AN INVESTIGATION ON SEPARATION EFFECTS OF DISCFILTER AS PRE-TREATMENT AT VOMBVERKET, SWEDEN.

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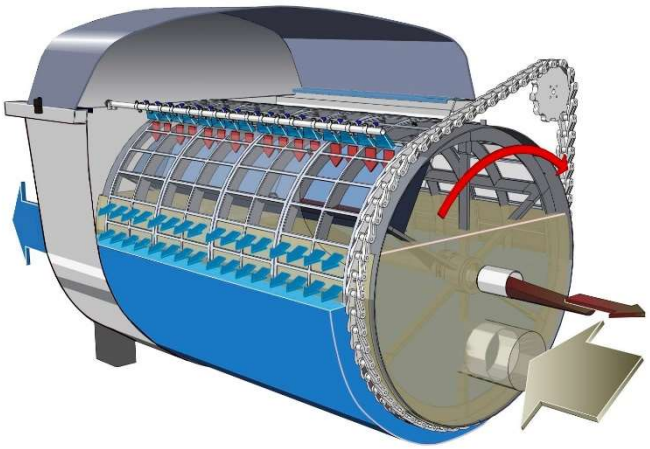

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Abstract

Sydvatten AB is a Swedish company providing drinking water for more than 500 000 inhabitants in Skåne. Raw water come from two lakes: Bolmen and Vombjön. In the second one, this study location, first step is to filter water to avoid a too quick clogging in next artificial sand ponds. At present, the Vombjön drinking water plant applies four units of drum filters with 500 µm pores size as pre-treatment. Filters become old and their efficiency is limitated. In addition, these filters allow cyanobacteria to pass through which can be a problem for the next treatment water steps. To ovoid this, Sydvatten plans to change these old drum filters by a more recent technology: disc filters using 30 µm pores size. A pilot was set up in 2015. The aim of this study was to measure and quantify the different efficiency between these two types of filters during a summer period (June until August 2016). Results showed that disc filter is more efficient than drum filter. In average, disc filters can remove 59% of cyanobacteria biomass against 32% for drum filter. Results are similar for turbidity and volatile suspended solids: respectively 42% against 24% and 66% against 53%.

In addition, the results of this study also provided a basis to set up a monitoring system for cyanobacteria blooming, specially using chlorophyll-a monitoring method.

Résumé

Sydvatten AB est une entreprise suédoise qui fournit de l'eau potable à plus de 500 000 habitants en Skåne. L'eau brute provient de deux lacs : Bolmen et Vombjön. L'étude se déroule au niveau du lac Vombjon. La première étape du traitement de l'eau est sa filtration afin d'éviter un colmatage trop rapide des étangs à sable artificiels utilisés dans la suite du traitement. Jusqu'à aujourd'hui, quatre unités de filtres à tambour possédant des mailles de 500 µm sont utilisées. Ces filtres deviennent âgés et leur efficacité devient limitée. Ils laissent passer les cyanobactéries qui sont difficiles à retirer et qui peuvent devenir un danger pour la santé du consommateur. Pour éviter cela, Sydvatten pense à changer ces filtres par une technologie plus récente : des filtres à disques avec des pores de 30 µm. Un pilote a été mis en place en 2015. Le but de cette étude était de mesurer et quantifier la différence d'efficacité entre ces deux filtres afin de poser les premières bases nécessaires pour un déploiement à grande échelle. Les mesures ont été effectuées durant la période estivale de juin à août 2016. Les résultats montrent que les filtres à disques sont plus performants : en moyenne les filtres à disques abattent 59% de la biomasse en cyanobactérie contre 32% pour les filtres à tambour. Il en est de même pour la turbidité et les matières volatiles en suspension : respectivement 42% contre 24% et 66% contre 53%.

De plus, les résultats de cette étude fournissent une base pour mettre en place un système de suivi de la problématique des blooms algaux avec notamment le suivi de la chlorophylle-a.

Aknowledgements

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Introduction

Vombjön is a fresh water reservoir used by Sydvatten which is the biggest water supply company in south Sweden providing drinking water for 500 000 inhabitants. Due to nutrient rich runoffs from agricultural land dominating the catchment area of Vombjön and decentralized sewage system runoffs from individual households, the lake receives high levels of phosphorus causing eutrophication in the lake. The eutrophication leads to substantial algal bloom with consequence of high risk of harmful algal production. Harmful algal toxins are risky for both human and animal's health. They can produce several types of toxins, like microcystins which has been shown to be one of the most harmful ones and less than 1 µg/L suggested by WHO for drinking water supply as guideline value. Microcystins are frequently present in eutrophic lakes while unwelcomed to be in fresh water reservoir like Vombsjön for drinking water supply. The treatment process is original: before conventional treatment, raw water is pumping from lake and spread on several ponds. This allows to create artificial water using sand under ponds. With this, microorganisms leaving in the sand can catch some particles and pollutants, decreasing as well chemicals using.

Today there is not much information about presence of microcystins in Lake Vombjön and meanwhile there are not special barriers for cyanobacteria.

Furthermore, due to climate change, the weather is expected to be warmer and the presence of algae toxins is expected to increase in the future (Seckbach J, 2007).

In addition more total suspended solids in the ponds increase the clogging frequency. Some types of algae are growing and clog the sand in the artificial ponds. This causes to change and clean the ponds more often. A set of drum filters with 500 µm pores was set up between the raw water lake and ponds 40 years ago. Its goal was to reduce the organic load received from ponds to keep sand cleaner longer. Drum filters were initially set up with 30 µm cloth but water flow capacity and maintenance were not enough. Between 1975 and 1982, the cloth was changed by a 500 µm.

Today Expected results from 500 µm drum filters are not achieved and Sydvatten plans to change drum filter by disc filter. Those are equipped with 30 µm pores size and was expected to be more efficient.

To test this new process, a prototype was set up in parallel in 2015 with drum filter to compare the efficient between these two types of filters.

Main goal of this study is to test new disc filter to investigate separation effect on solids particles, cyanobacteria and toxins comparing to the old drum filters. Analysis results were provided to support Sydvatten for decision making whether they will deploy entirely this technology.

I Context and literature review

A Location and water treatment process

1) Sydvatten and Vomb Lake

This project is requested by Sydvaten AB. Sydvaten AB is a municipally owned company producing drinking water for 900,000 inhabitants in the region of Skåne (South Sweden). The company was founded in 1966 and is today one of Sweden's largest producers of drinking water. Sydvatten supplies drinking water to 16 municipalities in Skåne. Sydvatten is managed by a board compound of representatives of the 16 municipalities.

Sydvaten use raw water from Vomb Lake and Lake Bolmen, respectively around 1000 and 1400 l/s.

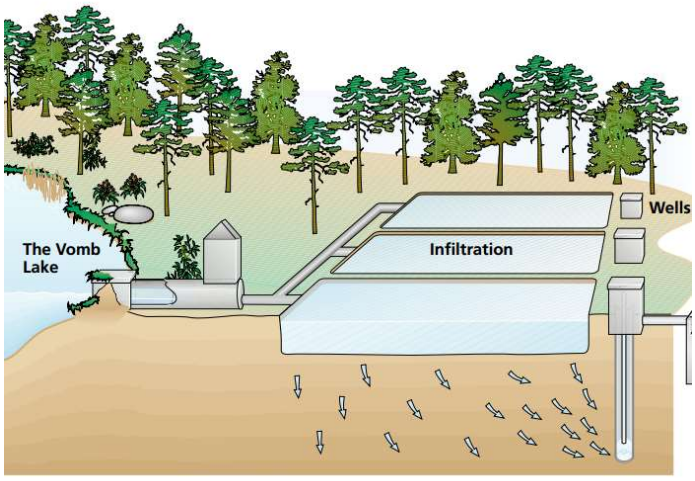
This study will focus on Lake Vomb. Next figure located the Lake Vomb.

Lake Vomb is located in south Sweden. It is 14,4 km long and has an 12 square meter area.

Figure 1 : Vomb Lake location

2) Water treatment process

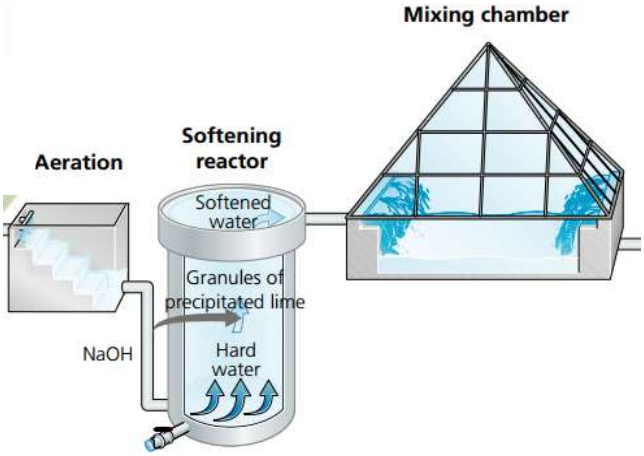
To understand context of study, it can be useful to know how the water treatment plant works. Figure 2 summarizes the process.



1) First of all raw water is pumped from lake and goes to the sieving station. The main goal at this sieving station is to remove particles from water like sand and algae. This is possible using two technology filters: drum filters with 500 um pores and disc filter 30 um pores.

The water is then channelled up to 58 artificial ponds for a total surface area of 400,000 square metres. Water seeps slowly through the alluvium of gravel and sand to a natural groundwater storage level. This process is called artificial groundwater infiltration.

After two to three months, the water is pumped up from one of the 114 wells and into the Vomb Water Works for final processing.



2) The water is aerated to remove iron and manganese and then treated in the softening reactors to remove calcium ions, by adding sodium hydroxide. The calcium ions in the hard water are precipitated as lime on grains of sand and soft water is released at the top of the reactor. The grains of sand containing precipitated lime, sink to the bottom of the reactor, and are then removed.

3) After the softening reactors, the water is combined in the mixing chamber with a minor dosage of ferrous chloride, to bind the remaining lime crystals together in flocks. These are then removed in the next stage using rapid sand filters.

Figure 2: Water treatment process :

Before the drinking water is pumped out to the pipe network, chlorine is added to the water to prevent micro bacterial activities in the pipe network.

B Problematics in Vomb

1) Clogging pond sand

This study is focused at the sieving station. This process is the first link in the chain. Sieving station has to remove the most part of sand and algae to avoid clogging in next artificial sand ponds. With this, pressure loss can be slow down and the sand pond can be used longer.

Figure 3: Artificial sand ponds, Google Earth

Today, drum filters are used. They are able to catch particles above 500 µm but results of filtration are not very satisfactory. Most algae or bacteria cells can go through filter and growing in next ponds. Some algae proliferations are observed which blocked sand in ponds forcing to change it more often. In addition, when sand ponds have just been changed, water seeps too quickly, decreasing efficiency of these artificial ponds. Gradually with clogging, water takes too much time to go through sand, allowing algae and cyanobacteria proliferation. Figure 3 shows algae proliferations problems in some ponds. To avoid this, Sydvatten sets up a new filter technology: disc filter. This filter has 30 um pores. Compare to drum filter 500 µm, it should be more efficient.

2) Cyanobacteria

Figure 5: Cyanobacterial scum in an artificial pond at Vomb water work (photo Cronberg)

Adding the clog of ponds problem, Sydvatten want to decrease algae and cyanobacteria concentration to protect raw water. Indeed, between 1994-2002 some cyanobacteria blooms were observed in Lake Vomb (figure 5) (Cromber, Annadotter; 2006). Cyanobacteria can be a problem due to cyanotoxins productions. Cyanotoxins are highly diversified but the most widespread is peptide toxins in the class called microcystins, structure view is presented with figure 4. There are at least 80 known microcystins, including Microcystin-LR, which is generally considered one of the most toxic (World Health Organization, 2003). Most of the drinking water guidelines are based on the World Health Organization provisional value for drinking waters of 1.0 µg/L microcystin-LR (World Health Organization, 2011).

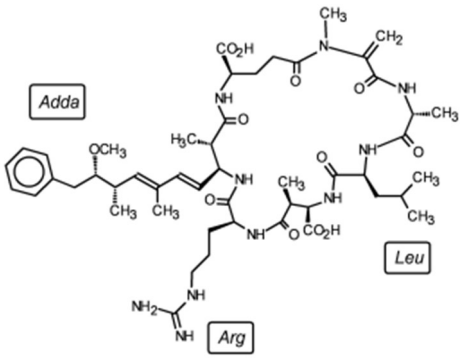


Figure 4: Microcystin-LR structure

Cyanobacterial blooms can be harmful to human health. In 1994, gastroenteritis befell 121 persons in three South Swedish villages. The illness took place simultaneous with a contamination of the municipal drinking water with polluted water from the River Kävlingean, the outlet of the eutrophic lake Vombjön. The content of toxic cyanobacteria (1µg/L of microcysitins), the fact that some persons fell ill from having consumed only boiled, drinking water, indicated that outbreak was caused by cyanotoxin. (Annadotter et al, 2001).

In addition, blooms decay consumes oxygen, creating hypoxic conditions which result in plant and animal die-off. Figure 6 shows some dead fishes on Lake Vomb, which happens every summer. Under favourable conditions of light and nutrients, some species of cyanobacteria produce toxic secondary metabolites, known as cyanotoxins. The conditions that cause cyanobacteria to produce cyanotoxins are not well understood. Some species with the ability to produce toxins may not produce them under all conditions (Srivastava A-K, Rai A-N, Neilan B, 2013).Both nontoxic and toxic varieties of most of the common toxin-producing cyanobacteria exist, and it is impossible to tell if a species is toxic or not toxic. In addition, even when toxin producing cyanobacteria are present, they may not actually produce toxins. According some studies, cyanotoxins can be release under stress and unfavourable condition (Djanette Khiari, Water Research Foundation, 2016). In most cases, the cyanobacterial toxins naturally exist intracellularly (in the cytoplasm) and are retained within the cell. When the cell dies or the cell membrane ruptures the toxins are released into the water (extracellular toxins). It is not easy to remove cyanotoxin from water. The easiest way is to remove cyanobacteria before releasing cyanotoxin. Some processes exist and are summarized in next Table 1 (Environmental Protection Agency United States, 2014).

Figure 6 : Dead fishes on Vomb lake beach, Photo: Martina Greiffe

Table 1 : Treatment processes against intracellular cyanotoxins

Treatment Process	Relative Effectiveness
Pre-treatment oxidation	Oxidation often lyses cyanobacteria cells releasing the cyanotoxin to the water column. If oxidation is required to water treatment, consider using lower doses of an oxidant less likely to lyse cells. If oxidation at higher doses must be used, sufficiently high doses should be used to not only lyse cells but also destroy total toxins present
Coagulation/ Sedimentation/ Filtration	Effective for the removal of intracellular toxins when cells accumulated in sludge or discharge water are isolated from the water plant and not reuse to supply water after sludge separation.
Membranes	Study data are limited; it is assumed that membranes would be effective for removal of intracellular cyanotoxins. Microfiltration and ultrafiltration are effective when cells are not allowed to accumulate on membranes for long periods of time
Flotation	Flotation processes, such as Dissolved Air Flotation (DAF), are effective for removal of intracellular cyanotoxins since many of the toxin-forming cyanobacteria are floatable.

Some treatment process are effective to remove intracellular toxin. At Vomb water plant, filtration was chosen. It is appear that a 500 µm pores is not enough to remove cynaobacteria. New disc filter process with 30 µm pores can be remove cyanobacteria. Size of cyanobacteria cells are around 0,5 -10 µm depending species but most of them live in colony. Up to 1 meter filaments can be observed. (Camacho F., Bongiovani M., Arakawa F.S. et al, 2013).

For unfilament colony, some of them can reach 200 µm diameter like microcystis (Yamamoto Y., SHIAH F-k, 2010). Next table shows different processes to remove toxin after release in water.

Table 2 : Treatment process against extra-cellular cyanotoxins

Treatment Process	Relative Effectiveness
Membranes	Depends on membrane pores size distribution and water quality. Nanofiltration is generally effective in removing extracellular microcystin. Reverse osmosis filtration is generally applicable for removal of extracellular microcystin and cylindrospermopsin. Cell lysis is highly likely.
Potassium Permanganate	Effective for oxidizing microcystins and anatoxins.
Ozone	Very effective for oxidizing extracellular microcystin, anatoxin-a, and cylindrospermopsin.
Chloramine	Not effective.
Chlorination	Effective for oxidizing extracellular cyanotoxins as long as the pH is below 8; ineffective for anatoxin-a
UV radiation	Effective at degrading microcystin and cylindrospermopsin but at impractically high doses.
Activated Charbon	Powdered activated carbon (PAC): Effectiveness varies highly based on type of carbon and pores size. Wood-based activated carbons are generally the most effective at microcystin adsorption. Carbon is not as effective at adsorbing saxitoxin or taste and odor compounds. Doses in excess of 20mg/L may be needed for complete toxin removal. Granular activated carbon (GAC): Effective for microcystin but less effective for anatoxin-a and cylindrospermopsins.

The only way to remove extracellular cyanotoxin is to use ozone which is a strong oxidizing. There is not ozone treatment at Vomb water plant. To decrease chemicals using, Sydvatten prefers to remove cyanobacteria from raw water in sieving station and in artificial groundwater.

c) Comparison of drum and disc filters

Technology

Drum filter is an approved technology. Water gets through filter like showing on figure 7. The filter cloth is stretched around a drum. This drum turns around an axe and is cleaned up with water nozzles. Sludge water is extracted with a specific gutter. To avoid spoiling clean water, cleaning process is in running only when filter is clogged. This can be measured with different water heights between raw water and clean water like the orange line on figure 7. It's not common to use drum filter with tight pores. It is more used to treat loaded effluents.

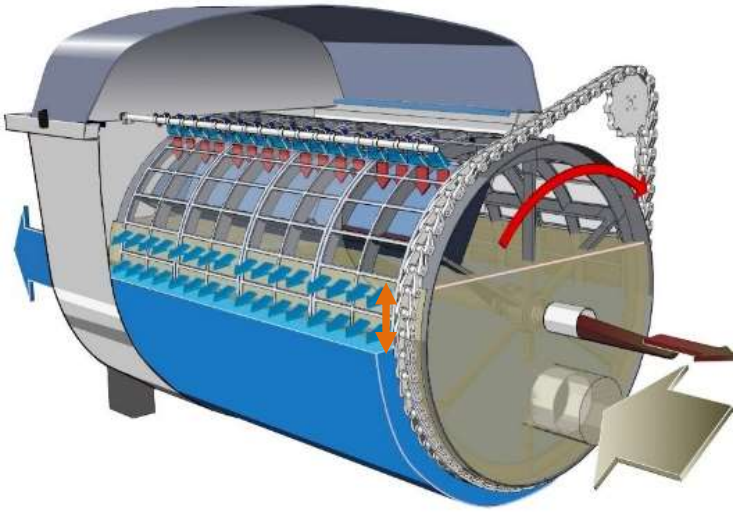


Figure 7 : Drum filter shematic running

Conversely, disc filter is a recent technology. Water is guided into rotor drum and flows by gravity into the filter disc through openings in the drum and passes through the filter media (figure 8). Suspended solids are separated and accumulated on the inside of filter cloth. When the water level inside the filter rotor increases to a pre-set point, the filter rotor starts rotating and the backwash spray removes the accumulate suspended solids into the reject flume inside the filter. The suspended solids are then discharges via a reject pipe. Discs are submerged around 65% and water level of the filtrate is kept by a level tank (Nordic water, 2016).

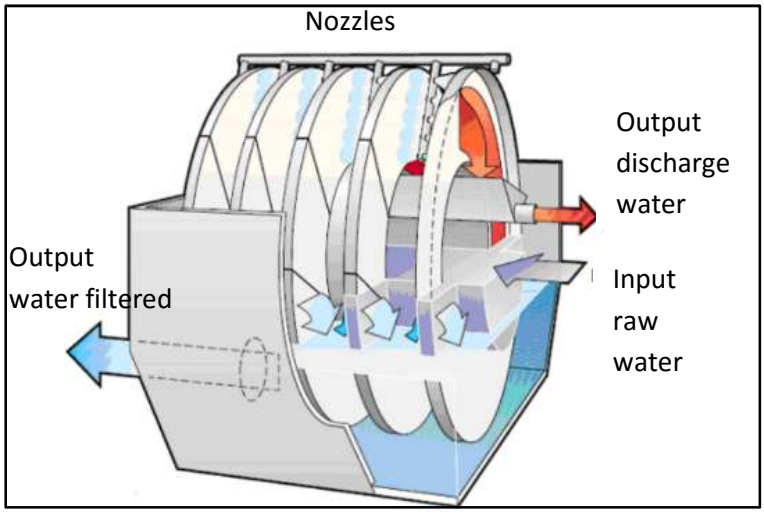


Figure 8: Disc filter schematic running

For same productivity, disc filter are more compact. Another interest is maintenance. It is easier to add and change disc filter element than on a drum filter which allow adapting with raw water charge.

Filter set up at Sieving station

The difference between these filters is showed below. It is easy to see the space difference. The water flow pilot in disc filters is only a tenth comparing with drum filters (Figure 9).

Figure 9 : Difference between drum filters and disc filters cloth

Water flow: 77,4 l/s
Discharge water flow : around 0,17 l/s
2 disks with 8 parts each
Total filtration surface : 5,6 m²

Water flow: around 1200 l/s
4 drum filter unit
Total filtration area: 53,6 m²

II Materials and methods

A) Sampling

To compare efficiency of Drum and Disc filter, it can be necessary to compare filtered water from drum and disc in parallel with raw water.

Four places are sampled, RAW water is sampled in the disc filters tank, discharge water from disc filter, filtered water from drum and disc filters. It would have been interesting to compare discharge from two kinds of filters but discharge water from drum filter was not accessible. Samples locations are presented below on Figure 10.

Disc filters discharge

Samples from disc filters

Samples from drum filters

Samples from raw water

Figure 10: Sampling location in Vombverket sieving station

Sampling was conducted during all summer to follow evolution of raw water quality. Indeed, bloom algae are spontaneous and rapid phenomenon. Filtration efficiency is not always the same and can depends on raw water organic charge.

Sampling was usually done 2 times per week. At each sampling point, 10L were sampled using a sampling rod.

B) Characterisation size of solids particles

Total solids particles in raw water come from different sources. Most of them are from algae and living beings in the lake. Other particles come from soil erosion like sand, clay etc.

Knowing distribution of these particles gives a lot of information for treatment process: what kind of particles are in the raw water and what are their sizes?

It is for example useless to set up a 10 µm filter if there are no particles between 10 and 50 µm.

Procedure is to sample raw water and filter it through filter with pores size from big to small (1000 and 1 µm filters). After each step, water is sampled to do TSS standard analyse. To study the difference between TSS after each step would provide distribution of particles solids size in raw water. Experiment can be summarized like Figure 11.

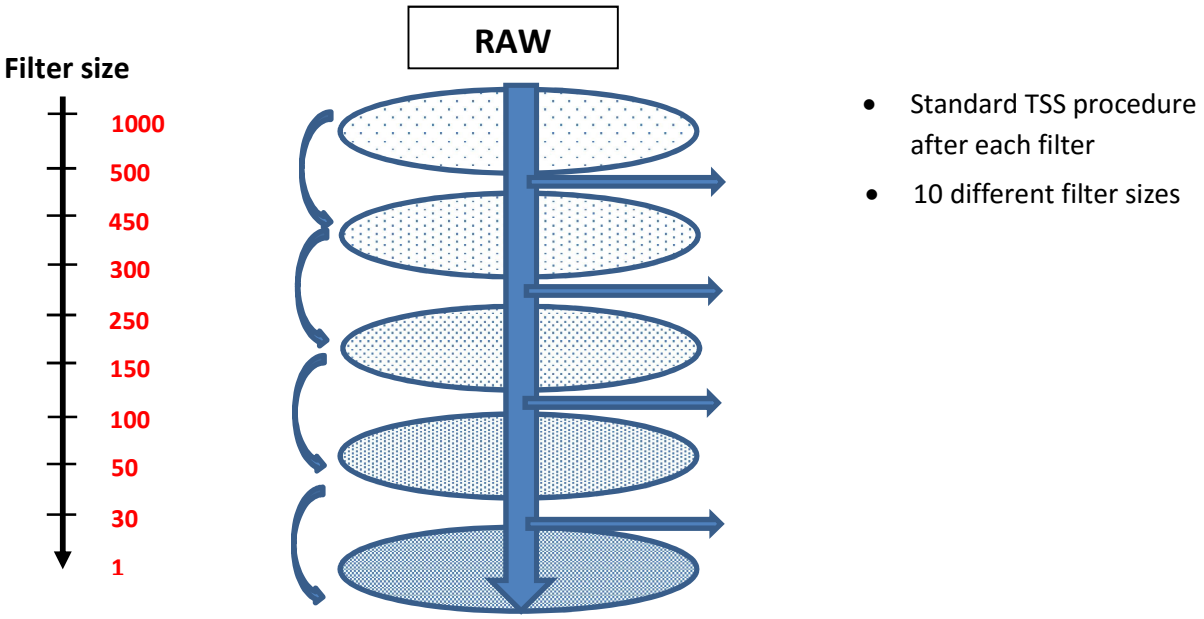


Figure 11 : schematic view of characterisation solids particles

Filters are usually used to catch plankton in water. Pores sizes were checked by a grid under reverse microscope. Here is difference between 1000 and 1 µm filters size. (Figure 12)

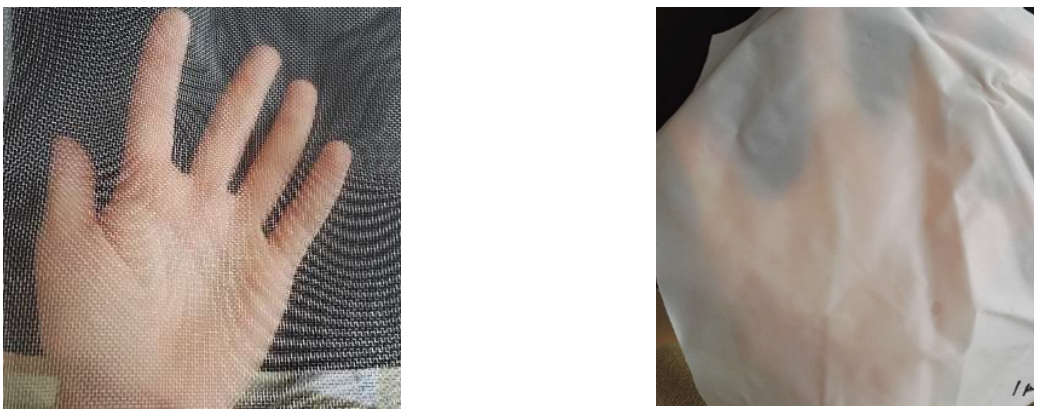


Figure 12 : filtration nets

C) Parameters monitored

Final goal of this study is to measure disc filters efficiency compared to drum filters.

Efficiency can be assessed with different parameters. First of all, TSS (total suspended solids) is an adapted parameter showing directly filtration capacity. TSS is composed by MMS (mineral suspended solids) and VSS (volatile suspended solids). Sand is not a real problem for treatment and ponds. VSS concerns all organic solids like bacteria, algae etc. This is exactly what Sydvatten wants to remove by the filters.

1) Total, volatile and mineral suspended solids

Raw water from lake contain solids particles called TSS for total suspended solids. These contain sand (MSS: mineral suspended solids) and organic components (VSS: volatile suspended solids).

Comparison between water from disc and drum water shows directly efficiency of removal particles.

Material needed:

-Filtration kit (vacuum pomp, fennel)
-filter in glass fibre (0,45 µm pores)
-Water
-stove in 105°C
-Ashes stoves 550°C
-precision scale
-desiccator

Method

- First step is to burn empty filters in 550°C to remove all manufactural residues during 3 hours. One filter is used for 1 sample. After burning, and cooling in desiccator measure mass of empty filter.

- Filter maximum volume water, which depend on particles charge. Filter more water increase measure accurate but time too. It should be to find the best compromise. Usually between (500-3000) ml was filtered. Filters have now to be dry in a 105°C stove. Time depends of how many particles are on the filter. Different drying time can be test until measuring a constant mass.

-Wait cooling filters in desiccator before to measure weigh. TSS can now be estimate doing difference between mass after and before filtration reported with volume water filtered.

-To know repartition between VSS and MSS in TSS, another burning have to be done. Put same filter in ashes furnace in 550°C. Time depends, like before on organic charge and time furnace warms up.

-After cooling waiting, measure filter weigh. Difference mass between previous gives VSS: TSS=VSS+MSS

2) Microcystin-LR

Microcystin is the most widespread toxin. Like said before, microcystin can be dangerous for human. It is useful to know if filtration on drum or disc filters can remove a part of it. Different methods exist to know concentration of toxins but most of them need heavy and expensive instruments. There is one method using quick test kit which is easier and more adapted for this project: Micro Beacon. The kit is able to measure sample between 0 and 5ppb. Samples with higher concentration have to be diluted.

Material:

-Tubes, one for each sample
-Freezer
-Micropipette P1000 with tip
-Spectrophotometer (450nm)

Use principles and procedure

Figure 13: Microcystin-LR kit

The Beacon Microcystin Tube Kit (Figure 13) uses a polyclonal antibody that binds both Microcystins and a Microcystin-enzyme conjugate. Microcystins in the sample compete with the Microcystin-enzyme conjugate for a limited number of antibody binding sites. The test tube is coated with anti-rabbit IgG to capture antibody. In the test tube is added:

- 500 µL Microcystin-enzyme conjugate
- 500 µL water sample or calibrator
- 500 µL Antibody solution

The conjugate competes with any Microcystins in the sample for the same antibody binding sites and antibody is connected to test tube. After 20 minutes incubation, flood the tubes completely with wash solution previously prepared by diluting 100 times the wash solution with distilled water.

Add 500 µL clear substrate solution to each tube. In the presence of bound Microcystin-enzyme conjugate, the substrate is converted to a blue compound. One enzyme molecule can convert many substrate molecules. Since the same number of antibody binding sites is available in every tube, and each tube receives the same number of Microcystin-enzyme conjugate molecules, a sample containing a low concentration of Microcystins allows the antibody to bind many Microcystin-enzyme conjugate molecules. The result is a dark blue solution. Conversely, a high concentration of Microcystins allows fewer Microcystin-enzyme conjugate molecules to be bounded by the antibodies, resulting in a lighter blue solution. After twenty minutes, add 500 µL of stop solution (HCL 1M) and read the sample in 450nm on spectrophotometer.

In six test tubes, it is necessary to add calibrator instead of sample to draw a reference curve. Cyanotoxins concentrations of calibrators are 0 ppb (negative control), 0.2 ppb, 0.8 ppb, 1 ppb, 2 ppb and 5 ppb.

Concentrations calculation:

After reading all of the tube, calculate the %BO as follows. %BO = OD of calibrator or sample x 100OD of negative control. Graph the %Bo of each calibrator on the Y (linear) axis against its microcystin concentration on the X (log) axis using semi-log. Draw the reference curve and show equation of the line and the coefficient of determination r^2. Use this equation and the samples %BO to find logarithms of the concentrations and then the samples concentrations.

3) Cyanobacteria counting

Monitoring the concentration of cyanobacteria can be used to understand when and how bloom appear. During a bloom period, it can be useful to measure efficiency of each filter technology.

There are different methods to count cyanobacteria cells number. Utermöhl chamber method will be used in this study. The principle of the Utermöhl method is to settle a known volume of water. Adding lugol, cyanobacteria and algae sink on the bottom. A reverse microscope allow to count this cells.

Counting all cells takes too long time. In some of microscope, a grid is already included. Another grid like Malassez cells can be brought but this tool is a quite expansive. This method is to count cells into square with known size. Total concentration can be also converted for the all chamber (WHO, 1999).

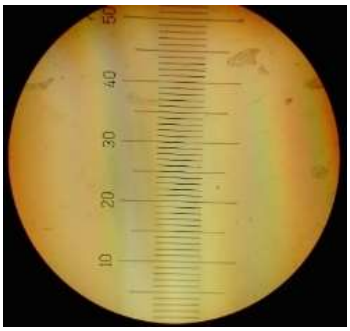


Figure 14 : microscope grid

Sydvatten doesn't have this grid and another counting method was used here. Custom method is to count all cyanobacteria cells in random microscope's field of view (Figure 15). Knowing the total area of chamber and area for each zoom of microscope's field of view, it is possible to do the link and calculate the concentration for all chamber and for 1l of water. To know area to each zoom view it's necessary to use a scale (Figure 14).

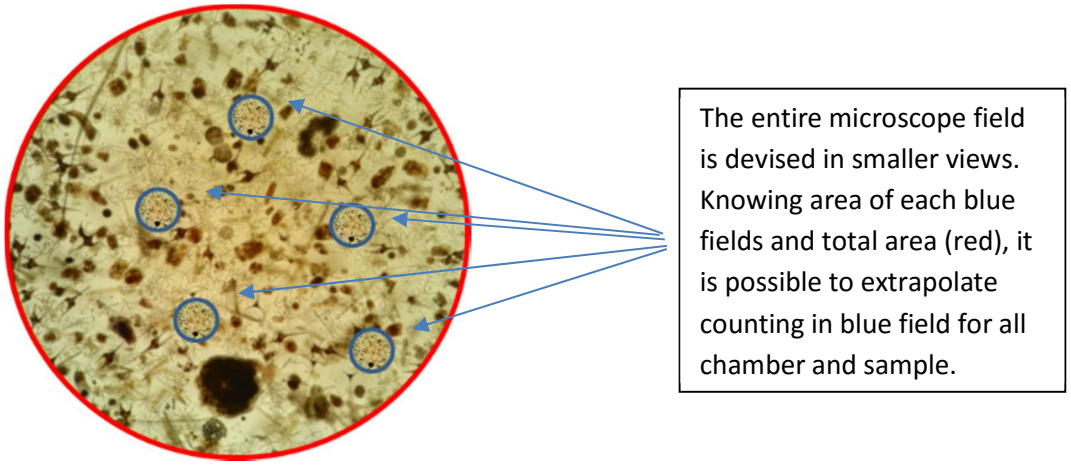


Figure 15 : schematic view of cyanobacteria counting method

To check if this method can be used in future, samples are also sent to Lund University where Pablo Uracia Cordero does standard counting using a better microscope and a counting grid.

4) Phosphorus

Phosphor is a nutrient for cyanobacteria growing. Phosphorus monitoring forms part of a large study conducted by Jing Lie to know specified parameters which influence cyanobacteria growth.

Phosphorus can be found in ortho-phosphorus and total phosphorus. First can be use by algae or another species to grow up. Total phosphorus take account phosphorus into cells.

Sydvatten bought phosphorus kit, easy to use. Method gives results between 0,05-1,5mg P-PO_4^{3-}

Use principle:

Phosphate ions react with molybdate and antimony ions in an acidic solution to form an antimonylphosphomolybdate complex, which is reduced by ascorbic acid to phosphomolybdenum blue.

Method

Analyses with kit is quick. Process can be summarized with next figure.

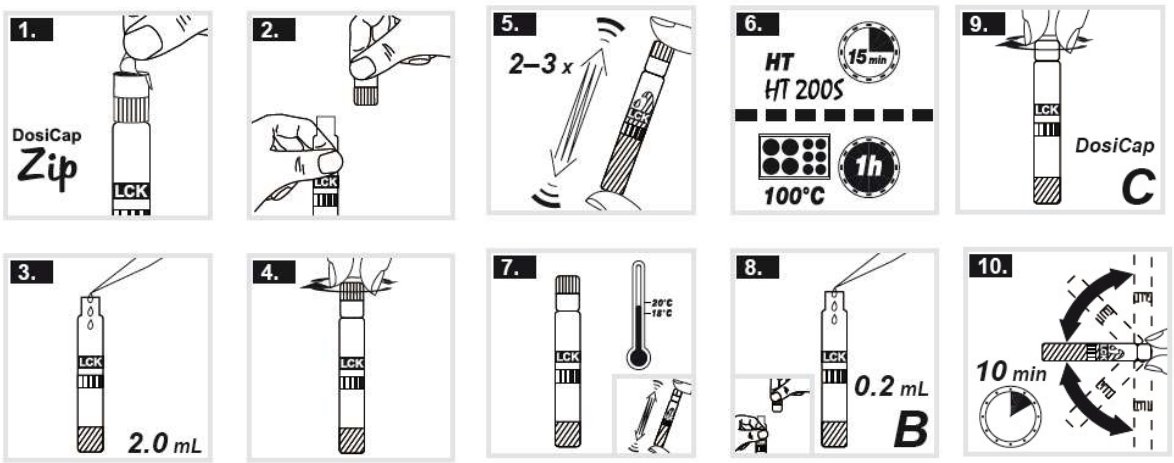


Figure 16 : Method to use phosphor kit

5) UV and color

Absorption in 254 nm is a total parameter measuring the dissolved organic material. It can be used to measure the organic load of the raw water source. Assessment of changes in dissolved natural organic matter (humic and fulvic acids) in the influent helps operators control downstream processing such as coagulation dose adjustment. UV 254 nm concern aromatic cycles and carbon double bonds.

Assay procedure

Method is to take absorbance at 436 nm (colour) and 254nm on filtered and unfiltered samples. This allows to distinguee colour and UV due to dissolve and particles matters.

6) Chlorophyll-a

Two methods will be realized: one quick method to have a quick idea of global charge and one standard method, more accurate.

First method: Measurements principle

Figure 17: bbe fluorometer, chlorophyll-a determination

The fluorescence of algae via excitation with visible light mainly depends on the chlorophyll-a, pigment wide-spread in the plant world. The presence of other pigments is typical for different algae classes. The interaction of these different pigments systems with chlorophyll-a result in a special excitation spectrum for taxonomic algae classes. (Strasser R.J, Merope Tsimilli-Michael M, Alaka Srivastava A, 2004).

The special patterns of this algal fluorescence - so-called fingerprints - are used in the machine for the qualification of different algae classes. The light sources for the excitation are LEDs with selected wavelengths. The fingerprints of four algae classes and for yellow substances are pre-defined in the instrument (figure 17). However, special user-specific fingerprints can also be defined.

This method is a quit new and should be checked by the standard method with ethanol extraction which is realized by Lund University.

Second method:

The second method is based on a standard procedure with ethanol extraction: Chlorophyll-a absorbs in 665 nm. Main goal is to extract molecule from cell.

Filtration of a known sample volume thought a GF/F filter 47 mm. 7 ml of 96% ethanol is add in vial with filter. Vials is store in a dark place for 4-20 hours. After removing filter from vials, use a syringe for filtration using GF/C filters. Spectrophotometer blank is done with 96% ethanol. Sample is read at 665 and 750 nm.

Specific absorption coefficient for chlorophll-a in 96% ethanol is 83,4 l/g/cm (Wintermanns & DeMots 1965).

Calculation of Chlorophyll-a

$$C = \frac{(A665 - A750) * v * 1000}{83{,}4 * V * l}$$

Where

C=concentration of chlorophyll-a ug/L
A665-A750= absorbance at 665nm – absorbance 750nm
v= volume ethanol
83,4= absorption coefficient for chlorophyll-a
V= volume filtered water (l)
L=length of cuvette (mm)

III Results and analyses

There are different ways to present results. Main goal of this study is to show efficiency of disc filter compared to drum filter. Another goal is to have data about cyanobacteria and to know if disc filter can be a good way against this threat.

For each parameter, data from raw water (RAW) and data on water after drum (DRUM) or disc filter (DISC) will be shown and compare.

A) Data from probes

Some probes are directly connected with the control room. They are used to monitor process and detect any issue. Appendices 1 and 2 show a screen from a control room view.

Concerning disc filers, two types of information given by probes can be useful: discharge water flow and time between two cleaning cycles. These parameters are reported directly from raw water flow: when raw water is charged by particles, time between two cleaning cycle decreases due to a rapid filter clogging. Consequently, discharge water flow is increasing. These two parameters are presented below.

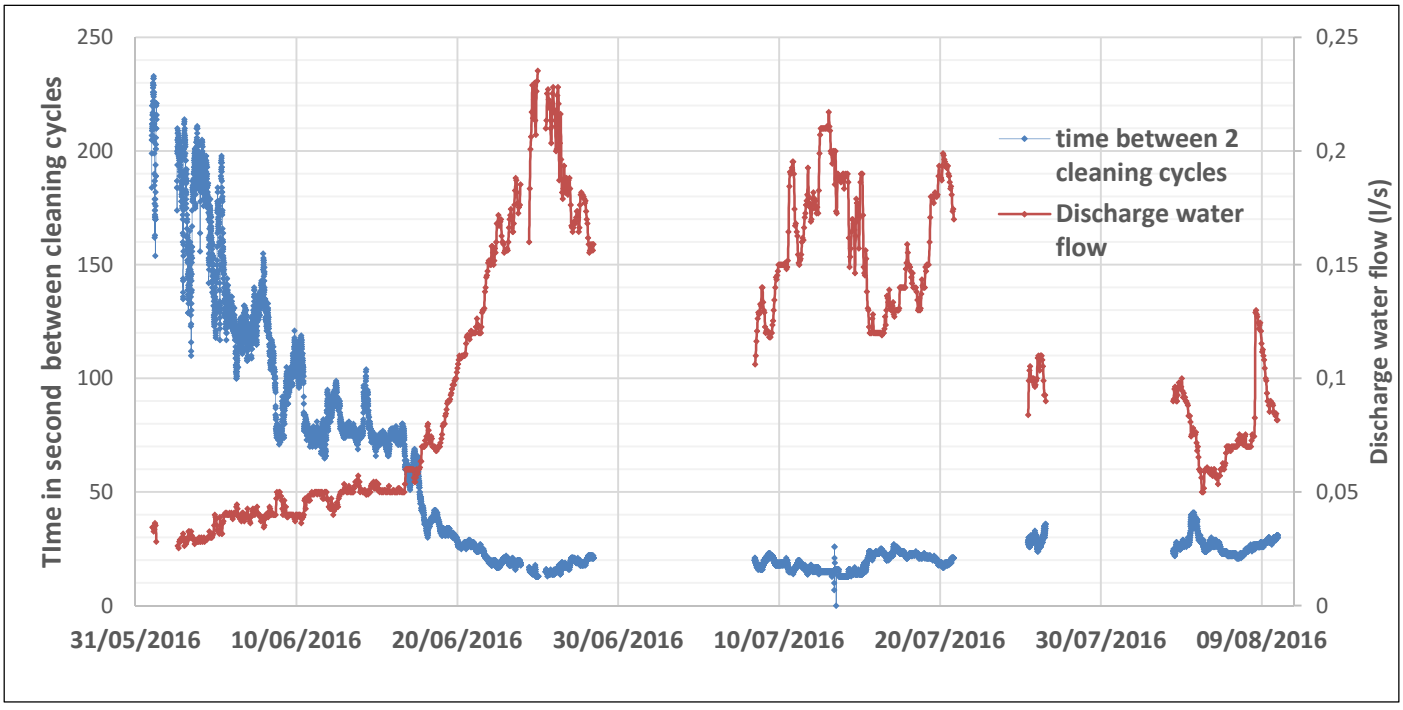


Figure 18: Cleaning process parameter on disc filter (input: 77, 4 l/s)

The input water flow is around 77,4 l/s. Since beginning of my internship, raw water was increasingly dirty. This is due to warm and light weather, facilitating algae and cyanobacteria growing. More results below will confirm this trend.

B) Physical parameters

Physical parameters are focused on determination of particles in water to know how these ones are influenced the filtration process.

1) Total suspended solids.

TSS distribution: Distribution of particles in raw water is the first information to know before set up a filtration unit. Width of filter pores or mesh size depends on particles you want to catch. Result of particles size characterisation are presented below on Figure 19.

Experiment was conducted in one day. Results are influenced by the weather, especially wind condition which mixed the water column. It would be interesting to repeat this experiment for different weather condition and times of year to see variations.

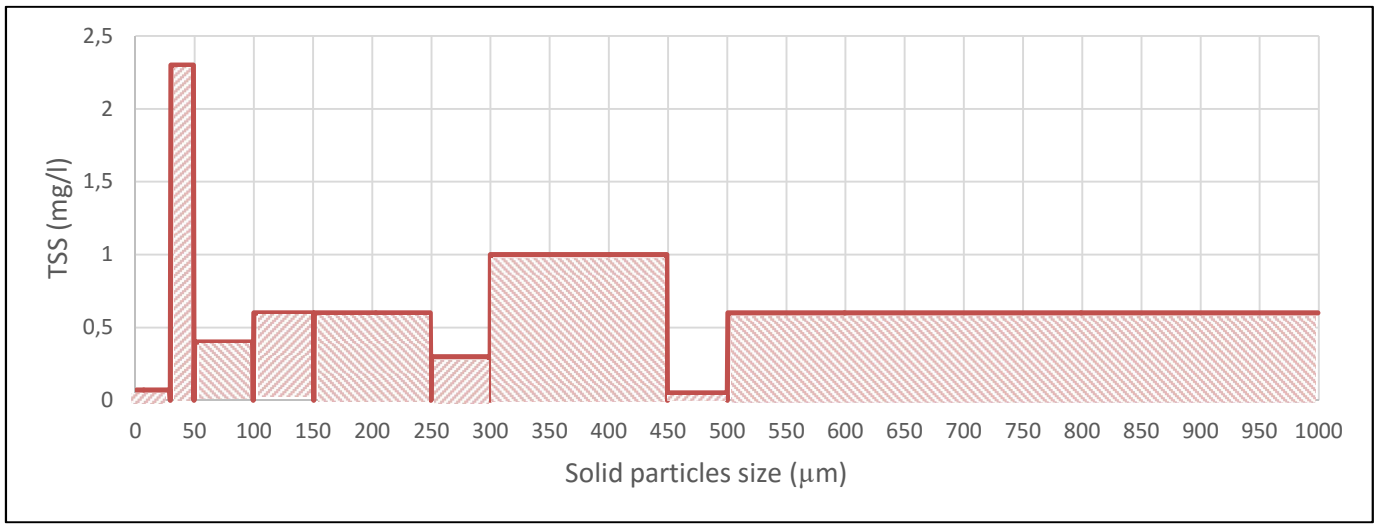


Figure 20 : Totals particles distribution function of size

The Figure 20 shows that there are no many particles above 500 µm, drum filter with 500 µm mesh size should not catch most particles. This filter is not adapted here. The 30 µm disc filter can remove most part of particles. Another presentation (Figure 20) shows with this experiment, a 500 µm filter can catch 10% of total particle while a 30 µm filter catch 98%.

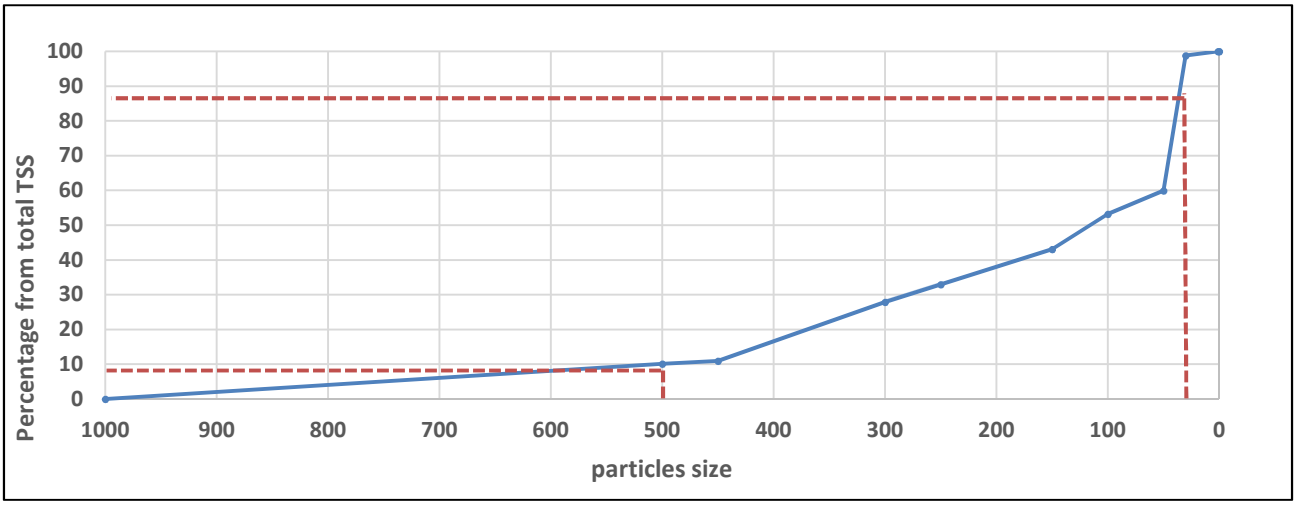


Figure 19 : Percentage distribution on TSS, function of size

This conclusion should be taken carefully. Results between lab and industrial processes can be different due to a scale effect. In addition, filtration is not conduct with the same conditions. Pressure and water flow are not similar. Here is the theoretical model which gives some guidelines.

VSS and MSS: Total suspended solids are composed by mineral (MSS) and organic matters, volatile in 550°C (VSS). Mineral matters are not a problem for treatment due to next artificial sand ponds. Target is more focus on VSS, organic particles including algae and cyanobacteria. Figure below shows repartition between these two kinds of matters in raw water.

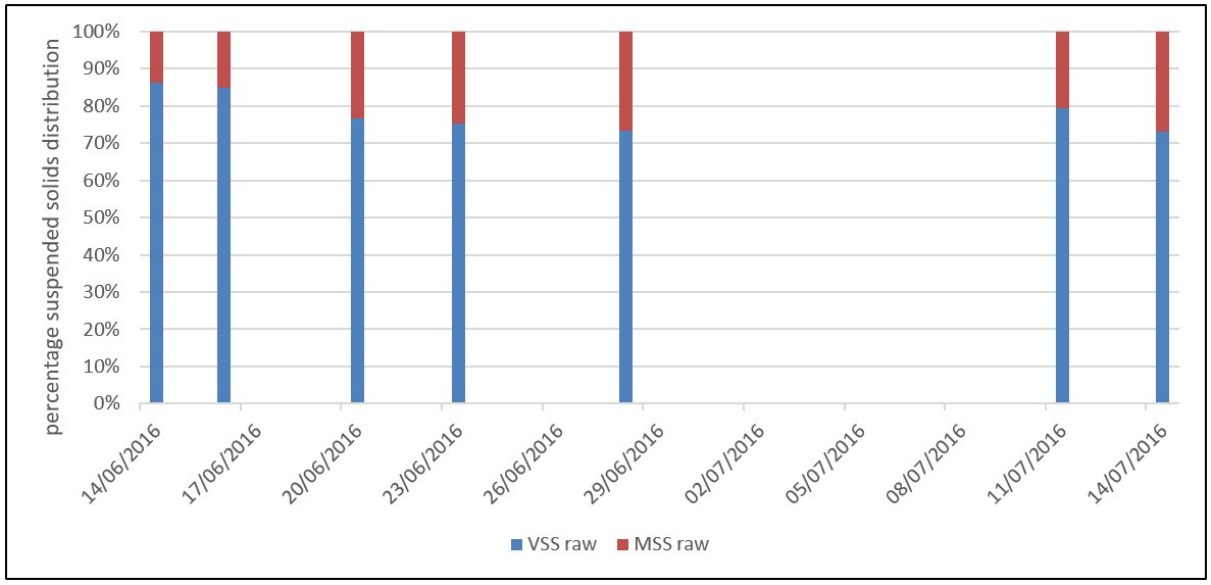


Figure 21 : Repartition of TSS components in raw water

The distribution is quite similar over the study time, organic particles represent around 75% of total suspended solids. Results are similar after filtration process for both drum and disc filter and are not shown here. TSS evolution from raw water reports evolution of water quality. Compared with water after two type of filters technology, efficiency of each can be seen. TSS evolution is represented with Figure 22 for raw water and the two filters types.

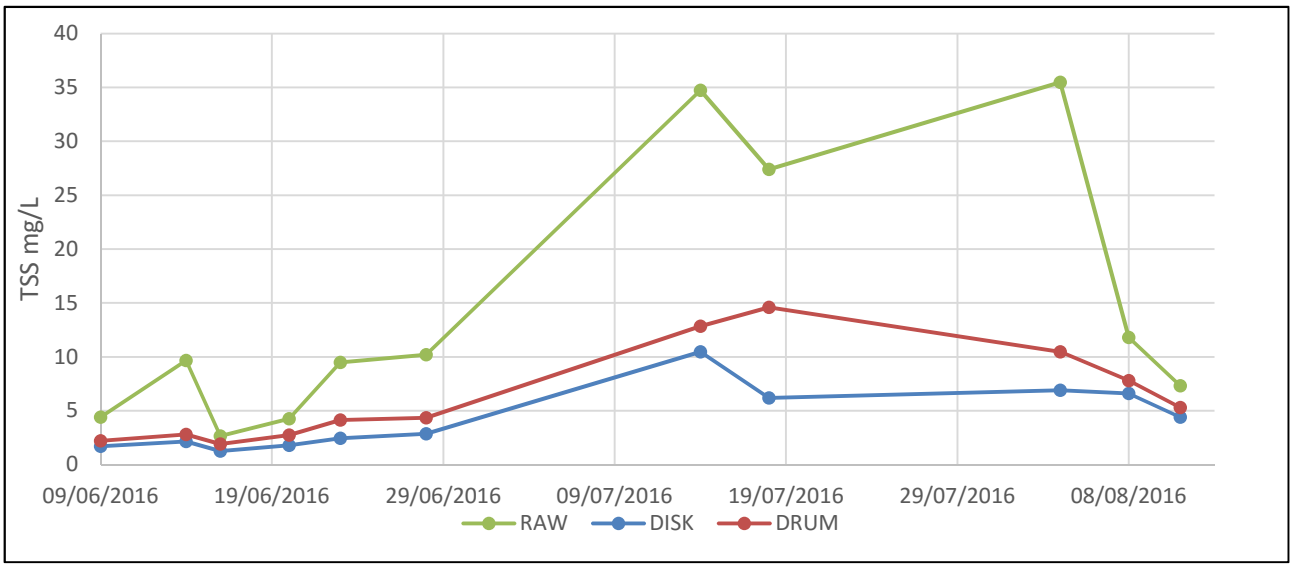


Figure 22 : TSS evolution

First of all, TSS in raw water is not constant at all. For example, in less than one month (16/06-14/07), TSS is multiplied by 13. This highlights the need of taking into account a large result period to size a new filter. In parallel, disc filter appears better than drum filter but results are closed while mash size is 30 µm against 500µm. In addition, as seen previously, efficiency of disc filter should be better due to high TSS above 30 µm. This shows a first difference between theory and practice.

To bring in light efficiency difference, the percentages of particle removing from two filters are represented below. Only VSS are presented to avoid a too overload graph (Figure 23).

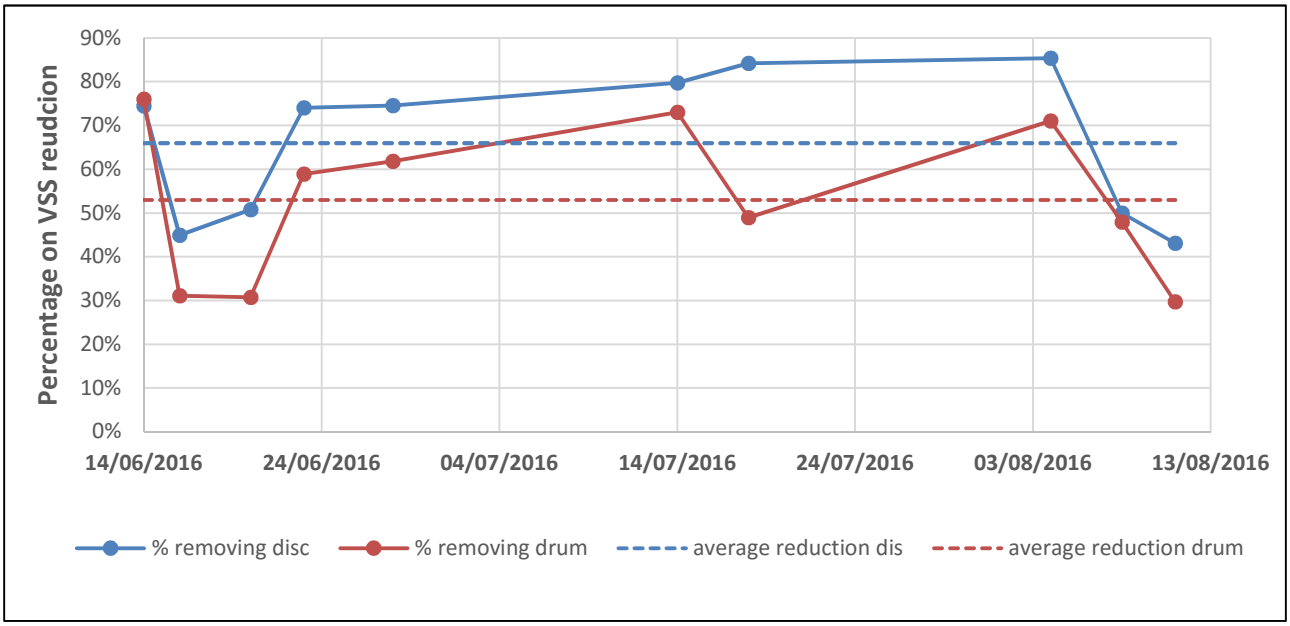


Figure 23 : Comparison on VSS reduction

Efficiency is not constant. Percentage removing is depending with VSS raw water value. It is easier to have a better percentage removing when raw water is dirtier. Disc filter is always better than drum filter. But once again, results are close. In average Drum filter can remove 66 % raw water VSS, against 53 % with disc filter.

2) Turbidity

In addition to TSS/VSS, turbidity is also compared.

Turbidity is measured with a turbidity meter. To ovoid particles sedimentation effects, sample is constantly pumped in chamber where measure is processing. Evolution on turbidity is presented in next figure 24.

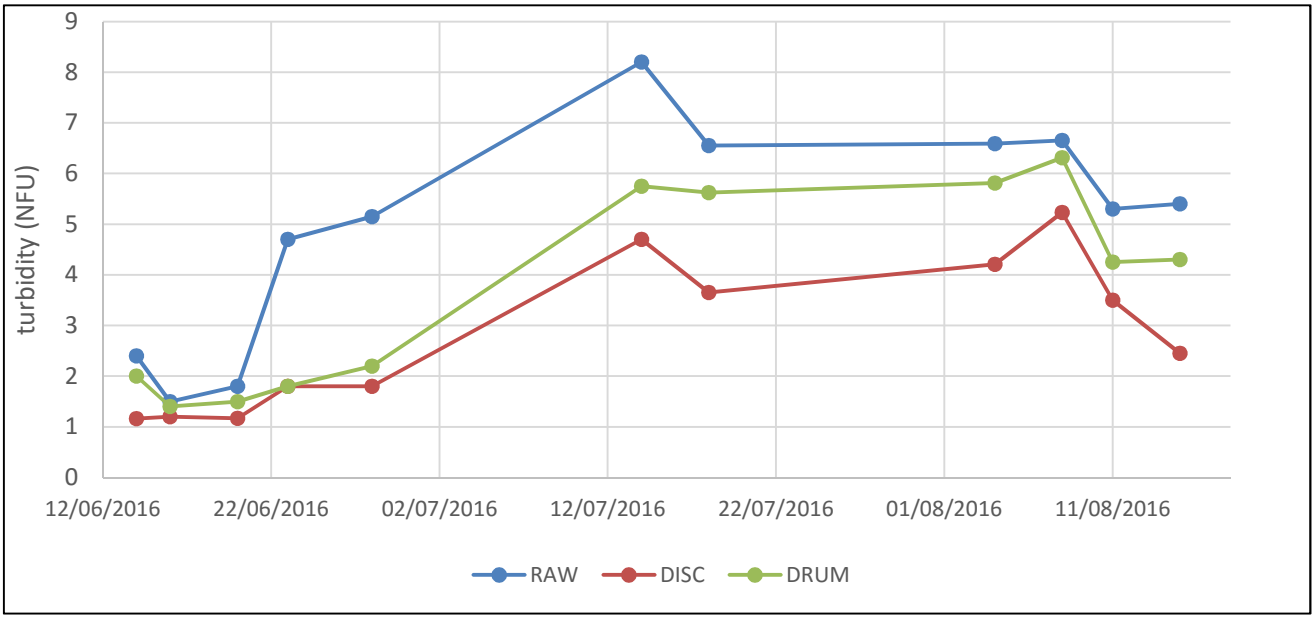


Figure 24 : Turbidity evolution

Turbidity is due to particles and dissolves matter. Indeed, turbidity was also measured on filtered samples (0,45µm). Results are always around 0,16 NFU. That shows turbidity is mostly due to particles matters. Disc filters can remove more particles than drum filters, it is logical to find again this trend here.

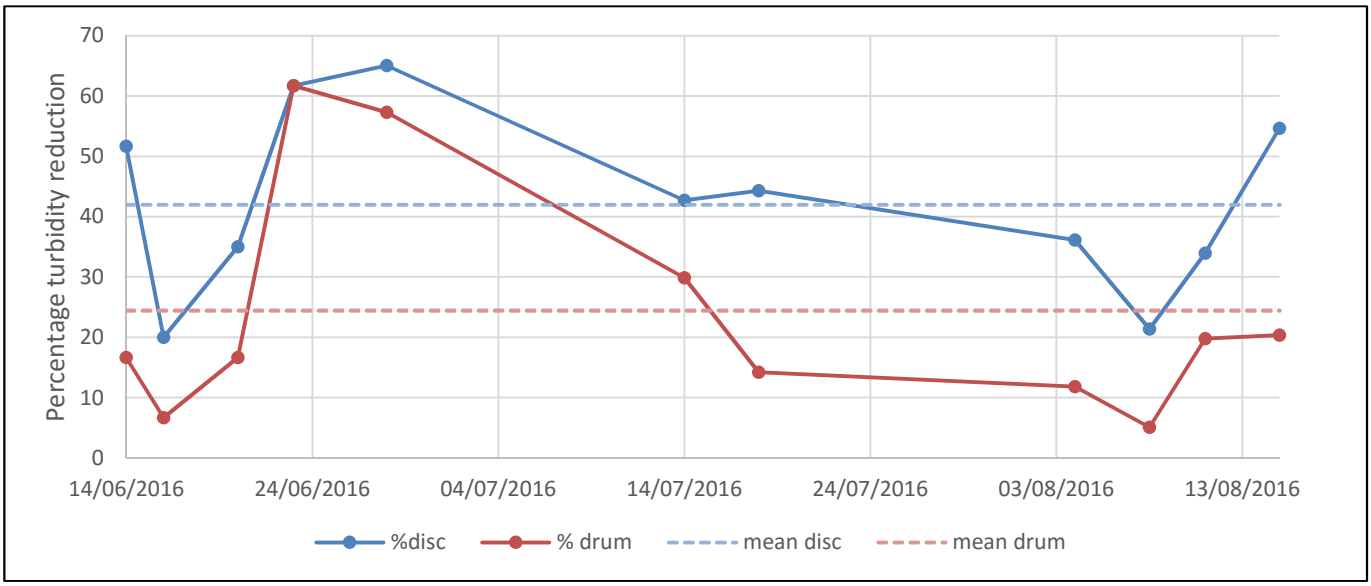


Figure 25: Comparison of percentage reduction on turbidity

Like previously percentage efficiency is not constant and is depending with raw organic charge. Correlations between percentage efficiency function of organic charge like turbidity or TSS were tried but no linear or polynomial correlation was found.

In average, disc filter reduce turbidity by 42% against 25% for drum filter.

3) Absorption parameters

UV and Color

UV, color and phosphate are all, measured by spectrophotometric method. UV and color are influenced by dissolved matters. Filtration should not have any effects on them. They were processed to have a global idea with total charge parameter.

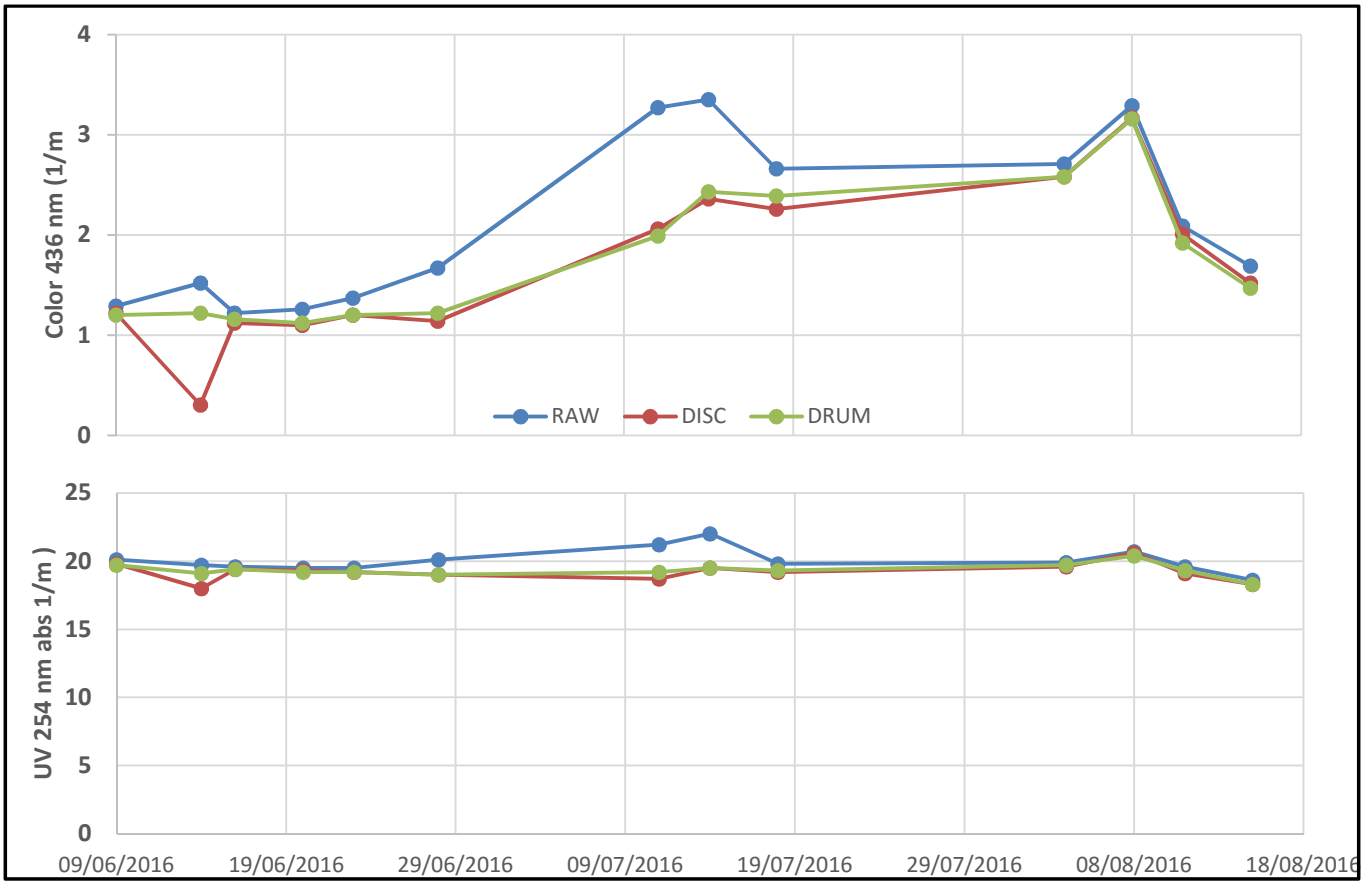


Figure 26: Evolution of color and UV 254 nm

These values are not too high for north lakes. Another lake in Nordic countries was observed with an absorbance 254 nm around 40 (1/m) (Norwegian Institute for Water Research, 2002).

Phosphate: Phosphate is main parameter, responsible for cyanobacteria growing. As shown previously, with material and method part, a Hach kit was used. The range of this Kit is between 0,05-1,5 mg $P\text{-}PO_4^{3-}$. Entire values were above this limit and cannot be used. This kit method is not adapted for raw water. Another method like the standard one or more accurate kit should be used for a future study.

C) Case of cyanobacteria

Cyanobacteria is the main target for filtration. The removing of cyanobacteria can avoid bloom development in next step in artificial ponds. In addition, to focus on cyanobacteria will give acknowledgments about cyanobacteria growth for Sydvatten which should be used for future studies.

1) Cyanobacteria cells number

The cyanobacteria cells counting was performed by Pablo Uracia Cordero, PhD at Lund University. In fact, the custom method used at Sydvatten by reverse microscope was not accurate enough. Although there are some determination keys (Cromberg G, Annadotter H, 2006), it was too difficult to differentiate cyanobacteria species. Results from standard method and custom cannot be compared. Only standard method will be presented.

More than 16 different cyanobacteria species were found. Name and picture of each are presented in Appendix p 3&4. Total cyanobacteria cells are figured bellow.

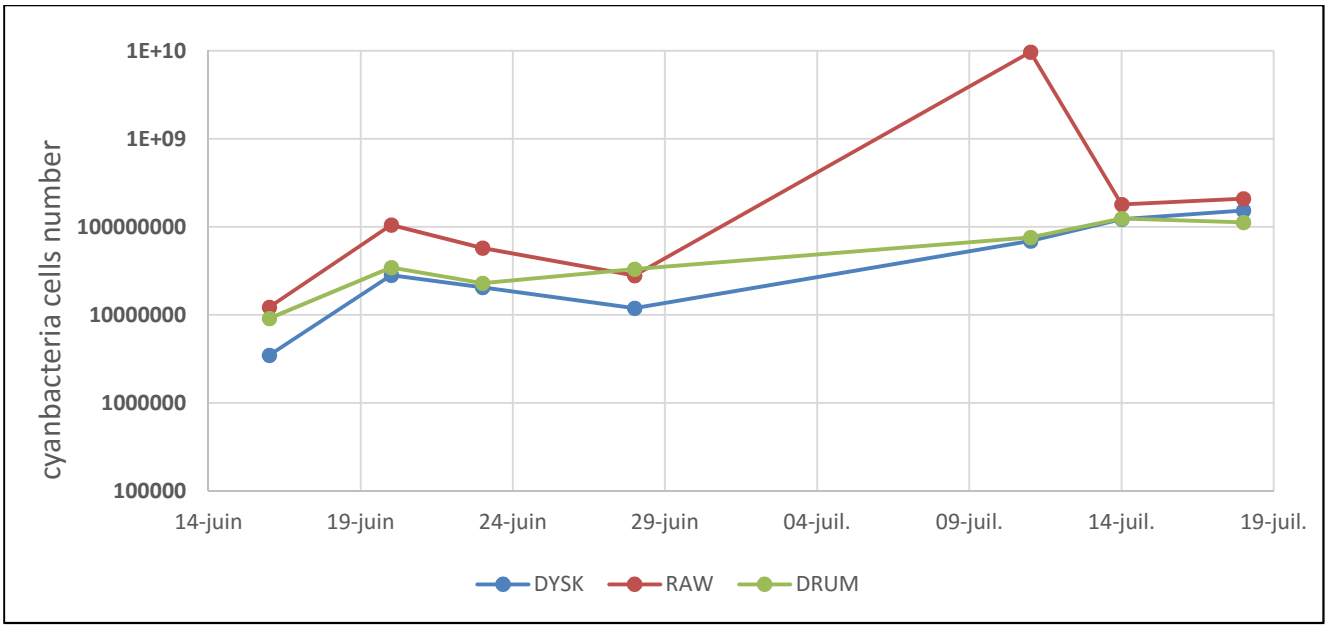


Figure 27: Evolution of total cyanobacteria cells /L

The number of cyanobacteria seems highly concentrated. Interpretation of this result should be done carefully. Indeed, impacts of one type of cyanobacteria specie cells depend of its size and “biomass”. It is better to use total biomass to compare all cyanobacteria like following part. Cells number can be used to compare only one cyanobacteria specie.

2) Cyanobacteria biomass

Compared to cyanobacteria cells, cyanobacteria biomass is a better way to analyses the evolution. Among cyanobacteria, their sizes are very various. One cyanobacteria cell can be 10x bigger than another and produce more toxin. To compare biomass give a global situation of cyanobacteria charge. Conversion between cells number and biomass is not easy. It depends on each cyanobacteria specie. It exists some tables which give global shape and size for each cyanobacteria specie, which makes it possible for this conversion. Figure 28 shows evolution of total cyanobacteria biomass.

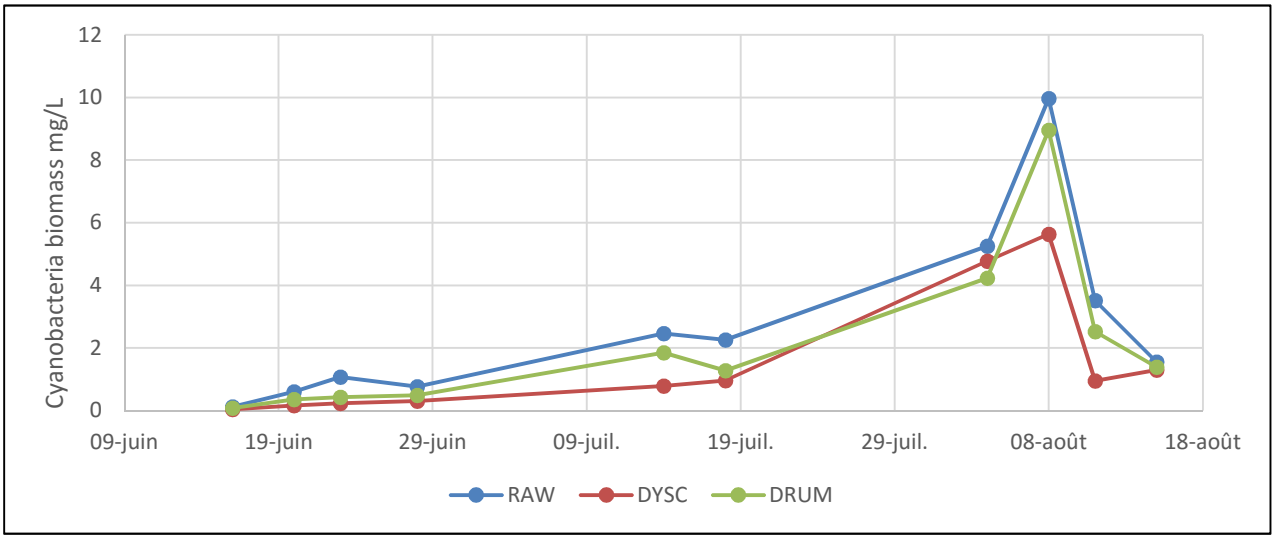


Figure 28: Evolution of cyanobacteria total biomass per liter

Since beginning of experiment, total biomass is increasing significantly. When biomass is going up in raw water, water after drum filters and disc filters, (to a lesser extent) are following the same increasing trend. On average, cyanobacteria represent 10% of TSS. Disc filter is more efficient than drum filter to remove cyanobacteria. On average, as indicate with next figure, the percentage reduction is 60% for disc filter and only 32% for drum filter.

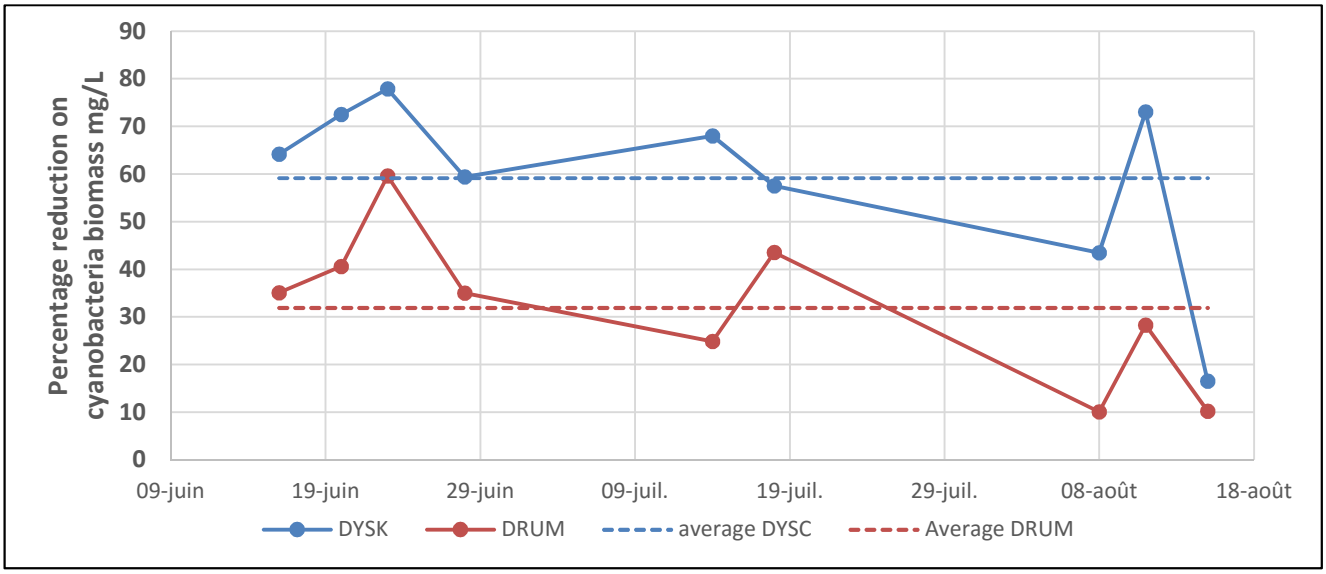


Figure 29: Evolution of percentage reduction on cyanobacteria biomass

Cyanobacteria biomass reduction is the main goal of filtration to avoid a quick clogging in artificial sand ponds. Regarding this parameter, it can be useful to deploy disc filter entirely.

3) Chlorophyll-a

Chlorophyll is measure by two ways: quick analyse using visible light and fluorescence and standard method. Results for the first method are presented below in Figure 30. The peak on the 08/08 is a quite surprising because it is not found on other parameters.

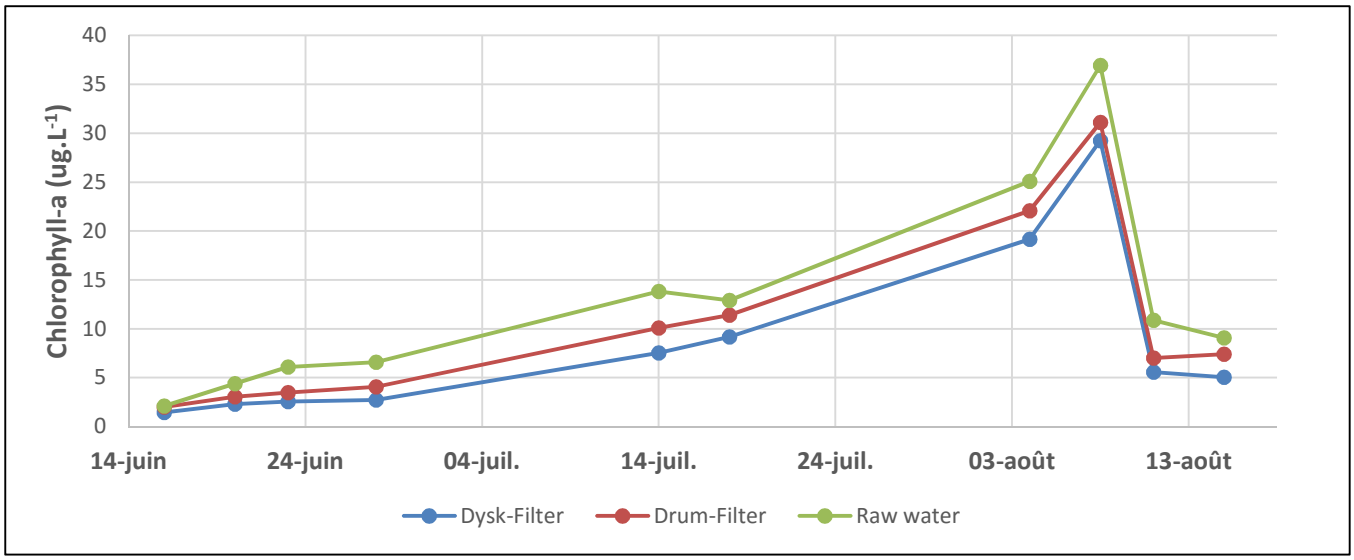


Figure 30: Evolution of cyanobacteria chlorophyll-a

The comparison on chlorophyll-a reduction shows another unexpected result. When chlorophyll-a increase, efficiency decreases. The trend is not found for other parameters. It is usual to find the opposite. No explanation is found.

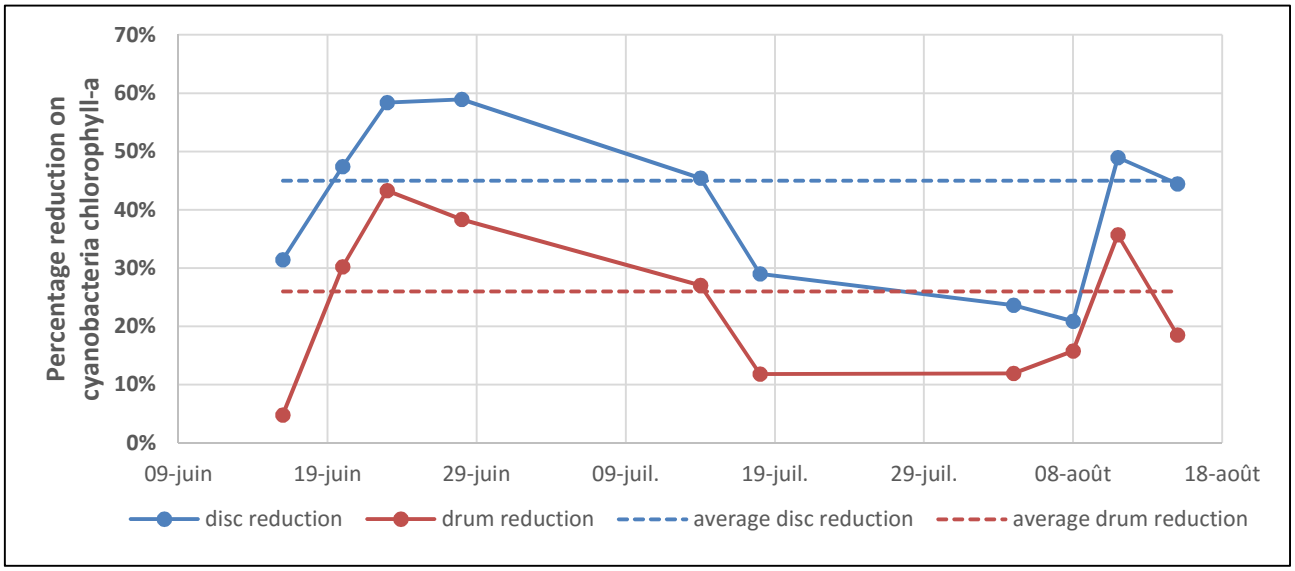


Figure 31: Comparison on cyanobacteria chlorophyll-a reduction

4) Cyanotoxin : Microcysin-LR.

Cyanotoxin analyses use a calibration curve to realise each time. Method is described in previous part. Figure 32 represents the calibration curve obtained with process described previously.

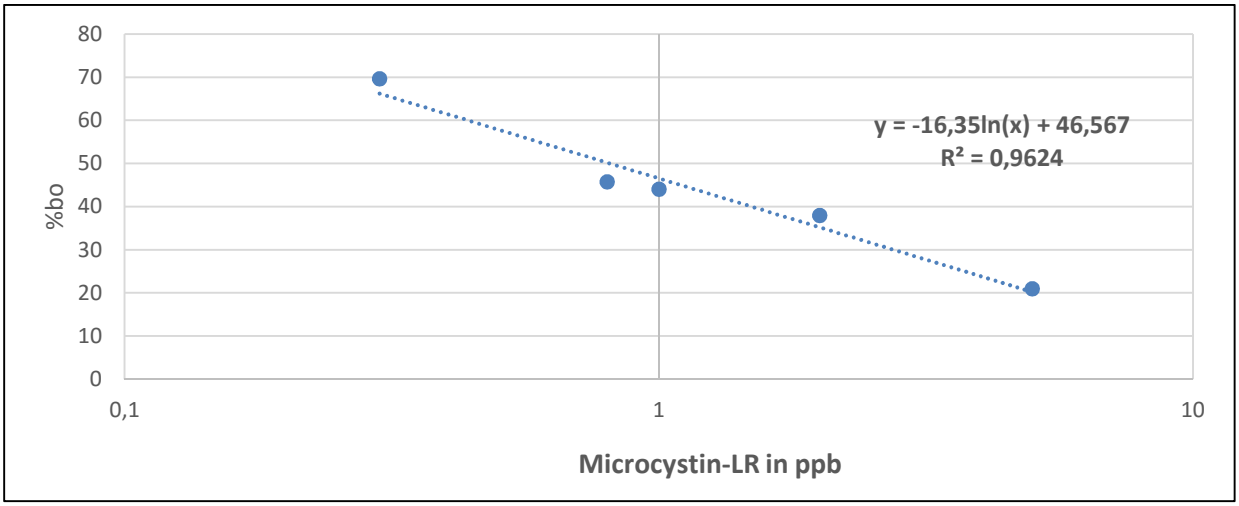


Figure 32: Microcystin-LR calibration

A 0,96 R^2 is enough to validate process and analyses results. Method is used for total microcystin-LR both extra and intracellular.

According guideline values from (WHO, 2011) total microcystin-LR above 1 µg/L can be dangerous for human health and should not be used for drinking water. Results from experiment are figured bellow for each sampling point:

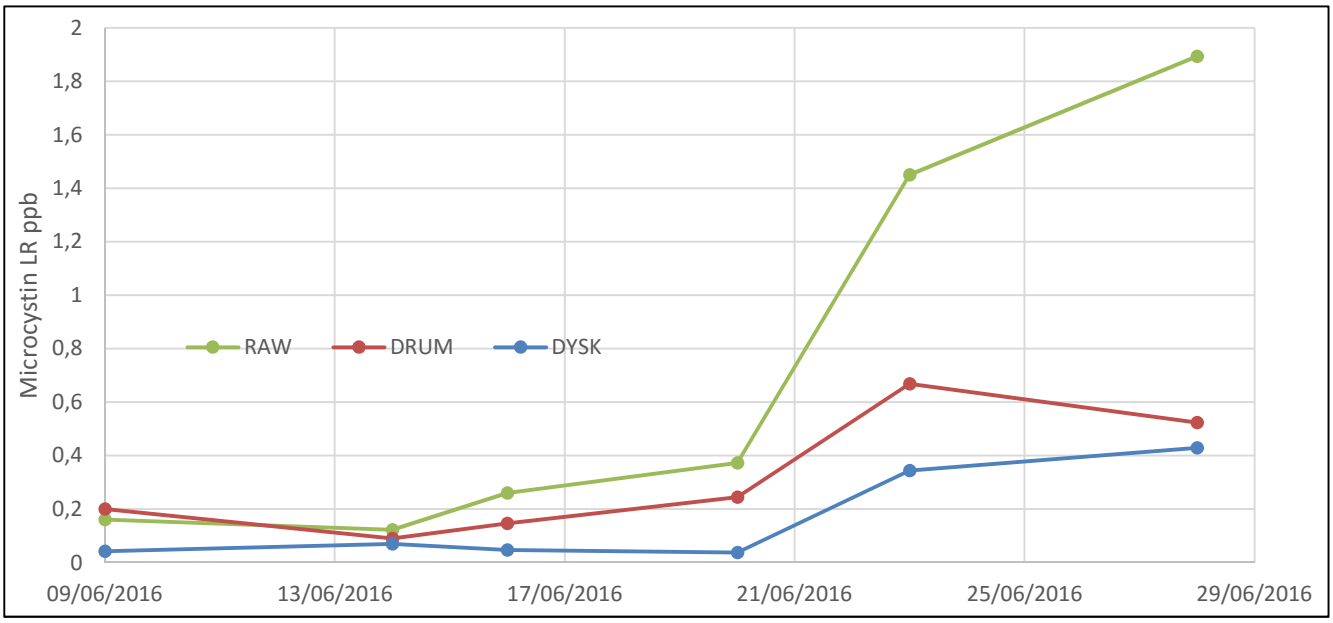


Figure 33: Evolution of total microcystin-LR in ppb

As mentioned at the beginning of this part, raw water quality is dirtier every day, like another parameter we found again this trend.

Since the 20/06/2016, microcystin-LR is above guideline limit and should not be used for drinking water. Disc filter is the best way to remove this cyanotoxin thanks to remove most part of cyanobacteria cells. With disc filter, microcystin Lr is always under 1 ug/L. The latest data are not added here because experiment is not finished at the writing time.

5) Looking for parameters correlation

It seems some parameters are linked and it is logical: cyanobacteria biomass, cyanobacteria chlorophyll-a and cyanotoxin-LR. We would like to check correlation between these parameters. If there is one, to know one parameter can give idea for another.

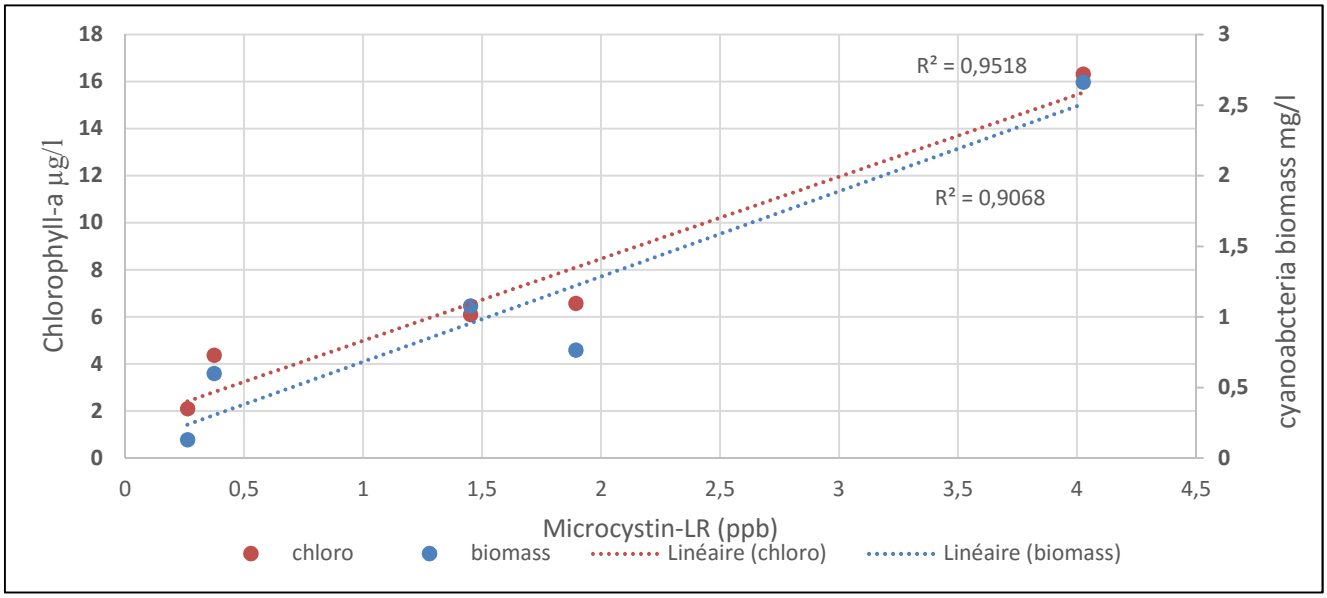


Figure 34: Correlation between microcystin-LR function of cyanobacteria biomass and chlorophyll-a from raw water

Correlation coefficient is enough close from 1 to say the correlation working well. It seems that this only works for raw water. If we know chlorophyll-a from cyanobacteria we can now try to predict toxin concentration or cyanobacteria toxin. This gives an idea but it's no enough accurate to use for another thing. In addition, the correlation is built with only 5 points. Latest data should be added to verify this.

Same results are observed for disc filters. On the other hand, correlation doesn't work for drum filters and discharge water. These correlations should be work only for summer months. Indeed, according to Britt-Marie Pott (Sydvatten process Engineer), during autumn, when cyanobacteria are dying, cyanotoxin are released in water. It also possible to have a high toxin concentration and a low cyanobacteria biomass or cells.

To check if rapid method using fluorescence propriety can be used to monitor cyanobacteria evolution, both results from this method and the standard one are presented in Figure 35.

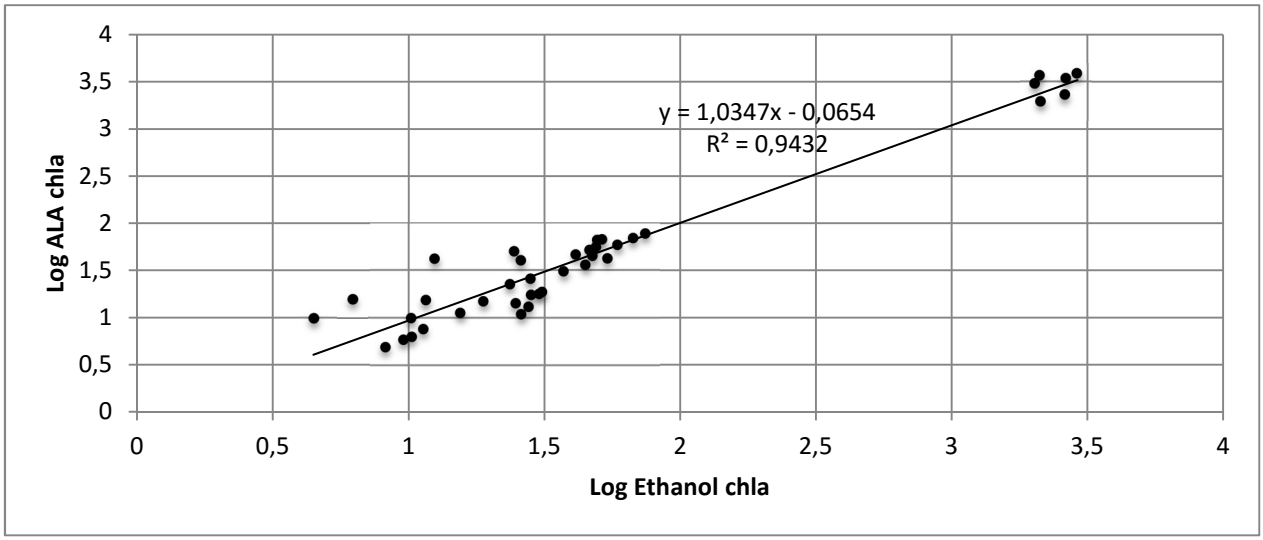


Figure 35: Correlation between log chlorophyll-a from fluorescence method ALA and ethanol extraction

The curve shows a good correlation between the two methods. The slop is close to 1, indicating the method has no deviations. In future this method can be used to follow evolution on cyanobacteria growing during summer time. This method provides quick results allowing adapting treatment fast enough in case of cyanobacteria bloom.

6) Test with a 10 µm disc filter: elements for sizing

A test with 10 µm pores disc filters was performed. It is the smallest pores size for this technology. Main goal was to test organic input charge limit. All discs were changed by 10 µm element. To replace filters is easy but takes some time. Water was sampled in the same day: 8h00 for 30 µm samples and 13h00 for 10 µm samples. Figure 36 below shows evolutions of TSS, cyanobacteria chlorophyll-a and cyanobacteria biomass for the two disc sizes.

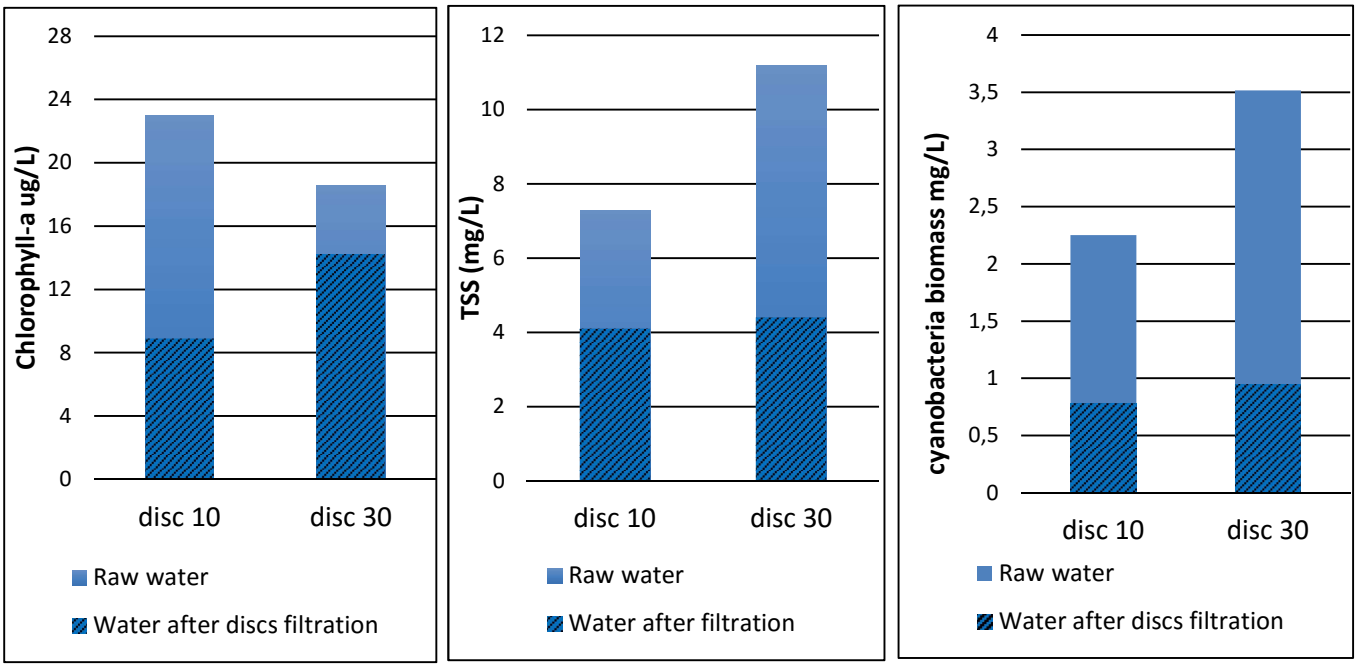


Figure 36 : TSS and chlorophyll-a comparison on disc filters 30 µm/ 10 µm

Raw water quality is too different to conclude on efficiency difference. Samplings for 30 µm disc were conducted during morning 8h00 and 10 µm, at 13H. During the day, cyanobacteria and another algae in water can go close to the top amount to have a maximum light using vacuole (Head R.M, Jones R.I, Bailey-Watts A.E, 1999). This can explain why more chlorophyll-a were found in the afternoon samples. However, it is a quite surprising to not find this trend on cyanobacteria biomass. This difference on sampling time can explain differences in raw water quality.

Water after 10 µm disc is a quite better: (TSS: 4,1 mg/l against 4,4 mg/l) but it is maybe due to the difference in water input.

Sizing aspects

During the running with 10 µm disc, cleaning process was always in process. The water height in tank and disc filters surface were stabilized. The maximum capacity was reached.

This test is interesting because it can be used to size the future disc filters installation.

During this test, the water flow input was 53 l/s for two 10 µm discs corresponding to 5,8 m² of filtration surface. Organic charge input was 7,3 mg/L in raw water.

The future installation will be sized for 2000l/s. By supposing there are not scale effects, future installation will need of (2000/53)*2 = 75 discs. This result is for 7mg/L TSS in raw water. During summer a peak with 35mg/L TSS was reached.

Disc filter manufacturer can used the same actual drum filters emplacement to set up 4 disc filters units composed by 12 discs each. It seems difficult to set up a 10 µm cloth without extend the building.

In addition, the set-up of 10 µm should be realized through getting more data for analysis. Ideally, the 10 µm test should be realized when raw water is the dirtiest.

7) Efficiency comparison

In summary Figure 37 shows the result of removing average percentage for different parameters.

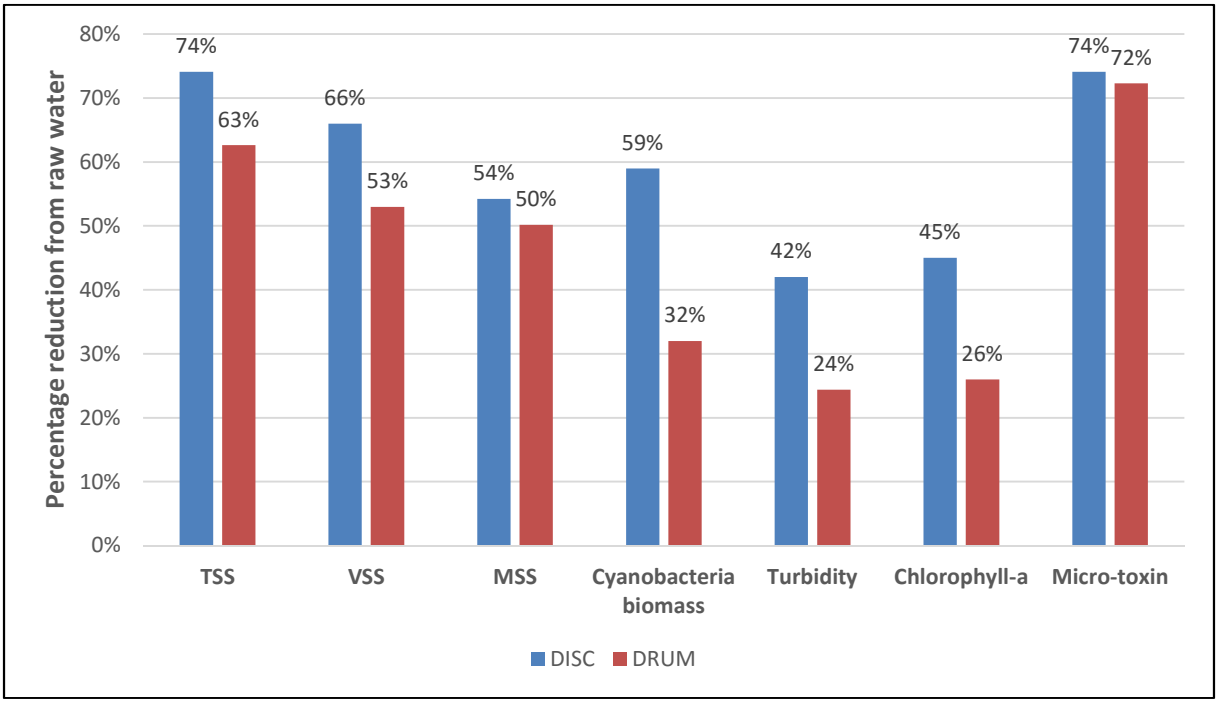


Figure 37 : Comparison of percentage reduction for different parameters

According to the results, differences between two filters are not very significant. The model of particles distribution as function of size, shows disc filter should be more efficient.

First hypothesis to explain this small difference is the formation of a filtration cake on drum filters. This cake clogs the filter cloth of drum filters, decreasing the pores size and allowing a better filtration. To test this, different samples from drum filter in different time after the cleaning process were measured. It demonstrated that there is no evolution on filtration efficiency. The cake formation is not revealed here.

The disc filters are efficient on cyanobacteria biomass removal, which is the main target. In addition, main goal of disc filters is to remove cyanobacteria during a bloom period. To measure the efficiency in high organic charged water, same figures can be drawn only by one sample. This representation is not given here, all results are not received at the time of writing this report.

Conclusion

Main goal of this study was to measure different efficiency between old drum filter unit (500 µm) and new 30 µm mash disc filters. This efficiency was focusing on organic particles, especially cyanobacteria to avoid a bloom proliferation in next artificial sand ponds. According to particles distribution by size, the difference of TSS removal is less than expected. The drum filters seem to work better than expected. Even if they have a 500 µm cloth, some smaller particles can be caught. Unfortunately, the cake formation was not demonstrated, which might explain this.

However, disc filters are much more effective on cyanobacteria biomass reduction than drum filters (65% against 35%). The results are similar for turbidity and chlorophyll-a reduction, respectively (42% against 24% and 45% against 26%). Replacing all drum filters by disc filters will allow having cleaner water entering in artificial ponds.

The set-up of 10 µm pores size can be considered but the organic charges from raw water has to be monitored to avoid overload. In addition, 48 disc filers using 10 µm meshes seem to be not enough during blooms period in summer. The extension of sieving station should be taken in account if 10 µm pore size will be chosen. Results from this study can be used to size the future unit to replace all old filters at sieving station.

In addition, some correlations between different parameters were found: microcystins-LR and cyanobacteria biomass was analysed with the correlation factor as 0,95. Furthermore, the correlation between microcystins and chlorophyll –a was high as well with r^2 equals 0,93.

This allows us to monitor cyanobacteria evolution in an easier way by measuring chlorophyll- content than cells counting. In fact, the monitoring of chlorophyll-a by using fluorescence propriety is enough to have an idea about cyanobacteria biomass concentration and results are similar than the standard method using ethanol extraction.

Bibliography

ANNADOTTER H ET ALL, 2001. An extensive outbreak of gastroenteritis associate with the toxic cyanobacterium *Planktothrix agardhii* in Scania, south Sweden. In **CHORUS I, 2012**. Cyanotoxins, occurrence, causes, consequence. Springer-Verlag. Pp200-208

CAMACHO F., BONGIOVANI M., ARAKAWA F.S. *ET AL*, 2013. Advanced processes of cyanobacteria and cyanotoxins removal in supply water treatment. *Chemical Engineering Transactions*, pp421-426

CROMBERG G, ANNADOTTER H, 2006. Manual on aquatic cyanobacteria: A photo guide and a synopsis of their toxicology. *International Society for the Harmful Algae*. p 106

DJANETTE KHIARI, WATER RESEARCH FOUNDATION, 2016. Managing Cyanotoxins. Available on internet: *
http://www.waterrf.org/resources/StateOfTheScienceReports/Cyanotoxins_StateOfTheScience.pdf

ENVIRONMENTAL PROTECTION AGENCY UNITED STATES, **2014**. Cyanobacteria and Cyanotoxins: Information for Drinking Water Systems. Available on internet :
https://www.epa.gov/sites/production/files/2014-08/documents/cyanobacteria_factsheet.pdf

HEAD R.M, JONES R.I, BAILEY-WATTS A.E, 1999. Vertical movements by planktonic cyanobacteria and the translocation of phosphorus: implications for lake restoration. In *Aquatic conservation* Pp 111–120

NORDIC WATER, 2016. Discs filters: High capacity on a small footprint. Available on internet :
http://www.nordicwater.com/wp-content/uploads/2016/04/S1401_DynaDisc-Brochure_EN_A4_web.compressed.pdf

NORWEGIAN INSTITUTE FOR WATER RESEARCH, 2002. The color of water: Climate induced water color increase in Nordic lakes and streams due to humus. Available on internet :http://info1.ma.slu.se/ima/publikationer/brochure/the_color_of_water.pdf

SECKBACH J, 2007. Algae and Cyanobacteria in Extreme Environments. *Springer Science & Business Media*, 813p

SRIVASTAVA A-K, RAI A-N, NEILAN B, 2013. Stress Biology of Cyanobacteria: Molecular Mechanisms to Cellular Responses. *CRC Press* p394.

STRASSER R.J, MEROPE TSIMILLI-MICHAEL M, ALAKA SRIVASTAVA A, 2004. Analysis of the Chlorophyll a Fluorescence Transient. In *A Signature of Photosynthesis.* pp 321-362

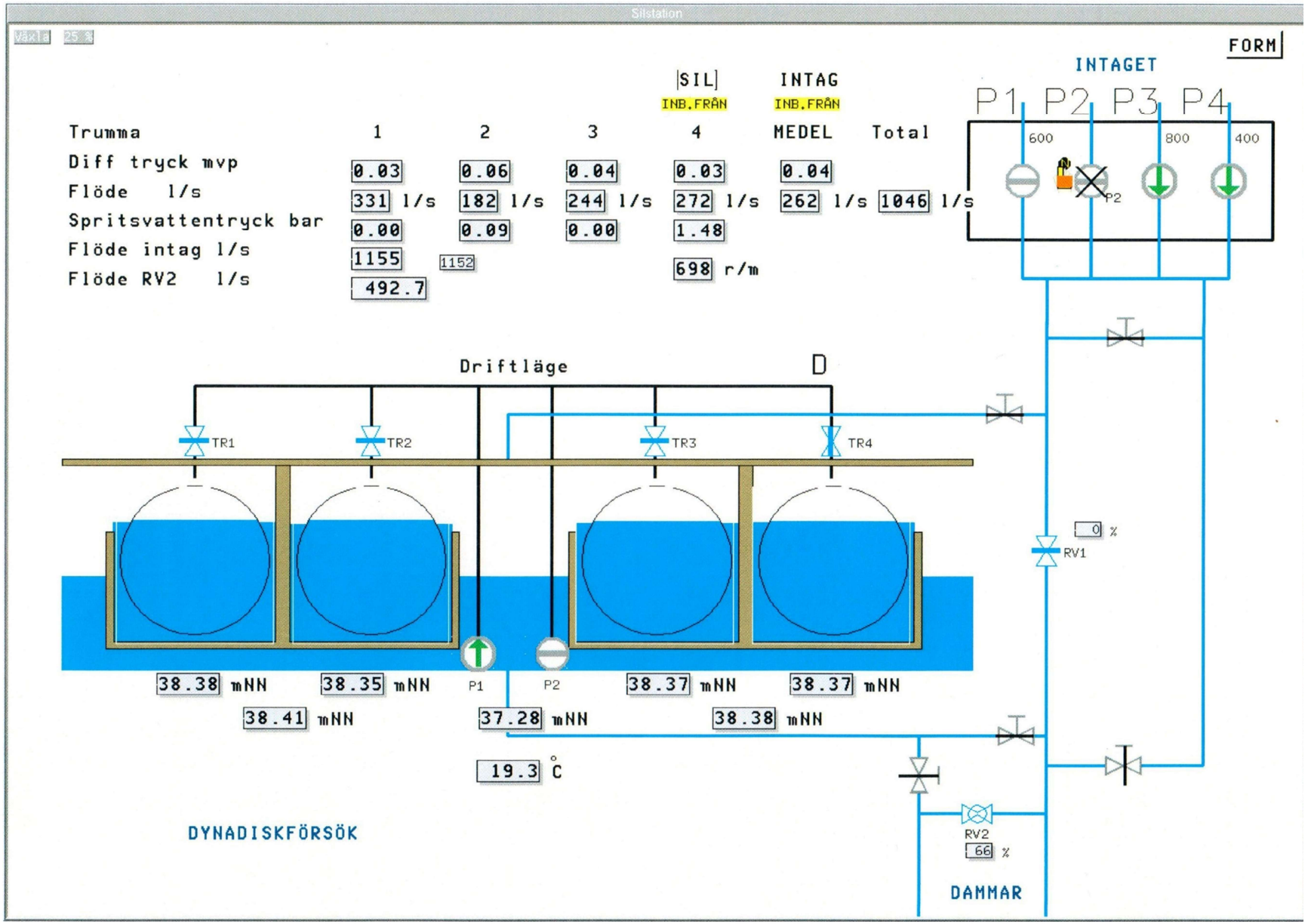
WORLD HEALTH ORGANIZATION, 1999. Toxic Cyanobacteria in Water: A guide to their public health consequences, monitoring and management. Available on internet :
http://www.who.int/water_sanitation_health/resourcesquality/toxcyanchap12.pdf

WORLD HEALTH ORGANIZATION, 2003. Cyanobacterial toxins: Microcystin-LR in Drinking-water, available on internet:
http://www.who.int/water_sanitation_health/dwq/chemicals/cyanobactoxins.pdf

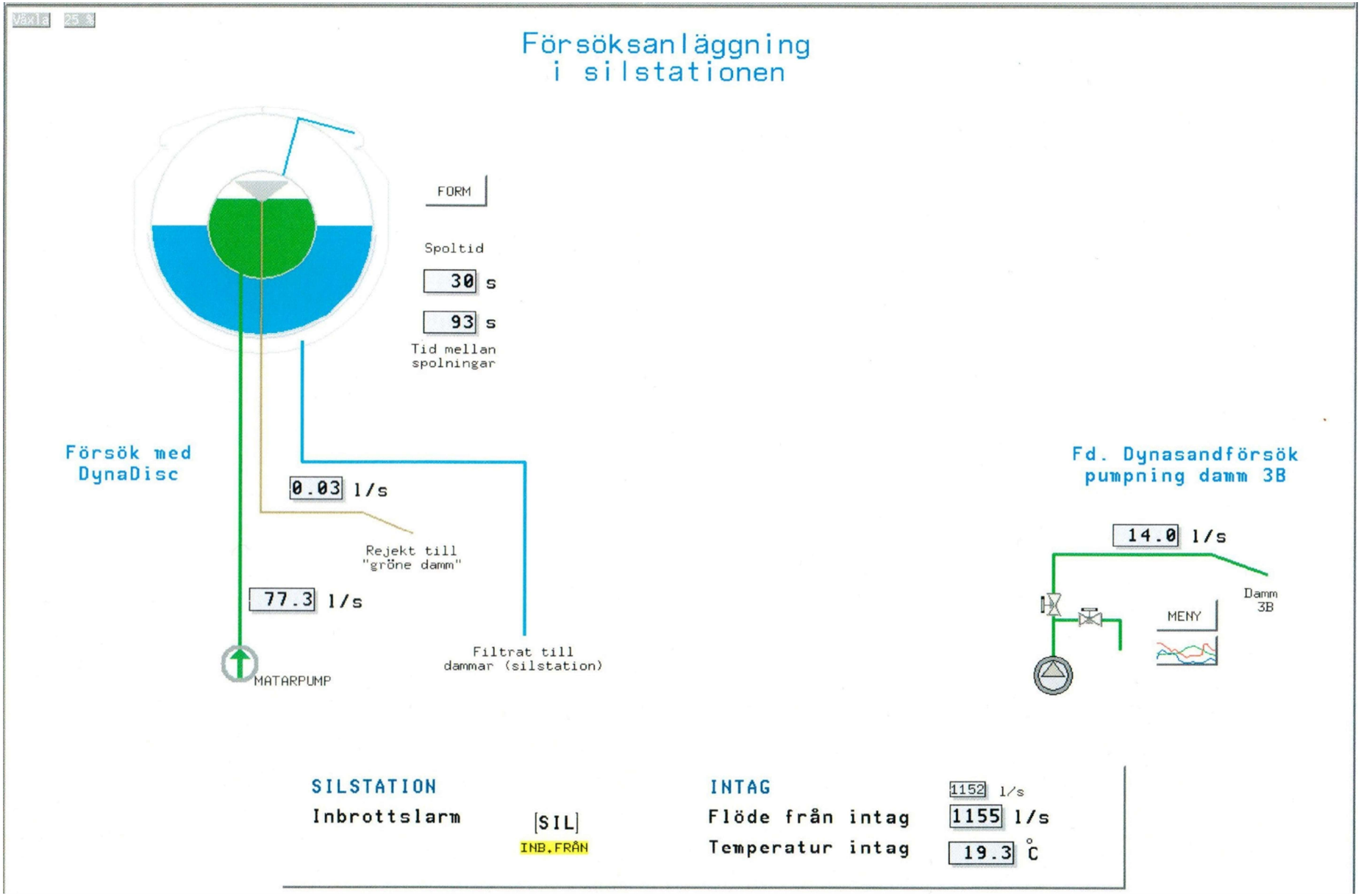
WORLD HEALTH ORGANIZATION, 2011. Guidelines for drinking-water quality, fourth edition, available on internet:
http://www.who.int/water_sanitation_health/publications/2011/dwq_chapters/en/

YAMAMOTO Y., SHIAH F-K, 2010: Variation in the growth of Microcystis aeruginosa depending on colony size and position in colonies. Ann. Limnol. – *International Journal of Limnology. 46 (2010)* p 47–52

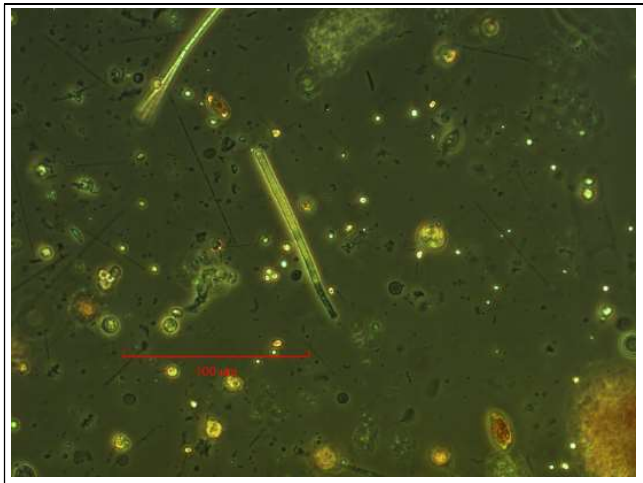
Appendices



Appendix 1: Drum filters view in control room

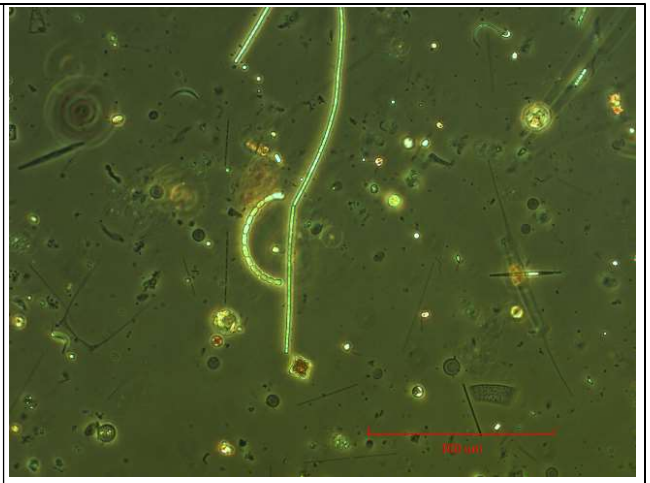


Appendix 2: Disc filters view in control room



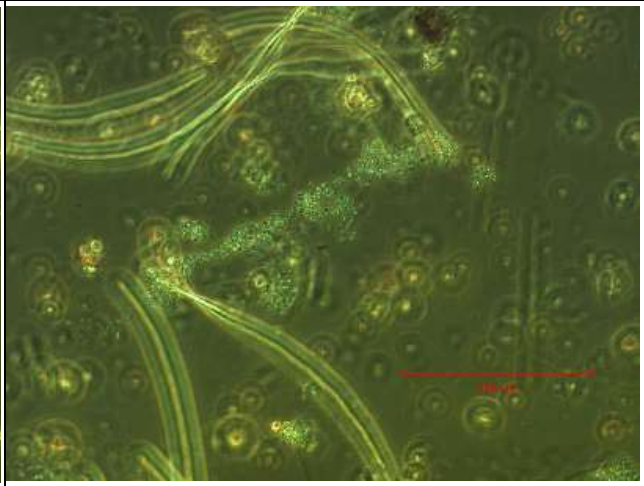
Aphanizomenon klebanhi

Anabaena macrospora

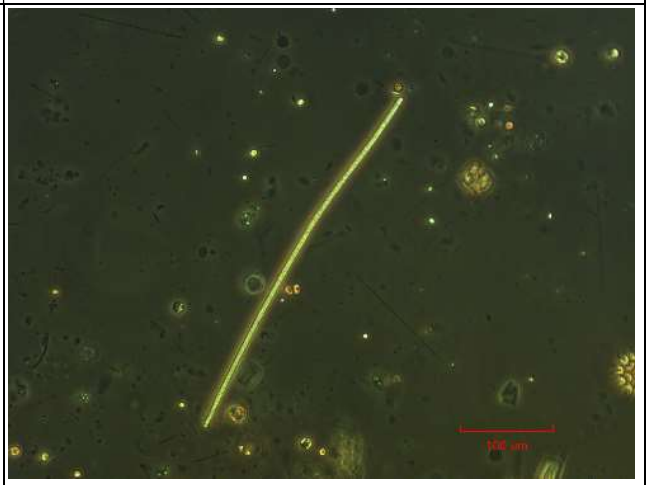


Anabaena lemmermmanii

Pseudoanabaena

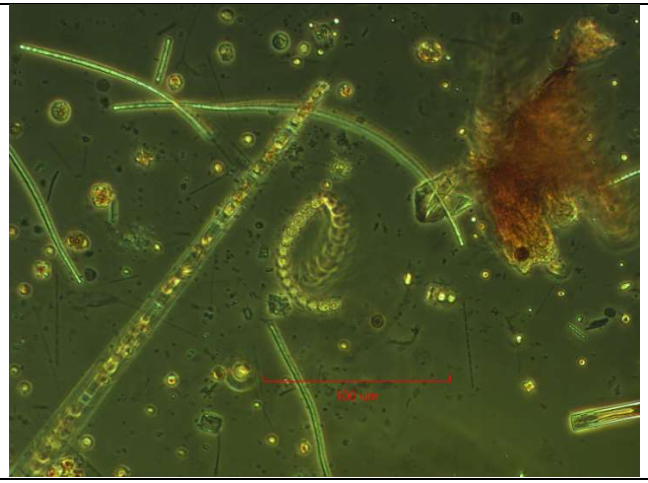
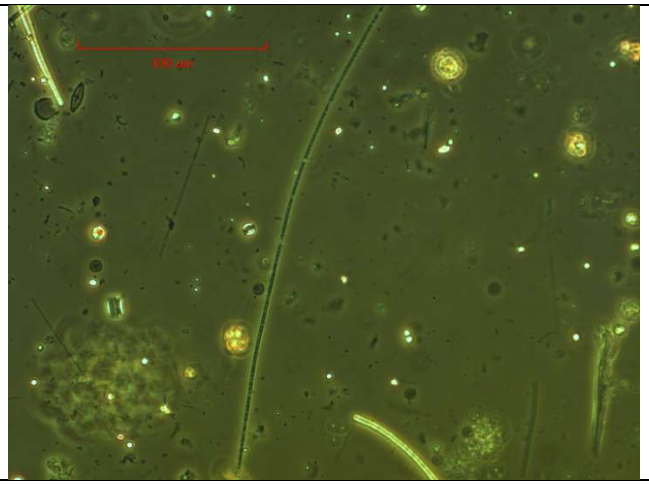
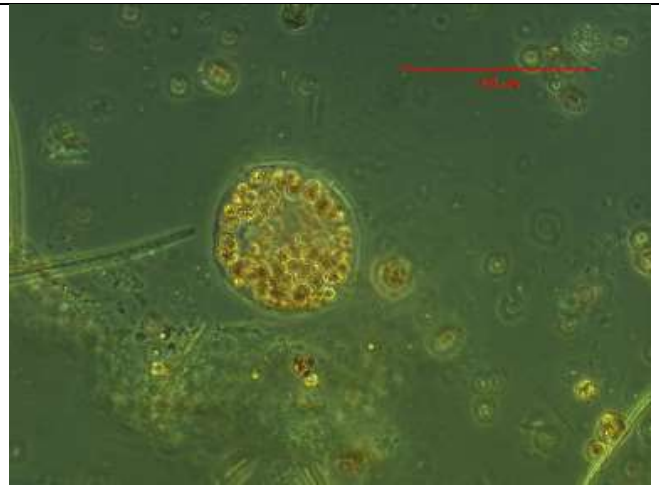
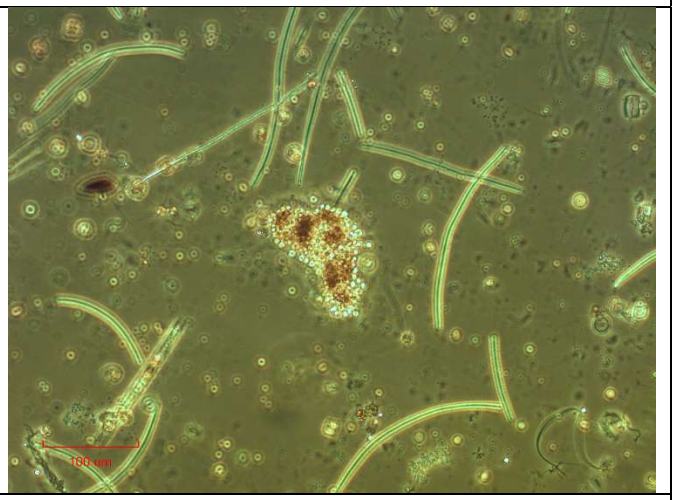


Picocyanobacteria



Planktothrix agardhii

Appendix 3 &4: Most common cyanobacteria found in raw water: summer 2016

		
Anabaena sp	**Anabaena flos-aquae**	**Limnothrix redekei**
		
Worochinia	**Microcystis wesenbergii**	**Microcystis sp**