Discfilters for tertiary treatment of wastewater at the Rya wastewater treatment plant in Göteborg

Master of Science Thesis in the Master's programme Geo and Water Engineering

IMAN BEHZADIRAD

Department of Civil and Environmental Engineering
Division of Water Environment Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover:
The outer view of the discfilters building at the Rya WWTP.

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ABSTRACT

New effluent standard levels compelled Rya wastewater treatment plant (WWTP) to upgrade it by means of microscreening and through installing a set of 32 discfilters as a tertiary treatment. This project was principally focused on how effective discfilters were removing particles in effluent to show whether discfilters can meet new standards or not. To do this effluent wastewater was characterized through different tests. Characterization of effluent were done by the use of a variety of tests such as Particle Size Analysis (PSA), concentration of total nitrogen and phosphorous (Ntot, Ptot), Suspended Solids (SS), and COD, microbial analysis and turbidity. Five sampling and investigation occasions were performed in spring 2010 at the Rya WWTP. Results showed that discfilters were removing P and SS effectively and it was proved that physical blocking were the chief mechanism in particle removal.

Key words: discfilter, disc filtration, microscreening, particle separation, particle size distribution, phosphorous removal, tertiary treatment, particle removal, wastewater characterization

Contents

Preface

This work has been carried out at Water and Environment Technology (WET), at the department of Civil and Environmental Engineering, Chalmers University of Technology, Sweden. The Rya WWTP facilitated the work through allowing me to do sampling and using their advanced laboratory anytime I got an individual laboratory at the treatment plant. I gratefully acknowledge my supervisor at the Rya WWTP Ann Mattsson and other nice and kind personnel particularly, Anette Jansson.

I sincerely want to express my appreciation to my supervisor, Britt-Marie Wilén, whose encouragement, guidance and support from the initial to the last level motivated me to perform a better job during the completion of project at Chalmers University.

Lastly, I would love to thank my family, friends and all of those who inspired and supported me in any respect during the completion of the project.

Göteborg October 2010

Iman Behzadirad

Notations

0, 100	“Zero”, Unfiltered water
COD	Chemical Oxygen Demand [mg O_2/l]
MBBR	Moving Bed Biofilm Reactor
N_{tot}	Total Nitrogen [mg/l]
PSA	Particle Size Analysis
P_{tot}	Total Phosphorous [mg/l]
SS	Suspended Solids [mg/l]
TSS	Total Suspended Solids [mg/l]
WPC	Water Particle Counter
WWTP	Wastewater Treatment Plant

1 Introduction

Effluents (treated wastewater) from wastewater treatment plants (WWTP) are widely used in different industries e.g. agriculture, cooling towers and so on, or back directly to the ecosystem through discharging to surface or ground water. These far and wide usages of treated wastewater compel legislators to set stringent rules and regulations with respect to WWTP effluents. These strict regulations oblige treatment plants to reconsider concerning the ways which they treat wastewater for instance add a new step or unit to meet that specific new standard. Basically, water boards and WWTPs pick new treatment methods dependent on new effluent standards and likewise their practical experience (Ødegaard, 1999).

In recent years tertiary treatment of effluents has been in focus for many WWTPs (Fuchs et al., 2006). The main intention of tertiary treatment (effluent polishing) is reach to the standards criteria and improves the quality of effluents from WWTPs as a last step before it leaves the treatment plant. Microscreening (or discfilter) is one of the positive tertiary treatment processes which is used frequently these days. Due to the fact that it has small footprint, it has attracted a lot attentions, therefore many WWTPs are considering it in their upgrading plans (Ljunggren, 2006).

1.1 Background

The Rya WWTP (see Figure 1.1) serves around 832 000 population equivalent from Göteborg and five other surrounding municipalities (Ale, Härryda, Kungälv, Mölndal and Partille) with an average flow of approximately 373 000 m^3/d (4.32 m^3/s). Pre-denitrification and post-nitrification are implemented in a non-nitrifying activated sludge system and trickling filter, respectively (Balmér *et al.*, 1998). Simultaneous precipitation is used to remove phosphorus from wastewater. The annual basis of total phosphorus and nitrogen in effluent has been 0.4-0.6 gP/m^3 and 12 gN/m^3, respectively (Wilén *et al*., 2006; Gryaab, 2009).

Figure 1.1 Rya WWTP before the installation of discfilters and MBBR

Owing to new standards the phosphorous and nitrogen effluent level should be below 0.3 mg P/l and 10 mg N/l, respectively. Hence the Rya WWTP decided to implement some improvements to reach those goals. The expanding and upgrading of Gryaab's WWTP Rya in Göteborg was finished in spring 2010 to meet these new effluent criteria for phosphorous and nitrogen. Microscreening by means of discfilters has been shown to improve the particle separation and mainly increase removal efficiency of total phosphorus. As a result, they built and installed a set of 32 discfilters with a total filter surface area of 3580 m^2 which are the largest discfilters in the world (Mattson, et al 2009).

1.2 Aim

The aim of this thesis is to characterize wastewater before and after installation of new discfilters at the Rya WWTP plant.

This thesis has focus on discfilters to analyze the effluent quality from the Rya WWTP and find out the influences of discfilters on particles and measure the effectiveness of discfilters on particle removal.

1.3 Limitations

This project is limited to characterization of wastewater particles in micrometer size in the effluent water of the Rya WWTP. A few parameters are examined to symbolize the quality of effluent water.

2 Particle Characterization

Most of the wastewater contaminants and pollutants are particles, or altered into particles before removal (Lawler, 1997). Thus, to have a better overview on particle separation and particle removal processes it is important to gain more knowledge about particle characterization. Particles play a significant role in wastewater contaminants, since a major part of the different kinds of contaminants are related to particles (Van Nieuwenhuizen & Mels, 2002).

2.1 Definition

Particles are small parts or tiny pieces of suspended solids in wastewater or activated sludge. Although, particles are very small, their sizes matters and they should not be neglected. Basically, one of the fundamental issues in particle separation and removal is particle size. Due to this size property, particles are historically defined in four different categories: settleable (>100 µm), supracolloidal (1-100 µm), colloidal (0,001-1 µm), and dissolved (<0,001 µm) (Levine *et al.*, 1991).

2.2 Particle size distribution and wastewater processing

A number of WWTP processes such as mechanical, chemical, and biological are causing to shift the particle size. Separation efficiency in those processes depends upon particle size as well. In mechanical treatment particle size distribution changes mainly according to settling and rise rates, and likewise microscreening. In microscreening, particles size changes owing to floc break-up and flocculation (Ljunggren, 2006).

Initially, the size distribution of particles in an untreated wastewater is site specific (Levine *et al.*, 1991) and as mentioned above size distributions change due to different treatment processes.

2.2.1 Schematic particle size distribution

To make a relation between particle size and contaminants distribution in wastewater based on data from different literatures the schematic graph in Figure 2.1 was created (Van Nieuwenhuizen, 2002). In the down part of the graph a range of different factors in wastewater in terms of the particle sizes are illustrated. In the upper part of the graph a variety of different removal and treatment methods with relation to dissimilar removal ambits are pointed out.

By using the following graph it can be elucidated that the microscreening technique (see chapter 3) which is in the size range of more than 10 µm can be used to remove organisms for instance algae and protozoa, bacteria, and bacteria flocs, and additionally human organic waste. The microfilteration in the size range of between 0.1 and 1 µm is also counted as a fine method for removing of viruses, DNA and cell particles.

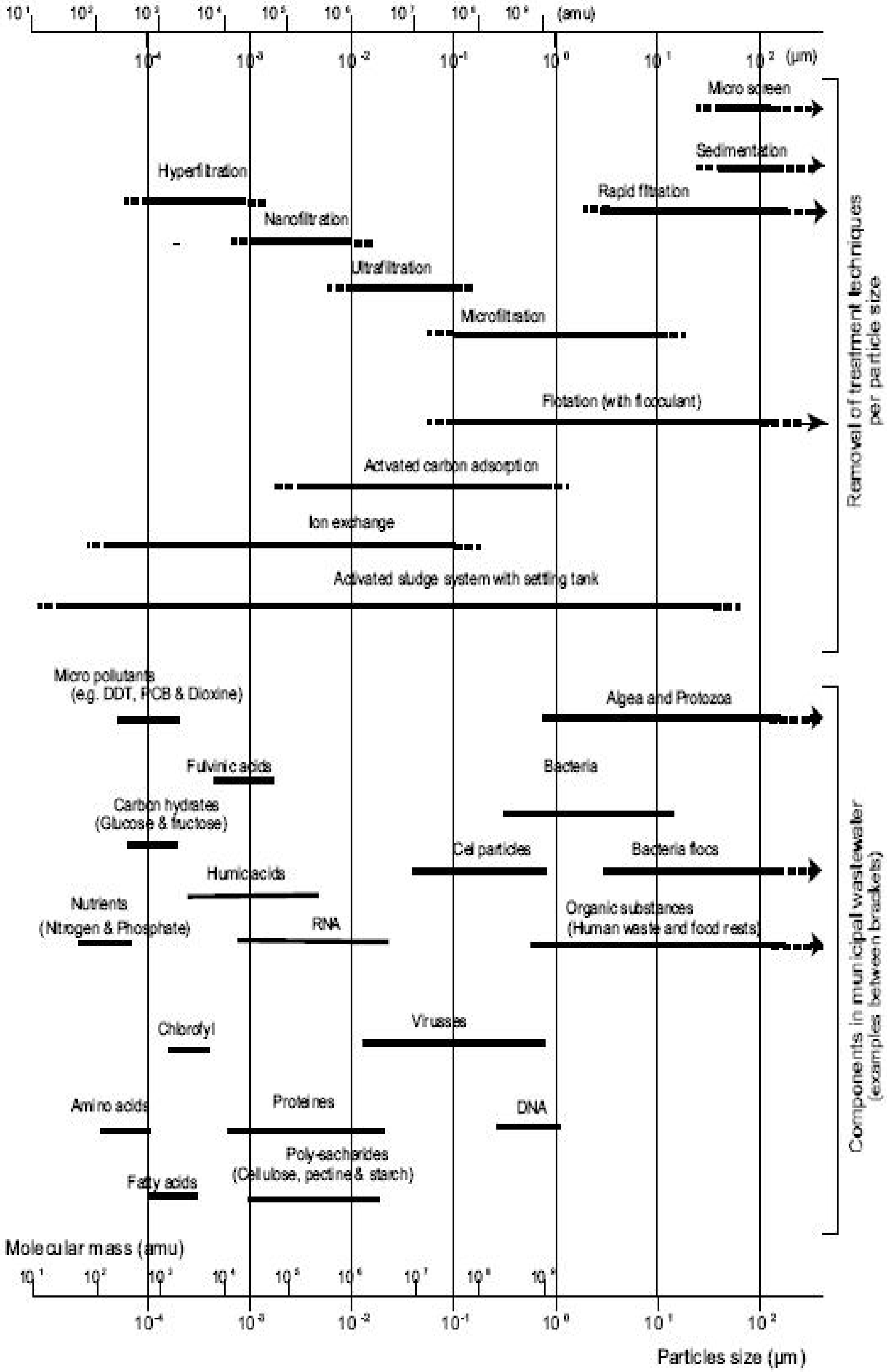

Figure 2.1 Particle size distribution in municipal wastewater and particle removal methods per particle size (Van Nieuwenhuizen, 2002).

3 Tertiary Microscreening

Treatment unit operations further than secondary are called tertiary (advanced) treatment. This level of treatment is used before discharging of effluent and it aims to increase pollution removal efficiency of a WWTP and processes which use are dissimilar to primary and secondary ones. This process is performed by using different biological, chemical or physical treatment methods to boost the total removal of suspended and dissolved solids, organic matter, toxic substances and nutrients (Wang, *et al.,* 2006).

The reason for including tertiary treatment in processes may come from:

- High COD after secondary treatment
- High Nutrient after secondary treatment
- High SS after secondary treatment
- High color after secondary treatment
- Stringent standards on COD, SS or phosphorous (Eimco, 2009)

3.1 Discfilter

A wide variety of tertiary treatment processes and units have been utilized in recent years of which microscreening (discfilter) is one of these process units. Microscreening works properly in removing of additional suspended solids from effluent (Wang *et al.,* 2006). It includes some major parts such as rotating discs with cloth media filters, backwash system, influent and effluent and overflow weir, drive motor and so on (see Figure 3.1).

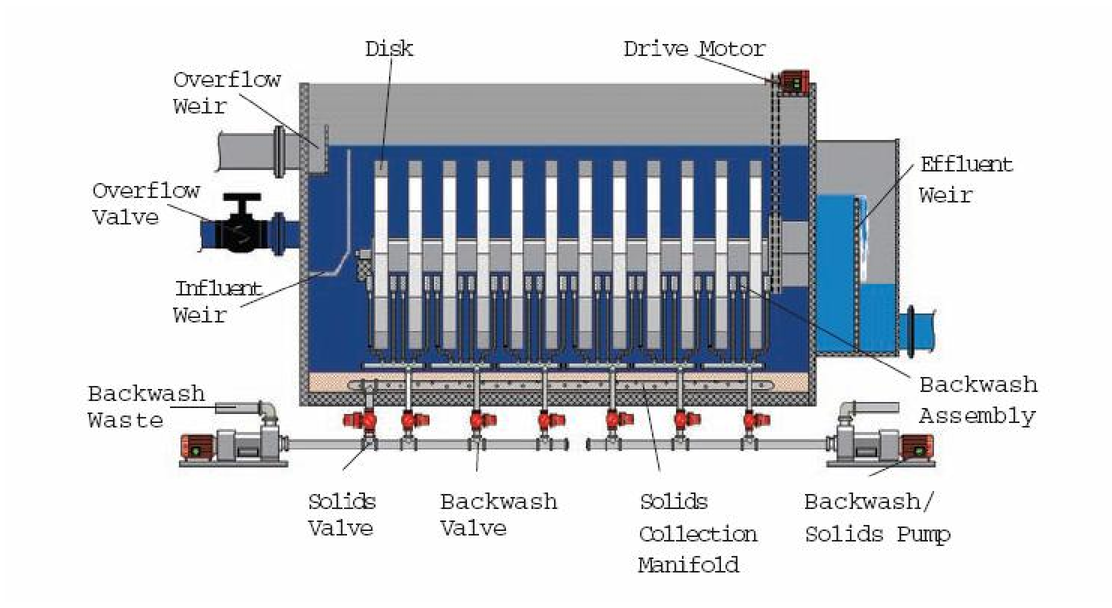

Figure 3.1 Process scheme of a discfilter

Disc filter operation starts via entering wastewater to its tank subsequently the cloth filter is totally submerged into that liquid. This liquid wastewater passes the microscreening filter through gravity (see Figure 3.2). Throughout filtration solids are collected on and within the filter panels, and as a result water level inside the discfilter increases and eventually at a prearranged time or level, backwashing is initiated to clean the cloth filter (see Figure 3.3). In the meantime, the filtrated effluent collected and conveyed to the inside part of drum and discharged ultimately. Filtration is continuous and not stopped during the backwashing cycle.

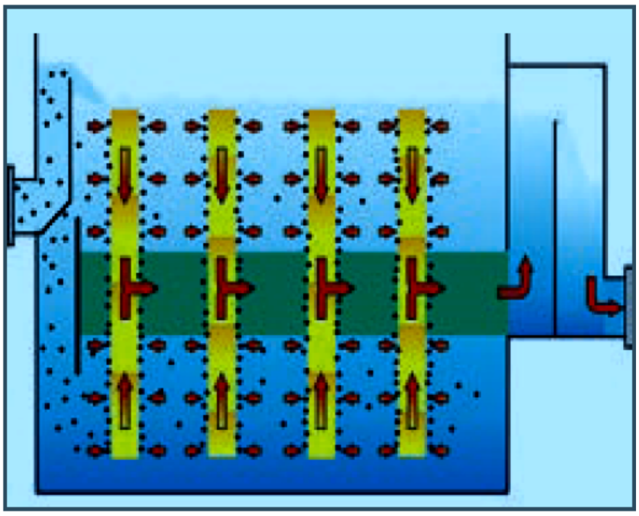

Figure 3.2 Discfilter submerged into liquid

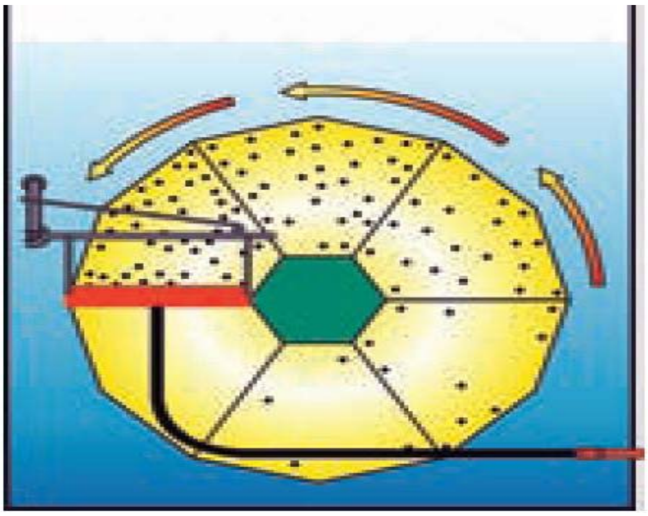

Figure 3.3 Backwashing process in a discfilter

At the Rya WWTP discfilters (see Figure 3.4) capture the small particles inside the water which comes from secondary settlers and the Moving Bed Biofilm Reactor (MBBR) and bring them back to the influent of the activated sludge tanks where they are mixed and the small particles can attach to larger sludge flocs which can be separated in the secondary settlers.

Figure 3.4 Discfilter at Rya WWTP.

4 Experimental Set-Up

To determine how contaminants at the Rya WWTP effluents were distributed the characterization of particles was done before and after the discfilter over the spring period when the full-scale discfilters were in operation. If the amount of particles in the effluent from the discfilters was in the same amount and size range as before the filters had been installed, there would be no problem with shearing of the particles. However, if a trend towards higher numbers of small particles leaving the filters with time, there was probable due to a build-up of small particles in the system that was not removed efficiently. The influent and effluent from the discfilters were analyzed on particle size distribution, suspended solids, total phosphorus, total nitrogen, turbidity, COD as well as microbial parameters (four different indicator organisms).

Most of the analyses were done at the Rya WWTP laboratories, although some of them were carried out at Chalmers or Lackarebäcks laboratory. Different analysis and way of implementing them were chosen by Britt-Marie Wilen at Water and Environment Technology and Ann Mattson at Gryaab in continuance with Ann Johansen Master's degree project (Johansen, 2010). In Ann Johansen's thesis work a methodology was developed for wastewater characterization.

4.1 Equipments

The method for wastewater characterization was used (Johansen, 2010) which include some devices and tools provided at the Rya WWTP or Chalmers laboratories. The main ones are listed here:

- Filter cloths in different sizes (40, 20, 15 and 10 μm) from Hydrotech AB to create a similar situation to full-scale discfilters and simulate them
- Filter papers in two different sizes, 1.2 μm (Munktell -MGA Glassmicrofibredisc) and 0.45 μm (Millipnore-MCE 0.45U Membrane filters, Nitrocellulose) to fractionate wastewater effluents before analysis
- Vacuum device for 1.2 and 0.45 μm filtration and also it is used in TSS analysis
- Water Particle Counter (WPC) from ARTI to identify particle size and distribution and a logger connected to it to help in reading and preserving the data
- HACH Turbidimeter to measure the turbidity or cloudiness of wastewater effluent
- Different equipments to analyze COD, N_{tot}, P_{tot}, TSS
- Microbial analyses equipments for indicator organisms at Chalmers and Lackarebäck

- Different sizes plastic and glass bottles and a plastic tube for filtration

4.2 Analyses (Characterization of effluents)

To obtain proper information regarding wastewater effluent quality and to characterize it appropriately some analyses were carried out at the Rya such as particle size analysis (PSA), chemical oxygen demand (COD), total phosphorous (P_{tot}), total nitrogen (N_{tot}), and total suspended solids (TSS), microbial analyses at Lackarebäck treatment plants and turbidity at Chalmers laboratory. Dissimilar sample sizes were used in each analysis which is shown in Table 4.1:

Table 4.1 Sampling volumes

Analysis	Sample Volume (ml)
COD	2
N_{tot}	>10
P_{tot}	>30
TSS	≥200
Turbidity	30
PSA	300-500
Microbial	250

4.2.1 Particle Size Analysis (PSA)

It is a laboratory technique which determines number of particles (same size range) in specific volume of water. PSA was assessed and implemented through using of water particle counter (WPC) device (see Figure 4.1).

The used WPC counts particles distributed in eight groups as follows (can be chosen individually): 1-2, 2-5, 5-10, 10-15, 15-20, 20-30, 30-50 and >50 µm . These size ranges were considered appropriate for this type of study (Johanssen, 2010). The logger which was connected to the WPC could collect data from four channels, such as 1-2, 2-5, 5-10 and >10 µm and showed them in 4 different graphs and tables. While the values were getting stable, manual reading and writing of the results was performed.

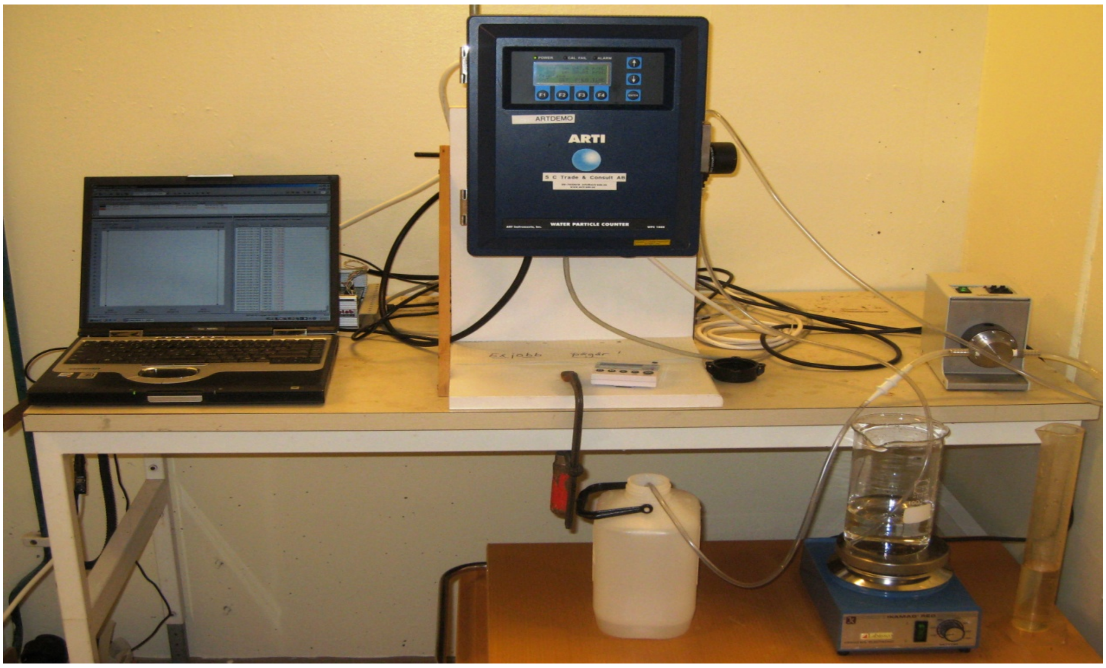

Figure 4.1 Water particle counter and a logger connected to it.

4.2.2 Chemical Oxygen Demand (COD)

COD is a test which is performed to show the amount of organic pollutants and contaminants in a liquid and it is stated in milligram per liter (mg/l).

2 ml of wastewater was added to prepared COD vials and it was shaken several times back and forth. Afterwards in the analysis the sample was oxidized with potassium dichromate in acid solution at 150 °C for two hours. Subsequently COD was determined by means of Hach Spectrophotometer DR 5000 (see Figure 4.2).

Figure 4.2 The Hach Spectrophotometer DR 5000.

4.2.3 Total Phosphorous (P_{tot})

The analysis of total phosphorous was performed at the Rya WWTP laboratory. The highest phosphorus content which could be determined without dilution was 0.80 mg/l and minimum determinable concentration was 0.02 mg/l.

Samples were shaken and transferred to 15 ml digestion vials and three spoonfuls of Oxisolv reagent (350 g) were added to vial. Subsequently samples were put in autoclave 25 T to boil for 30 minutes (120 °C) and by using of Hach Spectrophotometer DR 5000 (program 490) the amount of phosphorous were determined.

4.2.4 Total Nitrogen (N_{tot})

The analysis of total nitrogen was performed at the Rya WWTP laboratory which determines the total amount of nitrogen (inorganic and organic compounds) in water.

The starting steps were similar to phosphorous analysis, just the reagent was different. After the autoclave (25 T) the samples were analyzed through Spectrophotometer FIAstar 5000 (Flow Injection Analyzer).

4.2.5 Total Suspended Solids (TSS)

TSS is a water quality test which shows amount of particulate matters in water and expressed in milligram per liter (mg/l).

In Rys's laboratory 700 ml of the sample was filtered through a pre-weighted filter and subsequently the used filter was dried at 105 °C in an oven (8 minutes in a microwave oven with 750 watts power). Afterwards the dried filter was weighted again and the TSS was calculated according to the equation below.

$$TSS = \frac{A - B}{Sample\ Volume\ (l)} \left(\frac{mg}{l}\right) \tag{4.1}$$

A= weight of filter + dried residue (mg)

B= weight of filter (mg)

4.2.6 Turbidity

Turbidity is due to suspended solids (particles) in a liquid. It is another water quality measurement which determines the cloudiness, muddiness or haziness of water and expressed in NTU.

This test was performed in Chalmers Laboratory by using a HACH turbidimeter (see Figure 4.3).

Figure 4.3 Hach Ratio/XR Turbidimeter.

4.2.7 Microbial analysis

3 different types of samples (effluent of secondary settler, 15 µm filtrated effluent of secondary settler and direct 15 µm filtration of effluent of secondary settler) were treated in 3 different ways (no treated, mild sonication and mechanical (through Miniprep machine)) to make 9 different samples, and they were sent to Lackarebäck laboratory for microbial analyses regarding 4 different indicator bacteria, Coliform, E. Coli, Entrococcous and Clostridium.

4.3 Sampling

In all analyses samples were taken at dry weather conditions. In 5 different occasions samples were taken in a large container (10 l) from two different sampling points, before discfilter (after secondary settlers) and after it. Table 4.2 shows different sampling times and points during the whole analyses. Those large plastic water containers with water inside them were immediately carried to Rya laboratory for fractionation and other analyses.

Table 4.2 Sampling dates and places.

Date	Sampling place
2010-03-15	Channel before discfilter (after secondary settlers)
2010-04-20	Channel before discfilter (after secondary settlers)
2010-05-18	Channel before discfilter (after secondary settlers) Effluent after discfilter
2010-05-27	Channel before discfilter (after secondary settlers) Effluent after discfilter
2010-06-01	Channel before discfilter (after secondary settlers) Effluent after discfilter

4.4 Fractionation procedure

In Fractionation, all samples were passed through clean filters with six different pore sizes (40, 20, 15, 10, 1.2 and 0.45 µm) as illustrated in Figure 4.5. The wastewater samples were fractionated by using of a tube which has a filter at the end of it (see Figure 4.4), and for each filtration only the end filter was changed. The used filter was washed by HCL acid and MilliQ water.

Figure 4.4 Tube and filter at the end of it which used to fractionate different samples

1 litre of sample water was poured into an inclined tube (45°) equipped with a filter. The tube was rotated instantly into a vertical position after water was poured. While the height in the tube was at its maximum, it led to a similar pressure as in the discfilters. Maximum time for filtration was 8-10 s, when the possible not-filtered liquid was thrown away. Under these conditions, the actual conditions in a full-scale discfilter were simulated in a good way.

Most of the analyses for instance PSA, COD, and TSS were carried out just after the fractionation of samples, and for P_{tot} samples were preserved in a fridge at around 5ºC and samples for N_{tot} tests were frozen at -30 degree to be analyzed in proper time. Samples for turbidity and microbial analyses were brought to Chalmers laboratory and Lackarebäck respectively, for immediate analysis.

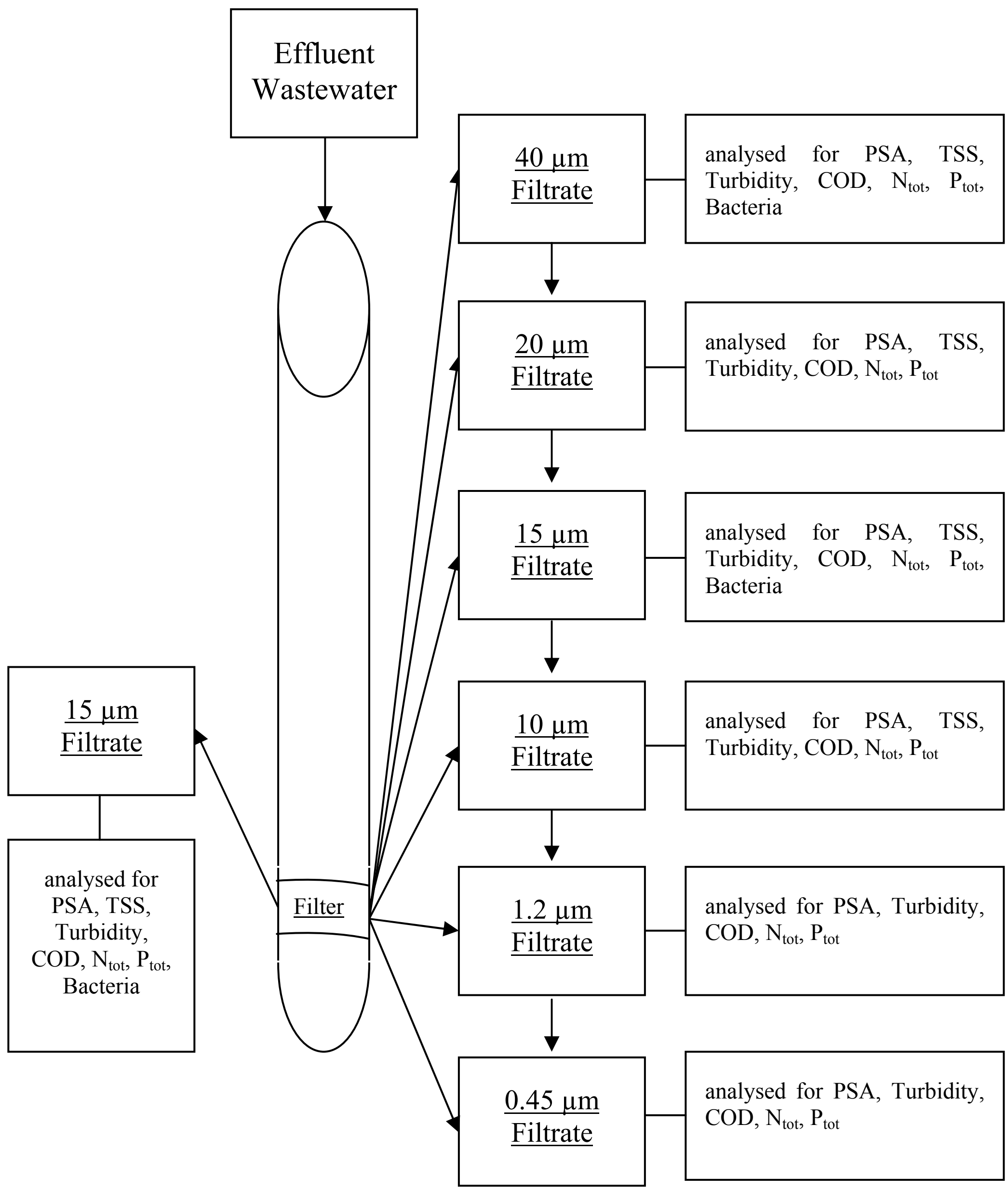

Figure 4.5 Schematic view of the Fractionation procedure.

5 Results and Discussions

In the three months time span five main analyses has been done, the two first ones were done before the full-scale operation of the discfilters were started and the rest performed when discfilters were in operation. In addition, one measurement (only particle size analysis) performed by the help of Professor Britt-Marie Wilén, since the discfilters were not working properly.

In the first two analyses the discfilter operation was simulated by filtering through different filter pore sizes which was mentioned in previous chapter (see section 4.4), and in the following analyses filtration was done for only the 15 µm filter which was the same as the full-scale discfilter. In the second test it was decided to do a direct 15 µm filtration on effluent wastewater to compare it with the normal filtration which was from 40 µm to 20 µm, 15 µm and 10 µm step by step and the measurements showed similar results for both direct 15 µm filtration and step by step 15 µm filtration (see Appendix J). Consequently, it was decided to do only direct filtration with 15 µm filter as it was quicker.

The results of the forth experiment showed that there was a problem in operation of the full-scale discfilter and the test discfilters during that sampling day; the results of the full-scale discfilter and the test discfilters were extremely dissimilar.

In the second experiment microbial analyses were performed to see the removal effects of filtration (discfilter) on indicator bacteria which exist in wastewater. In the following all results according to their relevant analyses are discussed.

5.1 PSA

In order to gain more detailed data regarding separation mechanism, particle size analysis were carried out in the Rya WWTP laboratory. In the first and second test and after filtering process (see section 4.4) the PSA test were performed. In the third, fourth and fifth test only direct 15 µm filtrated of effluent after secondary settlers and discfilters were analyzed through WPC device. For the last measurement which was performed by the help of Professor Britt-Marie Wilén five samples: effluent from secondary settlers, MBBR effluent and influent and discfilters influent and effluent were analyzed.

The results of the PSA show that particle removal for particles larger than 15 µm was more than 80% and the removal rate for particles larger than 20 µm reached close to 99%. Figure 5.3, 5.4 and 5.5 show that separation efficiency was directly related to particle size. The relative difference in number of particles for different size intervals before and after filtration is called separation efficiency (Ljunggren, 2006). Separation efficiency was calculated through following formula:

$$separation\ efficiency = 100 - (\frac{x_1}{x_2} * 100) \tag{5.1}$$

x_1, x_2 = result of PSA for two consecutive size range

Results prove that the separation mechanism in discfilters was chiefly done by physical blocking of particles, and basically particles which were larger than or close to pore size opening were separated. In some experiments (for the most part in effluent of discfilter samples) some particles larger than the filter pore size were detected and the main reason could be (re-)flocculation of particles (Ljunggren, 2006). Shearing of particles or floc breakage could also be explained as a main reason for finding numerous small particles (smaller than 10µm) in our results.

Figure 5.1 and 5.2 illustrate particle size distribution and differences in particle size distribution of different samples in experiment 1, 2, 3, 4 and 5.

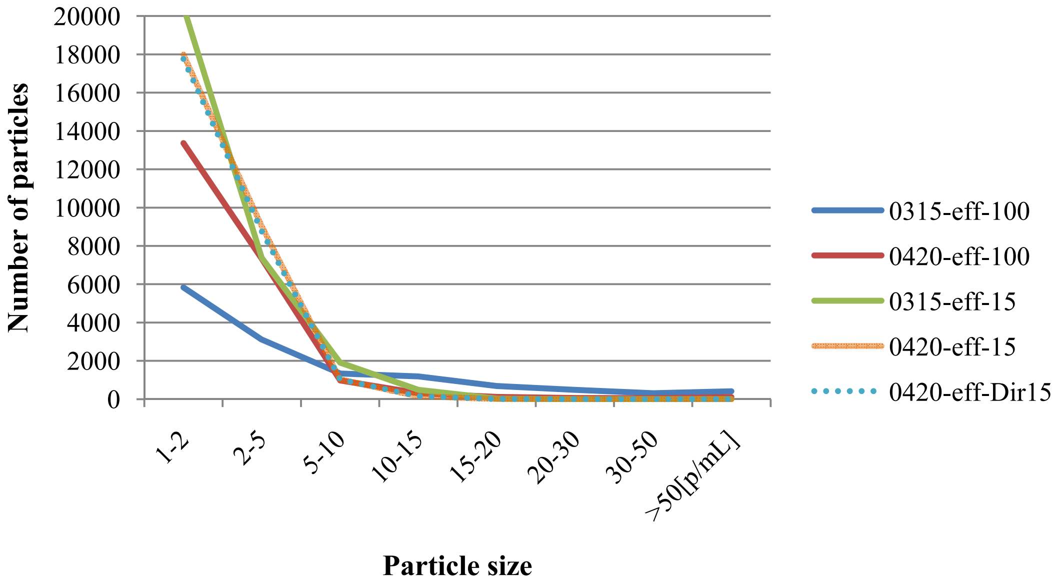

Figure 5.1 Particle size distribution in 5 different samples in 2 experiments, 100 means effluent before discfilter and 15 shows the filter pore size in µm.

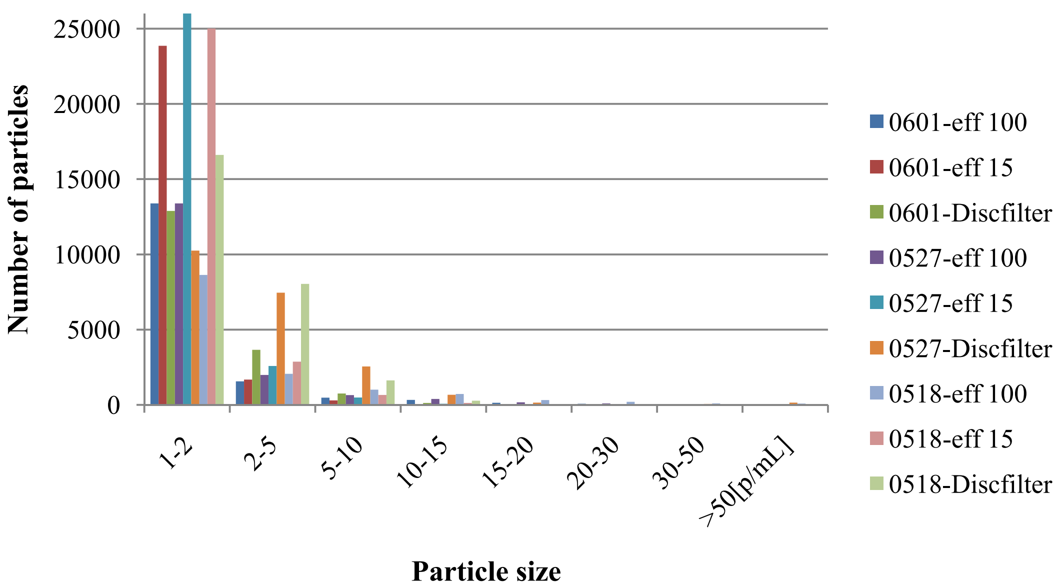

Figure 5.2 Particle size distribution in 10 different samples in 3 different experiments, 100 means effluent before discfilter and 15 shows the filter pore size in µm.

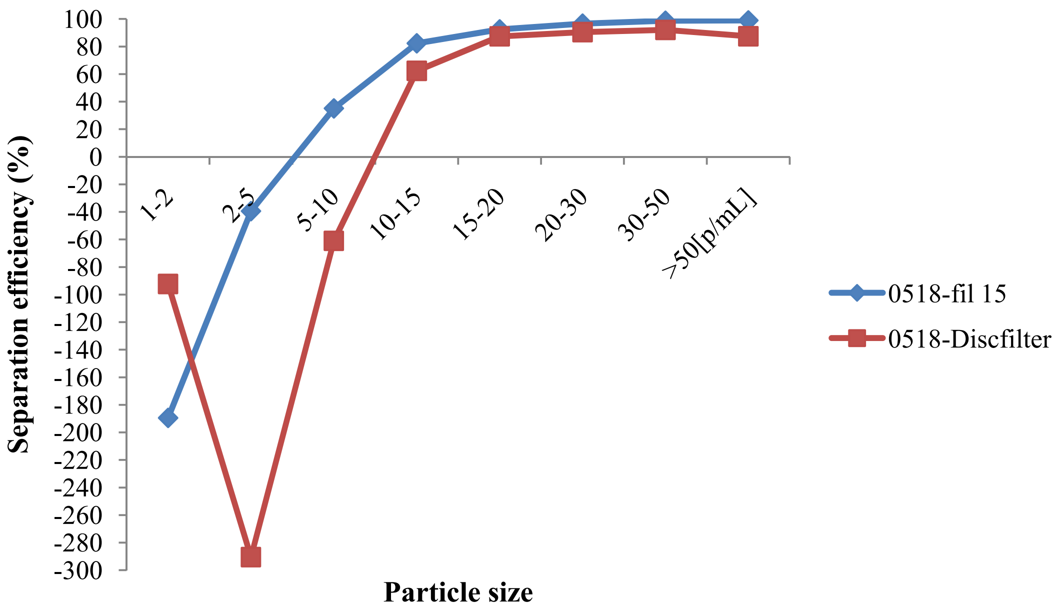

Figure 5.3 Separation efficiency for full-scale discfilter effluent and test filtration in experiment 3, 15 shows the filter pore size in µm.

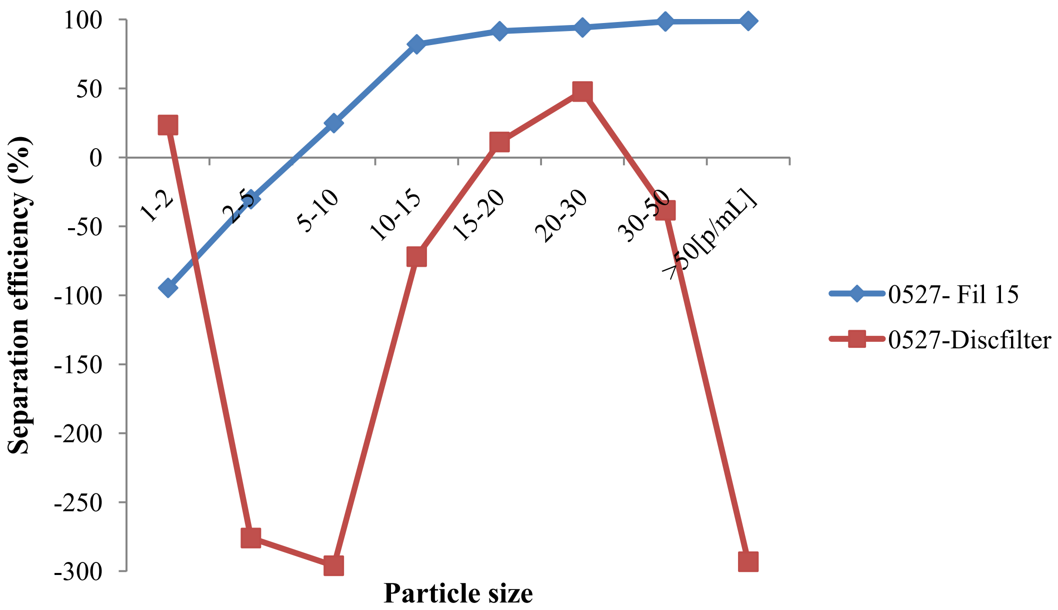

Figure 5.4 Separation efficiency for full-scale discfilter effluent and test filtration in experiment 4, 15 shows the filter pore size in µm.

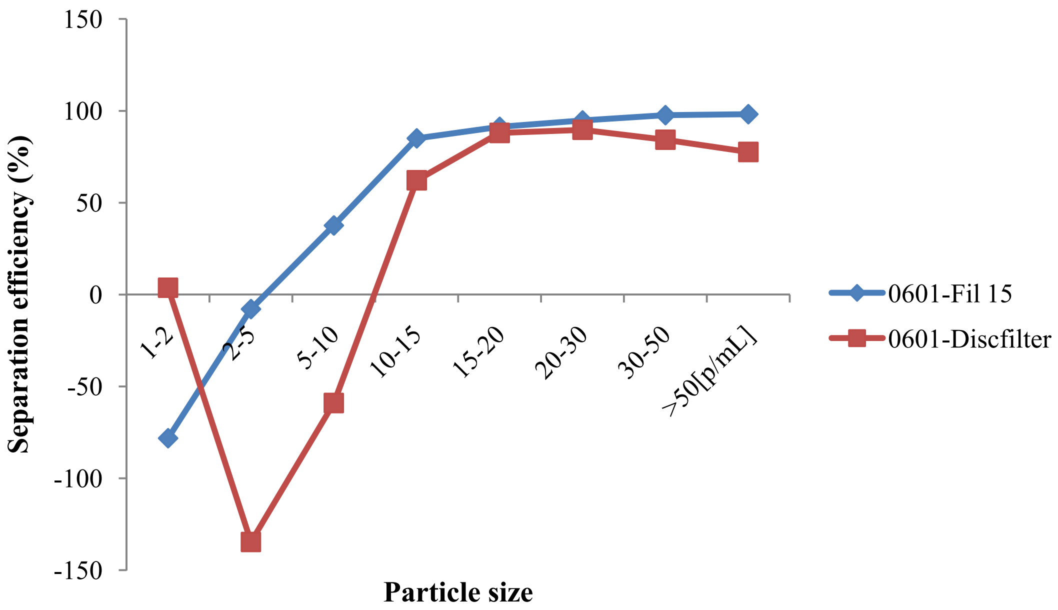

Figure 5.5 Separation efficiency for full-scale discfilter effluent and test filtration in experiment 5, 15 shows the filter pore size in µm.

It can be elucidated from figure 5.3, 5.4 and 5.5 that the full-scale discfilter filter form less very small (1-2 µm particles) but there are more in the range 2-10 µm.

For full details of results and other graphs and tables check Appendix A.

5.2 TSS

Total suspended solids measurements were also performed in the laboratory at the Rya WWTP. Through careful looking at the results it is oblivious that amount of suspended solids in effluent from the discfilter were decreased, and for all of the measurements the number of particles in the effluents after the discfilter or after filtration gave similar results. Hence, it can be concluded that discfilters had a consistent particle removal regardless of widely varying concentration of suspended solids in influent.

Figure 5.6 shows that discfilters and 15µm filter, filter the effluent equally well (except in experiment 4, which discfilters were not working properly) irrespective of suspended solids concentration of the water entering the filter, to suspended solids concentration of 1.5-3.5 mg SS/l.

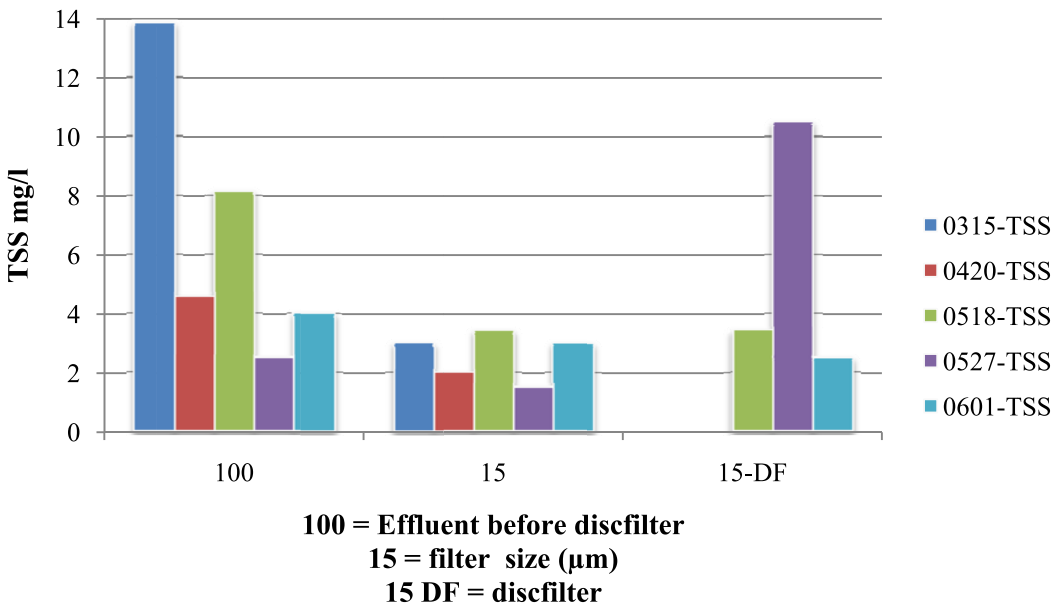

Figure 5.6 Different amounts of suspended solids in experiment 1 to 5.

For full details of results and other graphs and tables check Appendix B.

5.3 COD

The results of the chemical oxygen demand measurements show that discfilters had a small effect in removal of the suspended fractions of organic matter in wastewater. All in all, the concentration of COD in the influent and effluent to discfilters were on average approximately the same (see figure 5.7 and 5.8).

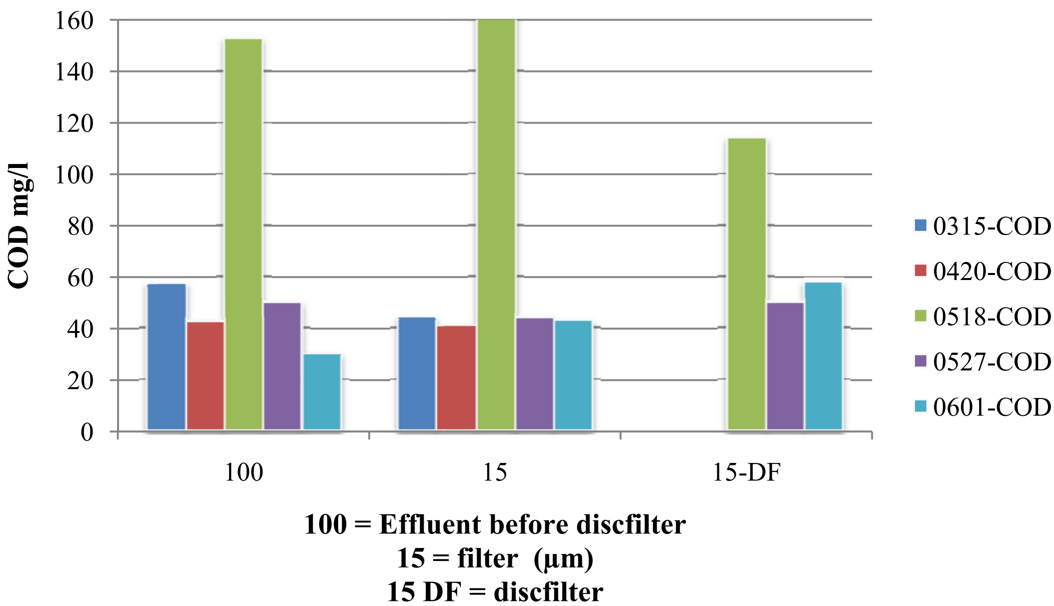

Figure 5.7 Different concentrations of COD in experiment 1 to 5.

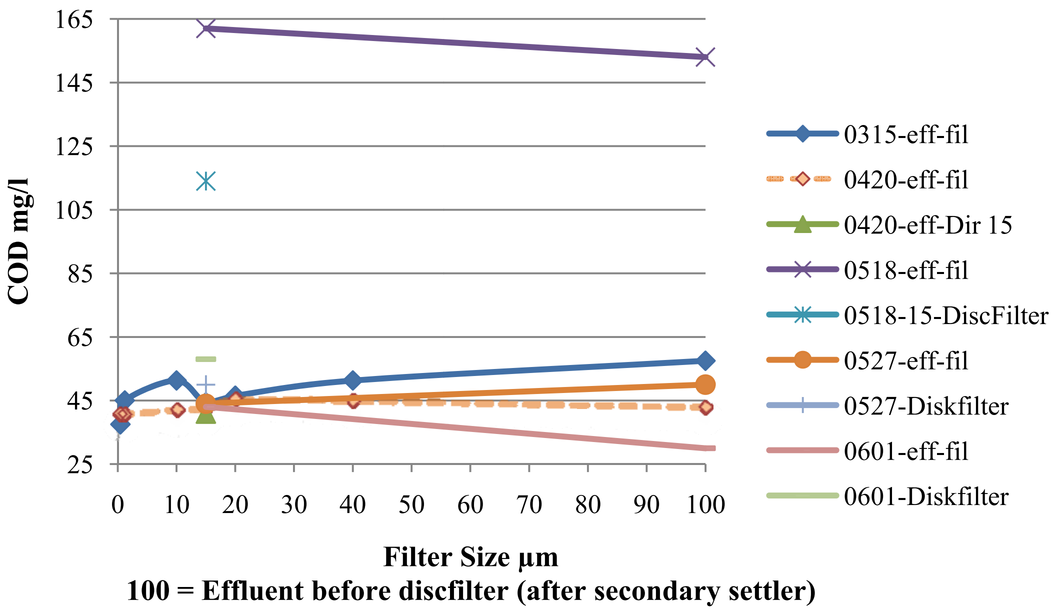

Figure 5.8 Different concentrations of COD in effluent before (after secondary settler) and after discfilter in experiment 1 to 5.

The result of experiment 3 shows higher values than the others, therefore the concentration of COD in the influent wastewater to the WWTP was checked; in experiment 3 and 4 it was 410 mg O2/l and 560 mg O2/l, respectively. It can be suspected that there was some kind of mistake (human, device, and etc) in the measurement or the reduction of COD was not good in experiment 3 and something was left untreated in the effluent.

For full details of results and other graphs and tables check Appendix C.

5.4 Ptot

The results of these tests prove that discfilters were reducing the Ptot concentration to the new effluent limit, 0.3 mg/l. One of the reasons to install discfilter was to reach to the effluent level for Ptot in the effluent water which goes out of WWTP. The results show that indeed the Ptot concentration which was roughly between 0.4 and 0.5 mg/l for effluent before discfilters reached to just under 0.3 mg/l for the effluent after discfilters (see figure 5.9 and 5.10). It can also be seen in figure 5.9 that discfilters gave lower Ptot values compare to direct 15 µm filtration. In addition figure 5.10 proves that there was a direct relation between filter pore size and removal rate of Ptot; by decreasing the filter pore size the Ptot removal rate also went down.

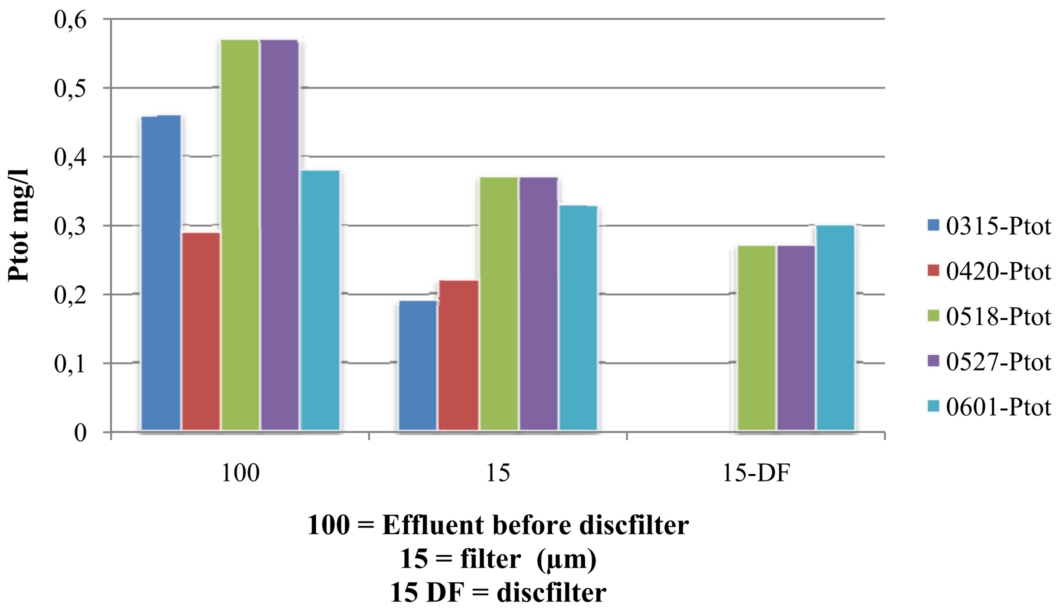

Figure 5.9 Different concentrations of Ptot in experiment 1 to 5.

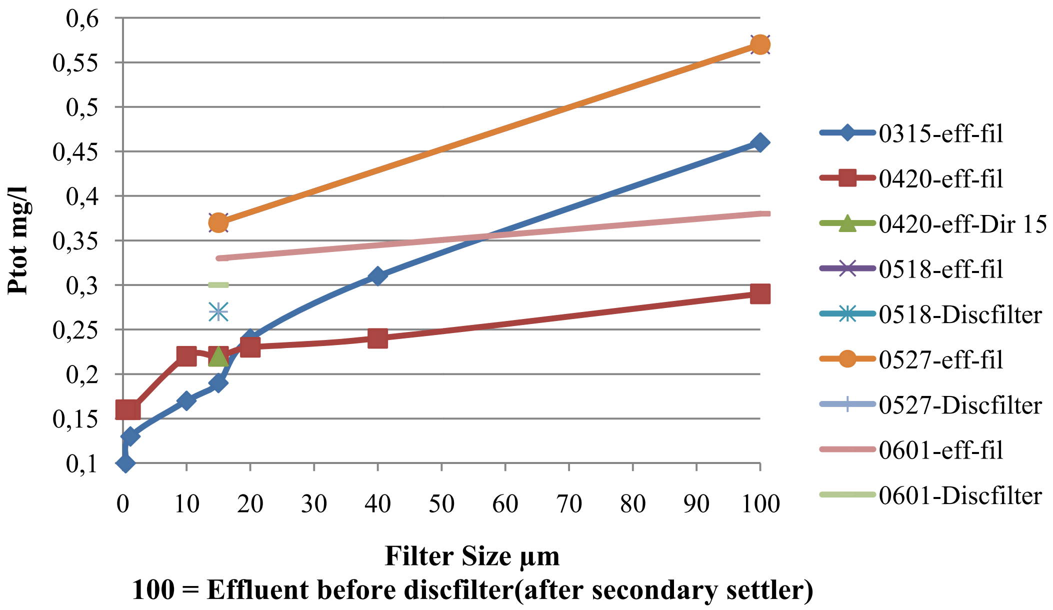

Figure 5.10 Different concentrations of Ntot in effluent before (after secondary settler) and after discfilter in experiment 1 to 5.

For full details of results and other graphs and tables check Appendix D.

5.5 Ntot

By reviewing the results of the three last experiments when the discfilters were in full operation and included in the tests as well, it can be seen that the concentration of

Ntot after discfilters diminished dramatically. The concentration of Ntot in the effluent after secondary settlers and before discfilters was almost between 12 mg/l and 19 mg/l and after water passed through the discfilters the results show that the concentration went down to around 5 mg/l (see Figure 5.11 and 5.12). The effluent limit for Ntot concentration in the effluent is 10 mg/l and the results shows this concentration in the effluent after discfilter is far below that level.

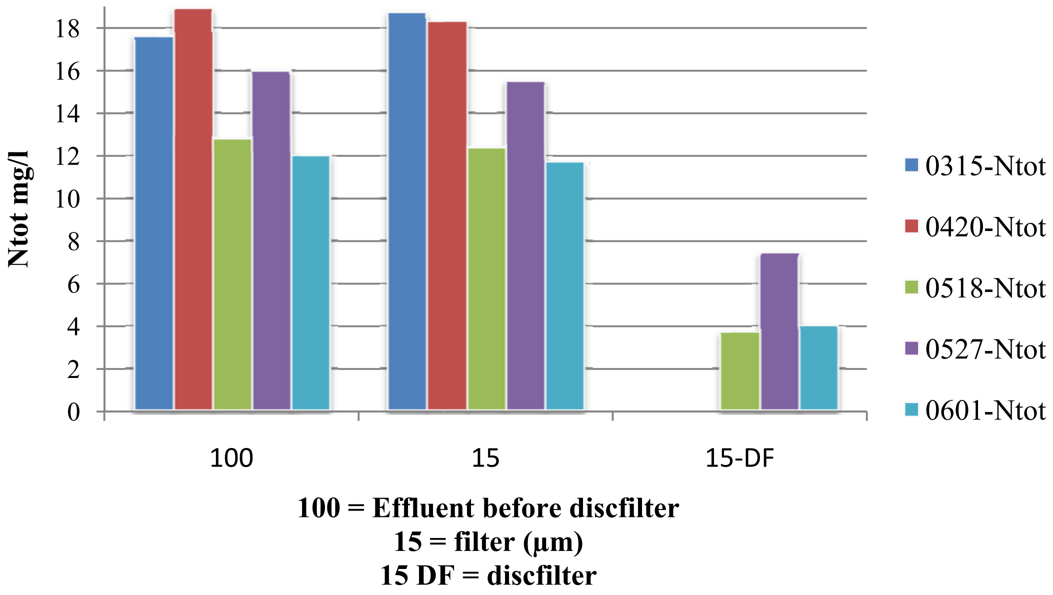

Figure 5.11 Different concentrations of Ntot in experiment 1 to 5.

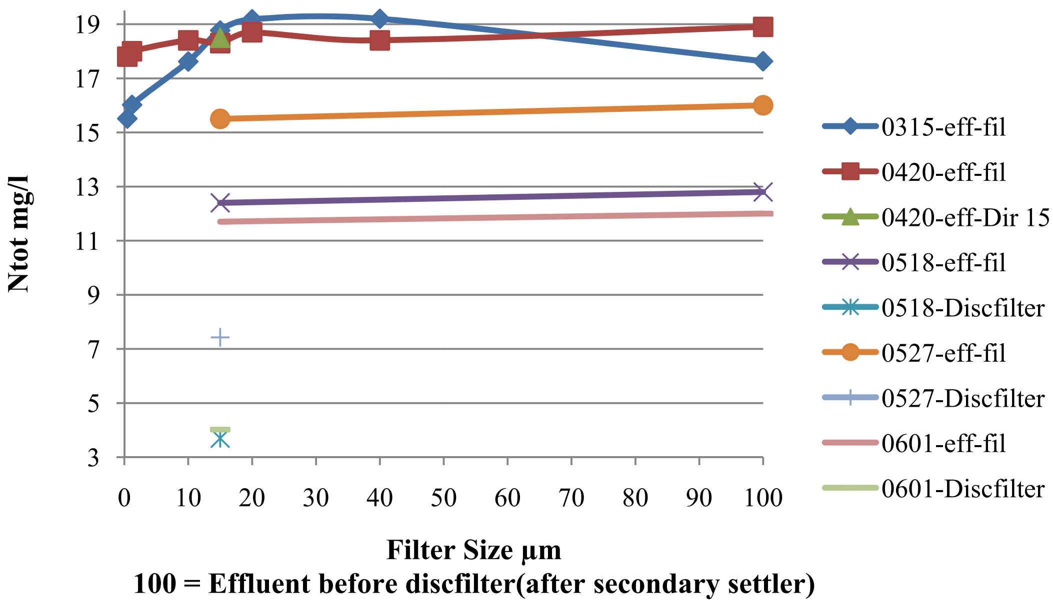

Figure 5.12 Different concentrations of Ntot in effluent before (after secondary settler) and after discfilter in experiment 1 to 5.

Results of 15 µm filtration and discfilter should be approximately close to each other (both discfilters and filters have a similar function and operate on physical blocking of particles). Moreover, most of Ntot are dissolved and cannot be removed through discfilter or filters. Furthermore, MBBR as a unit which removes Ntot efficiently was located before discfilter (one part of water what enter to discfilters was coming from secondary settlers and the rest was from MBBR). Therefore, the above issues can be counted as main reasons for diminishing of Ntot after discfilters.

For full details of results and other graphs and tables check Appendix E.

5.6 N:P Ratio

Eutrophication appears in aquatic systems (marine, fresh water, ponds and etc.) by an increase in the concentration of nutrients such as nitrogen and phosphorous (Hutchinson, 1973). The excess amount of a nutrient change the ratio between nutrient compounds and it helps the growing of alga blooms. In order to manage and prevent eutrophication in aquatic systems it is essential to control the nitrogen/phosphorous ratio in a certain range (Oxmann, 2009). The N:P ratio below 14 indicates nitrogen limitation whereas over 16 is a sign of phosphorus limitations. To impede eutrophication and limiting the plant growth elemental N:P ratio should be between 14 to 16 in order to make a co-limitation by N and P (Koerselman & Meuleman, 1996).

A review of tests results reveals that the N:P ratio of effluent after discfilters was normally around 14 except in experiment 4 which there should be a mistake in some parts of this experiment(see Figure 5.13). Accordingly, results prove that either N or P is limiting or eutrophication co-limited by N and P jointly.

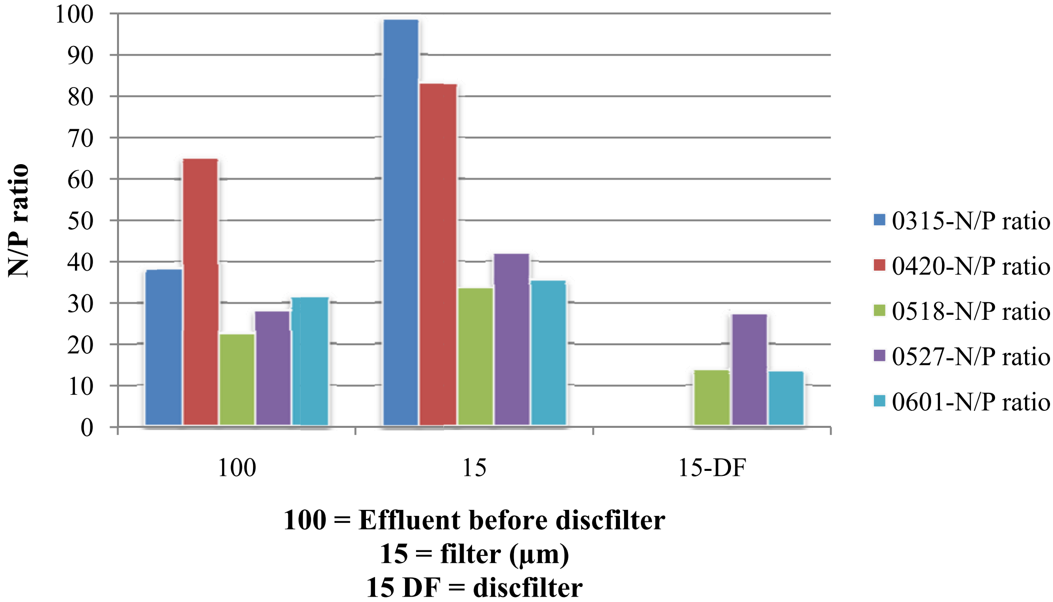

Figure 5.13 The results of N:P ratio in experiment 1 to 5.

For full details of results and other graphs and tables check Appendix H.

5.7 Microbiological Analysis

4 different indicator bacteria, Coliform, E. Coli, Entrococcous and Clostridium were analysed through 3 different methods (no treated, mild sonication and mechanical (Miniprep)). The result values were varying a lot and were not consistent. Hence it is difficult to draw conclusions from these measurements. More duplicate measurements should be performed.

This failure might happen as a result of improper handling of samples or sticking of some bacteria or particles inside (onto the wall) of the sampling bottles.

Figure 5.14, 5.15, 5.16 and 5.17 reveal that there was a mistake in this experiment since the trend of 4 different bacteria weren't declining after filtration, moreover the values were low.

For full details of results and other graphs and tables check Appendix F.

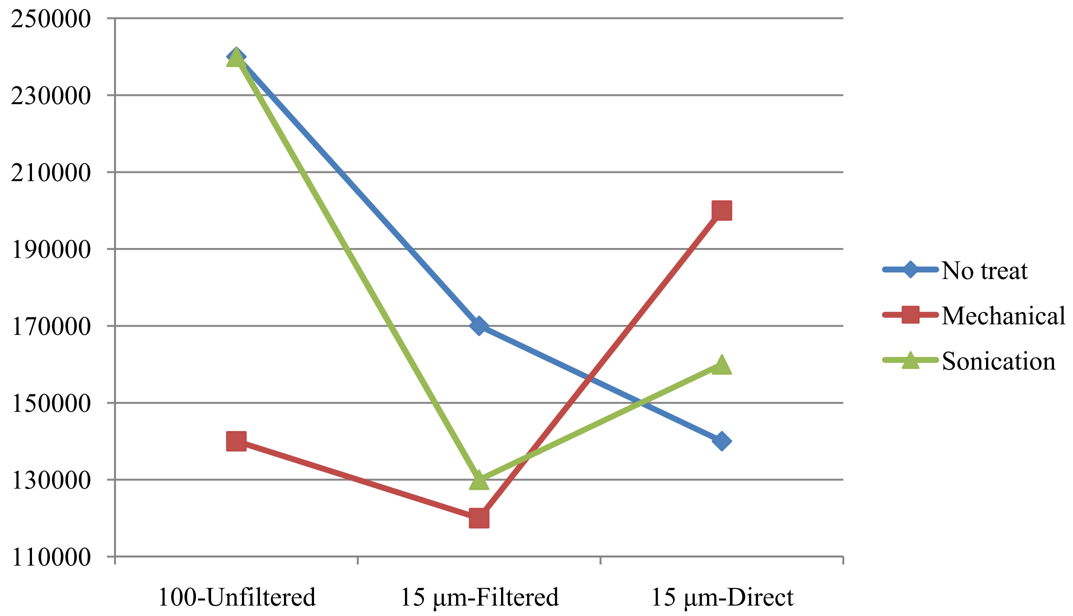

Figure 5.14 Result of Coliform analysis after 3 different treatments.

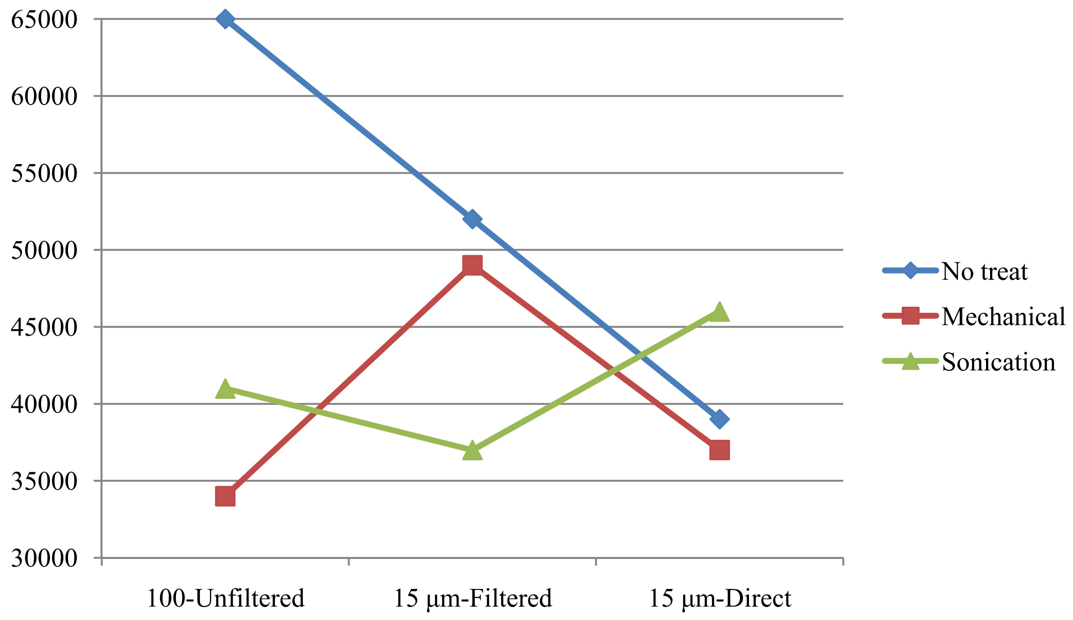

Figure 5.15 Result of E. Coli analysis after 3 different treatments.

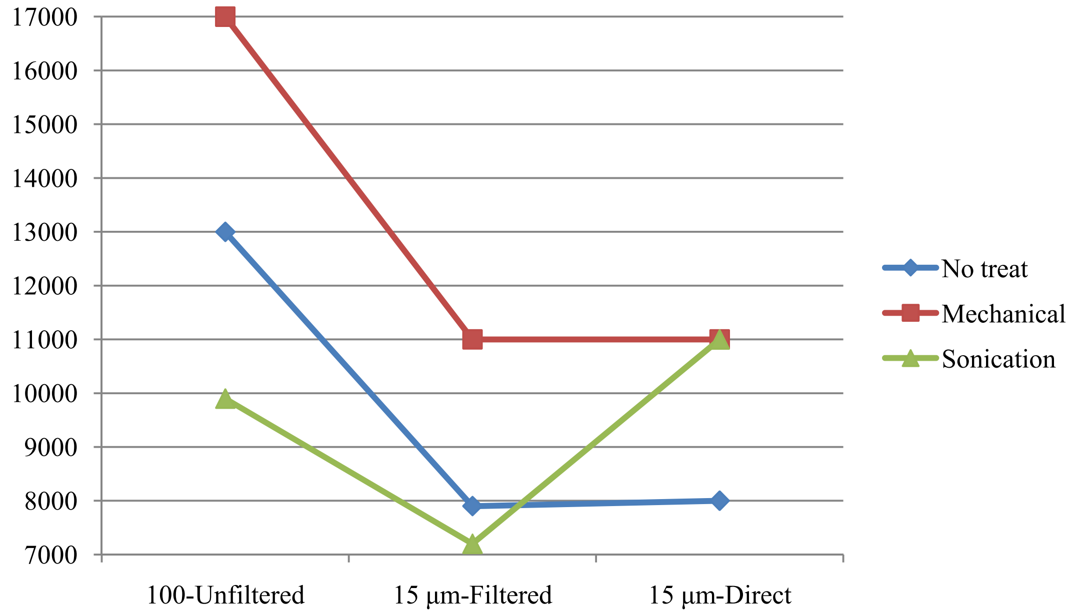

Figure 5.16 Result of Entrococcous analysis after 3 different treatments.

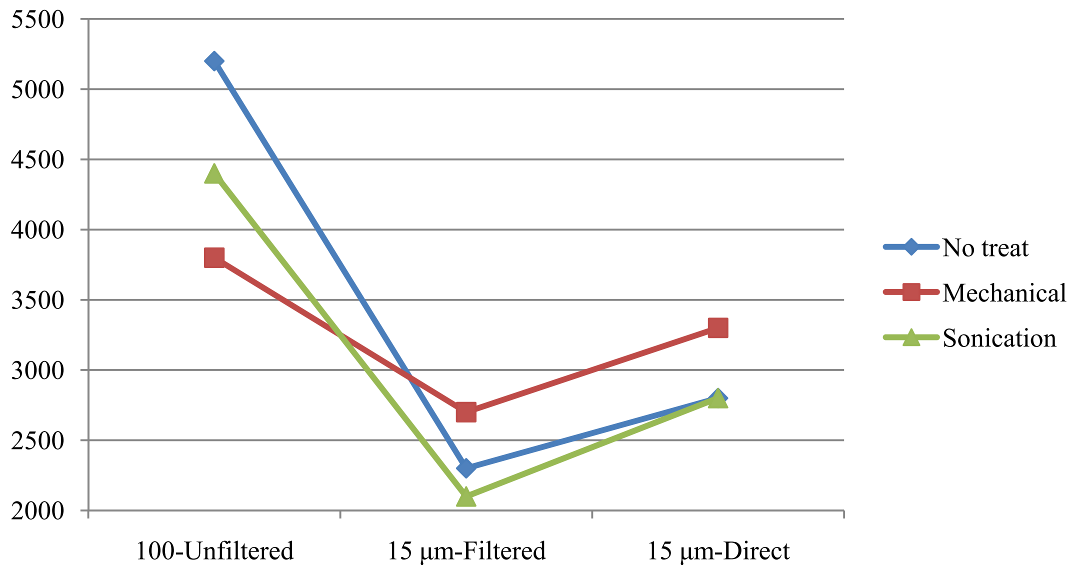

Figure 5.17 Result of Clostridium analysis after 3 different treatments.

5.8 TSS correlation with COD, Ptot, Ntot

While there should be a correlation between SS and COD as well as between P and SS, nevertheless there is no correlation between N and SS, since majority of N in wastewater is dissolved.

Figure 5.18, 5.19, 5.20 and 5.21 provide evidence that COD and P were mostly in the supracolloidal or settleable particle category with size range larger than 15 µm since majority of them were removed through discfilters whereas SS also were separated by in the meantime. In addition Figure 5.22 and 5.23 illustrates that N was mainly dissolved since it can be seen that the SS to N ratio was amplified in the discfilter.

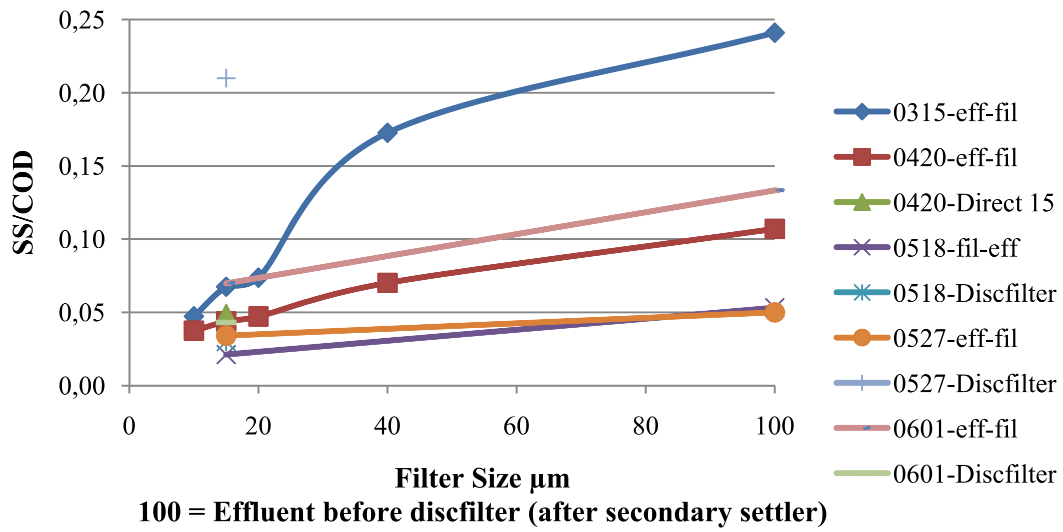

Figure 5.18 SS and COD ratio in effluent before (after secondary settler) and after discfilter in experiment 1 to 5.

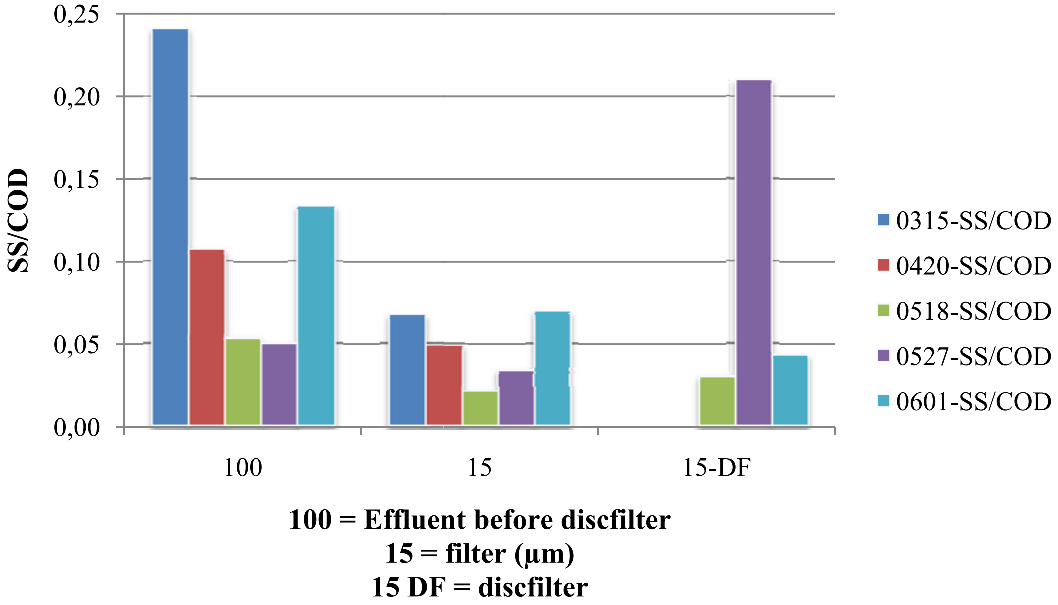

Figure 5.19 SS and COD ratio in experiment 1 to 5.

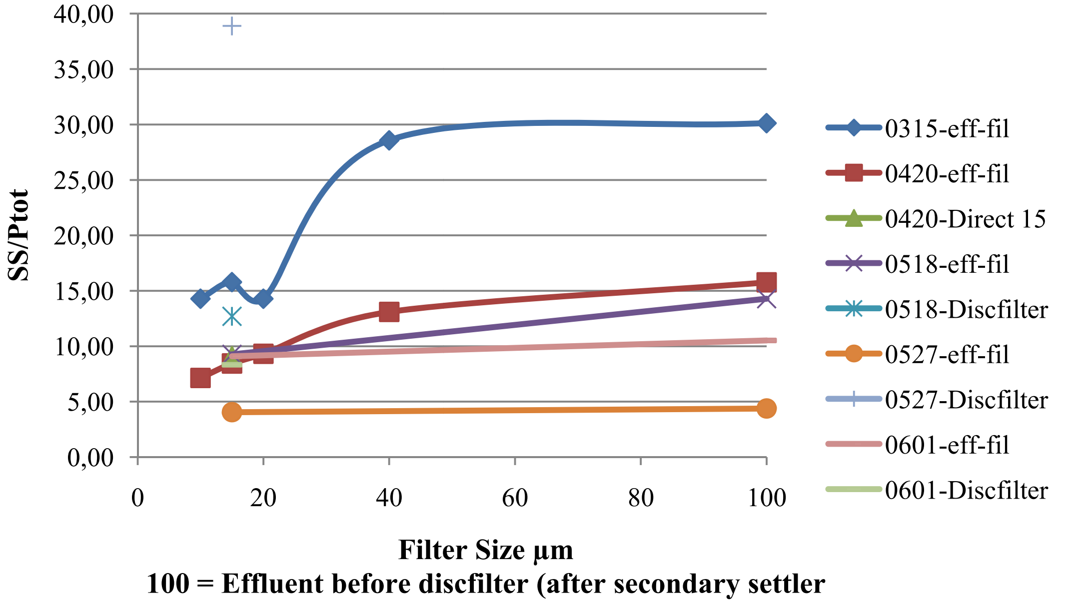

Figure 5.20 SS and Ptot ratio in effluent before (after secondary settler) and after discfilter in experiment 1 to 5.

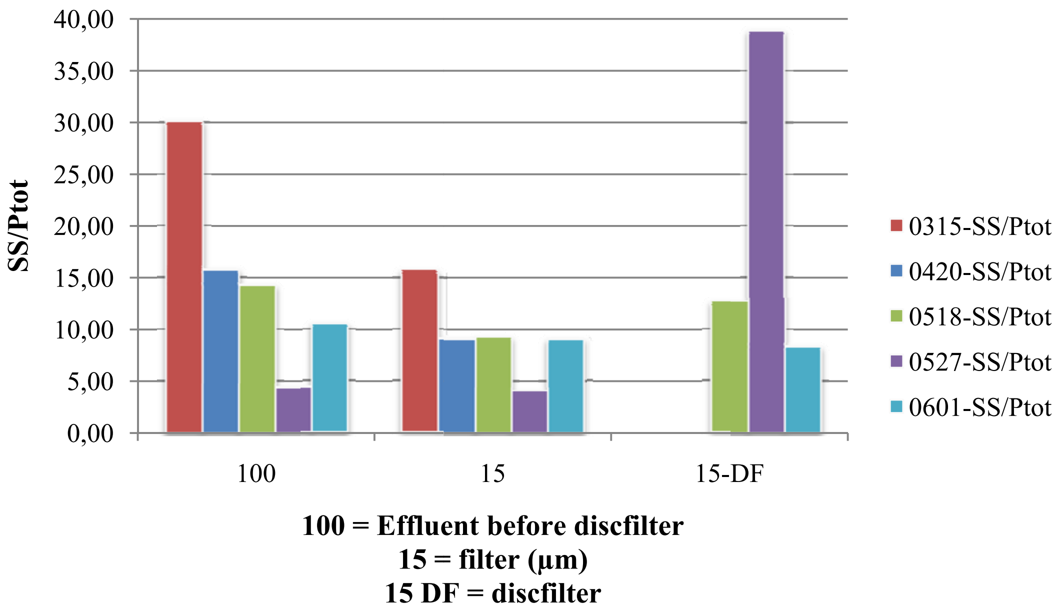

Figure 5.21 SS and Ptot ratio in experiment 1 to 5.

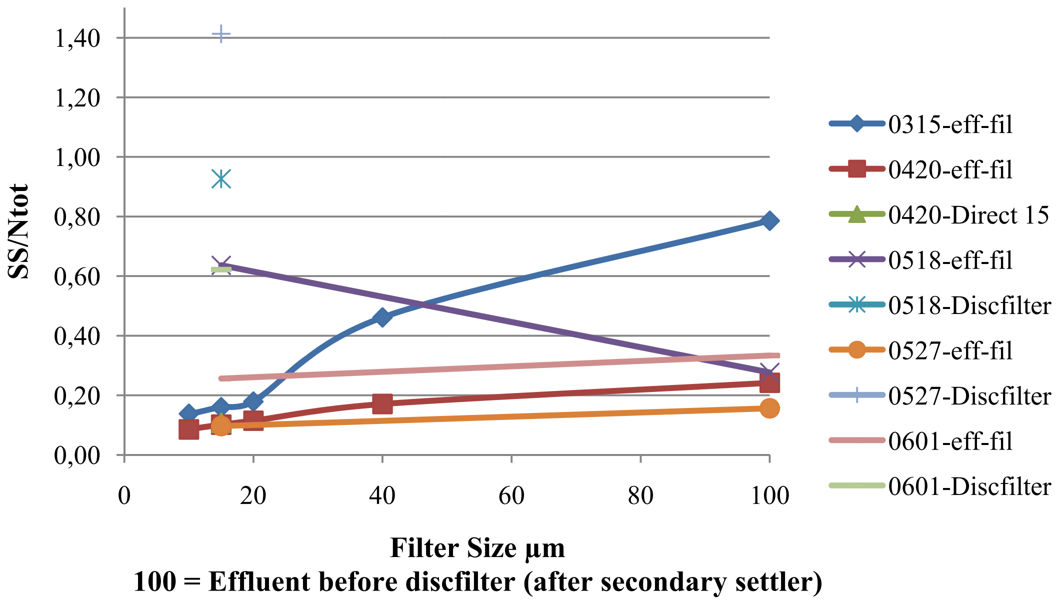

Figure 5.22 SS and Ntot ratio in effluent before (after secondary settler) and after discfilter in experiment 1 to 5.

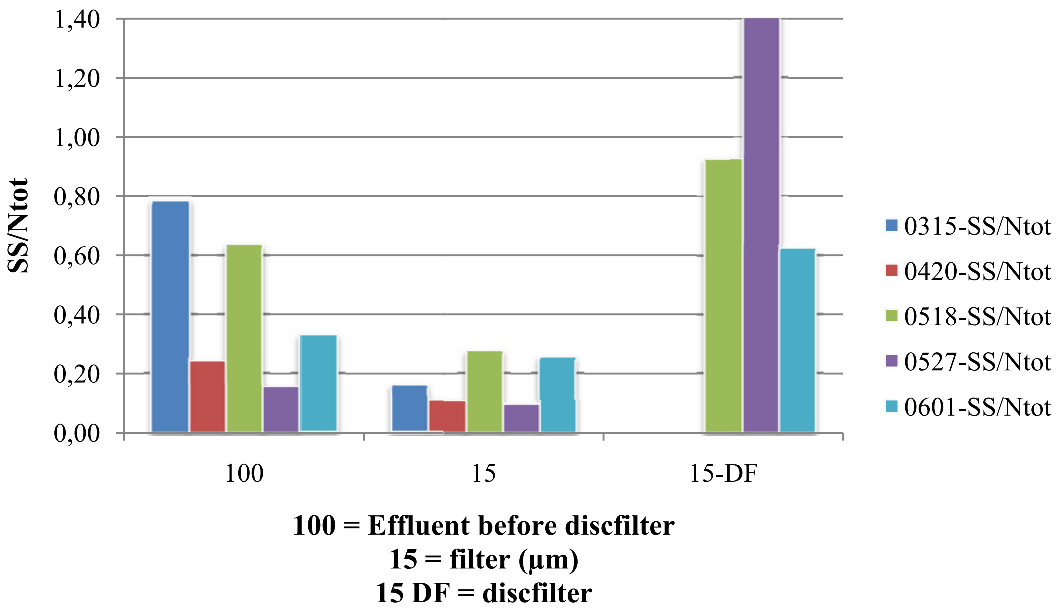

Figure 5.23 SS and Ntot ratio in experiment 1 to 5.

For full details of results and other graphs and tables check Appendix I.

5.9 Turbidity

Turbidity test result shows the amount of suspended solids in water. The results of these tests prove that discfilters were reducing the particles in the effluent. As it can be seen in Figure 5.24 turbidity in the effluent after discfilter decreased except in experiment 4 which there was a mistake in that experiment.

For full details of results and other graphs and tables check Appendix G.

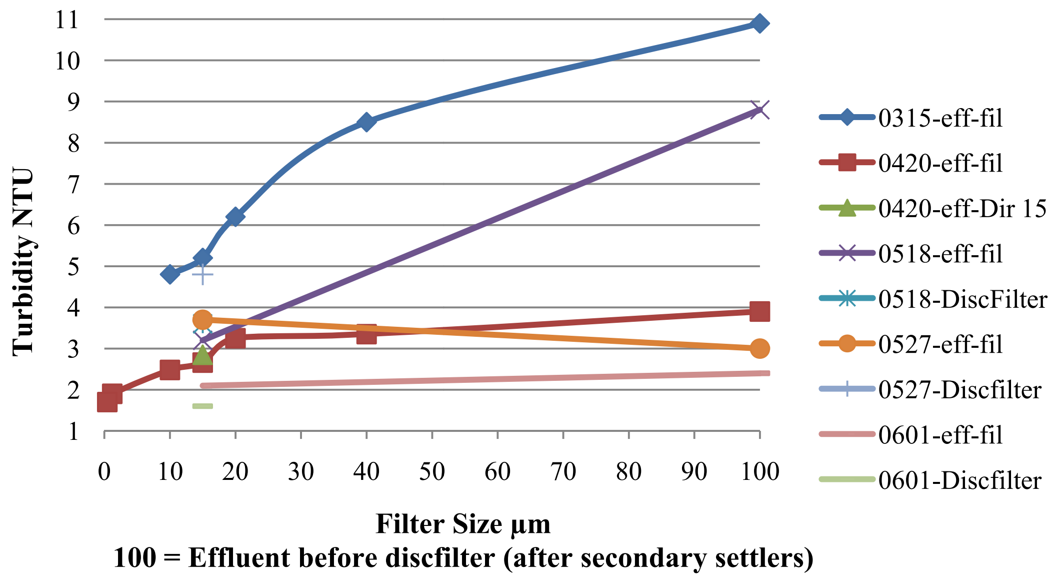

Figure 5.24 Differences of turbidity in effluent before (after secondary settler) and after discfilter in experiment 1 to 5

6 Conclusion

Main goals of installing discfilters at Rya WWTP were removing more particles and phosphorous from effluent wastewater and reaching to the new standard levels of P and N in discharging water from WWTP. Through reviewing of all different tests results and data it can be proved that discfilters were separating Ptot and SS effectively from effluent water.

In the first two experiments the step by step filtration from 40 µm to 15 µm performed and by comparing the results of step by step filtration to direct filtration via 15 µm filter it was deduced that both ways gave similar results and as direct filtration could be done quicker it was decided to skip step by step filtration and perform only direct filtration.

PSA performed by means of WPC, and results mainly illustrated discfilters removed particles larger than 15 µm (discfilter pore size) effectively. In PSA results some particles smaller than 10 µm were found and it the main reason can be shearing of flocs and particles during the filtration process. Results of COD and Ntot showed that the discfilter did not remove these fractions. The results from the microbial analysis indicated some removal but more analyses are needed to be able to draw any definite conclusions since the method is associated with a large standard deviation between samples.

7 References

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8 Appendix A: Results of PSA

8.1 Experiment 1

Table 8.1 Result of particle size analysis in experiment 1.

Filter Size µm	1-2	2-5	5-10	10-15	15-20	20-30	30-50	>50[p/mL]
0	5829,00	3113,00	1340,00	1187,00	685,10	484,50	309,60	414,10
40	7460,00	4174,00	1817,00	1483,00	738,00	494,00	170,70	69,30
20	14907,00	6232,00	2063,00	1134,00	259,00	58,70	5,62	1,83
15	20482,00	7376,00	1910,00	490,10	30,38	4,72	0,79	0,63
10	24252,00	7086,00	1234,00	155,80	6,94	1,53	0,41	0,43

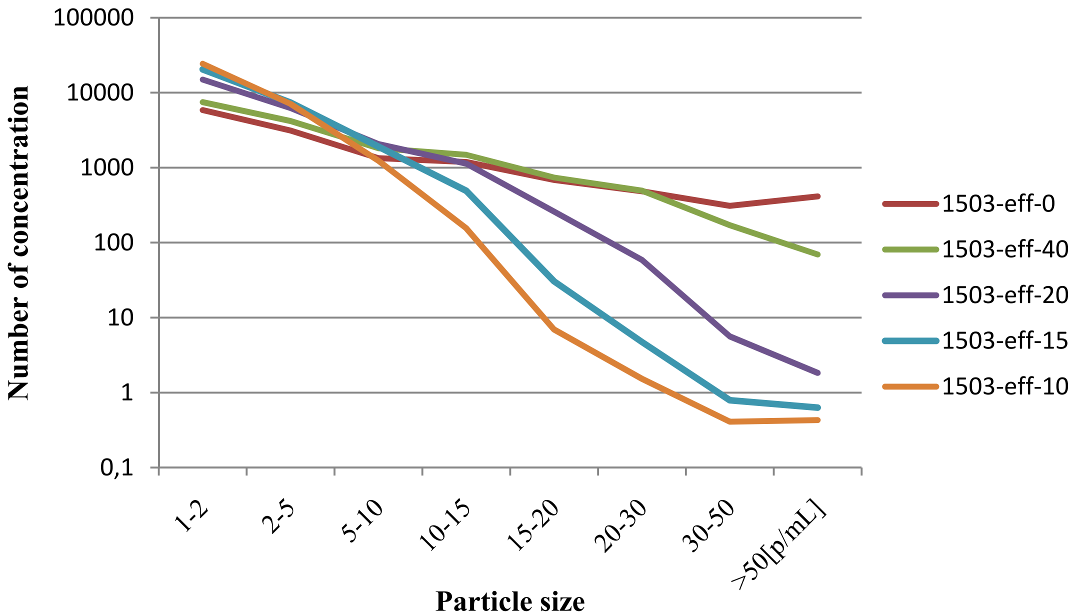

Figure 8.1 Effluent PSD from secondary settlers in experiment 1, 40, 20, 15 and 10 show different filter sizes in µm.

8.2 Experiment 2

Table 8.2 Result of particle size analysis in experiment 2.

Filter Size µm	1-2	2-5	5-10	10-15	15-20	20-30	30-50	>50[p/mL]
0	13368	7332	982,5	311,8	116,4	61,7	55,1	114,1
40	15239	7969	1056	342,5	96,5	53,4	14,5	8,1
20	17000	9065	1180	260,9	33,7	9,2	1,8	1,1
15	17984	9033	1026	153,4	9,1	2,6	0,4	0,2
10	18477	9125	953,9	119,3	8,1	2,1	0,5	0,3
1.2	16261	5004	494,4	70,4	5,4	1,2	0,3	0,2
0.45	1958	400	135,2	43,67	6,19	1,6	0,1	0,02
Direct 15	17763	8774	1030	155,8	10,8	2,7	0,5	0,4

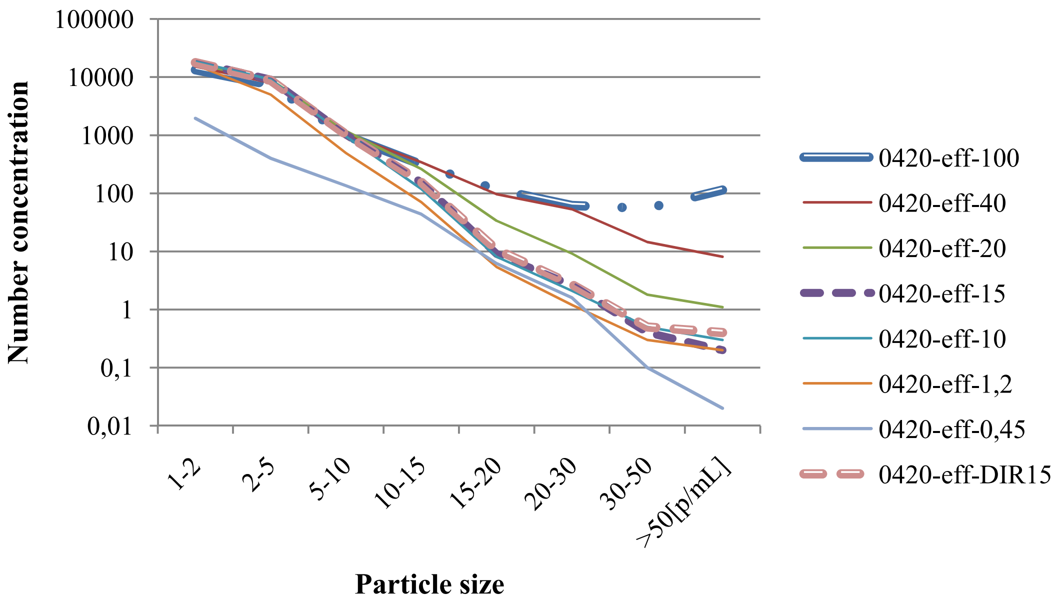

Figure 8.2 Effluent PSD from secondary settlers in experiment 1, 40, 20, 15, 10, 1.2 and 0.45 shows different filter sizes in µm. DIR15 shows a direct filtration by 15 µm filter.

8.3 Experiment 3

Table 8.3 Result of particle size analysis in experiment 3 (DF means discfilter).

Filter Size µm	1-2	2-5	5-10	10-15	15-20	20-30	30-50	>50[p/mL]
0	8639	2059	1008	722,8	314,5	198,4	91,6	86,6
15	25011	2871	654	127,6	23,79	6,74	1,2	0,9
15-DF	16611	8040	1623	272,3	39,7	18,9	7,3	10,9

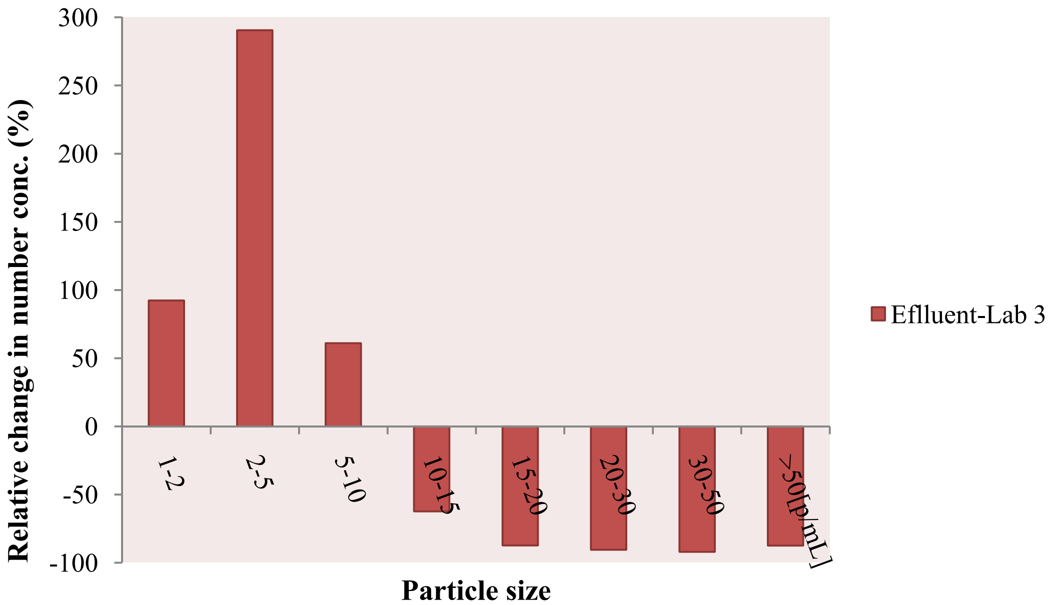

Figure 8.3 Relative changes in number concentration of particles in influent and effluent of discfilters in experiment 3.

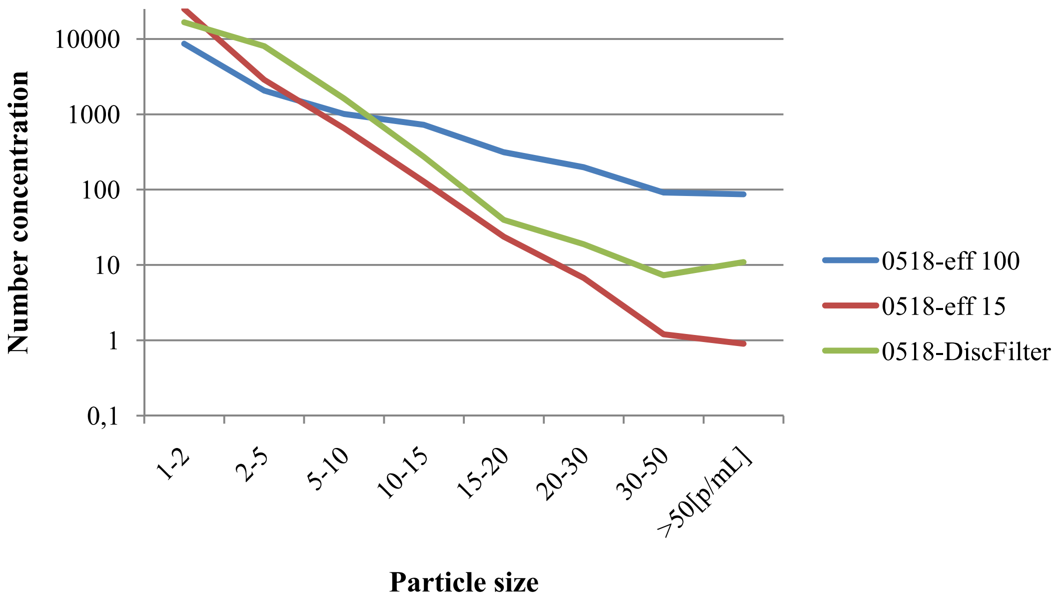

Figure 8.4 Effluent PSD from secondary settlers and after discfilters in experiment 3, 100 means effluent before discfilter and 15 shows the filter size in µm.

8.4 Experiment 4

Table 8.4 Result of particle size analysis in experiment 4 (DF means discfilter).

Filter Size µm	1-2	2-5	5-10	10-15	15-20	20-30	30-50	>50[p/mL]
0	13386	1981	644,4	389,3	165,2	93,3	40,4	37,9
15	26053	2582	484,1	70	14	5,4	0,6	0,4
15-DF	10248	7448	2552	669,4	146,8	48,8	55,9	149

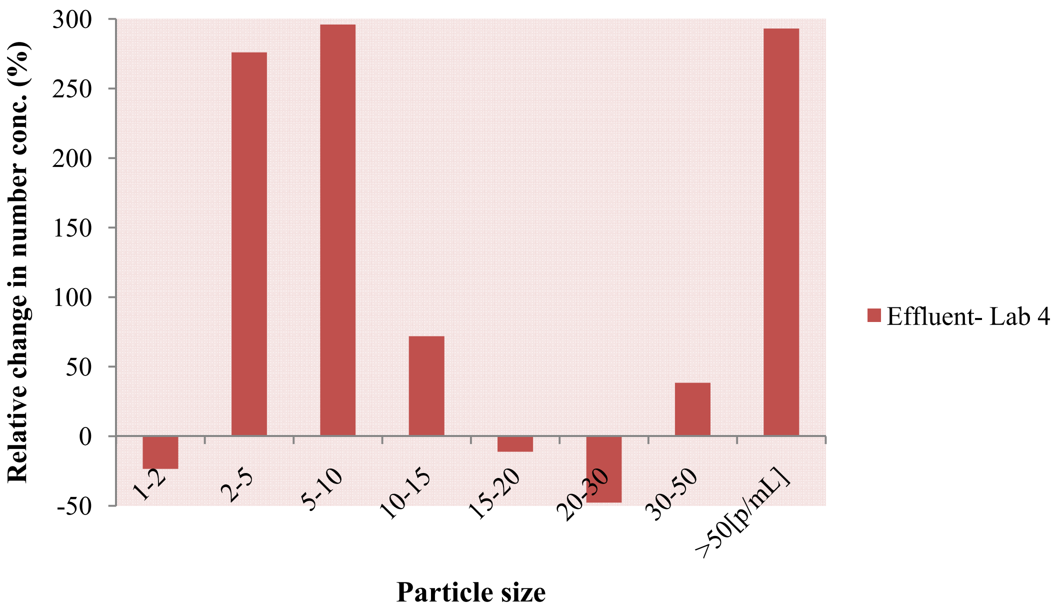

Figure 8.5 Relative changes in number concentration of particles in influent and effluent of discfilters in experiment 4.

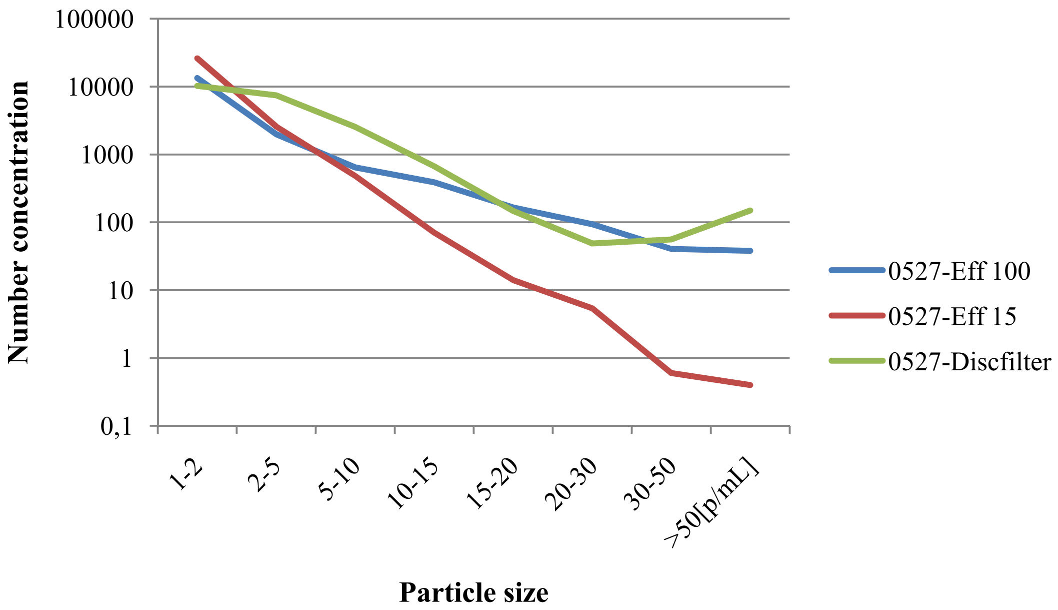

Figure 8.6 Effluent PSD from secondary settlers and after discfilters in experiment 4, 100 means effluent before discfilter and 15 shows the filter size in µm.

8.5 Experiment 5

Table 8.5 Result of particle size analysis in experiment 5 (DF means discfilter).

Filter Size µm	1-2	2-5	5-10	10-15	15-20	20-30	30-50	>50[p/mL]
0	13392	1559	473,8	326	133,3	72,6	29,9	27,7
15	23861	1682	295,6	48,8	11,6	3,8	0,7	0,5
15-DF	12893	3658	753,3	123,3	16	7,5	4,7	6,2

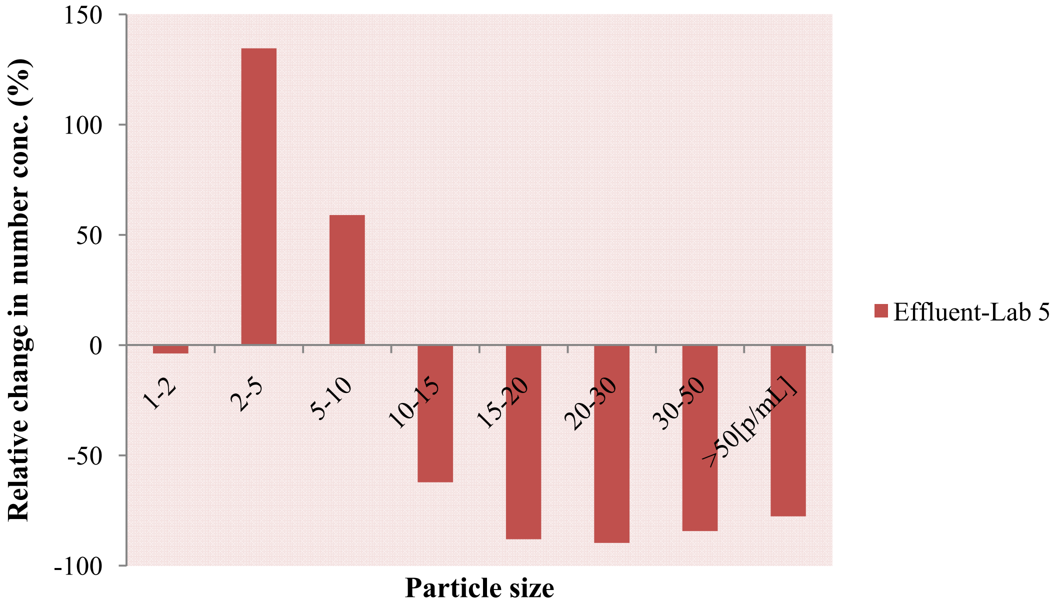

Figure 8.7 Relative changes in number concentration of particles in influent and effluent of discfilters in experiment 5.

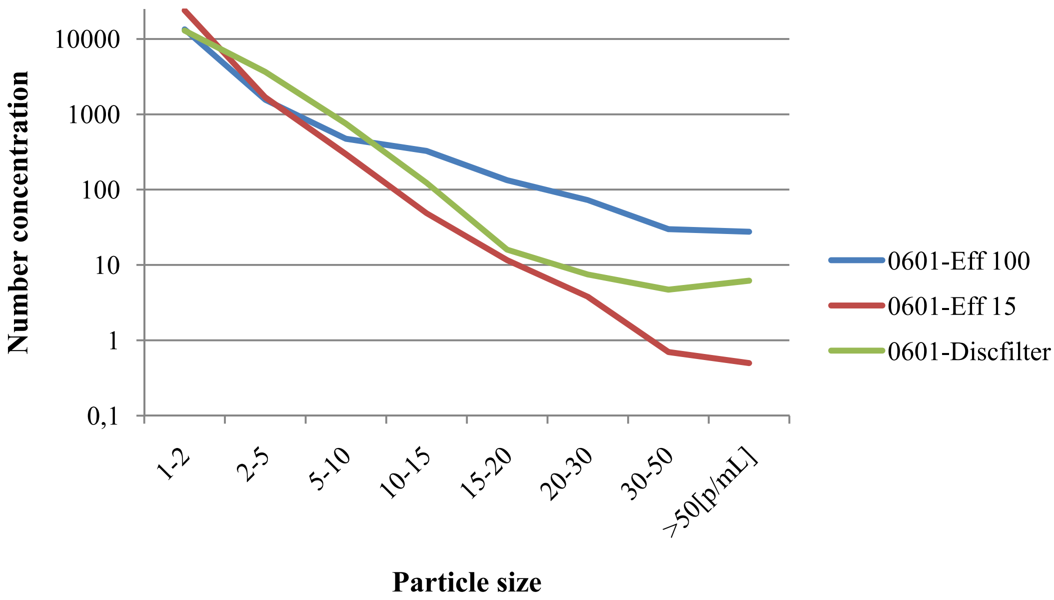

Figure 8.8 Effluent PSD from secondary settlers and after discfilters in experiment 5, 100 means effluent before discfilter and 15 shows the filter size in µm.

8.6 Experiment 6

Table 8.6 Result of particle size analysis in experiment 6.

	Effluent_seconadry settlers	**Disc filter effluent**	**Disc filter effluent**	**Effluent_post-denitrification**	**In_post-denitrification**
	Channel	**SF_XZ9960**	**mixing shell**	**ED_TA9930**	**ED_TA9910**
particle size					
1-2 µm	9753	16471	15386	4379	7649
2-5 µm	2348	3641	3014	1794	3769
5-10 µm	1357	600	523	817	1745
10-15 µm	643	134	92	485	642
15-20 µm	150	32	19	183	170
20-30 µm	57	12	7	80	90
30-50 µm	19	5	2	81	48
>50 µm	16	9	3	202	54

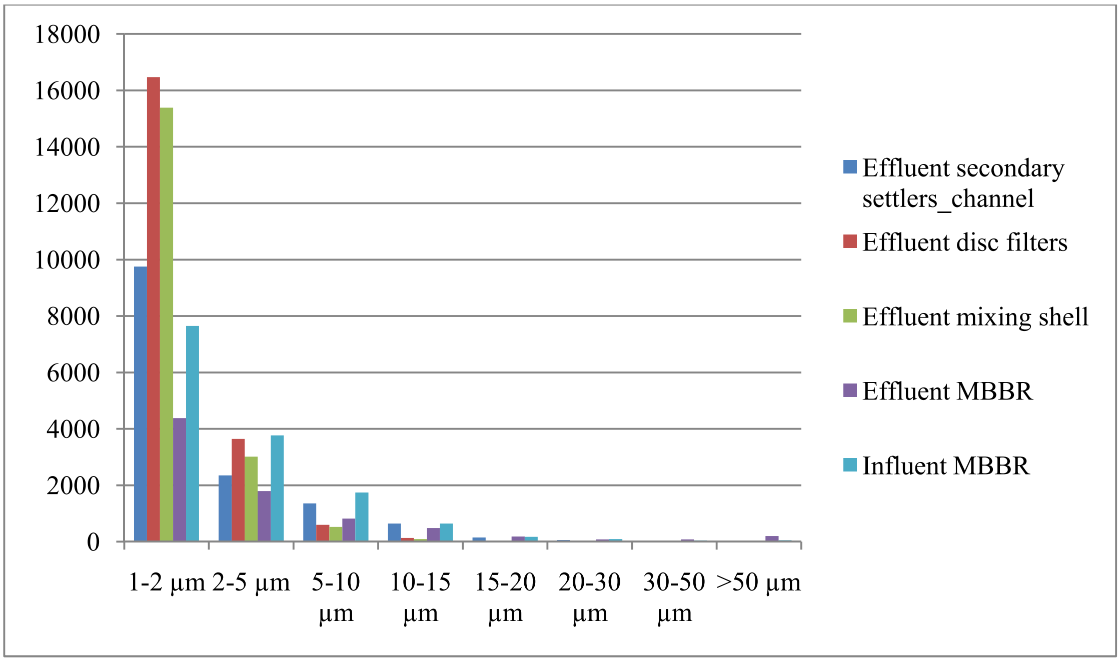

Figure 8.9 Particle size distribution in 5 different samples in experiment 6.

9 Appendix B: Results of TSS Measurements

Table 9.1 Result of TSS in experiment 1.

Filter Size µm	SS (mg/l)	Reduction (%)	Difference (mg/l)
100	13,85714	0	0
40	8,857143	36,08247423	5
20	3,428571	75,25773196	5,428571429
15	3	78,35051546	0,428571429
10	2,428571	82,4742268	0,571428571

Table 9.2 Result of TSS in experiment 2.

Filter Size µm	SS (mg/l)	Reduction (%)	Difference (mg/l)
100	4,571429	0	0
40	3,142857	31,25	1,428571429
20	2,142857	53,125	1
15	1,857143	59,375	0,285714286
10	1,571429	65,625	0,285714286
Direct 15	2	56,25	2,571428571

Table 9.3 Result of TSS in experiment 3.

Filter Size µm	SS (mg/l)	Reduction (%)	Difference (mg/l)
100	8,142857	0	0
15	3,428571	57,89473684	4,714
15-DF	3,428571	57,89473684	4,714

Table 9.4 Result of TSS in experiment 4.

Filter Size µm	SS (mg/l)	Reduction (%)	Difference (mg/l)
100	2,5	0	0
15	1,5	40	1,000
15-DF	10,5	-320	-8,000

Table 9.5 Result of TSS in experiment 5.

Filter Size µm	SS (mg/l)	Reduction (%)	Difference (mg/l)
100	4	0	0
15	3	25	1,000
15-DF	2,5	37,5	1,500

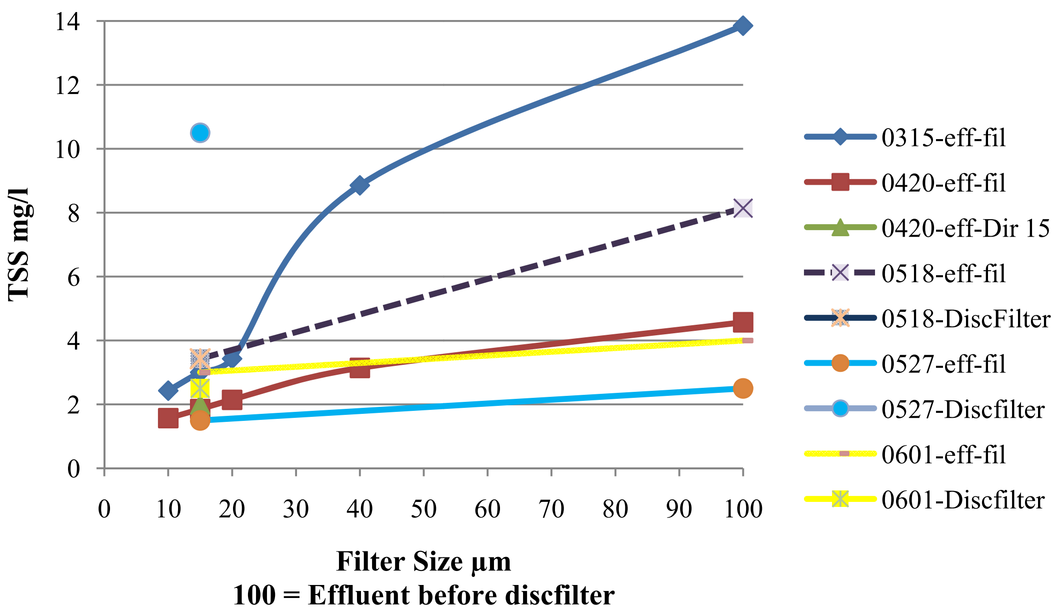

Figure 9.1 Different amount of suspended solids in experiment 1 to 5.

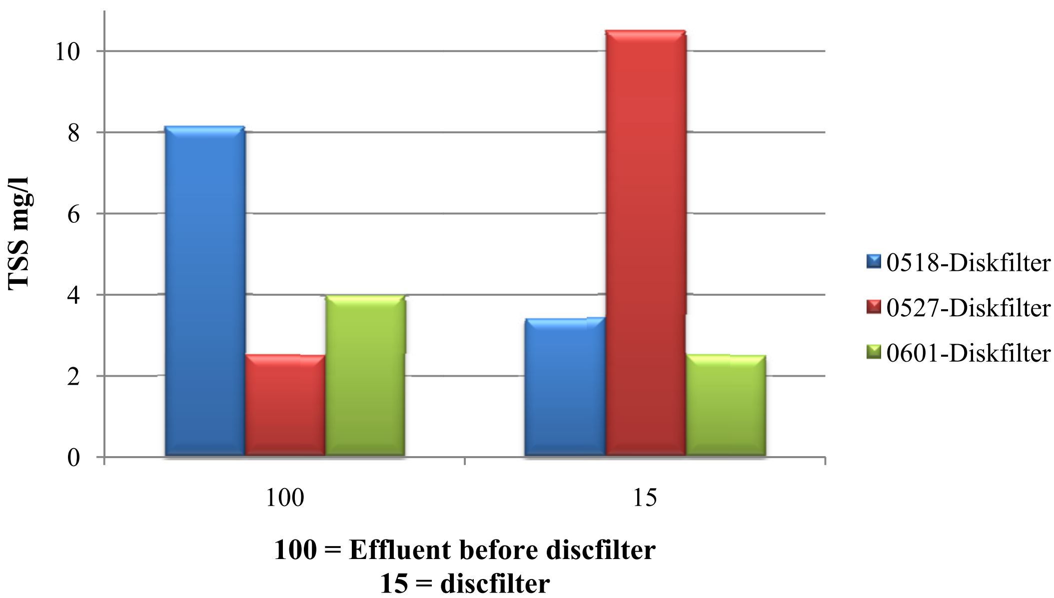

Figure 9.2 Different amounts of suspended solids in effluent before and after discfilter in experiment 3 to 5.

10 Appendix C: Results of COD Measurements

Table 10.1 Result of COD in experiment 1.

Filter Size µm	COD (mg O2/l)	Reduction %	Difference (mg O2/l)
100	57,5	0	0
40	51,3	10,7826087	6,2
20	46,5	19,13043478	4,8
15	44,4	22,7826087	2,1
10	51,3	10,7826087	-6,9
1,2	45	21,73913043	6,3
0,45	37,5	34,7826087	7,5

Table 10.2 Result of COD in experiment 2.

Filter Size µm	COD (mg O2/l)	Reduction %	Difference (mg O2/l)
100	42,7	0,000	0
40	44,8	-4,918	-2,1
20	45,4	-6,323	-0,6
15	42,4	0,703	3
10	41,9	1,874	0,5
1,2	40,6	4,918	1,3
0,45	40,7	4,684	-0,1
Direct 15	40,9	4,215	1,8

Table 10.3 Result of COD in experiment 3.

Filter Size µm	COD (mg O2/l)	Reduction %	Difference (mg O2/l)
100	153	0,000	0
15	162	-5,882	-9
15-DF	114	25,490	39

Table 10.4 Result of COD in experiment 4.

Filter Size µm	COD (mg O2/l)	Reduction %	Difference (mg O2/l)
100	50	0,000	0
15	44	12,000	6
15-DF	50	0,000	0

Table 10.5 Result of COD in experiment 5.

Filter Size µm	COD (mg O2/l)	Reduction %	Difference (mg O2/l)
100	30	0,000	0
15	43	-43,333	-13
15-DF	58	-93,333	-28

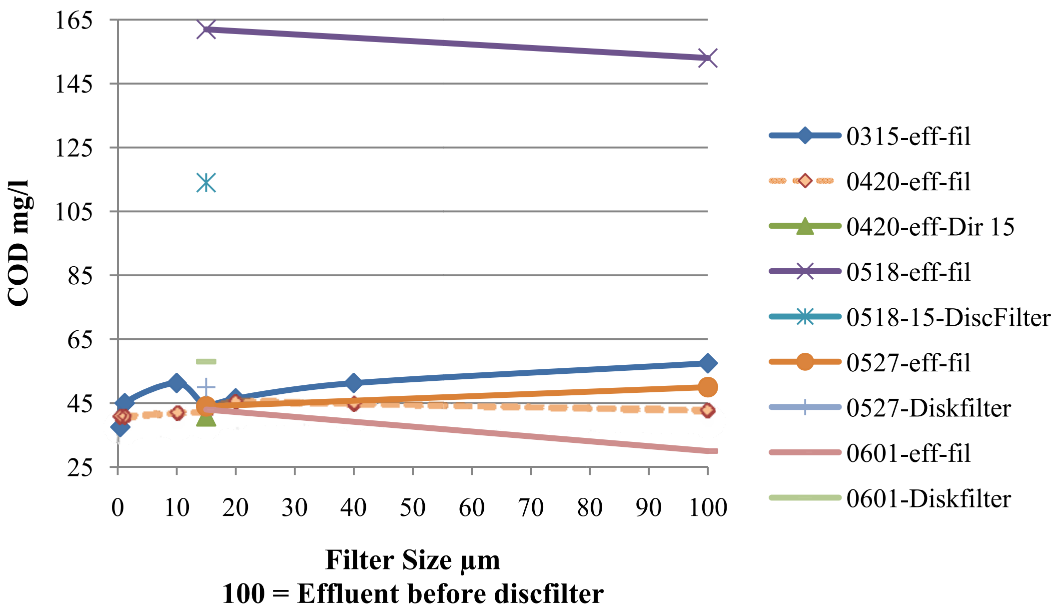

Figure 10.1 Different concentrations of COD in effluent before and after discfilter in experiment 1 to 5.

11 Appendix D: Results of Ptot Measurements

Table 11.1 Result of Ptot in experiment 1.

Filter Size µm	Ptot (mg/l)	Reduction (%)	Difference (mg/l)
100	0,46	0	0
40	0,31	32,60869565	0,15
20	0,24	47,82608696	0,07
15	0,19	58,69565217	0,05
10	0,17	63,04347826	0,02
1,2	0,13	71,73913043	0,04
0,45	0,1	78,26086957	0,03

Table 11.2 Result of Ptot in experiment 2.

Filter Size µm	Ptot (mg/l)	Reduction (%)	Difference (mg/l)
100	0,29	0	0
40	0,24	17,24137931	0,05
20	0,23	20,68965517	0,01
15	0,22	24,13793103	0,01
10	0,22	24,13793103	0
1,2	0,16	44,82758621	0,06
0,45	0,16	44,82758621	0
Direct 15	0,22	24,13793103	0,07

Table 11.3 Result of Ptot in experiment 3.

Filter Size µm	Ptot (mg/l)	Reduction (%)	Difference (mg/l)
100	0,57	0	0
15	0,37	35,0877193	0,2
15-DF	0,27	52,63157895	0,3

Table 11.4 Result of Ptot in experiment 4.

Filter Size µm	Ptot (mg/l)	Reduction (%)	Difference (mg/l)
100	0,57	0	0
15	0,37	35,0877193	0,2
15-DF	0,27	52,63157895	0,3

Table 11.5 Result of Ptot in experiment 5.

Filter Size µm	Ptot (mg/l)	Reduction (%)	Difference (mg/l)
100	0,38	0	0
15	0,33	13,15789474	0,05
15-DF	0,3	21,05263158	0,08

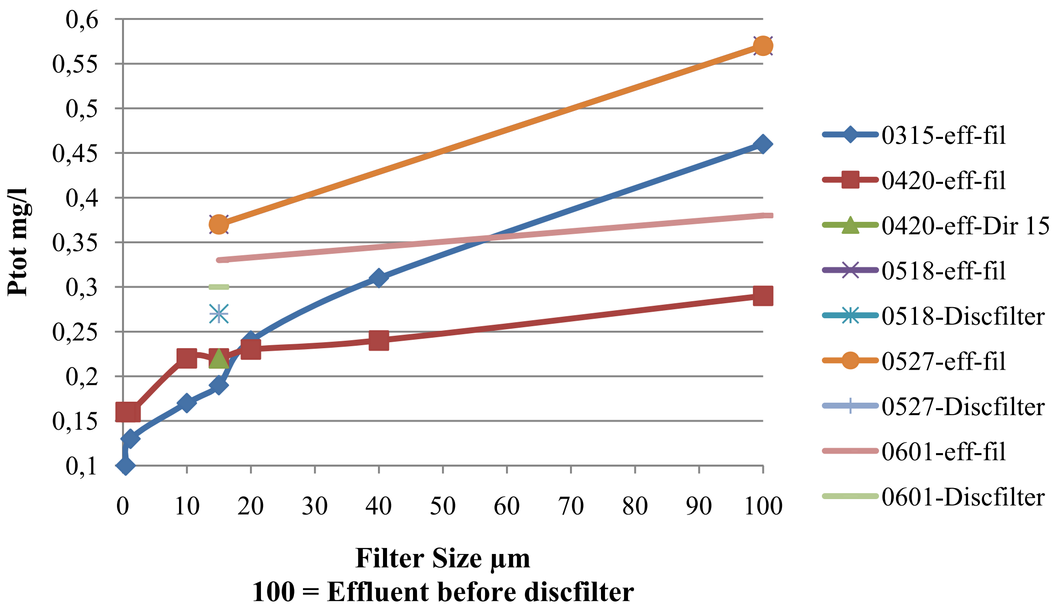

Figure 11.1 Different concentrations of Ptot in effluent before and after discfilter in experiment 1 to 5.

12 Appendix E: Results of Ntot Measurements

Table 12.1 Result of Ntot in experiment 1.

Filter Size µm	Ntot (mg/l)	Reduction (%)	Difference (mg/l)
100	17,63	0	0
40	19,2	-8,905275099	-1,57
20	19,18	-8,791832104	0,02
15	18,77	-6,466250709	0,41
10	17,62	0,056721497	1,15
1,2	16,02	9,132161089	1,6
0,45	15,51	12,02495746	0,51

Table 12.2 Result of Ntot in experiment 2.

Filter Size µm	Ntot (mg/l)	Reduction (%)	Difference (mg/l)
100	18,9	0	0
40	18,4	2,645502646	0,5
20	18,7	1,058201058	-0,3
15	18,3	3,174603175	0,4
10	18,4	2,645502646	-0,1
1,2	18	4,761904762	0,4
0,45	17,8	5,82010582	0,2
Direct 15	18,5	2,116402116	5,9

Table 12.3 Result of Ntot in experiment 3.

Filter Size µm	Ntot (mg/l)	Reduction (%)	Difference (mg/l)
100	12,8	0	0
15	12,4	3,125	0,4
15-DF	3,7	71,09375	9,1

Table 12.4 Result of Ntot in experiment 4.

Filter Size µm	Ntot (mg/l)	Reduction (%)	Difference (mg/l)
100	16	0	0
15	15,5	3,125	0,5
15-DF	7,43	53,5625	8,57

Table 12.5 Result of Ntot in experiment 5.

Filter Size µm	Ntot (mg/l)	Reduction (%)	Difference (mg/l)
100	12	0	0
15	11,7	2,5	0,3
15-DF	4,02	66,5	7,98

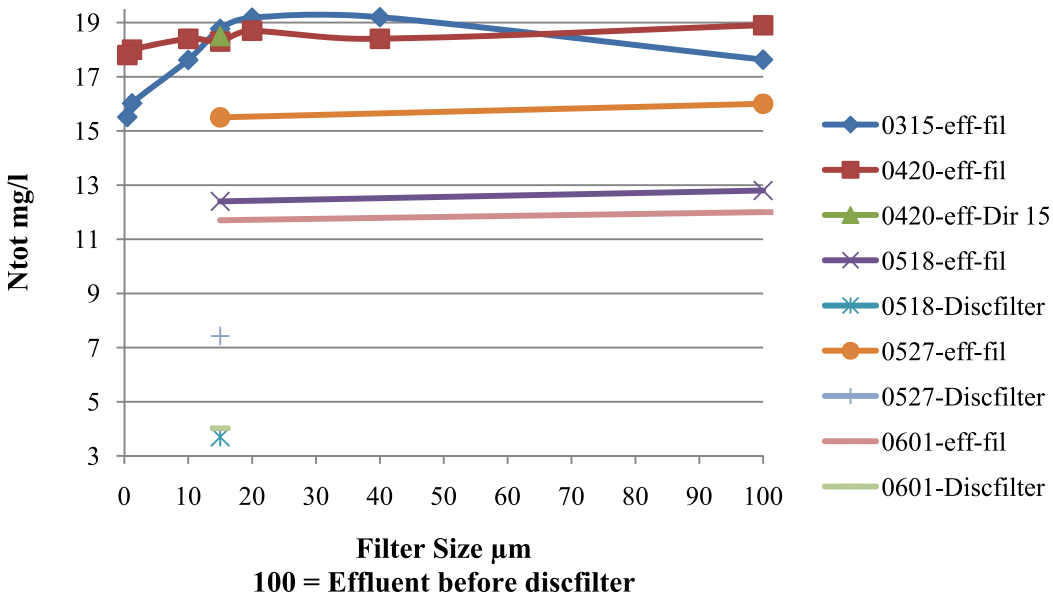

Figure 12.1 Different concentrations of Ntot in effluent before and after discfilter in experiment 1 to 5.

13 Appendix F: Microbial Analysis

Table 13.1 Results of Coliform analysis for 3 different samples and after 3 different treatments.

	Treatment method	100-Unfiltered	15 µm-Filtered	15 µm-Direct
Coliform ant/100ml	No treat	240000	170000	140000
	Mechanical	140000	120000	200000
	Sonication	240000	130000	160000

Table 13.2 Results of E. Coli analysis for 3 different samples and after 3 different treatments.

	Treatment method	100-Unfiltered	15 µm-Filtered	15 µm-Direct
E. Coli ant/100ml	No treat	65000	52000	39000
	Mechanical	34000	49000	37000
	Sonication	41000	37000	46000

Table 13.3 Results of Entrococcous analysis for 3 different samples and after 3 different treatments.

	Treatment method	100-Unfiltered	15 µm-Filtered	15 µm-Direct
Entrococcous CFU/100ml	No treat	13000	7900	8000
	Mechanical	17000	11000	11000
	Sonication	9900	7200	11000

Table 13.4 Results of Clostridium analysis for 3 different samples and after 3 different treatments.

	Treatment method	100-Unfiltered	15 µm-Filtered	15 µm-Direct
Clostridium CFU/100ml	No treat	5200	2300	2800
	Mechanical	3800	2700	3300
	Sonication	4400	2100	2800

14 Appendix G: Results of Turbidity Measurements

Table 14.1 Results of Turbidity measurements in experiment 1.

Filter Size µm	Turbidity (NTU)
100	10,9
40	8,5
20	6,2
15	5,2
10	4,8

Table 14.2 Results of Turbidity measurements in experiment 2.

Filter Size µm	Turbidity (NTU)
100	3,9
40	3,35
20	3,25
15	2,66
10	2,48
1,2	1,9
0,45	1,7
Direct 15	2,85

Table 14.3 Results of Turbidity measurements in experiment 3.

Filter Size µm	Turbidity (NTU)
100	8,8
15	3,2
15-DF	3,6

Table 14.4 Results of Turbidity measurements in experiment 4.

Filter Size µm	**Turbidity (NTU)**
100	3
15	3,7
15-DF	4,8

Table 14.5 Results of Turbidity measurements in experiment 5.

Filter Size µm	**Turbidity (NTU)**
100	2,4
15	2,1
15-DF	1,6

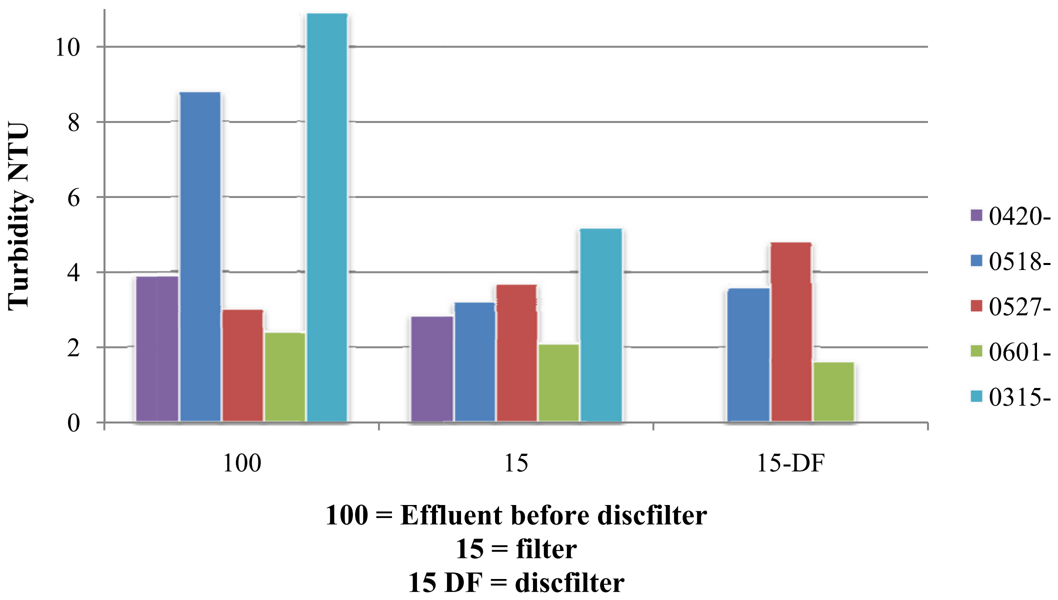

Figure 14.1 Differences of turbidity in effluent before and discfilter in experiment 1 to 5.

15 Appendix H: N:P ratio

Table 15.1 N:P ratio in experiment 1.

Filter Size µm	Ntot (mg/l)	Ptot (mg/l)	N/P ratio
100	17,63	0,46	38,32608696
40	19,2	0,31	61,93548387
20	19,18	0,24	79,91666667
15	18,77	0,19	98,78947368
10	17,62	0,17	103,6470588
1,2	16,02	0,13	123,2307692
0,45	15,51	0,1	155,1

Table 15.2 N:P ratio in experiment 2.

Filter Size µm	Ntot (mg/l)	Ptot (mg/l)	N/P ratio
100	18,9	0,29	65,17241379
40	18,4	0,24	76,66666667
20	18,7	0,23	81,30434783
15	18,3	0,22	83,18181818
10	18,4	0,22	83,63636364
1,2	18	0,16	112,5
0,45	17,8	0,16	111,25
Direct 15	18,5	0,22	84,09090909

Table 15.3 N:P ratio in experiment 3.

Filter Size µm	Ntot (mg/l)	Ptot (mg/l)	N/P ratio
100	12,8	0,57	22,45614035
15	12,4	0,37	33,51351351
15-DF	3,7	0,27	13,7037037

Table 15.4 N:P ratio in experiment 4.

Filter Size µm	Ntot (mg/l)	Ptot (mg/l)	N/P ratio
100	16	0,57	28,07017544
15	15,5	0,37	41,89189189
15-DF	7,43	0,27	27,51851852

Table 15.5 N:P ratio in experiment 5.

Filter Size µm	Ntot (mg/l)	Ptot (mg/l)	N/P ratio
100	12	0,38	31,57894737
15	11,7	0,33	35,45454545
15-DF	4,02	0,3	13,4

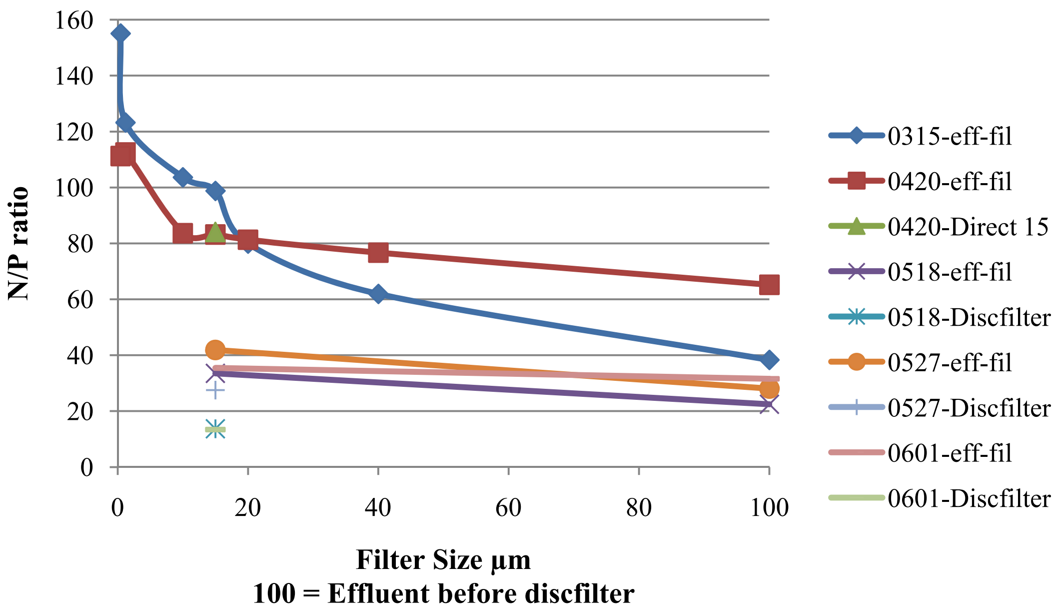

Figure 15.1 The results of N:P ratio in experiment 1 to 5.

16 Appendix I: TSS correlation with COD, Ptot and Ntot

For the full details and related tables and dataset of COD, P and N in all experiments check Appendix C (Chapter 10), D (Chapter 11) and E (Chapter 12), respectively.

Table 16.1 SS ratio with COD, N and P in experiment 1.

Filter Size µm	SS/COD	SS/Ntot	SS/ptot
100	0,241	0,786	30,124
40	0,173	0,461	28,571
20	0,074	0,179	14,286
15	0,068	0,160	15,789
10	0,047	0,138	14,286

Table 16.2 SS ratio with COD, N and P in experiment 2.

Filter Size µm	SS/COD	SS/Ntot	SS/Ptot
100	0,107	0,242	15,764
40	0,070	0,171	13,095
20	0,047	0,115	9,317
15	0,044	0,101	8,442
10	0,038	0,085	7,143
Direct 15	0,049	0,108	9,091

Table 16.3 SS ratio with COD, N and P in experiment 3.

Filter Size µm	SS/COD	SS/Ntot	SS/Ptot
100	0,053	0,636	14,286
15	0,021	0,276	9,266
15-DF	0,030	0,927	12,698

Table 16.4 SS ratio with COD, N and P in experiment 4.

Filter Size µm	SS/COD	SS/Ntot	SS/Ptot
100	0,050	0,156	4,386
15	0,034	0,097	4,054
15-DF	0,210	1,413	38,889

Table 16.5 SS ratio with COD, N and P in experiment 5.

Filter Size µm	SS/COD	SS/Ntot	SS/Ptot
100	0,133	0,333	10,526
15	0,070	0,256	9,091
15-DF	0,043	0,622	8,333

17 Appendix J: Experiment 2

Results of experiment two ensured this fact that the result of direct filtration through 15 µm filter and step by step filtration from 40 µm to 20 µm, and 15 µm were very close to one another, consequently it came to a decision of using direct filtration by the use of 15 µm filter.

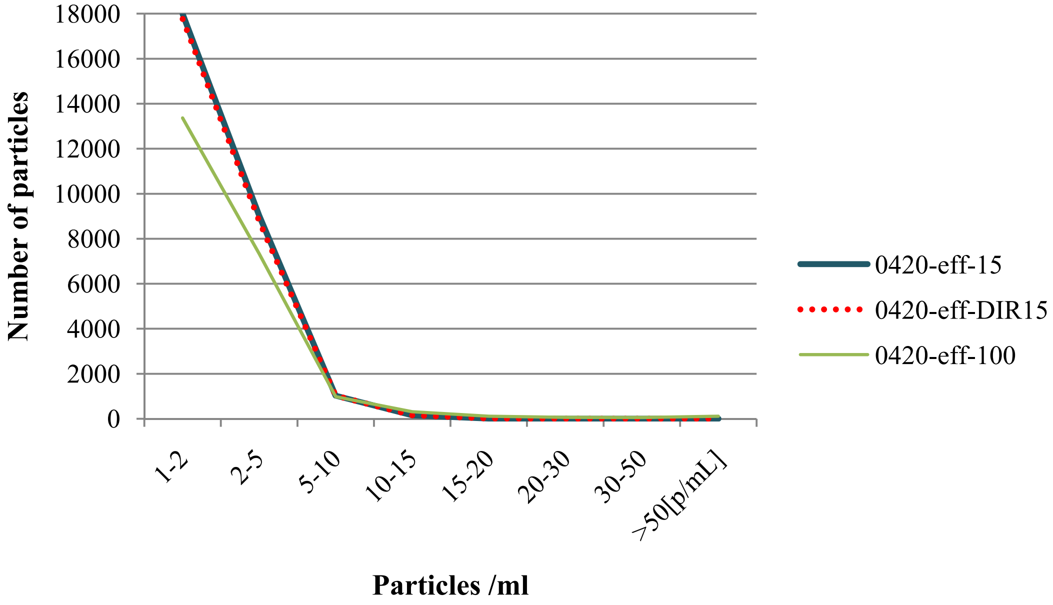

Figure 17.1 Result of PSA in experiment 2 illustrates there is a negligible difference between direct 15 µm filtration and step by step to 15 µm filtration.

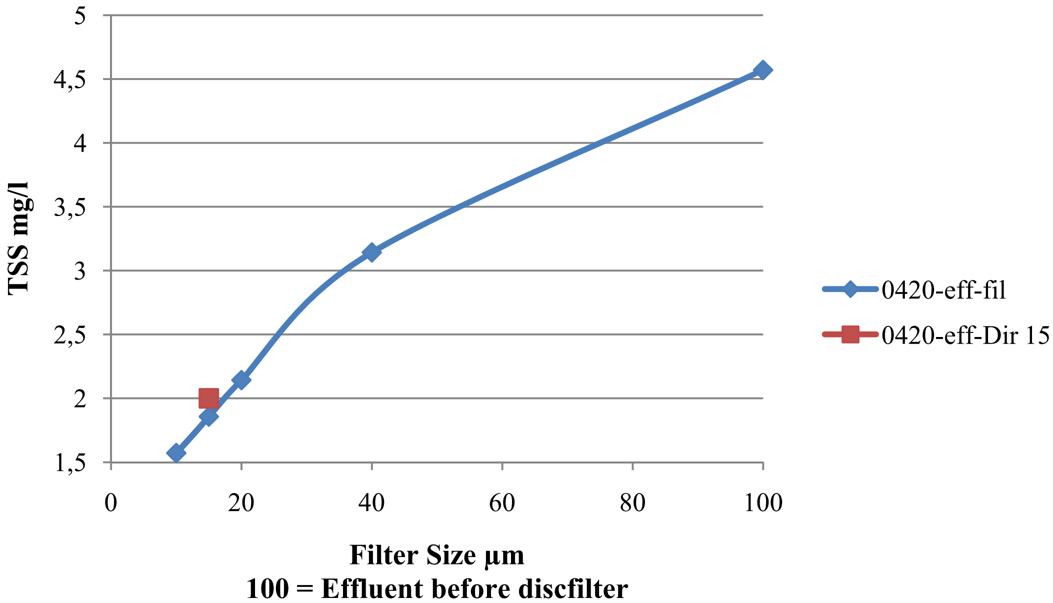

Figure 17.2 Result of TSS in experiment 2 illustrates there is a negligible difference between direct 15 µm filtration and step by step to 15 µm filtration.

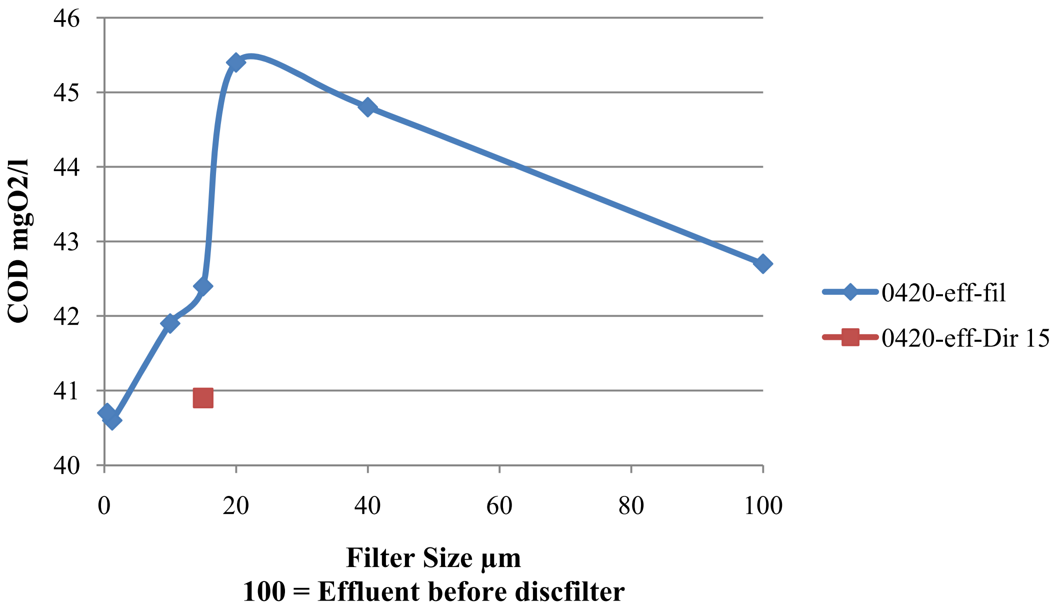

Figure 17.3 Result of COD in experiment 2 illustrates there is a negligible difference between direct 15 µm filtration and step by step to 15 µm filtration.

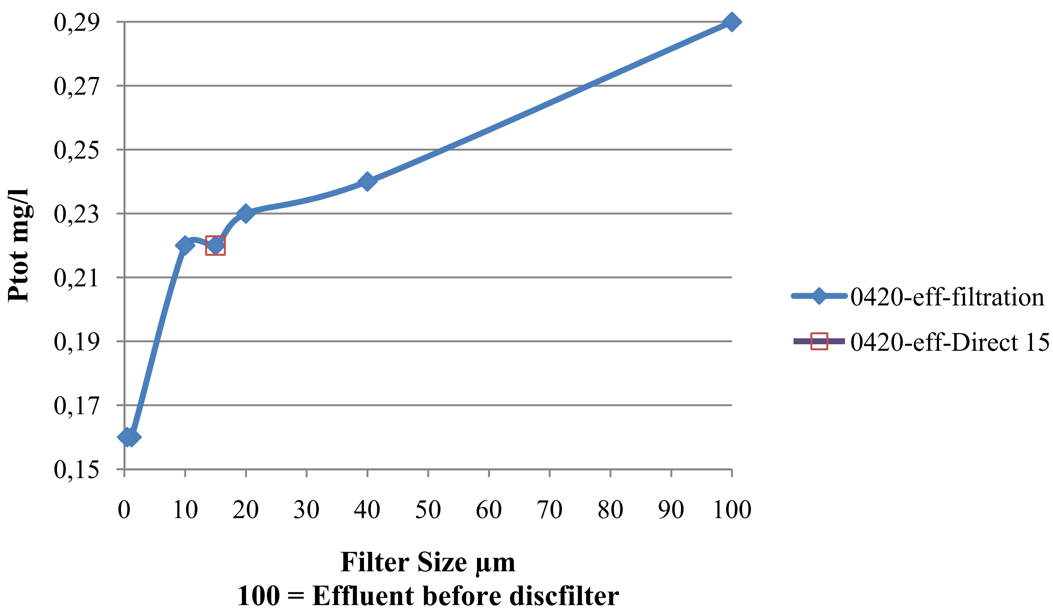

Figure 17.4 Result of Ptot in experiment 2 illustrates there is a negligible difference between direct 15 µm filtration and step by step to 15 µm filtration.

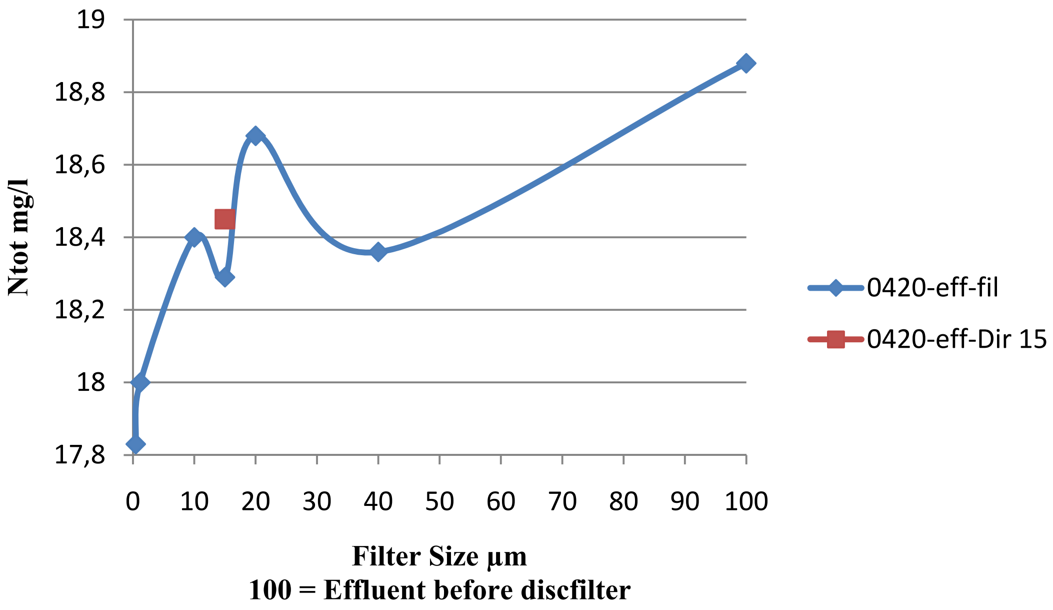

Figure 17.5 Result of Ntot in experiment 2 illustrates there is a negligible difference between direct 15 µm filtration and step by step to 15 µm filtration.

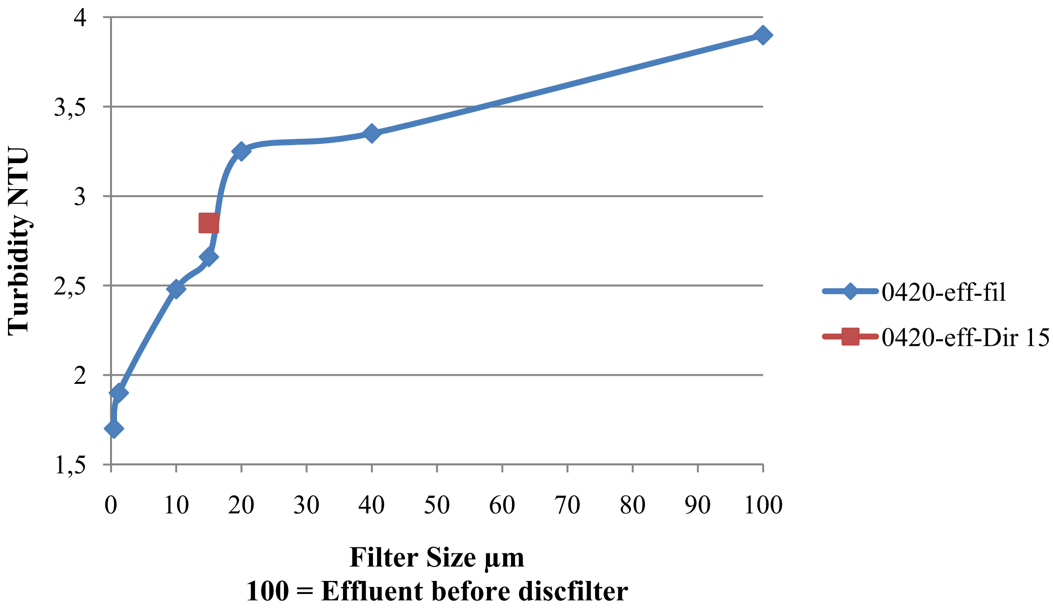

Figure 17.6 Result of Turbidity in experiment 2 illustrates there is a negligible difference between direct 15 µm filtration and step by step to 15 µm filtration.