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Dewatering of backwash water containing cyanobacterias by wedge wire and geotextile drying beds

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Problem description

Background

Increased urbanisation and human activity puts a bigger pressure on the nature than ever. As an action to protect our water sources and surounding environments countries started to demand treatment of effluents both from WTP and WWTP. Lake Peri WTP has tried several solutions for treating the backwash water without any good results. Sludge drying beds is a cheap and easy operated dewatering method and one of the most widely used methods for sludge dewatering. Wedge wire is an adapted drying bed using a wedge wire blocks as surface to enhance sludge drying and drainage time. After good results of implementing wedge wire drying beds in other WTP's the water and sanitation company of Santa Catarina (CASAN) requested a study to evaluate the performance of wedge wire blocks for dewatering the backwash water at their WTP in Lake Peri. Based on the request, this study evaluates dosages of PAC and cationic polymer as conditioner before application in the wedge-water drying bed. The tests are performed using Jar tests and pilots of a wedge wire drying bed as well as a filter cloth drying bed for reference. After the optimum dose is determined, pilot tests for evaluating the performace over time were performed. Parameters to perform water quality result are turbidity, BOD, COD, SS, Settleable matter and cyanobacterial cells.

Objective

- Operational conditions: Optimalisation of coagulant concentration, duration of the drainage phase of the sludge

- Performance: Evaluate the effluent from the draining blocks in terms of physical chemical parameters and cyanobacterias.

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Abstract

Treatment of effluents are processes with the aim to decrease contaminants to a level were it can be returned to a water source with minimal impact on the environment. In order to release effluents, treatment goals set by respective governments need to be met. A common method to dewater sludge is sludge drying beds that is an easy and cheap method to dewater sludge. Upgraded versions of the conventional sand drying beds is the wedge wire blocks and geotextile filter cloth, which enhances the sludge drying and drainage time.

The purpose of this research was to evaluate the performance of the mentioned drying beds as a method to dewater the backwash water from the WTP at Lake Peri, Brazil. The laboroatory tests were conducted at the site starting by determining the optimum dosage of conditioner. These tests were carried out by adding different doses in the Jar-test equipment before filtering the water through pilots of the drying beds before the drained water was collected to measure turbitity. The optimum conditioner dosage were determined to be 12,5 mg/L PAC and 1 mg/L cationic polymer with a removal in turbidiy of 37% and 92 % in the WW and FC filters respectively. The pilots were built in isopor boxes with a inner dimension of 30 x 30 cm. The wedge-wire block has openings of 0,38 mm x 1,8 cm with a total open area of 11%, while the filter cloth had a density of 700 threads per meter in the horizontal direction, giving a pore opening of 1mm. A sedimentation test was performed to evaluate if sedimentation prior to the drainage test could be a solution, but very light flocs with good floating properties resulted in not implementing this step in the pilot. Further experiments with the pilots showed respectively 49% and 53% removal of BOD5 in the WW- and FC-pilots, which is not meeting the treatment requirement of 60%. Settleable matter increased from 1,8 mL/L to 34 mL/L in the WW-pilot, moving far from the requirement of 1 mL/, while it in the FC-pilot decreased to 0,8 mL/L. The results from the study indicated that neither of the evaluated pilots are suitable for dewatering of the backashwater at lake Peri WTP.

Keywords: cyanobacteria, conditioning, dewatering, drying bed, rapid filtration, wedge wire, water treatment

Sammendrag

Behandling av avløpsvann er prosesser med sikte på å redusere forurensninger til et nivå der det kan returneres til en vannkilde med minimal innvirkning på miljøet. For å slippe ut avløp må rensekrav satt av respektive regjeringer og instanser oppfylles. En vanlig metode for avvanning av slam er slamsenger som er en enkel og billig metode for avvanning av slam. Oppgraderte versjoner av de konvensjonelle slamsengene i sand, er wedge wire dreneringsblokker og slamsenger basert på geotekstiler, noe som forbedrer både slamtørkingen og dreneringstiden.

Formålet med denne masteren var å evaluere ytelsen til de nevnte slamsengene som en metode for å avvanne tilbakespylingsvannet fra vannbehandlingsanlegget ved innsjøen Peri, Brasil. Laboratorietestene ble utført på stedet ved først å bestemme optimal dosering av koagulant. Disse testene ble utført ved å teste forskjellige doser i Jar-test apparatet før drenert vann fra piloter av slamsengene ble evaluert med tanke på turbiditet. Den optimale koagulantdosen ble bestemt til å være 12,5 mg/L PAC og 1 mg/L kationisk polymer med en fjerning i turbiditet på henholdsvis 37% og 92% i WW og FC-filtrene. Pilotene ble bygget i isopor bokser med en indre dimensjon på 30 x 30 cm. Wedge wire blokken hadde åpninger på 0,38 mm x 1,8 cm med et totalt åpent areal på 11%, mens filterduken hadde en tetthet på 700 tråder per meter i horisontal retning, og poreåpning på 1 mm. En sedimenteringstest ble utført for å vurdere om sedimentering før dreneringstesten kunne være en løsning, men meget skjøre flokker med gode flytende egenskaper resulterte i ikke å implementere dette trinnet i piloten. Ytterligere eksperimenter med pilotene viste henholdsvis 49% og 53% fjerning av BOD_5 i WW- og FC-pilotene, noe som ikke oppfyller rensekravet på 60%. Sedimenterbart stoff økte fra 1,8 mL/L til 34 mL/L i WW-piloten, langt fra kravet på 1 mL /, mens det i FC-piloten minsket til 0,8 m /L. Resultatene fra studien indikerte at ingen av de testede pilotene er egnet for avvanning av tilbakespylingsvannet i Peri vannbehandlingsanlegg.

Nøkkelord: cyanobakterier, avvanning, slam seng, direktefiltrering, vannbehandling wedge wire

Preface

This master thesis is submitted to the Norwegian University of Science and Technology (NTNU) as part of the 5-years master degree programme Civil and Environmental Engineering. It is conducted to the course TVM4905 – Water and Wastewater Engineering and accounts for 30 ECTS. The thesis is about wedge-wire and geotextile drying beds as dewatering systems for backwash water at Lake Peri water treatment plant in Brazil. The project is carried out on a request of the Catarinense Sanitary Company, CASAN, after good results of wedge-wire drying beds at one of their other WTPs. The laboratory measurements were conducted at the Lake Peri Water Treatment Plant and the Laboratory of Water Treatment of UFSC, LAPOA.

First I want to give a special thanks to Sveinung Sægrov and Thomas Meyn at the department of Civil and Environmental Engineering at NTNU for believing in me and giving me the opportunity to do this master thesis abroad.

I also want to express my gratitude to my co-supervisor Professor Maurício Luiz Sens at the Federal University in Santa Catarina. First of all, thank you for giving me the opportunity to write this master under supervision of you and for creating different possible projects. Thank you for your guidance and discussions during this process

At last I want to give a big thanks to Felipe Gustavo Trennepohl and Rafael Luiz Prim from Santa Catarina Sanitation Company for all the support and time you have spent on me. I appreciate all the help and advices as well as the interesting discussions. Without you I would not have been able to conduct this work.

Florianopolis, 19th of July 2018

Maud Moldal

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Abbreviations

ANTX-a	Anatoxin-a
ABNT	Associação Brasileira de Normas Técnicas
AWWA	American Water Works Association
BOD	Biological oxygen demand
COD	Chemical oxygen demand
CST	Capillary suction time
CASAN	Companhia Catarinense de Aguas e Saneamento
CONAMA	Conselho Nacional do Meio Ambiente
CYL	Cylindrospermopsin
FC	Filter cloth
IBM	Institutt for Bygg- og Miljøteknikk
LAPOA	Laboratório de Potabilização das Águas
MC	Microcystin
MHCLG	Ministry of housing, communities and local government
PAC	Polyalumuinium Chloride
SR	Specific resistance
SS	Suspended Solids
TTD	Time to drain
TS	Total Solids
UFSC	Universidade Federal da Santa Catarina
WTP	Water Treatment Plant
WW	Wedge Wire

List of symbols

A	Area (m^2)
b	Slope of linear part of a curve (s/ m^6)
c	Mass of dry solids per volume of filtrate (kg / m^3)
d	Thickness of the sludge layer (m)
E	Average evaporation rate (m / month).
L	Sludge load (kgST / m^2);
nc	Number of drying cycles per year
P	Vacuum pressure (N / m^2)
pc	Percentage of total applied volume collected by the bed drainage system.
ρ	Density of sludge (kg / m3)
r	Specific resistance (m/kg)
SS	Solid concentration (% dry weight);
T	Drying time (month)
µ	Dynamic viscosity of the filtrate (N.s / m^2)
V	Volume (m^3)

1 Introduction

1.1 Background

For the drinking water industry, one of the biggest challenges lies in the ultimate disposal of sludge. To find economically viable and environmentally advantageous solutions for treatment and final disposal of WTP sludge is a big challenge in several countries. Among these countries, we find Brazil, where treatment of WTP sludge is a recent subject. Due to the Brazilian standard NBR 10.004 /2004, sludge generated in the water purification industry is classified as solid waste and should therefore not be released into water bodies without previous treatment. Today the majority of WTPs in Brazil dispose their waste directly into water bodies, contrary to the current legislation, causing various environmental impacts (Achon et al, 2013).

In most WTP filtration represents the main treatment process and is defined as a process for particle removal through a porous medium (Bernardo & Dantas, 2005; Crittenden et al, 2012). When particles accumulate in the filter bed, the filtration capacity decreases and the particles need to be washed out. The process of washing the filters is called a backwash and is done by applying a stream of filtered water in the opposite direction of which the filter normally is working. The backwash water removes the retained particles and is now forming the WTP sludge (Crittenden et al, 2012).

The backwash can in many cases be recycled to the head of the WTP, often in combination with a separate filtration or treatment step to not reintroduce the particles in to the water. However this will in many cases require a complicated treatment that is unsuitable in developing countries such as Brazil. Another parameter speaking against recycling of the backwash water at Lake Peri where this project is conducted is the relatively constant high concentration of cyanobacterias. As the faith of the cyanobacterias and their released metabolisms during the water treatment is unclear and the risk of accumulation of cyanotoxins in the backwash water is high, recycling of backwash water without further treatment is not recommended.

As the backwash water is released to the water body, it is classified as effluent from the WTP at Lake Peri and is therefore underlying the CONAMA resolution 430/2011. From section II, article 16 in the CONAMA resolution 430/2011 following standards is determined as effluent release conditions to be met:

a) pH between 5 to 9;

b) Temperature less than 40 °C, whereby the temperature variation of the receiving body must not exceed 3 ° C at the boundary of the mixing zone;

c) Settleable matter up to 1 mL / L in 1 hour test in Inmhoff cone. For launching in lakes and ponds, whose circulation velocity is practically zero, settleable matter should be virtually absent;

d) Discharge system with maximum flow rate up to 1.5 times the average flow of the daily activity period of the pollutant, except in cases allowed by the competent authority;

e) Oils and greases: 1. Mineral oils: up to 20 mg / L; 2. Vegetable oils and animal fats: up to 50 mg / L;

f) Absence of floating materials;

g) Biochemical oxygen demand (BOD 5 days at 20 ° C): minimum removal of 60% of BOD and this limit can only be reduced in the case of a self-purification study of the water body that proves to meet the targets of the receiver body (CONAMA, 430/2011).

In the addition of the national limits the Santa Catarina state law N° 14.675, from 13th of April 2009, Chapter VII, Art 176 & 177 describes limits of maximum 60 mg/L BOD_5 (20°C) or at least 80% reduction (ALESC, 2009).

It is therefore necessary to implement a treatment step for the backwash water at Lake Peri to comply these standards. A solution could be implementing dewatering systems for solid-liquid separation, such as belt presses, centrifuges, sludge ponds and drying beds. As Brazil is a spacious country with relatively high temperatures, natural treatment systems such as drying beds might be favourable (Achon et al, 2005).

1.2 Thesis description

The objective of this study was to analyse a low cost and easy operated dewatering technology at the WTP at Lake Peri to dewater the backwash water from direct filtration. The selected dewater technology for this project consisted of wedge wire draining beds on request of CASAN after good results using this method on another WTP of theirs (see APPENDIX A for further information).

The experiment was carried out as a pilot study at reduced scale, considering the following technical aspects:

- Operational conditions: Optimisation of coagulant concentration.

- Performance: Evaluate the effluent from the draining blocks in terms of physical chemical parameters and cyanobacterias. Registrate time to drain in both of the pilots.

1.3 Lake Peri WTP

Lake Peri is a subtropical lake located in Florianopolis in the south of Brazil (Figure 1). The lake has an area of 5,2 km^2 with a medium depth of 7 m, with 11 m at the maximum (Oliveira, 2002). The temperature in the region ranges from an average of 24,3°C in the summer to 14,4°C in the winter. The average precipitation is 1519 mm/year, with the highest intensities from October – March (Simonassi 2001; Mondardo 2004). The lake is surrounded by Atlantic rain forest and is a part of a national park, meaning that the anthropogenic influence is limited and restricted by laws (Romero et al, 2013). Cyanobacterial blooms are naturally present during the whole year and are dominated by the specie Cylindospermopsis raciborskii (Romero et al, 2013).

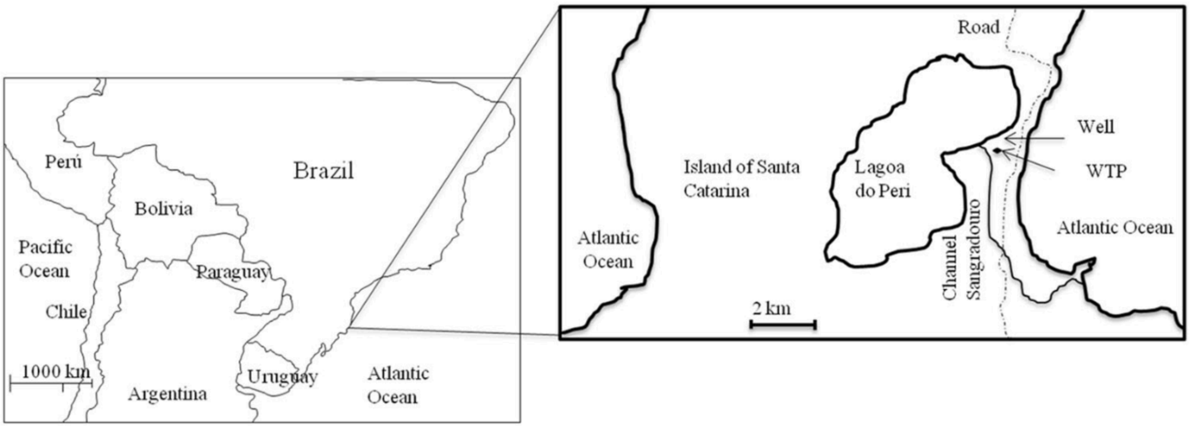

Figure 1: Location of Lake Peri, Florianopólis, Brazil (Source: Romero et al, 2013)

The WTP at Lake Peri was constructed in 2000 by the Santa Catarina's Sanitation Company, CASAN and has a capacity to supply water for up to 100,000 people (Romero, 2013). The WTP consists of contact filtration, with a double layer filter consisting of anthracite and sand (Dalsasso & Sens, 2006). The WTP uses aluminium sulphate as coagulant before the direct filtration, followed by addition of chlorine, fluoride and PH-adjustment (CASAN, 2012).

Figure 2: Image of Lake Peri, Florianopólis, Brazil (Source: Source: CASAN)

The WTP experiences several operational problems related to cyanobacterial blooms, like rapidly clogging of filters and the risk of toxin release throughout the treatment process. The frequent clogging requires frequent cleaning, leading to a high sludge production, increased manpower demand and high treatment costs. The risk of breakthrough of either cyanobacterial cells or the toxins throughout the treatment process makes it unfavourable to recycle the backwash water, which means that the backwash water should be treated as a sludge from the water treatment plant. Dalsasso & Sens (2006) counted occurrences up to 250 000 ind/mL of phytoplankton, dominated by the specie *cylindrospermopsis raciborskii* compared to 10 000 ind/mL that was registrated at the start of the operations at the WTP.

For raw water with particles smaller than 5 µm, Di Bernardo & Dantas (2005) states that flocculation is recommended before filtration. Particle tests have shown that the water at Lake Peri predominates of particles between 2 and 3 µm, which gives an explanation of the operational problems. Dalasso (2005) suggested implementation of flocculation before the filtration as well as replacement of the filter elements. Another suggested solution is bank filtration, which showed a 100% removal of phytoplankton (Mondardo, 2009).

Figure 3: Location of the WTP at Lake Peri (Source: CASAN, 2016)

2 Literature review

Residues from WTP normally come from decanters as settled sludge or from filters as backwash water. This sludge is classified as solid waste and should be treated before it is released into water bodies or disposed in proper areas (Achon et al, 2013). This study will evaluate the process of natural dewatering by use of adapted versions of draining beds for backwash water coming from contact filtration at Lake Peri, Brazil. To get a better understanding of the problem a chapter in this report is delegated to rapid filters, their mechanisms and their need for backwash, which creates the sludge at the WTP. Further on a chapter is dedicated to cyanobacterias and cyanotoxins to describe why this backwash water is different from traditional WTP sludge, and which special considerations that needs to be done. In the end a chapter is delegated to dewatering methods with a focus on drying beds.

2.1 Sludge production from rapid filtration

2.1.1 Rapid filtration

Filtration is a common technology used for removing particles from water by a porous medium such as sand, anthracite, granular activated carbon or membranes, either alone or in combination. It is widely used for treating surface waters, and improves the water quality by removing algae, sediments, clay and other organic and inorganic components. Filters have a long history for treatment of water and are mentioned as a purifying method for drinking water already 2000 BC in India (Baker, 1948). For granular filters, rapid filtration is the most common technology in water treatment. Rapid filtration is distinguished by slow filtration by operational rates up to 100 times greater than slow filtration, caused by a uniform granular material, use of coagulant as precondition and systems for removing accumulated solids in the filter bed (Crittenden et al, 2012).

The uniform size of the granular media allows a higher hydraulic loading rate and a lower head loss. The primary removal mechanism for removal of particles is therefore depth filtration. Depth filtration take an advantage of the accumulation of particles throughout the depth of the filters, caused by collisions and adhersion to the media, resulting in capture of particles several times smaller than the original pore space in the filter bed. This means that the particles are removed throughout the entire depth of the filter, giving the filter a high capacity for solid retention without being rapidly clogged (Crittenden et al, 2012).

The coagulation is a pre-treatment step, which aims to destabilize the particles by changing the natural charge of the particle, making it easier to adherse to the filter media.

According Crittenden et al (2012) rapid filtration can be divided into four different types, distinguished by the level of pre-treatment;

1. **Conventional filtration:**

Conventional filtration (figure 4) is the type of rapid filtration that is most commonly used in water treatment. It exists of coagulation, flocculation and sedimentation prior to the filtration step. It adapts quickly to changes in raw water quality and can also be used for water with very high turbidity.

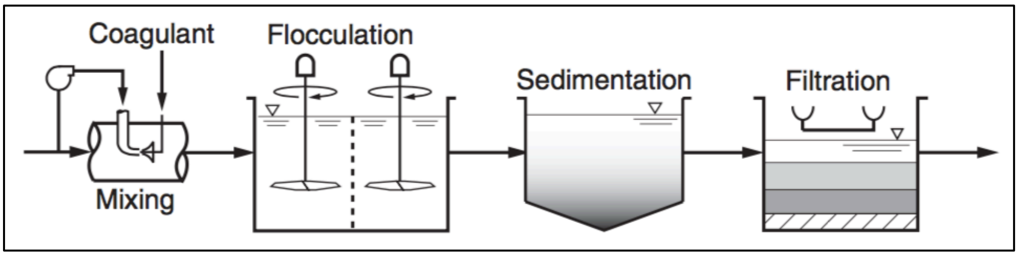

Figure 4: Conventional filtration (Source: Crittenden et al, 2012)

2. **Direct filtration**

Direct filtration (figure 5) is distinguished from conventional filtration by the absence of the sedimentation step. The process are slightly more sensitive to turbidity and is therefore recommended for waters with turbidity < 15 NTU, which makes it inappropriate for most rivers.

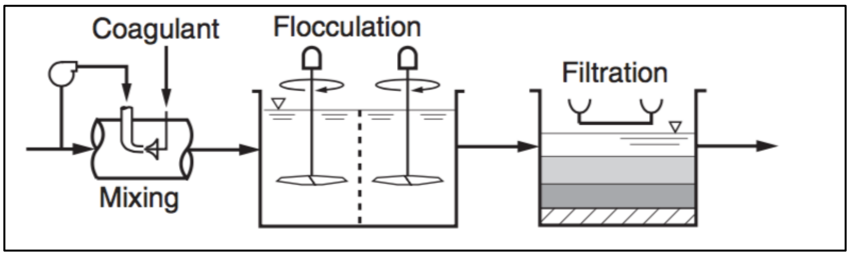

Figure 5: Direct filtration (Source: Crittenden et al, 2012)

3. Contact filtration

Contact filtration (Figure 6) consists only of coagulation prior to filtration, making it a process for high quality surface water with little variation and turbidity < 10 NTU. Crittenden et al (2012) also recommend that the raw water for this type of filtration should have no clay or sediment particles.

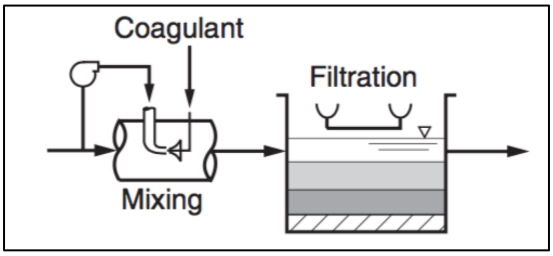

Figure 6: Contact filtration (Source: Crittenden, 2012)

4. Two-stage filtration

Two-stage filtration (figure 7) is the last type of rapid filtration and is pre-engineered systems for use in small WTP. The process response very well to water quality changes and handles turbidity until 100 NTU.

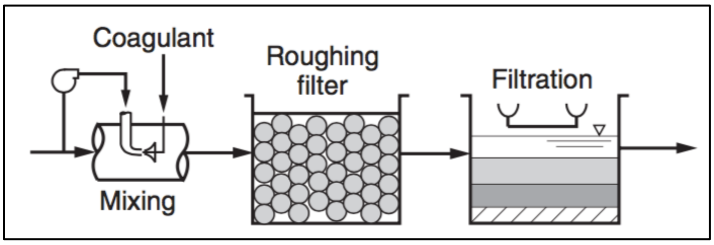

Figure 7: Two-stage filtration (Source: Crittenden et al, 2012)

Removal of accumulated solids within the filter bed is done by backwashing, where water is flushed in the opposite direction of normal filter run. A backwash is normally done every 1-4 day and takes about 15 to 30 min (Crittenden et al, 2012).

The efficiency of the filter is measured by the head loss during the filter run as well as effluent turbidity. The turbidity follows a certain pattern divided into three steps; ripening, effective filtration and breakthrough as shown in figure 4.

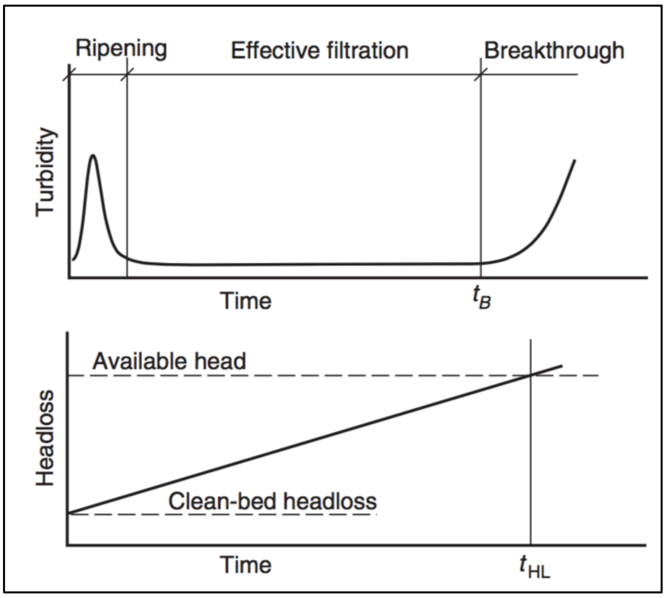

Figure 8: Effluent turbidity and head loss versus time during operation of a rapid filter (Crittenden et al, 2012)

Ripening of the filter is the start-up phase after a backwash. In this phase particles will be captured in the filter and help to improve the filtration efficiency. After this phase, the effluent turbidity will be maintained almost constant, while the head-loss continuously increases as a result of particle accumulation in the filter. The filter reaches breakthrough when the accumulation of particles reaches a level where it no longer can filter effectively and will result in increased effluent turbidity. To prevent effluent water with a turbidity level above the limit, backwash should be done when the filters reached breakthrough. Backwash can also be necessary if the head loss exceeds the limiting head. For an optimal designed filter, breakthrough and limiting head should be occurring at the same time (Crittenden et al, 2012).

2.1.2 Backwash of filters

Backwash of filters is a process for removing the accumulated solids in the filters by reversing the water flow, often in combination with air bubbles. The backwash requires a certain flow rate to flush the accumulated particles out of the filter, however, it should not be that great that the filter media is flushed out of the filter. To establish which flow to apply the bed expansion of fluidized media should be determined (Crittenden et al, 2012).

Recycling of backwash water is common practice in many WTP and decreases the demand of freshwater. However, the recycling may reintroduce contaminants that are removed through the filters. Because of the accumulation of these contaminants in the filters, there is a risk of introducing a bigger quantity of contaminants to the inlet of the treatment plant than it is designed for. To ensure the water quality standards are met in the WTP a separate treatment of the backwash water could be implemented. Common treatment steps for backwash water consist of solid removal followed by disinfection. The solid removal can for example be sedimentation or flotation in combination with or without flocculation, while disinfection often is done by chlorine or UV (Arendze & Sibiya, 2014).

2.2 Cyanobacterias in drinking water

Cyanobacterias can be found naturally in all types of waters and are normal components of aquatic phytoplankton (AWWA, 2010). They are essentially aerobic photoautotrophs that use photosynthesis for energy metabolism (Fay, 1965). Cyanobacterias carries chlorophyll-a pigments, which enable them to harvest light energy efficiently from green, yellow and orange light giving them an advantage from other phytoplankton species (Cohen-Bazir and Bryant, 1982). To maintain cell function, they require just a small amount of energy and can therefore maintain a relatively high growth rate also in lakes with high turbidity (Van Liere & Mur, 1979).

2.2.1 Cyanotoxins

Cyanobacterias possess a wide diversity and more than 20 different cyanobacterial genera has been identified as potent producers of cyanotoxins (Funari and Testai, 2008). Cyanotoxins are a secondary metabolism of cyanobacterias and are produced within the cyanobacterial cells, referred to as intracellular toxins. During cell senescence, lysis or death cyanotoxins are released from the cells resulting in extracellular toxins in the water (Chorus and Bartram, 1999). For healthy log-phase cultures, laboratory studies have shown that only 10-20% of the toxins exist extracellular (Sivonen, 1990; Lehtimäki et al., 1997; Negri et al., 1997; Rapala et al., 1997). Other studies have also shown that the intracellular toxin concentration is several orders of magnitude higher than the extracellular toxin concentration in a healthy bloom population (Lindholm and Meriluoto, 1991; Jones and Orr, 1994; Tsuji et al., 1996; Ueno et al., 1996; Lahti et al., 1997). Since toxin release may occur during cell death, the extracellular toxin concentration may increase in an ageing or declining bloom.

Cyanotoxins can be divided into groups depending on which properties they poses that may affect the human health, ranging from neurotoxins that attack the nervous system, hepatoxins that affects the liver functions and dermatoxins, which irritates the skin and mucous membranes (Chorus and Bartram, 1999; AWWA, 2010; Žegura et al., 2011; Merel et al., 2013). Another common classification is by chemical structure, shown in table 1.

A short summary of the most common cyanotoxins will be described in the following.

Table 1: Cyanotoxins and their cyanobacteria genera (Source adapted from Chorus & Bartram, 1999; Holtcamp, 2012)

Structure	Cyanotoxin	Primary target organ in mammals	Cyanobacteria genera
Cyclic peptide	Microcystin	Liver (hepatoxin)	Microcystis, Anabaena, Planktothrix (Oscillatoria), Nostoc, Hapalosiphon, Anabaenopsis
	Nodularin	Liver	Nodularia
Alkaloids	Anatoxin-a	Nerve synapse	Anabaena, Planktothrix (Oscillatoria), Aphanizomenon
	Anatoxin-s (S)	Nerve synapse	Anabaena
	Cylindrospermopsin	Liver	Cylindrospermopsis, Aphanizomenon, Umezakia

	Lyngbyatoxin-a	Skin, gastrointestinal tract	Lyngbya
	Saxitoxin	Nerve axons	Anabaena, Ahpanizomenon, Lyngbya, Cylindrospermopsis
Lipopolysaccharides	Lipopolysaccharides	Potential irritant, affects any exposed tissue	All
Polykektides	Aplysiatoxins	Skin	Lyngbya, Schizothrix, Planktothrix (Oscillatoria)
Amino Acid	BMAA	Nervous system	All[1]

[1] Kubo et al (2008)

2.2.1.1 Microcystin

Microcystin, MC is the most widespread and frequently studied cyanotoxin with a reported occurrence in Asia, Europe, North Africa, North America and Scandinavia (Fristachi and Sinclair, 2008). It is a hepatoxin that is quickly adsorbed in the liver, where they cause inhibition of protein phosphate (Fischer et al, 2000). The inhibition may lead to accumulation of phosphorylated proteins in the liver, cell necrosis, mass haemorrhage and cause death in the most severe cases (Merel et al, 2013). It is also suggested to be a potential tumour promoter (Falconer, 1991; Nishiwaki-Matsushima et al., 1992). Related to human ingestion, most of the incidents has been related to gastro-enteritis (Kuiper- Goodman et al., 1999; Teixeira et al., 1993) However, more severe poisoning has been reported, for example in Brazil in 1996 when water containing MCs was used for haemodialysis, causing the death of 60 patients (Azevedo et al., 2002).

MCs are differentiated into more than 80 variants with MC- LR, -RR, -LA and -YR being the four of special concern (Westrick et al, 2010). MC usually remains within the cyanobacterial cells and is only released upon a substantial amount of cell lysis. This property as well as its chemical stability and water solubility gives it an environmental persistence causing implications all over the world (Chorus and Bartram, 1999).

WHOs drinking water guideline suggests a maximum concentration of 1 μg/L for MC-LR (WHO, 1998).

Cyanobacterial generas that produces MCs includes: Anabaena, Anabaenopsis, Microcystis, Nostoc, Oscillatoria and Plantothrix (Westrick et al, 2010)

2.2.1.2 Nodularin

Nodularin is a cyclic peptide with hepatoxic properties just like MC. However, there is no suggested guideline for Nodularin in drinking water due to no reported intoxication of humans and insufficient studies (Merel et al, 2013).

2.2.1.3 Anatoxin-a

Anatoxin-a, ANTX-a, is a potent neurotoxin inducing respiratory paralysis by affecting the muscles involved in breathing activity that in the worst case may lead to death (Osswald et al, 2007). No human poisoning has been reported as far as the author know, but several animal poisonings resulting in vomiting, seizure and respiratory arrest have been documented (Gugger et al., 2005; Henriksen et al., 1997; Krienitz et al., 2003; Wood et al., 2007).

There is no official guideline for ANTX-a in drinking water since toxicity studies have given dissimilarly results (Kuiper-Goodman et al., 1999), However, Fawell et al recommended 1 ug/L in 1999, while Svreck and Smith suggested a value of 3 µg/L in 2004 (Svreck and Smith, 2004).

ANTX-a has been found in the cyanobacterias generas Anabaena, Aphanizomenon and Planktothrix (Osswald et al., 2007; van Apeldoorn et al., 2007).

2.2.1.4 Anatoxin-a (s)

Anatoxin-a (s) is another potent neurotoxin, only differentiated from ANTX-a by their different chemical structure. Due to lack of studies no guideline for ANTX-a (s) in drinking water has been proposed yet (Merel et al, 2013).

ANTX-a (s) has been found in the cyanobacteria Anabaena in restricted areas including Denmark, Brazil, Scotland and the United States (Molica et al., 2005; Onodera et al., 1997; Sivonen and Jones, 1999).

2.2.1.5 Cylindrospermopsins

Cylindrospermopsin, CYL is a hemotoxin essentially targeting liver functions by irreversible inhibition of protein synthesis leading to cell death (Froscio et al., 2003, 2008). Exposure of CYL can also lead to fatal toxicity, tumor initiation, micronucleus induction and chromosome loss (Rogers et al., 2007; Falconer and Humpage, 2001; Humpage et al., 2000).

The most famous incident related to CYL is referred to as the “Palm Island mystery disease” that occurred in Australia in 1979, where more than 100 children were sent to the hospital after consumption of drinking water containing CYL (Bourke et al., 1983; Byth, 1980; Griffiths and Saker, 2003).

CYL is found in cyanobacterial generas like Cylindrospermopsis raciborskii, Aphanizomenon ovalisporum, Raphidiopsis curvata and Umezakia natans (Banker et al., 1997; Fristachi and Sinclair, 2008).

There is no official guideline for maximum concentration of CYL in drinking water, but Humpage and Falconer, 2003, has suggested a limit of 1 μg/L after testing on mice (Humpage and Falconer, 2003).

2.2.1.6 Saxitoxins

Saxotoxins, STXs is a neurotoxin maybe most known as paralytic shellfish poison and is commonly found also in seawater. The toxin block sodium ion channels in nerve membrane and indices nerve dysfunction, paralysis and death due to respiratory failure (van Apeldoorn et al., 2007). STX is much more potent than CYL and numerous human intoxication associated with STXs has been detected over the last century, resulting in numbness, paralysis and death (Kuiper-Goodman et al., 1999).

WHO has no guideline for STXs in drinking water, as no intoxication related to drinking water has been documented so far. However Australia has set a maximum concentration of 3 μg STX eq/L (van Apeldoorn et al., 2007).

STX is mainly found in Anabaena circinalis and Aphanizomenon flosaquae but is also observed in Lyngbya and C. raciborskii (Nicholson et al., 2003).

2.2.1.7 β-N-methylamino-L-alanine

β-N-methylamino-L-alanine, BMAA, is a non-protein amino acid and a potent neurotoxin. It mostly affects motor neurons by fixation of glutamate receptors, but it can also cause intraneuronal protein misfolding (Cox et al, 2005). Some studies even suggest a relation with BMMA and neurodegenerative diseases such as ALS, PDC and Alzheimer's disease (Banack et al., 2010; Murch et al., 2004; Pablo et al., 2009). There is a lack of studies in β-N-methylamino-L-alanine (BMAA) but recent studies indicate that the toxin may be present in all cyanobacterias with a worldwide distribution (Cox et al, 2005).

2.2.2 Treatment processes for water with cyanobacterias

To protect consumers from cyanobacterias and their metabolite toxins, an efficient treatment is required. Roughly said, the treatment processes can be distinguished into two groups; retention or degradation of contaminants. Retention of contaminants is for example clarification, adsorption and filtration, while the degrading treatment techniques involves UV, ozonation and chlorination (Merel et al, 2013).

The removal or inactivation of cyanotoxins relies on numerous factors, with the most significant being if the majority of cyanotoxins exist intracellular or extracellular (Westrick et al, 2010).

For removal of intracellular cyanotoxins the aim is to remove intact cells as particulate matter. This is especially relevant for cyanobacterias containing Anatoxin-a, Microcystin and Saxitoxin since 95% of the toxins exist intercellularly during growth (Chorus et al, 1999). Intracellular toxins can be released in large proportions when the cyanobacterial bloom hit a collapse due to unfavourable environmental conditions like lack of nutrients, predation, temperature change, flow change or addition of chemicals. Such conditions can stop the cell growth resulting in a senesce of the population (Westrick et al, 2010).

For cyanobacterial blooms containing other toxins then the ones mentioned above the ratio of intracellular vs. extracellular toxins may change. For example is the cyanotoxin

Cylindrospermopsin naturally released from the cells at a ratio of intracellular vs. extracellular around 50/50 (Griffiths and Saker, 2003).

Giving this knowledge, the type of toxins that the WTP is facing should be an important factor when determining treatment method.

For extracellular removal we distinguish between physical removal, chemical inactivation and biological inactivation. Physical removal includes adsorption and membrane filtration, while chemical and biological inactivation includes UV radiation, oxidants and biological activity (Westrick et al, 2010).

Other properties that affect the treatment efficiency are molecular size, functional groups, hydrophilicity and hydrophobicity that all should be considered upon optimizing the treatment process for removal of cyanobacterias and toxins (Westrick et al, 20120).

2.2.3 Sludge handling for water containing cyanobacterias

Sludge treatment in WTP with presence of cyanobacterias may cause a release of toxic metabolites and pose a treat to the water quality, especially if the supernatant is recycled to the head of the plant. Also backwash water can contain a large amount of cyanobacterial cells, especially for WTP with direct filtration. Whether or not the cells contain their integrity or result in metabolite release are unsure (Ho et al, 2012).

A study from Dreyfus et al (2016) revealed an increase of Cylindrospermopsis and Microcystis during a simulated sludge treatment, indicating an accumulation of cyanobacterial cells and high concentration of metabolisms if the cell lysis (Dreyfus et al, 2016). Also Pestana et al (2016) demonstrated a great risk associated to recycling of sludge supernatant when stating that the metabolite concentration can increase to more than 500% over several days in sludge supernatant (Pestana et al, 2016).

Based on this, Pestana et al (2006) recommended to implement a risk assessment for concentrations 2-5 higher than at the inlet of the plant if recycling the supernatant. If the risk assessment shows that the existing treatment processes are insufficient for these concentrations, the supernatant should not be recycled under the duration of the bloom. Under normal circumstances a bloom will diminish after a period of 3-4 weeks as well as the metabolisms will be degraded. For WTP experiencing constant cyanobacterial blooms exceptions can be done if the metabolites are monitored and demonstrate significant reduction within the sludge treatment (Pestana et al, 2016). For cyanobacterias with STX, a special attention should be given because they are intractable to biological degradation (Pestana et al, 2016). If supernatant recycling cannot be avoided a sufficient amount of chlorine could be applied (Ho et al, 2012).

2.3 Conditioning of sludge

2.3.1 General

Conditioning of sludge is a process that enhances the water removal and improves the solid capture by adhersion of particles and formation of bigger flakes (Wang et al, 2007). It is a process that in application prior to dewatering has the main objective to form flakes that has the ability to form a permeable cake that rapidly looses water by filtration (Marinetti, 2010). By improving the dewatering characteristics, conditioning can lead to reduced drainage time, equipment cost and operation cost (Novak & O'Brien, 1975).

The dewaterability of the sludge depends on the characteristics of the sludge mass, such as particle size, particle distribution, surface charge, degree of hydration and the interaction between the particles. Common for all these characteristics is that conditioning has the ability to change these properties making easier to dewater (Wang et al, 2007).

The most important of these characteristics is the particle size. A decreased particle size results in higher chemical demand and increased dewaterability resistance due to increased surface/volume ratio and more hydration because of increased surface area (US EPA, 1982). The particle distribution of common materials is showed in figure 9. A commonly municipal wastewater contains a large fraction of colloids, 1-10 µm, which results in a high demand of conditioner to improve the dewaterability (Wang et al, 2007). For backwash water the particle distribution will depend on the raw water quality. Lake Peri, which is the raw water source in this study, has a predominant particle size < 2 µm (Dalasso & Sens, 2006).

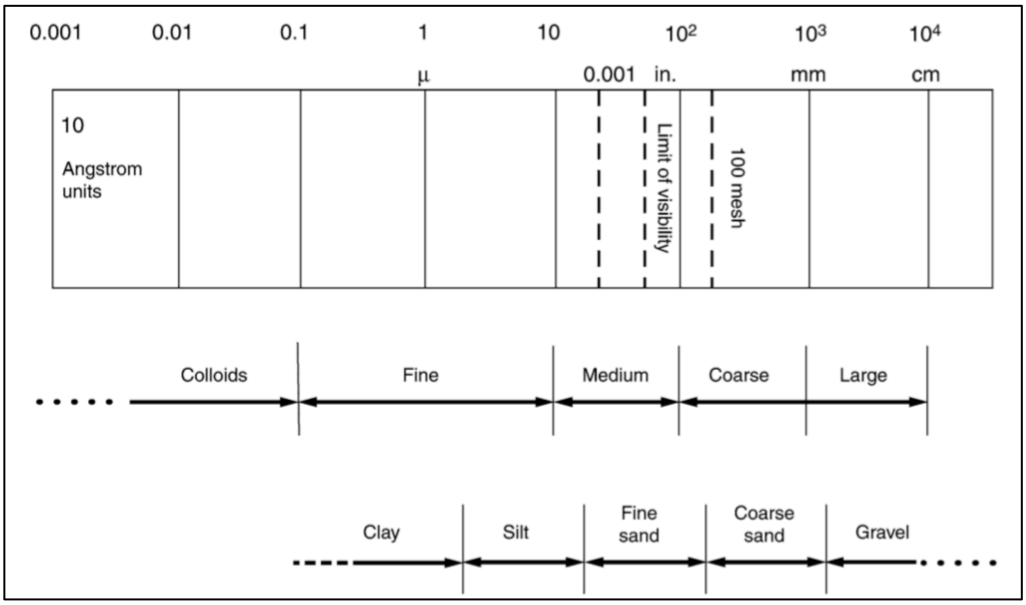

Figure 9: Particle size distribution of common materials (Source: US EPA)

The main purpose of conditioning is to create flocs and increase the particle size. This is done by a combination of coagulation and flocculation where the first step involves destabilizing or neutralizing the negative charge of the particles that repel them from each other. This neutralization of the charge is done by compression of the electrical double layer that surrounds each particle, resulting in a decreased magnitude of repulsive electrostatic interaction. Flocculation follows after coagulation, which aims to cluster the colloids and suspended matter by mixing. It is important that the mixing condition is slow enough to not break the newly formed flocs due to shear stress (Shammas, 2005).

Conditioners can be divided into three main groups that will be described further in the following:

1. Inorganic chemicals
2. Organic polymers
3. Thermal conditioning

2.3.2 Inorganic chemicals

Inorganic chemicals are mostly used for dewatering processes like vacuum and pressure filtration. The chemicals consist of ferric chloride and lime, aluminium sulphate, ferrous chloride and ferrous sulphate (Wang et al, 2007).

According to Wang et al (2007), ferric chloride is the most popular inorganic chemical for dewatering. It is added in conjunction with lime and hydrolyses in the water. For optimum efficiency the pH should be in between 4,5 – 6 for ferric chloride and ferric sulphate (Matilainen et al, 2010). The hydrolyzation forms positively charged soluble iron complexes, which reacts and neutralizes the negatively charged particles in the sludge. The ferric chloride also acts like a flocculant by forming hydroxides with the bicarbonate alkalinity in the sludge. The lime is added for pH control, odour reduction, disinfection as well as it increases the porosity of the bio solids.
An important factor to have in mind when considering inorganic chemicals is that it increases the sludge production and lowers the fuel value of the sludge.

Polyalumuinium chloride, PAC is another coagulant that is frequently used in water and wastewater treatment. It is made by partial hydrolysis of aluminium chloride and is popular because its high efficiency and low costs compared to the traditional flocculants (Wang et al, 2004). PAC has the best efficiency at a pH ranging from 5,5 – 6,5 and consume less alkalinity than for example alum salts (Yan et al, 2008). Another advantage is the lower residual aluminium in the effluent as well as less produced sludge because the efficiency that requires smaller dosages (Matilainen et al, 2010).

2.3.3 Organic polymers

Polymer conditioners also known as polyelectrolytes are widely spread in matters of chemical composition, functional effectiveness and cost, with new polymers continuously being introduced to the market. Common for all the synthetic organic polymers is the backbone of monomer acrylamide (Wang et al, 2007). The polymers are distinguished in to following three groups, distinguished by their ionic charge (Wang et al, 2007):

1. Non-ionic polymers
2. Anionic polymers / anionic polyelectrolytes
3. Cationic polymers / cationic polyelectrolytes

Common for all the synthetic organic polymers is the backbone monomer acrylamide (Wang et al, 2007). In aqueous solutions anionic polymers has a negative electrical charge, while the cationic polymers carries a positive charge. The electrical charge is made by small modifications in the acrylamide, either by hydrolysing an amide group (NH_2), chemical modification of a non-ionic polymer or by combining the acrylamide with an anionic or cationic monomer (Wang et al, 2007).

Because of the negative charge that most sludge carries, cationic polymers are therefore most commonly used for conditioning of sludge. To determine which polymer to apply, both the sludge characteristics and the dewatering/thickening method should be considered. For example will both finer particles and increased hydration require an increased degree of charge (Wang et al, 2007)?

Two mechanisms occurs due to the adhering of the polymer to the surface of sludge particles, causing the formation of a sludge cake:

1. Desorption of bound surface water (Wang et al, 2007)
2. Agglomeration of small particulates by bridging between particles (US EPA, 1979)

Figure 10 shows the desired reactions for polymer addition.

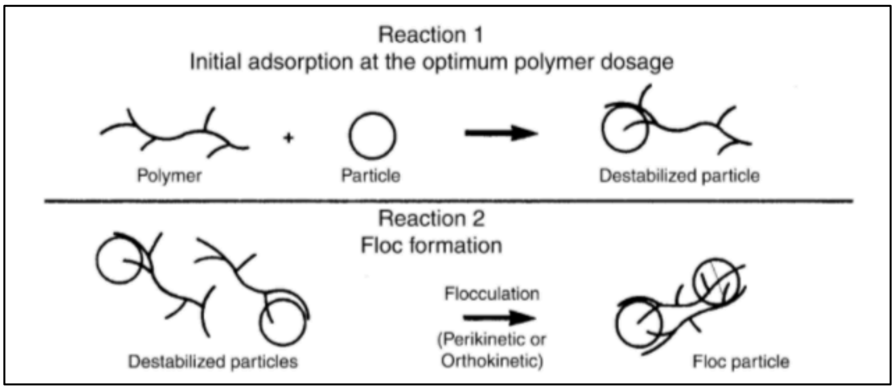

Figure 10: Schematic representation of the desired attachment mechanisms of polymers (Source: US EPA).

Over dosage or undesirable high shear of flocculated sludge may cause unwanted reactions showed in figure 11.

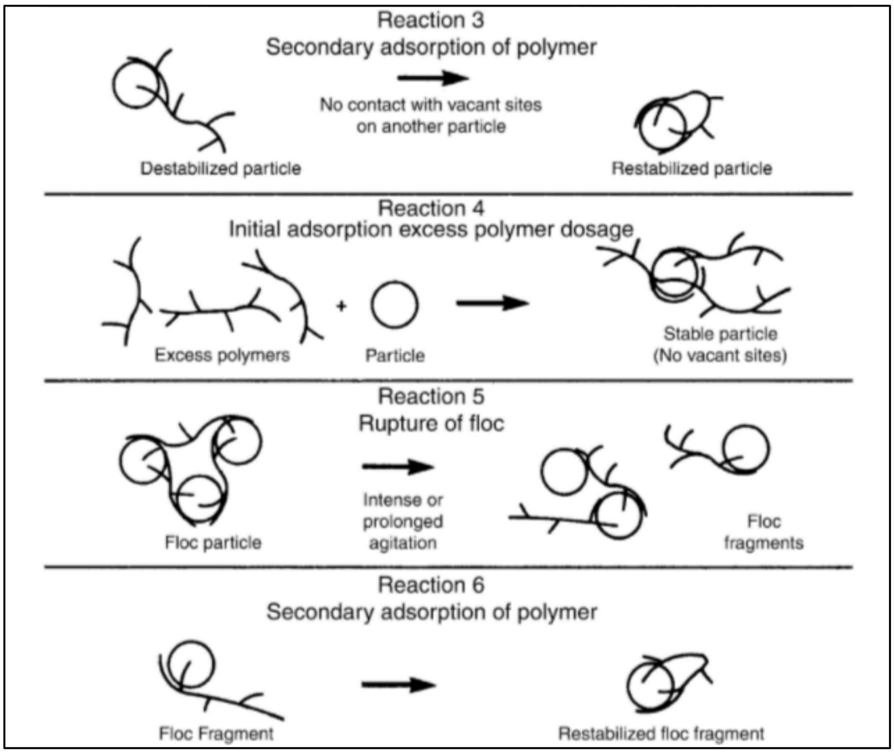

Figure 11: Schematic representation of the destabilisation of colloids by polymers (Source: US EPA).

A great advantage of using polymers as conditioner instead of other inorganic chemical conditioners is the small additional sludge mass that is produced (15-30 % increase) (Wang et al, 2007).

2.3.4 Thermal conditioning

Application of heat and pressure is another conditioning process that increases the dewatering properties of the sludge. Thermal conditioning can be divided into two types; heat treatment (HP) and low-pressure oxidation (LPO) that add air to the process. Similar for both processes is a heating period of 15-40 min under temperatures of 177-204°C in a reactor under a pressure of 1720-2750 kPa (US EPA, 1985).

Thermal conditioning gives excellent dewatering characteristic of the sludge, and a cake with solid concentration of 30-50% in a conventional dewatering process. It both sterilizes and stabilizes the sludge and is insensitive to changes in the sludge characteristics. However, the cost is high and requires skilled operators and high maintenance. (US EPA, 1985; US EPA 1979).

2.3.5 Selection of conditioner

When selecting the type of conditioner many factors like performance, material handling, storage requirements, type of dewatering unit and final disposal should be considered. Looking at these factors as well as capital, operational and maintenance cost, polymer conditioning usually comes out at the better choice (Wang et al, 2007). However, the effect may be improved by combining organic polymer and inorganic chemicals, as Novak & O'Brien demonstrated in 1979. The study showed that a WTP using aluminium salts as a coagulant had a beneficial influence in reducing the required dose by addition of organic polymers as well as decreased drainage time (Novak & O'Brien, 1979). A summarize of effects from the different conditioners are showed in table 2.

Table 2: Effects of conditioners (Source: Wang et al, 2007)

	Inorganic chemicals	**Organic polymers**	**Heat**
Conditioning mechanism	Coagulation and flocculation	Coagulation and flocculation	Alters surface properties and ruptures biomass cells, releases chemicals, hydrolysis
Allowable solids loading rate	Increases	Increases	Significally increases
Supernatant stream	Improves suspended solids capture	Improves suspended solids capture	Significally increase in colour, suspended solids, soluble BOD, NH_3 and COD
Manpower	Little effect	Little effect	Requires skilled operators and a strong preventive maintenance program
Sludge mass	Significantly increases	None	Reduces present mass but may increase mass through recycle

To determine the best conditioning agent, a Jar test experiment can be carried out to observe the flock formation and settling for several conditioners and dosages. The test consists of 6 beakers with a volume of 1-2 L where the sludge can be filled. Then, different dosages of different conditioning chemicals can be added to the samples before the stirrer mixes the solutions. After a certain mixing time at a certain velocity, the mixing is stopped, and the settling can be observed and used to evaluate the performance of each conditioner (Veisilind, 2003)

2.4 Dewatering of sludge

2.4.1 General

Dewatering are physical processes that aims to increase the solid concentration to 15% or higher. Wang et al (2007) defined dewatered sludge as “that sludge whose water content has been significantly reduced by natural or mechanical means such that it no longer flows as a liquid. Dewatered sludge is therefore commonly known as cake”. The increased solid concentration leads to volume reduction, which again leads to reduced transportation costs, improved sludge handling characteristics, reduced landfill leachate production and reduced odour problems (Metcalf & Eddy, 2003).

Common practices for dewatering are pre-treatment by thickening and conditioning, where thickening normally doubles the solid contents by gravity and conditioning aid the water separation by addition of chemicals (Wang et al, 2007). Dewatering techniques includes filters, belt presses, vacuum filtration, drying beds and centrifugation. As mentioned in the introduction, Brazil favours natural dewatering systems like drying beds because of relatively high temperatures and plentiful supply of land (Achon et al, 2005). These facts considered among that drying beds are a low cost and easily operated technique, make drying beds the selected method that CASAN wants to test at Lake Peri WTP and will be described further in 2.5.

2.4.3 Evaluation of dewaterability

The dewaterability of sludge is evaluated through various laboratory tests described in the literature. Both general tests or specialized for certain dewatering methods. Common for all the laboratory tests are that they determine the dewaterability of sludge, which creates a foundation for following purposes (US EPA, 1982):

1. Sizing criteria for pilot scale or full scale installations
2. Testing of conditioners

3. Operational control

The methods that are described further in this report is capillary suction time (CST), specific resistance test and Time to drain, which can be seen in table 3 with their following references. The CST and specific resistance test are frequently described in the literature and commonly used methods. The drainage time test is a simplified test, which has a great similarity with the drainage process in drainage beds and is therefore described here. The list is not complete, but contains the most relevant tests as far as the author knows.

Table 3: Methods for determination of dewaterability

Method	Source
Capillary suction time (CST)	Gale & Baskerville, 1967; US EPA, 1982; Singh et al, 2004
Specific resistance test (SR)	US EPA, 1982; Mortara, 2011
Time to drain (TTD)	Christensen et al, 1995; Miki 1998

2.4.3.1 Capillary suction time

Capillary suction time (CST) is defined as the time the liquid fraction of the sludge takes to travel a certain distance on a porous media, normally a filter paper (Gale & Baskerville, 1967) A typical CST test set-up is showed in figure 12. The sludge is placed in the cylinder on top of the filter paper, here the sludge will form a sediment bed and the water will start to drain through and into the filter paper because of the capillary suction pressure (Singh et al, 2004). Two sensors are placed on the filter paper, registrating the time the water takes to percolate from one to another. The drainage rate depends mainly of two factors (Singh et al, 2004);

1. Porosity of the bed
2. Water holding capacity of the solids in suspension

A reference value for CST of sludge with good drainage capacity is 20 seconds (Spavier et al 1997) Unconditioned sludge may reach a value of 200 seconds, and a filter press requires a CST of 10 seconds or less (US EPA 1979).

The main advantage of the CST is that it is simple test, which gives a quick indication of the dewaterability of the sludge. However, the result needs to be correlated with a specific resistance test or similar to be operated at the CST that corresponds to the desired specific resistance (US EPA, 1982).

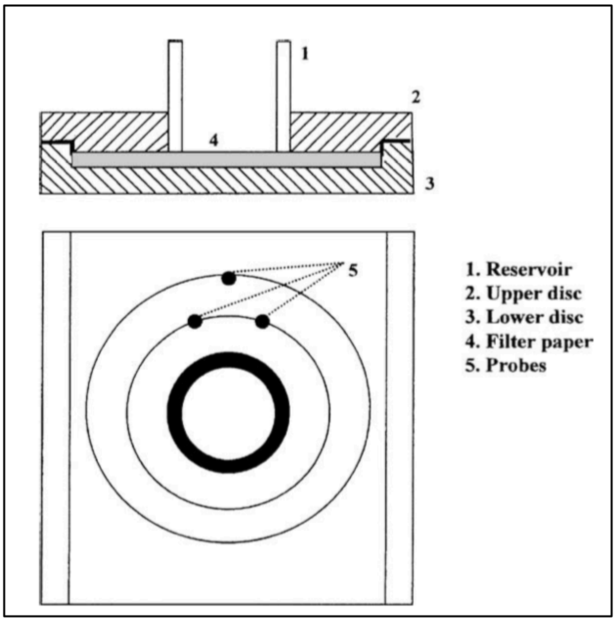

Figure 12: Schematic diagram of CST apparatus (Source: Singh et al, 2004)

2.6.3.2 Specific resistance test

The Specific Resistance test, or Buncher Funnel method is a test to determine dewaterability of sludge. It consists of a Buncher funnel (figure 13) with a paper filter on top of the graduated cylinder. Sludge is then added to the Buncher Funnel, and a vacuum is applied.

Filtrated volume is registrated at predetermined time intervals, and a plot of time/filtrate volume over filtrate volume (t / V x V) is generated as shown in figure 14:

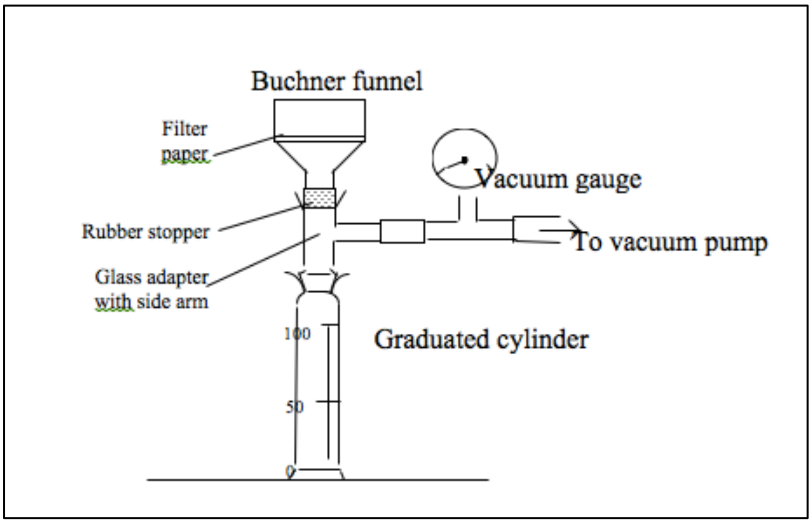

Figure 13: Buchner funnel test apparatus used for the determination of the specific resistance of sludge (Source: University of Waterloo)

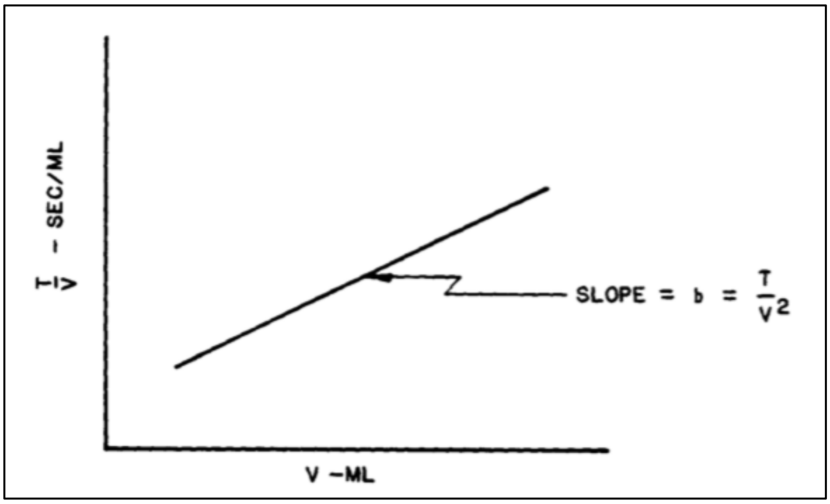

Figure 14: Time/filtrate volume over filtrate volume plot for use in specific resistance tests (US EPA, 1982)

The specific resistance (r) can then be determined by using the slope of the line and formula 1;

$$r = \frac{2\,PA^2b}{\mu c} \qquad (1)$$

Where:

r - specific resistance (m/kg)
b - slope of the linear part of the curve of t / V x V (s / m^6)
P - vacuum pressure (N / m^2)
A - filtration area (m^2)
μ - dynamic viscosity of the filtrate (N.s / m^2)
c - mass of dry solids per volume of filtrate (kg / m^3)

The lower the r-value, the lower the resistance of the sludge to drain water, and the better is the drainage capacity of the sludge (Mortara, 2011). Mortara, 2011 states that a r-value of 108 m/kg indicates a good drainable sludge.

The specific resistance test is not recommended for calculations of filter size and loading, because of the difficulty in determining the exact moment when the curve loses linearity caused by the vacuum breaking when the cracks in the sludge cake appear (Mortara, 2011).

However, US EPA states that the specific resistance test is suitable for determining optimum conditioning chemical dose as illustrated in figure 15.

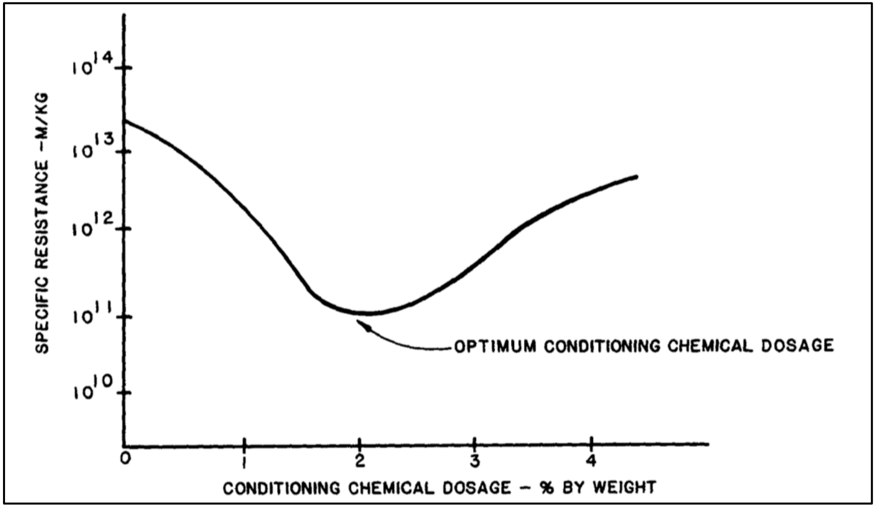

Figure 15: Use of specific resistance to determine optimum chemical dosage (Source: US EPA, 1982)

2.4.3.3 Time to drain

The TTD test determines the sludge drainability as the time required to drain a fixed volume through a support medium (Christensen et al, 1995). It is a simplified variation of the specific resistant test and consists of the same equipment, except from vacuum pump. (Miki, 1998) The lack of vacuum, results in gravity force as the driving force for this test. The measured value is the time a pre-established volume of drained water takes to be reached. The dewaterability is therefore determined by the time to obtain a specific volume.

2.4.4 Characteristic influencing the dewatering

2.4.4.1 General

There are several factors affecting the dewaterability of sludge, including the source of the sludge, prior treatment of the sludge and storage of the sludge that may change its characteristics. Common for the characteristics that influence the dewaterability is that they somehow relate to the difficulty of water movement in between solids and the force keeping the solids apart. The characteristics of a sludge that most significantly affect the dewaterability are listed below and will be described further in the following sections;

- Particle surface charge
- Particle size

- Compressibility
- Temperature
- Ratio of volatile vs. fixed solids
- PH

2.4.4.2 Particle surface charge

Sludge particles comes with a negative surface charge and will therefore repel each other when they are forced together. This is a strong force that increases exponentially when the particles are forced closer together. The negative surface charges, in addition to work with repulsive forces, tend to attract water molecules to the particle surface either by adsorption or capillary between particles (US EPA, 1982). Both of these characteristics decreases the dewaterability significantly but can be altered by introducing conditioning chemicals. The conditioning chemical changes the surface charge of the particles, causing an elimination of the repulsive forces and permits the particles to come together. Conditioning is explained further in chapter 2.3

2.4.4.3 Particle size

Particle size is by most authors described as the most significant factor influencing the dewaterability. In general, when the particle size decreases, the surface area of the sludge increases, leading to several effects of the sludge properties. The increased area of negatively charged surfaces results in an extensive electrical repulsion between the particles. The increased area is also resulting in more adsorption area, which creates a greater attraction of water to the particle surface. An increased area will also result in an increased frictional resistance that restricts the movement of water (US EPA, 1982).

Also the granulometric distribution or the distribution of particle size has a great influence of the dewaterability. It indicates the percentages of solids that belong to the same range of diameters and is commonly described by the uniformity coefficient; Cu. Cu is the ratio between the diameter that is bigger than the 10 % and 60 % of the particles in the material. A sludge mass with particles diameters evenly distributed is called a well-graded material and will form arcs of particles that retain the finer solids (Vidal, 2002).

The particle size is influenced by both prior treatment and the sludge source. In general, a secondary sludge tends to dewater better than a primary sludge because it has a larger average particle size. Also digested sludge has a tendency to decrease the average particle size, which is the reason that digested sludge is harder to dewater than raw sludge. Also mixing, transport and storage may decrease the particle size and should be minimized to maximize the dewaterability of the sludge (US EPA, 1982).

2.4.4.4 Compressibility

Sludge particles are slightly compressible, meaning that they have the ability to deform and reduce the void area in between each other. When this void area is reduced, the water movement through this area gets inhibited and reduces the dewaterability of the sludge in this compressed area (US EPA, 1982).

2.4.4.5 Temperature

Temperature mainly affects the viscosity of the water in the sludge. As the temperature increase, the viscosity of the water decreases. This has a big relevance to the dewatering, and especially on centrifuges that is based on sedimentation. For example is it shown that the rate of centrifugal acceleration in centrifuges increases by 100% when the viscosity is decreased with 50%. However, dewatering methods based on filtration, like filter presses and vacuum filters is not expected to be affected by temperature in the same degree as centrifuges (US EPA, 1982).

2.4.4.6 Ratio of volatile vs. fixed solids

The degree of mineralization, or the ratio of volatile to total solids in the sludge also impacts the dewaterability, as sludge has a tendency to dewater better when the fixed solid percentage increases. This means that the greater degree of mineralization, the better is the dewaterability of the sludge (Metcalf & Eddy, 1991; US EPA, 1982).

For wastewater sludge, the dewaterability will depend on if the digestion process is anaerobic or aerobic, as an aerobic digestion generates sludge with greater dewaterability. For example has Samuido (1993) demonstrated that the drainage accounts for 70% of the water loss from aerobically sludge in a conventional drying bed, while the anaerobically digested sludge only accounts for 20 %.

2.4.4.7 pH

PH affects the surface charge on the particles as well as it has great influence on the efficiency of the conditioner. For example will a anionic polymer work best for a lime conditioned sludge with high pH, while a cationic polymer works better for a pH closer to 7 (US EPA, 1982).

2.5 Sludge drying beds

2.5.1 General

Sludge drying beds is a natural dewatering method that utilizes the mechanisms of evaporation and filtration. It is the most used dewatering method and especially popular in many developing countries where the use of natural dewatering methods of sludge is favoured by advantageous space conditions, cheap labour and favourable climatic characteristics (Samuido, 1993. In Brazil for example, is draining beds used in 2/3 of the sludge treatment facilities (Cordeiro, 2001). The procedure involves transfer of the liquid sludge into the drying bed surface, followed by a drying period until desired solid concentration is reached. The water removal rate is falling as the percentage of free water and the hydraulic load on the filter decreases as well as the particles are deposited and accumulated on the filter (Samuido, 1993). As the free water content is being reduced, evaporation becomes the main process for sludge drying (Cordeiro, 2001). The final solid concentration depends on many factors e.g. type of sludge, drying period and if the sludge is conditioned or not, varying between 18 and 60%. Compared to other mechanized dewatering methods, drying beds has an operational simplicity with reduced operational and energy cost. The disadvantages is that they are vulnerable to climatic variations such as precipitation, solar irradiation and temperature, which causes them to be less constant and reliable compared to mechanised methods (WEF, 1998) Advantages and disadvantages of drying beds in relation to other dewatering methods are presented in table 4:

Table 4: Advantages and disadvantages of drying beds (Source: USEPA, 1982)

Advantages	Disadvantages
• Low capital cost (excluding land cost) • Low operational labour/skill requirement • Low energy • Low maintenance material cost • Little or no chemicals required • High cake solids content possible	• Weather conditions such as rainfall and freezing have an impact • Requires large and areas • High labour requirement for sludge removal • May be aesthetically unpleasing, depending on location • Potential odour problem with poorly stabilized sludge

The conventional drying bed consists of a filter medium of sand and is called a sand drying bed. The typical composition is an upper layer of sand with a specific uniformity coefficient and effective diameter to prevent creeping and early clogging. Recommended height, uniformity coefficient and effective diameter of the sand layer varies from author to aurhot and is demonstrated in table 5:

Table 5: Recommended height, uniformity coefficient and effective diameter for sand layer in sand drying beds

	Metcalf & Eddy (1991)	WPCF (1983)	ABNT NBR 12.209 (1992)
Height (cm)	23-30	30	7,5 -15
Uniformity coefficient (Cu)	< 4	< 4	< 5
Effective diameter (mm)	0,3 – 0,75	0,3 – 0,75	0,3 – 1,2

Under the sand layer a support layer of gravel is found to support the drainage system. A cutting of a typical sand drying bed is shown in figure 16:

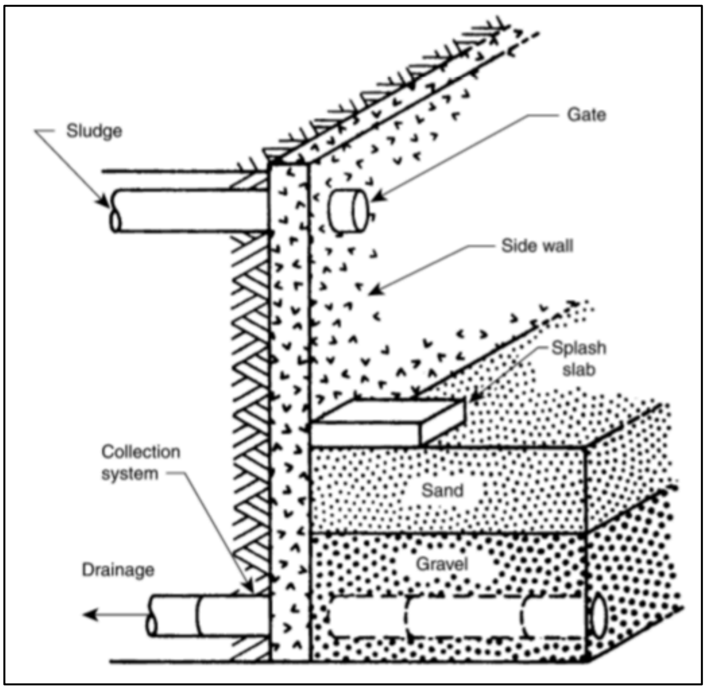

Figure 16: Cutting of a typical sand drying bed composition (Wang et al, 2007)

An overlaying layer of bricks is a common practice to avoid excessive sand loss, improve sludge distribution and facilitate sludge cake removal. The bricks should be placed with a distance of 2-3 cm and not exceed 85 % of the total bed area (Goncalves, 1999; Samuido, 1993).

Under good weather conditions a sludge cake of 40-45% can be achieved in a period of 2-6 weeks. The period can be reduced to the half with use of chemical conditioning. Use of chemical conditioners also permit higher sludge porosity and reduces the maintenance need of the drying bed. (Wang et al, 2007). For the first 1-3 days water drainage is the most important mechanism for dewatering the sludge, leaving solid concentrations up to 15-25% (Eckenfelder & O'Connor, 1961; Eckenfelder & Ford, 1970). The drained water is normally collected and recycled to the head of the treatment plant or to the recipient.

Each drying cycle is determined by when the sludge has reached the desired solid content. The removal of sludge from the drying beds is usually done manually with use of plastic tools and brooms or by a mechanical scrapper (Fontana 2004).

Drying beds have been modified over time to increase their efficiency. The most common of them includes; Paved drying beds, vacuum assisted drying beds wedge wire drying beds or draining bed with a geotextile filter cloth. Both wedge wire drying beds and geotextile draining bed will be described further in this text, since it is the ones that are being evaluated in this study. Information about the others is widely found in the literature for further reading.

2.5.2 Wedge wire drying beds

Wedge wire drying beds is an improved version of the conventional sand drying bed to improve the efficiency in terms of dewatering time and sludge loading rate. The sludge loading rate in a 24-hour operating cycle can exceed a sludge loading rate of 1600 kg/m^2.yr, which exceeds a conventional sand drying bed loading in orders of magnitude (USEPA, 1987). It is a system that according to USEPA (1987) is physically similar to the assisted vacuum process. The wedge wire bed systems consist of preconstructed polystyrene blocks with a dimension of 30 x 30 cm, and grooves for water drainage. See figure 17 for typical configuration of a wedge wire drying bed:

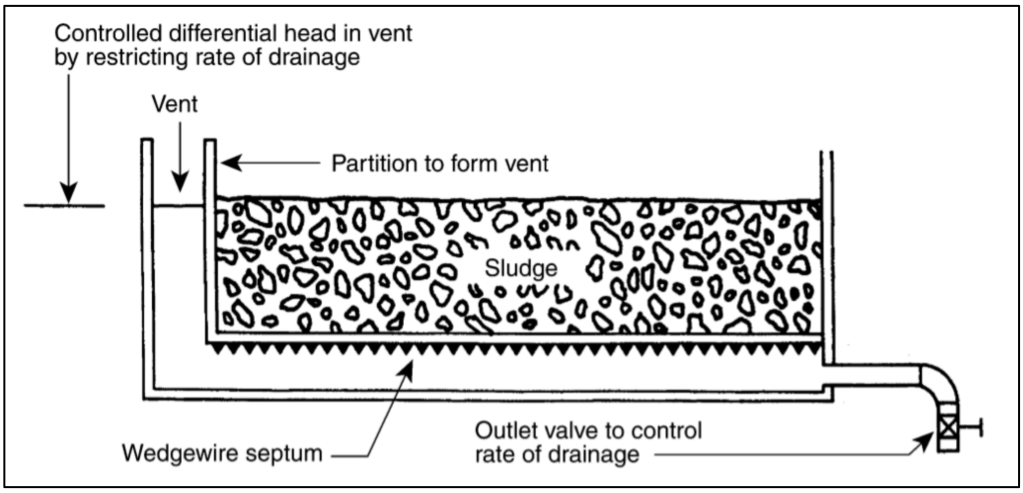

Figure 17: Cross-section of a wedge wire drying bed (Source: US EPA 1987)

The wedge wire septum or blocks has a fitting system for interconnections on the side to facilitate construction of a proper bed. The block can be seen in figure 17. A principle sketch of wedge wire drainage is demonstrated in figure 18:

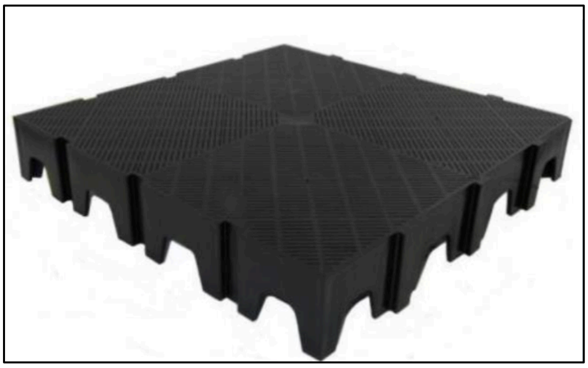

Figure 18: Figure of an individual wedge wire draining block with fitting connections

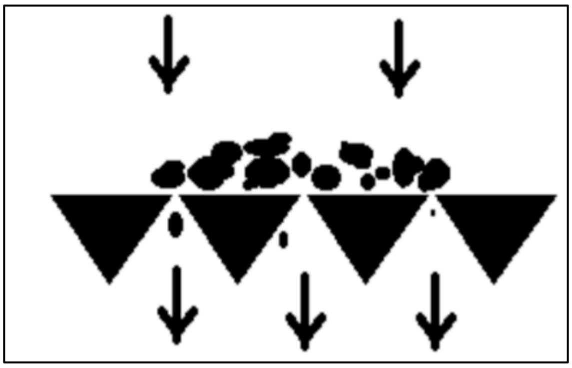

Figure 19: Principle of dewatering by wedge wire blocks

A typical solid load application rate ranges from 2 to 5 kgTS/m^2.cycle (USEAP, 1987). However load criteria's varies from manufacture to manufacture as well as to the specific sludge characteristics and climatic factors. To determine polymer dose and solid loading a combination of databases from the producer and pilot studies could be implemented (USEPA, 1987). Implementation of wedge wire drying beds appears as the best sludge treatment system for small plants located in moderate climates (Almeida, 2012).

The drainage phase in a wedge wire bed is usually complete after 24 hours, leaving a sludge pie with a solid content about 8 – 12 % (USEPA, 1987). The typical application height ranges from 10 – 25 cm. The use of polymer conditioners is essential for the operation, with the optimization determined by experiments.

A summary of advantages of wedge wire drying beds compared to conventional sand drying beds is listed in table 6:

Table 6: Advantages of wedge wire drying beds compared to sand drying beds (Source: Wang et al, 2007; Neubauer, 1968)

Advantages of wedge wire drying beds
• No clogging of the media • Constant and rapid drainage • Higher throughput rate than sand drying beds • Easy maintenance • Can dry difficult-to-dewater sludges like aerobically digested sludge • Dewatered sludge is easier to remove compared to sand drying beds

2.5.2 Geotextile draining beds

Geotextiles are geosynthetic materials that are most commonly used for slope protection and drainage in road construction. The blankets have several functions including retention of soil and particles, drainage of free water, separation of materials and surface erosion control (Vidal, 2002). The draining beds based on geotextile replaces the conventional sand layer to only a layer of the geotextile.

The geotextiles can be divided in to two groups; woven and non-woven fabrics as demonstrated in figure 20 and 21:

Figure 20: Woven geotextiles on the left and non-woven to the right (Vidal, 2002)

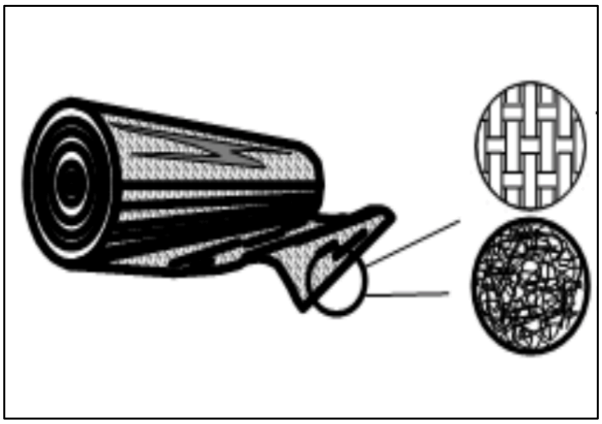

Figure 21: Illustration of the geotextile fabric (Vidal, 2002)

The woven fabric is produced in conventional textile machines from interlacing of filaments, while the nonwoven fabric are composed of randomly distributed materials which are interconnected by mechanical, thermal or chemical processes (Mortara, 2011).

The efficiency of a geotextile as a filter element depends on the sizing of the poresize vs. the solids in the water. As the particles will form arcs around the pores, the chosen filter cloth should not have openings smaller than the smallest particle size, as this will restrict the permaibility of the geotextile (Mortara et al, 2011). Three different processes; blocking, binding and clogging can cause clogging of the geotextile. Blocking of the filter happens when a particle with a particle size bigger than the poresize close the passage and blocks the pore. Binding occurs under accumulation of soldis on top of the filter cloth, preventing flow and filtration. While clogging occurs when particles smaller than the poresize penetrates the filter and retains along the thickness of the filter (Mortara et al, 2011).

2.5.3 Operational variables and design parameters

Drying beds consist of few operational variables that make it an easy operated treatment process. The variables can be summarized to the solid content and height of the applied layer, which determines the sludge loading application rate in each cycle (kg/m^2.cycle) (Mortara, 2011). A short summary of the different factors influencing the draining time as well as operational variables is described in the following.

2.5.3.1 thickness of the sludge layer

As demonstrated in table 5, different literatures suggest different thicknesses of the sludge layer. The recommended values ranges from 7,5 – 30 cm with a preference for 20 cm (Strande et al, 2014). An increased thickness in the sludge layer results in longer drying time and a reduction in the number of cycles that can be applied to the beds each year. Pescod (1971) demonstrated this in his study that showed a prolonged drying time by 50 – 100% with a sludge thickness increase of just 10 cm.

2.5.3.2 sludge loading rate

Sludge loading rate is a number for the mass of solid that is dried on one m^2 of a drying bed each cycle or year. Because of great variations both climatically and for each specific sludge general numbers linked to bed surface area, loading depth and sludge loading rate should only work as estimations (Pescod, 1971). However, a typically sludge loading rates ranges from 50 kgTS/m^2.year in temperate climates such as Europe, to 200 kgTS/m^2.year in tropical climates with optimum conditions. Optimal conditions includes high temperatures, low humidity, low amount of precipitation and stabilized sludge, while poor conditions comprises low temperatures, high humidity, long periods of rainfall and large proportions of fresh faecal sludge (Strande et al, 2014).

2.5.3.3 type of sludge

The type of sludge plays a significant role in the drying process. A septic sludge has less bound water and therefore a less resistance for dewatering. This causes a more rapidly dewatering, which again allows a higher sludge load application rate (Strande et al, 2014).

2.5.3.4 climate factors

The operation of sludge drying beds is affected by several climate factors. For example will decreased temperature and increased humidity lead to reduced evaporation, while high winds enhance the evaporation process. Frequent or heavy rainfall may rewet the sludge, which makes locations with heavy rainfall not feasible for sludge drying beds. For locations with rainy seasons, the sludge bed may be unfeasible during the rains season or covered by roof (Strande et al, 2014).

2.5.4 Dimensioning

Cornwell & Vandermayden (1999) describes two modelling methods for sizing of non-mechanical dewatering systems in a report for AWWA. The first model is based on annual number of cycles while the second method uses a specific drying bed yield. Both methods are described further in the following.

2.5.4.1 Model incorporating annual number of uses

The model of estimating required drying bed area based on number of sludge applications and depth is a commonly used method and described of AWWA and ASCE in 1990. The required area can be determined by formula 2.

$$A_e = V \times 365 / d \times nc \qquad (2)$$

Where:
A_e = Required specific area (m^2)
V= Quantity of sludge produced in the WTP (m^3 / day)
d = thickness of the sludge layer applied in each cycle (m)
nc = number of drying cycles per year

The number of cycles per year is a function of drainage time, drying through evaporation and cleaning of the bed. The estimation of this number gives a great source of insecurity, which is why Rolan (1980) came up with a new modelling method for drying beds.

2.5.4.2 Mathematical model for determination of bed yield

The mathematical model for determination of the sludge drying bed yield was described by Rolan (1980) and consist of a series of equations. The model incorporates several factors that affect the yield, including temperature, wind velocity, precipitation, sludge characteristics and initial solids concentration (Cornwell & Wandermeyden, 1999).

First the model calculates the initial sludge load through equation 3.

$$L = \rho_i \times D_i \times SS_i / 100 \qquad (3)$$

Where:

L = sludge load applied in each cycle (kgST / m^2);
ρ_i = density of sludge (kg / m3);
D_i = initial depth of the sludge layer (m);
SS_i = initial solid concentration (% dry weight);

The final thickness of the sludge layer, which depends on the solids content desired in the final sludge cake is calculated by the following equation:

$$D_{ii} = 100 \times L / \rho_{ii} \times SS_{ii} \qquad (4)$$

Where:

D_{ii} = final thickness of the dry cake (m);
SS_{ii} = solids content that is desired in the dry cake (%);
ρ_{ii} = specific mass of the drained sludge (kg / m3);

The difference between the initial and final thickness of the sludge is found by using formula 5.

$$\Delta D = D_i - D_{ii} \qquad (5)$$

ΔD = Total variation of cake thickness (m).

The variation of this thickness is determined by:

$$\Delta D_u = \Delta D \times Pc \tag{6}$$

Where:

Pc = percentage of total applied volume that is collected by the bed drainage system.

As a reference number for the Pc in drying beds, Rolan (1980) and Samuido, (1993) registrated values between 20 and 30 %. However, conditioning or the use of geosynthetic blankets my increase the numbers drastically (Montera, 2011).

Thus, the thickness of the cake after the drainage step is found by equation 7.

$$D_e = \Delta D - \Delta D_u \tag{7}$$

Following, the time required for the moisture of this cake to be evaporated is found by:

$$T = D_e / E \tag{8}$$

Where:

D_e = pie thickness after drainage (m);
T = drying time by evaporation (months);
E = average evaporation rate (m / month).

Finally, the number of cycles per year, nc and the annual sludge load, L_a (kgST / m^2.year) are determined by:

$$nc = 12 \text{ months per year} / T \tag{9}$$

$$L_a = L \times nc \tag{10}$$

2.5.4.3 Other ways to determine area

For domestic sewage typical values for required specific area can be found by using recommended sludge loading rates or areas as shown in table 7 and 8. These values are often both place specific and dependent on the type of sludge that is dewatered.

Table 7: Solids loading per unit bed area (Adapted from Eckenfelder & O´Connor, 1961)

Type of sludge	Sludge loading rate (dry solids lb/ft^2.yr)	Sludge loading rate (kg/m^2.yr)
Primary	27,5	134,3
Primary trickling filter	22	107,4
Primary activated	15	73,2
Chemically precipitated	22	107,4

Table 8: Recommended sand area for England (Adapted from MHCLG, 1954)

Type of sludge	Open bed area (ft^2/capita)	Open bed area (m^2/capita)
Primary	1,3	0,12
Trickling filter	1,5	0,14
Digested, mixed	1	0,09
Undigested, mixed	2,25	0,21
Greasy sludge	3	0,28

To determine the sludge loading rate, following equations can be utilised:

$$\text{Dry solid (kg)} = \frac{\text{Volume } \left(\text{m}^3\right) \text{ x Concentration } (\text{g/m}^3)}{1000 \text{ (g/kg)}} \tag{11}$$

$$\text{Application rate (kgST/m}^2\text{)} = \frac{\text{Dry solid (kg)}}{\text{Area } (\text{m}^2)} \tag{12}$$

For Brazil, the Brazilian standard ABNT NBR 12.209 (1992) suggests the application of up to 15 kg of total suspended solids per m^2 of drying bed area per cycle.

3 Material and methods

The first tests in this study had the aim to evaluate the sedimentable properties of the backwash water and determine whether a thickening stage in form of sedimentation should be added as a pre-step before the draining beds.

The second tests were conducted with the objective of determine the polymer and coagulant dose to be used in the pilot tests. Different doses of the cationic polymer SEDIFLOC 660CHH produced by KEMIRA and 18% aluminium polychloride, PAC, delivered from Avanex were tested and evaluated for use with backwash water collected at Lake Peri WTP.

The following tests included more comprehensive laboratory tests of the drained backwash water from the pilots. One pilot based on the wedge wire draining bed technique was constructed as well as one based on geotextile. The drained water was collected after different loadings of backwash water to also evaluate the performance over time.

The WTP in Lake Peri consists of rapid mixing of coagulant, 5 direct filters, followed by chlorination, pH correction and fluorination. It has a capacity of producing 200 L/s. The filters are cleaned 7 times per day, consuming approximately 80 m^3 in each cycle, resulting in 560 m^3/d or 6,48 L/s.

All the experiments were carried out on site at the WTP at Lake Peri either in LAPOA, the laboratory administrated by UFSC or in the laboratories of CASAN.

3.1 Collection and characterization of sludge

Backwashing of the filters are done by a process of draining existent water from the filters, before air bubbles are introduced together with water in the opposite of the filter direction to clean the filter. After a few minutes, this water is being discarded and end up as spent filter backwash water that goes to a separate piping system. This process is repeated two times to ensure proper cleaning of the filters.

Collection of backwash water for the experiments was done during the first backwash of each filter to obtain water with as much particles as possible. The backwash water is lead from the filters trough a pipe in to a sedimentation basin, which today only work as a storage basin before further distribution. The piping leading to the storage basin has a faucet for collection and testing of backwash water, and was used to collect the backwash water for the experiments. The backwash water was collected and stored in a 150 L container. The storage container was equipped with a faucet in the bottom that was used for transferring the backwash water from the container to the experiments by use of a bucket. Photos of the collections is shown in figure 22:

Figure 22: Collection of backwash water at Lake Peri WTP

A new collection of backwash water was collected each day of experiments to ensure accurate values of the different water quality parameters. As the solids have a tendency to settle after a certain period of time, the collected material was agitated to homogenize the mixture before further use and examination.

Simple water quality parameters as turbidity, temperature and pH were performed on site, while the other more complex analysis were performed at CASANs wastewater laboratory under help of CASANs biochemist. These analysis included SS, BOD, COD, Settleable matter and total nitrogen. All analysis is performed following AWWA's Standard methods for examination of water and wastewater (AWWA, 2017) and can be seen in table 9:

Table 9: Performed water quality tests

Parameter	Methods based on standard methods for examination of water
Suspended solids (mg/L)	2540D (gravimetric)
BOD (mgO^2/L)	5210 (respirometric/manometric)
COD (mgO^2/L)	5220 (colorimetric, closed reflux digestion)
Settleable matter (mL/L)	2540F
Cyanobacterias (cell/mL)	See described method below
PH (-)	4500
Turbidity (NTU)	2130
Temperature (°C)	2550

In addition to the water quality tests described above, counting of cyanobacterial cells were done by CASANs biologist. The analysis and counting were done by following procedure:

1. Homogenization.
2. Dilution 1:10 (10mL of in natura sample + 90mL distilled water = 100mL diluted sample).
3. Addition of lugol solution in a ratio of 1: 100.
4. Transfer of an aliquot of the diluted sample to the 2.4mL Utermohl chamber using a Pasteur pipette.
5. Resting the subsample in a vacuum desiccator, for a few hours, for sedimentation of the material to be analysed.
6. Analysis in inverted optical microscope with increase of 600x.
7. Random observation in fields of the Whipple Reticle.

3.2 Sedimentation tests

As the WTP has a sedimentation basin with outlets at three different heights, one idea was to let the backwash water sediment prior to the dewatering and send the supernatant either to the head of the plant or out to the recipient.

Today, backwash of the filters are done 7 times per day, with filters of a working time of 24 h, giving 3,5 h between each backwash. A sedimentation test of untreated backwash water was therefore performed with a total duration of 3,5 hours because this is the maximum time that the sedimentation basin would stand still without mixing of additional water. The test was performed in a Jar-test beaker with collection of supernatant for turbidity testing each 30 min.

In addition to the sedimentation test of raw backwash water, another sedimentation test was carried out with backwash water conditioned with 12,5 mg/L PAC and 1 mg/L cationic polymer. The conditioners were added under a rotational speed of 350 rpm for a period of one minute. The PAC was dosed first, then the polymer. The rapid mixing was followed by a 20 min period of slow mixing at a speed of 30 rpm to support floc formation. This test was carried out after same procedure as the raw backwash water but with time intervals of 5 minutes until 30 min followed with one reading after 90 min and 180 min.
Both tests were triplicated to avoid errors.

3.3 Determination of conditioner

For determination of conditioner, several doses of polymers and the inorganic coagulant PAC 18% were tested by use of Jar test equipment. To evaluate the floc formation, the conditioned water was filtrated through pilots of the drying beds and evaluated by testing the turbidity of the effluent.

Another method that was considered was determination floc size distribution. However, due to complex analysis and results that are interfered with by the methods of analysis it was chosen to evaluate the coagulation properties empirically by using the filters. The tests had the objective of determine the optimum conditioning dosage for the backwash water in Lake Peri in terms of solid capture and drainage of free water through the drying beds.

3.3.1 Materials

To evaluate the optimum coagulant dose Jar test equipment, 303 M from MILAN, consisting of 6 beakers of 2L, each equipped with automatic propellers were used. 1L beakers were used to transfer collected backwash water from the 20 L bucket to the jar test beakers. Pipettes of 2 mL and 10 mL were used to transfer polymer and PAC respectively. The cationic polymer came granulated, while the PAC came in a solution of 421 g/L. Preparation and dilution is described further in 3.3.2 and 3.3.3.

Two pilots were constructed to evaluate the floc formation in terms of performance with the wedge wire block and geotextile filter cloth. The pilots were installed in isopor boxes with an inner diameter of 30 x 30 cm. One pilot consisting of the wedge wire block only and a tube for drainage in the bottom. The wedge wire block is a 30 x 30 cm polystyrene block with puzzles in the edge for easy connection with other blocks to create a bigger surface. The surface has openings of 0,38 mm x 18 mm creating a open surface of 11%. A figure of the wedge wire block can be seen in figure 23.

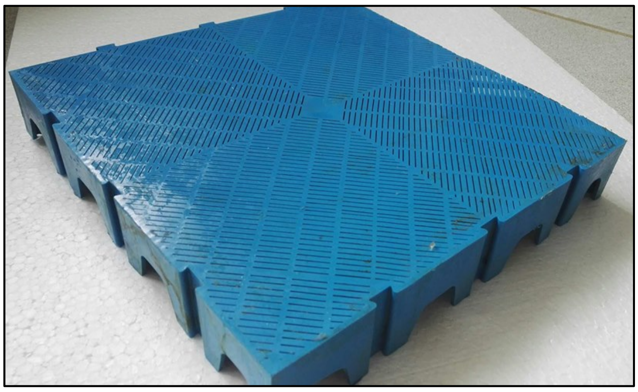

Figure 23: Picture of the wedge wire block. The block has openings of 0,38mm x 1,8 cm and a total open area of 11%. The dimensions of the block is 30 cm x 30 cm x 5 cm height

The second pilot were constructed with a wedge wire block as support layer and a geotextile filter cloth on top. The filter cloth was a woven geotextile with a pore opening of 1mm, consisting of 700 threads in the horizontal direction. A picture of the filter cloth can be seen in figure 24:

Figure 24: Picture showing the woven geotextile filter cloth with pore openings of 1mm

A schematic representation of the pilots is shown in figure 25:

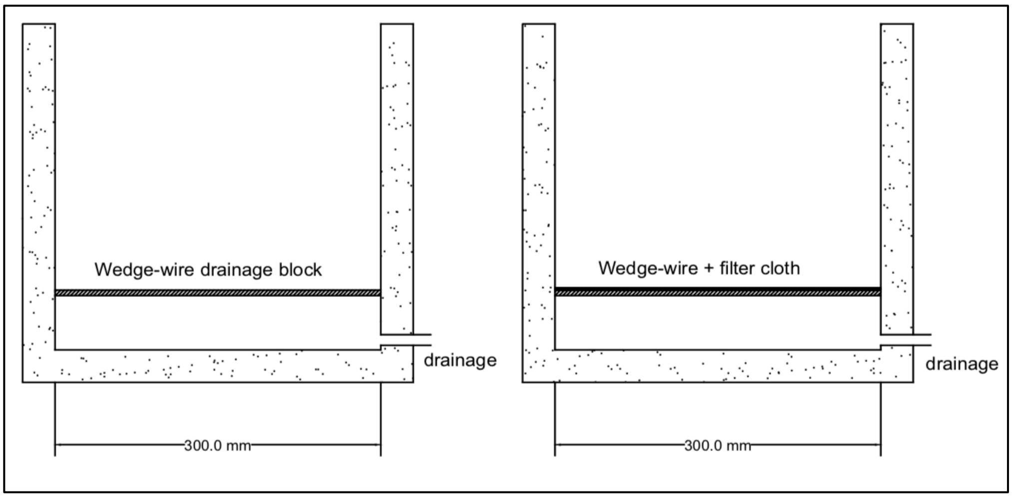

Figure 25: Drawings of the pilots, wedge wire pilot on the left, and the wedge wire with filter cloth to the right

For more pictures from the pilots, see appendix D4.

To evaluate the performance a Hatch 2100Q turbidity meter was applied as well as a GEHAKA PG1800 pH-meter.

3.3.2 Preparation of polymer

To prepare the polymer 1 g granulated cationic polymer (Appendix F) was carefully added in to 1 L mixed water in the Jar test equipment, preventing the polymer from coming into contact with the walls or shaft as well as being evenly distributed in the water phase. Rotation speed of the mixing propeller where set to 250 rpm under addition of polymer and 120 rpm for the further dilution. The mixing time were determined by visual observation of the polymer in dilution, varying from 1-2 hours.

Diluted polymer solutions were visually analysed to verify the formation of overly concentrated plots both in the walls of the preparation vessels and in suspension, where those with such appearance were discarded. The solutions were stored briefly in 300 mL containers and stored cold and dark. The samples were replaced after 3 days as the efficiency of polymers in solution tend to decrease with storage time.

3.3.3 Dilution and dosing of PAC

The 18% PAC used in this experiment came in a stock solution of 421 g/L. In order to dose correctly, samples of PAC were diluted in a ratio of 1:100 resulting in a solution of 4,21 g/L PAC: This were done by adding 5 mL 421 g/L PAC in a 500 mL volumetric flask and dilute with distilled water until the mark. The solution were mixed properly and stored briefly in the fridge.

Calculations of desired dosage of PAC in the experiments were done by the dilution equation;

$$C_1 * V_1 = C_2 * V_2 \qquad (13)$$

By arranging formula 13 the required volume, V_1 of 4,21 g/L PAC could be added in the Jar-tests beakers of 2L:

$$V_1 = (C_2 * V_2) / C_1 \qquad (14)$$

Where V_1 = volume of 4,21 g/L Pac to be added in solution
C_2 = Desired PAC concentration in g/L
V_2 = Volume of prepared solution in the beakers, 2L
C_1 = concentration of undiluted PAC, 4,21 g/L

3.3.4 Description of the test

Three sets of tests were performed to evaluate the floc formation of different coagulant doses. The first series with experiments evaluated the drainage turbidity for backwash water coagulated with different dosages of PAC. A sample of backwash water were collected during the filter backwash as described in 3.1 and carried in a 20 L bucket from the outside of the WTP in to the laboratory to perform the analysis. All 6 beakers in the Jar-test equipment were filled with 2L samples, while a reference sample were taken to evaluate initial turbidity, temperature and pH. Dosages ranging from 5 – 35 mg/L PAC were added to the different beakers by test tubes located over the beakers in the jar-test equipment. The rotational speed was set to 350 rpm the first minute to ensure sufficient mixing and reduced to 30 rpm for the next 30 minutes to support floc formation. The coagulated sludge was then manually added to the pilots by trasfering the liquid into the filter surface. This was done as slow as possible to avoid unnecessary turbulence and breaks of flocs. Turbidity in the drained water were then collected and evaluated in terms of turbidity. Each set of tests was triplicated to reduce errors. The pilots were washed carefully in between each test to ensure the same circumstances for all the tests.

The same procedure were followed for the next to series of tests were the first were done with a constant dosage of cationic polymer, 1 mg/L, while altering the PAC dosage from 0 – 35 mg/L. The intervals between the PAC dosages started with 5 mg/L and were then repeated with a smaller interval around the best result (10 mg/L). When dosing the PAC and polymer, the rapid mixing was set to 2 minutes so that the PAC could be added first and then the polymer. The polymer was added approximately 1 minute after the PAC.

By determining the optimum PAC doses from series number 2, the series number 3 was conducted using this PAC dosage and varying the cationic polymer dosage from 0 to 2,5 mg/L. The best result from this 3rd series where then applied as the optimum conditioner dosage in the rest of the experiments. All the experiments were duplicated and for the ones with varying results triplicated to ensure accurancy of the results.

3.4 Drained water quality test

Using the same materials as in the test described in chapter 3.3 a more extensive pilot experiment was performed using the conditioning dose determined by the previous test. The objective of this experiment was to evaluate the performance of the pilots when they were exposed for greater volumes than in the previous test. In lack of mixer and to ensure adequate mixing of the conditioner the jar-test equipment was used to perform the experiments.

New samples of backwash water were collected and distributed into the beakers of 2 L. Each beaker was then conditioned with 12,5 mg/L PAC and 1 mg/L cationic polymer as described in chapter 3.3. After coagulation time of 20 min, 6 L were applied to each pilot to evaluate both drainage time and treatment performance. In relation to evaluate drainage time each drained litre were counted with the drainage time registrated. As 6 litres were applied in each cycle the water pressure decreased for each drained litre and may have affected the drainage time. However, as the same procedure was followed for both pilots and during the whole experiments, the results will still indicate the trends. The tests were repeated until the pilot started to show sign of a clogging as in case for the filter cloth or until 78 L for the wedge wire pilot.

In the same experiment samples for the drained volume were collected to evaluate the treatment performance in terms of turbidity removal. This was done as accumulation of solids on the drying bed surface tends to improve treatment efficiency.

Also more severe laboratory analysis were performed to measure the treatment efficiency in terms of BOD, SS, Settleable solids, COD and cyanobacterial cells. One test were collected from the two first drained litres, while a second test were collected after respectively 60 L and 18 L for the wedge wire pilot and the filter cloth pilot. The reason that they were not collected after the same applied volume was that we wanted to evaluate the performance after a certain accumulation of solids on the drying bed surface. Due to long draining times, the sample from the filter cloth pilot was collected after just 18L. These test were performed in CASANs wastewater lab following AWWAs standard methods. Explanation of the cyanobacterial cell counting is described in chapter 3.1.

3.4.2 Methodology of the pilot experiment

The methodology for the pilot experiment can be summarized into following steps:

1. Preparation of polymer and PAC (see chapter 3.3.2 and 3.3.3)
2. Collection of backwash water (chapter 3.1)
3. Evaluation of reference sample of raw backwash water (turbidity, temperature and pH)
4. Addition of backwash water in 2L beakers from jar test equipment
5. Addition and mixing of PAC and polymer (chapter 3.3.4)
6. Transference of conditioned backwash water in to the pilots. This was done manually with a slow and steady movement to avoid unnecessary turbulence in the water.
7. Registration of drainage time
8. Collection of drainage for turbidity testing and other water quality analysis.
9. Repetition until desired drained volume were reached.

4 Results and discussion

4.1 Characterisation of the backwash water

Average values for collected samples from the backwash water in the period of April 29th to June 29th 2018 are listed in table 9 below and compared to the consisting legislation to effluents. The complete datasheet for backwash characterisation can be found in APPENDIX D3.

Table 10: Characterisation of the backwash water

Parameter	Value	Std. aviation	Limit for released effluent	Status
Suspended solids (mg/L)	201	40,2	No limit	Ok
BOD (mgO^2/L)	38	3,0	< 60 mgO2/L and > 60% rem.	Not ok
COD (mgO^2/L)	192	43,4	No limit	-
Settleable matter (mL/L)	1,8	1,2	< 1	Not ok
Total nitrogen (mg/L)	<10	-	No limit	-
Cyanobacterias (cell/mL)	14249882,5	789771,1	No limit	-
PH (-)	7,5	0,6	Between 5-9	Ok
Turbidity (NTU)	172	53	No limit	-
Temperature (°C)	21,4	5,3	< 40	Ok

Referring the national resolution for effluents, CONAMA 430/2011 and the Santa Catarina state law, ALESC 14.675/2009 following standards need to be met for releasing of the effluent from the WTP at lake Peri:

- PH between 6,0 - 9,0 (ALESC 14.675/2009 Art 177, I)
- Absence of visible floating materials (ALESC 14.675/2009, Art 177, III)
- BOD_5: maximum 60 mg /l, and this limit can only be exceeded in the case of biological

wastewater treatment system effluent which reduces the pollutant load in terms of BOD_5 (20 ° C) of the eviction by at least 80% (ALESC 14.675/2009, Art 177, XI)

- BOD_5: minimum removal of 60% of BOD and this limit can only be reduced in the case of a self-purification study of the water body that proves to meet the targets of the receiver body (CONAMA 430/2011, Art 16, section II)
- Sedimentable materials up to 1 mL / L in 1 hour test in Inmhoff cone. For launching in lakes and ponds, whose circulation velocity is practically zero, sedimentable materials should be virtually absent (CONAMA 430/2011, Art 16, section II)

Looking at the limits given in the legislation it can be observed that the untreated backwash water exceeds the value of settleable matter with a value almost two times above the limit.

Another parameter that is exceeding the limit is the BOD_5 that needs to meet both requirements of 60% removal and a maximum concentrartion of 60 mg/L. As the backwash water is untreated, the reduction of 60% is therefore not met.

4.2 Sedimentation experiment of the backwash water

4.2.1 Sedimentation tests with raw backwash water

The result of the sedimentation experiment of raw backwash water (Figure 26) demonstrates very poor settling properties. This also confirms the data given in the characterisation of the backwash water in section 4.1 of an average settleable solid content of 1,8 mL/L. The result of this test indicates that the whole amount of backwash water should be added coagulant to improve sedimentation properties by floc formation.

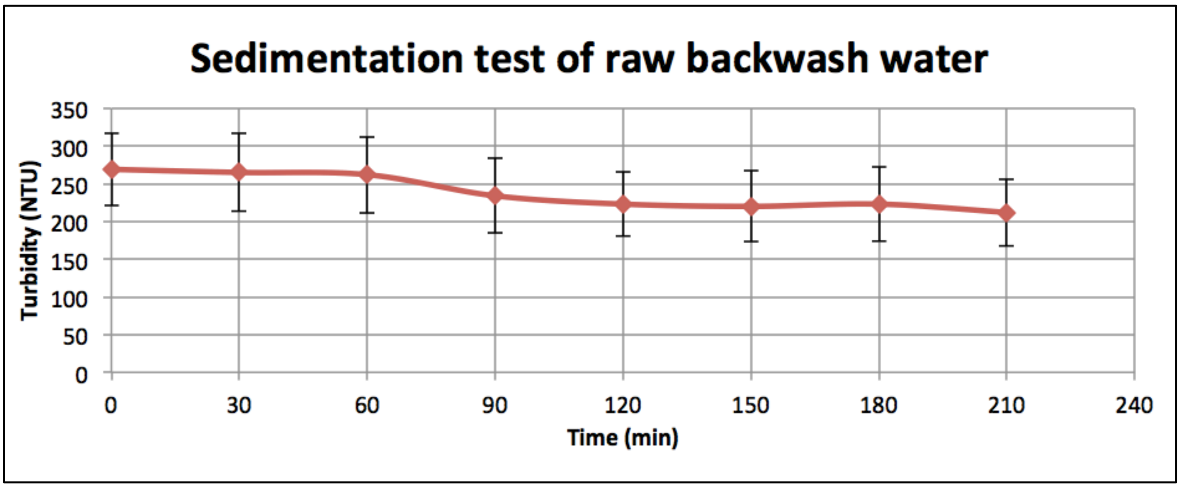

Figure 26: Turbidity in supernatant in sedimentation tests of raw backwash water

4.2.2 Sedimentation tests with conditioned backwash water

Sedimentation test with conditioned backwash water demonstrated a much better result than without conditioner. The turbidity in the supernatant after conditioning with 12,5 mg/L PAC and 1 mg / L cationic polymer is presented in figure 27:

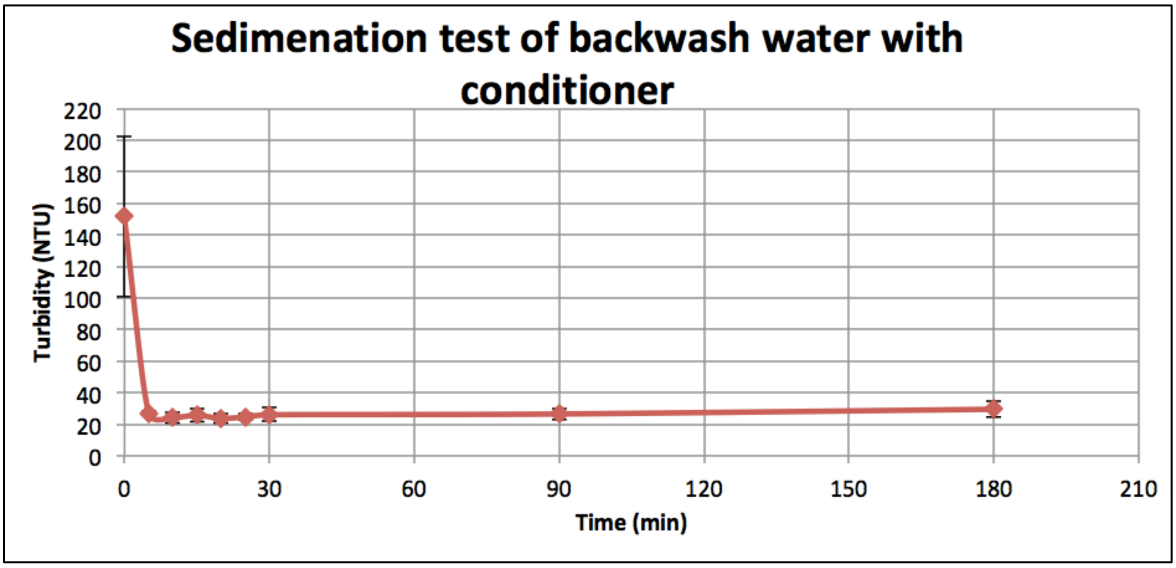

Figure 27: Turbidity in supernatant in sedimentation experiment with conditioner

Even though the turbidity levels in the supernatant in the sedimentation test with conditioner showed very good removal, the results of this test lead to the decision of not installing a sedimentation step prior to the drying beds. The decision is based upon visual examination of the jar-test beakers under the sedimentation experiments. Even though it clearly showed a layer of coagulated mass in the bottom of the beakers, it also demonstrated a significant layer floating on the top and in the middle of the water phase. The coagulated mass also seemed to move around in the water as well as the flocs breaking apart with just a little turbulence introduced in the water.

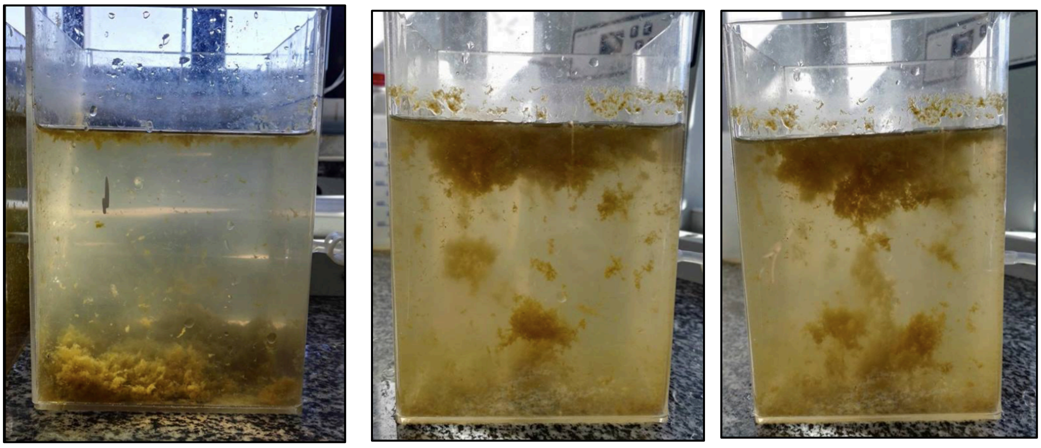

Figure 28: Picture showing the sedimentation properties of conditioned backwash water from Lake Peri

4.3 Determination of conditioner

Three sets of coagulation tests were performed to verify the behaviour of the backwash water at different dosages of conditioner. The first series of tests (APPENDIX B1) indicated that PAC alone did result in insufficient floc formation to retain solids on the wedge water surface at any of the tested dosages ranging from 0-35 mg/L. For the filter cloth pilot, the PAC seemed to achieve 60-70% removal at dosages higher than 20 mg/L. A presentation of residual turbidity in drained water is shown in figure 29:

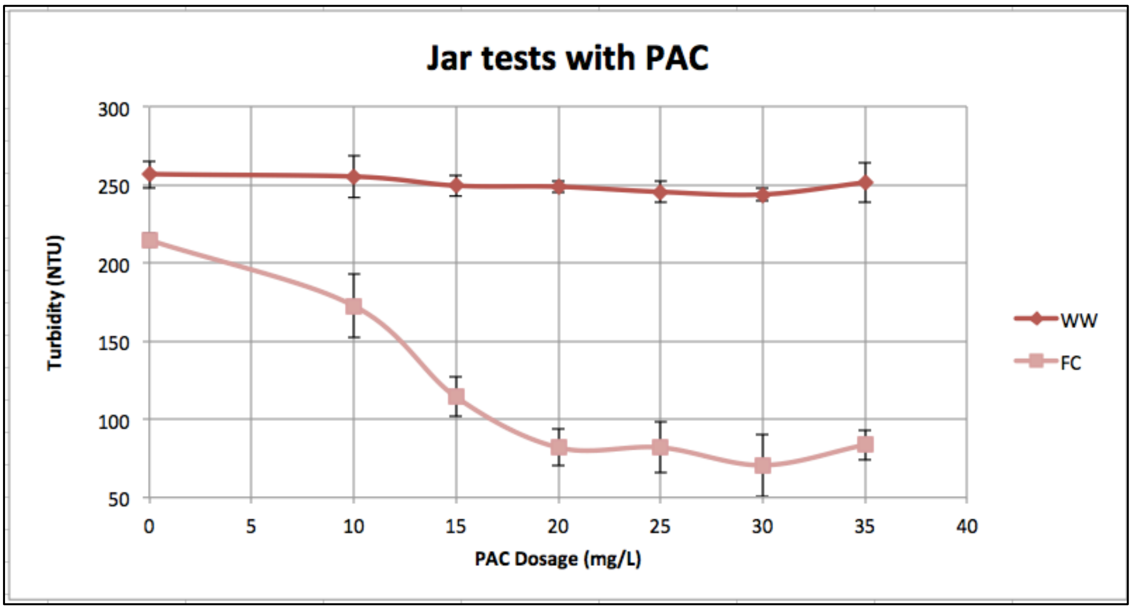

Figure 29: Drained water quality after PAC coagulation

The second series with test was performed with a stabile polymer concentration of 1 mg/L and varying PAC dosages from 0 – 35 mg/L. The results can be seen in figure 30 below, with further information in APPENDIX B2.

As the graphs show, the dosage with the best turbidity removal was 12,5 mg/L for both the wedge wire pilot and the geotrxtile filter cloth pilot, giving a removal of respectively 44 % and 92 %.

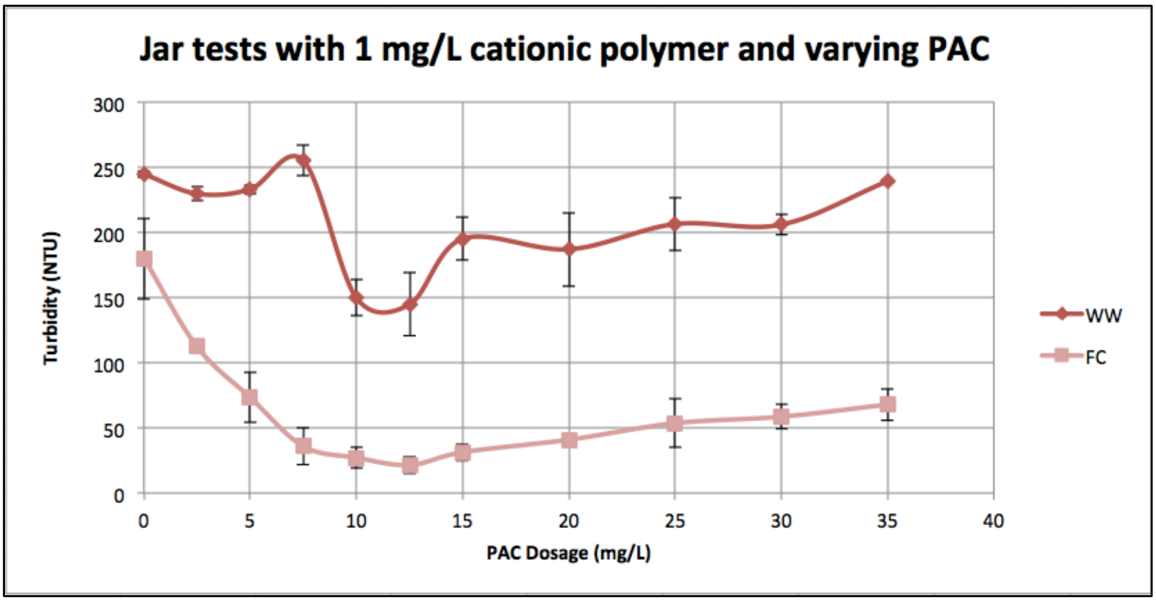

Figure 30: Residual turbidity in drained water from the pilots with backwashwater conditioned with 1 mg/L polymer and varying PAC

The third and last series to determine the optimum conditioning dosage as performed by altering the polymer dosage while keeping the PAC dosage stabile at 12,5 mg/L which was the best result from series number 2. The results from the experiment are presented in figure 31 with associated data in APPENDIX B3.

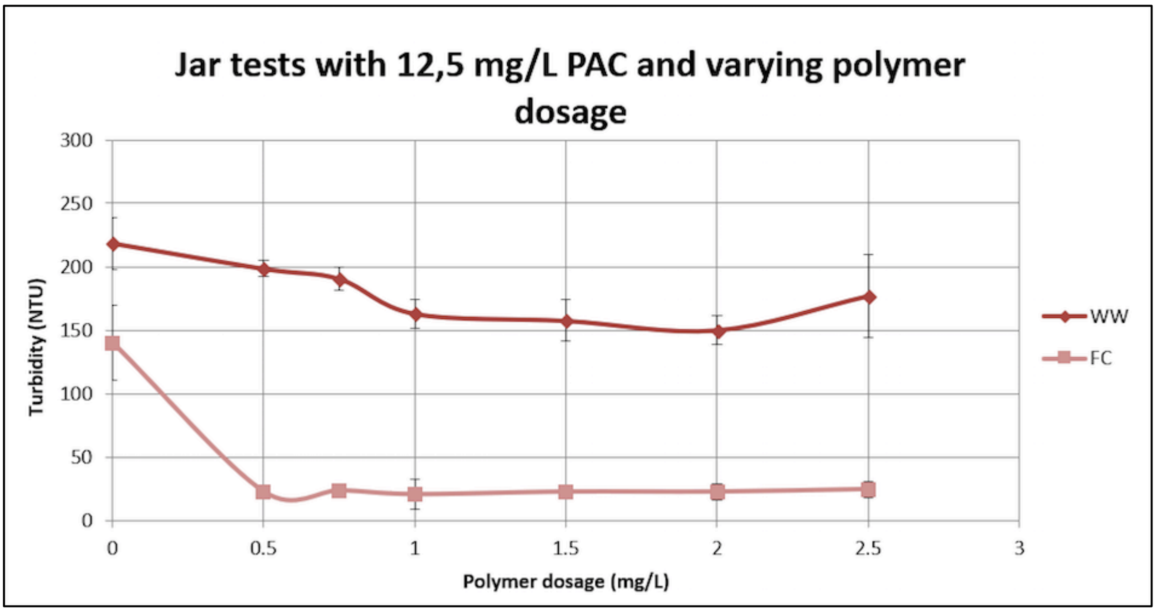

Figure 31: Residual turbidity in drained water from the pilots with backwash water conditioned with 12,5 mg/L and varying cationic polymer dosage

As the graph shows, all tested dosages varying from 0,5 – 2,5 mg/L cationic polymer demonstrated a good removal efficiency in the filter cloth pilot with a percent removal between 91-92 %. However it could be observed that the drainage time seemed to be prolonged in line with the increased dosage. For the wedge wire pilot the best efficiency were obtained at a dosage of 2 mg/L with a removal efficiency of 42%. The results from the WW-pilot also demonstrated a relatively small difference in the removal efficiency for the dosages between 1-2 mg/L. Due to economically advantages as well as a shortened drainage time, the dosage of 1 mg/L was determined to be the optimum dosage for the following experiments in this study.

4.4 Pilot test

The pilot tests were carried out in terms of evaluating effluent turbidity over time, as the filters tend to improve the efficiency after a solid accumulation on the surface. Another point of interest was the drainage time, to evaluate if the filters seemed to be clogged fast. At last, samples were collected for a more comprehensive evaluation of water quality parameters in the effluent.

4.4.1 Drained water quality

Results from the drained water turbidity are presented in figure 32 and as percent removal in figure 33. As the figures shows, the turbidy levels varied a lot, indicating that the flocs on the surface were unstable. This can especially be seen in the curve from the wedge wire pilot, where the pore size were bigger and facilitated a passage of broken flocs. The average removal efficiency in terms of turbidity was 41% for the wedge wire pilot, which is similar to the results from the conditioning test in 4.3. More detailed data from the drained water turbidity test can be obtained in APPENDIX D1 and D2.

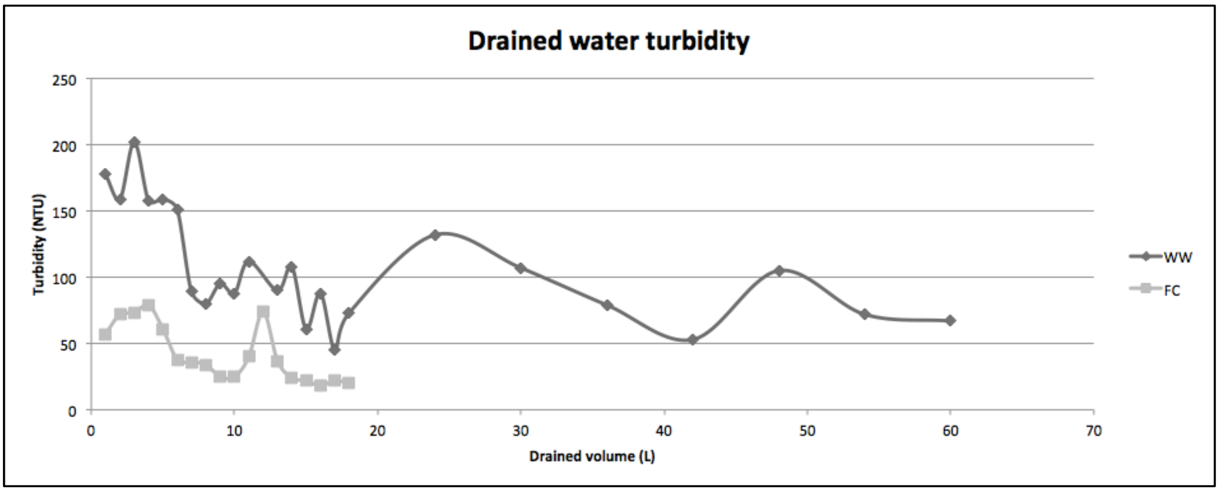

Figure 32: Turbidity in drained water from the pilots. Variation over increased volume

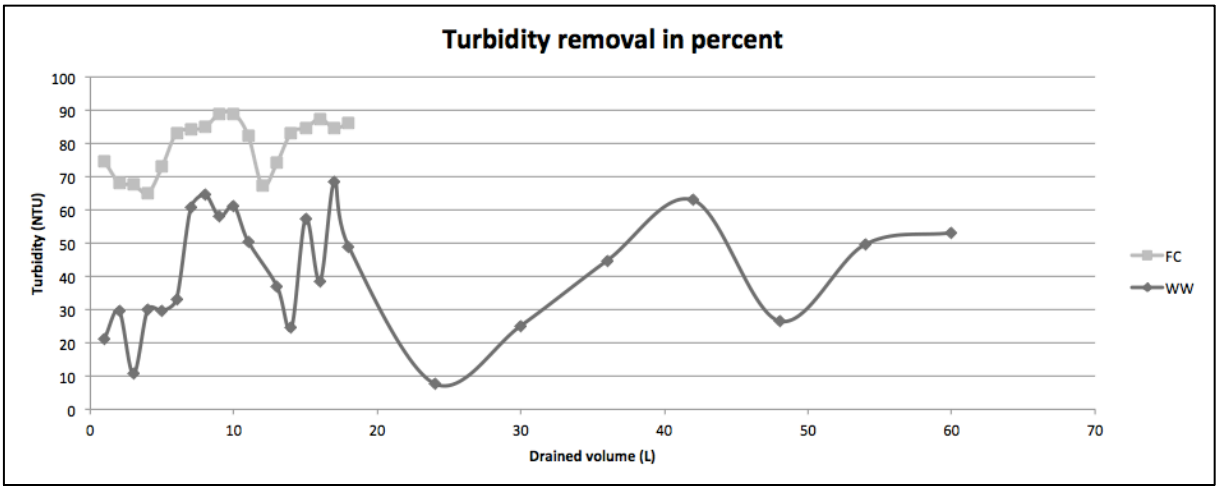

Figure 33: Turbidity removal in drained water vs. untreated backwash water in percent

The filter cloth pilot followed a more conventional curve for filters including ripening in the first four drained litres, followed by a decreasing turbidy. However, at 12 litres, the effluent demonstrated a great jump in the turbidity, which can only be described as due succion from when the water level dropped. The filter cloth pilot only showed turbidity in he effluent until 18 L, which is the point where the filter got clogged. The average removal efficiency in this interval was 79%, which is a litte lower than in the tests performed in 3.4. However, this can be explained by a bigger loading at the filter, resulting in a higher pressure on the filter cloth, which may help to open up the pores.

For the other water quality parameters the values can be obtained in figure 34. The value is an average from the first drained litres from the pilots and respectively after the 60th and 18th drained litres from the wedge wire pilot and the filter cloth pilot. This was done to see if the removal improved upon accumulation of sludge in the filters. A table with complete data from this test is shown in appendix D3.

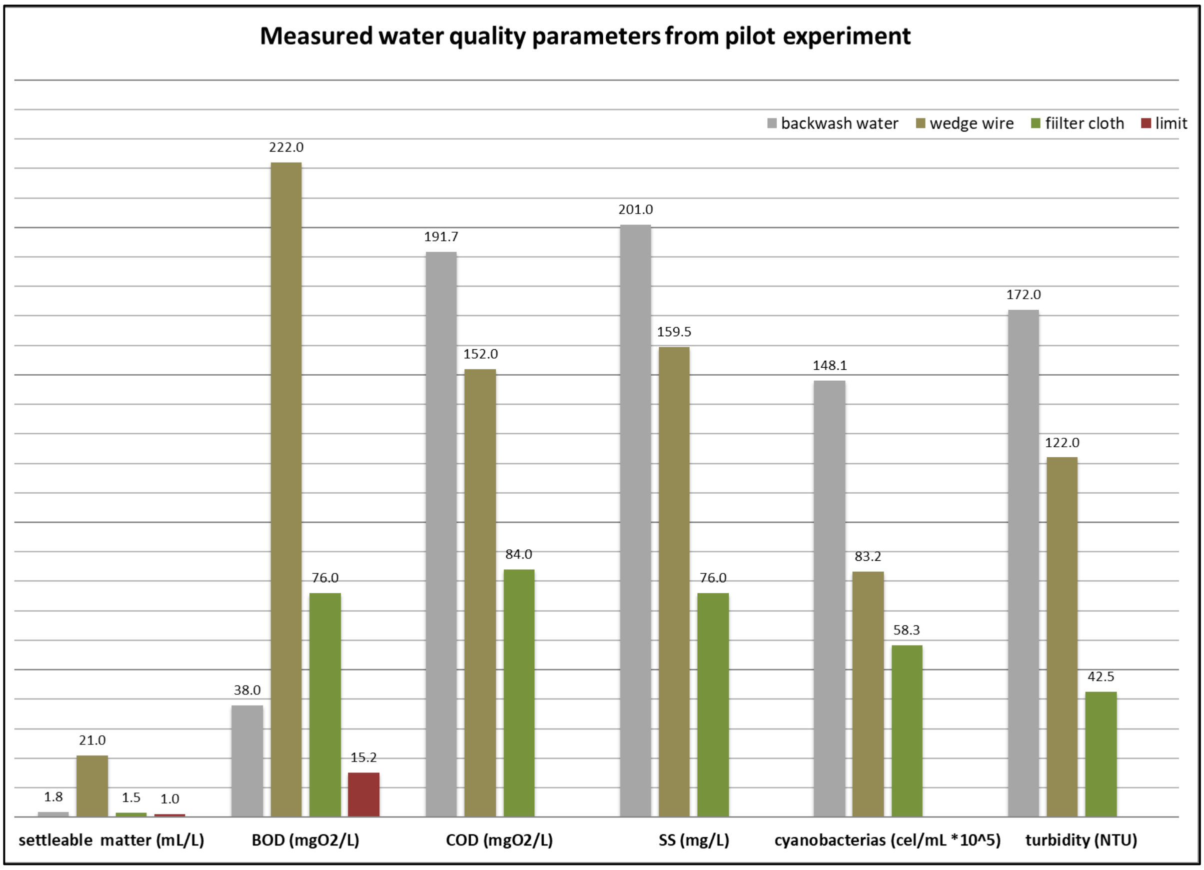

Figure 34: Average value for measured water quality parameters from drained water and untreated backwash water at Lake Peri. The red column represents the highest legal value for effluents according the Brazilian and Santa Catarina State legislation

Figure 34 demonstrates that the filter cloth pilot has a better removal efficiency compared to the wedge wire pilot for all parameters evaluated in this study. Looking again at the legislation for effluent release, both settleable matter and BOD removal is insufficient for both the draining beds evaluated in this study. This is also seen in figure 34, where the red column imitates the limits in the legislations. As the legislation requires both a minimum value of 60 mg/L BOD_5 as well as at least 60 % decrease, the limiting value for the backwash water at lake Peri WTP will be 60% removal, which equals 15,2 mg/L BOD_5. The gray column indicates the levels in untreated backwash water. The figure also demonstrates that both settleable matter and BOD have increased values compared to untreated backwash water. This can be explained by floc formation after conditioning, but is moving the effluents in wrong directions in terms of the effluent release legislations.

For the test conducted relating to draining time, both figure 35 and 36 represent the data collected in the test.

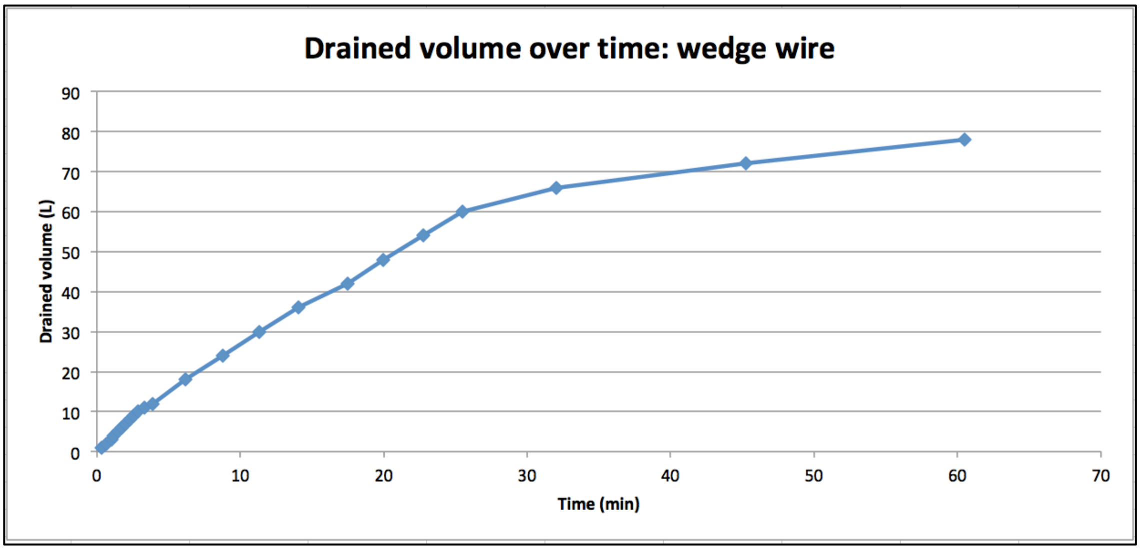

Figure 35: time to drain for the wedge wire pilot

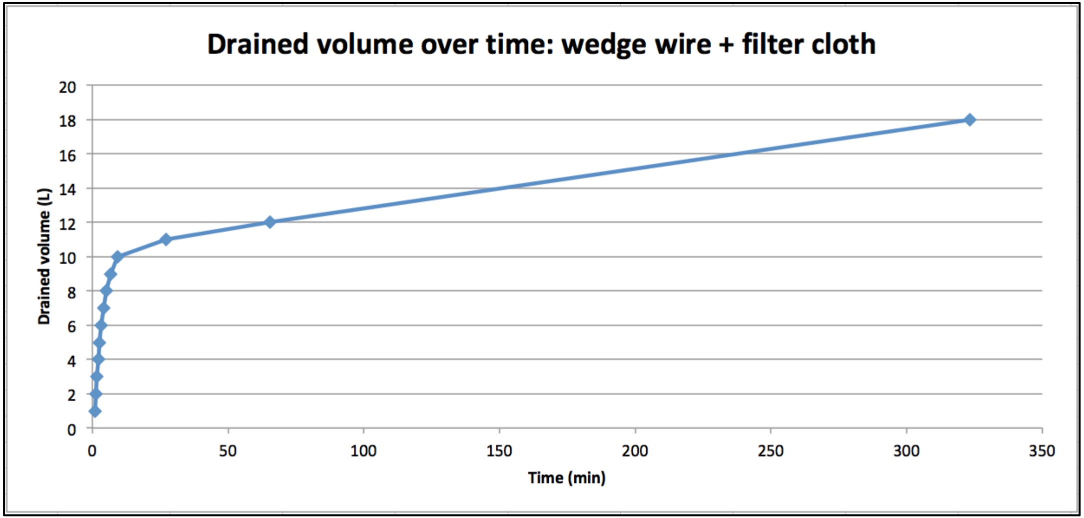

Figure 36: Time to drain in the filter cloth pilot

As demonstrated in the figures, the wedge wire pilot had much shorter draining times than the filter cloth pilot. The wedge wire pilot had draining times around 20 s/L for the first drained litres and approximately 2,5 min/L for volumes between the 66th and 78th drained liter. In comparison, the filter cloth pilot demonstrated draining times around 40min/L between the 12th and 18th drained liter.

Looking at the results obtained from the pilot experiments, neither of the pilots is recommended for dewatering the backwash water in Lake Peri.

4.5 Unsuccessful experiments and challenges during the project

The project experienced different challenges ranging from delay, shortage in communication and unsuccessful experiments that will be mentioned here in this chapter. One of the main problems was the shortage in communication and expetations, which caused delays in the project. The first delayed was linked to that the study was conducted under assistance of the Federal University in Santa Catarina, Brazil, which only started the semester in the beginning of march in comparison of NTNU that starts the semester in the beginning of January. Meetings were held prior to the semester start to hasten the project, but with many involved parts, the determination of objective delayed. As the time passed, the first experiments were carried out under guidance from the sanitation company. A set of coagulation experiments were conducted, but due to insufficient data from this experiments, the result could not be used in this study after further consulting with the supervisors. However, the tests gave an indication of which coagulants and polymers to use, and were repeated later to collect data for this report. The coagulant dose where determined by the jar-test experiment described in chapter 4.2 but without the filtering part. Meaning that it was the supernatant turbidity that got tested. The test was performed after 8 minutes sedimentation.

After consulting with the supervisor it was clear that this data could not be used as the polymer and PAC were added at the same time as well as the sedimentation properties does not indicate the size of the flocs and the best dose for filtration. These tests were therefor dismissed and a new set of experiments where conducted instead, described in 4.2.

In addition to the first set of experiments, two pilots were installed to evaluate the treatment efficiency of the wedge-wire block using the pre-determined coagulant dose. The pilots consisted of one wedge-wire pilot with an inner area of 30 x 60 cm as well as a reference pilot with a conventional sludge drying bed layout, with the same area as the wedge wire pilot. This pilot was constructed with a 10 cm support layer of gravel, a 10 cm anthracite layer and bricklayer on the top. Both of the pilots were filled several times with conditioned backwash water but both experienced operational problems. The wedge wire pilot ended up with not holding the solids back because of to big turbulence under the addition of the backwash water, resulting on broken flocs that easily passed the filter openings. The backwash water were collected in big quantity and mixed by hand under lack of more sophisticated tools. This could also have influenced the bad efficiency of the wedge wire pilot.

The sand drying bed pilot demonstrated in the other hand an effluent of very good water quality. One water quality test was performed for the drained water quality of these pilots and the results demonstrated a 91% removal of BOD from the sand drying bed pilot. This drainage water did also have a content of sedimentable solids under 0,1 mL/L which equals at least 96 % removal. However, the pH decreased from 5,79 to 3,14 during the filtration. The sand drying pilot did also clog after the first addition of 70 L, and were therefore later in the study replaced with the filter cloth pilot for easier maintenance and cleaning. Data from the first experiment can be obtained in appendix B.

As the first experiment had a several factors that could influence the experiments, two new pilots in a smaller scale were created to obtain more control over the conditions. To be sure of right mixing conditions the mixing was only done in the jar tests apparatus and only a small quantity of water were transferred to the pilots to make sure of creating as little turbulence as possible. This pilots where made of the lightweight material isopor compared to the first ones in glassfiber. This made it also easier to clean the filters in between the experiments.

5 Conclusion

The results from this study indicates that both the wedge wire draining blocks and the geotextile filter cloth used in this experiments are inadequate for sludge dewatering at Lake Peri. The backwash water has a very low total solid content and could with great advantage be thickened upon further dewatering or sludge handling. As the sedimentation experiment demonstrated, the backwash water has very poor sedimentable properties, which makes sedimentation unsuitable. In terms of forming flocs, the best result was obtained at a PAC dosage of 12,5 mg /L in combination with a polymer dosage at 2 mg/L. Since the difference were only 5 % from the dosage of 1 mg/L and 2 mg/L, a combined dosage of 12,5 mg /L PAC and 1 mg/L cationic polymer were determined as the optimum dosage due to a good treatment efficiency, economical aspects and draining time.

The flocs that were created were observed to be very fragile, showing destruction of flocs just by introducing a little movement in the water. This, as well as buoyant properties of the flocs makes sedimentation with coagulant inadvisable. The author envisages that flotation may be a better solution for solid separation, as a part of the flocs already tend to float naturally.

For solid capture and treatment efficiency for unthicken backwash water from Lake Peri WTP, the wedge wire pilot demonstrated an average SS removal of 21%, while the filter cloth demonstrated a 76 % removal. In terms of meeting the Brazilian and the local state legislation for effluent release both pilots demonstrated insufficient removal of both BOD_5 and settleable matter. Due to the legislation a BOD_5 removal of 60% should be met as well as a settleable solid content should be lower than 1 mL/L. For BOD_5 removal the wedge wire pilot demonstrated a removal of 20 % while the filter cloth demonstrated a removal of 53% approaching the removal goal of 60%. For settleable solids both pilots showed an increased value compared to the unconditioned backwash water, moving further away from the effluent release legislation. The values were 1,8 m/L and 34 m/L respectively for the wedge water and filter cloth.

The study suggests that the pore openings of the wedge wire blocks are too big for unthickened backwash water from Lake Peri. The results from the filter cloth pilot indicates that also this is inaproriate for the backwash water in lake Peri, both due to the unachieved treatment goals as well as the rapid clogging.

The study also shows that a treatment method that works for one type of sludge may not be appropriate to another type of sludge and is why each treatment plant needs treatment processes that are adapted to their specific water.

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APPENDIX A – Summary from wedge wire experiment at Bara Velha WTP

Introduction

A project was carried out by CASAN at the WTP in Barra Velha to evaluate the wedge wire draining block as a dewatering method. The treatment plant wanted to reduce the production of sludge and were looking at wedge wire. The WTP was operated with a sludge decantation pond where the decanted sludge was pumped to a drying pond, which was the pond they were considering to implement wedge-wire blocks to improve the dewatering.

Materials and methods

The sludge from the settling pond of ETA Barra Velha was collected with the aid of a 1000 L reservoir. A sample of this material was collected for analysis of total solids. It was developed a wedge wire drainage bed pilot in the dimensions of 30 x 30 cm, to simulate a bed that would be implanted in the ETA. The maximum capacity of this bed, due to the height, is 20 liters.

The solutions of cationic, nonionic and anionic polymer, all the concentration of 2g / L, were prepared. A test jar was tested for flake formation, however, due to the large amount of solids in the slurry, the mixing gradient of the equipment was not sufficient. A inversion methodology was them implemented between two beckeres, simulating a vigorous mixture.

Results

The results obtained with the test of the different polymers are described in table 1:

Table 11: Results from polymer tests in Barra Velha WTP

Polymer	Dosage (ppm)	Result in flocculation	Stability of the flocs
Cationic	5-90	Very good from 80ppm	Very stable, even after inversion test
Non-ionic	5-90	Good from 80 ppm	Unstable flakes after inversion test
Anionic	5-90	Bad in all dosages	Not performed due to lack of flocculation

It was found that the cationic polymer at the 80 ppm dosage was very efficient in flocculating and maintaining the flakes, allowing the sludge to be drained.

After the initial tests were done, the pilot-scale analyzes were performed. 10 liters of slurry was taken and 80 ppm of cationic polymer was added. The quick mixing was done with the aid of another bucket. After formation of large and stable flakes, the contents of the bucket were added to the pilot drainage bed with the aid of a 1000 ml Becker. The sequence of pictures (figure 27) shows the behavior of the sludge in the bed over time.

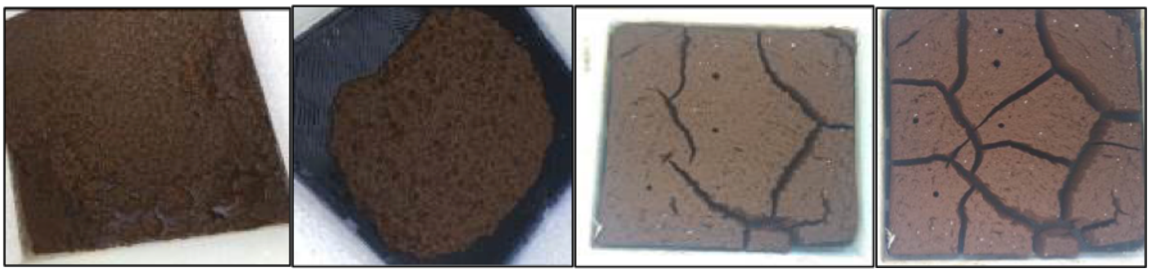


Figure 37: Pictures from pilot experiment in Barra Velha WTP. Picture to the left shows the pilot after application of 10 L sludge. Picture 2 demonstrates the sludge mass after 10 min. Picture 3 shows the pilot 72 hours after sludge application and picture 4 shows the pilot after one week.

The pilot was kept in the shade without any influence of wind to simulate worst drying conditions.

Results from total solid analysis is presented in table 13:

Table 12: total solids from the pilot experiment in Barra Velha

Sample	Total solids (mg/L)
Raw sludge	9113
Sludge after 10 min in the pilot	22760
Drained water from the pilot	309

It can be seen that 60% of the water present in the initial sludge sample is separated immediately (10 minutes initial). The rest would be evaporated by the action of the sun / wind.

Conclusion

The drainage bed technology for the sludge drainage of the ETA Barra Velha proved to be efficient in the tests using the pilot described in this report. Based on the amount of sludge present in ETA, the system should be designed for rapid mixing of the polymer and bed area.

APPENDIX B – Data from the experiments determing coagulant dose

B1 Coagulation with PAC

Quality of untreated backwash water:	Turbidity: 259 NTU
	Temperature: 15,2 °C
	pH: 7,4

Table 13: Data from turbidity of drainage from wedge-wire after coagulation with PAC

PAC (mg/L)	Turbidity TEST 1	Turbidity TEST 2	Turbidity TEST 3	Average turb.(NTU)	Std. Avation	% removal
0	247	263	260	257	8,5	**0,9**
10	246	159	265	256	13,4	**1,4**
15	244	248	257	250	6,7	**3,6**
20	245	253	249	249	4,0	**3,9**
25	253	245	239	246	7,0	**5,1**
30	248	244	240	244	4,0	**5,8**
35	263	238	254	252	12,7	**2,8**

Table 14: Data from turbidity of drainage from filter cloth after coagulation with PAC

PAC (mg/L)	Turbidity TEST 1	Turbidity TEST 2	Turbidity TEST 3	Average turb. (NTU)	Std. Avation	% removal
0	218	216	210	215	4,2	**17,1**
10	149	186	183	173	20,6	**33,3**
15	107	129	107	114	12,7	**55,9**
20	92	69	85	82	11,8	**68,3**
25	69	100	77	82	16,1	**68,3**
30	50	72	90	71	20,0	**72,7**
35	84	74	93	84	9,5	**67,7**

B2 Coagulation with varying PAC and fixed cationic polymer

Quality of untreated backwash water:	Turbidity: 270 NTU
	Temperature: 15,0 °C
	pH: 7,4

Table 15: Data from turbidity of drainage from filter cloth after coagulation with PAC and 1mg/L cationic polymer

Cat. Polym.	PAC (mg/L)	Turbid. TEST 1	Turbid. TEST 2	Turbid. TEST 3	Turbid. TEST 4	Turbid. TEST 5	Average (NTU)	Std. Avation	% removal
0	0	247	247	243	243		245	2,3	5,4
1	2,5	234	226				230	5,7	11,2
1	5	236	231				234	3,5	9,8
1	7,5	264	247				256	12,0	1,4
1	10	151	164	162	132	141	150	13,7	42,1
1	12,5	128	162				145	24,0	44,0
1	15	191	214	179	211	182	195	16,3	24,6
1	20	173	220	169			187	28,4	27,7
1	25	216	221	183			207	20,6	20,2
1	30	200	215	204			206	7,8	20,3
1	35	239	239	241			240	1,2	7,5

Quality of untreated backwash water: Turbidity: 265 NTU
Temperature: 15,3 °C
pH: 7,2

Table 16: Data from turbidity of drainage from filter cloth after coagulation with PAC and 1 mg/L cationic polymer

Cat. Polym.	PAC (mg/L)	Turbid. TEST 1	Turbid. TEST 2	Turbid. TEST 3	Turbid. TEST 4	Turbid. TEST 5	Average (NTU)	Std. Avation	% removal
0	0	209	173	147	192		180	31,1	30,4
1	2,5				114	111	113	2,1	56,6
1	5				87	60	74	19,1	71,6
1	7,5				46	26	36	14,1	86,1
1	10	36	23	36	17	24	27	8,5	89,5
1	12,5				17	26	22	6,4	91,7
1	15	38	36	34	24	25	31	6,5	87,9
1	20	40	40	43			41	1,7	84,2
1	25	42	44	75			54	18,5	79,3
1	30	64	64	48			59	9,2	77,3
1	35	75	75	54			68	12,1	73,7

B3 Coagulation with fixed PAC dose and varying cationic polymer

Quality of untreated backwash water:	Turbidity: 261 NTU
	Temperature: 15,3 °C
	pH: 7,2

Table 17: Turbidity in drained water from WW-pilot for tests with varying polymer dose and 12,5 mg/L PAC

Polymer (mg/L)	PAC (mg/L)	Turbid. TEST 1	Turbid. TEST 2	Average turb. (NTU)	Std. Avation	% removal
0,00	0	204	233	219	20,5	15,6
0,50	12,5	203	194	199	6,4	23,4
0,75	12,5	197	184	191	9,2	26,4
1,00	12,5	155	171	163	11,3	37,1
1,50	12,5	146	169	158	16,3	39,2
2,00	12,5	142	158	150	11,3	42,1
2,50	12,5	200	154	177	32,5	31,7

Table 18: Turbidity in drained water from FC-pilot for tests with varying polymer dose and 12,5 mg/L PAC

Polym. (mg/L)	PAC (mg/L)	Turbid. TEST 1	Turbid. TEST 2	Average (NTU)	Std. Avation	% removal
0,00	0	161	119	140	29,7	45,9
0,50	12,5	22	23	23	0,7	91,3
0,75	12,5	22	25	24	2,1	90,9
1,00	12,5	12	29	21	12,0	92,1
1,50	12,5	20	25	23	3,5	91,3
2,00	12,5	18	27	23	6,4	91,3
2,50	12,5	20	29	25	6,4	90,5

APPENDIX C – Data from sedimentation tests

Table 19: Turbidity in supernatant in sedimentation test of raw backwash water

Time (min)	Time (h)	Turbidity TEST 1	Turbidity TEST 2	Turbidity TEST 3	Average	Std. Aviation
0	0	269	184	187	213,3	48,2
30	0,5	265	181	172	206,0	51,3
60	1	262	182	168	204,0	50,7
90	1,5	234	154	143	177,0	49,7
120	2	223	154	146	174,3	42,3
150	2,5	220	143	136	166,3	46,6
180	3	223	138	138	166,3	49,1
210	3,5	212	140	131	161,0	44,4

Table 20: Turbidity in supernatant in sedimentation test of coonditioned backwash water

Time (min)	Turbidity TEST 1	Turbidity TEST 2	Turbidity TEST 3	Average	Std. Aviation
0	93	180	182	152	50,8
5	28	27	26	27	1,0
10	21	24	28	24	3,5
15	21	28	28	26	4,0
20	22	22	27	24	2,9
25	23	24	27	25	2,1
30	23	24	31	26	4,4
90		24	29	27	3,5
180		26	33	30	4,9

APPENDIX D – Data from pilot experiment

D1 Turbidity in drainage

Table 21: Turbidity in drained water from wedge wire pilot

Drained volume (L)	Turbidity in drained water (NTU)	% removal	Polymer (mg/L)	PAC (mg/L)	Turbidity backwash water
1	178	21,2	0	0	226
2	159	29,7	1	12,5	226
3	202	10,6	1	12,5	226
4	158	30,1	1	12,5	226
5	159	29,7	1	12,5	226
6	151	33,2	1	12,5	226
7	89	60,6	1	12,5	226
8	80	64,6	1	12,5	226
9	95	58,0	1	12,5	226
10	88	61,1	1	12,5	226
11	112	50,4	1	12,5	226
~~12~~	~~383~~	~~-69,5~~	~~1~~	~~12,5~~	~~226~~
13	90	37,1	1	12,5	143
14	108	24,5	1	12,5	143
15	61	57,3	1	12,5	143
16	88	38,5	1	12,5	143
17	45	68,5	1	12,5	143
18	73	48,9	1	12,5	143
24	132	7,7	1	12,5	143
30	107	25,2	1	12,5	143
36	79	44,8	1	12,5	143
42	53	62,9	1	12,5	143
48	105	26,6	1	12,5	143
54	72	49,7	1	12,5	143
60	67	53,2	1	12,5	143
AVERAGE:	**106,3**	**41,4**			

Table 22: Turbidity in drained water from filter cloth pilot

Drained volume (L)	Turbidity (NTU)	% removal	Polymer (mg/L)	PAC (mg/L)	pH	temp	turbidity backwash water
1	57	75	0	0	6,16	18	226
2	72	68	1	12,5	6,16	18	226
3	73	68	1	12,5	6,16	18	226
4	79	65	1	12,5	6,16	18	226
5	61	73	1	12,5	6,16	18	226
6	38	83	1	12,5	6,16	18	226
7	36	84	1	12,5	6,16	18	226
8	34	85	1	12,5	6,16	18	226
9	25	89	1	12,5	6,16	18	226
10	25	89	1	12,5	6,16	18	226
11	40	82	1	12,5	6,16	18	226
12	74	67	1	12,5	6,16	18	226
13	37	74	1	12,5	6,16	18	143
14	24	83	1	12,5	6,16	18	143
15	22	85	1	12,5	6,16	18	143
16	18	87	1	12,5	6,16	18	143
17	22	85	1	12,5	6,16	18	143
18	20	86	1	12,5	6,16	18	143
AVERAGE:	**42,1**	**79**	**1**	**12,5**			

D2 Time to drain

Table 23: Data showing the draining time vs drained volume

Volume (L)	Wedge wire Time [hh:mm:ss]	Filter cloth Time [hh:mm:ss]
1	00:00:21	00:01:03
2	00:00:38	00:01:21
3	00:01:00	00:01:42
4	00:01:11	00:02:09
5	00:01:27	00:02:43
6	00:01:44	00:03:15
7	00:02:00	00:04:05
8	00:02:16	00:05:12
9	00:02:33	00:06:43
10	00:02:51	00:09:14
11	00:03:19	00:27:20
12	00:03:54	01:05:36
18	00:06:14	05:23:15
24	00:08:46	
30	00:11:20	
36	00:14:02	
42	00:17:28	
48	00:19:58	
54	00:22:44	
60	00:25:30	
66	00:32:00	
72	00:45:14	
78	00:60:29	

D3 Water quality parameters before and after drainage

Table 24: Caractherization of backwash water, data collected in between April 29th to june 29th.

Parameter	Test 1	Test 2	Test 3	Average	Std. Aviation
Suspended solids (mg/L)	168	246	190	201	40,2
BOD (mg O2/L)	41	38	35	38	3
COD (mgO2/L)	156	240	179	191,7	43,4
Settleable matter (mL/L)	2,5	2,5	0,5	1,8	1,2
total nitrogen (mg/L)	<10	-	-	<10	-
Cyanobacterias (cel/mL)	14808335	13691430	-	14249882,5	789771,1
pH (-)	7,08	8,24	7,3	7,54	0,6
Turbidity (NTU)	226	171	120	172,3	53,0
Temperature (°C)	18	27,5	18,8	21,4	5,3

Table 25: Drained water quality from pilots

Parameter	Back-wash water	Wedge-wire Test 1	Wedge-wire Test 2**	Wedge wire avrg.	Avrg % remov.	Filter cloth Test 1*	Filter cloth Test 2**	Filter cloth avrg.	Avrg. % remov.
Suspended solids (mg/L)	201	222	97	159,5	21	76	21	48,5	75,9
BOD (mg O2/L)	38	25	14	19,5	49	26	10	18	52,6
COD (mgO2/L)	192	203	101	152	21	117	51	84	56,2
Settleable matter (mL/L)	1,8	48	20	34	-1789	1,5	0,1	0,8	55,6
Cyano-bacterias (cel/mL)	14808335	8324235		8324235	43,8	5831190		5831190	60,6
pH (-)	7,5	6,16	6,79	6,475	-	6,2	6,8	6,5	-
Turbidity (NTU)	172	169	75	122	29	65	20	42,5	75
Temperature (°C)	21	18,4	18,9	18,65	-	18,4	18,7	18,6	-

* Test 1 was performed in the first 2 L of drained water from the pilots

** Test 2 were performed in the 60th L of drainage in the Wedge wire pilot and in the 18th L of drainage in the filter cloth

D4 Pictures from the experiment

Figure 38: Pictures showing backwashing of filters, and collected backwash water

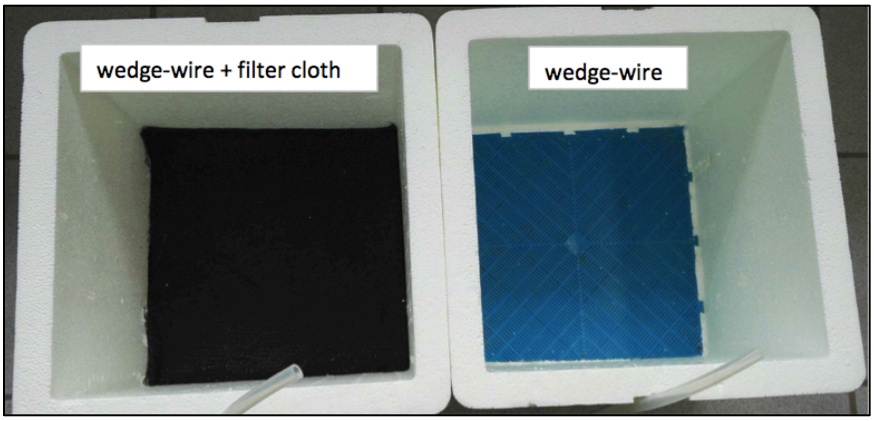


Figure 39: Picture of the pilots

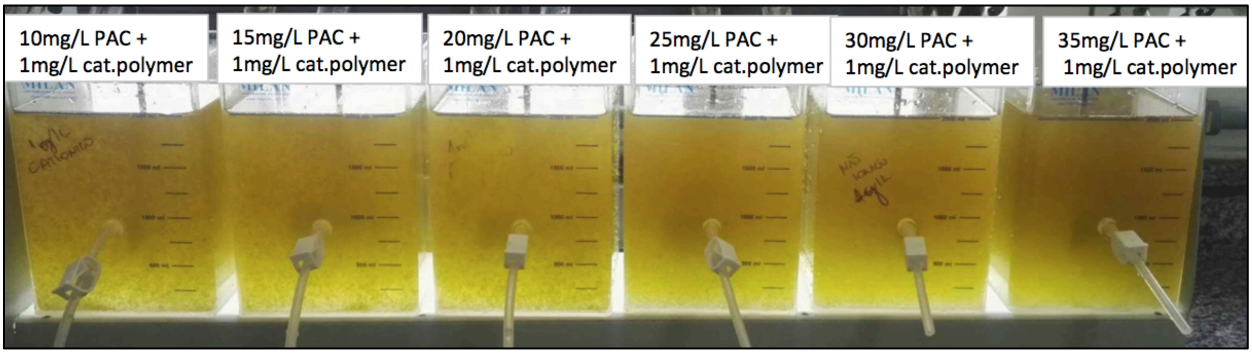


Figure 40: Picture demonstration the floc formation after addition of different dosages of PAC together with 1 mg/L polymer

Figure 41: Pictures demonstrating the sludge accumulation on the filter cloth

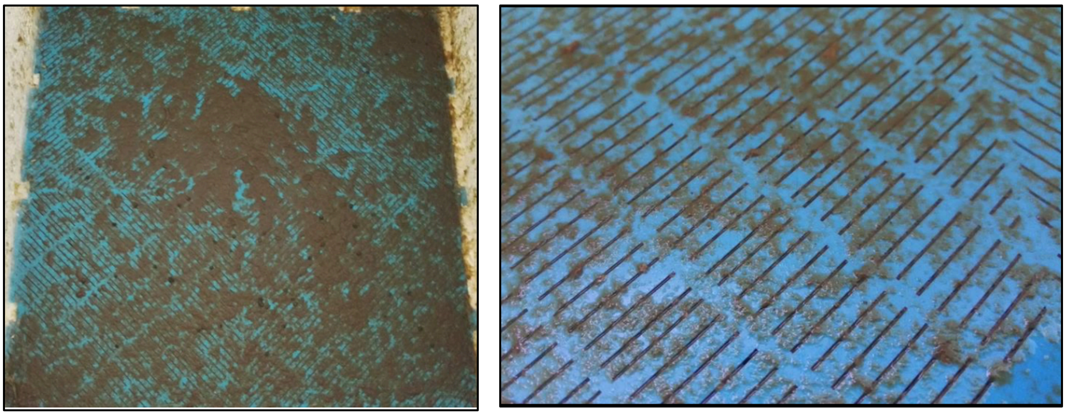


Figure 42: Pictures demonstrating the sludge accumulation on the wedge wire

APPENDIX E – Data from the unsuccessful experiment

E1 Detailed data from experiments

Table 26: water quality parameters from 1st experiment.

Parameter	backwash water	wedge-wire	% removal	sand drying bed	% removal
pH (-)	6,71	5,79	-	3,14	-
turbidity (NTU)	134	28*	79,1	16	88,1
temperature(°C)	27,5	27,5	-	27,5	-
total suspended solids (mg/L)	168	41*	75,6	15	91,1
total suspended solids (mg/L)	41	10*	75,6	19	53,7
COD (mgO2/L)	156	18*	88,5	29	81,4
sedimentable solids (mL/L	2,5	7	-180	0,1	96

*The results from the wedge wire pilot could show a value that indicates a better treatment efficiency than reality because the valvue was closed until a certain ammount of water had passed the drainage block. This resulted in a certain time for the sediments to settle in the bottom of the pilot and not appear in the drainage water as the valvue for collecting drainage was placed 5 cm deom the bottom of the pilot. When cleaning the pilot after use a large amount of solids could be observed, confirming this concern.

Table 27: backwash water parameters from following experiments

Parameter	TEST 1 11.05.18	TEST 2 23.05.18	TEST 3 06.06.18	Average
pH (-)	8,24	7,34	7,24	7,6
turbidity (NTU)	171	120	263	184,7
temperature(°C)	27,5	18,8	22,2	22,8

Table 28: Wedge wire drainage parameters from following experiments

Parameter	TEST 1 11.05.18	TEST 2 23.05.18	TEST 3 06.06.18	Average	Avrg. % removal
pH (-)	6,38	6,24	6,1	6,2	-
turbidity (NTU)	78	82	169	109,7	40,6
temperature(°C)	25	19,9	22	22,3	-

Table 29: Sand drying bed drainage parameters from following experiments

Parameter	TEST 1 11.05.18	TEST 2 23.05.18	TEST 3 06.06.18	Average	Avrg. % removal
pH (-)	3,45	2,64	2,65	2,9	
turbidity (NTU)	3,08	3,84	4,46	3,8	97,9
temperature(°C)	24	17,8	20,5	20,8	

E2 Figure and pictures

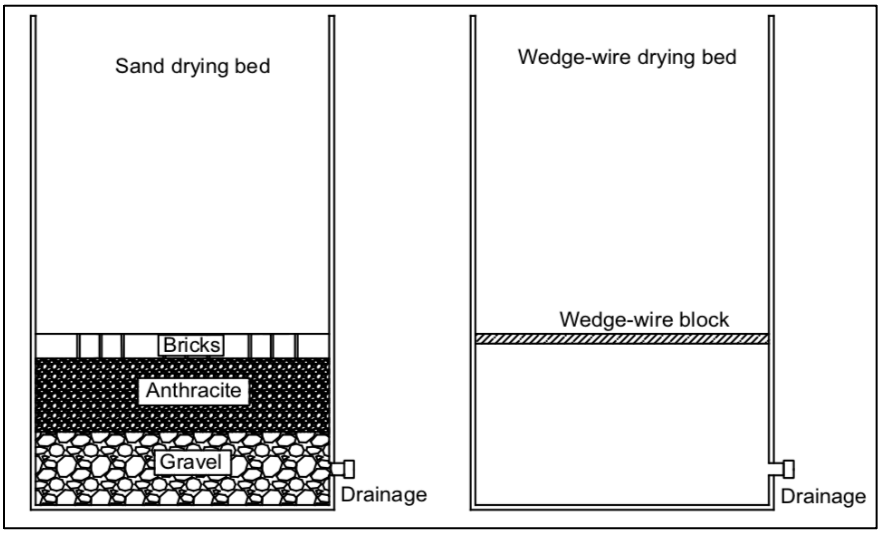


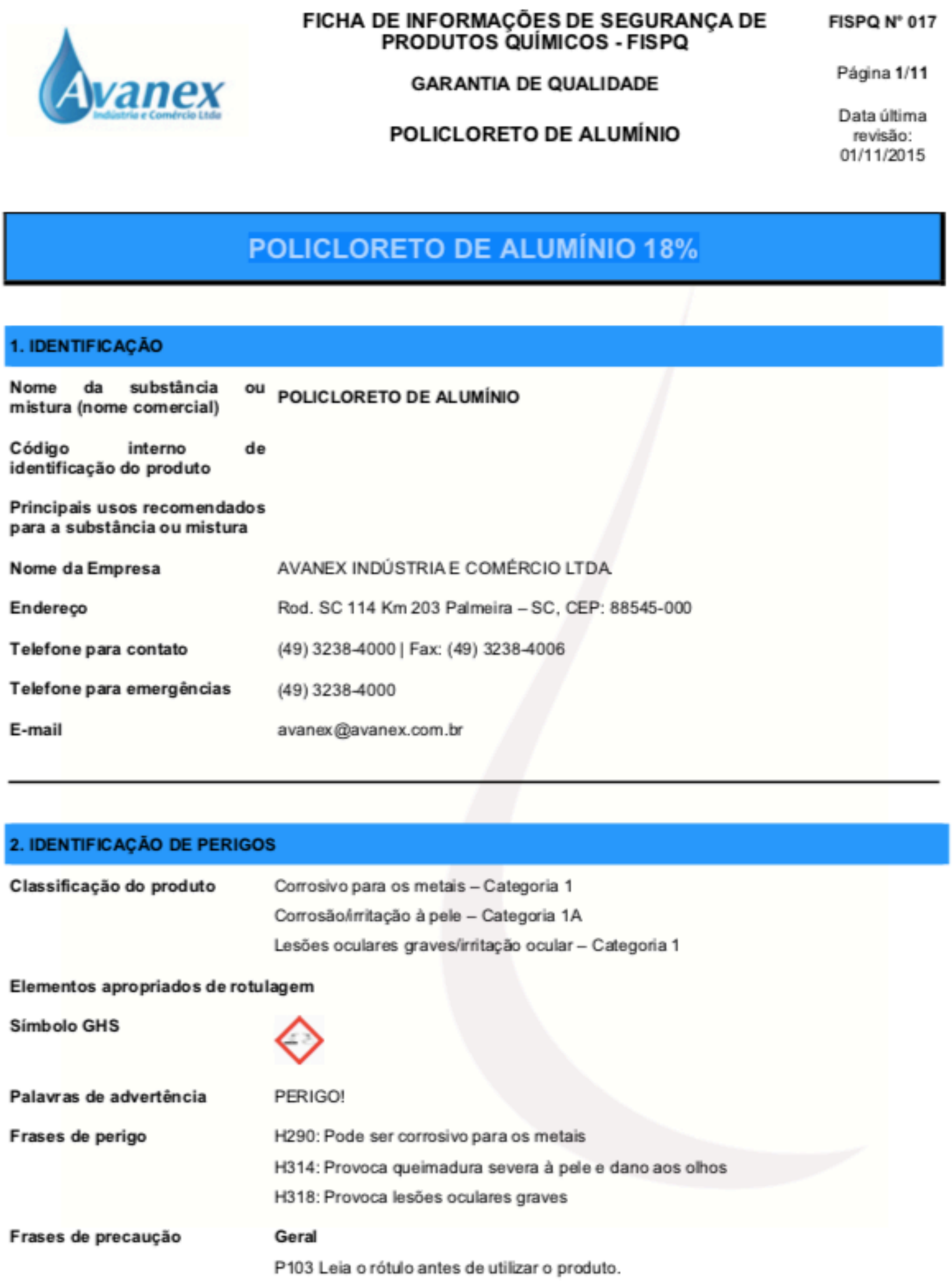
Figure 43: Section drawing for the composition of the first pilots

Figure 44: Picture taken looking down at the pilots

Figure 45: Pictures showing drainage from the pilots and mixing conditions for the conditioner

APPENDIX F – Chemical datasheets

F1 PAC



FICHA DE INFORMAÇÕES DE SEGURANÇA DE PRODUTOS QUÍMICOS - FISPQ

GARANTIA DE QUALIDADE

POLICLORETO DE ALUMÍNIO

FISPQ N° 017

Página **1/11**

Data última revisão: 01/11/2015

POLICLORETO DE ALUMÍNIO 18%

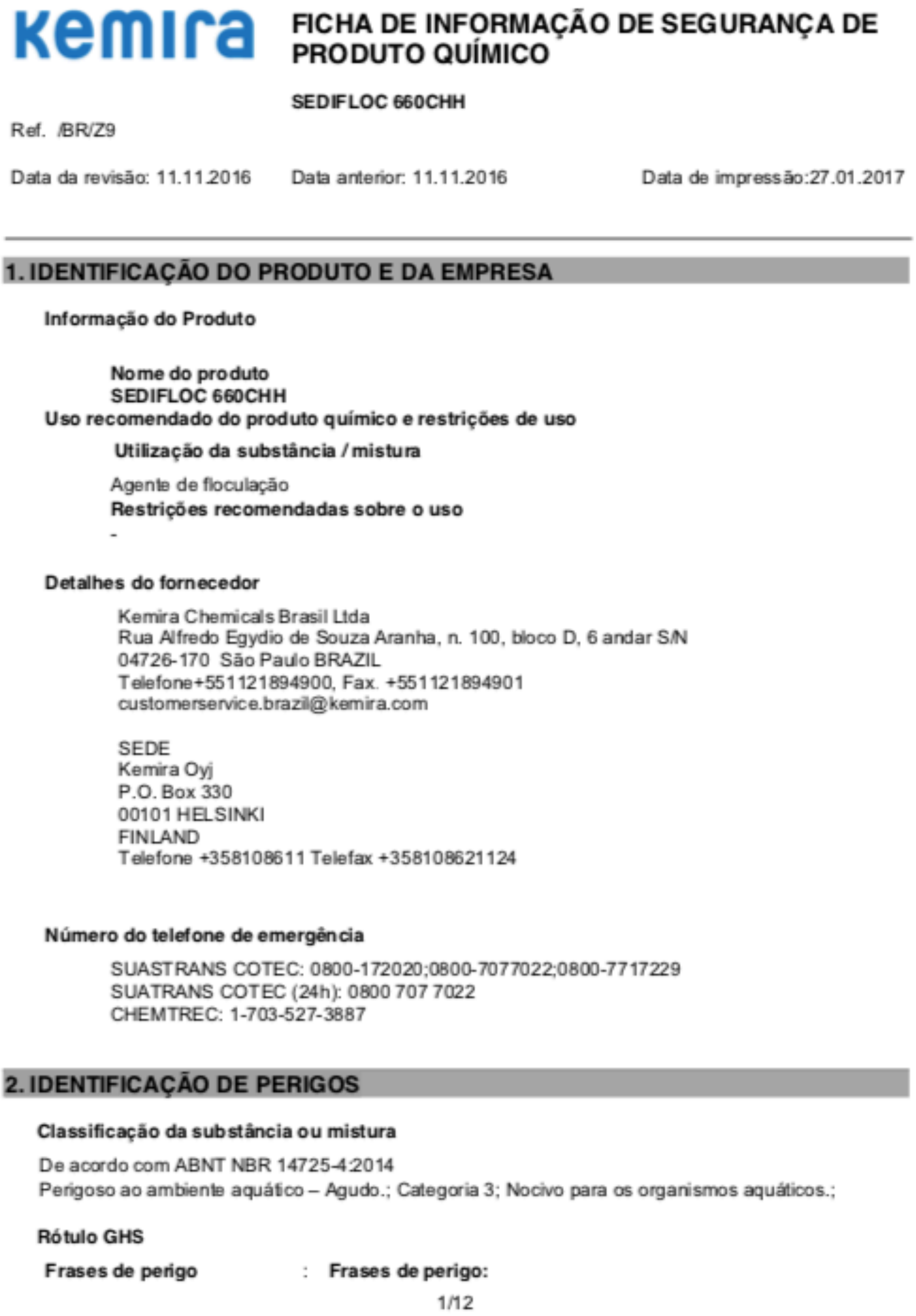
1. IDENTIFICAÇÃO

Nome da substância ou mistura (nome comercial)	**POLICLORETO DE ALUMÍNIO**
Código interno de identificação do produto	
Principais usos recomendados para a substância ou mistura	
Nome da Empresa	AVANEX INDÚSTRIA E COMÉRCIO LTDA
Endereço	Rod. SC 114 Km 203 Palmeira – SC, CEP: 88545-000
Telefone para contato	(49) 3238-4000 | Fax: (49) 3238-4006
Telefone para emergências	(49) 3238-4000
E-mail	avanex@avanex.com.br

2. IDENTIFICAÇÃO DE PERIGOS

Classificação do produto	Corrosivo para os metais – Categoria 1 Corrosão/irritação à pele – Categoria 1A Lesões oculares graves/irritação ocular – Categoria 1
Elementos apropriados de rotulagem	
Símbolo GHS	
Palavras de advertência	PERIGO!
Frases de perigo	H290: Pode ser corrosivo para os metais H314: Provoca queimadura severa à pele e dano aos olhos H318: Provoca lesões oculares graves
Frases de precaução	**Geral** P103 Leia o rótulo antes de utilizar o produto.

F2 Cationic polymer



FICHA DE INFORMAÇÃO DE SEGURANÇA DE PRODUTO QUÍMICO

SEDIFLOC 660CHH

Ref. /BR/Z9

Data da revisão: 11.11.2016 Data anterior: 11.11.2016 Data de impressão:27.01.2017

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1. IDENTIFICAÇÃO DO PRODUTO E DA EMPRESA

Informação do Produto

Nome do produto
SEDIFLOC 660CHH

Uso recomendado do produto químico e restrições de uso

Utilização da substância / mistura

Agente de floculação

Restrições recomendadas sobre o uso

-

Detalhes do fornecedor

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Telefone +358108611 Telefax +358108621124

Número do telefone de emergência

SUASTRANS COTEC: 0800-172020;0800-7077022;0800-7717229
SUATRANS COTEC (24h): 0800 707 7022
CHEMTREC: 1-703-527-3887

2. IDENTIFICAÇÃO DE PERIGOS

Classificação da substância ou mistura

De acordo com ABNT NBR 14725-4:2014
Perigoso ao ambiente aquático – Agudo.; Categoria 3; Nocivo para os organismos aquáticos.;

Rótulo GHS

Frases de perigo : **Frases de perigo:**