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Particle size characterization and follow-up of the performance during long-term operation of the discfilter plant at Arvidstorp WWTP

Master's thesis in Infrastructure and Environmental Engineering

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ABSTRACT

Microscreening using discfilters is an efficient technology used for effluent polishing in wastewater treatment. The Arvidstorp wastewater treatment plant in Trollhättan uses six discfilters as tertiary treatment which provides a total filtration area of 1188m^2. The discfilters treat a combination of effluents from the non-nitrifying activated sludge and post-denitrifying system. The goal of this thesis was to investigate the effects of particle characteristics on the discfilters and to evaluate the performance of the system during a period of approximately 6 months.

A comparison of particle fractionation methods suggested that parallel filtration is more suitable than serial filtration for determining the particle size distribution because it is easy to perform, quick results are obtained and lower volume of sample is consumed.

The long-term study of discfilter performance demonstrated that they operated succesfully during variations in flow and solids loading with 70-80% solids removal efficiency during days of no chemical pre-treatment. Interestingly, clogging of filter panels is not uniform within a discfilter. The panels in the rear end of the system clogged faster than the ones in the front. Similarly, within a filter panel the clogging was faster in the bottom region of the panel compared to the top and middle regions. Further analysis showed that the discfilters in the end of the influent channel after 90 days of operations still operated at 50 % capacity.

Key words: wastewater, discfilter, microscreen, particle size distribution

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1 Table of Contents

2 Introduction

2.1 Background

The discharge of treated wastewater in Sweden is regulated by the environmental code that briefly describes that the municipality in charge of treating wastewater may use any technology that suits best for the environment (Svenskt vatten, Naturvardsverket). Sweden imparts stringent limits on the solids, biodegradable organics, nutrients, and metals in the effluent of WWTP before discharging the wastewater to avoid deleterious environmental effects of the receiving water body. This generates the need to include a tertiary treatment step in WWTP for effluent polishing.

Evaluating the particle size in wastewater is necessary for numerous reasons. First, size has a prominent impact on settling velocity of the particles which is an input in the design of sedimentation tanks. Second, biological and chemical contaminants, metals, nutrients and toxic substances are found to be bound to the particles, hence it guides in choosing suitable treatment steps for necessary contaminant removal. Third, high particle removal efficiency can be attained by particle aggregation through coagulation; coagulant dosage is affected by particle size. Fourth, to forecast the suspended solids (SS) concentration, turbidity, color and chemical oxygen demand (COD) (Gulliver et.al. 2010, Li 2016, Ben et.al. 1997).

Micro screening (discfiltration) has lately been a desirable technology for tertiary treatment in many wastewater treatment plants (WWTP) around the world (Bourgeous, et.al 2003, Ljunggren 2006). Micro screening works on a basic principle of physically blocking particles that are bigger than the size of the aperture of the filter media. The preference to implement micro screening is attributed to its many advantages. First, retrofitting in space limited WWTPs due to its low foot print area demand. Also, the performance of discfilters can be governed by automated control systems. Second, a low head loss accompanied by a high hydraulic loading is easily attained for a low filtration area hence, less space and energy is used for the conveyance of water and operation of filters. Third, high resistance and longevity of the filter cloths during different operating scenarios and weather conditions and at the same time achieving desired effluent standards (Grabbe et al. 1998, Wilen et al 2012).

Tertiary treatment is adopted in WWTP for mainly two reasons. Firstly, polishing of effluent from activated sludge stage due to stricter environmental legislations. Secondly, when biological treatment stage of WWTP has reached its treatment capacity due to increased load from increasing population equivalents and high flow occasions (e.g. during heavy rainfalls). The suspended solids present in the secondary effluent arise due to high hydraulic loading, poor settling behavior of activated sludge or insufficient tank depth (Persson et al 2006).

The filtering fabrics (polyester fiber) used in discfilters for tertiary treatment of wastewater are in the range of 10-25 µm. The solids get trapped on the fabrics and removed by backwashing using high-pressure jets. In a study by Persson et al (2006) proved that discfilters employing filter media of pore size 10-18 µm achieve 90% solids removal efficiency. However, the challenge faced in the use of discfilter included filter panel clogging during long term operation. This drawback is overcome by regular chemical cleaning of filter panels in order to retain initial filtering capacity and to allow designed surface loads on the filter. Discfilters prove to be an efficient alternative to sand filters in terms of SS removal from wastewater and attaining high water flow rate with an integrated backwashing system that allows filtration even during operation (International filtration news, Hydrotech).

Discfilters using appropriate pore size along with chemical pre-treatment were successful in achieving the desired effluent standards (Wilen et al 2012, Väänänen et al. 2013, Kängsepp_et al. 2016). From previous studies conducted in WWTP Trollhättan (Arvidstorp) concluded that the average SS concentration in wastewater effluent is less than 5mg/l (Kängsepp_et al_2016).

In wastewater, solids exist as organic and inorganic materials in variable sizes.These particles can be measured as total suspended solids (TSS) which prevent the removal of micropollutants by shielding them. TSS is defined/measured as particles that are retained on Whatman glass fiber filter, which is of pore size of 1.58 µm, after being oven dried at 105˚C(Metcalf & Eddy). In general, the total suspended solids (TSS) in the wastewater can be between 120 to 400 mg/l (Metcalf & Eddy). In Sweden, the TSS in the effluent of urban WWTP must not exceed 35-60 mg/l for WWTPs with population equivalent (PE) between 10,000 and 99,000 (SLU and IVL 2014, the environment protection act 2002). Hence, it becomes vital to develope particle size distribution (PSD) of solids as it grants greater understanding of the range of size of solids present in the wastewater in different steps of WWTP.

2.2 Aim of the Study

The main purpose of this thesis is to analyze the influence of particle characteristics in operation without 2-stage chemical pre-treatment and effect on frequency of chemical cleaning of the discfilter plant in Arvidstorp WWTP, Trollhättan. This aim is achieved by dividing the work into three stages. Stage one: developing a reliable method for determining the size distribution of solids in the influent. Stage two: using the developed method from the previous step on the effluent from biological treatment and in different operating conditions such as during dry and wet weather conditions. Stage three: determine hydraulic filtration capacity measurements of filter panels from full-scale discfilters using ET-equipment and to determine clogging rate of the filter panels during long-term operation.

2.3 Specific objectives

The following questions need to be answered:

Developing a method for particle size distribution

- Which among parallel and serial filtration is the most suitable method for particle size distribution?
- Are the turbidity, TSS and hydraulic capacity obtained from the two methods similar?

Characterization of particles in the influent

- What is the particle size distribution (PSD) in the influent wastewater to disc filters for different operating scenarios?
- What is the PSD of particles below 10 µm size?

Capacity measurements of filter panels

- How does the filtering property change of disc filter panels change over time?
- What is the pattern for long-term clogging in filter panels?
- What is the optimal frequency for chemical cleaning of the disc filter panels?

3 Literature review

3.1 Particle Characterization

3.1.1 Definition

Particle characterization and size distribution was first developed by Levine et al (1991), this categorizing is a necessary step in design and operation of wastewater treatment process. The classification of matter in sewage is performed according to table 1. In general the matter is classified as dissolved or particulate and a membrane of size 0.45-1.6 µm is used to separate dissolved matter from particulate matter. They are categorized as settleable (>100 µm), supra colloidal (1-100 µm), colloidal (0.001-1 µm), and dissolved (<0.001 µm). Particles belonging to the colloidal, supra colloidal and settleable groups are classified as particulate matter of sewage.

Table 1 Classification of particles in wastewater (- adapted from Metcalf & Eddy)

Designation	**Dissolved**	**Colloidal**	**Supra colloidal**	**Settleable**
Particle size(µm)	<0.01	0.01-1	1-100	>100

The particles were further classified based on their physical and chemical characteristics for better evaluation of particle degradation and removal mechanisms. Figure 1 represents the various sizes of particles and their appropriate removal technology from wastewater.

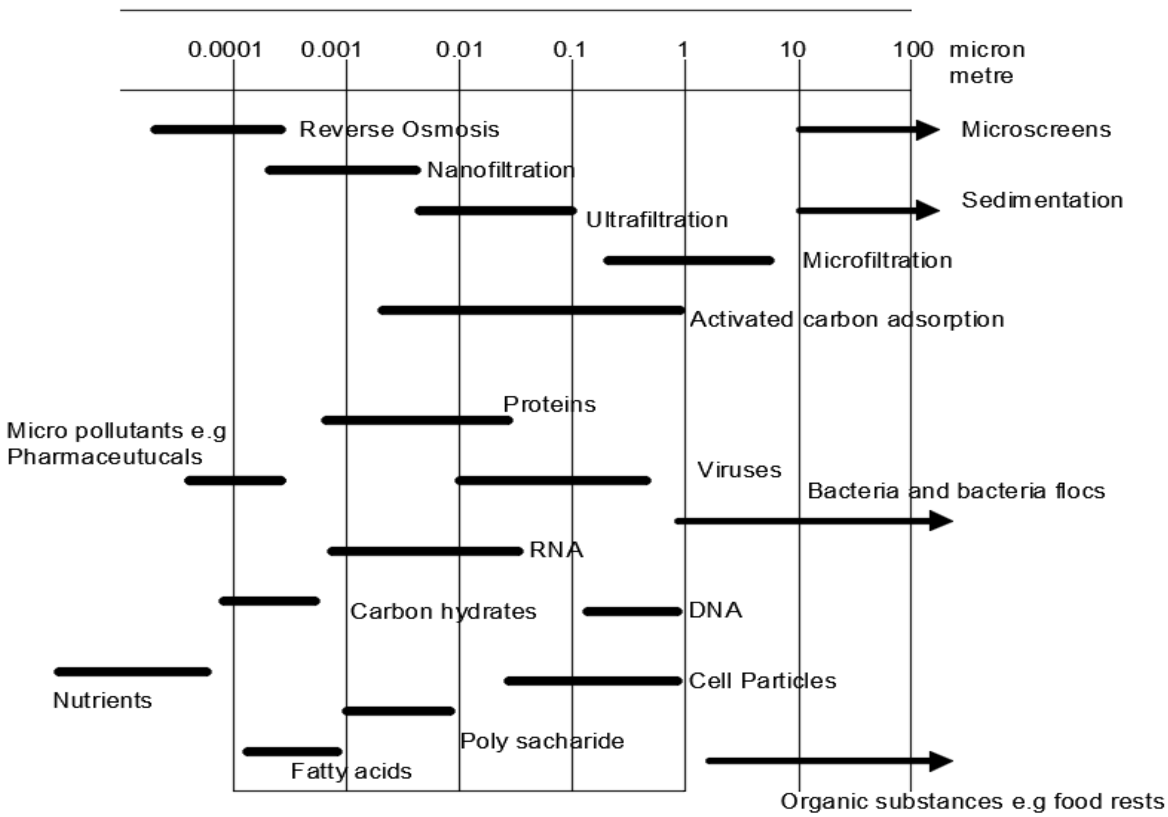

Figure 1 Classification of solids in wastewater and their appropriate removal technologies (adapted from Metcalf & Eddy and designed using AutoCAD)

3.1.2 Methods for determination of particle size distribution

In this work the measurement of the particle size is undertaken to comprehend the characteristics of particles that constitute total suspended solids in wastewater. There are many methods to determine particle size distribution in water. They are generalized as techniques based on observation and measurement technique and separation and analysis technique. In the study of assessment of sludge particles, Wilen et al. (2012) uses WPC- Art instruments Inc.,(electronic particle counter) and also use polyester filter cloths manufactured by Hydrotech AB for serial filtration to determine the particle size distribution. Similarly, Neis and Tiehm (1997), in their study of particle size analysis in wastewater used light blockage technology and membrane filtration. Among other techniques of measurement, the most common methods of particle size measurement are microscopic analysis, conductivity difference and change of electrical resistance, light scattering and field flow measurement (Neis et al. 1997). To obtain reliable and consistent results these techniques must be repeated several times. The methods used in this work to quantify wastewater particles are – Serial Filtration and Parallel Filtration using polyester filter cloths and electronic particle counting instrument (PAMAS S40).

3.1.3 Particle Size distribution in Tertiary wastewater

The studies at Gryaab AB/Rya WWTP in Gothenberg showed high removal efficiency for particles larger or equal in size to the pore. The discfilters of pore size 15-20 µm were able to remove 95-99% of particles greater than 15-20µm and discfilter of size 10 µm was able to remove 80-85% of particles greater than 10 µm (Behzadirad 2010 and Abudouweili 2011). Distribution of contaminants over particle fraction and particle removal efficiency cannot be generalized, as wastewater composition changes based on WWTP. Many tests conducted on contaminants related to particle size, indicated that BOD, COD and total phosphorus are bound to particles in the range of 5 to 63 µm in size and total nitrogen is often associated to particles smaller than 0.1 µm. 44% of BOD, 38% of COD,35 % of phosphorus and 13% of nitrogen is associated with suspended solids (Levine *et al.*, 1991,Nieuwenhuijzen et al., 2004) .In a recent study, it was revealed that the particles in the range of 2-6.3µm made up almost 80% of the total suspended solids.(Wang S et al. 2014). Figure 2 shows a schematic representation of contaminant distribution over size fraction.

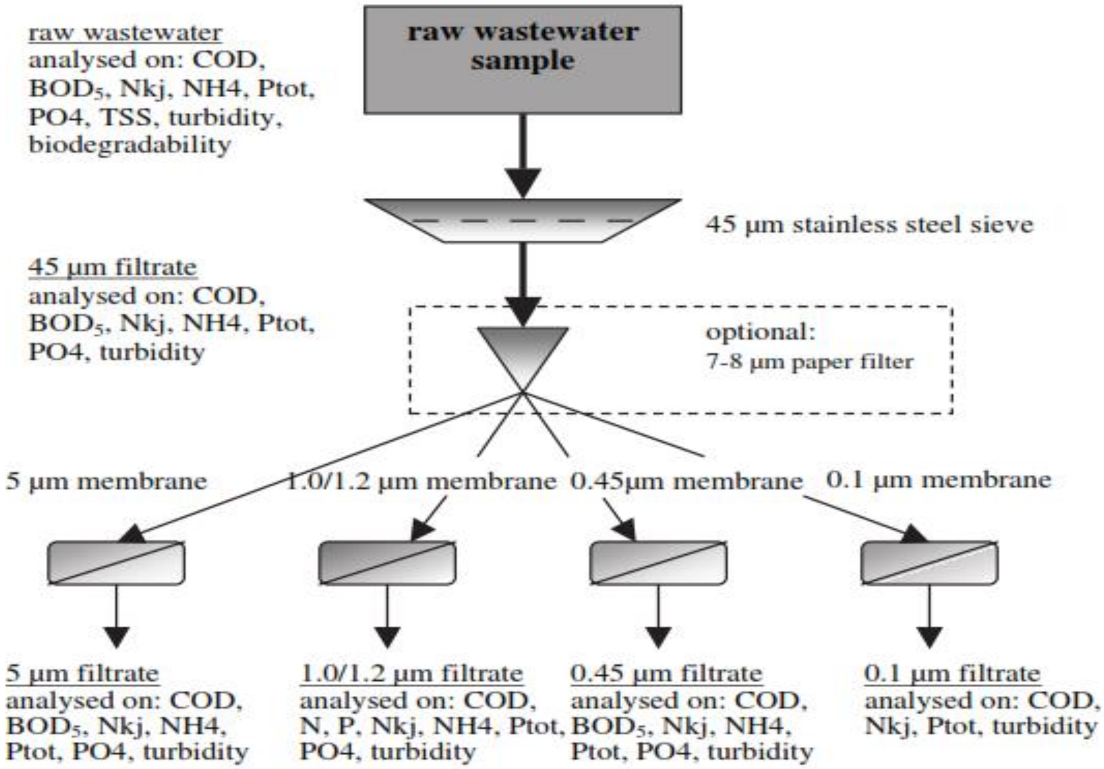

Figure 2 Schematic explanation of fractionation analysis (adapted from Abudoweili 2011 and Behzadirad 2010)

3.2 Discfiltration

3.2.1 Mechanism

The Hydrotech discfilters (Figure 3) is a mechanical and self-cleaning filter offering large filter area in a small footprint. The wastewater to be treated is introduced to the center of the drum under the influence of gravity. The outer surface of the drum is reinforced with vertical discs made of filter media. The wastewater flows through the filter and the solid particles are refrained from passing and settle on the filter media. This reduces the surface area for filtration and increases the water level inside the filter. The level sensor triggers backwashing where the drum rotates and the nozzles fitted on the overhead bar sprays pressurized water, solids get detached from the filter media and are collected in a trough and channeled to sludge dewatering station. Backwashing starts when the water level difference is around 200 mm. Filtration is continued even during backwashing and usually filtered effluent is used in backwashing.

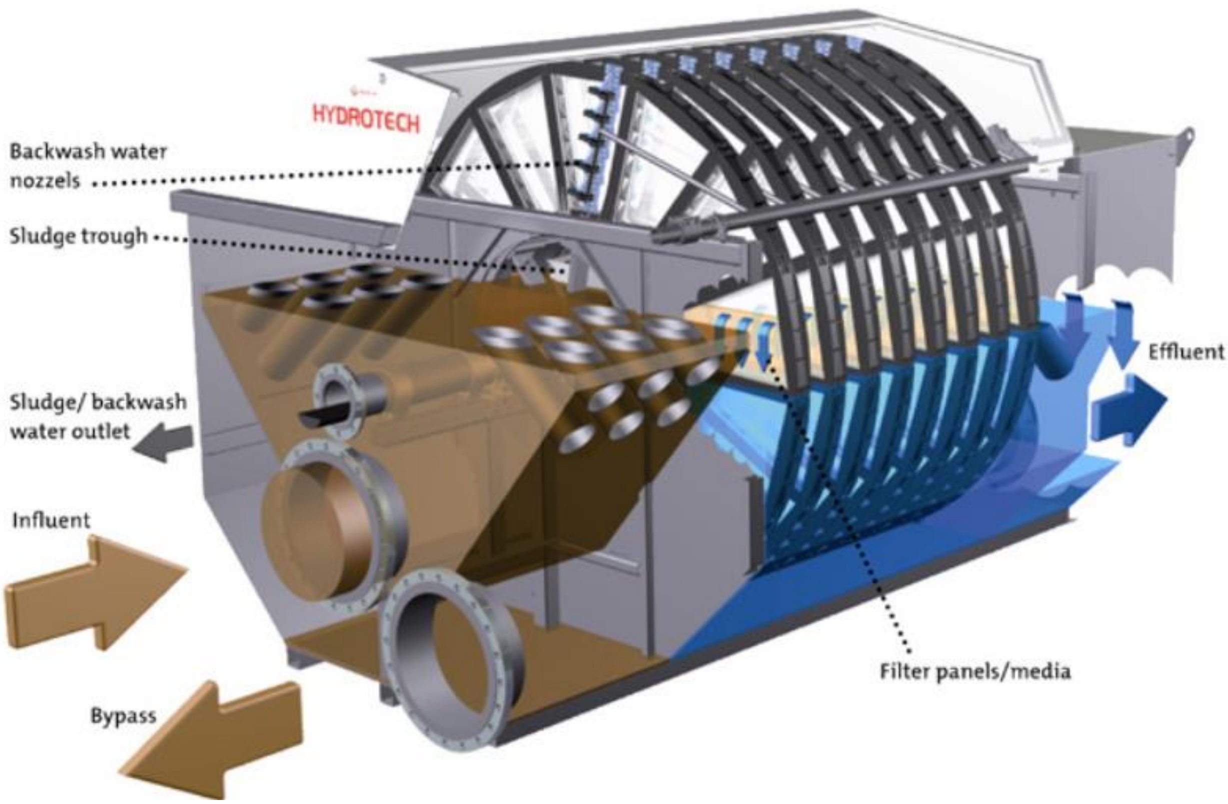

Figure 3 Hydrotech discfilters (adapted from Veolia photo library)

3.2.2 Using discfilters for tertiary treatment of wastewater

At Gryaab AB/Rya WWTP, Gothenburg, 32 discfilters of 15 µm were able to reduce the suspended solids concentration to 1 mg/l and total phosphorus concentration to less than 0.2 mg/l (Wilen et.al 2012). Also in the same WWTP in 2010 and 2011 the discfilters was achieving 85-90% SS removal efficiency by producing effluent containing SS, 1.5-5 mg/l (Behzadirad 2010, Abudouweili 2011). Correspondingly, in 2016 in Arvidstorp WWTP, Trollhättan, 6 discfilters of 10 µm performed very well by achieving low concentration of suspended solids (<5 mg/l) and total phosphorus (<0.2 mg/l) in the effluent (Kängsepp et al. 2016). Moreover, pilot experiments conducted by Väänänen et al. (2013), in Ruhleben WWTP in Berlin, Germany, proved that discfilters of size 10µm could produce 0.05-0.06 mgTP/l in the effluent when the wastewater is chemically pretreated. Also Ljunggren 2006 in his study projects concludes that, there is an overall general acceptance of discfilters as a well-accepted alternative for primary, tertiary and stormwater treatment. His work also agrees to the fact that when wastewater is chemically treated, the discfilters are capable in achieving high (>90%) SS removal efficiency.

3.2.3 Filter cloth fouling and chemical cleaning

The key issue associated with operation of discfilters is long-term clogging of the filter media. The filter media is made of polyester. To demonstrate a good service life and flow characteristics, the material needs to be chemically washed using acid solution (10-15 % HCl) and alkali solution (4 % NaCLO). Usually this chemical cleaning cycle is performed every 4-6 weeks depending on the extent of fouling of the filter. Meanwhile cleaning and prevention of fouling is undertaken by an automated backwashing system which sprays high pressure (4-8 bar) water to remove deposited particles from the filter media (Ljunggren 2006).

At Gryaab AB/Rya WWTP, Gothenburg, the chemical cleaning frequency occurs every 6^{th} week. Similarly, in Arvidstorp WWTP, Trollhättan, during the first year of discfilter operation, the chemical cleaning of discfilters occurred every 6^{th} week. This frequency in chemical cleaning cycle seemed appropriate to maintain a high filtration capacity (Kängsepp et al. 2016). Furthermore, the pilot study in Ruhleben WWTP in Berlin, Germany also revealed that for a process to be operated economically, chemical cleaning was necessary every 3-4 weeks.

3.3 Theory of Microfiltration

Microfiltration performance is controlled by the interaction of particle (or aggregates) with the micro sieve. All experiments conducted during the testing period show that there is a substantial decrease in hydraulic conductivity and this is due to temporary binding of suspended particles (cake) on the micro sieve. The temporary binding is removed by automated backwashing system and long term binding (or clogging) is removed by chemical cleaning of micro sieve. Bowen et al. (1995), in their work have described the various assumptions and theoretical models to understand the blocking mechanism of particles during filtration. Figure 4 shows different types of blocking,

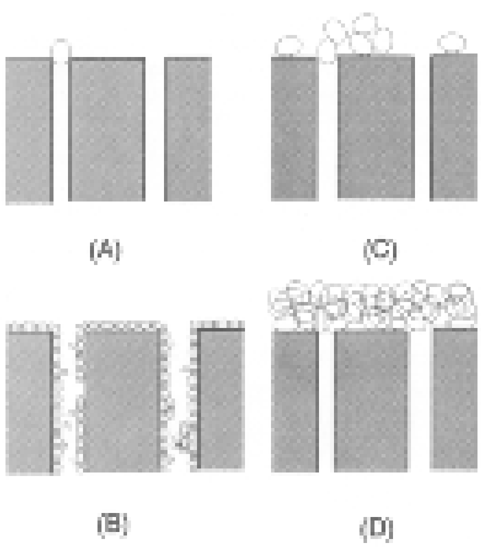

Figure 4 Schematic diagram of fouling mechanism (adapted from W.R Bowen et al 1994)

A-Complete blocking –This phenomenon occurs when a particle or aggregate completely covers a pore with no overlapping or superposition of other particles.

B-Standard blocking-A common occurrence during filtration, in which the particles bind to the inner walls of the membrane, causing a decrease in pore opening size.

C-Intermediate blocking-The assumption made in this model is that each particle completely or partially super positions the particle that had previously arrived. This can cause direct or complete blocking of pores and also there is scope for deposition on the walls of the membrane.

D-Cake filtration-This is the most common situation, where newly arriving particles locates itself on previously arrived particles that are partially or completely blocking the pores and there is no scope for deposition on the walls of the membrane.

Bowen et al. (1994), found that even though the pore size was bigger than the particle diameter, total permeate volume decreased significantly over time. It is also seen that filtration velocity decreased faster for more concentrated solution (wastewater with high SS) due to rapid deposition process.

3.3.1 Cake formation

Pyung-Kyu Park et al. (2006), describes the benefits of cake formation. The porosity of the sieve is uniformly distributed but the cake formation on the discfilters is not uniform, this affects the overall performance, as it varies the filtration capacity and the SS removal efficiency between the filters. Cake formation on the surface of the membrane is preferred as it traps particles smaller than sieve opening. It is strongly recommended to maintain the cake formation and its permeability on the filters, which in turn improves the removal efficiency. The porosity of the cake formed depends on the size and shape of the incoming aggregate and their fractal dimensions, in a study it has been concluded that larger aggregates with higher fractal dimension have higher inner porosity.

Bowen et al. (1994), determined a series of steps for cake formation (1) Inner surfaces of pores getting covered by small particles, reducing the diameter of the pore opening also known as standard blocking, (2) formation of aggregates in the pore entrance due to shear stress, leading to partial or complete blocking of certain pores also known as combination of complete and intermediate blocking, and (3) then newly arriving particles gradually get super imposed on pre-existing particles and finally a cake starts to build. The different phases of cake formation cannot be clearly distinguished as it occurs swiftly due to the pressure applied. Furthermore, the retention of cake is longer for small pore radii and at low pressures. Shear stress also influences cake formation and is interpreted in two ways, high shear stress can lead to less interaction time for particles with membrane and on the other hand shear occurring at the junction of the micro pores can change the structure of the particles leading to increase in the formation of aggregates. But naturally the Van der Waals forces and hydrophobicity between filter material and particles the reason for solids deposition.

4 Methodology

4.1 Research site: Arvidstorp WWTP

Trollhättan currently home to a population of 59,000 has a WWTP located in Arvidstorp, controlled and managed by Trollhättan Energi AB and it is designed for treating 70 g/p.d BOD (Per Lundquist, personal communication, October 2017). The average flow to the plant is 35888 m^3/d. The plant has a mechanical grit removal followed by a sand trap. Ferric chloride and the polymer are added before wastewater enters the primary sedimentation tank to remove large suspended particles through settling. The primary clarified water enters a biological treatment zone where 1/3 of the flow is subjected to nitrogen reduction and 2/3 of the flow is treated for BOD removal using an activated sludge system process before wastewater finally enters the secondary sedimentation tank. In 2013, an effluent polishing step was installed with an aim to produce an effluent of total phosphorus (TP) concentration less than 0.3mg/l as shown in figure 5. It consists of a chemical pretreatment step of coagulation and flocculation accompanied by six disc filters (HSF2626/26-2F). In the beginning of 2017, 8 additional discs on each of the 6 discfilter were mounted (from 18 to 26 discs per filter) to increase the plant's capacity. Each discfilter, with 26 discs made of 10 µm filter cloth panels contribute about 198 m^2 area for filtration. The primary sedimentation tank is designed to receive 3600 m^3/h flow. If the flow exceeds it directly bypasses the river Göta älv. The biological treatment is designed to treat a flow of 1800 m^3/h. If the incoming flow from primary sedimentation tank is higher than 1800 m^3/h, then the flow is diverted to discfilter hall. The discfilters are designed to treat up to 5000 m^3/h and if flow is higher it is bypassed and channeled to the tunnel connecting river Göta älv.

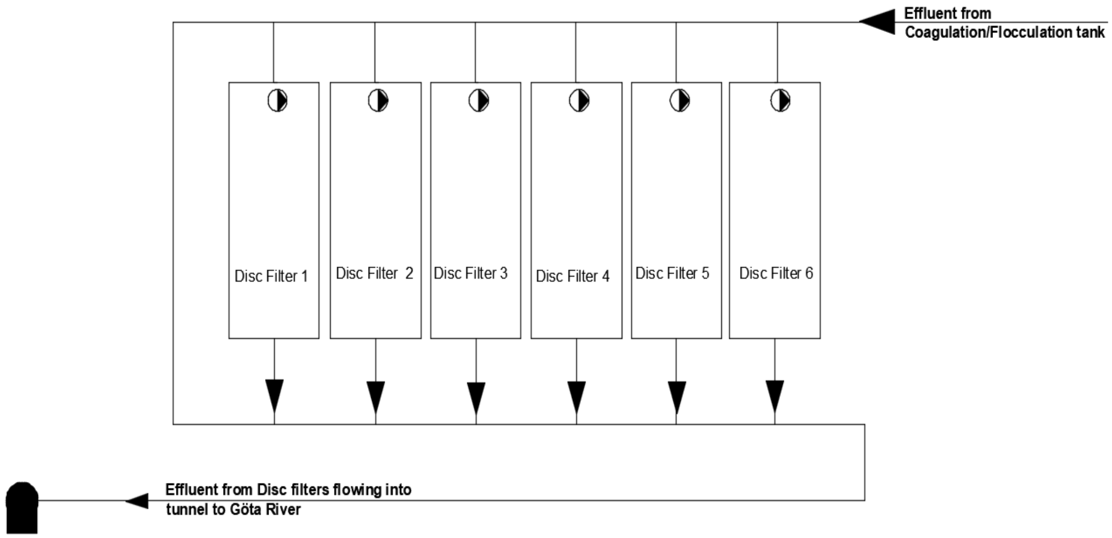

Figure 5 Schematic diagram of the discfilter facility and flow of wastewater

4.2 Full-scale follow up study of discfilter plant

4.2.1 Chronology

Many activities were executed during the study of operation of discfilters. These activities were applied to test the behavior of discfilters under different conditions. The following sections will have events arranged in order of their occurrence.

4.2.1.1 Performance of discfilter plant and individual filters

TSS concentrations were estimated in grab samples taken in the influent channels of all discfilters. This test was carried out in November before the commencement of filter cloth performance and full scale operation of discfilters. The samples were taken during two consecutive weeks in November when the flow was between 20,000-22,500 m^3/day. The purpose for this test was to investigate if TSS concentration varies in the influent channel and if all discfilters receive the same solids loading. Only one filter could be selected for detail investigation of long term performance and behavior of filter panels. Thus this test was helpful to find out a filter which is most loaded for further testing.

4.2.1.2 Period of chemical pre treatment

The nutrients are attached to particles smaller than the pore size of discfilter and in order to remove nutrients from the secondary effluent, certain coagulants and polymers are added to the wastewater to flocculate the small particles. This step occurs before the water enters into the discfilters. This activity occurred for a brief period in the month of November from 19/11 to 30/11 and was followed by a chemical cleaning. The TSS concentration in the effluent was below 1 mg/l during this phase.

4.2.1.3 Period of chemical cleaning on discfilter

Chemical cleaning is done to remove fouling on the filters and to regain the original filtration capacity of the filter panel. Two chemicals were used HCl (10-15%) and NaClO (4%) in cyclical order which dissolves the inorganic and organic impurities. This was carried out during various months and weeks to test the most optimum cleaning frequency of the discfilters. The cleaning occurred twice in November, once in December, January and March as shown in figure 6.

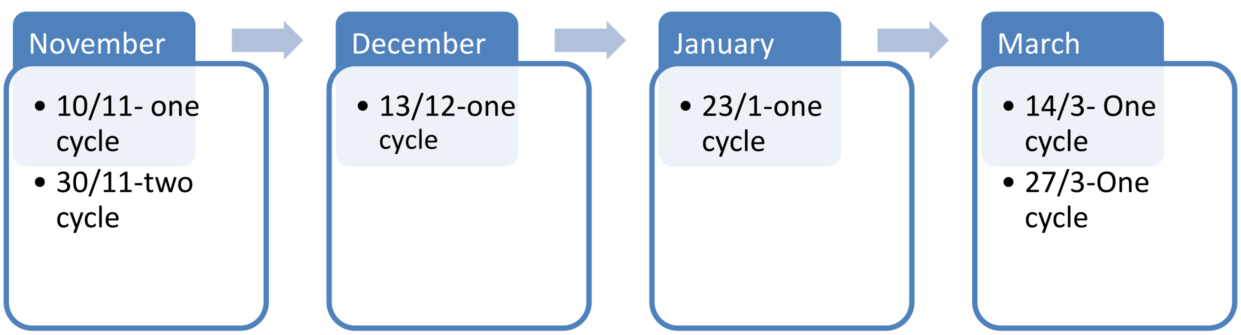

Figure 6 Periodical representation of no. of cycles of chemical cleaning on discfilters

4.2.2 On-line Measurements

Suspended solid measurements are necessary to monitor deviations in the performance of discfilter hence a Hach sc200 universal controller configurator was installed for online measurement of SS concentration from the influent and effluent of the discfilter installation.

In order to independently control the discfilter, each discfilter was connected to Allen Bradley monitoring and control systems. Recording data from individual discfilters is useful in making comparative studies of single discfilter with other discfilter installations. This mountable instrument can record the flow through the filters, difference in water level across the discfilter, pump and drum rotation hours and start counters and many more advance elements.

On-line BW measurement system (developed by Veolia Water Technology) was used to measure backwash frequency during 4-10 April 2018. In this system, the pressure switch was mounted at the position of the manometer on the Hydrotech filters. The switch was closed at approximately 1 bar to indicate when the backwash is on and vice versa. The sensors were connected to the logger (programmed using the supplied software and adapted for the application) and data was recorded to the memory card.

4.2.3 Investigation of the filter cloth performance in time

When Hydrotech inspected the discpanels they found that the fouling level and fouling pattern was not same within a discpanel and in between the discpanels of a discfilter. To further explore this oddity, three disc panels were selected from of discfilter 6 that is in the front (discpanel 2), middle (discpanel 13) and rear end (discpanel 25). Each of the discpanel surfaces is divided into top, middle and down. The image on the left below (figure 7) shows the open hatch discfilter, the discpanels on top were sprayed in yellow which shows the position of the discpanels within the disc filter. New discpanels were inserted in this position and all the experiment were carried out on the same discpanels throughout the period of work. The image on the right below (figure 7) shows a new discpanel and the plastic ridge has divided the discpanel surface into three different regions. Measurement with tap water were conducted by ET-equipment (see section 4.2.3.1 and 5.3.3 ET-equipment) once per week (always at the same time when it was possible, namely Mondays between 10:00 to 15:00.

Figure 7 Discfilter at Trollhättan treatment plant and a discpanel showing different regions

4.2.3.1 ET-Equipment

The rate of filtration (m/h) in a discpanel is determined using ET-equipment (technology developed by Hydrotech). The disc panels are placed in the ET-equipment as shown in the image above and by using tap water and wastewater the filtration rate of the filter panels is calculated every week.

4.2.3.1.1 Filtration velocity

Filtration velocity is the volume of water that passes through a pre-defined filter during a standard test period of 10 seconds. The intention of obtaining this information is for the design of pilot and full-scale filters. It is also known as hydraulic loading and is preferably expressed in m/h. The filtration velocity is greatly affected by the suspended solids concentration in the sample and is calculated using the equation shown below.

$$Q_{filtration} = \frac{V \times 10^{-6}}{A \times \frac{t}{3600}} \frac{m^3}{m^2 \times h}$$

A=effective area in m^2 (0.0035 m^2);
V=amount of tap water filtrated through the filter cloth in ml (2000 ml);
T=measured filtration time recorded in seconds;

4.2.3.1.2 Tap water hydraulic capacity

In this procedure a filter panel is selected and placed in the ET-equipment and two liters of tap water is made to pass through. The time is recorded and by already knowing the filtered volume and area under influence, the hydraulic filtration capacity of the filter can be estimated using the equation in section 4.2.3.1.1.

4.2.4 Manual measurements at the site and laboratory

4.2.4.1 Turbidity

Turbidity test is another test to indicate water quality with respect to the residual suspended matter. Turbidity works on the principle of the intensity of light scattered by the suspended solids in a sample. The turbidity results are represented in FNU (Formazin Nephelometric Units). Care was taken that air bubbles are not introduced in the sample as it can disrupt the result and also due to a high degree of variability observed in the results, a minimum of two turbidity readings were taken for each sample. HACH turbidity meter (Hach 2100Q, Germany) was used in this study.

4.2.4.2 Total suspended solids analysis

TSS is a universally accepted water quality test to assess the particulate matter concentration in wastewater. Based on the type and origin of wastewater 500-1000 ml of the sample is filtered through pre-weighed filter paper of size 1.58 µm. After filtration, the filter paper is transferred to an Al muffin form and placed in an oven for 105 ˚C for minimum two hours. The dried filter paper is cooled down and weighed again and the equation shown below is used to determine the weight of suspended solids retained on the filter.

$$TSS\ concentration\ = \frac{(X-Y)\times 1000\ \ mg}{Sample\ volume\ \ l}$$

X=weight of dry filter + dried residue (g)

Y=weight of filter paper (g)

4.2.4.3 Removal Efficiency

Removal efficiency is used to analyze the performance of a filter of a certain pore size in retaining particles. In other words, removal efficiency can provide the percentage of solids of a certain size range passing through the filter of a definite pore size. The relation shown below is used for determining the removal efficiency of filters.

$$Removal\ efficiency = \frac{X-Y}{X} \times 100$$

X= TSS in the influent, Y=TSS in effluent from a filter of certain pore size

4.3 Developing the method for particle size characterization and fractionation

4.3.1 Particle size characterization occasions

The TSS concentration in wastewater is mostly controlled by weather conditions and human activities because of which the fractionation procedure was carried out on different months, i.e during October (Autumn), November (Winter), December (Winter and Holiday season), January (Winter and Holiday season) and finally in April (Spring).

4.3.2 Procedure for using Hydrotech test tube equipment for particle fractionation

The method for particle fractionation requires some devices and tools that were provided by Hydrotech AB. A test tube fabricated from PVC plastic which is 300 mm long and 75 mm wide, a clamp with rubber joint to secure filter at the bottom of the test tube, filter discs made of polyester cloth with pore openings 60, 40, 25, 18, 15, 10 µm and a filter disc made of cloth filter with pore opening about 5 µm, a TSS equipment and whatman filter paper, measuring flask and cylinder, oven, electronic weight balance and 1-liter sample storing bottles.

The filter disc is attached to the bottom of the test tube by a rubber clamp and is made wet by placing it under tap water. A measured volume of wastewater is taken in a beaker and is poured quickly through the filter discs. The volume of wastewater passed in 10 seconds is recorded and filtration velocity is determined using the equation stated in section 4.2.3.1.1. Then, the concentration of suspended solids in the filtered wastewater is analyzed using TSS equipment. This procedure is repeated several times to obtain reliable values. The turbidity results are accompanied by TSS results for both methods and a comparison study is made. Two methods (parallel and serial) will be conducted using test-tube filtration unit to analyze the particle size distribution.

4.3.2.1 Parallel filtration

In the first method, the wastewater sample is made to pass through the test tube with a predetermined filter disc (for eg: 60 µm) for 10 seconds while maintaining a head of 200 mm. The hydraulic filtration capacity of the filter disc and TSS concentration is determined for the influent and effluent (filtered water) water. Later the same procedure is repeated for different decreasing sized filter discs (for eg: 40 µm, 25 µm) as shown in the figure 8. The filter discs were soaked in water for about one hour before every experiment to ensure complete wetting and avoiding hydrophobicity (suggested by Hydrotech engineers).

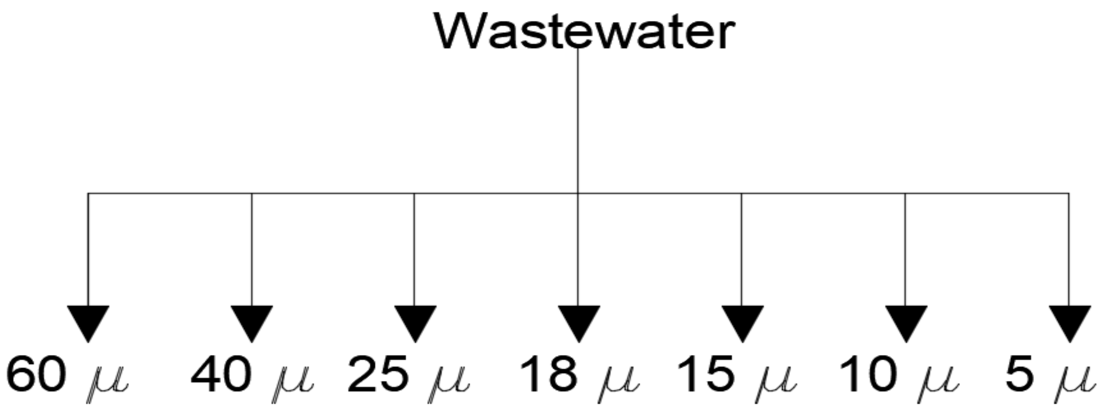

Figure 8 Schematic presentation of parallel fractionation

4.3.2.2 Serial filtration

In the second method, the measured volume of wastewater is taken and made to pass swiftly through the largest sized filter disc (in this case 60 µm) for 10 seconds while maintaining a 200 mm head and then the filtration capacity along with TSS is determined of the filtered volume of water. Now again the same measured volume of filtered wastewater which passed through 60 µm will be passed through a lower sized filter disc (40 µm) and again the TSS and filtration capacity will be determined from the filtered water. This procedure will be repeated in a sequential order of decreasing filter disc size as shown in the figure 9. The results from the two methods will be compared with each other and the most reliable method will be selected.

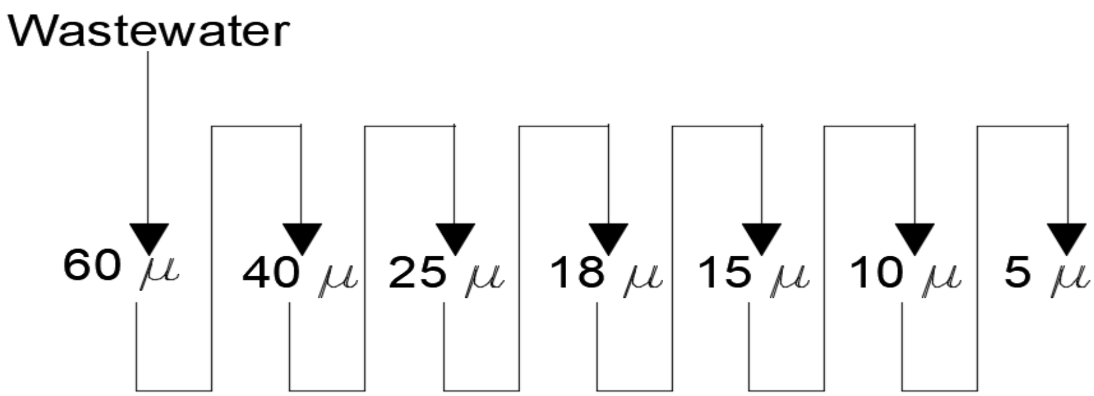

Figure 9 Schematic representation of serial fractionation

4.3.3 Wastewater samples for investigation

In all analysis, grab samples (18-20 L) were taken during under normal flow condition in the WWTP. The samples were collected at two points, influent wastewater to the discfilters and effluent wastewater from the discfilter. Since the physical, chemical and biological characteristics of the sample are bound to change during different periods of the day, sample collection was done at a specific time during the day between 9.00-10.00 am. The samples were stored in a laboratory approved plastic containers. The immediate analysis is undoubtedly the best procedure to avoid errors due to sampling distortion but during certain days due to lack of time, samples were preserved in the Arvidstorp laboratory to prevent deterioration.

Particle size fractionation was carried out on the wastewater influent to the disc filter. Grab samples were collected during dry and wet weather flow. The analysis was conducted approximately two hours after samples were collected. The samples were gently shaken to assure re-suspension of particles in the sample. All the analyses were conducted in the Arvidstorp WWTP laboratories.

4.3.4 Particle size distribution by PAMAS

The count of different sized particles from different samples was obtained by using an electronic particle counter, PAMAS S40 as seen in figure 10. The highly sophisticated sensor cell and optics guarantees good resolution and accuracy. The equipment is portable and is designed to measure particles in the size range of 2-100 µm. The equipment can assess maximum of 24,000 particles/ml and at a flow rate of 25 ml/ min. The equipment is highly versatile due to a built in 32-bit microprocessor which allows multiple automated sampling. The results are generated instantaneously through an integrated printer that provides instant hard copies. The user friendly software also allows easy transfer of measured data into a PC.

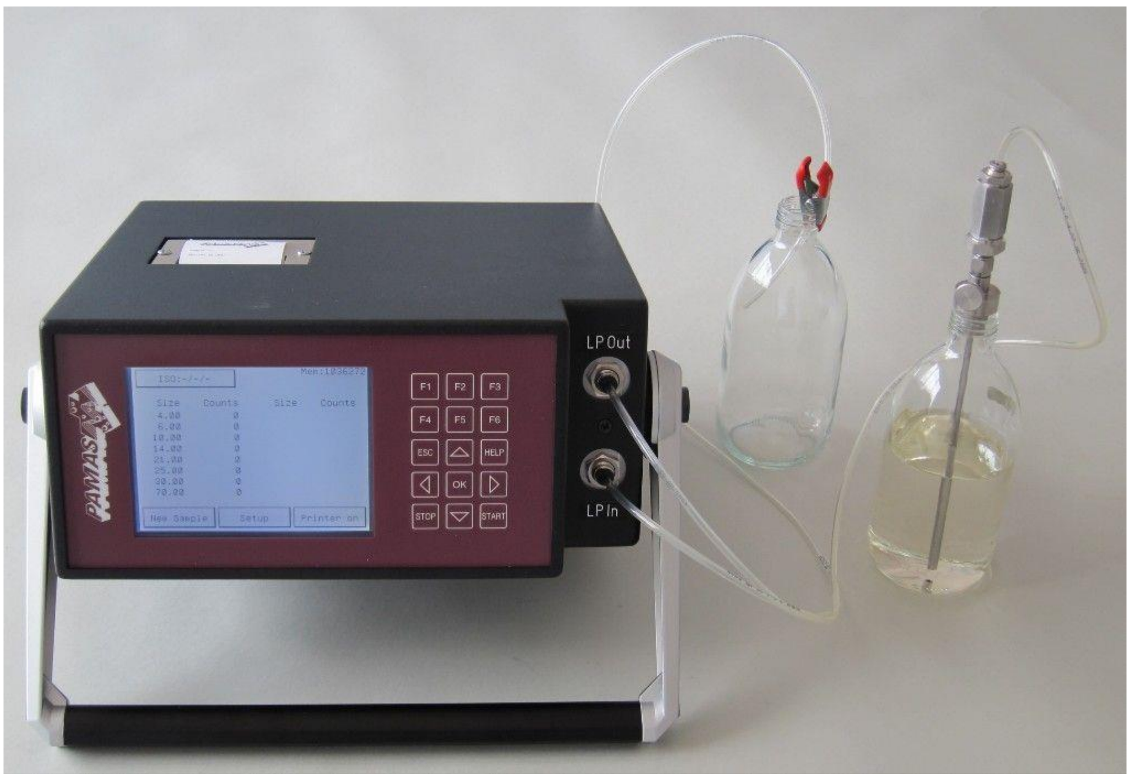

Figure 10 Particle characterization using pamas S40-(captured by anamatrix instruments technology)

5 Results and discussion

5.1 General performance of discfilter plant

5.1.1 Influent and effluent turbidity and SS concentrations

From figure 11, it is quite clear that the relationship between particle concentration for influent and effluent is almost linear. Higher particle concentration in the influent produces higher particle concentration in the effluent. When the influent TSS is fluctuating the filter cannot produce a constant TSS in the effluent because of the linear relationship between influent and effluent. Whereas,during chemical pretreatment filters achieved 99 % TSS removal and in the absence of chemical pretreatment filters were found to have a removal efficiency TSS ranging between 30-70 % with respect to particle concentration in the influent.

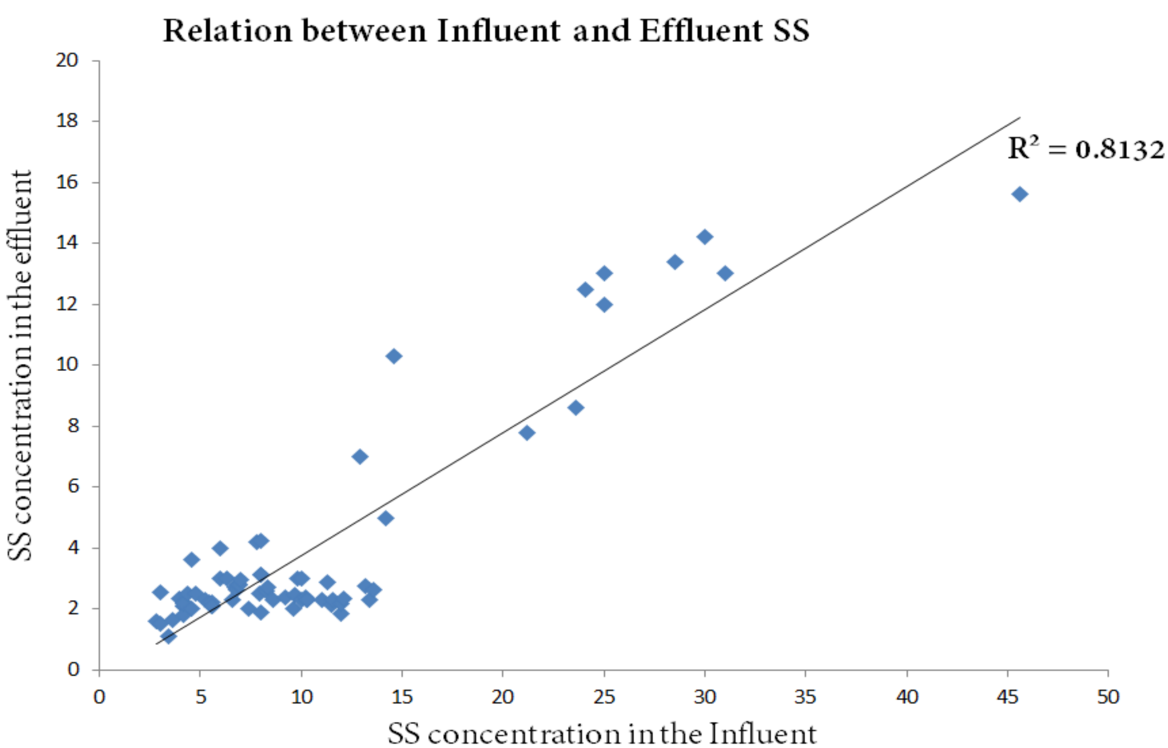

Figure 11 Relation between influent and effluent SS during normal days (i.e without chemical pretreatment and dry weather condition)

5.1.2 TSS vs Turbidity

Estimating suspended solids concentration for a large number of wastewater samples is very time-consuming. In this work, every TSS measurement is coupled with a quick turbidity measurement and the measurements are for the month of November and December 2017. The lowest and highest TSS recorded in the effluent from discfilter was 2.1 mg/l and 28 mg/l and turbidity measurement were 1.5 FNU and 15 FNU respectively.

The plotted data showed a reasonably good relation between TSS and turbidity of influent as seen in figure 12, with a coefficient of determination (R^2) of 0.6363. Also during wet weather conditions, the increased flow carrying sediments of erosion into WWTP causes the wastewater from primary sedimentation tank to directly bypass into discfilter hall so TSS in the influent to discfilter appeared to be a lot higher than the TSS of effluent from secondary sedimentation. Even though turbidity is not a test to identify TSS and turbidity measurements cannot be totally substituted for TSS measurements, it serves as a good estimate and is the most economical and least time-consuming method of predicting TSS. The fairly linear relationship and correlation between turbidity and TSS prove that turbidity can be used as a reliable tool in future predictions. (Hannouche et al. 2012, Daphne et al. 2011).

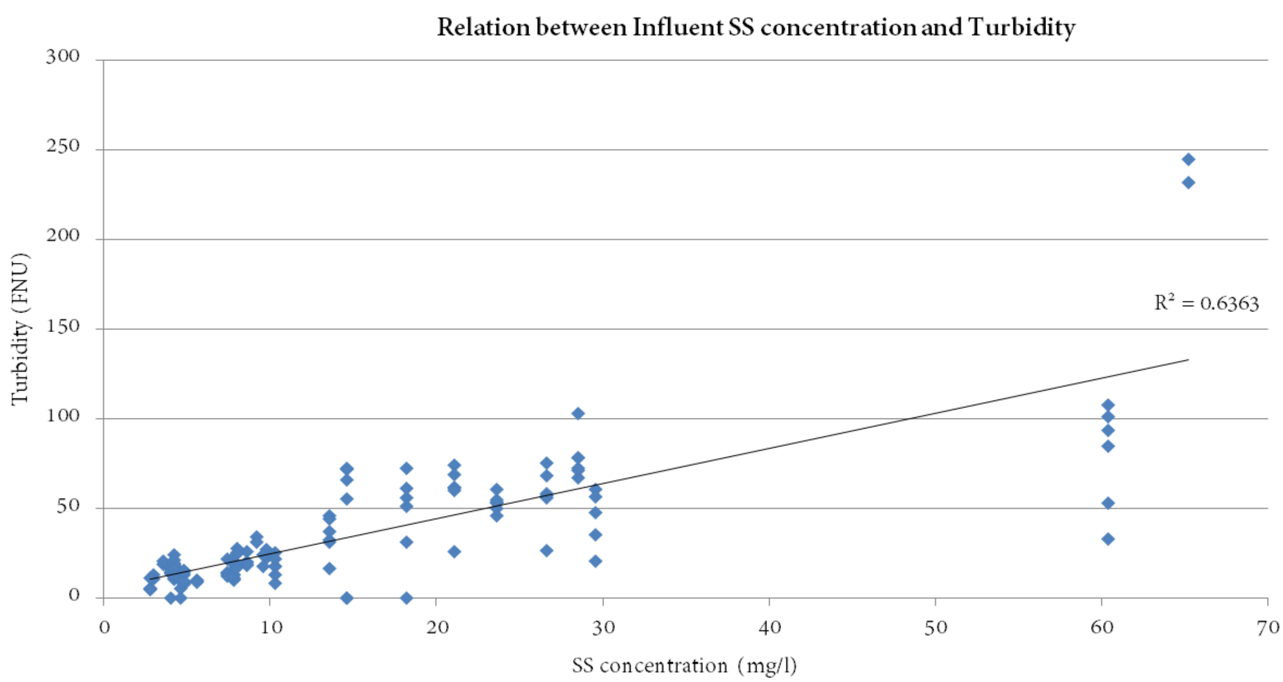

Figure 12 TSS and turbidity in the influent to the discfilters during dry and wet weather conditions

5.1.3 Flow to discfilters

As shown in figure 13, during the period of testing the average flow to the plant was 35,888 m^3/day. The highest flow occurred in December and January when close to 50,000 m^3/day was observed and in March the lowest flow of 26,259 m^3/day was recorded.

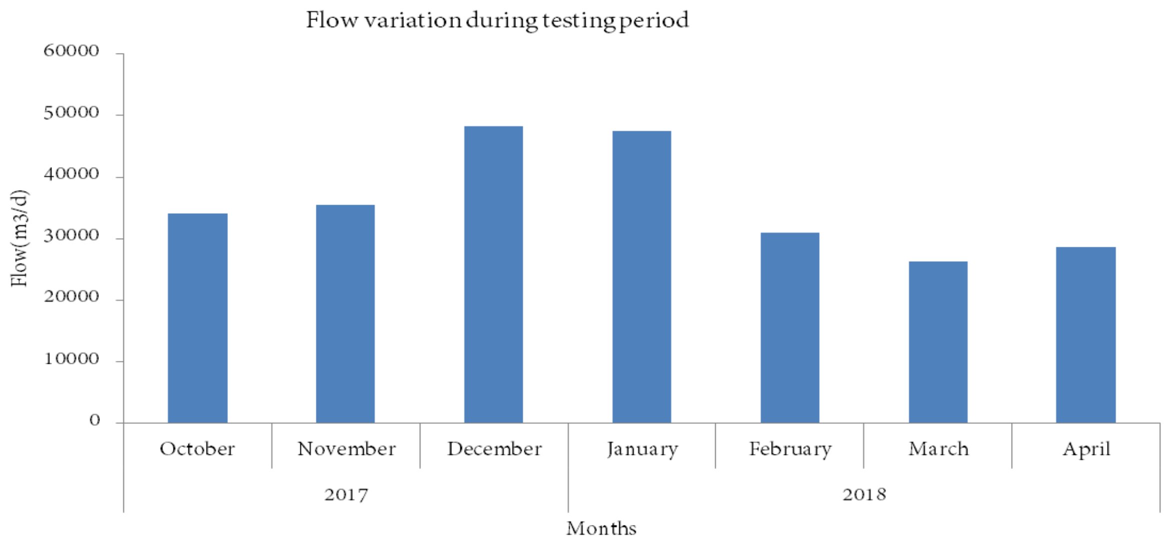

Figure 13 Flow variation influent to the discfilter plant during different months of testing

5.2 Performance of Individual filters in the discfilter facility

Before the start of the follow-up full-scale performance, the samples were taken and SS concentration was recorded from the influent of all discfilters as seen in figure 14. Interestingly on both days of sampling, the SS concentration in the influent to discfilter 6 was the highest. Unfortunately, on 9/11/2017 due to damages on the filter paper, the SS concentration of discfilter 1 could not be recorded but results from 13/11/2017 reveal that discfilter 1 receives the lowest amount of SS concentration. Discfilter 6 was chosen to conduct all the experiments related to filter cloth performance since the discfilter located first in the influent channel receive the highest solid loading.

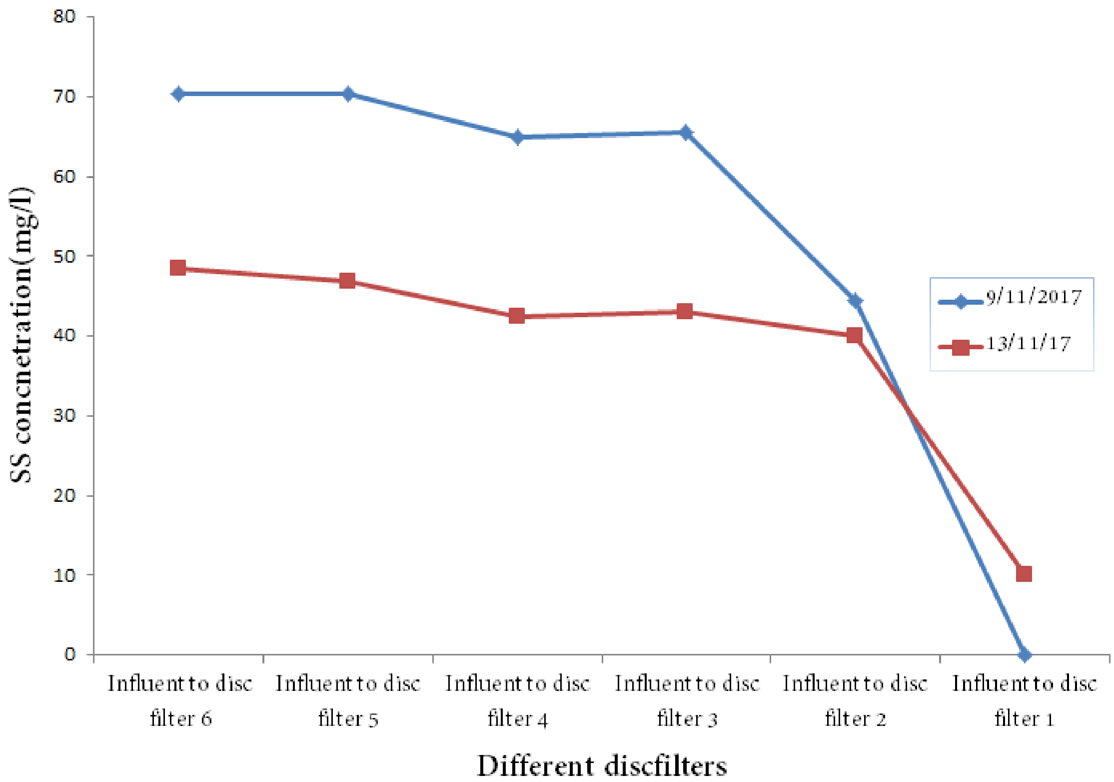

Figure 14 Difference in suspended solid concentration received by discfilters (variation of SS concentration in the influent channel)

The flow was not constant among the discfilters, Discfilter 6 and 5 received and treated majority of the incoming flow. This may not be a big concern since the nutrient concentration in the effluent was below the stringent limit but the concern rises when certain discfilters are overused compared to others which could lead to different maintenance problems such as breakdown. Figure 15 shows a comparison of flows received by different discfilters. The graph suggests that discfilter 6, 5 and 3 initially participated efficiently by receiving and treating high flows in the first 60 days of testing after that the previously mentioned discfilters started to receive less flow whereas the remaining discfilters 1, 2 and 4 started to receive higher flows and this trend continued till day 100. But after day 100, discfilter 1, 2 and sometimes 6 were solely receiving and treating almost 50 % more flow than other discfilters.

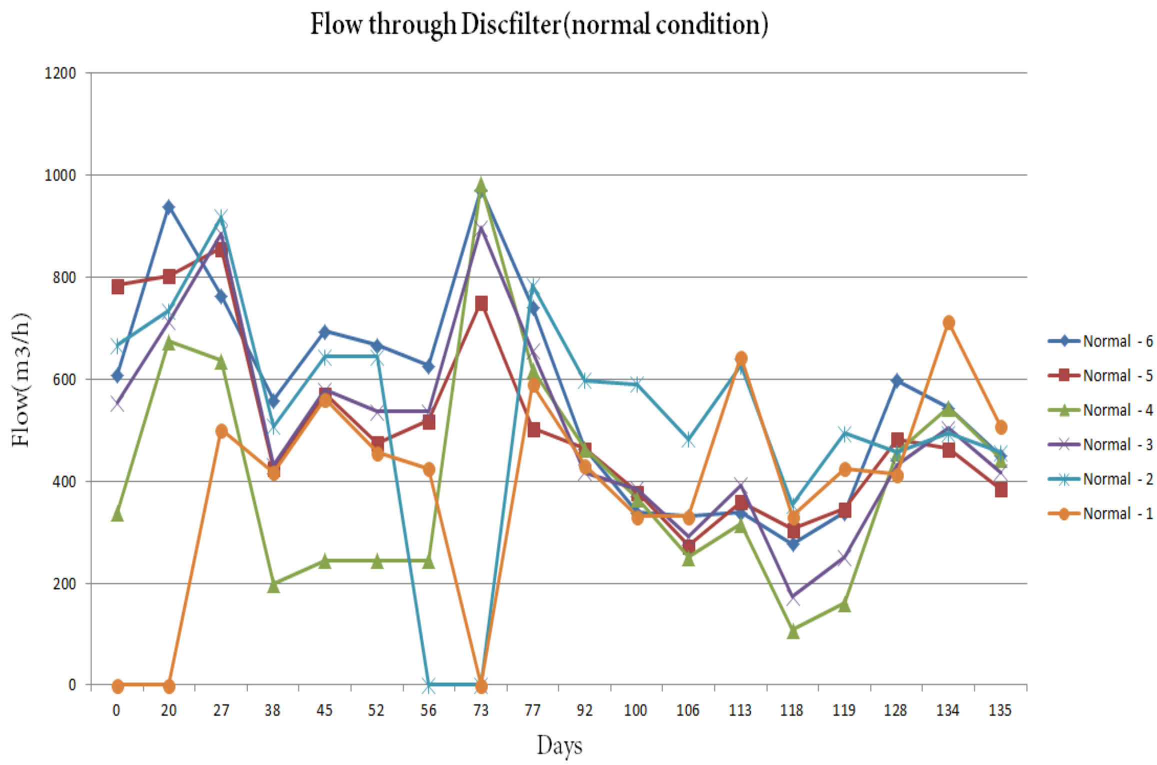

Figure 15 Flow through different discfilters during operation

Figure 16 shows a variation in flow between DF 6 and 1. It clearly depicts that DF 6 receives a higher flow than DF 1 and its treating capacity reaches 50 % in just 90 days. After 90 days, DF 1 started receiving all the diverted flow from DF 6 and its treating capacity rises from 300 m^3/h to 600 m^3/h in just 3 days and continues to treat greater amount flows. But the concern rises when these filters are chemically washed, initially discfilters 1, 2 did not clog as fast as other discfilters. Since chemical cleaning of the panels takes place on all filters at the same time. This could prove disadvantageous since a large amount of chemical solution is being used up while those discfilters are not contributing enough to treating the flow. Also when discfilter clogging takes place the backwashing occurs more frequently and this increases the energy consumption and that needs to be controlled. As a suggestion, the chemical used for cleaning DF

1, 2 and 4 can instead be used on D F 6, 5, 3 since they treat most of the flow in the first phase.

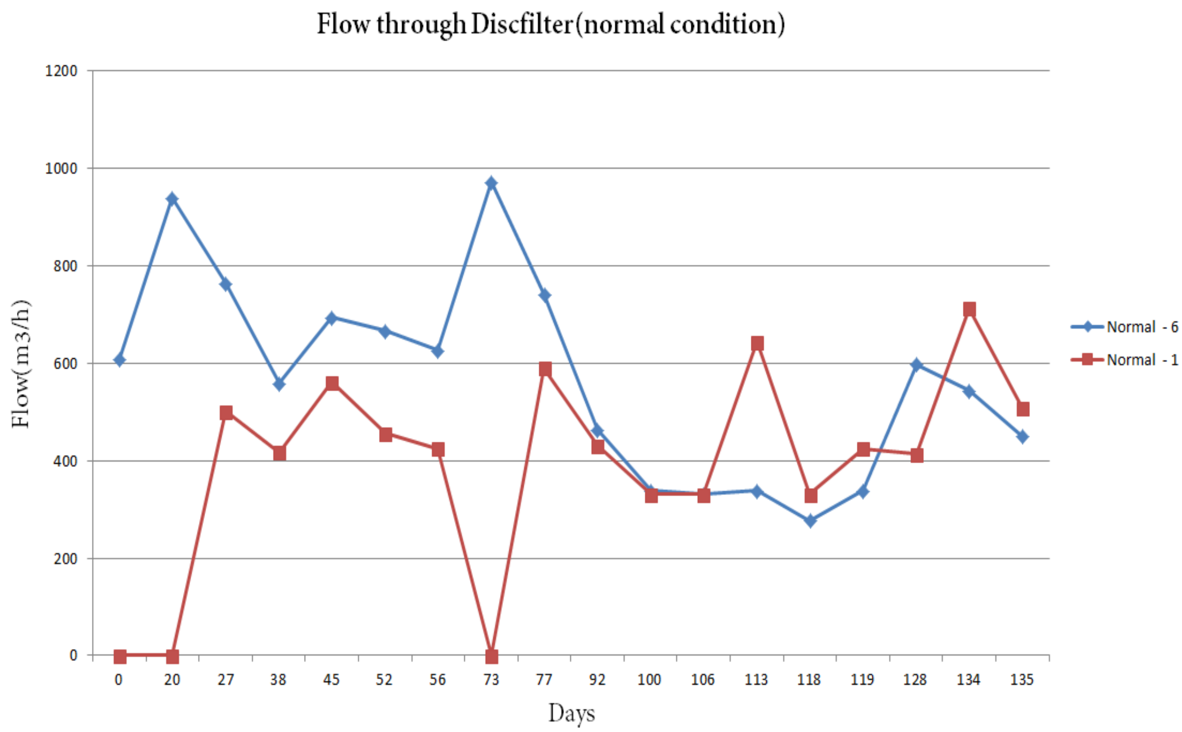

Figure 16 Difference in flow through discfilter 6 and 1

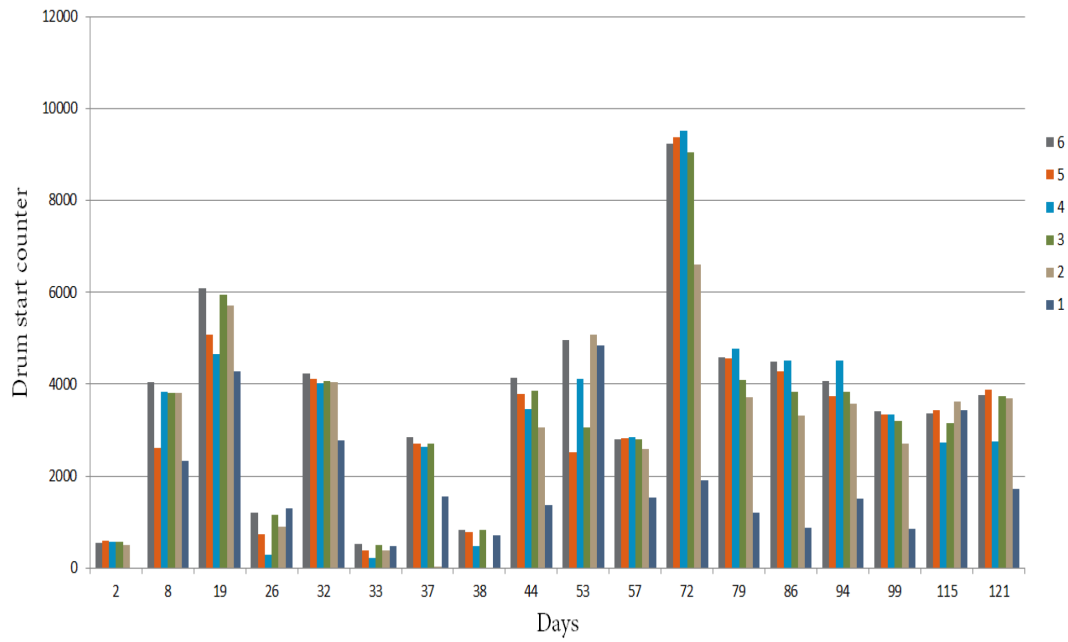

Figure 17 Drum start counter among different discfilters

The drum starts to rotate every time the automatic backwashing system is triggered. The figure 17 shows that the drum of discfilter 6 starts to rotate more often than discfilter 1 within a given period of time. For instance between day 57 and 72 all discfilters except discfilter 1 show an significant rise in the drum start counter. This means that these discfilter were extensively used whereas discfilter 1 shows merely little increase in the drum start counter proving the point that discfilter 1 is not totally contributing to filtration. The data from backwash pump rotation hours and discfilter drum start counter show that discfilter 6 is the most used when compared to other discfilters.

5.3 Investigation of filter media (panels) filtration properties in time

The filtration velocity(Fv) of tap water for the new disc panels (before installation) averaged at 283 m/h. The weekly analysis revealed that the filtration velocity (Fv) decreased at a rate of 2%-49% and after chemical cleaning, the filtration velocity ascended at a rate of 9%-51%. The rate of increase and decrease in Fv depends on the number of weeks after installation of new discs, the initial weeks showed a gradual dip of 20% whereas 7-8 weeks (49-56 days) after installation the Fv decreased by up to 50% and reached 110 m/h.

The symbol star on figure 18 represents the days of chemical cleaning (days 16, 29, 69,103) and immediately after that day the Fv observes a sudden rise in its value. After 16 weeks (112 days) of installation there was no sign of increase in Fv even after two cycles of chemical cleaning of the panels at the discfilter plant and the mean Fv of the discfilter was between 40-55 m/h. The weather condition also affects the Fv, the end of autumn and beginning of winter (day 6 to day 34) saw a rapid fluctuation in Fv which was accompanied by a sudden dip and then steady decrement in Fv during the winter months (day 50 onwards). The TSS concentration in the initial weeks was high which corresponded to the decrease in Fv. After 4 weeks (day 28 onwards) the TSS concentration in the influent to discfilter constantly oscillated between 5-15 mg/l throughout the time of experiment which indicates that it was the total dissolved solids which caused a rapid fouling in filter panels which ultimately decreases in Fv in discfilters.

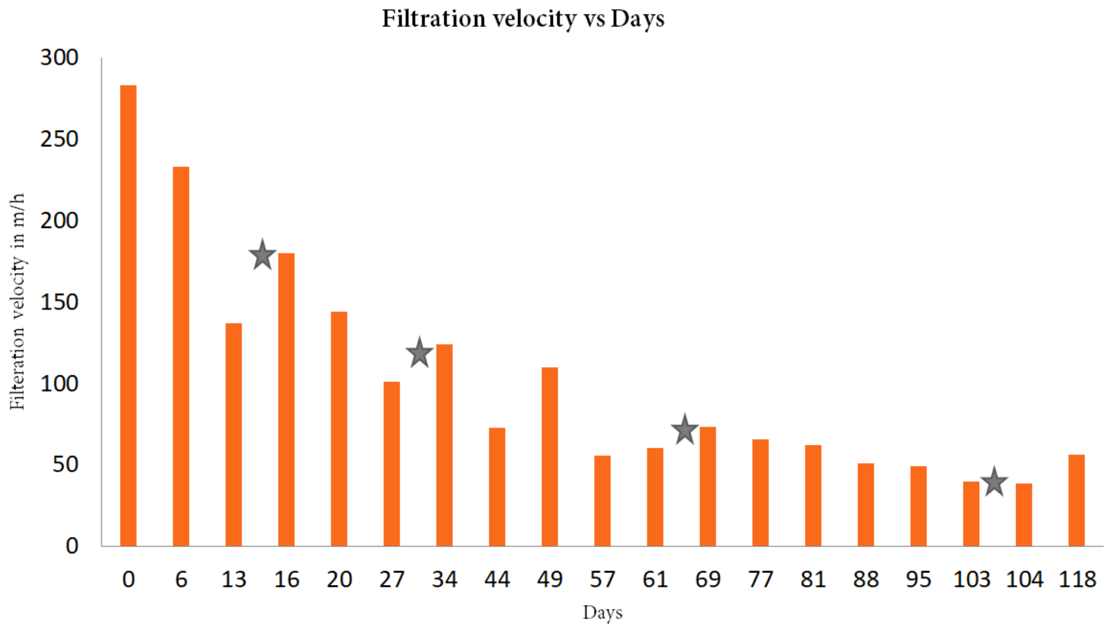

Figure 18 Change in filtration velocity of tap water through filter panels over a long period (from new to 118 days of use at the plant)

5.3.1 Properties depending on location of the panel on the discfilter (from disc 2 to 25)

The filtration velocity(Fv) data was collected from panels taken from three locations of the discfilter 6: disc panel 2 (front), disc panel 13 (middle) and disc panel 25 (end). Three panels are selected in order to show the non-uniformity in Fv and clogging in disc panels within a disc filter unit. Interestingly, the results as seen in figure 19, showed that disc panels 13 and 25 had lower filtration velocities than disc panel 2. This is again the case of hydraulics and the movement of water which pushes the particles to the end of the channel thereby causing the disc panels in the rear end of the discfilter to clog faster than the ones present in the front (hydrotech engineers, personal communication).

To avoid complex comparison, three days are chosen to represent the difference in Fv with tap water in between the disc panels. Days 20, 57 and 103 had the most interesting values of Fv and figure 20 expresses that on day 20, disc panel 2 had an Fv close to 200 m/h whereas the disc panels 13 and 25 averaged at 120 m/h. And correspondingly on day 103, the Fv of disc panel 2 was at 70 m/h meanwhile the Fv of disc panels 13 and 25 averaged at 30 m/h. This result concludes that 15 weeks after the installation of new disc panels the Fv of disc panel 13 and disc panel 25 clogged two times and four times faster than disc panel 2 respectively. From figure 22, it can also be infered that the chemical cleaning is effective on the disc panels in the front due to low levels of fouling but since the rate of clogging is high in the rear end then these panels require more cycles of chemical cleaning.

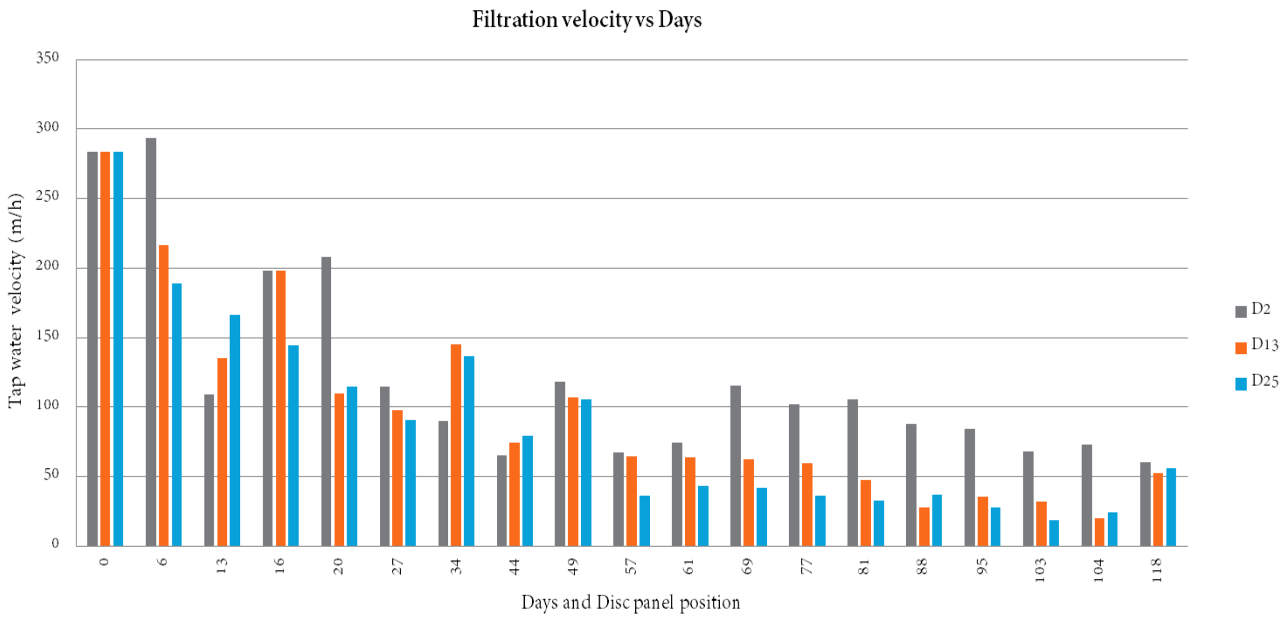

Figure 19 The difference in filtration velocity among different discpanels

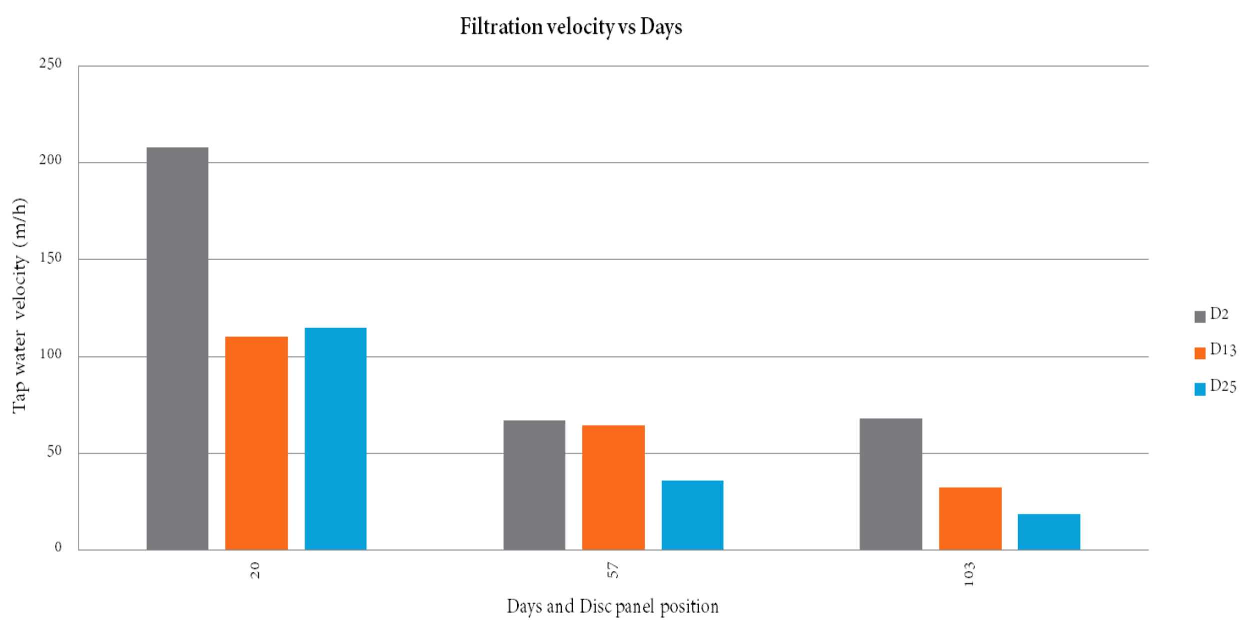

Figure 20 Difference in filtration velocity within a discfilter on specific days

5.3.2 Properties depending on place of the same panel (top, middle, down)

The contrast in filtration velocity continued when each disc panel was further classified into top, middle and bottom. In figure 21, the most striking observation made was that the bottom part of the disc panel had the fastest decrease in Fv whereas the Fv in the top part of the discpanel also reduced but remained higher than the middle and bottom part on most days of the experiment. This unique non-uniformity within the disc panel needs to be further investigated.

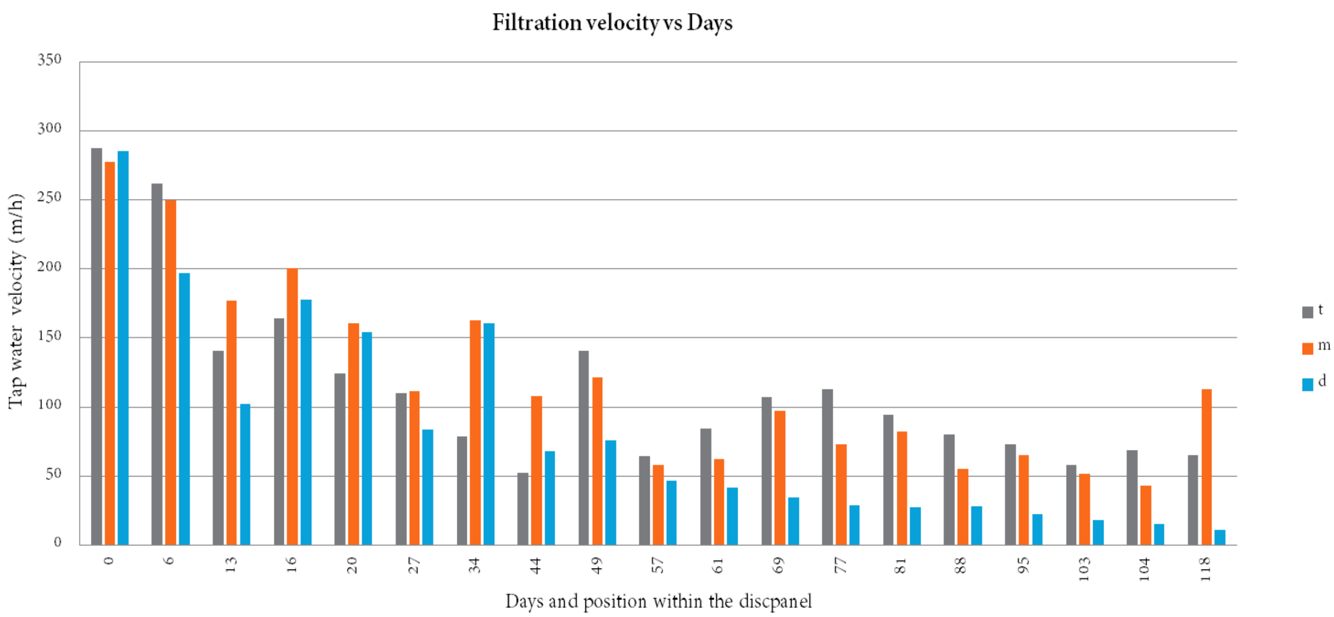

Figure 21 Difference in filtration velocity within a discpanel

After analyzing from the results one thing can be interpreted that the spraying of chemicals on the disc panel is not uniform over the surface and this might be causing the difference in Fv. In the Hydrotech discfilter unit the metal tube carrying chemicals runs tangential to all the discs and the nozzle to spray chemical is closest to the top part of the discpanel. The figure 22 displays the Fv of days after chemical cleaning and this proves that chemical cleaning is most effective on the top and middle part and least effective on the bottom part. This could be due to the angle of spraying on the discpanel which causes the bottom part to receive the least amount of spray whereas the top and middle part receive the largest share of the chemicals.

Another reason could be that the test panels have plastic ridge distinguishing the panel into top, middle and bottom and these ridges could be acting as a barrier to stop the chemical from trickling and reaching the down part of the disc panel. Further investigation needs to be done to test other possible reasons for the irregularity in Fv. The figure 22 explains that 77 days after installation of new discpanel the down part clogs 5 times and middle part clogs 2 times faster than the top part.

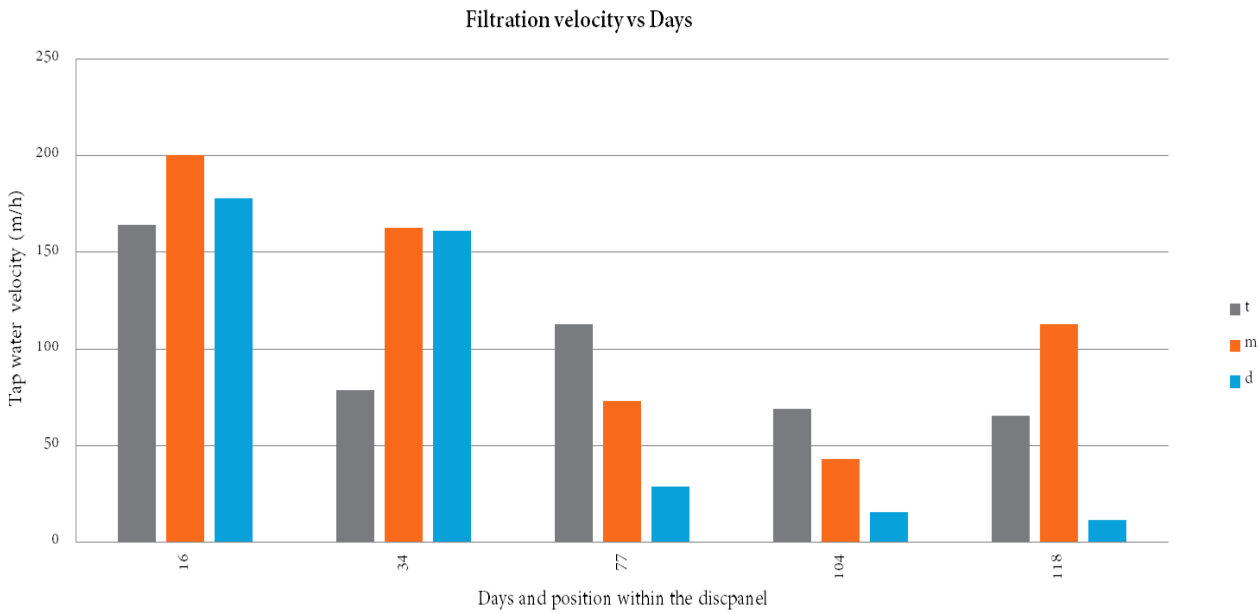

Figure 22 Difference in filtration velocity within a discapnel on specific days

5.3.3 Filtration rate using ET – equipment

Filtration rate measurement of filter panels is achieved by using ET-equipment (developed by Hydrotech) which aids in determining hydraulic capacity and suspended solids removal efficiency of filters over time. In discfilters, particles larger than the pore size of the filter are retained on the media. This leads to the formation of cake which gradually increases in thickness and forms smaller pores which are beneficial in retaining particles smaller than the pore size of the filter media. The suspended particles which get trapped within the filter media can lead to a partly or total reduction in the pore size of the media.

However, using partly clogged -pore apertures of filter media under operation could be also beneficial, since particles which are smaller than initial pore size can be most probably removed due to decreased pore openings. Thus in this case, the lower pore opening results in lower TSS in the effluent. Disadvantageous of this behavior is that a flux through filter media is reduced due to resistance to flow. Moreover, backwash would be more frequent in order to regain the original operational condition and the energy consumption would be higher than using clean panels at the same flow and SS concentration. In such cases, chemically cleaning is initiated to regain their original filtration capacity. So by frequently studying the hydraulic capacity of the filter panels in the disc filter facility, a pattern in clogging can be determined.

5.4 Particle size distribution

5.4.1 Particle size distribution by Pamas S40

The graph from figure 23 depicts that the biggest particle recorded is in the range of 125 to 150 µ size. Particles of size 2 to 7 µm appear to be increasing in number as the filter pore reduce in size however particles greater than 7 µm start to show a trend of gradual decrease in number as the filter pores reduce in size. The percentage of number of particles appears to be over 100% in most of the size ranges which implies that during filtration there is a high possibility of big or flocculated particles breaking into smaller fractions. In certain other cases particles bigger than a particular filter size reappear in the effluent this could be due to agglomeration of suspended particles or odd shapes of the particle (such as needle shape) which can easily pass through the filter pores.

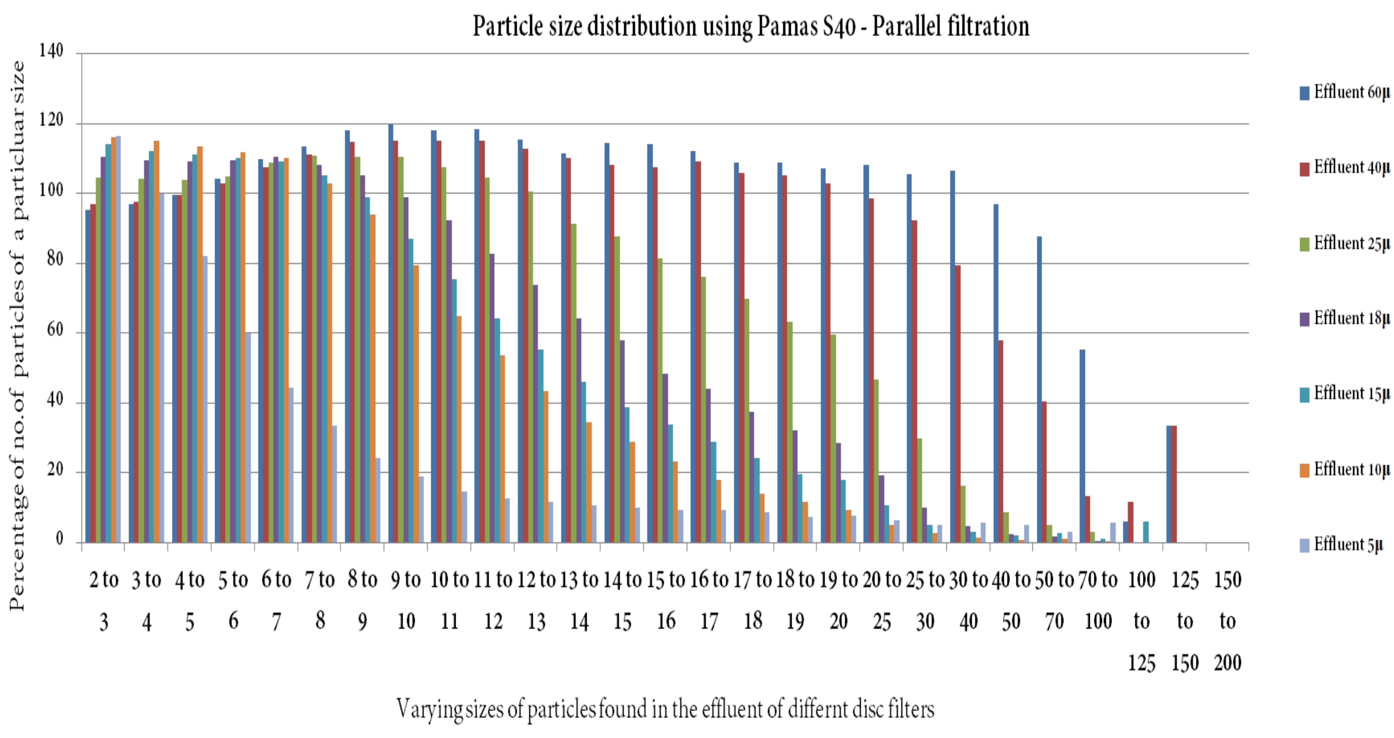

Figure 23 Particle size distribution in parallel filtration using Pamas S40

In serial filtration the results from 60 µm is not presented here due to loss of data. Anyhow the biggest particle recorded is in the range of 100 to 125 µm. However, the results from figure 24 suggest that between 15-25 % of the particles of a particular size same as the filter pore are still present in the effluent after filtration this could be due to agglomeration of suspended particles after filtration.

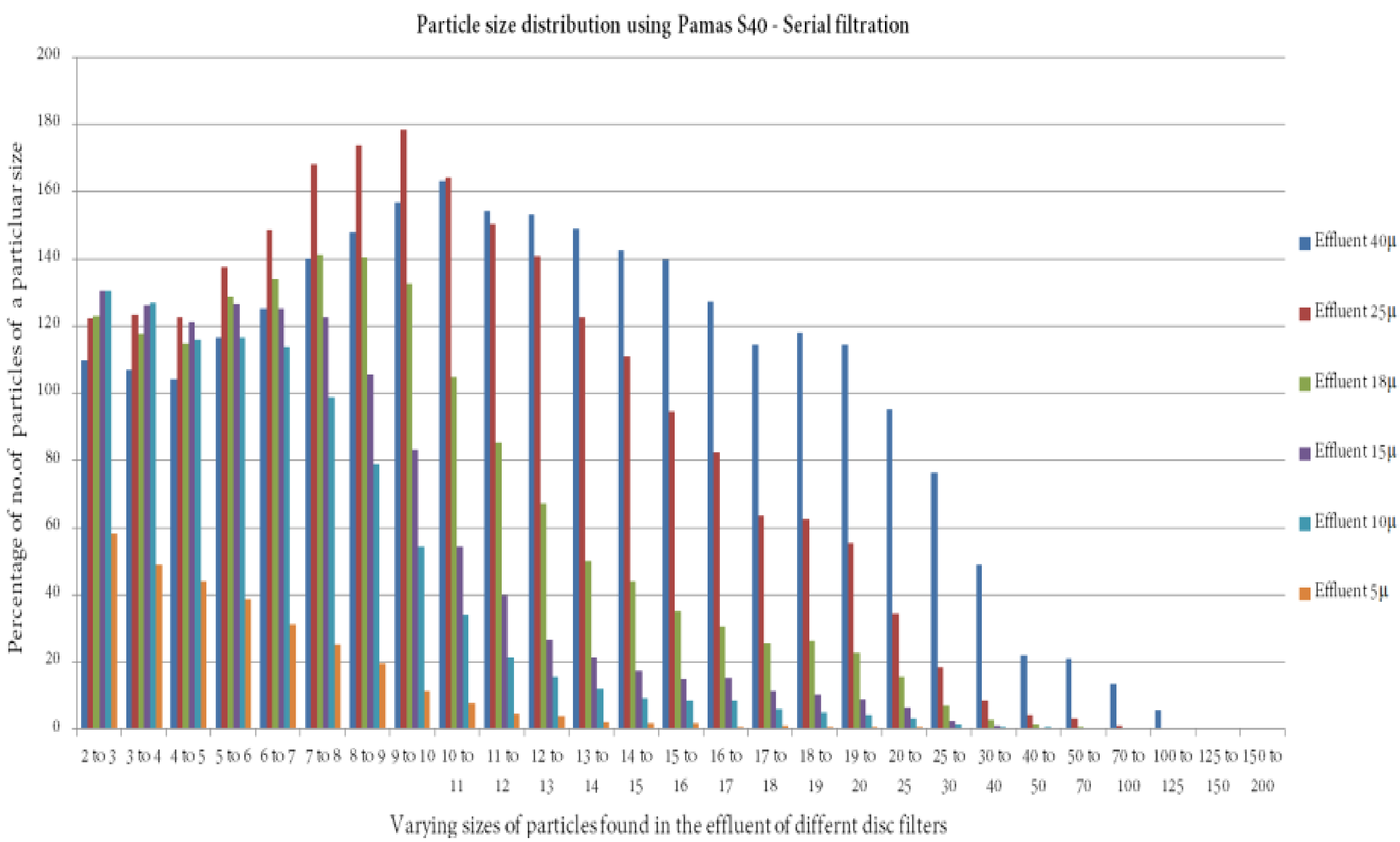

Figure 24 Particle size distribution in setrial filtration using Pamas S40

5.4.2 Period of particle fractionation

The results (figure 25) show that TSS in the influent to the discfilters (taken on the days when fractionation was carried out) varied during different months and proves that TSS concentration in wastewater is affected by weather conditions and human activities during different seasons.

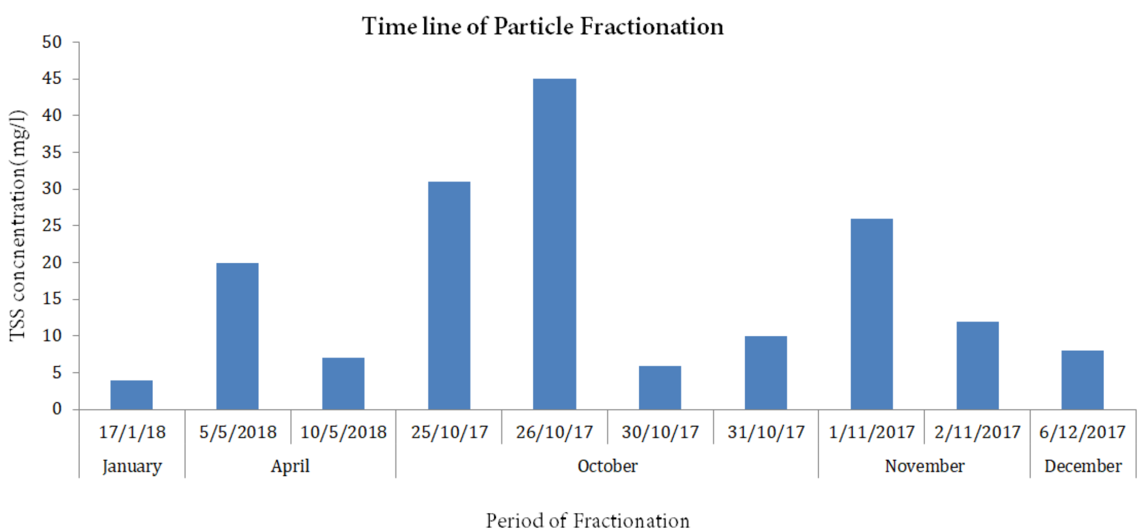

Figure 25 Different periods of particle fractionation

The results of particle fractionation from two seasons (autumn and wet weather) are presented in figure 26, the results during rainy weather fluctuated a lot because the influent SS concentration constantly varied and also particle fractionation was not conducted in summer hence those results are not presented here. It shows the comparison between SS concentration obtained from the effluent of different filter sizes ranging between 60 µm to 1.2 µm. Figure 26 suggests that during dry and wet weather both parallel and serial filtration produce comparable results.

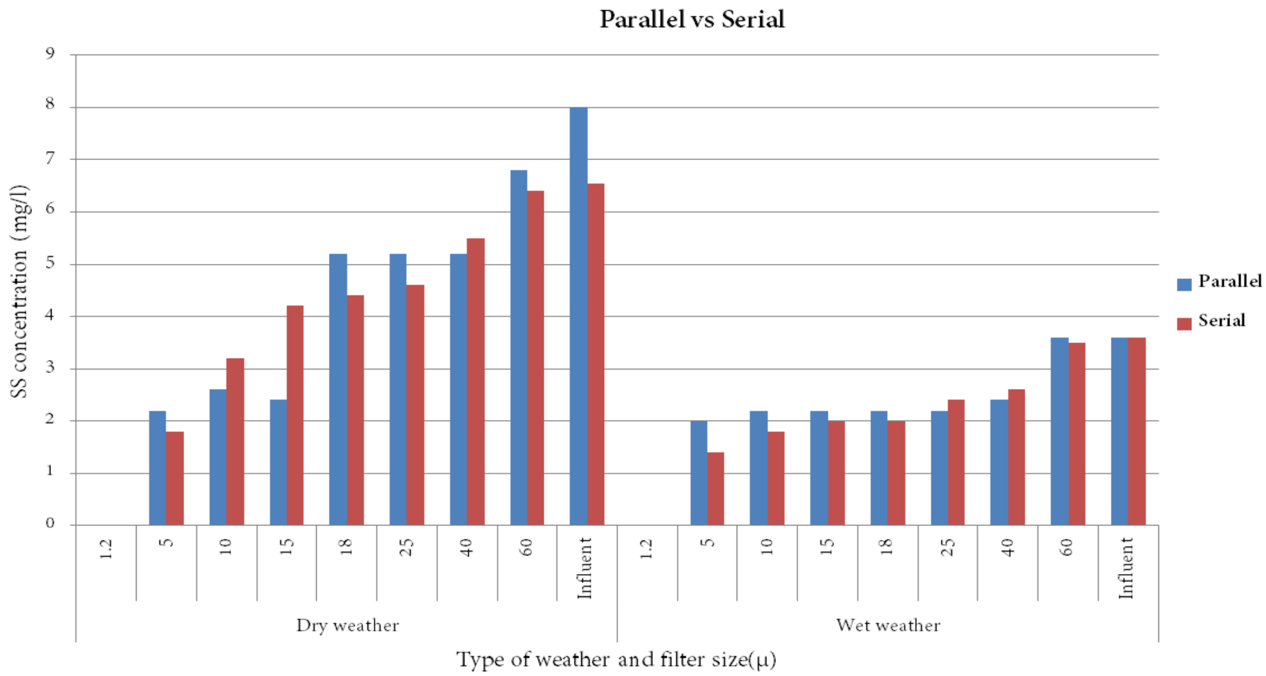

Figure 26 Difference in SS concentration during different weather

Whereas during rain weather the influent SS concentration for parallel fractionation was 20 mg/l whereas for serial filtration it was only 7 mg/l even though the sampling was done in the same hour of the day, the results during rain weather is not presented in figure 26. This is because the flow of incoming wastewater and its characteristic is not constant and homogeneous through the day, this can directly affect the particle fractionation. To overcome this discrepency, percentage of mass retention was calculated, this method helps in understanding the percentage of the original SS concnetration remaining in the effluent of a particular filter size.

So another study comparing the mass retention percentage is represented in the figure 27, it suggests that under all weather condition in serial filtration the concentration of solids above 10µm is equal to the amount of particle below 10µm. Whereas in parallel filtration the solids concentration above 10µm oscillated between 40 to 70 % and solids concentration below10µm was found to be between 30 to 60%. There are many reasons for such variations one such possibility is while experimenting there is a high chance of big particles breaking down into smaller particles and also particles that are not spherical or needle or cylindrical in shape get easily filtered.

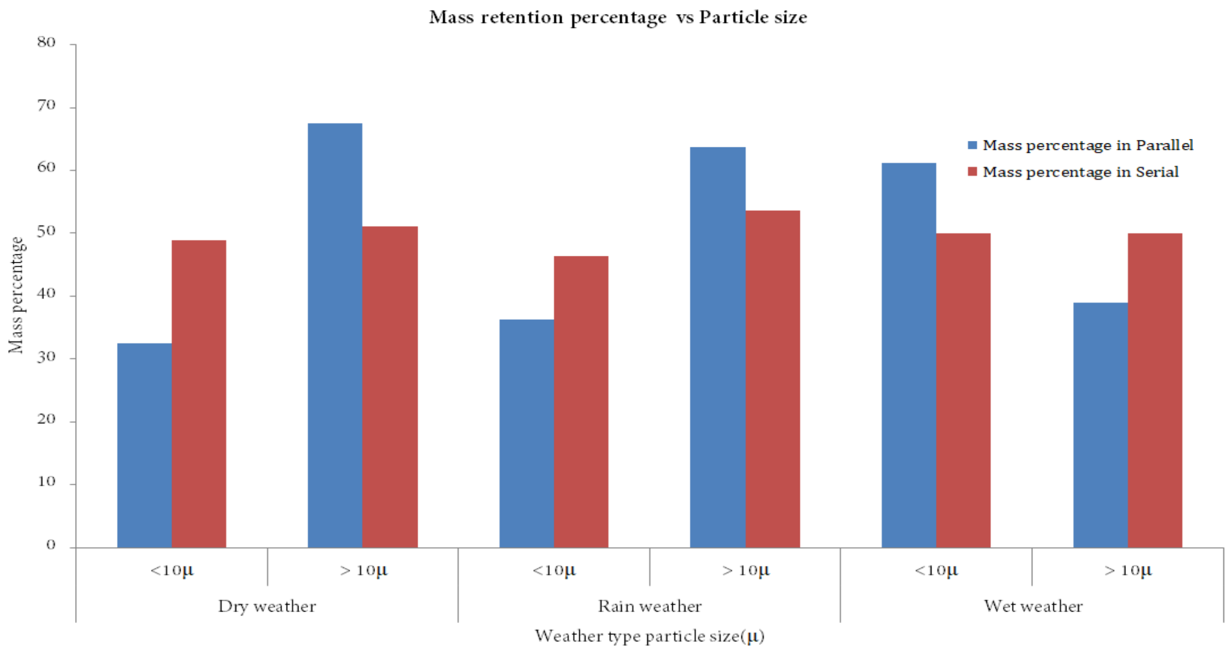

Figure 27 Comparison of mass retention during different weather conditions

5.4.3 Comparison of methods of fractionation

Parallel filtration provides more of a general representation of solids distribution based on mass, however, serial filtration has a more stepwise breakdown structure for defining particle distribution. Also, both methods complement each other by proving that majority of the particles in the secondary effluent are below 10 µm close to 30-50% by mass of the total solids in the secondary effluent.In parallel filtration, when the influent wastewater is filtered through small pore size filters like 25µm to 5 µm, there is high chance that the bigger particles completely cover the pore and prevent the smaller particles from passing through this could be the reason why the particle concentration in the effluents in the range of 25-5µm is lower compared to serial filtration. As a proof, in serial filtration the filtration velocity through disc filter was considerably high compared to filtration velocity in parallel filtration, this implies the absence of bigger particles from wastewater. There are times deviations in the SS concentration result and that needs to be taken into consideration, this could be due to high SS concentration in a particular grab sample or poor resuspension of particles. To assist the results from the two methods it is advisable to compare the turbidity values of the sample.The turbidity results and filtration velocity are also useful in making a comparitive assessment.

6 Conclusion

The two methods for particle size distribution are producing results that are comparable, for future experiments it is advisable to choose parallel filtration since it is easy to conduct and less time-consuming.

The relation between TSS of influent and effluent is linear. And also the relation between TSS and turbidity is linear hence both these relation are a good source of judgment for future measurements.

During rain and wet weather the particles above 10 µm was 50 % of the incoming solids but in dry weather particles above 10 µm was close to 70% of the total incoming solids. PSD of particles below 10 µm obtained from particle counter conveys that particles of range 2-4 µm make up 40-60% of the total particles and particles of size 5-7 µm are close to20- 40% followed by particles of size between 8-10 µm which add up to nearly10- 20% of the total particles. This corresponds well with full scale since the nutrient values are really low in the effluent.

The tap water used in the ET-experiment had a constant characteristic on all days of testing, unlike wastewater which changed its characteristic every day, hence filtration rate with tap water seemed more definitive and in agreement with assumptions made.

Within a discfilter it was found that the filter panels in the end are more clogged compared to the filters in the front. Similarly, within a discpanel the lower (or down) region clogged faster than the top part. Further investigation needs to be done to understand the reasons of differential clogging in between discfilters and within disc panels.

The flow to discfilter is not uniform and this needs to be overcome so that all discfilters receive and treat equal volumes of wastewater. One way to ensure equal fouling on all filters is to check the most and least clogged discfilters and to regulate the flow to only least clogged discfilters by shutting down extremely clogged discfilters or by changing the backwash level on the discfilter. Hence, during November to December it advised that chemical cleaning is done more frequently on discfilters 6 and 5 due to higher suspended loadings received by these two filters.

7 Future Studies

It is recommended that the following aspects are investigated further:

- To determine long term performance of discfilters during chemical pre-treatment.
- Optimization of chemical cleaning of discfilters to reach well optimized cost effective solution
- To examine the SS concentration in different positions within a discfilter unit.
- Testing different filter cloths such as 15 µm and 18 µm to determine its filtering properties and Phosphorus reduction capacity.

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