Preface

This thesis is a part of a bachelor's degree in chemistry and biotechnology at Sør-Trøndelag University College, spring 2012. The task is provided by SIAT (Centre for Sports Facilities and Technology) at NTNU. At NTNU, SIAT was established as an interdisciplinary forum for education and research on sports. SIAT has chosen use of energy in swimming pools as a specific target subject in 2010 -2012. The background of the thesis is a desire to identify appropriate technologies for the purification of water in swimming pools, and to find a concept for a possible development task in cooperation with a Norwegian industry partner.

I would like to thank my supervisor Bjørn Aas at SIAT. His knowledge of the Norwegian swimming pool situation, contribution to technical information, useful network of contacts, and his availability for questions and help has been invaluable.

I want to thank the staff at Husebybadet for their help, support and to be allowed to use their equipment at the swimming pool area.

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Abstract

Purification technology for swimming pools is a field in rapid development internationally. In Norway, many swimming pools are closed due to obsoleteness and high energy and water costs. In addition, the growing concern about chlorinated organic compounds and their potential impact on the visitors, have required research on other options of purification and disinfection of swimming pool water.

Traditionally, the use of pressurized sand filters is considered a good purification technology for swimming pools. This method is well developed technically and is considered to be relatively robust with respect to the performance at varying loads. In Germany and England, glass is considered a relevant alternative, and many experiments with glass as filter media have been set up. Both the durability of the filter media and the filters purification performance can be expected to improve by changing the filter media to glass particles. The solution is not well known in Norway, and to the editors knowledge, it has never before been attempted to utilize in a public swimming pool in Norway.

The objective of this thesis was to evaluate crushed recycled glass as a media for filtration of swimming pool water. A pilot plant was installed in a partial flow with the conventional pressurized sand filters at Husebybadet, a public swimming pool in Trondheim, Norway. The pilot plant included a pump, a rotameter and a pressurized glass filter. Over a period of three weeks, data for the flow rate and pressure drop across both the sand and the glass filter was collected. In addition, the backwash water was analyzed with respect to suspended solids, total solids, residue on ignition and residual coagulant. The residual coagulant was tested to find out if the flocculent was functioning.

It was concluded that glass shows promising performance as an alternative to silica sand as a filtration media for pressurized filters in swimming pools. The results showed that the glass filter has as good as, or even better purification performance than the sand filter. The experiment may indicate that the glass filter require a shorter backwashing than the sand filter. In addition, it was concluded that the flocculent was well functioning.

The experiment has thus laid a foundation for further work, in terms of analysis of bacteria, chlorine organic compounds, duration of the backwashing and potential cost and energy savings.

Sammendrag

Prosjekttittel: ”Bruk av glass som filtermedia i behandlingsanlegg for svømmebasseng”.

Renseteknologi for svømmebasseng er et felt i rask utvikling internasjonalt. I Norge må mange svømmebasseng stenges på grunn av foreldelse og høye energi- og vannkostnader. I tillegg er det økt bekymring internasjonalt for klororganiske forbindelser og deres potensielle innvirkning på badegjestene. Dette har ført til økt forskning på alternative metoder for rensing og desinfeksjon av vann i svømmebasseng.

Tradisjonelt betraktes bruk av trykksatte sandfiltre som en god teknologi for svømmebasseng. Denne rensemetoden er godt utviklet teknisk, og regnes for å være relativt robust med hensyn på ytelse og varierende belastning. I Tyskland og England betraktes glasspartikler som et relevant alternativ, og mange eksperimenter med glass som filtermedia er blitt satt opp. Både levetiden til filtermediet og renseytelse kan ventes å bli forbedret ved å endre filtermediet til glass partikler. Løsningen er lite kjent i Norge, og det er ikke kjennskap til at det er vært forsøkt å bruke glass som filtermedie i et offentlig svømmebasseng i Norge tidligere.

Målet med denne bacheloroppgaven var å vurdere knust, resirkulert glass som filtreringsmedie for rensing av bassengvann. Et pilotanlegg ble installert i en delstrøm med de konvensjonelle trykksatte sandfiltrene på Husebybadet, et offentlig svømmebasseng i Trondheim, Norge. Pilotanlegget inkluderte en pumpe, et rotameter og et trykksatt glassfilter. Over en tre ukers periode ble data for vannmengde og trykkfall over både sand og glassfilter samlet inn. I tillegg ble tilbakespylingsvannet analysert med hensyn på suspendert stoff, totalt tørrstoff, gløderest og rest koagulant. Rest koagulant ble testet for å undersøke om flokkuleringsmiddelet som tilsettes før filtrene fungerte tilfredsstillende.

Det ble konkludert med at glass er et lovende alternativ til sand som filtreringsmedie for rensing av vann i svømmebasseng. Forsøket indikerer at glassfiltermediet krever kortere tilbakespyling enn sandfiltermediet. I tillegg ble det konkludert med at flokkuleringsmiddelet fungerte tilfredsstillende.

Forsøket har dermed lagt et grunnlag for videre arbeid, i form av analyse av bakterier og klororganiske forbindelser, varighet av tilbakespyling, og potensiell reduksjon i kostnader og energiforbruk.

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Abbreviations

TS	Total Solids
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
SS	Suspended Solids
VSS	Volatile Suspended Solids
DBP	Disinfection by-products
THM	Trihalomethane
HAA	Halo acetic acid
HAN	Halo acetone nitrile
CH	Chloral hydrate
TOC	Total organic carbon
SUVA	Specific ultra violet absorbance
G1	Glass filter sample one
G2	Glass filter sample two
G3	Glass filter sample three
S1	Sand filter sample one
S2	Sand filter sample two
S3	Sand filter sample three
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
IVM	Department of Water and Environment
SIAT	Centre for Sports Facilities and Technology

1. Introduction

Purification technology for swimming pools is a field in rapid development internationally. In Norway, many swimming pools are closed due to obsoleteness and high energy and water costs. In addition, the growing concern about chlorinated organic compounds and their potential impact on the visitors, have required research on other options of purification and disinfection of swimming pool water.

Traditionally, the use of pressurized sand filters is considered a good purification technology for swimming pools. This method is well developed technically, and is considered to be relatively robust with respect to the performance at varying loads. In Germany and England, glass is considered a relevant alternative, and many experiments with glass as filter media have been set up. Both the durability of the filter media and the filters purification performance can be expected to improve by changing the filter media to glass particles. [1-7] The solution is not well known in Norway, and to the editor`s knowledge it has never before been attempted to utilize in a public swimming pool in Norway.

The objective of this thesis was to evaluate crushed recycled glass as a media for filtration of swimming pool water. A pilot plant was installed in a partial flow with the conventional pressurized sand filters at Husebybadet, a public swimming pool in Trondheim, Norway. During the study, the hydraulic loading in the filters were set as equal as possible by adjusting the flow rate. The pressure and flow rate in the filters were logged each day, for a period of three weeks. Both of the filters were backwashed after an experimental period of one week. A new experimental week started after the backwashing of the filters. During the backwashing, water samples were collected from the backwashing water of both the sand and the glass filter. Three samples were collected during the backwashing for each of the filters. The water samples were analyzed to find the amount of suspended solids, total solids, residue on ignition and residual coagulant. Residual coagulant was tested to find out if the flocculent was functioning.

Glass has several properties that can make it a superior alternative to sand as filtration media [8]:

- Higher durability than silica sand, with a lifetime of up to 100 years, compared to sand with about 8-15 years.
- Consumption of chemical products can be reduced up to 50 %.
- Thanks to its aseptic condition, glass as filter media helps to reduce the presence of chloramines in the water.
- The operating time between filter cleaning periods can be prolonged.
- The filter cleaning time process is reduced.
- The pressure drop of the hydraulic system is reduced.

This thesis discusses the target subject at SIAT 2010-2012, which is research on the energy use in swimming pools. The aim of the study is to identify appropriate technologies for the purification of water in swimming pools, and to find a concept for a possible development task in cooperation with the Norwegian industry. ABC Enwa Tech has been involved as the industrial manufacturer and contact during the thesis.

A review of the current sand filter media technology and it`s challenges is given to explain the background of the thesis. Information about glass as a filtration media and a more in depth description of the filtration process in general is then given. Further, the analyses and measurements taken in the study are explained. The methods and the reviews are then followed by the results and discussion of the conducted experiments.

2. Theory

The water used in swimming pools is usually taken from the water distribution network and must meet drinking water standards.[9]

2.1. Hydraulics and water circulation

Section (§) 14 in the regulations of Swimming pools and bathing plants says that "any circulatory system should have a treatment plant with a filter system ".[9]

It is very important that the pool has good circulation, so no areas with a high level of pollutants are created. The entire pool should have water of equal quality. It is thus critical to position inlets, outlets and surface withdrawals in the best possible way. [10]

The water purification process in most swimming pools in Norway today goes as follows:

Water from the pool flows into the overflow channels and the bottom end. This water enters an equalization basin. From the equalization basin, the water flows through a coarse filter. The coarse filter stops hair, bits of band-aids, fabrics and other relatively large particles in the water. The water then goes through the circulation pumps, usually two items in parallel. Flocculent, acid or CO_2 gas is then added before moving on to the sand filters. [11]

The sand filters are backwashed at a fixed time interval, and this water is sent to a gray water tank. After going through the sand filter, the water flows through a heat exchanger to maintain a set temperature. Before the water enters the pool again the water is added a predetermined amount of chlorine through a dosing tank. At some pool facilities UV systems and activated carbon filter are also used in the cleaning process. The water that is added to the equalization basin from the water distribution network meets the requirements for drinking water. [11]

Figure 1 shows a detailed flow chart of the swimming pool plant at Husebybadet, the actual plant of the study. The different pools, pumps, valves, filters and chemical dosage system are all included in the diagram. The arrows indicate the flow direction. The UV installation is not operating at the present moment.

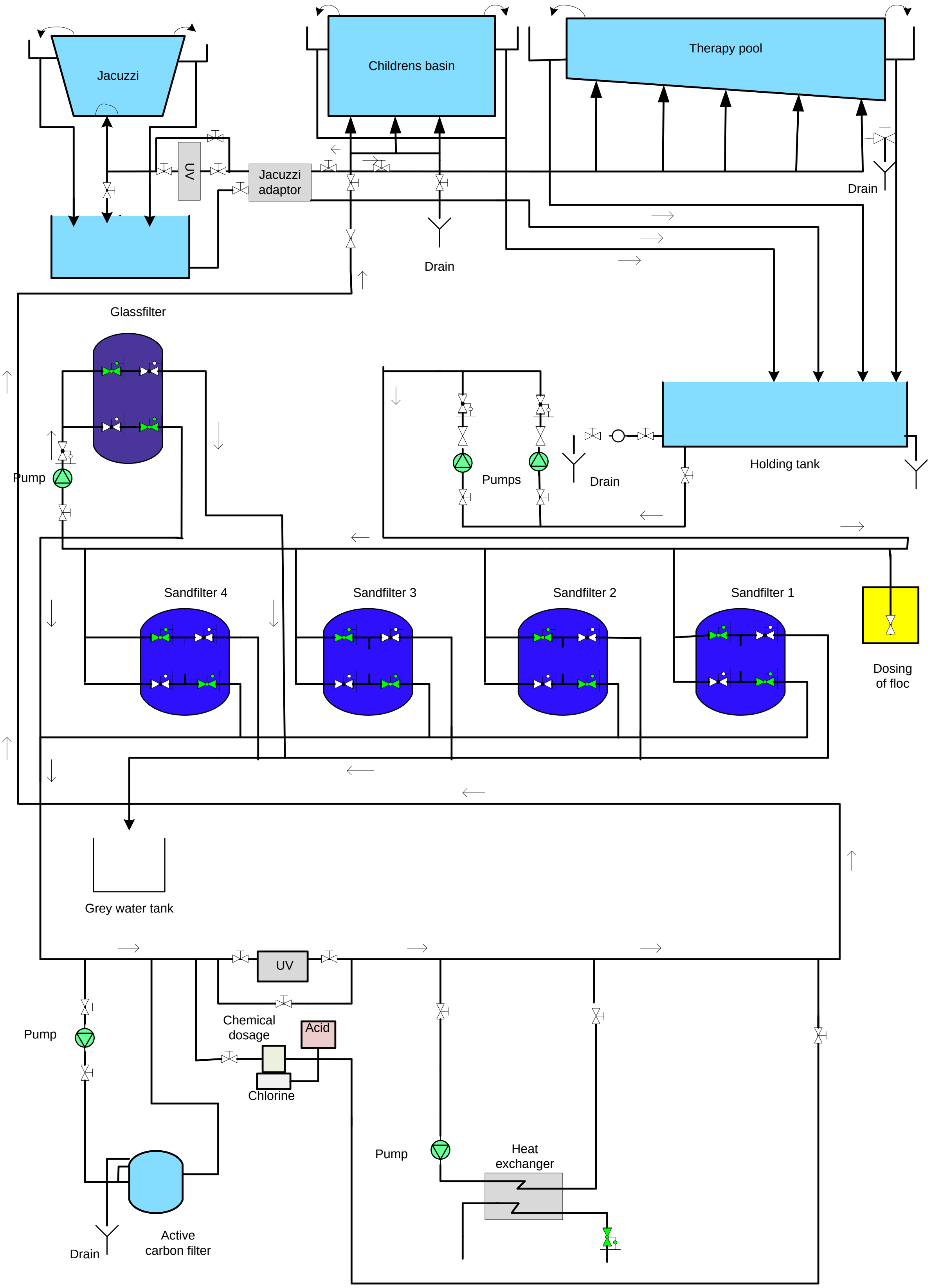

Figure 1: Illustration of the entire water cleansing system at the therapy pool at Husebybadet.

2.2. Filtration

Swimming pool water contains algae, urine, sweat, hair, excess skin and other organic and inorganic matter from the swimming pool users. Filtration is a step in the water treatment process that is used for removing particulate matter from the water. The water quality and the clarity of the water are improved by removing these particles. In addition, the water contains microorganisms that can cause waterborne illnesses. Filtration is therefore almost always required in conjunction with chemical disinfection to assure that the water is free of these pathogens. [12]

The filtration of the pool water is considered to be the most important step in the water purification process. The filter should stop all insoluble impurities in the water. The most common cause of poor water quality is caused by reduced work of the sand filters. The water circulation determines the dimensions of the filters at the swimming pool plant. Water circulation is determined by the pool`s size, design and bathing load. [9]

2.2.1. Historical perspective

Filters have been used for water purification for thousands of years. Indian lore mentions that filtration through sand and gravel was used to purify water as early as 2000 years BC. The Romans and Hippocrates also used filtration as a purification technique. [12]

During the 1750`s in France, the commercialization of filtration technology started. But it was in England and Scotland, during the 1800`s that the practice of filtering water through engineered systems began. Various filter media and flow directions were tested. Backwashing with reverse flow and different filter concepts were tried out. [12]

It started out with slow sand filtration, followed by rapid filtration in the 1880`s in the United States. The first regulation, the Surface Water Treatment Rule (SWTR), was passed in 1989, and required mandatory for filtration of municipal water. This breakthrough for water filtration came when it was discovered that the filtration step led to a decrease in the number of cases of water-borne diseases. [12]

2.2.2. Filtration in general

The filter system is normally a depth filter, where the particles in the water are separated from the water through the water passage by a bed of granular material (filter grain). [9] The filtration technique mostly used in Norway is rapid filtration. The filtration media is processed to a fairly uniform size, and the filters can operate at a higher hydraulic loading due to the uniform sizing. The particles are removed when they adhere to the filter grains. The entire depth of the filter bed is used to remove the particles, and the process is thus called depth filtration. [12]

For filtration of swimming pool water it is common to use mono media filters, which means that it is one layer with filter media. For drinking water other alternatives are also used, like dual media, which have two layers of filter media, and trimedia or mixed media, which have three layers with e.g. one layer with anthracite at the top, sand in the middle layer and garnet and ilmenite as the bottom layer. [12] Normally there is more than one filter. This gives greater flexibility and acts as a safeguard. [10]

2.2.3. Sand filters

Sand filters have been in use for more than 150 years, and is currently the most common filter material. The frequent use of sand filters is due to their reliability, robustness, and because they are easy to operate. [13] Figure 2 shows the sand filters at Husebybadet arranged in parallel.

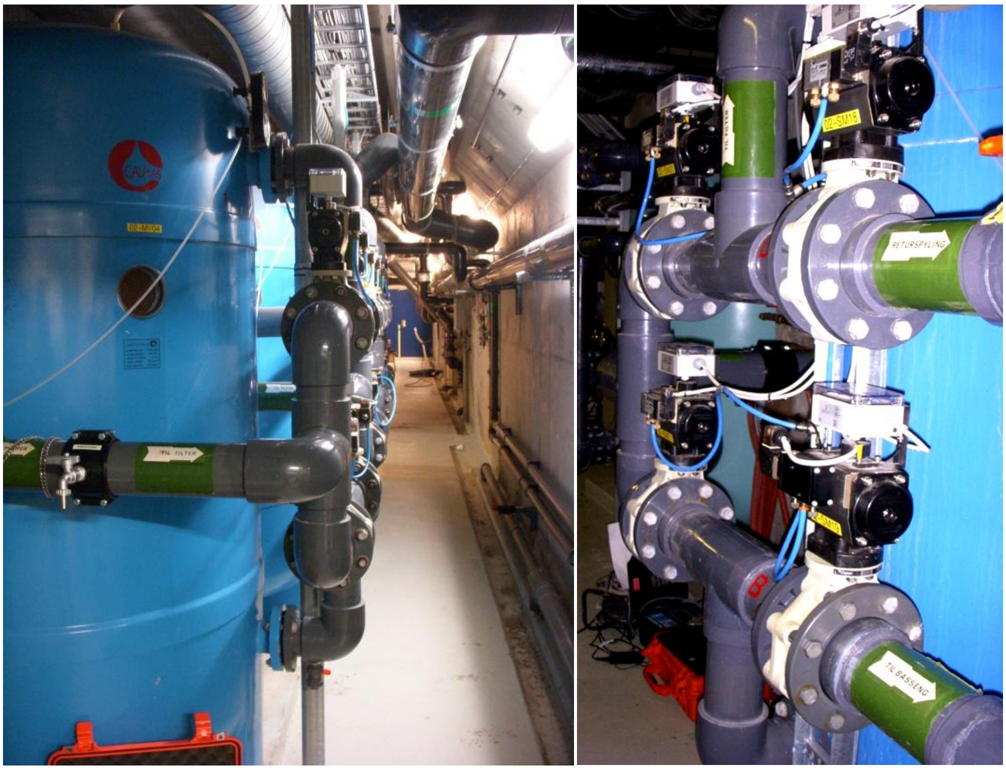

Figure 2: The sand filters at Husebybadet arranged in parallel. The filter nearby (picture to the left) is the sand filter used in the study. The picture to the right shows the valves which are opened and closed during backwashing and filtration.

There are four different types of filters in normal use; open sand filters, pressurized sand filters, pressurized diatomite filters and vacuum diatomite filters. [9]

Open sand filters typically have a bottom of concrete and are designed as a rectangular iron-concrete construction. Open sand filters are less used because they require much space, and the consumption of rinsing water is big. These types of filters have the advantage of direct observation of the filter process. Thus a problem can be fixed quickly. Open sand filters are very reliable, durable, and have few problems. However, the high velocity can cause formation of craters in the filter sand. [14]

Closed sand filters can be made of concrete, plastic, stainless steel or surface treated steel sheets, the latter being the most common. The circulation pump pushes the water through the filter material, and these filters are thus called pressurized sand filters. The closed sand filters are most commonly used because they have very good filter characteristics and requires less space than the open sand filters. The problem with the closed sand filters is that the filtration process is more difficult to observe, and it is thus difficult to detect problems. [11]

There are two types of sand used as filter media; fine-grained sand (diatomite) and coarse – grained quartz sand, the latter has to have flocculent added. Diatomite filters requires very little space and provides good water quality. The filtration process takes place when contaminants in the pool water are held back by passing through a layer of diatomite powder, due to straining. Diatomite filter material is derived from fossilized diatoms. [9]

Contaminated pool water is transferred by gravity, from the equalization tank, to the vacuum diatomite filter. It is then filtered through the filter screens with diatomite while the circulation pumps draw water from the filter canister and transfers the purified water to the pool. Diatomite particles must not under any circumstances get into the pool water, as these are harmful. The filter speed of the diatomite filter is 2-4 m/h. Diatomite is less and less used in Norway because the diatomite dust can damage the lungs, and needs a rigorous safety system. [9] During the filtration process most of the particles will lie at the sand layer surface. The finest particles will attach to the surface of the sand grains throughout the sand layer. [15]

2.2.4. Glass filter

As an alternative to the conventional sand filter media, there is a great deal of interest in glass as a replacement. Some researchers and producers believe that sand as a filter media has reached its peak performance, and that it is time for fresh thinking. [16]

In UK and other countries, glass is not recycled, just dumped on landfills. This is especially true for colored glass which cannot be recycled as glass containers. The color of the glass doesn`t matter in e.g. water purification processes, and can thus be used as a filter media. The recycled glass can be processed into smaller pieces and used as a filtration media, replacing the sand in e.g. pressurized sand filters. [16]

Glass filter media is often recycled glass that is crushed and ground down to a size close to a sugar grain. Glass is inert, meaning that it does not react chemically with any of the swimming pool chemicals. The entire thickness of the filter is operating, meaning there is less need for backwashing of the filters and less water- and chemical use. In sand filters, bio films can occur, causing clogging of the filter. This should not happen with a glass filter. [2]

Recycled glass is readily available and inexpensive. The fine sand used today must be ordered from abroad, and is not cheap. It is very important that the glass used as filter media, is cleaned and crushed to meet the requirements for a filtration media. If recycled household glass is not cleaned and sterilized it may contain organic matter which can react with chemicals in the water. [2]

It is claimed that glass filters have longer life than sand filters, and also that glass filters will provide a more effective water treatment, resulting in better water quality than with sand filters. It is also said that it is possible to save power and energy by using glass as a filtration media. In addition, glass has a lower specific density than sand, and less glass is needed in the filter container than with sand. [2] It is also said that formation of biomaterial is reduced with glass as a filtration media, compared to sand, because of the higher permeability of glass. [3]

The glass filter media in the current experiment was recycled glass treated in a special process to get a smoother surface and a uniform grain size (about 0.6 mm).The glass media is also activated in order to attract particles. [8] Figure 3 shows the pilot plant installed at Husebybadet. The pilot plant includes the glass filter on the picture to the left and the pump and rotameter system at the picture to the right.

Figure 3: The glass filter used in the experiment installed at Husebybadet is shown in the picture to the left. The picture to the right shows the pump and the rotameter installed before the glass filter as a part of the pilot plant.

The producer of the filter media, Kripsol, claims that their glass filter media “Vitrafil active filter glass” has advantages like; longevity, chemical products saving, water and energy savings, chloramines reduction and hydraulic benefits. [8]

Another producer of glass filter media, Dryden Aqua, has done lot of research and experimental setups with their glass filter media AFM (active filter media). Aquariums and fish farms needs to have perfectly clean water, free of chloramines and other toxic matter. The AFM media has thus been the standard filter media used by many Norwegian fish farms for the last 10 years. Dryden Aqua has experience with bio marine and biological mechanisms, and in cooperation with the European Commission and the Waste resource action program in UK, they did a 1.2 million Euro Research project to develop and optimize the process. The difference with this filter glass media is that it is not a waste recycled product. AFM is a combination of virgin grade glass and glass manufactured by Dryden Aqua, and the chemical composition of the glass is changed to give the filter media surface active properties. [7]

A laboratory experiment with cullet as filter media for swimming pool water treatment was set up in Poland. During the experiment, turbidity and total organic carbon were measured for a sand filter and a glass filter. The experiment showed comparable results for the filtration efficiency for both of the filters. Recycled glass was considered a useful material for optional filtration media. [1]

2.3. Mechanisms in the filtration process in general

2.3.1. Granular filtration

Granular filtration means all types of filtration media which consists of grains in different shapes and sizes. It is assumed that the same theory is also covering the glass filter media. Granular filters can remove particles much smaller than the pore openings in the filter. The pore openings in the filter is normally in the range of 35-50 μm, while the smallest particles that are removed will have a diameter down to about 1 μm. The separation is dependent on the particles attaching to the filter grains. [9]

Axial fluid pressure, friction and electrostatic attraction forces holds the particles on to filter grains or previously deposited particles. Erosion forces caused by water flow ensure disassembly of particles or particle fragments from the filter grains or previously deposited particles. If there are any available contact surfaces, the isolated particles could attach itself again further down the filter. However, there will be a gradual clogging of the filter as time since the last backwash increases. [9]

The effectiveness of the filter depends on the number of contact opportunities between the water particles and the filter grains. In addition, it is essential that the particles are so strongly attached to the filter grains that they are able to resist the erosion forces that occur in the filter. Erosion forces in the filter will gradually increase as a result of particle deposition and the associated clogging of the filter. [9]

The contaminants in the water are transported to the filter through the pipe system. The velocity of the contaminants inside the filter tank is much less than the velocity in the pipe system. The particles will thus move more slowly in the flow direction in the filter, than in the pipes. [11]

The water flow through the filter material is smooth and without turbulence, a laminar flow. [14] Contaminants will, due to chemical and physical forces of attraction (van der Waals forces or electrostatic forces), bind with the filter grains. The porosity through the filter depends on the filter surface that is exposed to contamination. Low porosity through the filter bed is caused by contamination, decreasing water flow. Some impurities can thus draw further down in the filter bed. The size of the impurity determines how far down into the filter bed the impurity goes. [11]

Granular filtration consists of five mechanisms; Mechanical strain, sedimentation, adsorption, chemical activity and biological activity.

Straining is a mechanism of particle capturing. If the ratio of the particle diameter to grain diameter is greater than 0.15, a closed-packed arrangement will cause straining. If the particles are smaller than this, they can pass through the media. Figure 4 shows a typical straining of a particle, between three granular media grains. [12]

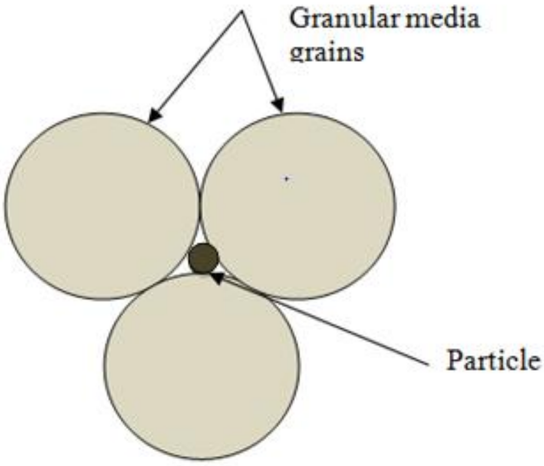

Figure 4: A spherical particle is captured by spherical media grains. The process is called straining, and occurs if the ratio of the particle to the granular media grain is greater than a certain amount. [12]

Big particles are mainly trapped on the surface of the filter bed. This is independent of the filter speed, but is dependent on the size of the granular filter particles. The smaller the filter grains are, the smaller the pores become, and smaller are the particles going through the filter. When particles are trapped, the pore size of the filter decreases. This clogging will increase the straining. [13]

Sedimentation is one of the dominating mechanisms of the particle transport to the filter grains, and is dependent on the gravitation, the inertia of the particles and the barrier effect of the filter grains. In addition, the size and density of the particles is important for the sedimentation process. The normal size of the particulate matter in the swimming pool water is in the colloidal area, which is about 0.001 -1 μm. Because of the small size of the particles it is desirable to get the particles to aggregate to make bigger particles. Bigger particles are easier to trap at the filter surface. To resolve this problem, it is common practice to add coagulants or flocculants. [9]

Adsorption is the most purifying mechanism in the filter process. Finely suspended matter is removed in addition to the colloidal matter. Adsorption means holding of a particle on the surface of a solid filter grain. [13]

2.3.2. Filtration rate

The flow rate through the filter divided by the surface area of the filter bed is called the filtration rate. The unit for filtration rate is volumetric flux reported in m/h. [12] The filtration efficiency is decreasing with increasing filtration rate. [10]

At a big public pool the requirements to the water quality is strict, and the number of filters has to be chosen. The overall capacity of the plant, the maximum dimensions of a single filter, the effect of filtration rate changes during backwashing and economic considerations, influences the choice of how many filters the plant should have. Four or more filters are normal at most water treatment plants. When one of the filters is backwashed and out of service, the filtration rate increases in the remaining filters. It is therefore beneficial to have more than two filters, because the flow rate then changes less when maintenance is performed. [12, 13]

There are a number of different filtration rate control systems. At Husebybadet a declining-rate filtration control is installed. With this type of system, all filters operate at the same head loss with each filter receiving a different quantity of influent water based on the accumulated solids (head loss) in the filter. There are no devices to measure the flow, and all the filters receive water from a common influent flow. The flow through each filter decreases as solids accumulate. The greatest flow goes through the filter that has been backwashed most recently. This method is simple to operate, but there are many disadvantages. Because there is no control of the flow rate in the filters, the designed filtration rate can be exceeded in the beginning of a filtration run. [12]

Head loss is the difference between the highest water level in the filter tank above the filter, and the water level at some downstream location. There are different methods of controlling the head loss. At Husebybadet, the head loss is maintained nearly constant, while the filtration rate declines as solids accumulate in the filter. [12]

The hydraulic loading of the sand filter can be determined from the equation (1);

$$\frac{Q_{sand\ filter}\left(\frac{m^3}{h}\right)}{A_{sand\ filter}(m^2)} = HL\left(\frac{m}{h}\right) \tag{1}$$

where;
$A_{sand\ filter}$ is the area of the sand filter,
$Q_{sand\ filter}$ is the flow through the sand filter,
HL is the hydraulic loading. [17]

The hydraulic loading found from equation (1) can be used to determine the flow rate of the glass filter from equation (2);

$$Q_{glass\ filter} = HL\left(\frac{m}{h}\right) \cdot A_{glass\ filter}(m^2) \tag{2}$$

where;
$Q_{glass\ filter}$ is the flow rate through the glass filter,
HL is the hydraulic loading,
$A_{glass\ filter}$ is the area of the glass filter. [17]

Normal flow for a high rate sand filter is usually between 25 to 50 $m^3/m^2/h$. [13]

It is important to run the filters with a constant velocity, to minimize the release of particles from the filter. Disassembly of the deposited material can easily happen if there is a rapid change in the pressure. [9]

Loss of head can occur if valves, fittings or other appurtenances disturb the water flow. In addition, friction loss in the pipe can result in head loss. Treatment plant piping and pumping stations are strongly influenced by valves and fittings, and these disturbances are a major part of the total losses. [18]

2.3.3. Backwashing

The water flows downward through the filter bed during the filtration process. The particles are collected, and the filter bed is filled with particles and accumulated material. [12] When the flow through the sand filter is significantly reduced due to clogging of the filter, the filter has to be backwashed. Backwashing means cleaning of the filter. During backwashing, the water is pumped bottom up and the sand is fluidized. Fluidizing means that the sand particles are moving relative to each other and this causes the dirt particles to be released from the sand surface and to be washed away with the water. The particles with the lowest sinking rate settle at the top of the filter, and the coarsest particles at the bottom. [15]

The backwashing stage is a very important stage of the filtration stage. The backwashing process consists of four steps: [12]

1. Isolation of filter influent and effluent lines with valves.
2. At the same time the waste wash water and the backwash supply valves are opened.
3. The backwash water is then directed upward through the filter bed and this upward flow flushes captured particles up and away from the filter bed.
4. When the backwash is finished, the valves are reversed and the filter is again back in service. The backwashing step can be done both manually and automatically at some swimming pools. Some plants also use air in the backwashing process, in addition to water.

When a filter is backwashed, the media is fluidized, and the void volume increases. This causes an overall expansion of the bed. The correct bed depth is important for efficient filtration. The grain size determines the precise depth of the filter bed. Fine sand can have a quite shallow bed. The expansion of the bed during backwashing is also one reason to have the right filter bed height. There must be room in the filter for the bed to expand. [12, 13]

Figure 5 shows the water stream in a pressurized filter during filtration and during backwashing.

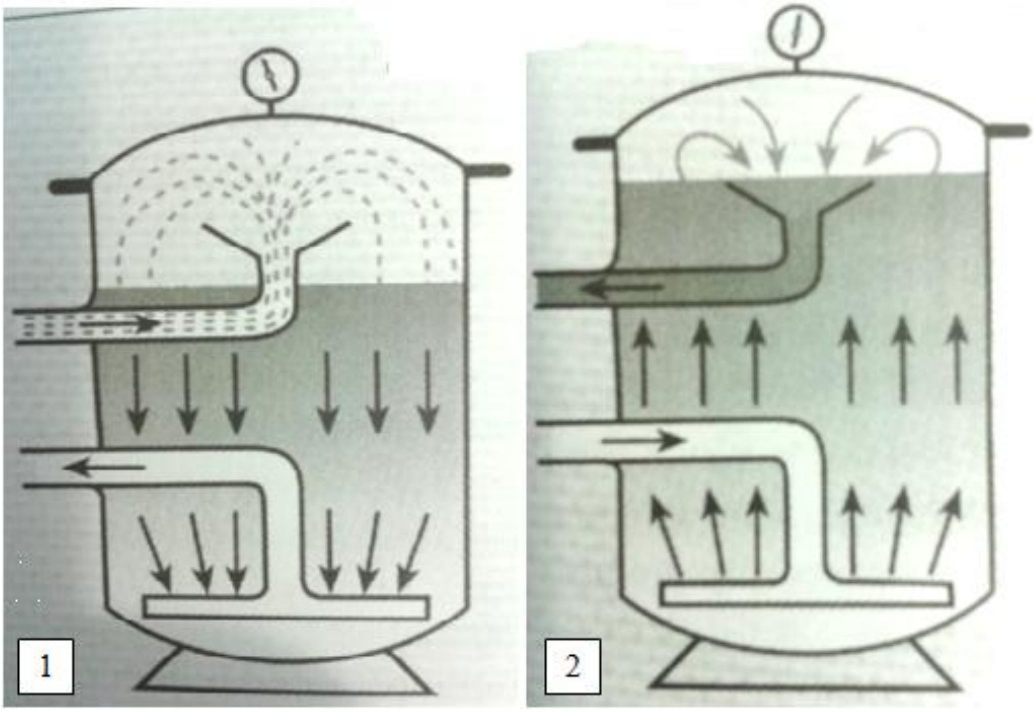

Figure 5: Picture 1 shows the water stream in a pressure filter during the normal filtration process. Picture 2 shows the water stream in a pressure filter during the backwashing process. [17]

Figure 6 shows two sand filters with different amount of sand filter media. One of the filters has too much sand filter media, while the other is correctly filled.

Figure 6: The picture to the left shows a correct filled sand filter, while the picture to the right shows a sand filter with too much sand.

At Husebybadet there are four sand filters and one activated carbon filter. This makes it possible to backwash one filter while the other filters are operational. The backwash flow rate can be determined by equation (3);

$$Q_{backwash\ filter} = HL \cdot A_{filter} \tag{3}$$

Where;
$Q_{backwash\ filter}$ is the flow rate during the backwash of the filter,
HL is the hydraulic loading,
A_{filter} is the area of the filter. [17]

The filter bed should expand about 15-25 % during backwashing. Thus the backwash flow must be rather fast for the filter bed to fluidize enough.0.5-1.0 mm sand grains should have a backwash flow of at least 30 $m^3/m^2/h$, while coarse grains needs faster flow. It is important though, that the flow is not too fast. If the flow is too fast, the bed could expand beyond the overflow level. [13]

Figure 7 shows the difference in the filter bed during filtration and backwashing. The bed is expanded during backwashing.

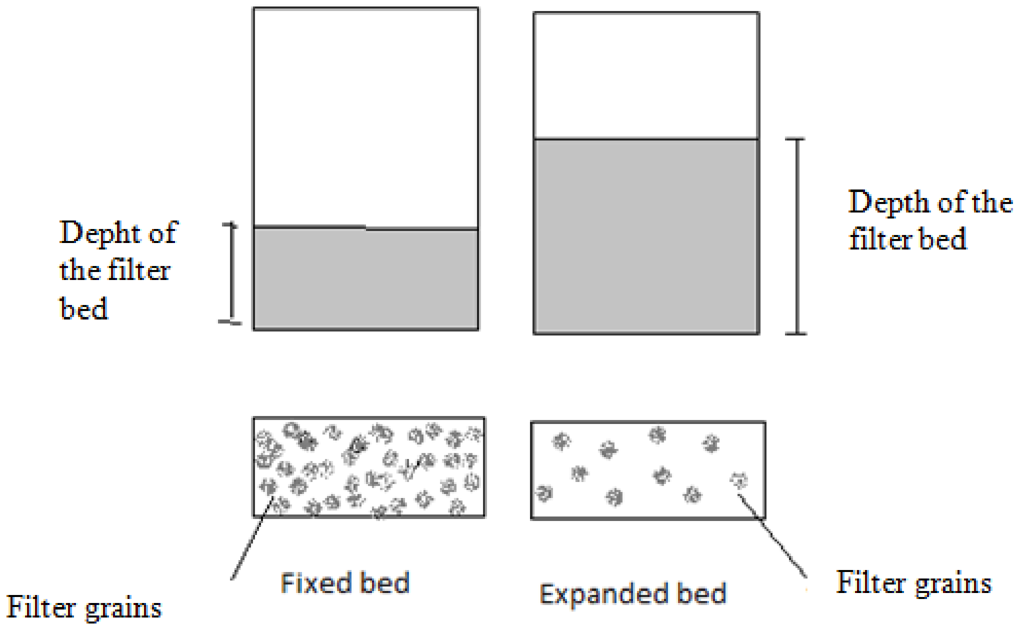

Figure 7; An expanded and a fixed bed during backwashing. The media grains are touching each other during filtration, but the bed expands during backwashing because the void volume increases when the media is fluidized.[12]

The backwash flow for the sand filters at Huseby is approximately 45 $m^3/m^2/h$.

The recommended backwash flow for the glass filter is $40\,\frac{\frac{m^3}{m^2}}{h} = 40\,\frac{m}{h}$. [8]

2.4. Particles, flocculation, coagulation and suspended solids

2.4.1. Particles in the water

Raw water may contain particles of different shape and size. It is common practice to distinguish between suspended deposed particles, suspended not deposed particles and colloidal particles. Suspended deposed particles means for example sand that would settle if the water was stagnant. Suspended not deposed particles means particles that would remain suspended in the water because of their own motion, such as algae and other organisms. Colloidal particles mean particles that are so small that they would settle extremely slowly due to their large surface area in relation to the volume. If the water contains particles and turbidity the disinfectant will work less efficiently because of the particles surrounding the microorganisms protects them from the disinfectant. [10]

2.4.2. Coagulation and flocculation

Colloidal particles carry an electrical charge (usually negative) and will thus be stable. They will thus not agglomerate and be separated from the water on their own. By the addition of a suitable chemical to the water, the charge could be affected. The forces of repulsion between the colloidal particles are overcome, and the adhesive forces between the particles are established. This process is called coagulation. The added chemicals are often called coagulants, and they are often salts from aluminum or iron. When the coagulants are added to the water, the chemicals will immediately disassociate to ions, and further react with the water through several intermediates, and precipitate as a metal hydroxide. The solubility of the precipitated metal hydroxides depends on the pH of the water during the reaction. [19]

Physical forces stabilize the particles in the water. Among other, the surface charge on the particles plays a dominant role in the stabilization process of the particles. Most particles carry a negative charge when they are suspended in the water. Because almost all the particles are carrying the same charge, they repel each other instead of attracting each other. This property causes the particles to remain in suspension instead of aggregating. During the flocculation and coagulation process, the forces of stabilization are overcome, causing the particles to attract each other and aggregate in flocs. [20]

The coagulation and flocculation process goes as follows:

1. The particle`s charges are destabilized. The adding of a coagulant with opposite charge of those of the suspended particles causes a neutralization of the particle`s charge. The particles are able to stick together when the charge is neutralized, and slightly larger particles, called micro flocs, are formed. The micro flocs are very small and are not possible to see without a microscope.
2. The second step is a mixing stage, where the particle`s sizes are increased from micro flocs to visible suspended particles. This step is called flocculation, and the flocs created during this step are called pin flocs and macro flocs. Pin flocs are visible flocs which are formed during collisions between micro floc particles. [20]

Figure 8 shows the processes of forces of attraction and repulsion with and without added flocculent.

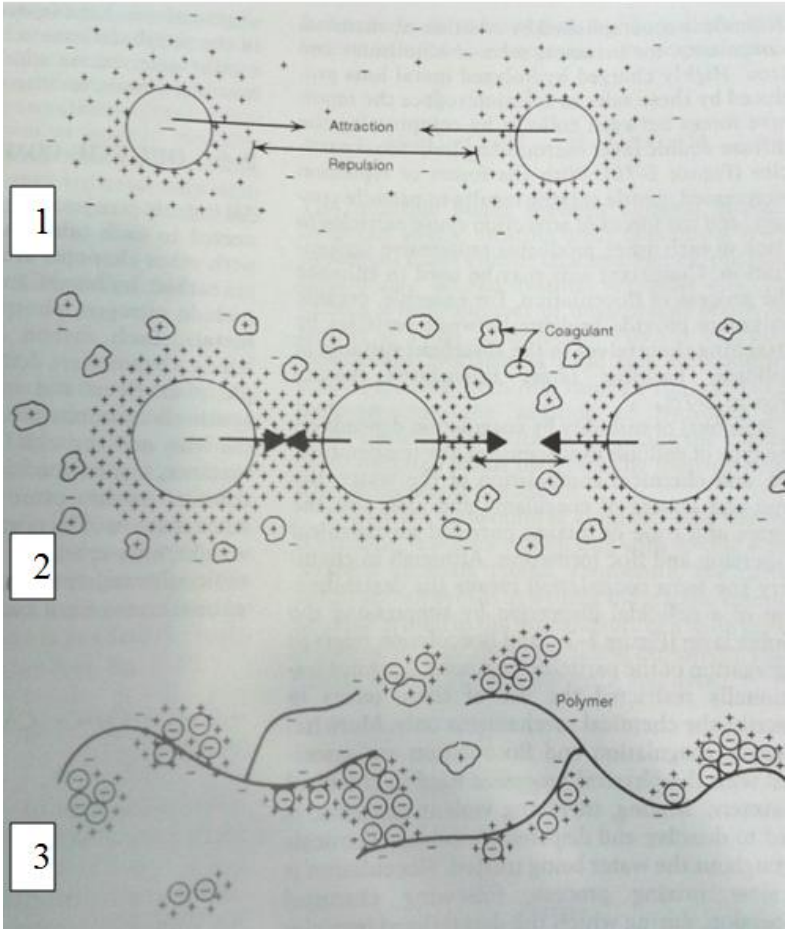

Figure 8 : The picture 1 shows the repulsion forces between the colloidal particles in the water. Picture 2 shows the attraction forces between the colloidal particles in the water after adding of coagulant. Picture 3 shows the polymer which are made when the particles aggregate in flocs. [12]

Especially the removal of cysts and oocysts of *Cryptosporidium* and *Giardia* is an important feature of the flocculants. Due to the small size of these protozoans (4-6 microns in diameter), addition of flocculent is required. The cysts and oocysts are relatively resistant to chlorine disinfectants, and without the formation of the flocks, the cysts and oocysts would pass through the filter. [10]

Sand filters in combination with flocculent leads to stable and clear pool water. Flocculent is constantly added by the circulation pump, and the effect of the flocculent is dependent on the pH in the water. If the pH is too high, it can cause cementation of the sand layer because of calcium deposition. [11]

The flocculation process should take place in the filter tank room, and the flocculent should thus be added before the filter. [21]

At Husebybadet, (PACl) Poly aluminum chloride ($Al_a (OH)_b (Cl)_c (SO_4)_d$) is used as the flocculent.

Figure 9 shows the system used for continuous addition of flocculent at Husebybadet.

Figure 9: The dosing station of the flocculent at Husebybadet. The arrangement on the wall is the continual dosing machine.

It is very important to have correct dosage and mixing of the flocculent. If too much flocculent is added, the particles will get a positive charge and become stable again. Less flocculent, can lead to insufficient flocculation. When adding the correct amount of flocculent the charge is neutralized and the particles will aggregate in flocs. It is not just the amount that has to be proper, it is also very important that the mixing of the flocculent is good. [12]

There are several parameters which have to be considered, when the type of coagulant should be chosen. The concentration and type of particulates, water temperature, water quality and the characteristics of the coagulant are all parameters that have to be thought of before choosing the coagulant. [12]

The flocs formed during flocculation are gelatinous, and can impair filtration if blockage or breakthrough is caused. To avoid this, good backwash is needed and dosage rate needs to be kept at a minimum. The best way to dose the coagulant correct, is to have a chemical dosing pump continuously dosing coagulant. [13]

2.4.3. Suspended solids and total solids

Common tests in polluted water include suspended and dissolved solids. Suspended and volatile solids are often used for the definition of industrial or municipal wastewater. The amount of solids removed can be used as a definition of operational efficiency of various treatment units. [18]

During the backwashing, a relatively large amount of waste water is produced. The waste water from the backwashing includes solids in low concentrations of about 100 to 1000 mg/l. The efficiency of pre- coagulation and sedimentation affects the content of total solids.
It is common to say that the volatile solids in wastewater are a measure of the biodegradable organic matter. This is a rough estimate, because many inorganic salts volatilize during ignition, and combustion of many pure organic compounds leaves ash. [18]

Suspended solids in a water sample can be found from the equation (4); [18]

$$X = \frac{1000(b - a + c)}{V} \tag{4}$$

where X is the content of suspended solids in the water sample in mg/l.
a is the weight of the filter in mg.
a_0 is the weight of three blank filters in mg.
b is the weight of the filter with dry matter in mg.
b_0 is the weight of three washed and dried blank filters in mg.
c is the blanks weight loss, $c = \frac{a_0 - b_0}{3}$
V is the filtrated sample volume, ml

Further, the residue on ignition can be found from equation (5); [18]

$$Y = \frac{1000(d - a + e)}{V} \tag{5}$$

where Y is the residue on ignition in mg/l.
a is the weight of the filter in mg, d is the weight of the filter with residue on ignition in mg.
d_0 is the weight of three ignited blank filters in mg.
e is the blanks total weight loss up to and including ignition in mg. $e = \frac{a_0 - d_0}{3} = c + f$, f is the blanks weight loss at ignition in mg $f = \frac{b_0 - d_0}{3}$.
V is the filtrated sample volume in ml.

Finally the Ignition loss, that is, the volatile matter can be found from equation (6); [18]

$$Z = \frac{1000(b - d - f)}{V} = X - Y \tag{6}$$

where Z is the ignition loss/ volatile matter in mg/l.

The analysis of the suspended solids measures the solids that are attached to the filter during the filtration. This means that some of the smallest particles and ions can go through the filter, and thus not be included in the results. By measuring the total solids in a water sample, all the solids are included in the results. Salts and ions go through the filter, but are included in the result of total solids. [22] The amount of total solids can be found from equation (7);

$$TS = \frac{m_R - m_S}{V} \cdot 10^3 \tag{7}$$

where TS is the total solids in grams per liter water sample.
m_R is the mass of the evaporation dish and the residue after drying in grams,
m_S is the mass of the evaporation dish in grams
V is filed quantity of sample in milliliters. [22]

2.5. Challenges and health issues with the current water treatment system, disinfection by-products and trichloramines.

Chlorine is one of the most widely used disinfectants in swimming pools because of its many benefits. Recently however, the disadvantages associated with the chlorine disinfectant have become a growing concern. When chlorine reacts with organic matter such as skin, hair and sweat from the visitors, potentially harmful by-products can be formed. [23]

According to the technological institute in Denmark, 0.6 g dissolved nitrogen, 5 g of dissolved organic matter, 1.5 g of particles and 10^7-10^8 pcs. of microorganisms is released per person in the water. [14]

By-products formed are referred to as DBP (disinfectant by-products) and are, amongst other things, trihalomethane (THM), bound chlorine (chloramines), halogenating compounds, haloacetic acid (HAA), halo acetone nitrile (HAN) and chloral hydrate (CH). Among the DBP, THM is the most widely known, and most research is done on THM. HAA, HAN and CH are less studied because measurements have shown that these DBP`s do not exist in large amounts. Because of this, there is little information and research on other DBP`s than THM. [24]

Swimming pools can also contain chemical contaminants such as nitrogen and carbon-containing components. Urine and sweat from bathers are typical sources of nitrogen compounds and consists mainly of urea. HOCl (hydro chlorous acid) in the water reacts with the nitrogen-containing components to form chloramines, especially NH_2Cl (monochloramine) and NCl_3 (nitrogen-trichloride). The odor of chlorine that is often felt in the pool is derived from these chloramines. [25]

Trichloramines and other chlorine amines are quickly released from the water in the swimming pool to the surrounding air, as these compositions are relatively volatile. Water turbulence, dosage of chlorine, the number of bathers and nitrogen compounding components all have an impact on the exposure amount the bathers receive through inhalation. [26]

The carbon-containing components may form DBP such as chloroform and chlorinated acetic acid. In the case of DBP, a great concern has particularly risen on chloroform and chloramines. The reason for this is that these components are very volatile. Today, there are no regulations or maximum value of the amount of chloramines in the air, and it is possible that there are relatively high concentrations of these substances in the air around the pool, especially if the air circulation system is not working adequately. Trichloramine is equally irritating as pure chlorine, and it is anticipated that chloroform is carcinogenic. [25]

Examinations have been made among elite swimmers, lifeguards, babies attending baby swimming and school children who have swimming lessons. All groups had an increased risk of developing asthma and respiratory, nose, eye and throat irritation. [14] The root cause of these problems is the high concentrations of THM and other DBP at the surface of the swimming pool. [27]

In particular, there is great concern over infants attending baby swimming. Infants are often in contact with more water due to ingestion during swimming, as well as baby skin being more permeable. It is believed that babies get as high doses of chloroform during a swimming lesson, as pool attendants get over a course of three weeks. [26, 28]

Exposure to pathogens in the water increases the longer the swimmers reside in the water and it is estimated that a person consumes an average of 100 ml of water during normal swimming training. In addition, the water penetrates the skin, and vapors can be inhaled. [29]

If the water drained into the pool from the water distribution system contains humus and other organic material, this may also react with chlorine and form DBP`s. This concentration, however, is much lower than the organic matter carried by the swimmers, so it will not be a great contributor. High levels of trichloramines have also shown a relation to corrosion of stainless steel material in swimming pools. [14]

3. Materials and experimental methods

3.1. Materials

Table 1 lists the different equipment that was used in the experimental part of the thesis.

Table 1: List of equipment used for the experimental part of the thesis.

Flow meter(Controlotron, 1010 PVN/PVDN Nema clamp-on multi-function flow meter)	GF/C filters (d=47 mm, pore size 1,2 µm)
Rotameter (ABC- Enwa Tech)	Heating furnace (105 °C)
Manometers (4 units, 0-4 bars)	Annealing furnace (muffle oven)(550 °C)
Taps (ABC- Enwa Tech)	Tweezer with flat ends
Alumina ignition dishes	Analytical balance
Porcelain bowls	Vacuum filtration set up
Plastic bottles (1 l)	Small plastic tubes (40 ml)
ICP-MS	HNO_3(0.1 M)

3.2. General procedure

Husebybadet, a public swimming pool in Trondheim in Norway, was used as the pilot plant in the experimental part of the thesis. Husebybadet has four different pools, and two purification systems. One system for the sports pool, and one system for the therapy pool (Figure 1), the children's basin and the jacuzzi. The purification system for the sports pool is not discussed in this thesis. Husebybadet had four pressurized sand filters installed in the purification system of the therapy pool. One of these was compared with the glass filter. The pressurized glass filter was installed by ABC Enwa Tech AS in a partial flow of the other filters. The glass filter had an additional pump. The glass filter was at a higher level than the sand filters, and needed a pump so the water got the correct flow rate. Details of the dimensions of the glass filter and the sand filter can be found in appendix A.

3.3. Flow and pressure measurements

The sand filters were run under constant pressure and variable flow. The flow through one of the sand filters was measured with a clamp-on flow meter after it had been recently cleaned. The flow measured was used as a reference value for the glass filter. The flow through the glass filter was adjusted so the two filters got equal hydraulic loading.

A clamp- on flow meter was installed at the pipe with the influent flow at the sand filter. This flow meter logged the flow through the sand filter every minute throughout the experimental period. The flow meter was based on the Doppler Effect and ultrasound. A flow meter is a device that is measuring the water flow through a pipe at a certain time. [30] The Doppler Effect is a phenomenon where the frequency of sound or light waves depends on the relative velocity between observer and source. The flow meter used in the experiment had a transmitter and a receiver. The relative motion was measured by the frequency shift between the ultrasonic source (the receiver) and the fluid carrier. [31] Figure 10 shows the experimental set-up of the flow meter that was installed at the sand filter inlet.

Figure 10: Experimental setup of the flow rate measurement on the sand filter. The picture to the left shows the data logger while the picture to the right shows the transducer and reflector installed at the water pipe.

The flow that should go through the glass filter was calculated from the flow rate in the newly backwashed sand filter. The flow rate was read to be 30 m^3/h. The equation (8) and (9) shows the calculation of the flow rate of the glass filter.

The hydraulic loading through the sand filter was;

$$Q_{sandfilter} = \frac{30\,\frac{m^3}{h}}{1{,}2\,m^2} = 25\,\frac{m}{h} \qquad (8)$$

the flow rate through the glass filter was set to;

$$Q_{glass\ filter} = 25\,\frac{m}{h} \cdot 0{,}32\,m^2 = \underline{8\,\frac{m^3}{h}} \qquad (9)$$

The recommended backwash flow is $40\,\frac{\frac{m^3}{h}}{m^2} = 40\,\frac{m}{h}$. [8] Equation (10) shows the recommended flow rate of the backwashing of the glass filter;

$$Q_{backwash\ glass\ filter} = 40\ \frac{m}{h} \cdot 0{,}32\ m^2 \ = \underline{12{,}8\ \frac{m^3}{h}} \qquad (10)$$

In addition, the flow through the glass filter was registered once a day by a rotameter installed prior to the glass filter.

Figure 11 shows the rotameter that was installed prior to the glass filter. This was a part of the pilot plant, and was used to read the flow rate .

Figure 11: The rotameter installed prior to the glass filter, used for readouts of the flow values.

Manometers were installed at the inlet and outlet of the sand and glass filter. These manometers were read once a day. Figure 12 shows the manometers which were installed on the inlet and outlet of the sand and glass filter.

Figure 12: Experimental setup of the manometers, for the pressure measurements. The picture to the left shows the manometer on the top of the glass filter.

3.4. Water samples from the backwash water

The following measurements were made on the backwash water of both glass and sand filter:

- Suspended solid (SS)
- Residue on ignition
- Total solid (TS)
- Residual coagulant (Aluminum)

SS, TS and residue on ignition was performed at the laboratory of IVM. The residual coagulant analysis was performed by Syverin Lierhagen at NTNU, Department of Chemistry. The water samples were collected in plastic bottles (0.5-1.0 l) during backwashing. The water samples were collected three times during the backwashing. The first experimental week there was no accurate timing of when in the backwash cycle the samples were collected. The second and third experimental week the water samples were collected after 0.5, 2.0 and 3.5 minutes during the backwashing period. The backwashing of the filters takes four minutes, and was performed after a filter run of one week. Figure 13 shows the bottles and tubes that were used for collecting the water samples. The small tubes were used for the samples analyzed on residual coagulant.

Figure 13: Water samples collected in the third experimental week.

Figure 14 shows the sample taps that was installed at the backwashing pipes at Husebybadet. These taps were used for collecting the water samples.

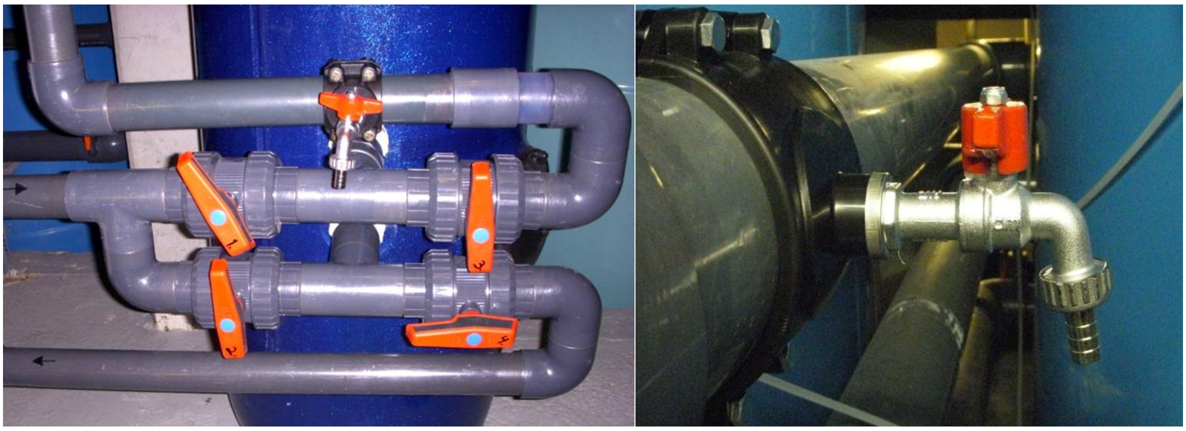

Figure 14: The sample taps installed at the backwashing pipes at Husebybadet on the glass filter to the left and the sand filter to the right.

3.4.1. Suspended solid (SS)

The analysis of the suspended solid was performed according to the Norwegian Standard NS 4733; "Water analysis, Determination of suspended solids in waste water and their residue on ignition". A known amount of water samples was filtered through a Whatman GF/C filter with 1.2 μm pore size and 47 mm diameter. The filters were weighed before the water samples were filtered, and then put in aluminum dishes. After filtration the filters were dried for two hours at 105 °C in the aluminum dishes. After drying, the filters were cooled in desiccators and weighed. [32] Figure 15-17 shows the experimental set-up of the suspended solid analysis.

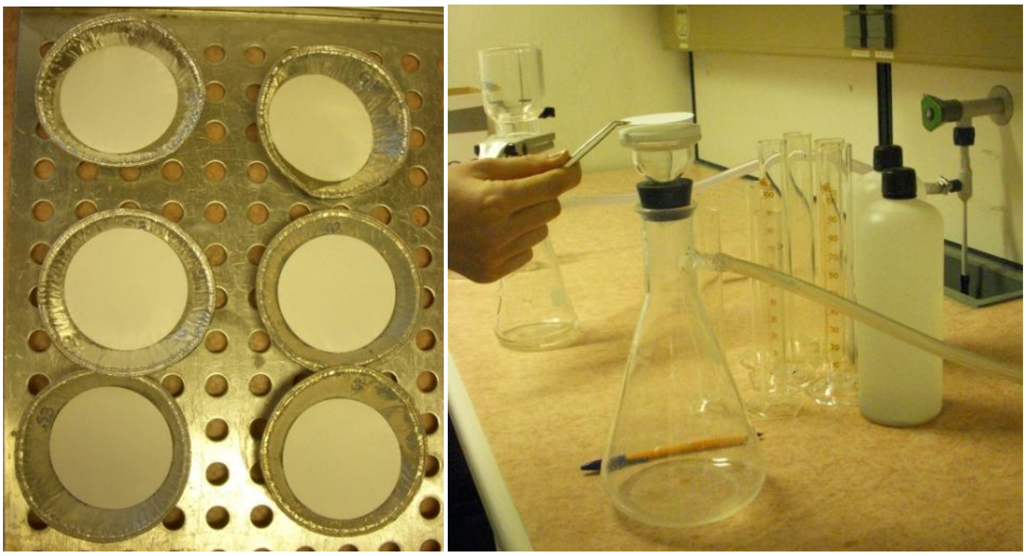

Figure 15: The picture to the left shows the GF/C filters in the aluminum dishes before filtration. The picture to the right shows the setup of the filtration system.

Figure 16: The picture to the left shows the filtration setup. The picture to the right shows the filter after filtration.

Figure 17: The picture to the left show the filtration setup after filtration of the water samples. The picture to the right shows the GF/C filter after filtration of the water samples, before drying.

3.4.2. Residue on ignition

The analysis of the residue on ignition vas performed according to the Norwegian Standard NS 4733; “Water analysis, Determination of suspended solids in waste water and their residue on ignition”.

For determination of residue on ignition, the filters in aluminum dishes from the analysis of suspended solids were combusted in a muffle oven at 550 °C. After combustion, the dishes with filters were cooled in desiccators. The weight of the filters and residue on ignition were measured on an analytical balance. [32]

3.4.3. Total solid (TS)

The analysis of the total solid was performed according to the Norwegian Standard NS 4764, “Water analysis, Total residue, and fixed residue in water, sludge and sediments“. Evaporation dishes of aluminum (porcelain the first week) were weighed before adding the water samples. A known amount of the water samples were then added in the aluminum dishes, and dried in a drying chamber at 105 °C, for 24 hours. The aluminum dishes with the dried matter were then weighed. [22]

3.4.4. Residual coagulant, Aluminum

The analysis of residual coagulant was done at NTNU, department for Chemistry, by Syverin Lierhagen. This test was done due to figure out the amount of aluminum in the water samples, to find out if the flocculation process was functioning well. The water samples were collected from the original one liter bottles, into small plastic sample tubes (40 ml). The samples were then unraveled in acid (0.1 M HNO_3) to get solute particles. The samples were then analyzed by using ICP-MS (Inductively coupled plasma mass spectrometry), which is a type of mass spectroscopy that detects metals and non-metals at very low concentrations. The sample is first ionized and then separated and quantified by the mass spectrometer. [33]

4. Results

4.1. Flow and pressure curve

Figure 18-21 shows the flow rate of the sand filter measured with the clamp-on flow meter during four different experimental set ups. Figure 18 shows a half experimental week, while the other shows full experimental weeks. All the figures show a decreasing flow-rate throughout the week. In addition all the figures show fluctuation drops during the curves. The drops occurring are caused by backwashing of the other filters. All the flow rate values from the measurements of the clamp-on flow meter can be studied in further details in the CD attached to the last page.

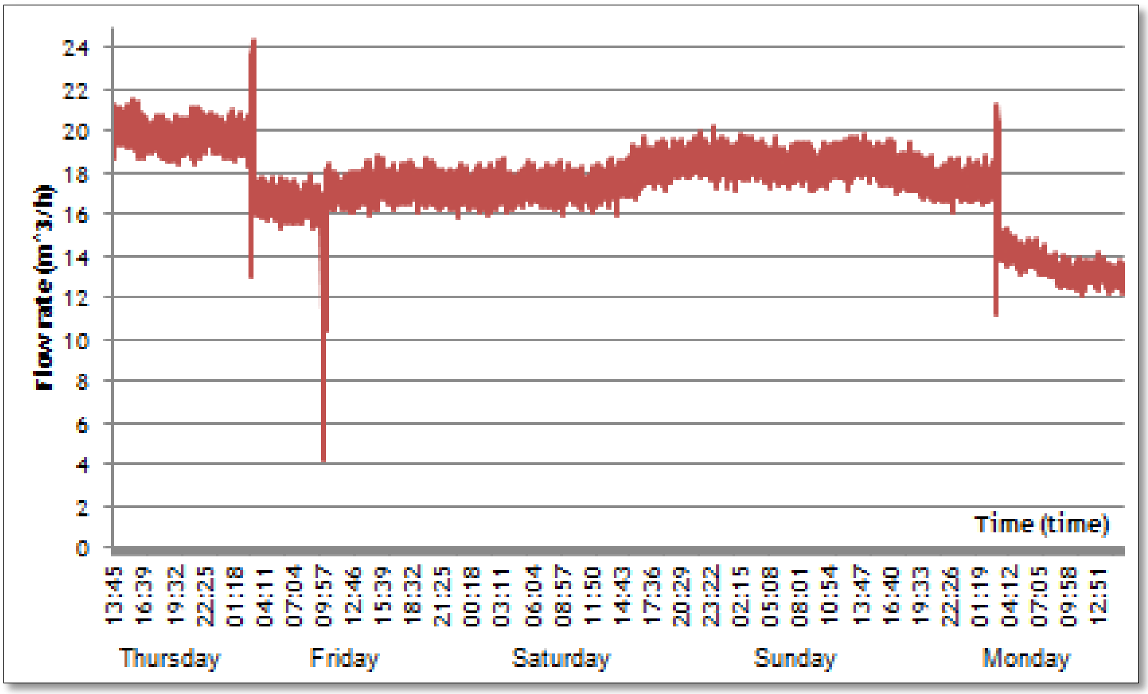

Figure 18: The flow rate curve of the sand filter in the end of week 15, measured with the clamp-on flow meter.

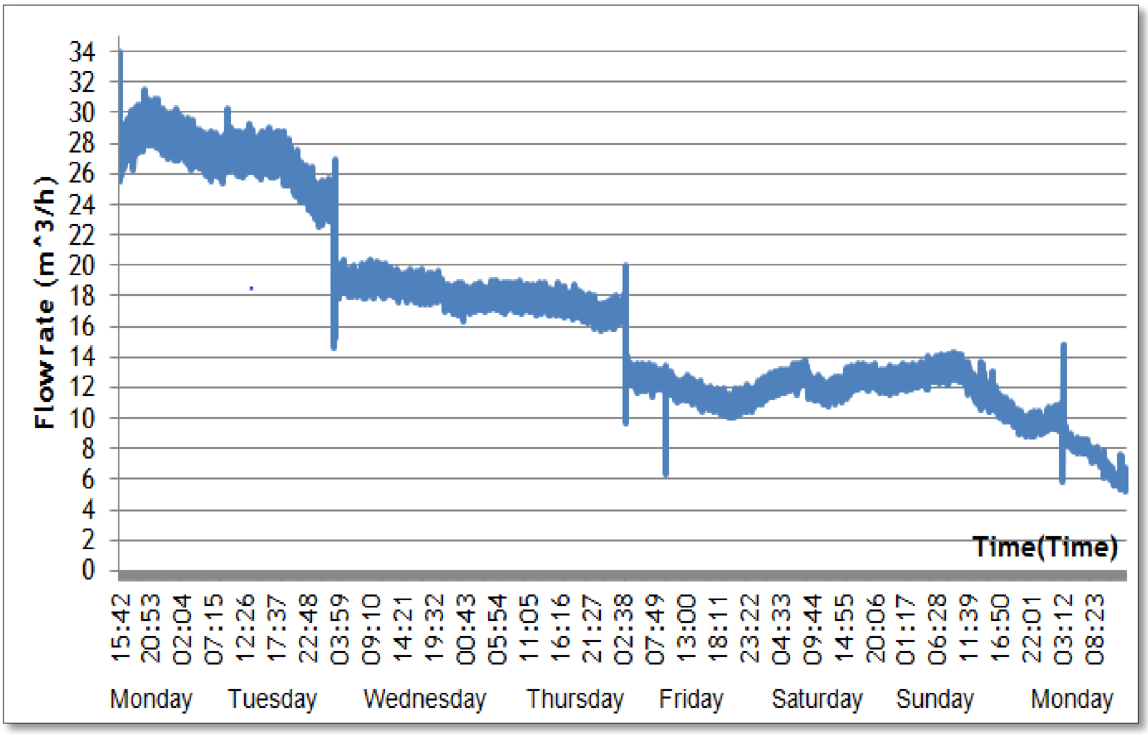

Figure 19: The flow rate curve of the sand filter during week 16, measured with the clamp-on flow meter.

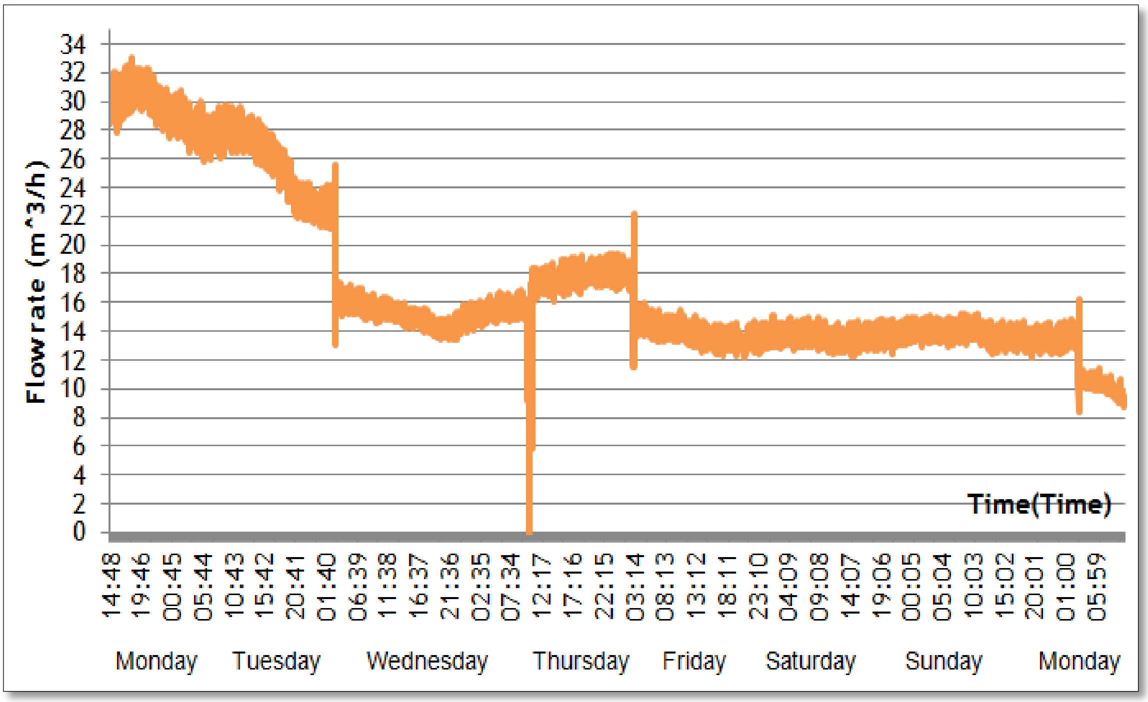

Figure 20: The flow rate curve of the sand filter during week 17, measured with the clamp-on flow meter.

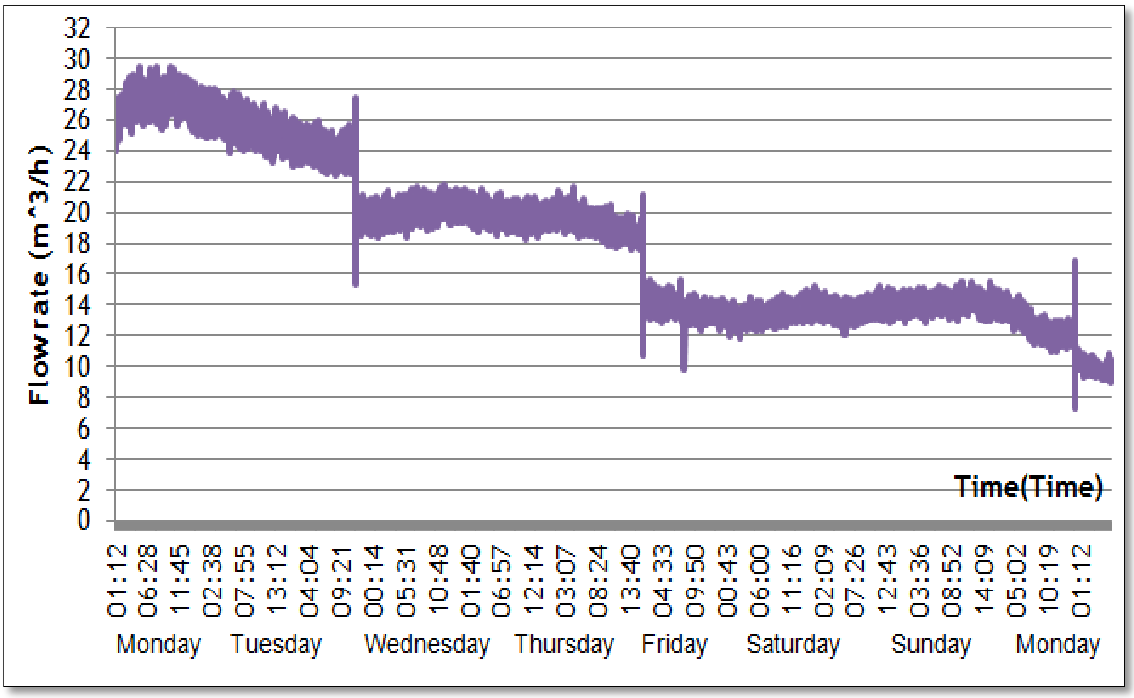

Figure 21: The flow rate curve of the sand filter during week 18, measured with a clamp-on flow meter.

Figure 22 and 23 shows the behavior of the hydraulic loading of the filters during the first and second experimental week. The line with triangles shows the curve of the glass filter, after calibrating the rotameter against the flow meter. The calibration curve can be seen in appendix C, and the values of the hydraulic loading are listed in table B-5 and B-6 in appendix B. The lowest spot circle on figure 23 shows the flow rate in the glass filter after reducing the inlet pressure to the starting point.

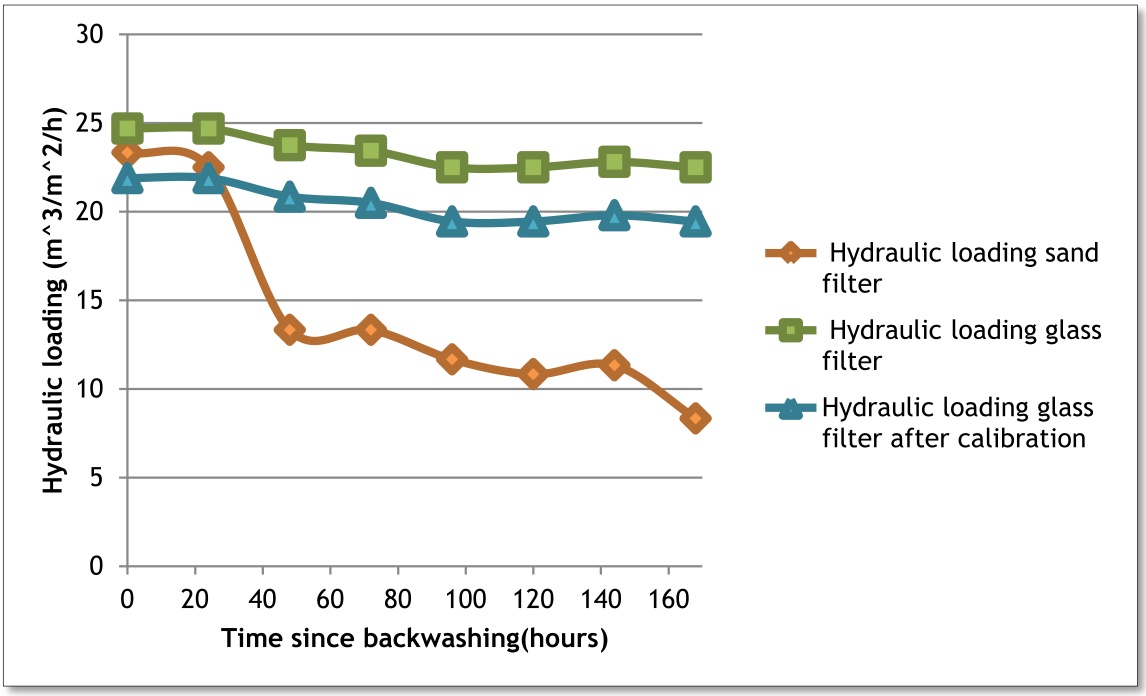

Figure 22: Hydraulic loading in the filters during first experimental week.

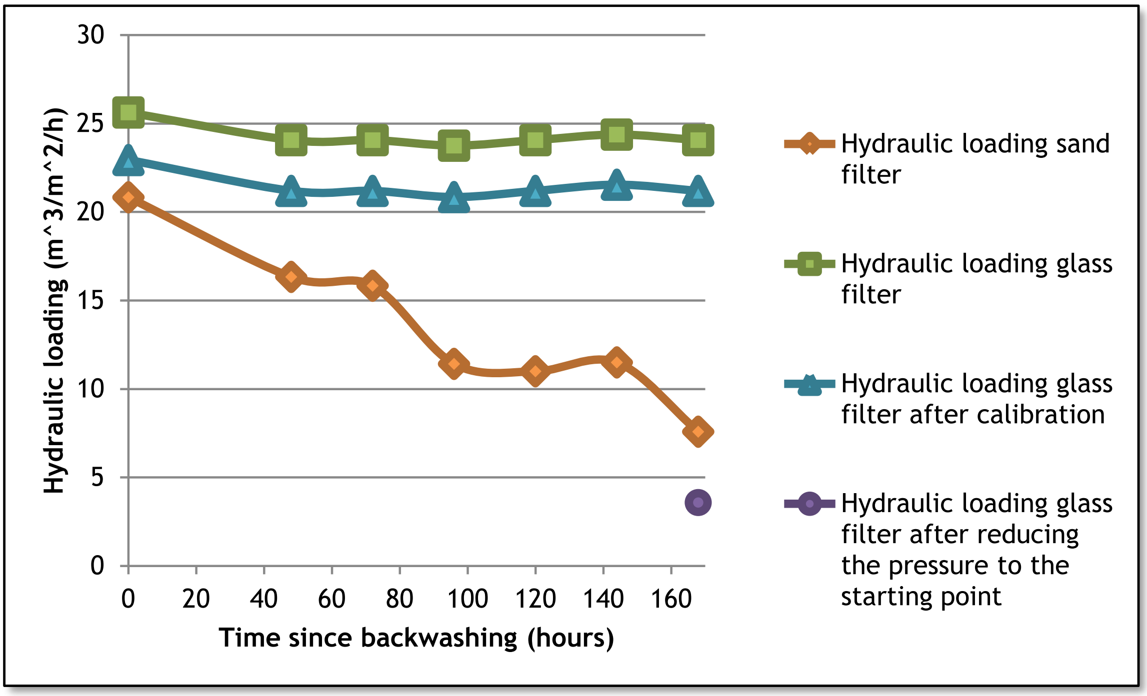

Figure 23: Hydraulic loading in the filters during second experimental week.

Table 2 shows the approximate amount of water that has gone through the filters during one experimental week. The calculations were done using excel and can be seen in equations (13)-(15), table D-1 and D-2 in appendix D. Table 2 shows that the amount of water through the filter is significantly greater in the glass filter than in the sand filter. The values are coarse, and are used to make a rough estimate of the differences in amount of water that goes through the filters.

Table 2: Amount of water through the filters during an experimental week.

	Area under curve ($m^3/m^2/h$)	Amount of water through the filter (($m^3/m^2/h$)·h)
Sand filter week 1	2372.00	398496.00
Glass filter week 1	3422.57	574991.72
Sand filter week 2	2373.00	341712.00
Glass filter week 2	3602.54	518765.22

Figure 24 shows the behavior of the flow rate in the sand filter with the correct amount of sand during a filter run of one week. The big fluctuation in the end of the curve is caused by backwashing of the filter itself. The other fluctuations during the filter run are caused by backwashing of some of the other sand filters.

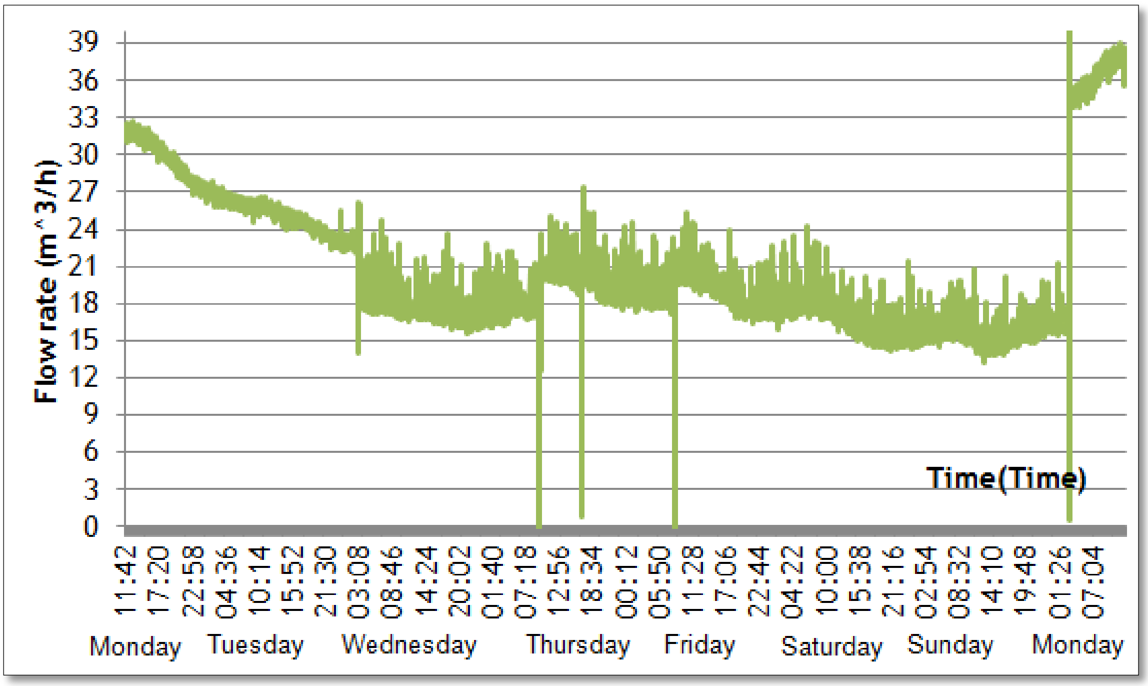

Figure 24: The flow rate in the sand filter with correct amount of sand during one week of a filter run.

4.2. Water quality in the backwash water

4.2.1. Suspended solids and residue on ignition

Table 3 shows the values of suspended solids and ignition loss in mg/l in the water samples from the backwashing water of the first experimental week.

Table 3: The values of the first week of samples of suspended solids and ignition loss are shown in the table.

Sample	Volume (ml)	Weight filter start (g)	Weight after drying 105C (g)	Weight after ignition (g)	SS (mg/l)	Residue on ignition (mg/l)	Ignition loss (mg/l)	% organic matter= % ignition loss
S1	795	0.12329	0.13312	0.12522	12.5	4.1	8.5	67
G1	295	0.12255	0.15081	0.12767	96.3	21.8	74.5	77
S2	79	0.12048	0.14343	0.13209	292.3	163.6	128.7	44
G2	87	0.12316	0.14675	0.13386	272.8	138.1	134.7	49
S3	77	0.12248	0.14229	0.12931	259.1	105.8	153.3	59
G3	67	0.12305	0.15162	0.13351	428.6	175.8	252.8	59
3*Bl		0.36610	0.36567	0.36215				

S1, S2 and S3 are the samples from the sand filter, while G1, G2 and G3 are the samples from the glass filter. The numbers indicate in which order the samples were taken. Bl are the blanks collected from three filters weighed together

An example of the calculated SS values is shown in equation (11).The rest of the values was calculated using Excel, and the values are shown in the table 3.

$$SS_{S1}=\frac{\left(0.13312g-0.12329g+\left(\frac{(0.36567-0.36610)}{3}\right)g\right)}{795\ ml}\cdot 10^6\,\frac{\frac{mg}{g}}{\frac{ml}{l}}=12.5\ mg/ \quad (11)$$

An example of the calculated residue on ignition values is shown in equation (12).The rest of the values was calculated using Excel, and the values are shown in table 3.

$$RI_{S1}=\frac{\left(0.12522g-0.12329g+\left(\frac{(0.36215-0.36610)}{3}\right)g\right)}{795\ ml}\cdot 10^6\,\frac{\frac{mg}{g}}{\frac{ml}{l}}=4.1\ mg/l \quad (12)$$

The ignition loss or volatile suspended solid are found by subtracting the residue on ignition from the SS value.

Figure 25 shows the suspended solids in water samples collected from the filters during backwashing during the first experimental week.

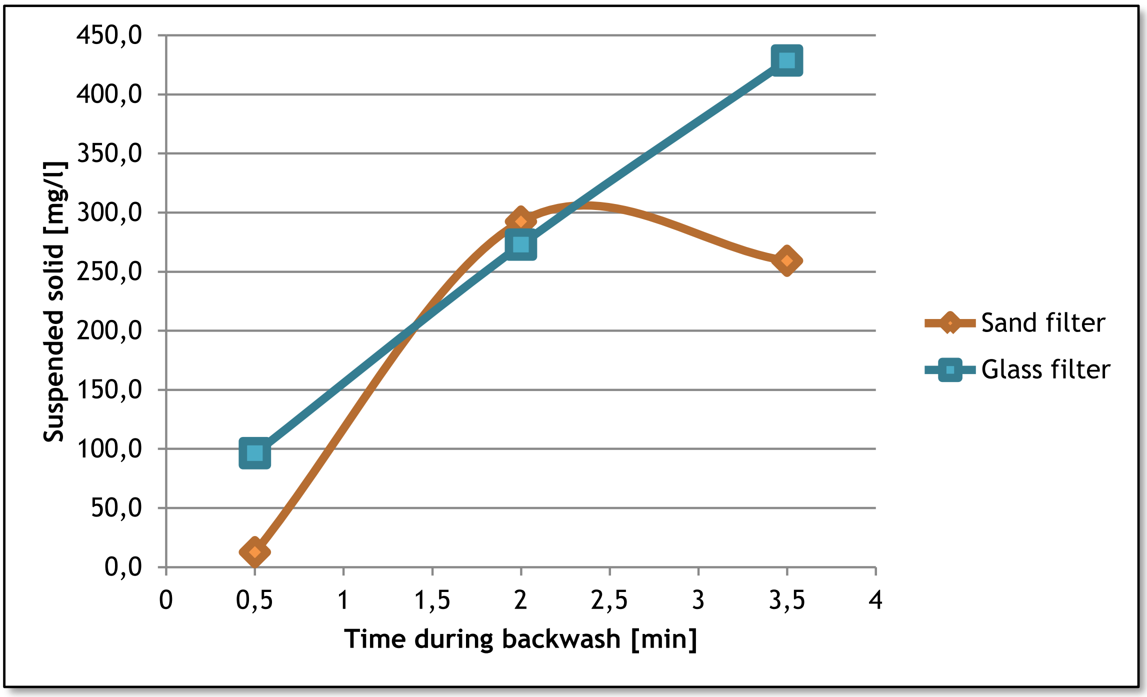

Figure 25: The suspended solids in the filters during the backwashing of the first experimental week.

Table 4 shows the values of the second week of samples of suspended solids and ignition loss in mg/l.

Table 4: The values of the second week of samples of suspended solids and ignition loss are shown in the table.

Sample number	Volume (ml)	Weight Filter start (g)	Weight after drying at 105°C (g)	Weight after ignition (g)	SS (mg/l)	Residue on ignition (mg/l)	Ignition loss (mg/l)	%Organic solid/ % ignition loss
S1	55.5	0.12456	0.13040	0.12537	108.71	38.74	69.97	64.36
G1	54	0.12216	0.14513	0.12981	428.95	166.48	283.70	63.02
S2	55	0.12320	0.13323	0.12624	185.88	79.64	127.09	61.48
G2	135	0.12181	0.13190	0.12495	76.17	33.19	51.48	60.80
S3	161	0.12219	0.13014	0.12474	50.58	24.16	33.54	58.13
G3	342	0.12427	0.13328	0.12785	26.91	14.39	15.88	52.46
3*Bl		0.37330	0.37272	0.36928	108.71			

Figure 26 shows the suspended solids in water samples collected from the filters during backwashing the second experimental week.

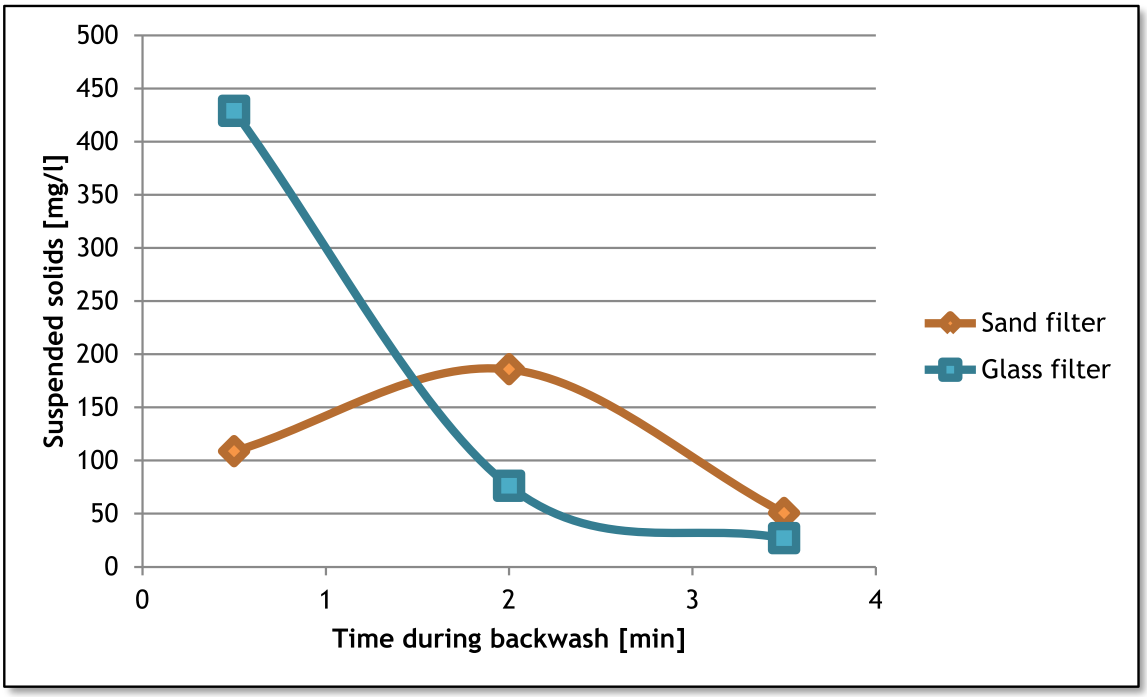

Figure 26: The suspended solids in the filters during the backwashing the second experimental week.

Table 5 shows the values of the area under the curves from figure 26. The values are coarse and are used to make a rough estimate of the total amount of suspended solids in the filters. These calculations are showed in table D-3, table D-4 and equation (16)-(20) in appendix D.

Table 5: The values of the area under the curve in figure 26.

Filter	Area under the curve (mg/l)/min	Total suspended solid in filter (mg/l)
Sand	398,28	$1.08\cdot10^6$
Glass	456,6	$1.23\cdot10^6$

Table 6 shows the values of suspended solids and ignition loss in mg/l in the water samples from the backwashing water of the third experimental week.

Table 6: The values of the suspended solids and ignition loss in the water samples from the backwashing water from week 3.

Sample number	Volume (ml)	Weight filter start (g)	Weight after drying at 105°C (g)	Weight after ignition (g)	SS (mg/l)	Residue on ignition (mg/l)	Ignition loss (mg/l)	% organic solid= %ignition loss
S1	108	0.12306	0.14087	0.12838	166.67	61.45	105.22	63.13
G1	88	0.12234	0.14944	0.13072	310.11	110.19	199.92	64.47
S2	101	0.12238	0.13998	0.12881	176.14	76.70	99.44	56.45
G2	202	0,12400	0.13575	0.12774	59.11	25.03	34.08	57.65
S3	262	0.12278	0.13816	0.12930	59.43	29.91	29.52	49.67
G3	552	0.12322	0.13705	0.13025	25.40	15.12	10.28	40.47
3*Bl		0.3688	0.36823					

Figure 27 shows the suspended solids in water samples collected from the filters during backwashing the third experimental week.

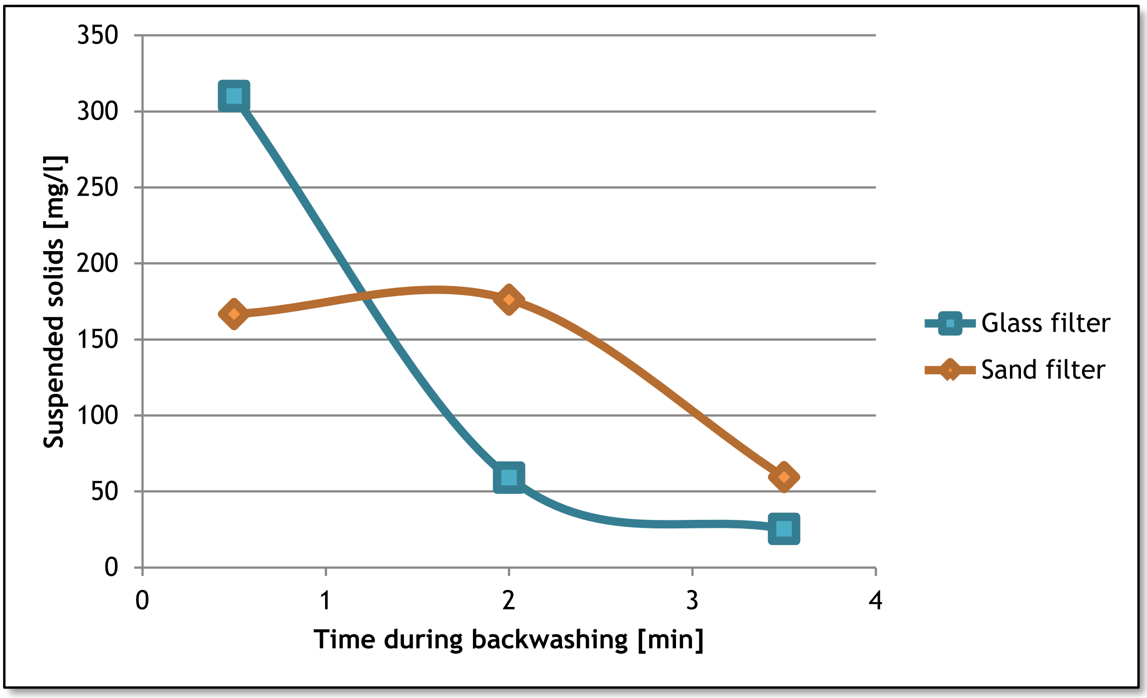

Figure 27: The suspended solids in the filters during backwashing the third experimental week.

Table 7 shows the values of the area under the curves from figure 27. The values are coarse and are used for a rough estimation of the total amount of suspended solids in the filters. The calculations and values can be seen in table D-3, table D-4 and equation (16)-(20) in appendix D.

Table 7: The table shows the values of the area under the curves on figure 27.

Filter	Area under the curve (mg/l)	Total suspended solid in filter
Sand	433.79	$1.17 \cdot 10^6$
Glass	340.30	$9.19 \cdot 10^5$

4.2.2. Total solids

Table 8-10 shows an overview of the total solids in the water samples collected from the backwashing water from the filters during the first, second and third experimental week. The values of the weight before and after drying, the sample volume and the amount of ions in the samples are also given.

Table 8: The values of the first week of samples of total residue are shown in the table.

Sample number	Volume (ml)	Weight of dish (g)	Weight after drying at 105°C (g)	TS (g/l)	TS-SS (mg/l)=Ions and small particles
G1	100	95.879	95.939	0.60	503.72
S1	100	95.000	95.057	0.57	557.45
G2	100	85.598	85.676	0.78	507.20
S2	100	81.025	81.107	0.82	527.68
S3	100	86.390	86.465	0.75	490.87
G3*	100	3.6539	3.7436	0.90	468.44

*The reason for the lower weight is that the other five samples were analyzed in a porcelain bowl, while G3 was analyzed in an aluminum dish.

Table 9: The values of the second week of total samples of total residue are shown in the table.

Sample number	Volume (ml)	Weight of dish (g)	Weight after drying at 105°C (g)	TS (g/l)	TS-SS (mg/l)= Ions and small particles
S1	69	1.9043	1.9505	0.67	560.86
G1	59	1.8835	1.9374	0.91	463.37
S2	64	1.8894	1.9373	0.75	541.71
G3	67	1.8847	1.9272	0.63	549.66
S3	66	1.9004	1.9441	0.66	604.42
G3	62	1.9067	1.9448	0.61	584.25
3*Bl		5.7153	5.7118		

Table 10: The values of the third week of total samples of total solids are shown in the table.

Sample number	Volume (ml)	Weight of dish (g)	Weight after drying at 105°C (g)	TS (g/l)	TS-SS (g/l)= Ions and small particles
S1	59	1.8945	1.9388	0.75	584.18
G1	63	1.9029	1.9559	0.84	531.16
S2	61	1.9068	1.9537	0.77	592.71
G2	61	1.9193	1.9618	0.70	637.61
S3	62	1.9134	1.9568	0.70	640.57
G3	69	1.9031	1.9421	0.57	539.82
3*Bl		5.7048	5.7016		

4.2.3. Residual coagulant

Table 11 and Table 12 shows the amount of residual coagulant, aluminum and aluminum hydroxide in µg/l in the water samples collected from the backwash water of the filters during the second and third experimental week. The calculations are showed in appendix E. The first glass filter sample (G1) showed the highest amount of aluminum of the samples. The highest value of aluminum in the sand filter water samples were the second sample (S2).

Table 11: The values of the residual coagulant, aluminum (Al) and the amount of aluminum hydroxide (Al $(OH)_3$) from the water samples of the second experimental week

Sample	Al (mg/l)	$Al(OH)_3$ (mg/l)
S1	8.81	25.45
G1	39.08	112.90
S2	21.81	63.01
G2	7.32	21.16
S3	6.85	19.78
G3	2.40	6.93

Table 12: The values of the residual coagulant Aluminum and the amount of Aluminum hydroxide from the water samples of the third experimental week.

Sample	Al (mg/l)	$Al(OH)_3$ (mg/l)
S1	18.48	53.40
G1	34.74	100.37
S2	21.42	61.88
G2	5.60	16.17
S3	8.30	23.96
G3	1.89	54.48

Figure 28 and 29 shows the amount of suspended solids, residue on ignition, residual coagulant (aluminum) and aluminum hydroxide in the water samples from the backwashing of the sand and glass filter from the second experimental week.

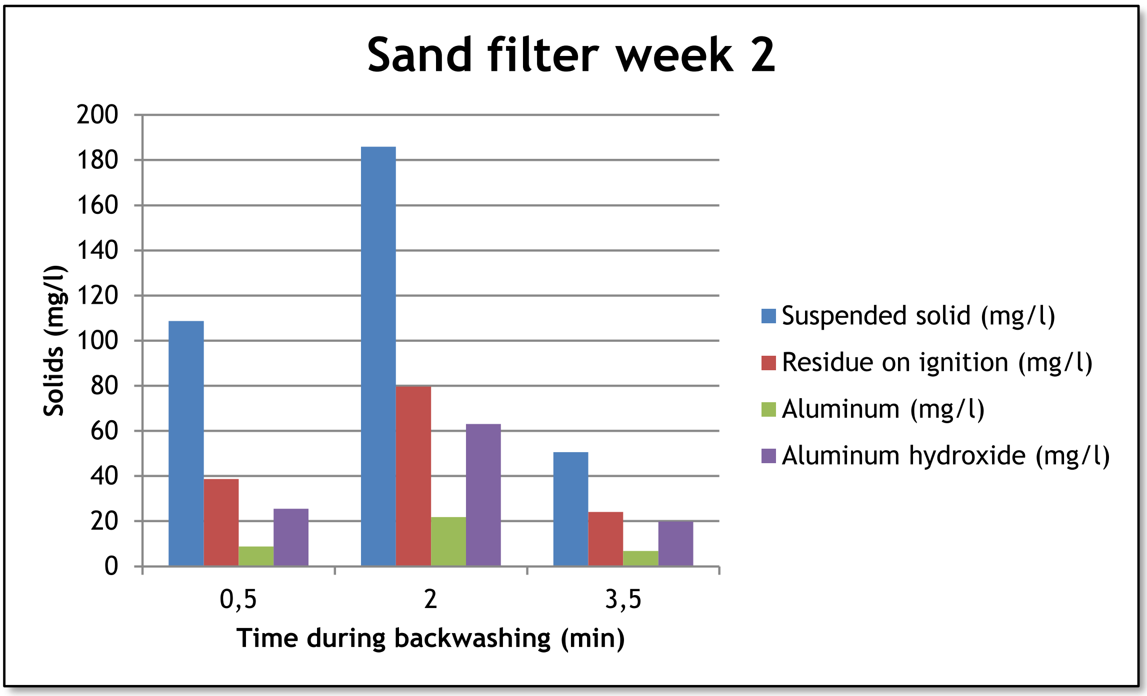

Figure 28: The amount of suspended solids, residue on ignition, aluminum and aluminum hydroxide in the water samples from the backwashing of the sand filter form the second experimental week.

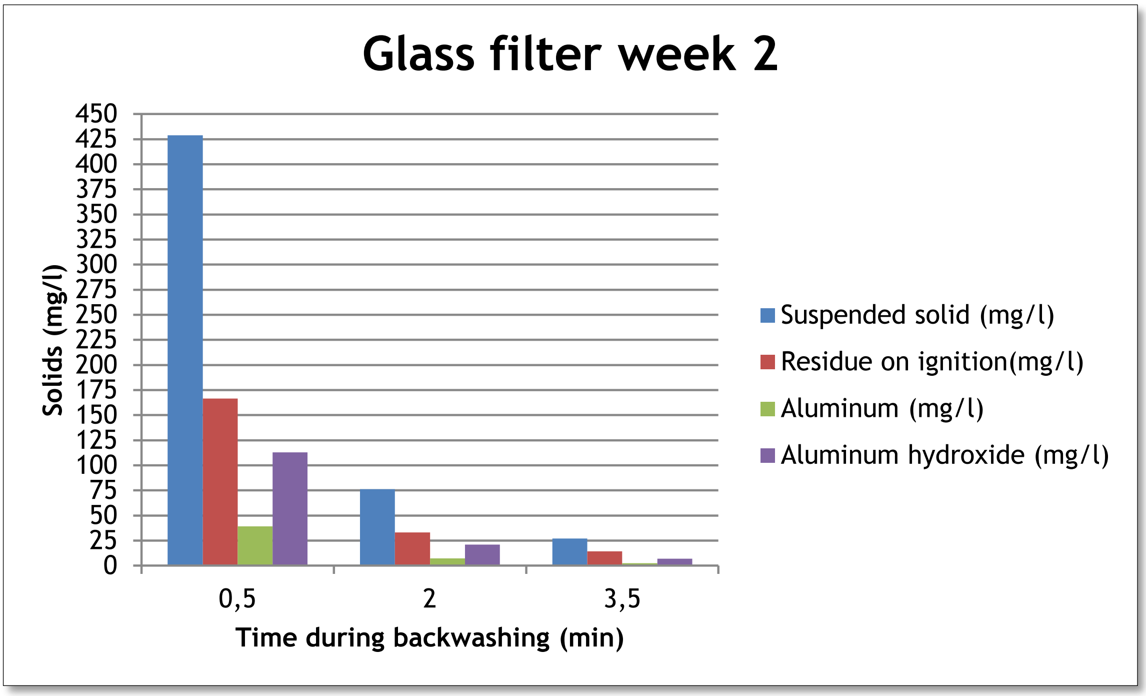

Figure 29: The amount of suspended solids, residue on ignition, aluminum and aluminum hydroxide in the water samples from the backwashing of the glass filter form the second experimental week.

Figure 30 and 31 shows the amount of suspended solids, residue on ignition, residual coagulant (aluminum) and aluminum hydroxide in the water samples from the backwashing of the sand and glass filter from the second experimental week.

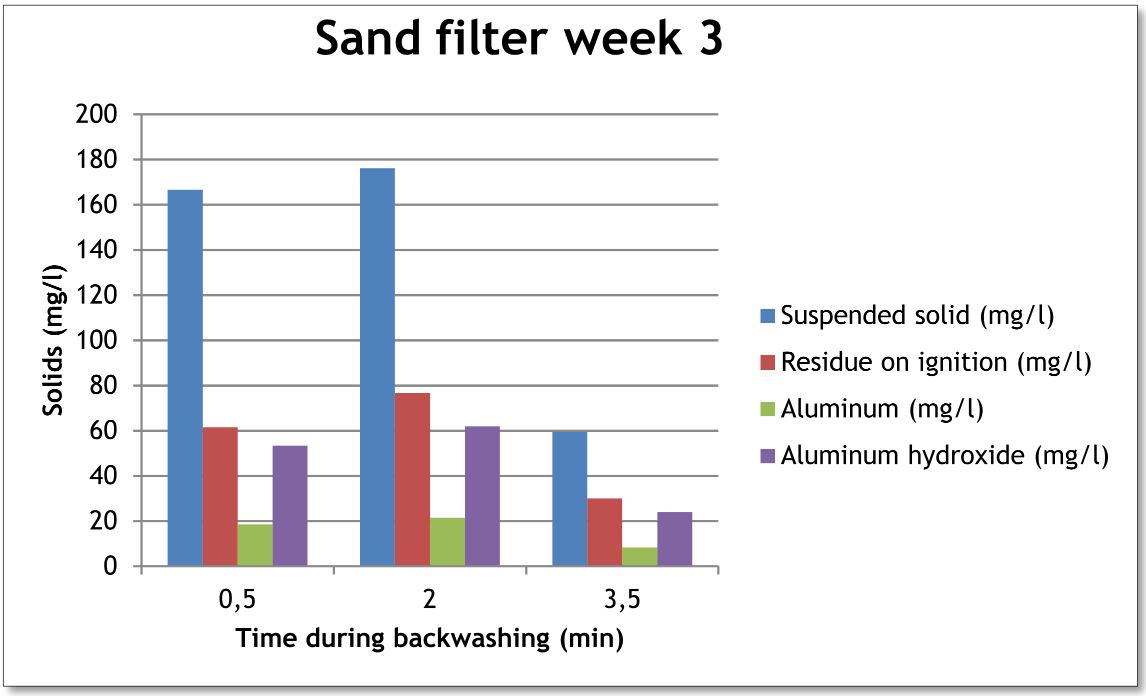

Figure 30: The amount of suspended solids, residue on ignition, aluminum and aluminum hydroxide in the water samples from the backwashing of the sand filter form the third experimental week.

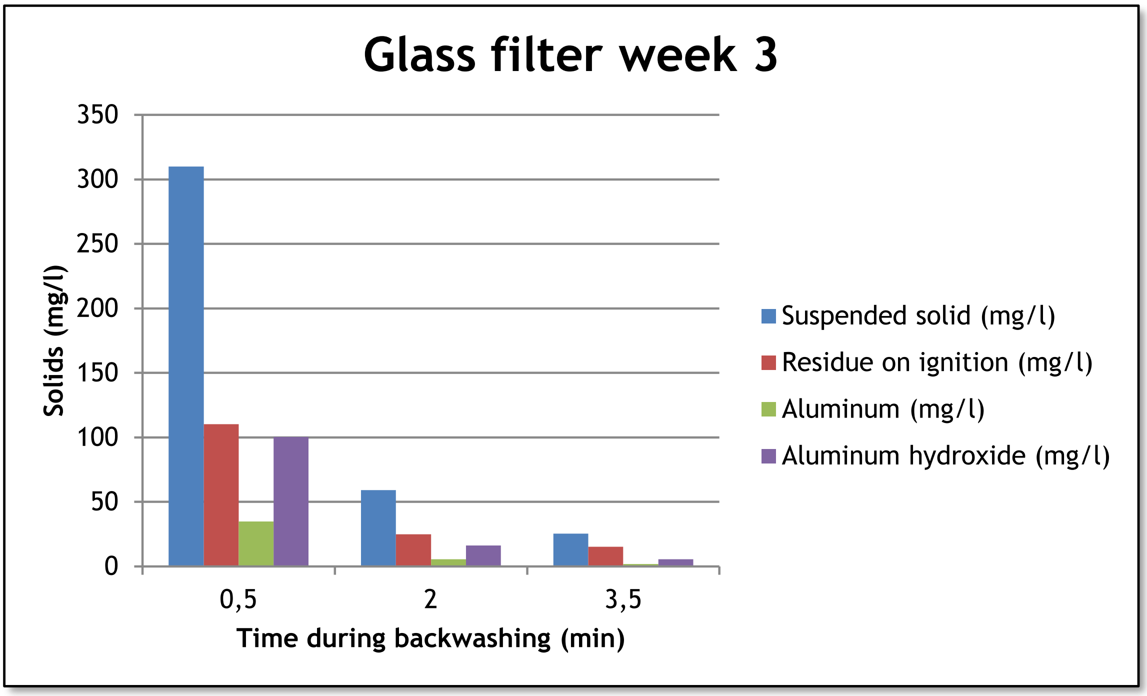

Figure 31: The amount of suspended solids, residue on ignition, aluminum and aluminum hydroxide in the water samples from the backwashing of the glass filter form the third experimental week.

5. Discussion

Due to differences in weather conditions, holidays etc., the bathing load can vary a lot, and the values of the analyses will reflect this.

The experiment was performed as a field trial. In a field trial, all the different operating parameters cannot be controlled in the same way as could be done in a lab. The different employees at Husebybadet do things in their own way. There are also great differences in bathing load and instrumental readouts. These were all potential sources of error throughout the experiment.

During the experiment several problems and difficulties arose. Due to the way Husebybadet is operated, and because people are using the swimming pools on a daily basis, the experiment had to be adjusted accordingly. This meant that the cycle of backwashing of the existing sand filters couldn't be changed.

Normally, swimming pool treatment systems are operated with constant flow and varying pressure. At Husebybadet the flow was varying and the pressure almost constant. This meant that the planned methods had to be changed. Initially, the turbidity breakthrough was most interesting and the main focus of the experiment. Due to lack of access to a usable turbidity meter, and because of the limitations at Husebybadet, the turbidity was not measured.

Another thing that was supposed to be done was to analyze the filtrated water with attention to total organic carbon (TOC) by using the UV and SUVA (Specific ultra violet absorbance) methods. At project start, the TOC instrument suddenly was broken, so this could not be done.

The reason the flow measurements and pressure measurements were noted for just two weeks, was due to the lack of manometers. The manometers that were finally delivered, had scales that were coarser than ideal, but they were used, as no time was available to wait for new ones.

5.1. Flow and pressure curves

The flow rate diagrams of the sand filter shown in figure 18-21 all show a decrease in flow during the week. The shape of the curves was relatively equal for all graphs. The flow started approximately at 28 m^3 /h and decreased to about 10 m^3/h. The decrease in flow was caused by clogging of the filter. During the experimental week the curve did multiple drops. These drops were caused by backwashing of one of the other sand filters. When one of the other sand filters were backwashed, the flow increased through the newly cleaned sand filter, and the flow decreased in the more dirty sand filters, as expected. [12]

The comparison of the glass filter and the sand filter was done on the basis of hydraulic loading. The flow rate through the glass filter was adjusted so the hydraulic loading would be equal to that of the sand filters. The flow rate in the sand filter that was used for the calculation of the flow rate in the glass filter was quite high at the time of readout. This resulted in a slightly higher hydraulic loading in the glass filter compared to the sand filter.

The rotameter that was used for the flow rate readings of the glass filter had some dust or other matter inside. It was feared that the rotameter could give readings that were too high or low. The clamp-on flow meter was moved to the glass filter to make a calibration curve for the rotameter. A valve prior to the glass filter was adjusted to different flow rates. Readings were made for both the flow meter and the rotameter for the different flow rates. Figure 22 and 23 both show the values for hydraulic loading before and after calibration for the glass filter. The values after calibration show that the rotameter readings were slightly higher than the actual values.

Figure 22 and 23 also show that the hydraulic loading in both filters decreased during the experimental weeks. During the experimental period, the head loss over the filter was measured, and the values are shown in table B-1 to B-4 in appendix B. The head loss should be almost constant due to the arrangement of the filters. The head loss for the sand filter fluctuated with about 0.10 bars during the experimental week. The head loss for the glass filter, however, increased evenly throughout the week. The inlet pressure especially, increased during the run.

Due to the differences between the two filters, an additional test on the glass filter was carried out. Before the last backwashing of the glass filter, the pressure was adjusted to the pressure of a newly cleaned filter. This was done to find out if the flow would be decreasing if the pressure was constant. When the pressure was adjusted, the flow rate dropped significantly. This indicates that the flow rate of the glass filter would have been more reduced during one filter run, than what was first presumed. When this drop in flow rate was discovered it was easy to think that the glass filter wasn't better than the sand filter at all. But when the values of the flow rate during time were calculated, the values in table 2 showed that the glass filter had processed a greater amount of water than the sand filter.

The non-decreasing flow-rate for the glass filter is probably caused by the installation of the extra pump before the glass filter. When a sand filter clogs, more flow is routed to the other sand filters. The pump before the glass filter prevents this redistribution from happening to the glass filter. When the glass filter clogs, the pressure increases as the pump tries to maintain the same flow.

During the experiment, it was discovered that the amount of sand media in the sand filters varied in the four sand filters. One filter had sand to half of the length of the window. The three others had their windows covered entirely by sand, and were therefore overfilled. The sand filter which was used in the study was one of the filters with too much sand. Too much sand in the filter can cause a decrease in the flow, because of bigger resistance. [12] The expansion of the filter bed could also be hindered, because of too little space to expand. [13] This can lead to incomplete backwashing, resulting in the filters not being cleaned as well as they should. Because of the unknown amount of sand in the filter used in the study, it was interesting to see if the filter with correct amount of sand had a significant higher flow rate than the other filters. As a last experiment, the clamp-on flow meter was moved to the sand filter with correct amount of sand, and the flow rate during one filter-run was measured. The results from this experiment shown in figure 24, shows that the flow rate in this filter was 34 m^3/h in average in the beginning. This result is a bit higher than the filtration rate in the sand filter which was used in the experiment. The flow rate measure right after backwashing was 37 m^3/h. The main cause of this high value is thought to be because of an error in the control system, causing two of the filters to not be backwashed as planned. Not because of its lower sand level, although this probably contributed a little bit too.

5.2. Water quality in the backwash water

5.2.1. Suspended solids and total solids

The water taps were supposed to be installed before the start of the experimental period. Due to a delay in the delivery of the water taps, a hole was bored in the drain water pipe at the glass filter. A hosepipe from the sand filter tank was used for the collection of backwash water of the sand filter. The water samples were collected in plastic bottles (1 l) to the utmost. It was, however, impossible to take the time accurately because the water splashed all over and was difficult to collect. Especially the water samples from the glass filter were difficult to collect. Due to the difficulties in sample collecting, and no accurate time measurement, the water samples from the first week have several sources of error, which can affect the results. It was expected that the content of solids would decrease as time progressed, because the filter should be cleaner after some time of backwashing. The results showed that the values for the last water samples were the highest, for both the glass filter and the sand filter. This can indicate that the water samples were collected too early in the cycle, and that samples were not taken at the end of the backwash, but in the middle.

After comparing the results, it was chosen to ignore the results from the first experimental week, due to the problems during collecting of the water samples. The results were not seen as representative for the actual water values, and were thus excluded.

The second week of samples showed quite different results (table 4, table 5 and figure 26). This week, the water taps were installed and it was much easier to collect the water samples, and keep accurate track of time. The samples were taken at 0.5 minutes, 2 minutes and 3.5 minutes of the 4 minute backwash period. The results showed that the glass filter had a large amount of suspended solids in the first 0.5 minutes, and the sand filter had less suspended solids in this time period. After 2 minutes, the glass filter showed a decrease in suspended solids, while the sand filter showed increased values. In the last 3.5 minutes sample, the glass filter showed a further decrease in the amount of suspended solids. The sand filter also showed decreased amounts of suspended solids compared to the 2 minutes sample. In addition, the sand filter showed a higher amount of suspended solids than the glass filter.

The third week of sampling was performed the same way as the second week. The results were very similar (table 6, table 7 and figure 27).The glass filter had the greatest amount of suspended solids during the first 0.5 minutes, and from then the amount of suspended solids was decreasing. The sand filter had the greatest amount of suspended solids after 2 minutes and decreased after this time.

These results indicate that the glass filter gets rid of the dirt in the early stage of the backwashing, and could indicate that the glass filter needs a shorter backwash period. The decrease in suspended solids in the last sample after 3.5 minutes was expected, because the filter should be almost clean in the end of the backwashing process. The increase in suspended solids in the sand filter after 2 minutes may indicate that the dirt is more stuck in the sand filter, and that it takes time to fluidize all the sand.

Residue on ignition was measured to get the ignition loss, also known as volatile suspended solids. The volatile suspended solids are the solids that have been vaporized during ignition of the water samples. It is presumed that the volatile suspended solids are representing the organic matter in the water samples. [18] The analyses showed that the volatile suspended solids were about the half of the total suspended solids. (Table 3, 4 and 6) The three experimental weeks showed almost the same results for the amount of volatile suspended solids.

For total solids, the same trend occurred as for the suspended solids (table 9 and 10).The results from the first week (table 8) was ignored due to the collecting problems. The glass filter showed the highest value in the start, while it decreased with time. The sand filter showed the highest value in the sample after 2 minutes. The total solids showed values that were quite high, compared to the suspended solids. This indicates that the total solid analysis was too rough in this case. The relatively high values of the total solids, means that the amount of ions in the water samples are much higher than the amount of particles in the samples. This makes the total solids test in this case inaccurate. The suspended solids test is thus a better examination method than the total solids for the water samples in question. When the suspended solids were eliminated from the total solids, the remaining values were almost equal. This was expected because the amount of ions in the water shouldn't change significantly. The difference is thus due to small particles that have been let through the filter during the suspended solids analysis, or due to some differences in the amount of ions in the water samples. [18, 22]

5.2.2. Residual coagulant

The samples from the first week were rejected because of the uncertainties regarding collection. These six water samples were thus not analyzed in terms of residual coagulant.

The samples of the backwash water for both the second and third experimental week showed the same trend as for the other water analyzes (table 11 and 12). The values were high for the first sample from the glass filter, and then decreasing, while the second value for the sand filter was the highest.

The values showed that the amount of aluminum was a large part of the total amount of solids in the water samples (figure 28 and 31).This indicates that the coagulant is working and is holding particles back. The aluminum is captured as aluminum hydroxide [18], and by looking at the amounts of aluminum hydroxide in the samples, it is seen that the aluminum hydroxide was a big amount of the suspended solids in the samples. The high amount of aluminum hydroxide in the water samples indicates that flocculent is holding back agglomerated particles in the filter, and that it is well functioning. [18, 22]

5.3. Comparison with other studies

Other experiments performed with recycled glass as a filtration media in water treatment has been studied. Similar experiments to the actual experiment in the thesis have not been found. Most of the other experiments have been performed as laboratory experiments, or with respect to drinking water. The parameters chosen for comparison in other experiments differ from the parameters used in this experiment. Due to the differences in the experimental set-up, the results cannot be directly compared. All the experiments concluded that the glass filter media showed promise as an alternative to silica sand in the filtration process. [1-7] This supports the interest for the glass filter media as a good replacement for the conventional sand filter media. In addition the results from one study show a decreased time of backwashing for the glass filter. [5] This supports the results in this thesis.

5.4. Further work

There are possibilities for further work on this project. The producer of the glass filter media claims that the filter helps to reduce the presence of chloramines in the water. The producer also argues that consumption of chemical products is reduced up to 50 %. In addition, the producer claims that the glass filter media will save water and reduce energy consumption. [8] In the light of the producer`s assertions, it would be interesting to have measurements on chloramines, chemicals and bacteria. Some research has indicated a prolonged period between backwashes for the glass filter. In addition it has been indicated that the glass filter media requires lower backwash flow rates and has a lower head loss. [5, 6] In the light of these studies it had been interesting to study whether the period between backwash cycles of the glass filter could be extended. It would also be interesting to see if the glass filter could have been backwashed with less water over a shorter time. Last, it could be studied if the flocculent is less needed with a glass filter than with a sand filter.

6. Conclusion

It was concluded that glass shows promise as an alternative to silica sand as a filtration media for pressure filters in swimming pools. The results showed that the glass filter has as good as, or even better purification performance than the sand filter. The experiment may indicate that the glass filter require a shorter backwashing than the sand filter. In addition, it was concluded that the flocculent was well functioning.

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Appendix A
Data sheet for the glass filter and the sand filter

The dimensions of the pilot glass filter unit are shown in figure A-1 and table A-1.

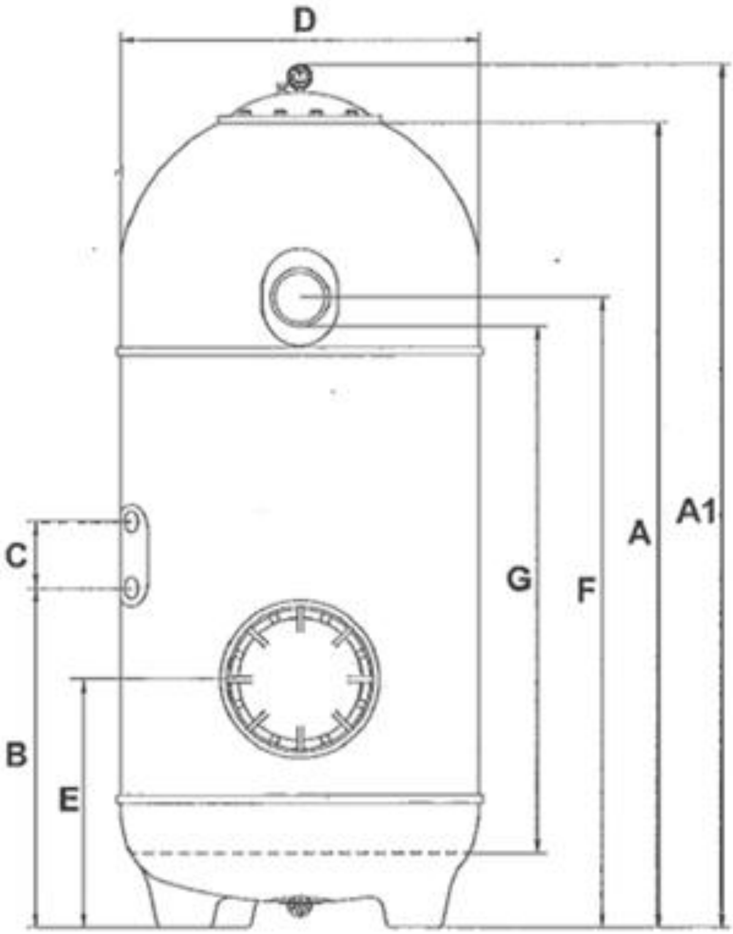

Figure A-1: The glass filter unit installed at Husebybadet. [8]

Table A-1 shows the dimensions of the glass filter unit shown in figure A-1.

Table A-1: Explenatory text of the dimensions of the glass filter unit in figure A-1. [8]

Explenatory text	Dimensions
A	1740 mm
A1	1800 mm
B	780 mm
C	140 mm
D	640 mm
E	550 mm
F	1455 mm
G	1200 mm

Table A-2 shows information and dimensions of the glass filter unit in figure A-1.

Table A-2: Information about the glass filter unit. [8]

Information about the filter unit	
Model	SBL 640.C
Filtration area	0.32 m^2
Diameter	640 mm
Volume	0.820 m^3
Weight	575 Kg.
Flow	V=40 m^3/h
Filtration rate	40 m^3/h
Working pressure	0.5÷1.6 Kg/cm^3
Maximum pressure	2 Kg/cm^2
Testing pressure	3 Kg/cm^2
Operating temperature	1 °C÷40 °C
Sand grading 0,4÷0,8 mm	525 Kg
Sand grading 1÷2	50 Kg
Filtration bed depth	1 M- 1.2 M

Table A-3 shows information about the glass beads in the glass filter unit.

Table A-3: Information about the glass beads in the glass filter unit. [8]

Grain calibration	0.6 mm
Generic composition:	
• SiO_2	70-73 %
• Na_2O	13-15 %
• CaO	8-13 %
Colors’	Clear, blue, green, yellow, combination
Average density of packed product	1.350 Kg./m^3
Backwash with water at	40 $m^3/h/m^2$
Air injection prior to water backwash	80 $m^3/h/m^2$

The dimensions of the sand filter unit are shown in figure A-2 and table A-4.

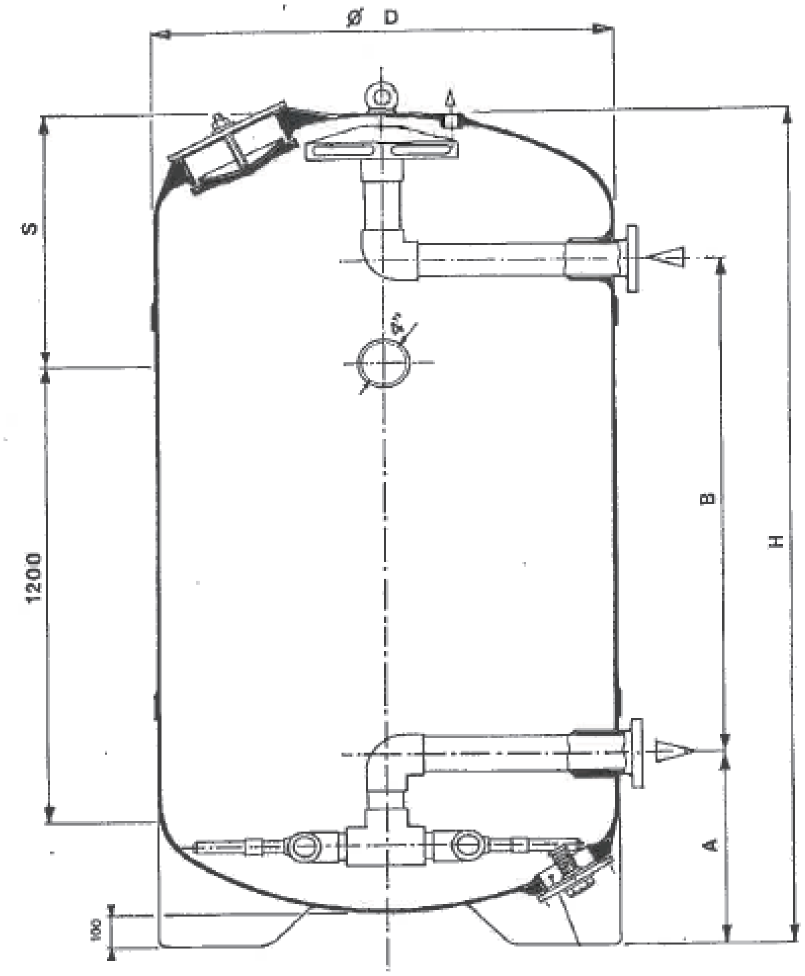

Figure A-2: The figure shows the dimensions of the sand filter unit, and the values are listed in table A-4. [34]

Table A-4: The table shows the dimensions of the sand filter unit shown in figure A-2. [34]

Explanatory text	Dimension/D in mm
A	530 mm
B	1070 mm
H	2305 mm
S	655 mm
V	4”
M	160 mm

Table A-5 shows information about the sand filter unit.

Table A-5: Information about the sand filter unit. [34]

Filter area	1.2 m^2
Filtration rate	20 m/h
Sand quantity in Kg. Total	1800 kg
Sand depht	1.2 m
Filtration bed depth	1.0 m

Table A-6 shows information about the sand filter media.

Table A-6: Information about the sand filter media. [35]

Grain shape	Circular edge
Grain size	0.6-0.8 mm
Turbidity	Max 4 FNU
SiO_2	<82%
Grain density	2.60 Mg/m^3
Bulk density	1.38 Mg/m^3
Void content	47 %
Hydrochloric acid solubility	<0.7 %
Iron content	<0.1 %
Humus	<1000 mg/l

Appendix B
Experimental values of the flow and pressure measurements

Table B-1 to B-4 shows the pressure and flow readings of the sand and glass filter during the first and second experimental week.

Table B-1: The flow and pressure measurements of the sand filter in the first experimental week.

	Sand filter			
	Flow (m^3/h)	Pressure in (bar)	Pressure out (bar)	ΔP (bar)
Monday	28	0.7	0.5	0.2
Tuesday	27	0.73	0.49	0.24
Wednesday	16	0.79	0.5	0.29
Thursday	16	0.79	0.52	0.27
Friday	14	0.76	0.55	0.21
Saturday	13	0.79	0.5	0.29
Sunday	13.6	0.82	0.5	0.32
Monday	10	0.8	0.5	0.3

Table B-2: The flow and pressure measurements of the glass filter in the first experimental week.

	Glass filter				
	Flow (m^3/h)	Pressure in(bar) (before valve)	Pressure in (bar)	Pressure out(bar)	ΔP (bar)
Monday	7.9	1.8	0.5	0.4	0.1
Tuesday	7.9	1.8	0.5	0.4	0.1
Wednesday	7.6	1.82	0.55	0.4	0.15
Thursday	7.5	1.7	0.59	0.44	0.15
Friday	7.2	1.6	0.64	0.49	0.15
Saturday	7.2	1.6	0.69	0.48	0.21
Sunday	7.3	1.7	0.7	0.43	0.27
Monday	7.2	1.8	0.75	0.43	0.32

Table B-3: The flow and pressure measurements of the sand filter in the second experimental week.

	Sand filter			
	Flow (m^3/h)	Pressure in (bar)	Pressure out (bar)	ΔP (bar)
Monday	25.0	0.75	0.50	0.25
Tuesday*				0
Wednesday	19.6	0.7	0.4	0.30
Thursday	19,0	0.77	0.48	0.29
Friday	13.7	0.75	0.50	0.25
Saturday	13.2	0.79	0.55	0.24
Sunday	13.8	0.82	0.50	0.32
Monday	9.1	0.82	0.50	0.32

*The lack of values is caused by closing of the swimming pool due to a public holiday.

Table B-4: The flow and pressure measurements of the glass filter in the second experimental week.

	Glass filter					
	Flow (m^3/h)	After calibration (m^3/h)	Pressure in(bar) (before valve)	Pressure in (bar)	Pressure out(bar)	ΔP (bar)
Monday	8.2	7.34	1.8	0.51	0.41	0.1
Tuesday*						
Wednesday	7.7	6.78	1.6	0.59	0.48	0.11
Thursday	7.7	6.78	1.6	0.59	0.48	0.11
Friday	7.6	6.67	1.6	0.61	0.48	0.13
Saturday	7.7	6.78	1.6	0.62	0.48	0.14
Sunday	7.8	6.89	1.7	0.67	0.43	0.24
Monday	7.7	6.78	1.7	0.74	0.42	0.32
Monday	2.65	1.15		0.5		

*The lack of values is caused by closing of the swimming pool due to a public holiday.

Table B-5 and B-6 shows the hydraulic loading in the sand and glass filter during the first and second experimental week. The calibrated values of the hydraulic loading in the glass filter are also shown in the tables. The calibration curve is showed in appendix C.

Table B-5: The hydraulic loading for the glass filter and the sand filter during the first experimental week.

	Hydraulic loading sand filter ($m^3/m^2/h$)	Hydraulic loading glass filter ($m^3/m^2/h$)	Hydraulic loading glass filter after calibration ($m^3/m^2/h$)
Monday	23.33	24.69	21.89
Tuesday	22.50	24.69	21.89
Wednesday	13.33	23.75	20.86
Thursday	13.33	23.44	20.50
Friday	11.67	22.50	19.45
Saturday	10.83	22.50	19.45
Sunday	11.33	22.81	19.80
Monday	8.33	22.50	19.45

Table B-6: The hydraulic loading for the glass filter and the sand filter during the second experimental week.

	Hydraulic loading sand ($m^3/m^2/h$)	Hydraulic loading glass ($m^3/m^2/h$)	Hydraulic loading after calibration ($m^3/m^2/h$)	After pressure change ($m^3/m^2/h$)
Monday	20.83	25.63	22.94	
Tuesday*				
Wednesday	16.33	24.06	21.19	
Thursday	15.83	24.06	21.19	
Friday	11.42	23.75	20.86	
Saturday	11.00	24.06	21.19	
Sunday	11.50	24.38	21.54	
Monday	7.58	24.06	21.19	3.58

*The lack of values is caused by closing of the swimming pool due to a public holiday.

Appendix C
Calibration curve for the glass filter

Figure C-1 shows the calibration curve of the rotameter at the glass filter against the clamp-on flow meter.

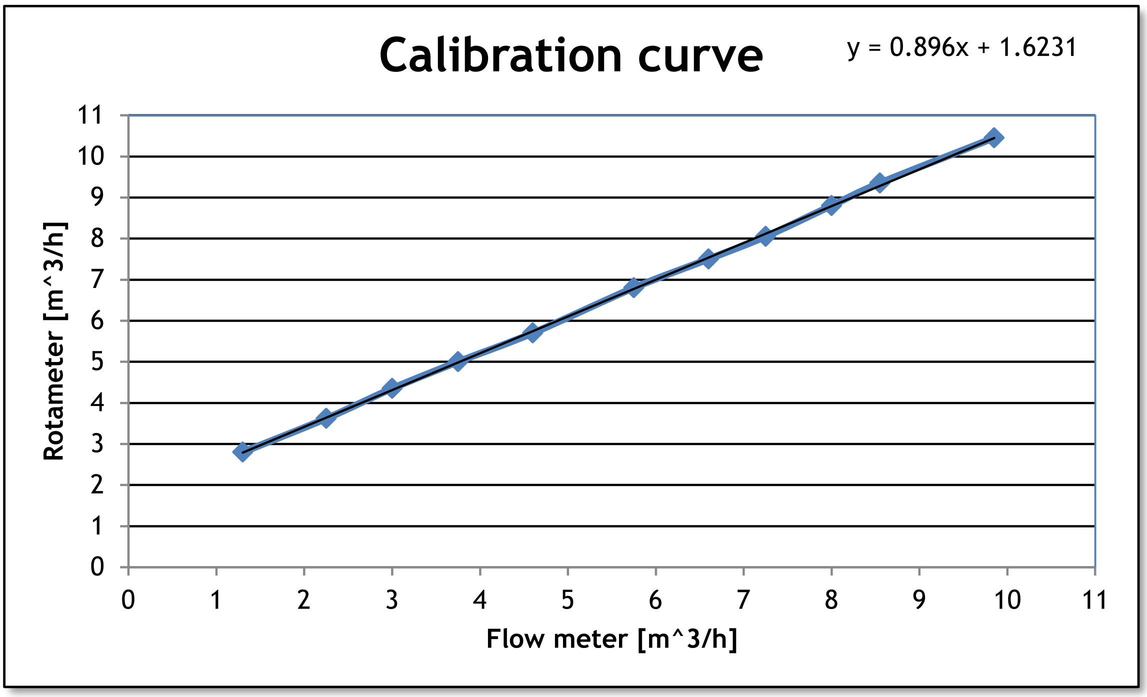

Figure C-1: Calibration curve for the rotameter before the glass filter against the flow measurements.

Table c-1 shows the experimental data used for the calibration curve of the rotameter at the glass filter against the clamp-on flow meter.

Table C-1: Experimental data of the calibration curve of the rotameter against the flow meter.

Rotameter (m^3/h)	Flow meter (m^3/h)
9.85	10.45
8.55	9.35
8.0	8.8
7.25	8.05
6.6	7.5
5.75	6.8
4.6	5.7
3.75	5.0
3.0	4.35
2.25	3.62
1.3	2.8

Appendix D
Experimental values and calculations with hydraulic loading and suspended solid.

Table D-1 and D-2 shows the total amount of water that has gone through the sand and glass filter during first and second experimental week.

Table D-1: Values of the area under the curve of the hydraulic loading through the sand and glass filter during the first experimental week. In addition is the total amount of water through the filters shown.

	Time since backwashing (h)	Hydaulic loading sand filter ($m^3/m^2/h$)	Hydraulic loading sand filter ($m^3/m^2/h$)	X,Y sand filter (area of column)	X,Y glass filter (area of column)
	0	23.33	21.89	550.00	525.41
	24	22.50	21.89	430.00	512.85
	48	13.33	20.85	320.00	496.11
	72	13.33	20.50	300.00	479.37
	96	11.67	19.45	270.00	466.82
	120	10.83	19.45	266.00	471.00
	144	11.33	19.80	236.00	471.00
	168	8.33	19.45	-	-
Total area under curve				2372.00	3422.57
Total flow rate				398496.00	574991.72

Table D-2: Values of the area under the curve of the hydraulic loading through the sand and glass filter during the second experimental week. In addition is the total amount of water through the filters shown.

	Time since backwashing (h)	Hydaulic loading sand filter ($m^3/m^2/h$)	Hydraulic loading sand filter ($m^3/m^2/h$)	X,Y sand filter (area of column)	X,Y glass filter (area of column)
	0	20.83	22.94	892.00	1059.19
	48	16.33	21.19	386.00	508.67
	72	15.83	21.19	327.00	504.48
	96	11.42	20.85	269.00	504.48
	120	11.00	21.19	270.00	512.85
	144	11.50	21.54	229.00	512.85
	168	7.58	21.19	-	-
Total area under curve				2373.00	3602.54
Total flow rate				341712.00	518765.22

An example of the calculation of the area of the curve and the total flow rate through the sand filter from the first experimental week is shown in equation (13)-(15).The values were calculated using excel:

$$A_{Column\ Sand} = \frac{(22.50 + 23.33)}{2} \cdot (24 - 0) = 550.00 \frac{\frac{m^3}{m^2}}{h} \quad (13)$$

$$A_{total\ Sand} = \sum A_{Column\ Sand} = 2372.00 \frac{\frac{m^3}{m^2}}{h} \quad (14)$$

$$Total\ flow_{Sand} = 2372.00 \frac{\frac{m^3}{m^2}}{h} \cdot 168\ h = 398496.00 \quad (15)$$

Table D-3 and D-4 the total amount of suspended solids that have gone through the sand and glass filter during the second and third experimental week.

Table D-3: Values of the area under the curve for the sand and glass filter for the suspended solids from week 2.

	Time during backwashing (min)	SS sand filter (mg/l)	SS glass filter (mg/l)	(x,y) sand filter (area of column)	(x,y) glass filter (area of column)
	0.5	108.71	428.95	220.94	378.84
	2	185.88	76.17	177.34	77.31
	3.5	50.58	26.91	-	-
Total area under curve (mg/l)/min				398.28	456.16
Total suspended solids in filter (mg/l)				$1.08 \cdot 10^6$	$1.23 \cdot 10^6$

Table D-4: Values of the area under the curve for the sand and glass filter for the suspended solids from week 3.

	Time during backwashing (min)	SS sand filter (mg/l)	SS glass filter (mg/l)	(x,y) sand filter (area of column)	(x,y) glass filter (area of column)
	0.5	166.67	310.11	257.1075	276.915
	2	176.14	59.11	176.6775	63.3825
	3.5	59.43	25.4	-	-
Total area under curve (mg/l)/min				433.785	340.2975
Total suspended solids in filter (mg/l)				$1.17 \cdot 10^6$	$9.19 \cdot 10^5$

The total amount of the suspended solids in the backwashing water can be estimated from equation (16);

$$m_{SS\ total} = A_{SS} \cdot Q_B \cdot t \qquad (16)$$

where m_{SS} is the total amount of suspended solids in the filter in mg.
A_{SS} is the area under the suspended solid curve in mg/l.
Q_B is the flow rate of the backwash in l/min, and t is the time in min.

Examples of the calculation that are used to estimate the total amount of suspended solids in the filters are shown for the glass filter from the second experimental week in the following equations;

$$Area\ column_{\ glass} = \left(\frac{(76.17 + 428.95)}{2}\right) \cdot (2.0 - 0.5) = 378.84 \qquad (17)$$

The areas of the columns are then summarized as equation (18) shows to find the Total area under the curve.

$$Area\ total_{\ glass} = \sum Area\ column_{\ glass} \qquad (18)$$

Equation (19) and (20) shows an example of the calculation of the total amount of suspended solids in the filters;

For the glass filter
The flow rate of the glass filter = 12.8m^3/h=213.33l/min
The duration of the backwashing is 4 minutes, but the water samples were just made for 3 of these minutes.

$$m_{ss\ total\ glass} = 456.155 \frac{mg}{l} \cdot \frac{213.33l}{min} \cdot 3min = 2.92 \cdot 10^6 mg \qquad (19)$$

Adjusting for the ratio of flow:

$$m_{ss\ total\ glass} = 1.23 \cdot 10^6 mg \cdot \frac{54\frac{m^3}{h}}{12.8\frac{m^3}{h}} =\cdot 10^6 mg \qquad (20)$$

Appendix E
Calculations with the residual coagulant

M_w Al=27 g/mol

M_w $Al(OH)_3$ =78 g/mol

The amount of aluminum hydroxide can thus be found from the equation (21);

$$Amount\ Al(OH)_3 = \frac{Amount\ Al \frac{mg}{l}}{27 \frac{g}{mol}} \cdot 78 \frac{g}{mol} \tag{21}$$

An example of the calculation is showed in equation (22). This is from the S1 sample of the second experimental week;

$$Amount\ Al(OH)_3 mg/l = \frac{8.81 \frac{mg}{l}}{27 \frac{g}{mol}} \cdot 78 \frac{g}{mol} = 25.45\ mg/l \tag{22}$$

The rest of the values are showed under the results in Table 11 and Table 12.

Appendix F
Popular scientific article

Has the sand filter media reached its peak performance?

By Elizabeth Martine Svendsen

Figure 1: Swimming pools are used for playing and recreation for children and adults (1).

Pool water is constantly undergoing treatment, which generally includes filtration, pH correction and disinfection. This is done to ensure clean water that is clear and free of microorganisms.

In recent years, there has been a growing concern about chlorinated organic compounds and their potential impact on the visitors. Hair, sweat, cosmetics and other organic matter from the visitors, can react with the chlorine in the water and make potentially harmful compounds. In addition many swimming pools are closed due to obsoleteness and high energy and water costs. This has led to increased focusing on other alternatives to the methods used for swimming pool purification today.

The filter system is normally a depth filter, where the particles in the water are separated from the water through the water passage by a bed of granular material (filter grain). The particles are removed when they adhere to the filter grains (2). Silica sand has been the most widely used granular media for water filtration for many years. Some researchers and producers believe that sand as a filter media has reached its peak performance, and that it is time for fresh thinking. There is a great deal of interest in glass as a replacement for the conventional sand filter media (3).

Glass filter media is often recycled glass that is crushed and ground down to a size close to a sugar grain. Glass is inert, meaning that it does not react chemically with any of the swimming pool chemicals (4).The producers of glass filter media claims that if the sand filter media is replaced with glass, the lifetime would be prolonged to about 100 years. In addition the glass filter media is claimed to have reduced cleaning time process, lower consumption of chemicals, and it is said that it reduces the amount of chloramines in the water (5).

During a period of three weeks, a pilot plant installed at Husebybadet in Trondheim was studied. The pilot plant consisted of a pump, a rotameter and a pressurized glass filter. The glass filter was compared with one of the conventional sand filters at Husebybadet, through water analyses, flow- and pressure measurements.

The water analyses dealt with suspended solids, residue on ignition, total solids and residual coagulant. The samples were collected from the effluent flow during backwashing of the filters. The water samples were taken after 0.5 minutes, 2 minutes and 3.5 minutes during the backwashing. The performance of the glass and sand filter was compared in terms of hydraulic loading and ability to retain particles.

The hydraulic loading in both filters showed a decrease during the experimental weeks. The results from the water analyses showed a larger amount of suspended solids in the first 0.5 minutes for the glass filter as for the sand filter. After 2 minutes, the glass filter showed a decrease in suspended solids, while the sand filter showed increased values. In the 3.5 minutes sample, the glass filter showed a further decrease in the amount of suspended solids. The sand filter also showed a decrease, but a higher amount of suspended solids than the glass filter.

Figure 2: The sand filter is showed in picture to the left, while the glass filter is showed to the right.

The results indicated that the glass filter got rid of the particles in the early stage of the backwashing. While the increase in suspended solids in the sand filter after 2 minutes may indicate that the particles is more stuck in the sand filter, and that it takes time to fluidize all the sand. This can indicate that the glass filter needs a shorter backwash period than the sand filter.
The results from the total solids showed values that were quite high, compared to the suspended solids. The relatively high values of the total solids, indicates a higher amount of ions than particles in the water samples.

The results from the analysis of residual coagulant showed that the water samples contained a relatively high amount of aluminum. This indicates that the flocculent is working well and is holding particles back.

It was concluded that crushed recycled glass shows promise as an alternative to silica sand as a filtration media for pressurized filters in swimming pools. The results showed that the glass filter has as good as, or even better purification performance than the sand filter. The experiment may indicate that the glass filter require a shorter backwashing than the sand filter. In addition, it was concluded that the flocculent was well functioning.

The experiment has thus laid a foundation for further work, in terms of analysis of bacteria, chlorine organic compounds, duration of the backwashing and potential cost and energy savings.

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