2300 NOK/ton in February 2016. Higher aluminium concentration in Ecoflock coagulants allows the volume to be reduced with similar dosage 1.7 mg/L (Al). The calculation of volume reduction is based on the calculation regards dilution of chemicals available in Appendix 5. As a reference the amount used is 1.10 mL/s of PAX-16. Equivalent amount of the same dosage for Ecoflock 91 is 0.92 mL/s. The reduction of coagulant volume is calculated to be:

$$\frac{1.10\,\frac{mL}{s} - 0.92\,\frac{mL}{s}}{1.10\,\frac{mL}{s}}\cdot 100\ \% = 16.36\ \%$$

Assuming a price of 2200 NOK/ton for Ecoflock 91 the annual costs is calculated to be:

$$230\,\frac{ton}{year}(1 - 0.1636)\cdot 2200\,\frac{NOK}{ton} = 423\ 218\,\frac{NOK}{year}$$

For Ecoflock 96 the equivalent amount is 0.89 mL/s. The reduction of coagulant volume is calculated to be:

$$\frac{1.10\,\frac{mL}{s} - 0.89\,\frac{mL}{s}}{1.10\,\frac{mL}{s}}\cdot 100\ \% = 19.10\ \%$$

Assuming a price of 2300 NOK/ton for Ecoflock 96 the annual costs is calculated to be:

$$230\frac{ton}{year}(1-0.191)\cdot 2300\frac{NOK}{ton}=427\ 961\frac{NOK}{year}$$

Univar delivers aluminium sulphate and has estimated a price of 3250 NOK/ton delivered to Seierstad WTP in Larvik. The quote was valid for February 2016. A higher dosage of 1.9 mg/L (Al) is recommended for aluminium sulphate (Ødegaard et al., 2012). The necessary corresponding amount of coagulant dosage is 1.47 mL/s. This is an increase in coagulant volume and it is calculated to be:

$$\frac{1.47\frac{mL}{s}-1.10\frac{mL}{s}}{1.10\frac{mL}{s}}\cdot 100\ \% = 33.63\ \%$$

With a price of 3250 NOK/ton of Aluminium sulphate the annual costs is calculated to be:

$$230\frac{ton}{year}(1+0.336)\cdot 3250\frac{NOK}{ton}=998\ 660\frac{NOK}{year}$$

The chemical is delivered in solid form. This will require additional costs in investment of process equipment for dilution and mixing, and variable costs associated with an implementation of new equipment in the process.

6 Discussion

A discussion of the results obtained from the experiments is presented in this chapter. The results from different coagulants and dosages are compared with each other and in relation to the theory. It is also made an attempt to explain unexpected events/behaviours.

6.1 Water quality comparison from pilot plant tests

As the aim of the study was to evaluate cost and performance of coagulants, the amounts of currently used coagulant was reduced to see how this affected the water quality. In the experiments with PAX-16, the currently used dosage of 1.7 mg/L (Al) provided the best results in terms of water quality. When the dosage was reduced, the turbidity and colour stabilized at a significantly higher level, with one exception. One of the tests with a dosage of 1.5 mg/L (Al) gave more satisfactory results. This indicates a critical dosage since the performances diverge. This can also be seen in the coagulation profiles, where the parameters indicating water quality is at a high level for all the reduced dosages, except for one of the tests.

Aluminium sulphate was tested in the Jar test and provided slightly more adequate water quality in terms of colour and turbidity compared to PAX-16. However, the chemical is more expensive and it requires a higher dosage, and is therefore not cost effective. In addition aluminium sulphate is delivered in solid form, which would require additional process equipment and possible complicate the handling of operation.

1.7 mg/L (Al) of Ecoflock 91 provided satisfactory results compared with PAX-16. The colour and turbidity stabilizes faster, resulting in a quicker ripening period. The results are in general more stable in terms of colour and turbidity. The indicated ripening period is approximately 1 – 1.5 hours compared to 1.5 – 2 hours for PAX-16. Reducing the dosage of Ecoflock 91 did not increase the water quality; the colour and residual aluminium were significantly higher with the dosage 1.5 mg/L (Al). The filter was utilized well with Ecoflock 91 and the cycle time was nearly twice as long. The available head reached 83 % before the filter reached breakthrough compared to 53 % with PAX-16.

Ecoflock 96 provides promising results as it gives the best water quality in terms of colour and TOC. The TOC is 2.7 mg/L (C) with this coagulant, for Ecoflock 91 the TOC is close to 3 mg/L (C) for all tests, and for PAX-16 the TOC varies between

2.9 and 4.1 mg/L (C) with the same dosage. Turbidity and residual aluminium results are also at a low level with Ecoflock 96. However, this is only based on one series of data. Further investigation may be necessary to support this.

In general polyaluminium chlorides have low alkalinity consumption, according to the literature. It is also stated that the chemical has better NOM removal capacity compared to aluminium sulphate. Also, it is less pH dependent, making it easier to operate. In addition PACl requires lower dosages and less sludge is produced.

6.2 Head loss and turbidity development

Filter cycle time for the different coagulants is determined by the development of turbidity and differential pressure. Experiments with PAX-16 and Ecoflock 91 gave results according to the theory, with a stable turbidity – and linear increase in differential pressure, until breakthrough occurred in the filter. Ecoflock 91 run for a longer period with 31 hours, compared to 17 hours with PAX-16. The filter was consequently more utilized in the run with Ecoflock 91. The filter run with Ecoflock 96 did not follow the turbidity development as the others. The filter was probably not run at optimal conditions due to occurrence of negative pressure. The closing valve at the bottom of the filter is automatically regulated to keep the water at a constant level in the filter. The pressure drops quickly when the closing valve is regulated, which could result in air binding and release of the retained material in the filter. The greatest increase in turbidity is when the pressure is unstable, as seen in the figure for differential pressure and turbidity development for Ecoflock 96. It is difficult to compare the cycle time of Ecoflock 96 with the others when the turbidity is high and unstable during the filter run.

The figures displaying head loss in the filter did not display any effect of the different densities and size in the different media layers of sand and Filtralite. This might have been visible with more risers mounted in the filter. Another reason may be the distribution of filter media. The media layers were mixed in a region at the border between them. This may also have an impact of the effectiveness of the different media layers. The reason may be that the flow of backwash water is not sufficiently enough to expand the filter properly. This would result in an inefficient settling of the particles in the media.

6.3 Coagulation dosage and pH dependency

According to the literature the coagulation results are highly pH dependent, and the optimal pH range for polyaluminium chloride is 5.8 – 6.6. When the dosage of coagulant reduces, the optimal pH range is narrowed down. The dependence of pH range was in general not behaving as expected with the coagulation tests at the pilot. In the coagulation profiles the results were expected to show low values for the various parameters at the middle of this pH range, and the increase as the pH reaches one or the other range of the scale. On the contrary, the experiments with PAX-16 achieve the lowest colour and turbidity values with the highest and lowest pH levels. The coagulation profiles with Ecoflock 91 do not show any effect at the different pH ranges corresponding with the literature. This might have been more visible if the tests were done at a wider pH range. When the CO_2 feed stopped by a mistake, the pH increased to 7 and the effect of coagulation was clearly reduced. A reason for the inconsistent pH dependence can be due to the pH meter displaying an erroneous pH level. It is mounted very close to the intake of the chemicals at the pilot – before the chemicals and raw water have been properly mixed. Also, micronized marble may settle in the pH meter giving a misleading pH, as a part of the flow is led into the pH meter.

6.4 Jar test compared with pilot plant

The Jar test provides different results with reduced coagulant dosage compared to the pilot plant. It is interesting to see that the reduction in colour and turbidity is better when the dosage is reduced for Ecoflock 91 and 96. A reason for this might be better effect of coagulation mechanisms due to more efficient mixing in the Jar test. The Jar tests intended to simulate the residence time and mixing at the main plant, which may not correspond to the conditions at the pilot plant. The chemicals are added just prior the filter at the pilot plant, and the flow regime and therefore the mixing intensity is unknown. Better mixing at the pilot may be obtained if the chemicals are added further upstream, if the flow of raw water is higher or if some type of mixing device is installed.

The improved coagulation at lower coagulant dosage in the Jar test compared to that obtained in the pilot plant suggests that: 1. The coagulants used in the pilot tests are not fully utilized due to inadequate mixing (a well known phenomena, as desctibed in Tchobanolous et al. (2014)). 2. The pilot plant should be modified by introducing improved mixing where the coagulant is introduced, to better simulate the conditions in the full-scale process. 3. It may be possible to significantly cut the amount and cost of coagulants use if it is fully utilized by appropriate mixing with the raw water. 4. The best cases of the pilot study presented here should be repeated after adequate mixing has been introduced.

6.5 Cost compared with effect of coagulants

The prizes obtained to evaluate the cost for different chemicals are estimated, and prizes may vary if an agreement gets posted to tender.

Ecoflock has higher aluminium content than PAX-16, resulting in a reduced coagulant volume with the same dosage of 1.7 mg/L (Al). According to the calculations done, there is a possibility to reduce the coagulant costs by 12 % with Ecoflock 91 compared with PAX-16. The Ecoflock coagulants are suitable alternatives as they show similar results in water quality as PAX-16. The prolonged cycle time with Ecoflock 91 implies a possibility to reduce costs. Also, a quicker ripening period would be cost-saving, as seen in the tests with Ecoflock 91.

The Jar test results suggest that the coagulant dosage can be cut by more than 20 %, implying a potential cost cut also above 20 %. This is more than the difference between the cheapest and most expensive PACl coagulant alternatives in the cost calculations. It is therefore recommended to modify the pilot plant and verify this potential before doing more detailed comparisons between types of coagulants. More Jar tests with different mixing intensities could also be useful and should be carried out together with improved pilot plant tests.

7 Conclusion

To conclude this thesis key findings are listed in this chapter. The objective of this study was to find whether alternative coagulants and lower coagulant dosage could provide benefits in terms of water quality and reduction of costs.

- The Jar test results suggest that the coagulant dosage should be cut by at least 20 %, but this was not verified by the pilot tests. This suggests that:
    - The coagulants used in the pilot tests are not fully utilized due to inadequate mixing.
    - The pilot plant should be modified by introducing improved mixing where the coagulant is introduced.
    - It may be possible to significantly cut the amount and cost of coagulants use if it is fully utilized by appropriate mixing with the raw water.
    - The best cases of the pilot study presented here should be repeated after adequate mixing has been introduced.

- Reducing the dosage of PAX-16 and hence reduce the coagulant cost, is not a good alternative because of decreased water quality.

- Aluminium sulphate is not a good alternative as it is more expensive, requires a higher dosage, and does not provide a notable better water quality.

- Ecoflock 91 and Ecoflock 96 are suitable alternatives to PAX-16 as they provide good results in terms of:
    - Water quality
    - Cost
    - Prolonged cycle time

- Water quality comparison:
    - The Ecoflock coagulants and PAX-16 show similar results in water quality after a stabilization period.
    - Ecoflock shows a more stable turbidity and colour reduction, in addition to a quicker ripening period.
    - Ecoflock 91 gives TOC values close to the recommended limit (3 mg/L C), while PAX-16 has slightly higher TOC (2.9 – 4.1 mg/L C).
    - Ecoflock 96 provides promising results as it provides the best water quality. The tests show the lowest colour value and TOC (2.7 mg/L C) in the treated water. It also shows a low turbidity and residual aluminium. However, this is only based on one series of data. Further investigation may be necessary to support this.

- Cost estimation:
    - Ecoflock has higher aluminium content than PAX-16, resulting in a reduced coagulant volume with the same dosage of 1.7 mg/L (Al). The annual costs associated with coagulant is calculated to be:
        - PAX-16: 483 000 NOK/year
        - Ecoflock 91: 423 000 NOK/year
        - Ecoflock 96: 428 000 NOK/year

- There is an even greater potential of reducing cost associated with coagulant than calculated above, if cycle time can be increased and ripening period reduced. This seems possible with Ecoflock.

8 References/literature

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Appendix

Appendix 1: Project Task Description

Appendix 2: Model of Seierstad water treatment plant

Appendix 3: Water quality parameters

Appendix 4: Chemical data sheets

Appendix 5: Calculation of chemical dosage and dilution

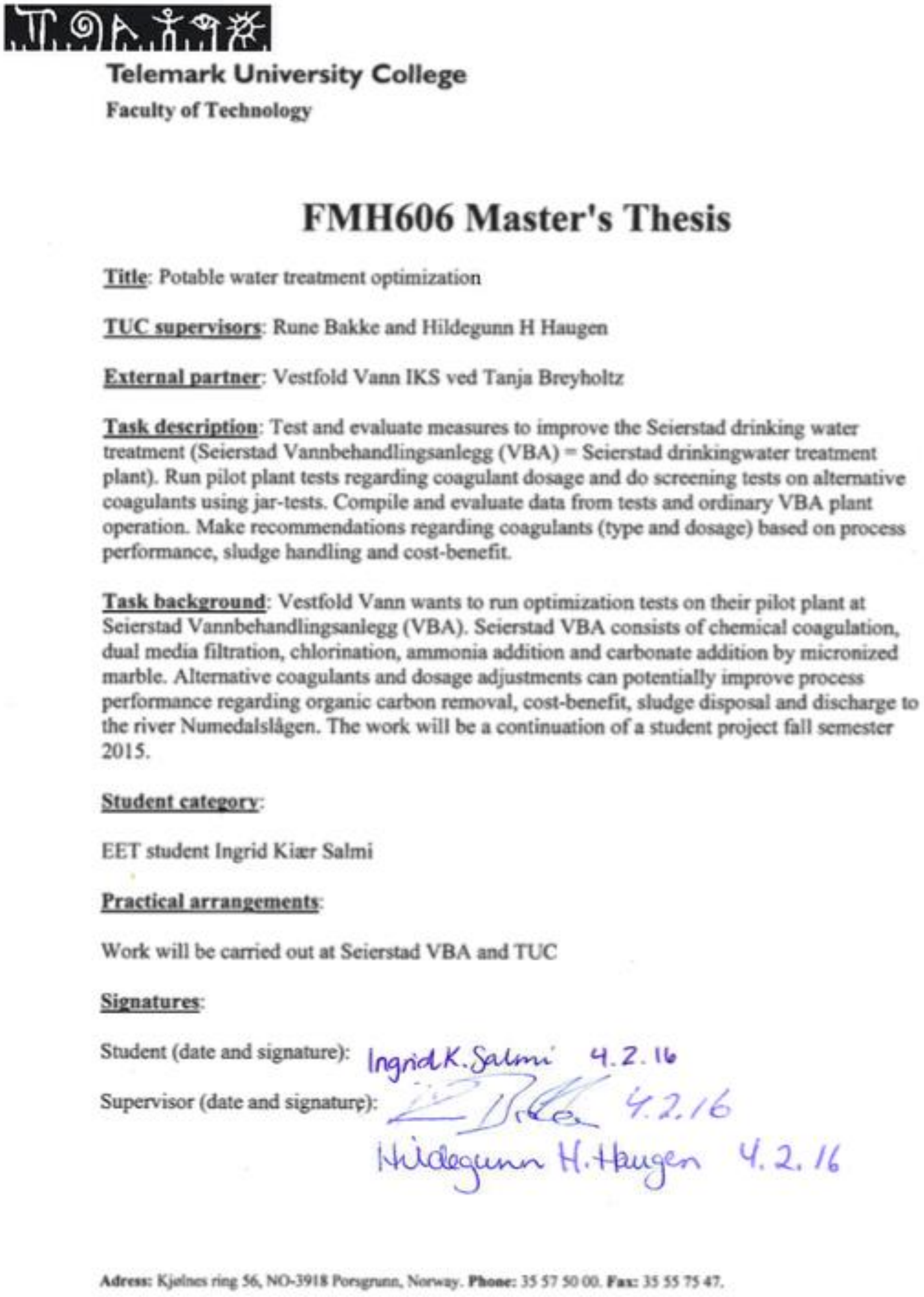
Appendix 6: Price quotes

Appendix 7: Data from pilot tests

Appendix 8: Data from Jar tests

Appendix 9: HSE report pilot plant

Appendix 1: Project Task Description



Telemark University College
Faculty of Technology

FMH606 Master's Thesis

Title: Potable water treatment optimization

TUC supervisors: Rune Bakke and Hildegunn H Haugen

External partner: Vestfold Vann IKS ved Tanja Breyholtz

Task description: Test and evaluate measures to improve the Seierstad drinking water treatment (Seierstad Vannbehandlingsanlegg (VBA) = Seierstad drinkingwater treatment plant). Run pilot plant tests regarding coagulant dosage and do screening tests on alternative coagulants using jar-tests. Compile and evaluate data from tests and ordinary VBA plant operation. Make recommendations regarding coagulants (type and dosage) based on process performance, sludge handling and cost-benefit.

Task background: Vestfold Vann wants to run optimization tests on their pilot plant at Seierstad Vannbehandlingsanlegg (VBA). Seierstad VBA consists of chemical coagulation, dual media filtration, chlorination, ammonia addition and carbonate addition by micronized marble. Alternative coagulants and dosage adjustments can potentially improve process performance regarding organic carbon removal, cost-benefit, sludge disposal and discharge to the river Numedalslågen. The work will be a continuation of a student project fall semester 2015.

Student category:

EET student Ingrid Kiær Salmi

Practical arrangements:

Work will be carried out at Seierstad VBA and TUC

Signatures:

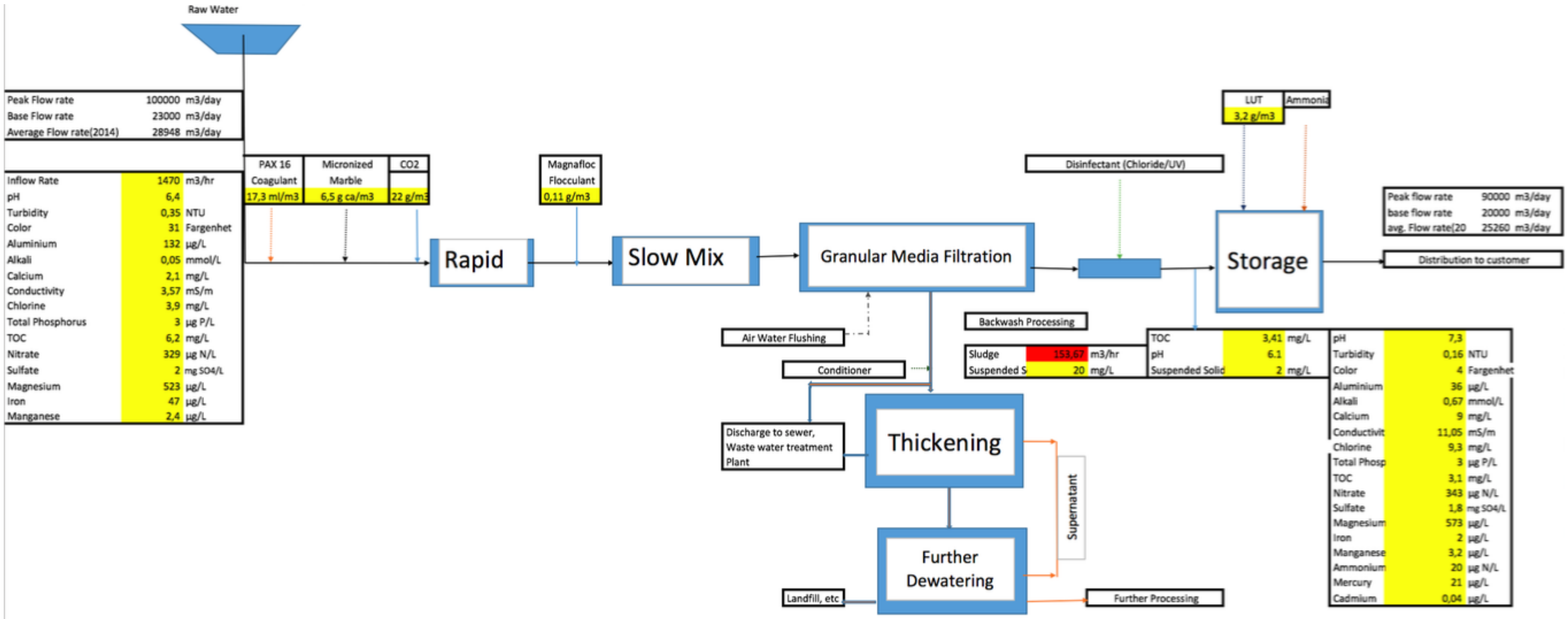
Student (date and signature): Ingrid K. Salmi 4.2.16

Supervisor (date and signature): 4.2.16

Hildegunn H. Haugen 4.2.16

Adress: Kjølnes ring 56, NO-3918 Porsgrunn, Norway. **Phone:** 35 57 50 00. **Fax:** 35 55 75 47.

Appendix 2: Model of Seierstad WTP



Appendix 3: Water quality parameters

Colour value of raw water

Date	Colour mg/L Pt	24.11.14	30	27.01.14	32	09.02.15	31
27.03.12	35	03.12.14	31	03.02.14	31	16.02.15	32
03.04.12	35	08.12.14	32	10.02.14	35	24.02.15	31
10.04.12	32	15.12.14	28	17.02.14	32	02.03.15	32
17.04.12	33	22.12.14	32	24.02.14	33	09.03.15	32
24.04.12	31	29.12.14	31	03.03.14	31	16.03.15	32
30.04.12	33	20.02.13	32	10.03.14	32	23.03.15	31
08.05.12	32	27.02.13	31	17.03.14	32	30.03.15	30
15.05.12	32	04.03.13	31	19.03.14		07.04.15	32
22.05.12	33	12.03.13	32	24.03.14	32	13.04.15	31
29.05.12	32	21.03.13	33	31.03.14	32	27.04.15	30
05.06.12	32	25.03.13	33	07.04.14	31	04.05.15	32
12.06.12	31	02.04.13	29	14.04.14	32	11.05.15	28
19.06.12	31	09.04.13	35	22.04.14	33	18.05.15	32
26.06.12	30	16.04.13	32	28.04.14	31	26.05.15	30
04.07.12	30	23.04.13	32	05.05.14	30	01.06.15	33
10.07.12	31	30.04.13	32	12.05.14	30	08.06.15	29
17.07.12	32	06.05.13	34	19.05.14	30	15.06.15	32
25.07.12	30	14.05.13	31	26.05.14	34	22.06.15	33
31.07.12	30	21.05.13	33	03.06.14	31	29.06.15	33
07.08.12	30	28.05.13	31	10.06.14	32	06.07.15	32
14.08.12	30	04.06.13	32	16.06.14	33	13.07.15	33
21.08.12	29	11.06.13	32	23.06.14	31	21.07.15	32
28.08.12	30	17.06.13	31	01.07.14	32	27.07.15	32
04.09.12	32	25.06.13	31	07.07.14	31	03.08.15	32
11.09.12	33	02.07.13	32	14.07.14	30	10.08.15	32
18.09.12	32	09.07.13	32	21.07.14	33	24.08.15	30
25.09.12	30	15.07.13	31	28.07.14	30	31.08.15	31
02.10.12	32	22.07.13	31	04.08.14	32	07.09.15	32
09.10.12	31	29.07.13	31	11.08.14	34	14.09.15	32
16.10.12	29	06.08.13	31	18.08.14	29	21.09.15	31
23.10.12	30	13.08.13	29	25.08.14	31	28.09.15	31
30.10.12	29	20.08.13	31	03.09.14	33	05.10.15	32
06.11.12	31	27.08.13	31	08.09.14	34	12.10.15	30
13.11.12	30	04.09.13	31	15.09.14	31	19.10.15	30
21.11.12	29	10.09.13	31	23.09.14	31	26.10.15	31
27.11.12	29	24.09.13	31	29.09.14	29	02.11.15	31
05.12.12	29	09.10.13	31	06.10.14	32	09.11.15	33
13.12.12	30	15.10.13	30	13.10.14	31	16.11.15	29
18.12.12	30	26.11.13	31	20.10.14	31	23.11.15	29
02.01.13	31	02.12.13	32	27.10.14	30	30.11.15	36
08.01.13	31	10.12.13	31	03.11.14	30	07.12.15	36
15.01.13	30	17.12.13	30	10.11.14	31	14.12.15	35
22.01.13	30	23.12.13	31	05.01.15	29	21.12.15	32
29.01.13	30	30.12.13	32	12.01.15	32	28.12.15	33
05.02.13	30	07.01.14	32	19.01.15	31		
12.02.13	30	14.01.14	31	26.01.15	33		

17.11.14	31	20.01.14	30	02.02.15	31

TOC values in raw water

Dag	TOC mg/L
16.03.10	5,2
15.06.10	5,7
14.09.10	5,7
14.12.10	5,1
15.03.11	5,1
14.06.11	4,8
13.09.11	4,8
12.06.12	6,4
18.09.12	5,2
18.12.12	5,7
12.03.13	6,3
17.06.13	6,0
10.09.13	4,9
17.12.13	7,4
17.03.14	6,0
16.06.14	6,9
15.09.14	5,2
15.12.14	7,8
16.03.15	5,5
22.06.15	6,0
14.09.15	6,5
14.12.15	5,7

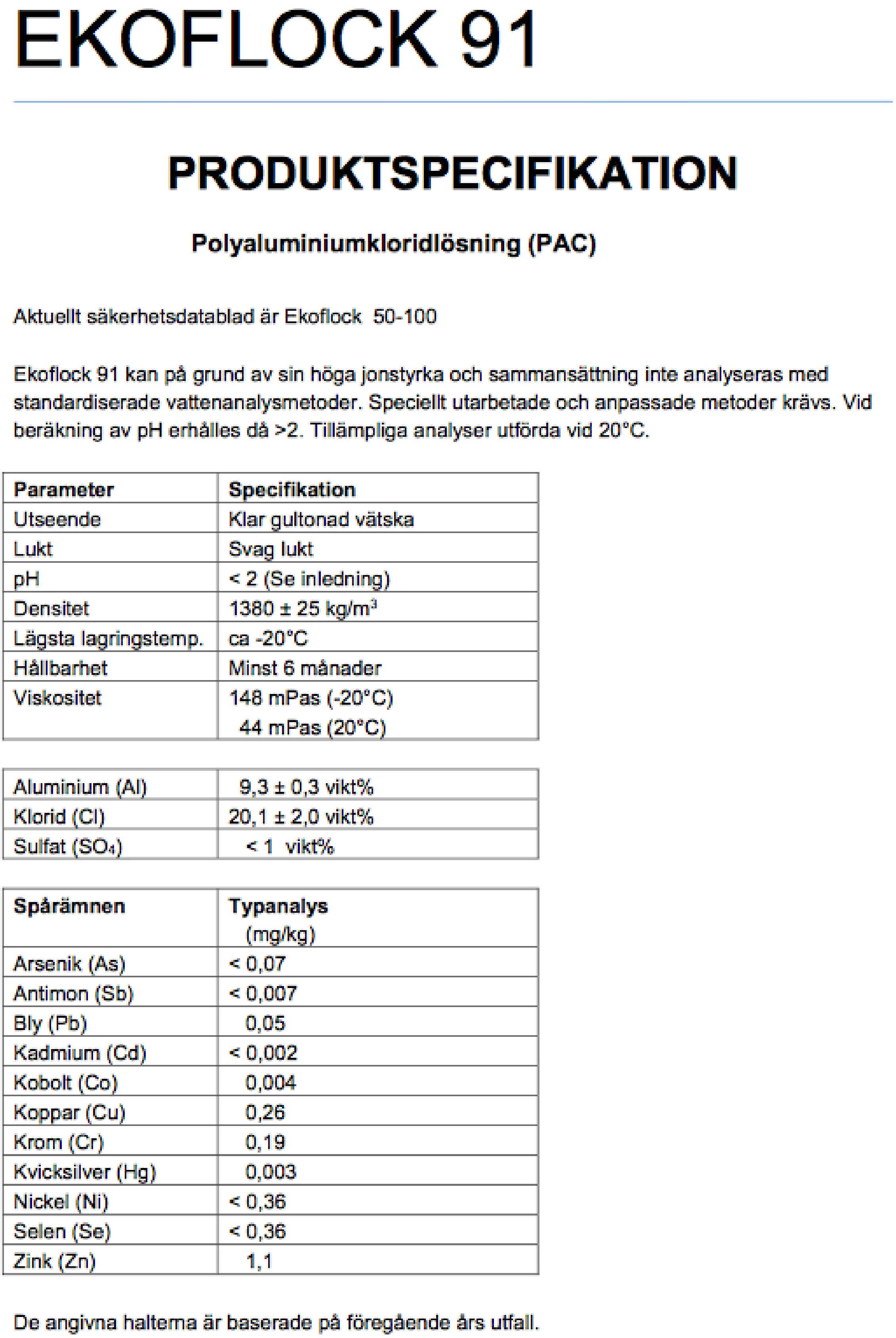
TOC values in treated water

Date	TOC mg/L C
16.03.10	2,6
15.06.10	3,1
16.06.10	3,4
17.08.10	3,1
14.09.10	3,7
16.11.10	2,4
14.12.10	2,3
18.01.11	3,4
15.03.11	2,8
16.05.11	2,4
14.06.11	2,3
12.07.11	2,2
13.09.11	2,4
14.11.11	2,6
15.05.12	2,5
12.06.12	3,0
17.07.12	3,3
18.09.12	2,4
13.11.12	2,9
18.12.12	2,3
15.01.13	2,4
12.03.13	3,1
14.05.13	2,9
15.07.13	3,5
10.09.13	2,1
14.01.14	3,6
17.03.14	4,0
12.05.14	2,5
14.07.14	3,0
15.09.14	3,2
17.11.14	3,1
03.12.14	3,4
08.12.14	3,1
15.12.14	3,6
22.12.14	2,6
29.12.14	3,5
05.01.15	3,1
12.01.15	3,3
19.01.15	3,1
26.01.15	3,0
02.02.15	2,3
09.02.15	2,6
16.02.15	2,7
24.02.15	3,5
02.03.15	3,0
09.03.15	2,8
16.03.15	2,5
23.03.15	3,1
30.03.15	3,1
07.04.15	3,1
13.04.15	3,2
27.04.15	3,3
04.05.15	3,2
11.05.15	3,2
18.05.15	3,2
26.05.15	2,4
01.06.15	3,2
08.06.15	3,3
15.06.15	3,3
22.06.15	2,2
29.06.15	4,5
06.07.15	3,4
13.07.15	3,3
21.07.15	2,4
27.07.15	3,2
03.08.15	3,0
10.08.15	2,6
24.08.15	3,2
31.08.15	2,7
07.09.15	2,7
14.09.15	3,5
21.09.15	2,9
28.09.15	3,5
05.10.15	3,4
12.10.15	2,6
19.10.15	2,4
26.10.15	2,6
02.11.15	2,5
09.11.15	3,1
16.11.15	2,3
23.11.15	2,9
30.11.15	2,9
07.12.15	3,3
14.12.15	2,2
21.12.15	3,3
28.12.15	3,3

Turbidity in raw water

05.01.15	0,30
12.01.15	0,41
19.01.15	0,38
26.01.15	0,35
02.02.15	0,40
09.02.15	0,35
16.02.15	0,40
24.02.15	0,37
02.03.15	0,41
09.03.15	0,39
16.03.15	0,39
23.03.15	0,34
30.03.15	0,30
07.04.15	0,39
13.04.15	0,36
27.04.15	0,40
04.05.15	0,41
11.05.15	0,47
18.05.15	0,61
26.05.15	0,45
01.06.15	0,43
08.06.15	0,53
15.06.15	0,31
22.06.15	0,37
29.06.15	0,29
06.07.15	0,34
13.07.15	0,34
21.07.15	0,34
27.07.15	0,59
03.08.15	0,25
10.08.15	0,25
24.08.15	0,29
31.08.15	0,26
07.09.15	0,31
14.09.15	0,28
21.09.15	0,30
28.09.15	0,45
05.10.15	0,35
12.10.15	0,25
19.10.15	0,46
26.10.15	0,48
02.11.15	0,34
09.11.15	0,24
16.11.15	0,40
23.11.15	0,31
30.11.15	0,51
07.12.15	0,26
14.12.15	0,35
21.12.15	0,62
28.12.15	0,40

Appendix 4: Chemical data sheets



EKOFLOCK 91

PRODUKTSPECIFIKATION

Polyaluminiumkloridlösning (PAC)

Aktuellt säkerhetsdatablad är Ekoflock 50-100

Ekoflock 91 kan på grund av sin höga jonstyrka och sammansättning inte analyseras med standardiserade vattenanalysmetoder. Speciellt utarbetade och anpassade metoder krävs. Vid beräkning av pH erhålles då >2. Tillämpliga analyser utförda vid 20°C.

Parameter	**Specifikation**
Utseende	Klar gultonad vätska
Lukt	Svag lukt
pH	< 2 (Se inledning)
Densitet	1380 ± 25 kg/m^3
Lägsta lagringstemp.	ca -20°C
Hållbarhet	Minst 6 månader
Viskositet	148 mPas (-20°C) 44 mPas (20°C)

Aluminium (Al)	9,3 ± 0,3 vikt%
Klorid (Cl)	20,1 ± 2,0 vikt%
Sulfat (SO_4)	< 1 vikt%

Spårämnen	**Typanalys** (mg/kg)
Arsenik (As)	< 0,07
Antimon (Sb)	< 0,007
Bly (Pb)	0,05
Kadmium (Cd)	< 0,002
Kobolt (Co)	0,004
Koppar (Cu)	0,26
Krom (Cr)	0,19
Kvicksilver (Hg)	0,003
Nickel (Ni)	< 0,36
Selen (Se)	< 0,36
Zink (Zn)	1,1

De angivna halterna är baserade på föregående års utfall.

SIKKERHETSDATABLAD

ACTICARB 90 V-ME 78%

AVSNITT 1: Identifikasjon av stoffet/stoffblandingen og selskapet/foretaket

1.1 Produktidentifikator

Produktnavn : ACTICARB 90 V-ME 78%
Produktkode : P026CL
Type produkt : væske

1.2 Relevante, identifiserte bruksområder for stoffet eller blandingen, og ikke-anbefalt bruk

Identifisert bruk
Industriell distribusjon. Industriell BRUK for formulering av kjemiske produktblandinger.

Bruk frarådet : Ingen identifisert.

1.3 Detaljer om leverandøren på sikkerhetsdatabladet

Yara Norge AS - Industrial Products

Adresse
Gate : Drammensveien 131
Postnummer : 0277
By : Oslo
Land : Norge

Postboks Adresse
Postboks : 343 Skøyen
Postnummer : 0213
By : Oslo
Land : Norge

Telefonnummer : +47 24 15 70 00
Faks nr. : +47 24 15 70 01
E-postadresse til person ansvarlig for dette sikkerhetsdatabladet : yara-kjemikalieordre@yara.com

1.4 Nødtelefonnummer

Nasjonalt rådgivingskontor/Giftinformasjonen
Navn : Giftinformasjonen (Poison Center)
Telefonnummer : +47 22 59 13 00
Åpningstider : 24h

Univar B.V.

106084 ALUMINIUM SULPHATE 17/18% 2 - 8 mm **November 2012**

Description: White grain

CAS NO: 16828-12-9 **FORMULA:** $Al_2(SO_4)_3$ approx 14 H_2O

EINECS NO: 233-135-0

Specification	**Unit**	**Value**
Aluminium (AL_3)	%	>9.0
Al_2O_3	%	≥ 17.0
Basicity	% Al_2O_3	≤ 0.5
Fe (iron free)	mg/kg	≤ 50
Insoluble in water	%	0.2
Tracers: max values according	to EN 878	
Cadmium – Cd	mg/kg	<0.27
Chromium – Cr	mg/kg	<2.72
Mercury – Hg	mg/kg	<0.36
Nickel – Ni	mg/kg	<1.82
Lead – Pb	mg/kg	<3.63
Antimony - Sb	mg/kg	<1.82
Selenium - Se	mg/kg	<1.82
Arsenic – As	mg/kg	<1.27
Density	kg/L	1.7
Bulk density	kg/L	1.0 ± 0.1

Text

Storage: Storage under dry conditions at room temperature.

Revision 00

Appendix 5: Calculation of chemical dosage and dilution

Raw water in

$$Q = 5.0\frac{m3}{h} = 5000\frac{l}{h} = \; 1.39\frac{l}{s}$$

The raw water pump delivers 11.1 m3/h at 100%. The pump curve is linear and can be adjusted on a scale from 0 -100 %.

$$Raw\ water\ pump = \frac{5\frac{m3}{h}}{11.1\frac{m3}{h}} \cdot 100\% \; = \mathbf{45}\%$$

Filter rate

$$Q = v \cdot A \qquad v = \frac{Q}{A}$$

$$A = \frac{\pi \cdot d^2}{4} \qquad d = 1m$$

$$v = \frac{5\ m3/h}{\frac{\pi \cdot 1}{4}} = \mathbf{6.4\frac{m}{h}}$$

Dosage PAX16

$$Q \cdot C = q \cdot c$$

Where,

$Q = pump\ capacity\ of\ the\ raw\ water$

$C = target\ concentration\ of\ aluminium\ in\ raw\ water$

$q = capacity\ of\ the\ dosage\ pump$

$c = concentration\ of\ aluminium\ in\ dosage\ basin$

Concentration of aluminium in dosage basin:

Aluminium content = 8.05%

Density= 1335 g/l

Dilution = 1 : 50 = 0.02

$$c = 1335\frac{g}{l} \cdot 0.0805 \cdot 0.02 = 2.15\frac{g}{l}\left(\frac{mg}{ml}\right)$$

Capacity dosage pump PAX-16

$$q = \frac{Q \cdot C}{c} = \frac{1.39\frac{l}{s} \cdot 1.7\frac{mg}{l}}{2.15\frac{mg}{ml}} = \mathbf{1.10\frac{ml}{s}}$$

The dosage pump delivers 1.47 mL/s at a frequency of 50 Hertz. The pump curve is linear and can be adjusted on a scale from 0 – 50 Hz. To get the correct dosage the pump was set to 37.4 Hz, which gives a pump flow of 1.10 mL/s.

$$Setting\ coagulant\ pumpe = \frac{1.10\frac{ml}{s}}{1.47\frac{ml}{s}} \cdot 50\ Hz = \mathbf{37.4\ Hz}$$

Dosage of micronized marble

C = target concentration of marble in raw water = 6.5 g/m3 (mg/L)

Concentration of calcium in dosage basin:

Acticarb 90 V-ME 78 %

Calcium content = 78 %

Density $= 1.9\frac{g}{cm3} = 1.9\frac{mg}{l}$

$$Calcium\ concentration\ Acticarb = 1.9\frac{mg}{l} \cdot 78\% \cdot \frac{Molvekt\ Ca}{Molvekt\ CaCO3}$$

$$Calcium\ concentration\ Acticarb = 1.9\frac{mg}{l} \cdot 0.78 \cdot \frac{40}{100} = 0.5928\frac{mg}{l}$$

$$= 592.8\frac{g}{l}\left(\frac{mg}{ml}\right)$$

Dilution = 1 : 150 = 0.0067

$$c = 592.8\frac{mg}{ml} \cdot 0.0067 = 3.592\frac{mg}{ml}$$

Capacity dosage pump

$$q = \frac{Q \cdot C}{c} = \frac{1.39\frac{l}{s} \cdot 6.5\frac{mg}{l}}{2.59\frac{mg}{ml}} = \mathbf{3.486\frac{ml}{s}}$$

The capacity setting percentage of the micronized marble pump was calculated to be 5.59 mL/s. The pump delivers 11.76 mL/s at 100 % capacity. The pump curve is linear and can be adjusted on a scale from 0 – 100 %. To get the correct dosage the pump was set to 29.6 %.

$$Setting\ micr. marble\ pump = \frac{3.486\frac{ml}{s}}{11.76\frac{ml}{s}} \cdot 100\% = \mathbf{29.64}\ \%$$

Dosage of CO_2

C = target concentration of CO_2 in raw water = 22 g/m3

Manual regulation for q $= 22\frac{\mathrm{g}}{\mathrm{m3}} \cdot 5\frac{m3}{h} = 110\frac{g}{h}$

Both rotameters are set to 10.

Dosage of polymer

To calculate the appropriate dilution and dosage of Magnaflock, the ratio of produced water and dosage on the main plant was used. The main plant uses 159 L/h of Magnaflock to 1 468 000 L/h raw water. The pilot uses 5004 L/h raw water. By using the ratio, the dosage then becomes:

$$x = \frac{159\frac{l}{h}}{1468000\frac{l}{h}} \cdot 5004\frac{l}{h} = 0.54\frac{l}{h}\ ,\quad 0.54\frac{l}{h} \cdot \frac{1h}{3600\ s} \cdot \frac{1000\ ml}{l} = 0.15\frac{ml}{s}$$

The polymer was diluted by 1:10. This means the dosage pump has to deliver 1.5 mL/s. The dosage pump delivers 1.53 mL/s at 100 % capacity; to get the correct dosage the pump was set to 98 %.

$$Setting\ polymer\ pump = \frac{1.5\frac{ml}{s}}{1.53\frac{ml}{s}} \cdot 100\ \% = \mathbf{98.04}\ \%$$

Dosage of Ecoflock 91

C = target concentration in raw water = 1.7 g/m3 (mg/l)

Concentration of aluminium in dosage basin:

Aluminium content = 9.3 %

Density = 1380 g/l

Dilution = 1: 50 = 0.02

$$c = 1380\frac{g}{l} \cdot 0.093 \cdot 0.02 = 2.57\frac{g}{l}\left(\frac{mg}{ml}\right)$$

Capacity dosage pump Ecoflock 91

$$q = \frac{Q \cdot C}{c} = \frac{1.39\frac{l}{s} \cdot 1.7\frac{mg}{l}}{2.57\frac{mg}{ml}} = \mathbf{0.92\frac{ml}{s}}$$

The dosage pump delivers 1 mL/s at a frequency of 50 Hertz. The pump curve is linear and can be adjusted on a scale from 0 – 50 Hz. To get the correct dosage the pump was set to 46 Hz, giving a pump flow of 0.92 mL/s.

$$Setting\ coagulant\ pump = \frac{0.92\frac{ml}{s}}{1\frac{ml}{s}} \cdot 50\ Hz = \mathbf{46\ Hz}$$

Dosage of Ecoflock 96

C = target concentration in raw water = 1.7 g/m3 (mg/l)

Concentration of aluminium in dosage basin:

Aluminium content = 9.6 %

Density *= 1380 g/l*

Dilution = 1 : 50 = 0.02

$$c = 1380\frac{g}{l} \cdot 0.096 \cdot 0.02 = 2.65\frac{g}{l}\left(\frac{mg}{ml}\right)$$

Capacity dosage pump Ecoflock 96:

$$q = \frac{Q \cdot C}{c} = \frac{1.39\frac{l}{s} \cdot 1.7\frac{mg}{l}}{2.65\frac{mg}{ml}} = \mathbf{0.89\frac{ml}{s}}$$

The dosage pump delivers 1 mL/s at a frequency of 50 Hertz. The pump curve is linear and can be adjusted on a scale from 0 – 50 Hz. To get the correct dosage the pump was set to 46 Hz, giving a pump flow of 0.89 mL/s.

$$Setting\ coagulant\ pump = \frac{0.89\frac{ml}{s}}{1\frac{ml}{s}} \cdot 50\ Hz = \mathbf{44.6\ Hz}$$

Dosage of Aluminium sulphate

Concentration of aluminium in dosage basin:

Aluminium content = 9 %

Density: 1000 kg/L

Dilution = 1 : 50 = 0.02

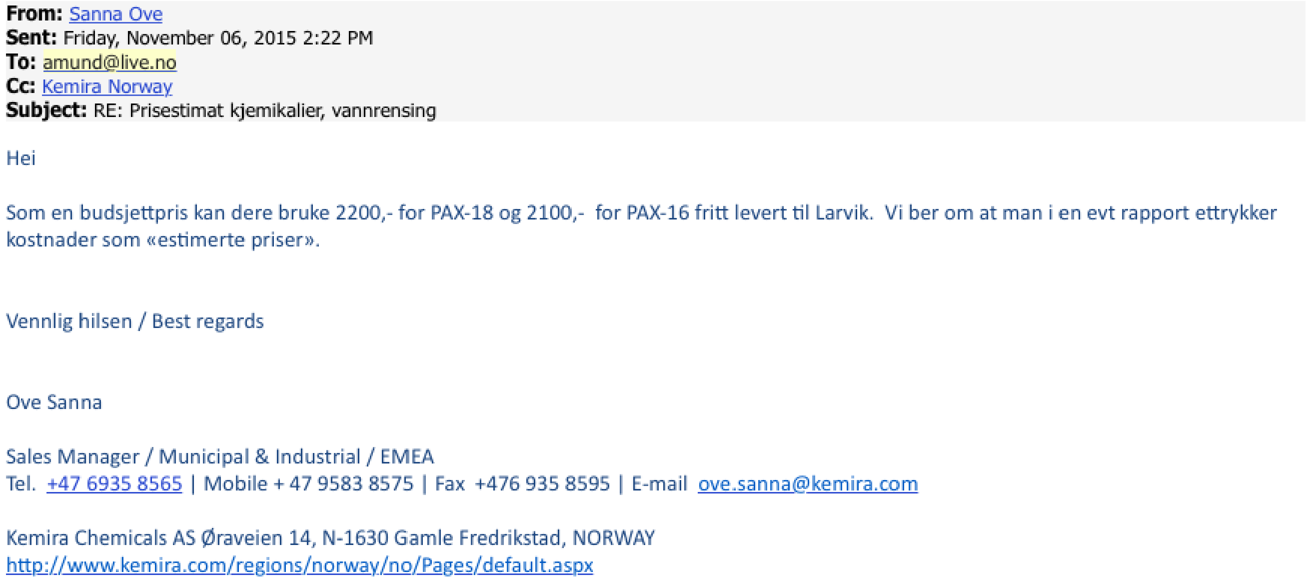
$$c = 1000\frac{g}{l} \cdot 0.09 \cdot 0.02 = 1.8\frac{g}{l}\ \left(\frac{mg}{ml}\right)$$

Capacity dosage pump:

$$q = \frac{Q \cdot C}{c} = \frac{1.39\frac{l}{s} \cdot 1.9\frac{mg}{l}}{1.8\frac{mg}{ml}} = \mathbf{1.47\frac{ml}{s}}$$

Appendix 6: Price quotes

Price quote from Kemira regarding PAX-16:



From: Sanna Ove
Sent: Friday, November 06, 2015 2:22 PM
To: amund@live.no
Cc: Kemira Norway
Subject: RE: Prisestimat kjemikalier, vannrensing

Hei

Som en budsjettpris kan dere bruke 2200,- for PAX-18 og 2100,- for PAX-16 fritt levert til Larvik. Vi ber om at man i en evt rapport ettrykker kostnader som «estimerte priser».

Vennlig hilsen / Best regards

Ove Sanna

Sales Manager / Municipal & Industrial / EMEA
Tel. +47 6935 8565 | Mobile + 47 9583 8575 | Fax +476 935 8595 | E-mail ove.sanna@kemira.com

Kemira Chemicals AS Øraveien 14, N-1630 Gamle Fredrikstad, NORWAY
http://www.kemira.com/regions/norway/no/Pages/default.aspx

Price quote from Kemetyl regarding Ecoflock coagulants:

Hvis det er av interesse så kan jeg sende produktprøver av de kjemikaliene du er interessert i.
Vi har følgende produkter:

- Ekoflock 54: 5,4 % Al, Ratio 0,6
- Ekoflock 70: 7,0 % Al, Ratio 1,4
- Ekoflock 71: 7,0 % Al, Ratio 1,0
- Ekoflock 90: 9,0 % Al, Ratio 1,3
- Ekoflock 91: 9,3 % Al, Ratio 1,3
- Ekoflock 96: 9,6 % Al, Ratio 1,5
- Ekomix 1091: 8,3 % Al, 1,0 % Fe
- Pluspac S 1465: 7,3 % Al, Ratio 1,9

Å gi nøyaktig pris avhenger av hvilket kjemikalie som det vil være størst interesse av, men ved uttak av fulle biler (33 tonn), vil prisen være ca. 2200-2300,- NOK/tonn.
Jeg har ikke produktprøver av alle variantene, men dette kan jeg ordne fra fabrikken i Sverige og vil kunne skaffe dette raskt.

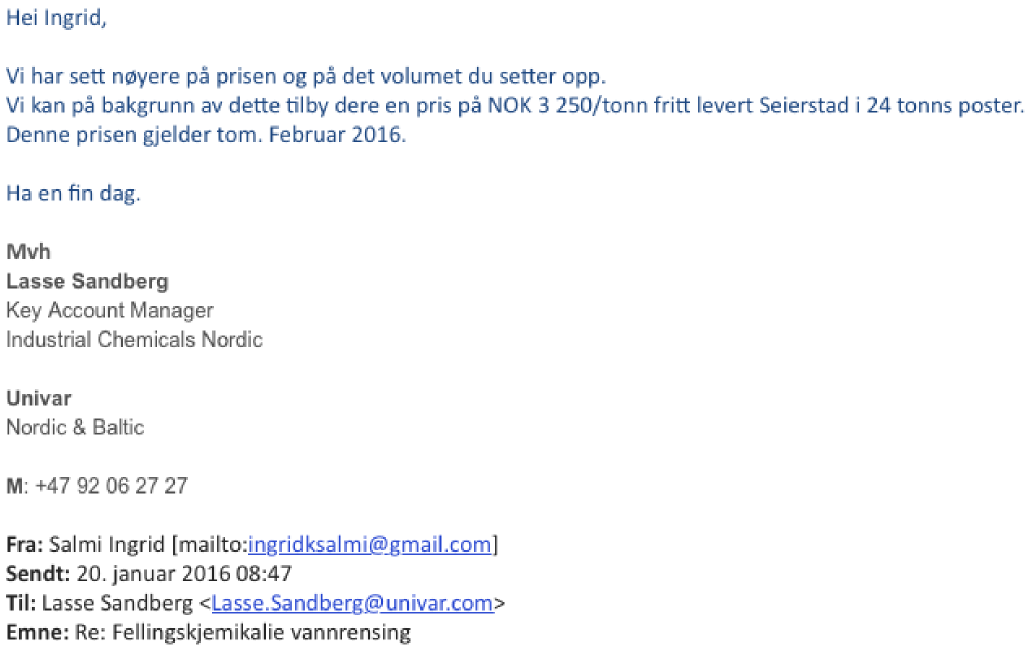
Håper dette er interessant og ser frem til din tilbakemelding.

We are relocating our head office!
From the 15th of December, you will find us at the following address:
Rosenholmveien 25, 1414 Trollåsen, Norway
Postal address: P.B. 476 1411, Kolbotn, Norway

We are also changing phone system. This means that the direct connection
64980869 will not be in use any more. For direct connection, please use my mobil.

Mvh/Best Regards
Bjørn Pedersen
Key Account Manager Nordic Industry
Kemetyl Norge AS
Mail: bjorn.pedersen@kemetyl.com
Mob: +47 906 14 937
Tlf. +47 64 98 08 00

Price quote from Univar regarding Aluminium sulphate:



Hei Ingrid,

Vi har sett nøyere på prisen og på det volumet du setter opp.
Vi kan på bakgrunn av dette tilby dere en pris på NOK 3 250/tonn fritt levert Seierstad i 24 tonns poster.
Denne prisen gjelder tom. Februar 2016.

Ha en fin dag.

Mvh
Lasse Sandberg
Key Account Manager
Industrial Chemicals Nordic

Univar
Nordic & Baltic

M: +47 92 06 27 27

Fra: Salmi Ingrid [mailto:ingridksalmi@gmail.com]
Sendt: 20. januar 2016 08:47
Til: Lasse Sandberg <Lasse.Sandberg@univar.com>
Emne: Re: Fellingskjemikalie vannrensing

Appendix 7: Data from pilot plant tests

- PAX-16 results:

Turbidity with 1.7 mg/L (Al):

Time	pH 5.7	pH 6	pH 6.1	pH 6.2	pH 6.3
0,5	0,14	1	0,8	1	0,16
1	0,22	1	0,51	0,57	0,2
1,5	0,17	0,4	0,42	0,43	0,11
2	0,14	0,3	0,37	0,39	0,11
2,5	0,12	0,29	0,7	0,39	0,12
3	0,09	0,27	0,5	0,4	0,07
3,5		0,26			
4		0,11			

Colour with 1.7 mg/L (Al):

Time	pH 5.7	pH 6	pH 6.1	pH 6.2	pH 6.3
0,5	6	26	17	19	6
1	6	24	12	9	7
1,5	5	9	11	10	6
2	5	8	11	9	6
2,5	5	8	15	9	6
3	5	7	9		6
3,5		6			6
4					5

Turbidity 1.5 mg/L (Al):

Time	pH 5.7/5.8	pH 6.2	pH 6.5
0,5	0,7	1	1
1	0,5	1	1
1,5	0,52	1	1
2	0,44	1	0,98
2,5	0,42	1	0,94
3	0,39	1	0,93
3,5		1	

Colour 1.5 mg/L (Al):

Time	pH 5.7/5.8	pH 6.2	pH 6.5
0,5	13	33	26
1	12	23	27
1,5	13	24	21
2	12	23	24
2,5	12	24	21
3	7	22	21

3,5		22	

Turbidity and colour 1.3 mg/L (Al):

Time	Turbidity	Colour
0,5	1	35
1	1	33
1,5	1	33
2	1	34
2,5	1	32
3	1	32
3,5	1	31

TOC Profile:

pH	1.7 mg/L (Al)	1.5 mg/L (Al)	1.3 mg/L (Al)	Drinking water regulation	Recommended limit
5,5				5	3
5,7	2,9			5	3
6	3			5	3
6,1	4,1			5	3
6,2	4	5		5	3
6,3				5	3
6,5		4,6	5,7	5	3
6,6				5	3

Residual aluminium profile:

pH	Dosage 1.7 mg/L (Al)	Dosage 1.5 mg/L (Al)	Dosage 1.3 mg/L (Al)	Drinking water regulation	Recommended limit
5				0,2	0,15
5,7	0,03	0,169		0,2	0,15
6	0,0028			0,2	0,15
6,1	0,118			0,2	0,15
6,2	0,094	0,409		0,2	0,15
6,3	0,002			0,2	0,15
6,5		0,353	0,605	0,2	0,15
7				0,2	0,15

Colour profile:

pH	Dosage 1.7 mg/L (Al)	Dosage 1.5 mg/L (Al)	Dosage 1.3 mg/L (Al)	Drinking water regulation	Recommended limit
5				10	5
5,7	6	12		10	5
6	6			10	5
6,1	9			10	5
6,2	9	22		10	5
6,3	6			10	5
6,4				10	5
6,5		21	31	10	5
7				10	5

Turbidity profile:

Dosage 1.5 mg/L (Al)	Dosage 1.3 mg/L (Al)	Drinking water regulation	Recommended limit
		1	0,2
0,39		1	0,2
		1	0,2
		1	0,2
1		1	0,2
		1	0,2
0,93	1	1	0,2
		1	0,2
		1	0,2

Filter test:

Time (h)	Differential head	Turbidity
1	0,66	0,67
2		0,66
3		0,58
4		0,51
5		0,52
6		0,5
7		0,53
8		0,57
9		0,5
10		0,49
11		0,56
12		0,53
13		0,53
14		0,57
15		0,58
16		0,39
17		0,69
18	1,38	2

Head loss curves

Filterhøyde	Static pressure	Pressure curve clean	Pressure curve 15 h	Water surface	Media border	Pressure curve 17 h
2,82	0			1,95	0,53	
2,15	0,67			1,95	0,53	
2,09	0,73	0,05		1,95	0,53	
1,77	1,05	0,56		1,95	0,53	
1,62	1,2	0,8		1,95	0,53	
1,45	1,37	1,06		1,95	0,53	
1,12	1,7	1,56		1,95	0,53	
1,06	1,76	1,66		1,95	0,53	
0,9	1,92	1,93		1,95	0,53	
0,89	1,93			1,95	0,53	
1,51			0,06			
1,13			0,56			
0,97			0,8			
0,81			1,06			
0,6			1,56			
0,89			1,93			
0,6	2,22			1,95	0,53	
1,41						0,06
1,08						0,56
0,91						0,8
0,75						1,06
0,56						1,56
0,89						1,93
0,97						
0,48	2,34			1,95	0,53	
0,36	2,46			1,95	0,53	
0,21	2,61			1,95	0,53	
0,89	1,93			1,95	0,53	
0,05	2,77			1,95	0,53	
0	2,82			1,95	0,53	

- Ecoflock 91 results:

Colour with 1.7 mg/L (Al):

Time	pH 6.1	pH 6.3	pH 6.4	pH 6.6
0,5	35	18	15	14
1	10	7	9	10
1,5	9	6	8	10
2	8	6	8	9
2,5	7	6	8	9
3	7	7	7	8
3,5	7		8	8
4	7		7	

Turbidity with 1.7 mg/L (Al):

Time	pH 6.1	pH 6.3	pH 6.4	pH 6.6
0,5	1	1	0,67	0,56
1	0,27	0,25	0,37	0,41
1,5	0,18	0,19	0,34	0,39
2	0,15	0,19	0,29	0,32
2,5	0,12	0,18	0,27	0,3
3	0,11	0,17	0,24	0,28
3,5	0,1		0,24	0,26
4	0,11		0,22	0,25

Turbidity and colour with 1.5 mg/L (Al):

Time	Turbidity	Colour
0,5	0,48	10
1	0,42	10
1,5	0,4	10
2	0,39	11
2,5	0,39	11
3	0,37	9

Colour profile:

pH	Dosage 1.7 mg Al/l	Dosage 1.5 mg Al/l	Dosage 1.3 mg Al/l	Drinking water regulation	Indicator value
5				10	5
5,7				10	5
6				10	5
6,1	7			10	5
6,2	9			10	5

6,3	6			10	5
6,4	7	12		10	5
6,6	8			10	5

Turbidity profile:

pH	Dosage 1.7 mg Al/l	Dosage 1.5 mg Al/l	Dosage 1.3 mg Al/l	Drinking water regulation	Indicator value
5				1	0,2
5,7				1	0,2
6				1	0,2
6,1	0,11			1	0,2
6,2	0,33			1	0,2
6,3	0,17			1	0,2
6,4	0,14	0,32		1	0,2
6,6	0,16			1	0,2
7				1	0,2

Residual aluminium profile:

pH	Dosage 1.7 mg Al/l	Dosage 1.5 mg Al/l	Dosage 1.3 mg Al/l	Drinking water regulation	Indicator value
5,7				0,2	0,15
6,7				0,2	0,15
6,1	0,047			0,2	0,15
6,2	0,12			0,2	0,15
6,3	0,048			0,2	0,15
6,4	0,1	0,215		0,2	0,15
6,6	0,079			0,2	0,15

TOC profile:

pH	1.7 mg Al/l	1.5 mg Al/l	Drinking water regulation	Indicator value
5,5			5	3
5,7			5	3
6,7			5	3
6,1	3		5	3
6,2	3,1		5	3
6,3	2,9		5	3
6,4	3,3	3,4	5	3
6,6	3		5	3

Filter test:

Time (h)	Differential head	Turbidity	kl
1	0,65	0,45	2110
2		0,38	2210
3		0,33	2310
4		0,32	10
5		0,3	110
6		0,31	210
7		0,28	310
8		0,32	410
9		0,33	510
10		0,32	610
11		0,33	710
12		0,39	810
13		0,39	910
14		0,4	1010
15		0,43	1110
16		0,57	1210
17		0,55	1310
18		0,55	1410
19		0,55	1510
20		0,6	1610
21		0,57	1710
22		0,58	1810
23		0,59	1910
24		0,63	2010
25		0,62	2110
26		0,6	2210
27		0,7	2310
28		0,7	2410
29		0,65	110
30		0,69	210
31		0,7	310
32		1	410
33	2,16	2,3	510

Head loss curves:

Filterhøyde	Static pressure	Pressure curve clean	Pressure curve 25 h	Water surface	Media border	Pressure curve 9 h
2,82	0			1,95	0,53	
2,15	0,67	0,05		1,95	0,53	
1,81	1,01	0,56		1,95	0,53	
1,65	1,17	0,8		1,95	0,53	
1,49	1,33	1,06		1,95	0,53	
1,15	1,67	1,56		1,95	0,53	
0,9	1,92	1,93	0,05	1,95	0,53	
0,89	1,93	1,93	0,06	1,95	0,53	
0,6	2,22		0,56	1,95	0,53	
0,48	2,34		0,8	1,95	0,53	
0,36	2,46		1,06	1,95	0,53	
0,21	2,61		1,56	1,95	0,53	
0,89	1,93		1,94	1,95	0,53	
0,05	2,77			1,95	0,53	
0	2,82			1,95	0,53	
1,8						0,05
1,81						0,06
1,46						0,56
1,3						0,8
1,14						1,06
0,88						1,56
0,9						1,94
3,5				1,95	0,53	

- Ecoflock 96 results:

Turbidity and colour 1.7 mg/L (Al)

Time	Turbidity	Colour
0,5	1	29
1	0,28	8
1,5	0,23	7
2	0,2	6
2,5	0,15	6
3	0,13	5
3,5	0,11	4
4	0,12	

Head loss curves

Filter height	Static pressure	Pressure curve clean	Pressure curve 5 h	Water surface	Media border	Pressure curve 20 h	Pressure curve 25,5 h
2,82	0			1,95	0,53		
2,09	0,73	0,05		1,95	0,53		
1,77	1,05	0,56		1,95	0,53		
1,62	1,2	0,8		1,95	0,53		
1,45	1,38	1,06		1,95	0,53		
1,12	1,7	1,56		1,95	0,53		
0,9	1,92	1,93		1,95	0,53		
0,99	1,83						
2,07	0,75		0,06	1,95	0,53		
1,68	1,14		0,56	1,95	0,53		
1,51	1,31		0,8	1,95	0,53		
1,33	1,49		1,06	1,95	0,53		
0,99	1,83		1,56	1,95	0,53		
0,89	1,93		1,94	1,95	0,53		
0,05	2,77			1,95	0,53		
0	2,82			1,95	0,53		
1,04						0,06	
0,74						0,56	
0,6						0,8	
0,47						1,06	
0,33						1,56	
0,89						1,94	
0,64							0,06
0,37							0,56
0,27							0,8
0,2							1,06
0,15							1,56
0,89							1,94

Filter test:

Time (h)	Differential head	Turbidity
1	0,65	0,45
2	0,69	0,38
3	0,7	0,33
4	0,72	0,32
5	0,78	0,3
6	0,82	0,31
7	0,89	0,28
8	0,93	0,32
9	0,96	0,33
10	1	0,32
11	1,05	0,33
12	1,1	0,39
13	1,14	0,39
14	1,19	0,4
15	1,23	0,43
16	1,24	0,57
17	1,3	0,55
18	1,38	0,55
19	1,47	0,55
20	1,5	0,6
21	1,55	0,57
22	1,6	0,58
23	1,66	0,59
24	1,72	0,63
25	1,75	0,62
26	1,8	0,6
27	1,84	0,7
28	1,88	0,7
29	1,95	0,65
30	2	0,69
31	2,06	0,7
32	2,14	1
33	2,16	2

Appendix 8: Data from Jar tests

Test	Colour	Turbidity
PAX16 (1.7 mg/L Al)	43	2.6
PAX16 (1.5 mg/L Al)	43	2.7
Eco.91 (1.7 mg/L Al)	44	2.3
Eco.91 (1.5 mg/L Al)	33	1.6
Eco.91 (1.3 mg/L Al)	24	1.3
Eco.91 (1.7 mg Al/l)	41	1.9
Al.Sulph (1.7 mg/L Al)	38	1.9
Al.Sulph (1.9 mg/L Al)	38	1.9
Eco.96 (1.7 mg/L Al)	41	1.9
Eco.96 (1.5 mg/L Al)	27	1.4
Eco.96 (1.3 mg/L Al)	24	1.2
Eco.96 (1.7 mg/L Al)	40	1.9

Appendix 9: HSE raport

Innledning

I forbindelse med en sommerjobb hos Vestfold Vann er det utarbeidet en rapport hvor pilotanlegget er risikovurdert med hensyn på helse, miljø og sikkerhet. Rapporten har som formål å gi en oversikt over tiltak og utbedringer slik at anlegget skal være sikkert å bruke til framtidig testing. Sikkerhetsdatabladene til de ulike kjemikaliene er brukt som underlag for å vurdere risiko og foreslå tiltak.

Metode

På grunnlag av arbeidstilsynets anbefalinger er risikovurderingen delt opp i ulike trinn, henholdsvis:

1) Kartlegging av hvilke kjemikalier som forekommer, og deres iboende egenskaper
2) Kartlegging og vurdering av eksponering
3) Risikovurdering
4) Tiltak

I følge kjemikalieforskriften skal en risikovurdering særlig ta hensyn til:

- Kjemikalienes farlige egenskaper
- Leverandørens informasjon om risiko for helse, miljø og sikkerhet
- Forholdene på arbeidsplassen
- Mengden og bruksmåten av kjemikalier
- Om arbeidsprosessene og arbeidsutstyret er hensiktsmessig
- Antall arbeidstakere som antas å bli eksponert
- Eksponeringens type, nivå, varighet, hyppighet og eksponeringsverdier
- Grenseverdier og administrative normer
- Effekten av iverksatte og planlagte forebyggende tiltak
- Konklusjoner fra gjennomførte helseundersøkelser

Vannbehandlingsprosessen

Pilotanlegget er laget for å gjøre lav skala-forsøk på vannbehandlingsprosessen. Kjemikalier som blir behandlet i denne prosessen er oppgitt i Tabell 1

Tabell 1: Oversikt over kjemikalier som brukes i pilotanlegget.

Kjemikalietype	**Kjemikalets navn**
CO_2	Karbondioksid, nedkjølt flytende
Lut	Kaustisk soda væske
Mikronisert marmor	Acticarb 90 V-ME 78 %
Polymer	MAGNAFLOC® LT22S-DWI
Pax-16	Kemira PAX-16 (aluminiumsalt)
Klor	Natriumhypokloritt væske 12 – 16 %

Vannrenseprosessen ved pilotanlegget skjer ved hjelp av kjemisk felling og direkte filtrering i et to-mediefelter. Tilsetning av PAX 16 og polymer koagulerer og danner flokker slik at løst organisk materiale blir fjernet i filteret. Mikronisert marmor er lagt til for karbonatisering og lut er tilsatt for enklere å kontrollere pH-verdien. Vannet passerer gjennom filteret, fylt med sand og Filtralite, og ender opp i et rentvannsbasseng. Vannstrømmen i filteret skal holdes konstant. Kjemikaliene brukt i prosessen er oppbevart i plasttanker og doseringen er kontrollert av frekvenspumper. I slutten av prosessen blir en liten mengde klor tilsatt for å drepe eventuelle bakterier eller mikroorganismer som kan være i vannet.

Kjemikalier brukt i prosessen

I dette kapittelet er kjemikaliene som skal brukes på pilotanlegget undersøkt. Det er satt opp en oversikt over kjemikalienes egenskaper, helseeffekter, førstehjelpstiltak samt anbefalt personlig verneutstyr.

Mikronisert marmor

Mikronisert marmor er i følge sikkerhetsdatabladet ikke klassifisert som helse- eller miljøfarlig.Ved øyekontakt skal det skyldes med store mengder rennende vann. Ved hudkontakt skal man vaske med vann og såpe. Ved svelging skal munnen vaskes grundig med vann.

Lut

Ifølge sikkerhetsdatabladet er kaustisk soda væske klassifisert som et etsende stoff. Faresetninger oppgitt i databladet:

- Gir alvorlige etseskader på hud og øyne
- Kan være etsende for metaller

Kjemikaliet forekommer i flytende form. Det kan tas opp i kroppen via innånding, hudkontakt, øyekontakt og svelging. Svelging fører til akutte magesmerter. Dødelig dose for mennesker er cirka 5 gram. Langtidsinhalering kan forårsake lokale skader i kroppen. Hudkontakt vil føre til permanent hudskade som brannsår. Det kan også føre til alvorlig eksem. Øyekontakt kan forårsake stor skade med dannelse av svulster på hornhinne og permanent svekkelse av synet. Administrativ norm for grenseverdi ved eksponering via innånding er 1,0 mg/m^3 og dermalt 2 %.

Førstehjelpstiltak

Hurtighet er avgjørende, dusjer og øyespylingsutstyr må være tilgjengelig ved behandlingspunkter. Ved innånding skal pasienten flyttes vekk fra eksponeringen, og vedkommende skal holdes varm og i ro. Gi oksygen hvis nødvendig. Ved svelging skyll munnen, ikke framkall brekning. Ved kontakt med huden, fjern tilsølte klær og skyll huden grundig med vann. Ved kontakt med øyne, skyll rikelig med vann i opptil 15 minutter. Fjern kontaktlinser hvis mulig. Risikohåndteringstiltak og driftsforhold fra sikkerhetsdatablad:

Generelt:

- Oppbevares adskilt fra syrer og klorerte hydrokarboner
- Vær forsiktig ved uttynning av oppløsninger
- Ved små mengder skal emballasjen holdes tett lukket

Personlig verneutstyr:

- Vernebriller og ansiktsskjerm
- Egnede verneklær og vernehansker
- Bruk hensiktsmessig åndedrettsvern dersom det er sannsynlig at den administrative norm vil bli overskredet. Bruk maske/filter.

CO_2

Karbondioksid er en flytende trykkgass emballert i sylindrene. Høye konsentrasjoner kan føre til rask kvelning, dette kan oppstå uten forvarsel. Kjemikalie kan tas opp i kroppen via innånding, hudkontakt og øyekontakt. Lav konsentrasjon av CO_2 frembringer økt pustefrekvens og hodepine. Kontakt med væsken kan forårsake forfrysninger. Grenseverdi ved 8 timers eksponering er 5000 ppm, eller 9000 mg/m^3. Faresetning oppgitt i databladet:

- Inneholder nedkjølt gass; kan forårsake alvorlige forfrysninger

Sylindere bør lagres stående og forsvarlig sikret mot å velte. Beholderen skal stå i et godt ventilert rom med temperatur under 50 °C. Områder hvor salt eller andre etsende materialer er til stede skal unngås. Rørsystemer og utstyr bør regelmessig sjekkes for lekkasje. Gassdetektor bør brukes.

Førstehjelpstiltak

Ved kontakt med øynene skal disse skylles grundig med vann i flere minutter (minst 15 min). Ved hudkontakt skylles frostskader i lunket vann i minst 15 minutter, deretter anvendes sterilt kompress. Ved innånding skal personen flyttes til frisk luft. Hvis den utsatte ikke puster, gi kunstig åndedrett.

Personlig verneutstyr:

- Bruk hansker ved håndtering av gassbeholdere
- Bruk vernebriller med sidebeskyttelse
- Vernesko ved håndtering av emballasje

Polymer

Magnafloc kommer i pulverform. Produktet er ikke klassifiseringspliktig i henhold til GHS kriteriene. Stoffet kan tas opp i kroppen via innånding, svelg, hudkontakt og øyekontakt. Faresetning oppgitt i sikkerhetsdatabladet:

- Kan gi alvorlig øyeskade eller øyeirritasjon

Stoffet kan forårsake en viss øyeirritasjon som bør opphøre etter at produktet er fjernet. Det kan forårsake en viss irritasjon av luftveiene ved innånding støv. Ved lengere påvirkning av produktet er hudirritasjoner mulig. Denne typen produkt har en tendens til å danne støv hvis det håndteres hardhendt. Ingen betydelige symptomer er forventet, ved korttids- eller langtidseksponering. Lav akutt LC50/EC50 for akvatiske organismer, men forårsaker ikke langsiktige skadevirkninger på det akvatiske miljøet. Kjemikalie kan forårsake kreft.

Grenseverdier for eksponering ved sjenerende støv:

- TLV 10 mg/m^3 - Total støv
- TLV 5 mg/m^3 – Inhalert støv

Akutt toksisitet tatt ut fra eksperimentelle data: LD50 (oral): > 5.000 mg/kg.

Førstehjelpstiltak

Ved ubehag etter innånding av støv skal personen inhalere frisk luft. Ved kontakt med huden, fjern tilsølte klær og skyll huden grundig med vann og såpe. Ved kontakt med øyne, skyll grundig med vann i minst 15 minutter. Fjern kontaktlinser hvis mulig. Ved svelging, skyll munnen grundig og drikk rikelig med vann.

Generelt:

- Oppbevar stoffet på et kjølig, tørt sted, atskilt fra antennelseskilder
- Sørg for skikkelig ventilasjon
- Må ikke slippes til kloakksystem/overflatevann/grunnvann
- Ikke spis, drikk, røyk eller bruk snus under arbeid

Personlig verneutstyr:

- Åndedrettsvern ved påfylling av større mengder: Partikkelfilter (f.eks. type P2 eller FFP2)
- Kjemikaliebestandige vernehansker, f.eks. nitrilgummi (0.4mm), polyvinylklorid (0,7mm) og andre.
- Vernebriller med sidebeskyttelse
- Lette beskyttelsesklær

Ifølge sikkerhetsdatabladet er PAX-16 klassifisert som irriterende. Det er ikke et brannfarlig produkt. Faresetninger oppgitt i databladet:

- Irriterer øyne og huden
- Store utslipp kan innvirke negativt i vannmiljø pga. lokal pH-senkning

PAX-16

Kjemikalie forekommer i flytende form. Det kan tas opp i kroppen via hudkontakt, øyekontakt eller svelging. Grenseverdien for helseeffekt LD50 oral er 2000 mg/kg. Damp virker irriterende på slimhinner, øyne og åndedrettsorganer. Ved innånding kan det forekomme irritasjon og eventuelt etsning i munn og svelg. Innånding av damp kan svi, gi hoste og pustebesvær. Dersom kjemikaliet kommer i kontakt med huden kan irritasjon, rødflammete og eksemlignende besvær oppstå ved langvarig eksponering. Svelging kan gi magesmerter og oppkast. Det kan virke irriterende i munn, svelg og mage. Kjemikaliet bør oppbevares i tett lukket beholder på et tørt, kjølig og godt ventilert sted.

Førstehjelpstiltak

Ved innånding må personen umiddelbart fjernes fra eksponeringskilden, inhalere frisk luft og holdes i ro. Ved kontakt med huden, skyll huden grundig med vann. Kontakt lege ved vedvarende irritasjon. Ved øyekontakt skyll øyeblikkelig med vann i 10-15 min. Hold øyene åpne, ikke gni øynene.

Ved svelging, drikk straks et par glass vann eller melk. Kontakt lege ved vedvarende symptomer.

Risikohåndteringstiltak og driftsforhold fra sikkerhetsdatablad:

Generelt:

- Øyespyleflaske skal være tilgjengelig
- Lukket system
- Minimer antall ansatte som blir eksponert
- Stabil under normale temperaturforhold og anbefalt bruk
- Unngå høy varme over lengre perioder
- Klassifiseres ikke som giftig eller skadelig i vannmiljø
- I tilfelle av en stor lekkasje til miljøet kan det redusere pH i vannet og skade vannlevende organismer (fisk)

Personlig verneutstyr:

- Bruk vernebriller og hansker ved håndtering
- Anbefalt vernesko og kjemikaliebestandig dress ved behov
- Ingen spesielle anbefalinger er gitt om åndedrettsvern, men det må benyttes hvis nivået overstiger administrativ norm.

Klor

Ifølge tilhørende sikkerhetsdatablad er natriumhypokloritt klassifisert som et miljøfarlig og etsende stoff. Det utvikles giftig gass ved kontakt med syre. Man skal ikke innånde tåke eller damp og unngå utslipp til miljøet. Faresetninger oppgitt i sikkerhetsdatabladet:

- Kan være etsende for metaller
- Gir alvorlige etseskader på hud og øyne
- Meget giftig for liv i vann

Kjemikaliet skal oppbevares på et godt ventilert sted. Beholderen holdes tett lukket. Stoffet er ikke brennbart, men kan medvirke til brann ved oksidering. Termisk nedbryting vil utvikle damp (klor). Beholdere kan sprenges hvis de blir overopphetet. Kjemikaliet forekommer i væskeform. Eksponering av stoffet kan skje gjennom innånding, hudkontakt og svelging. Grenseverdiene til natriumhypokloritt tar utgangspunkt i administrativ norm for klor: 0,5 ppm, 1,5 mg/m^3. Helseeffekter, både akutt og forsinket, er alvorlig hudforbrenning og fare for alvorlig øyeskade. Dersom det blir svelget vil det forårsake etseskader i munn, svelg og spiserør. Eksponering kan virke irriterende på luftveier.

Førstehjelpstiltak

Ved innånding skal pasienten flyttes vekk fra eksponeringen, og vedkommende skal holdes varm og i ro. Ved hår- eller hudkontakt må tilsølte klær fjernes straks, deretter skylle huden med vann. Her er hurtighet avgjørende. Hvis symptomene utvikler seg, skaff legehjelp. Ved kontakt med øynene (HURTIGHET ER AVGJØRENDE) skal øynene holdes atskilt og skylles med øyeskyll eller rent vann i minst 15 min. Skaff øyeblikkelig legehjelp. Ved svelging skal pasienten skylle munnen med vann, forutsatt at personen er ved bevissthet, og gi 200-300 ml (en kvart liter) vann å drikke. Ikke framkall brekninger. Sørg for legehjelp. Risikohåndteringstiltak og driftsforhold fra sikkerhetsdatablad:

Generelt:

- Lukket system
- Minimer antall ansatte som blir eksponert
- Separere utslippsprosessen
- Effektiv fjerning av forurensing
- God standard på generell ventilasjon
- Minimaliser manuelle operasjoner
- Unngå kontakt med kontaminert verktøy og gjenstander
- Regelmessig rensing av utstyr og arbeidsområde
- Opplæring av ansatte og god praksis
- God standard på personlig hygiene

Personlig verneutstyr:

- Riktige hansker i henhold til stoff/oppgave
- Huden tildekket med egnet barrieremateriale for potensiell kontakt med kjemikaliene
- Riktig åndedrettsvern i henhold til stoff/oppgave
- Valgfri ansiktsbeskyttelse
- Øyebeskyttelse

Kartlegging og vurdering av eksponering

Pilotanlegget kjøres periodevis til forsøk, og mengden av kjemikaliene varierer. Tall fra en tidligere masteroppgave er tatt utgangspunkt i for å beregne ca. mengde kjemikalier. Doseringen av de ulike kjemikaliene vist i Tabell 2. Ut i fra disse verdiene er det gjort en konservativ beregning på hvor store mengder av kjemikalie som vil brukes per uke. Beregnet vannhastighet er på 7,85 m^3/h og det er gått i ifra 8 timer per dag.

Tabell 2: Mengder av kjemikalie brukt i prosessen.

Kjemikalie	**Dosering**	**Mengde**
Polymer	0,12 g/m^3	37,68 g/uke
Mikr. Marmor	6,5 g Ca/m^3	2041 g/uke
PAX 16	1,6 g Al/m^3	502,4 g/uke
Lut	3,2 g/m^3	1004,8 g/uke

Arbeidstakere som kan bli eksponert er hovedsakelig studentgruppen som skal jobbe på pilotanlegget, ca. 4 personer. Ettersom kjemikaliene behandles i et lukket system skal i utgangspunktet ikke personer bli eksponert. Det kan imidlertid være risiko for eksponering av kjemikaliene ved lekkasje av fra slanger, rørsystemer og utstyr. Disse må teste på forhånd, eventuelt byttes ut. Annen eksponering kan være ved påfylling og tømming av tanker. Eksponeringens nivå, varighet og verdi vil derfor være vanskelig å anslå.

Risikovurdering

Modellen for risikovurdering er hentet fra Cardfelt (2002), som er brukt for å få en systematisk oversikt over risiko og risikohåndteringstiltak for de aktuelle kjemikaliene.

Klor

Eksponeringsvei/fare					
	Innånding	Hudkontakt	Svelging	Brann	Reaksjoner
Iboende egenskaper	Luftveiene kan skades av væske-dråper som inhaleres.	Gir etse-skader på hud og øyne allerede ved kortvarig kontakt.	Etseskader i munn, svelg og spiserør.	Oksiderende middel, kan medvirke til brann.	Kan danne giftig gass i kontakt med syre.
Risiko ved håndtering?	Nei. Det dannes ikke væske-dråper som kan inhaleres.	Ja.	Sprut mot åpen munn gir en viss risiko.	Gass som oppstår under brann er toksisk å innånde.	I tilfelle kontakt med syre.
Må det iverksettes tiltak?		Ja.	Tiltak iverksettes gjennom tiltakene mot hudkontakt.	Ja.	
Tiltak ved håndtering		Vernebriller med tett sidevern evt. Ansikts-skjerm, egnede verneklær og hansker skal brukes.		Synlig brann-luknings-apparat og exit-skilt.	Informasjon om risikoen for farlig reaksjon fra sikkerhetsdatablad.
Beredskaps-tiltak		Tilgang til øye-spylings-utstyr og nøddusj.			Hensiktsmessig utstyr for oppsamling av spill.

CO_2

Eksponeringsvei/fare					
	Innånding	Hudkontakt	Svelging	Brann	Reaksjoner
Iboende egenskaper	Kvelende ved høye konsentrasjoner.	Muligheten for frostskader.	Inntak gjennom munnen er ikke ansett for å være en potensiell eksponeringsvei.	Ikke brennbar.	Stabil under normale forhold. Ved påvirkning av brann kan flaskene eksplodere.
Risiko ved håndtering?	Ja.	Ja.	Nei.		
Må det iverksettes tiltak?	Det er allerede satt in en CO_2-Detektor og alarm.	Ja.	Nei.		
Tiltak ved håndtering		Hansker når du håndterer med sylinderen.			
Beredskapstiltak		Tilgang til øyespylingsutstyr, vask og nøddusj.			

PAX-16

Eksponeringsvei/fare					
	Innånding	Hudkontakt	Svelging	Brann	Reaksjoner
Iboende egenskaper	Luftveiene kan skades av væske-dråper som inhaleres.	Irritasjon, rødflammete og eksemlignende besvær ved langvarig eksponering.	Kan gi magesmerter og oppkast. Kan virke irriterende i munn, svelg og mage.	Ikke brann-farlig.	Ved oppvarming kan saltsyregass dannes.
Risiko ved håndtering?	Nei. Det dannes ikke gass som kan inhaleres, under gitte forhold.	Ja.	Sprut mot åpen munn gir en viss risiko.		
Må det iverksettes tiltak?		Ja.	Tiltak iverksettes gjennom tiltakene mot hudkontakt.		
Tiltak ved håndtering		Hansker og vernebriller skal brukes.			Informasjon om risikoen for farlig reaksjon fra sikkerhetsdatablad.
Beredskaps-tiltak		Tilgang til øyespylings-utstyr og nøddusj.			Hensiktsmessig utstyr for oppsamling av spill.

Lut

Eksponeringsvei/fare					
	Innånding	Hudkontakt	Svelging	Brann	Reaksjoner
Iboende egenskaper	Tåke kan føre til irritasjon av luftveiene. Effekten varierer fra irritasjon i neseslimhinnene til alvorlig lungeirritasjon.	Gir alvorlige etseskader på hud og øyne. Kan forårsake dannelse av svulster på hornhinne og permanent svekkelse av syn.	Vil straks gi etsning og skade på mage/ tarmkanal.	Ikke brann-farlig.	Kan være etsende for metaller. Svært reaktiv med aluminium, sink, tinn og legeringer- produserer brennbar hydrogengass. Kontakt med noen organiske kjemikalier kan føre til eksplosive reaksjoner. Kan reagere med sukkerrester og danne karbonmonoksid.
Risiko ved håndtering?	Unngå frembringelse av aerosol eller tåke.	Ja.			Normalt ikke, men et spill kan skje ved håndtering.
Må det iverksettes tiltak?		Ja.	Tiltak iverksettes gjennom tiltakene mot hudkontakt.		Ja.
Tiltak ved håndtering	Normalt ingen behov for åndedrettsvern. Hvis det er nødvendig åndedrettsvern type P2.	Hansker og vernebriller skal brukes.			Informasjon om risikoen for farlig reaksjon fra sikkerhetsdatablad
Beredskaps-tiltak		Tilgang til øyespylings-utstyr og nøddusj.			Hensiktsmessig utstyr for oppsamling av spill.

Polymer

Eksponeringsvei/fare					
	Innånding	Hudkontakt	Svelging	Brann	Reaksjoner
Iboende egenskaper	Inhalerte støv kan føre irritasjon av luftveiene.	Muligheten for hudirritasjon er mulig.		Ikke brann-farlig.	Stabil under normale forhold. Dannelse av fint støv kan føre til støveksplosjon.
Risiko ved håndtering?	Ja, inhalering av partiklene som kan skje når du håndterer større mengder, uten avtrekksanlegg.	Ja.	Nei.		Nei. Ikke under forskriftsmessige forhold.
Må det iverksettes tiltak?		Ja.	Nei.		
Tiltak ved håndtering	Bruk åndedrettsvern type P2 eller FFP2.	Bruk personlige verneklær.	Nei.		
Beredskaps-tiltak		Tilgang til vask og øyespyling-utstyr.			

Tiltak

På grunnlag av kartleggingen i risikovurderingen er følgende tiltak, vist i Tabell 3, foreslått for at pilotanlegget skal være sikkert å bruke.

Tabell 3: Oversikt over sikkerhetstiltak for pilotanlegget.

Tiltak	**Kommentar**
Nøddusj	Kan settes opp ved utgang.
Øyespylingsutstyr	Kan settes opp ved utgang.
Vask	Med tilhørende tørkerull.
Førstehjelpsutstyr	Henges opp på vegg.
Beholder med vernebriller/hansker/ørepropper	
Tilgang til sikkerhetsdatablad	Settes i en perm/beholder ved kjemikaliene.
Skilt: Exit, nødvendig med vernebriller	
Henge opp brannslukningsapparat	Henges opp ved utgang.
Testing av rørsystemer og utstyr	Fra kjemikalietanker og CO_2 – anlegget.
Reparere lås på dør nummer 2	Denne lirker seg ofte fast, må være mulig å åpne for lufting.