CHALMERS

Assessing the Performance of the Discfilters at the Rya Wastewater Treatment Plant in Gothenburg

Master of Science Thesis in the Master's Programme Environmental Measurement and Assessment

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Abstract

Stricter discharge limits for phosphorous and nitrogen has made it necessary for many wastewater treatment plants to be upgraded for tertiary treatment. Less footprint, lower head loss and less expensive investment costs are features of discfilters which has made it the preferable choice for tertiary treatment at many places in the world.

The seasonal performance variation of the discfilters at the Rya wastewater treatment plant was assessed using full-scale data from July2009 to November 2011. Particle distribution analysis was performed eight times from February to November in 2011 in order to investigate separating efficiency of the discfilters for particles in different size ranges. Wastewater fractionation analysis was done to characterize the wastewater from different points of the WWTP.

The discfilters were efficient for removing total phosphorous and total suspended solids. The discfilters reduced the concentration of total phosphorous and total suspended solids to lower level in the winter and beginning of the spring even if discharge limits were met in very few days.

The discfilters were efficient for blocking big particles in the size range 15-50µm. However, there were more small particles (1-10µm) present in the effluent of the discfilters. Opposite trends were found between the big and small particles in the some samples from the influent of the discfilters.

The fractionation analysis indicated that the cloth filters (40, 20, 15 an10µm) and filter papers (1.2 and 0.45 µm) are more efficient for removing P_{tot} and TSS from the wastewater of the effluent from the moving bed biofilm reactor than wastewater from the secondary settler. The cloth filters and filter papers showed the same particle separation efficiency for the wastewater from the sampling points above. However the separation efficiency for small particles was more negative for the wastewater from the MBBR than the other sampling points. The concentrations of total organic carbon, chemical oxygen demand and total nitrogen did not significantly decrease through the fractionation analysis.

Key words: Discfilters, Micro screenig, Wastewater treatment

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ACRONYMS

COD	Chemical Oxygen Demand
DFB	DiscFilter Building
MBBR	Moving Bed Biofilm Reactor
N_{tot}	Total Nitrogen
P_{tot}	Total Phosphorous
PDA	Particle Distribution Analysis
SSVI	Stirred Sludge Volume Index
ES-Channel	Secondary Settling Channel
TSS	Total Suspended Solid
TOC	Total Organic Carbon
WWTP	Wastewater Treatment Plant

1. Introduction

Particle separation is the most essential part of wastewater treatment since most pollutants are bound to particles. For most treatment plants it is hard to reach phosphorous concentrations below 0.3 mg P/l and suspended solids concentrations below 5 mg SS/l without some kind of filtration steps. Stricter discharge limits for phosphorous and nitrogen has made it necessary for many wastewater treatment plants to be upgraded for tertiary treatment (Wilén et al. , 2011). Micro screening has been the choice for tertiary treatment in many countries around the world.

Micro screening is a simple physical process where particles larger than the aperture of the filter are separated when wastewater is treated (Persson, et al., 2006). Discfilter is a type of micro screening filtration equipment which consists of several consecutive discs, where each disc is formed by combination of several sectors of filter media. Different cloth media with different pore size (40-10µm) are attached on the sectors. The cloth media works as surface filters where particles larger than the pore size are restrained.

Less footprint, lower head loss and lower cost are the features of discfilters which have made it the preferable choice for micro screening in many places in the world (Grabbe et al., 1998). Several studies have shown that discfilters have high performance for removing particles larger than 18µm (Persson et al., 2006; (Wilén et al., 2011). Different types of cloth media discfilters have been applied for wastewater treatment in Europe since 1978 and in the United States since 1992 (Bourgeous, et al., 2003).

Separation efficiency can be increased by applying small pore size discfilters, however this may cause filter clogging and less capacity for hydraulic load. Therefore, mainly discfilters with pore sizes 10 to 30µm or larger has been applied around the world (Bourgeous, et al., 2003). Common micro screening efficiency for removing suspended solid is on an average 55 percent and the most common problems are incomplete solid reduction and solid fluctuation (Tchobanoglous et al., 2004).

1.1 Background

The Rya Wastewater Treatment Plant (Rya WWTP) was built 1974 and treats domestic wastewater from 830000 population equivalents from the Gothenburg area. It is run by Gryaab AB which is a company owned by seven municipalities in the Gothenburg area: Ale, Gothenburg, Härryda, Kungälv and Lerum. The average flow is 4.32 m^3/d, and nitrogen is removed by pre-denitrification in activated sludge and post-nitrification in a trickling filter as shown in Figure 1 below. Phosphorus is removed by chemical precipitation (pre-precipitation or simultaneous precipitation) by addition of iron sulphate. Since the discharge limits for both phosphorus and nitrogen has become stricter; from 0.5 to 0.3 mg P/l and from 15 to 10 mg N/l respectively, the plant had to be extended. In June 2010, the treatment plant was upgraded for tertiary treatment by applying 32 discfilters to reduce the concentration of suspended solids and phosphorous in the effluent wastewater (Figure 1). To increase the removal efficiency for nitrogen, a post-denitrification (moving bed biofilm reactor) step was installed which treats a part of the effluent from the nitrifying trickling filters. The discfilters have shown good performance for removing phosphorus and suspended solid based on previous studies (Behzadirad, 2010; Johansen 2012).

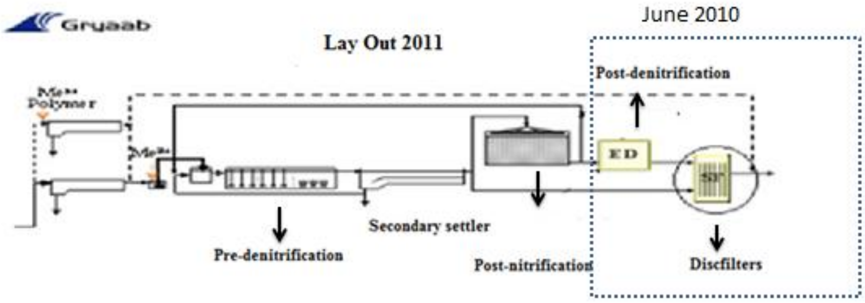

Figure 1 Schematic layout of the Rya Wastewater Treatment Plant in Gothenburg

1.2 Aim

The aim of this study is to investigate the performance of the full scale discfilters in more detail and to assess whether seasonal performance variations occur by using the full scale data from July 2009 to November 2011 and particles distribution analysis.

Characterization of the effluent wastewater from the secondary settlers as well as the effluent from the post-denitrification unit were performed by test filtration through cloth filters of different pore sizes.

2. Particle Characterization

Particles exist in any water in different size ranges and amounts. Organic materials and nutrients in the wastewater are mostly bound to particulate matter. In the wastewater treatment plant, particles are removed by physical-chemical pre-treatment, bio-flocculation, coagulation and sedimentation (Nieuwenhuijzen, 2002). The information about the particles in the wastewater is critical when assessing the performance of wastewater treatment processes such as secondary sedimentation, tertiary treatment and effluent disinfection (Bourgeous et, al., 2003), (Tchobanoglous, et al., 2004). From a recent study (Nieuwenhuijzen, 2002), total phosphorous and COD are more attached to the particles in size ranges 5 to 63µm where as total nitrogen is more attached to the particles smaller than 0.1µm which can be considered as dissolved form.

Tertiary treatment is a further treatment step after primary and secondary treatment processes; the purpose is additional removal of colloidal and suspended solids. Chemical coagulation and granular medium filtration are the most common methods. Micro screening is an alternative to granular medium filtration which has been used in many wastewater treatment plants for the purpose of tertiary treatment.

2.1 Discfilters

The Rya wastewater treatment plant was upgraded in June 2010 for tertiary treatment by installing discfilters at the end of the treatment process. This is the largest discfilters installation in the world; 32 discfilters, HSF 2600 series, are installed and they daily treat 864000 m^3 of wastewater and the filter pore size is 15µm (Hydrotech, 2010).

The wastewater after secondary treatment is introduced to the centre drum by gravity as shown in Figure 2. The wastewater is filtered through from inside to outside of the each disc. The captured solids on the filter impede the water flow, the water level increases and backwashing starts by water level sensors. The backwashed water is reintroduced to the secondary treatment system of the plant (activated sludge tank).

Figure 2 Discfilters Series HSF 2600

Recent research by Persson, et al. (2006) has found that discfilters in pore size 10 and 18μm can separate particles larger than the opening size of discfilters with an efficiency of 90 %. The discfilters has shown better efficiency for the wastewater from post-denitrifying Moving Bed Biofim process (Persson, et al., 2006). High removal efficiency has also been found for the particles which are bigger than the discfilters opening size in the studies by Wilén, et al (2011).

3. Method

The whole experimental work consists of three parts; 1) full scale data analysis, 2) particle distribution analysis, and 3) wastewater fractionation analysis.

3.1 Full Scale Data Analysis

The data from July 2009 to November 2011 was provided by Gryaab AB. The data included both on-line measurements (logged as hourly average based on 6 minute measurement data) and daily laboratory process measurements. In this work parameters judged as important for the seasonal performance of the discfilters operation were chosen for further analysis: effluent total suspended solid (TSS) concentrations, effluent total phosphorous (P_{tot}) concentrations, effluent chemical oxygen demand (COD) and stirred sludge volume index (SSVI).

3.2 Particle Distribution Analysis (PDA)

The numbers of different sized particles in the different samples were obtained by using a Water Particle Counter (WPC 1000, ARTI, Art Instrument, Inc.). The equipment can measure particles in the size range 1-400μm and is based on light extinction by exposing the particles to a laser beam. The sample is pumped into a sensor that can measure a maximum of 25000 particles/ml and is calibrated for a flow of 50 ml/min. As the instrument can measure high particle concentrations, the samples did not need any dilution before measurement.

Eight particle size intervals were measured in this study; 1-2, 2-5, 5-10, 10-15, 15-20, 20-30, 30-50, >50 µm. These intervals ware judged as the most appropriate to measure by a previous study (Johansen, 2012). WPC was connected to a data logger and consequently to a computer and the software Easy View 5.0 was used to display the measurement in figures and numbers. Due to limitations of the data-logger, only four channels could be logged during the measurements. The samples were analyzed immediately after sampling. The samples were carefully placed in a 1 liter jar with very slow stirring (magnetic stirring) just to keep the particles floating. When the particle number in the instrument had stabilized the measurements were taken. Between each measurement, the instrument was cleaned with milli Q water to reach particle numbers < 200 particles/ml in the 1-2 µm size intervals.

A pump was placed after the measurement detector so that the particles did not break up. The pump flow was checked regularly and found to be very stable (membrane pump). The particles could be disrupted during the transportation through the plastic tube. However, previous measurements indicated that this effect was marginal (Johansen, 2012).

The particle removal efficiency (E) was calculated for discfilters by the formula below.

$$E = (x1 - x2)/x1 \times 100$$

$x1 =$ Particle number in non-filtered water

$x2 =$ Particle number in filtered water

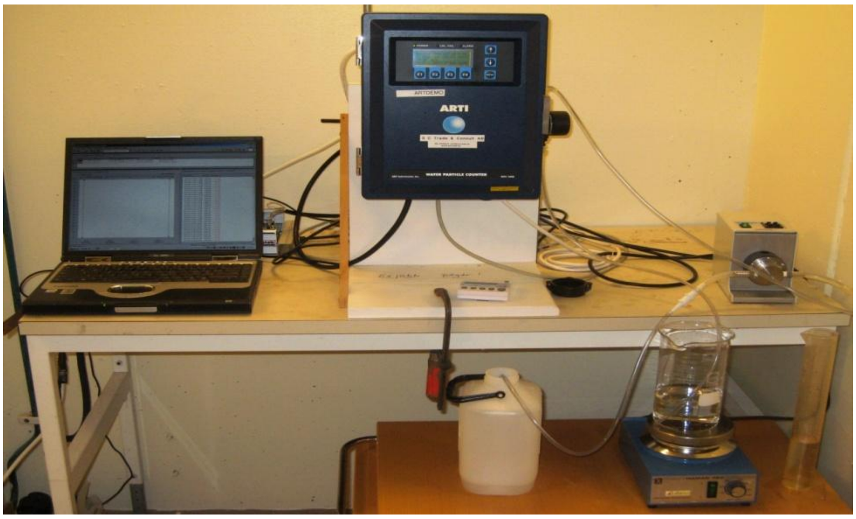

Figure 3 Water Particle Counter (WPC 1000)

3.3 Wastewater Fractionation Analysis

The pore size of the discfilters in the treatment plant is 15 µm. The same filter material, cloth filters, in size ranges 40, 20, 15, 10µm, and filter papers 1.2, 0.45 µm was tested for the removal of different pollutants. Apparently, the smaller is the pore size of cloth filter the better the performance is. However, water clogging happens with small pore size cloth filers. Therefore, the proper size ranges should be chosen based on the operation situations and removal targets.

Theoretically, only particles smaller than the pore size of the cloth filters can pass during filtrations. In reality, the particles are not completely spherical and therefore particles larger than the pore size can pass. Some flocculation/break-up of the particles in the measurement jar could also occur.

The samples were filtered through 40, 20, 15, 10µm cloth filters, and filter papers 1.2 and 0.45µm separately as shown in Figure 4. The fractionations of 40, 20, 15, 10µm were made at the treatment plant and the fractionations of 1.2 and 0.45µm were made in the laboratory at Chalmers at the same day of sampling. The fractionated samples were analyzed for chemical oxygen demand (COD), total organic carbon (TOC), total suspended solids (TSS), total phosphorous (P_{tot}), total nitrogen (N_{tot}) and particle distribution analysis (PDA).

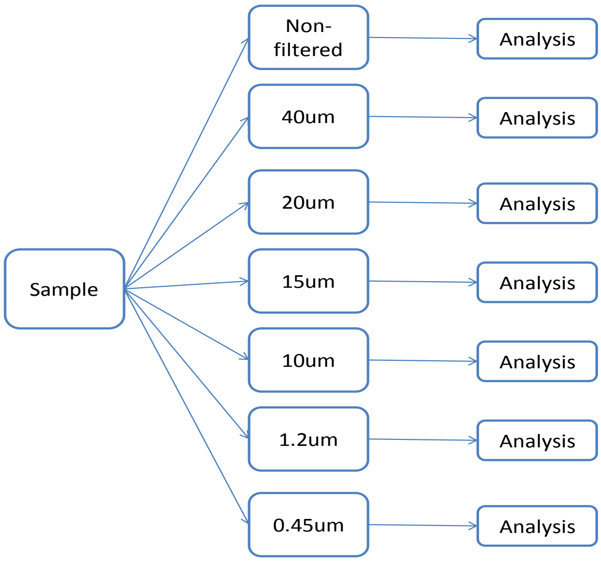

Figure 4 Schematic explanation of fractionation analysis

In order to characterize the different wastewater, the samples were taken from 3 different points as shown in Figure 5.

- The channel from the effluent from the secondary settlers (ES-channel).
- The effluent from the moving bed biofilm reactor (MBBR).
- The mixed effluent sample from the discfilters building (DFB).

For the purpose of comparing the removal efficiency of discfilters with test cloth filters, samples were also taken from the influent and effluent of two specific discfilters. They were not fractionated, but analyzed for the same parameters. The discfilters in the South part are mainly fed with the wastewater from the secondary settlers; the discfilters in the North part are mainly fed with the wastewater from the post-denitrification unit (the moving bed biofilm reactor).

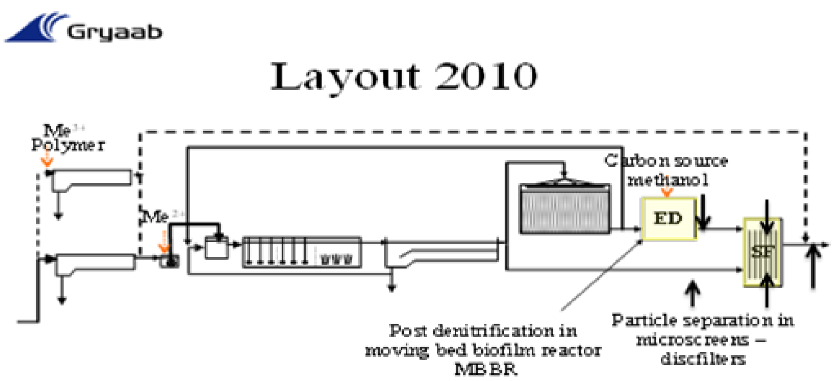

Figure 5 Fractionation analysis sampling points

A Perspex tube as shown in Figure 6 was used for fractionation. The test filters were attached by a rubber connection devise in the bottom of the tube. The fractionation tube had to be hold in 45° angle when wastewater was introduced and samples were poured slowly in order not to disturb the particles in the wastewater. The tube had to be hold in vertical position during filtration in order simulate the filtration mechanism of the full scale discfilters.

Filter clogging happened in every fractionation. Filtration was stopped after no more than 10 seconds of filtration and the sample should be re-introduced in order to demonstrate the operation of discfilters. The wastewater is introduced to each segment of the discfilters for 10 seconds with the rotation discs.

Figure 6 Wastewater fractionation tube

3.3.1 Total Phosphorous (P_{tot}) Analysis

Phosphorous present in the wastewater is mainly in the form of phosphate. Phosphorous is the limiting nutrient for most green organism in the water. Phosphates are the main contribution sources of phosphorous in domestic wastewater. They are mainly formed in biological processes and originated from body waste, food waste and washing detergents (Lenore et al., 1998).

In the effluent of the Rya wastewater treatment plant, the dissolved phosphorous concentrations is low (average values for 2011: P_{tot}=0.12±0.049 mg/l; PO_4^{-} P=0.071±0.035 mg/l)) since chemical precipitations is applied for the phosphorous treatment process and the main amount of phosphorous leaving the plant is bound to particles.

HACH spectrophotometer method was used for analysis of P_{tot}. The spectrophotometer measures the transmission and reflection properties of the solution. The concentration of the substances can be got by using Beer's law (Caprette, 2005). The colorimeter was used as shown in Figure 7 below for reading the value of P_{tot}.

Figure 7 Spectrophotometer

The different forms of phosphorous were converted to dissolve phosphate in sample by heating (120°C) the sample under the pressure and by adding a strong oxidation agent (Oxisolv). A 10 ml sample vial was filled with the sample, Phos Ver 3 phosphate Powder Pillow (HACH) was added to the vials and mixed immediately. The reaction was processed for two minutes. A blank sample was also prepared with Mili Q water for the requirement of the analysis (intensity of transmitted light through pure solvent).

3.3.2 Chemical Oxygen Demand (COD) Analysis

Chemical oxygen demand is the required amount of a specified oxidant for pollutants in water to be oxidized in controlled condition and time (Lenore, et al., 1998). HACH spectrophotometer method was also used for analysis for COD.

The samples were analyzed in duplicate. 2ml of sample was taken from every fractionated stored sample and added to COD digestion reagent vials. The vials were shaken several times and stayed in the COD reactor at temperature 150 °C for two hours. A blank sample was also prepared with Milli Q water for the requirement of the analysis (intensity of transmitted light through pure solvent). Colorimetric method was used to read COD concentration in mg per liter.

3.3.3 Total Suspended Solid (TSS) Analysis

Total suspended solids refer to the residue left on a specific pre-defined filter after filtration (Lenore, et al., 1998).

The samples were analyzed in duplicate. Only the non-filtrated sample and the fractionated samples from 40,20,15,10 µm filters were analyzed for TSS. Analyzing TSS for the fractionated samples from 1.2, 0.45 µm filter paper is not necessary because 1.2µm filter papers were used for analysis of TSS. The weight of residue left from the filtration of 1.2 µm filter paper was considered as TSS.

A filter paper of pore size 1.2 µm was weighted before analysis (Munktell, GVA). Well-mixed sample was filtered through the filter papers. The filter papers were dried in an oven at 103-105 °C**.** The increased value of the filter papers represents TSS. The formula below is used for calculation of the increased weight.

$TSS = (x - y) \div z$

$x =$ Weight of filter +dried solid

$y =$ Weight of filter

$z =$ Sample volume

3.3.4 Total Nitrogen (N_{tot}) Analysis

First, the samples are digested and mixed with a buffer solution. In a cadmium reactor, the nitrate in the samples is reduced to nitrite. The nitrite forms a diazo compound by adding an acidic Sulphanilamide solution. The diazo compound can couple with N-(1-naphty)-Ethylene Diamine Dihydrochoride and form a purple azo dye. The azo dye can be measured at 540nm.

3.3.5 Total Organic Carbon (TOC) Analysis

Carbon presents in two forms in the wastewater; organic form (OC), inorganic form (IC). The instrument used in this analysis, TOC-$V_{CPH/CPN}$ (Shimadzu), measures total carbon (TC) and inorganic carbon (IC) and the amount of total organic carbon can be got by the formula; TOC=TC-IC. The principles of measuring TC and IC are described below.

The total carbons in the sample are combusted at 680°C and oxidized to carbon dioxide by catalyst in a combustion tube. The combusted gas is carried by carrier gas and introduced to an electronic dehumidifier. The combusted gas is dehydrated in the electronic dehumidifier. Then, the combusted gas is introduced to a halogen scrubber unit to remove halogen and chlorine. The purified combusted gas was introduced to a non-dispersive infrared (NDIR) gas analyzer in final step. NDIR detect the carbon dioxide and send to TOC-Control V software.

The TOC equipment measure the carbon derived from carbonates, hydrogen carbonates and dissolved carbon dioxide as IC. By using hydrochloride acid the pH of the sample can decreased to 3 and all carbonated can be converted to carbon dioxide. The NDIR can detect the carbon dioxide.

3.3.6 Stirred Sludge Volume Index (SSVI)

Sludge volume index is a measure of the physical characteristics of activated sludge solids that refers to the occupied volume of 1g of activated sludge (as dry weight) after 30 minutes settling of the aerated liquor. Stirring is recommended for the release of entrained gases and water in the sample and to minimize wall effects. Stirred sludge volume index is normally lower than the sludge volume index.

4. Result and Discussion

4.1 Full-Scale Data Analysis for the Performance of Discfilters

4.1.1 Assessing Seasonal Performance Variations

The concentration of total phosphorous was analyzed daily in the effluent of the treatment plant. The number of days in a month when the concentration of P_{tot} was above the discharge limit (0.3 mg/l) are shown in Figure 8. The discfilters were set in operation in the treatment plant in June 2010. After the discfilters had been set in operation, the removal efficiency of the treatment plant for P_{tot} was improved. Before the discfilters were in operation, the removal efficiency of the plant for P_{tot} clearly reduced during the cold winter months. With discfilters in operations a similar trend can be seen, but the number of days when the concentration of P_{tot} was above the discharge limit was much less. It can be seen from the result that the discfilters showed good performance for phosphorous removal.

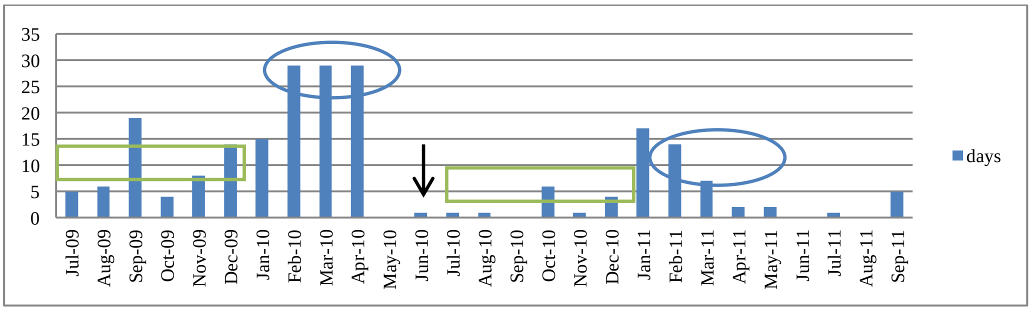

Figure 8 The number of days in a month the concentration of total phosphorous is above 0.3 mg/l in the effluent of WWTP

Figure 9 shows the number of days in a month when the concentration of total suspended solid was above the discharge limit (5mg/l). The number of days in a month the concentrations of TSS was above the limit was only marginally reduced during the months of January and February 2011 compared to previous year. However, the days when the concentration of TSS was above the limit (5mg/l) were apparently reduced in July, August, September, October and November in 2010 compare to the same time period in 2009. The result shows that the discfilters showed good performance for removing total suspended solid except in the winter.

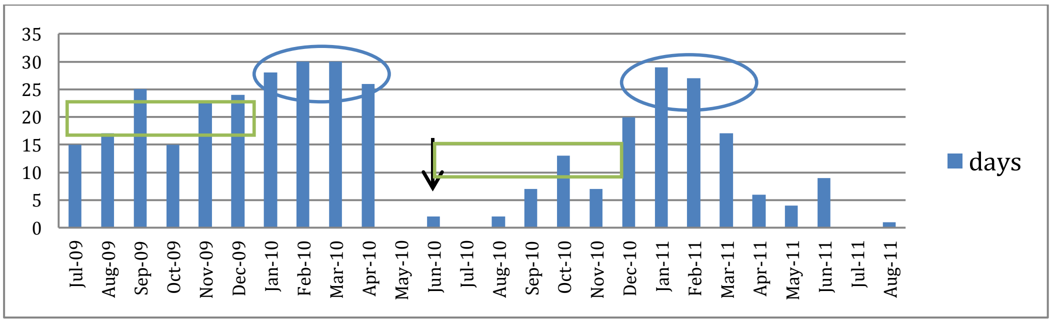

Figure 9 The number of days in a month the concentration of total suspended solid is above 5mg/l in the effluent of WWTP

The number of the days when the concentration of P_{tot} was above the limit was very high in February, March and April 2010 as shown in Figure 8. The actual concentration of P_{tot} in theses months and the same time period after the discfilters installation may provide with better information of effluent quality, therefore they are presented in Figure 10 and 11.

It can be seen from Figure 10 that the concentrations of P_{tot} were much higher at the end of February and beginning of March in 2010 compared to in April. After the discfilters installation, the concentrations of total phosphorous were decreased in same time period in 2011 as shown in Figure 11.In February 2011, there were some days when the concentrations of phosphorous were higher in the beginning of February and the concentrations decreased to the discharge limit in the rest of the month. After the discfilters installation in the plant, the concentrations of P_{tot} decreased to lower concentrations even if could not meet discharge limit in the winter.

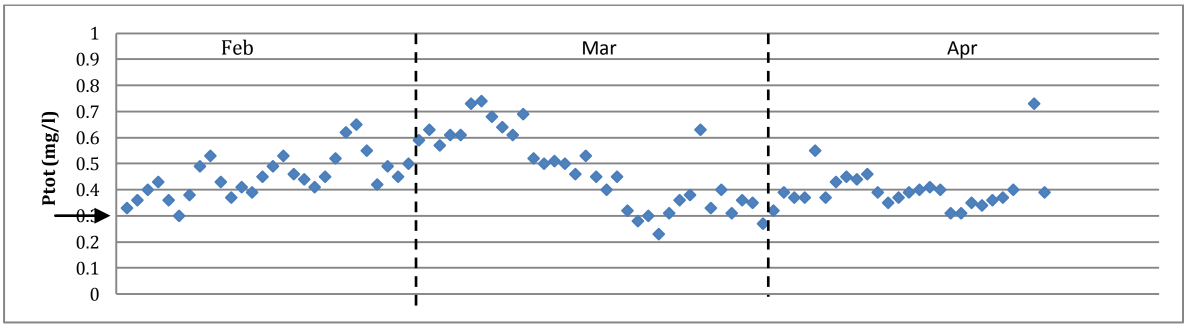

Figure 10 The concentration of total phosphorous in the effluent of WWTP in Feb, Mar, and Apr 2010

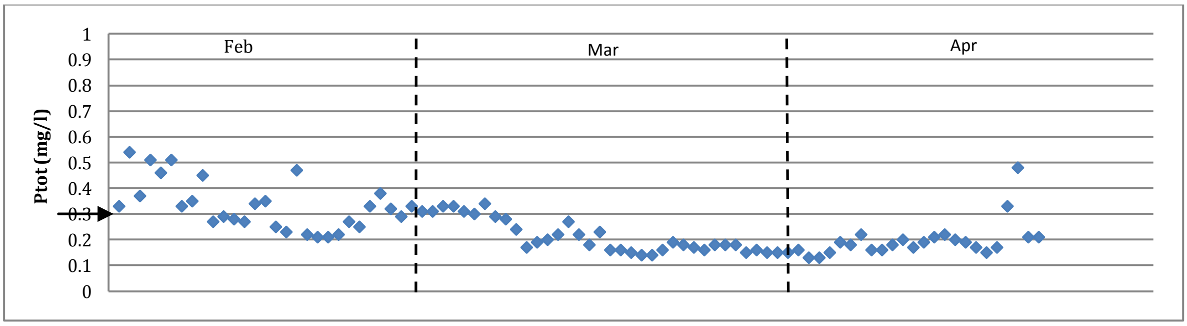

Figure 11 The concentration of total phosphorous in the effluent of WWTP in Feb, Mar, and Apr 2011

The same analysis was also made for the total suspended solids in the effluent of discfilters for the time period of January, February and March 2010, 2011. It can be seen from Figure 12 and 13 that the concentrations of TSS were increased in January and February 2011 even after the discfilters were in operations. The reason might be the cold weather interferes with the first and second treatment processes in the treatment plant. In general, the effluent quality deteriorates at the plant during the cold winter months (Wilén et al., 2011). The suspended solids might not have settled well in the settling tanks and high concentrations of suspended solids were introduced to the discfilters.

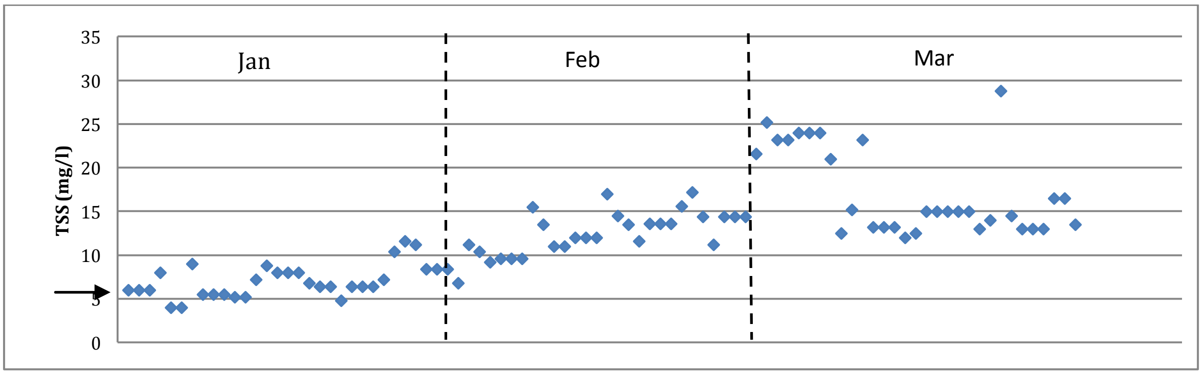

Figure 12 The concentration of total suspended solids in the effluent of WWTP in Jan, Feb and Mar 2010

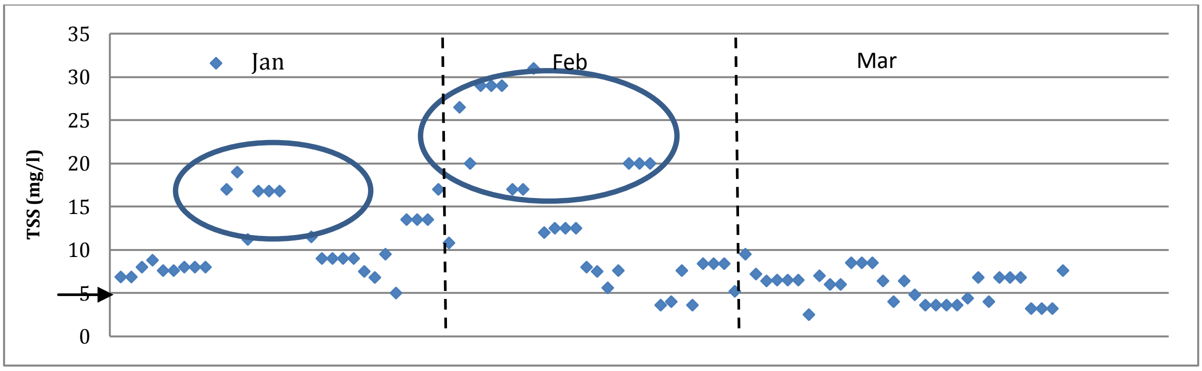

Figure 13 The concentration of total suspended solids in the effluent of WWTP in Jan, Feb and Mar 2011

4.1.2 Correlations between Total Suspended Solid and Phosphorus

Most phosphorous in the effluent water in the Rya WWTP is particle bound due to the efficient removal of orthophosphate by chemical precipitation. Total phosphorus is the sum up of all different forms of the phosphorous in the water; orthophosphate, polyphosphate and organically bound phosphorous (Tchobanoglous, et al., 2004). The main target for applying the discfilters at the Rya WWTP is to reduce the total phosphorous concentration to the new discharge limit (0.3 mg/l).

By finding correlation between total suspended solid and total phosphorous concentration, the importance of particle removal can be assessed. The correlation pattern was checked in monthly samples from June 2010 to August 2011in the effluent from the discfilters. Good correlations were found in some months, the examples shown in the Figure 14 and 15 whereas worse correlation were found for other months, they are presented in appendix (A). It can be seen the Figures 14 and 15 that there were good correlation between total suspended solid and total phosphorous. The concentration of total phosphorous and total suspended solids correlated with each other in the wastewater in this case.

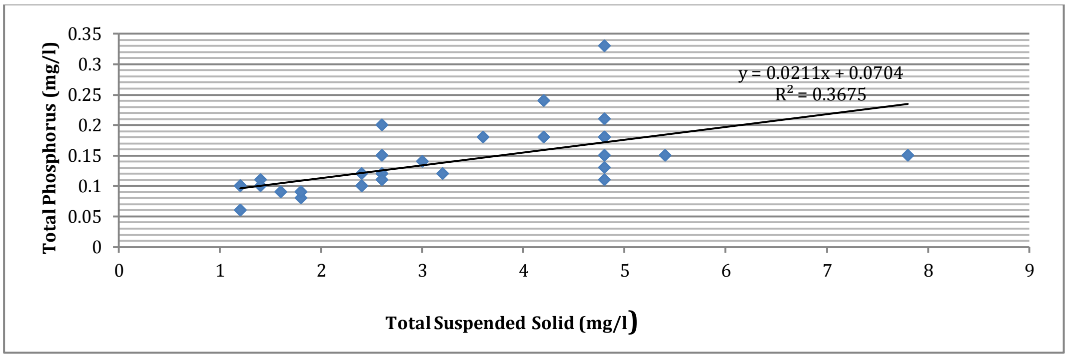

Figure 14 The correlation between total suspended solids and total phosphorous in the effluent of WWTP in Aug 2010

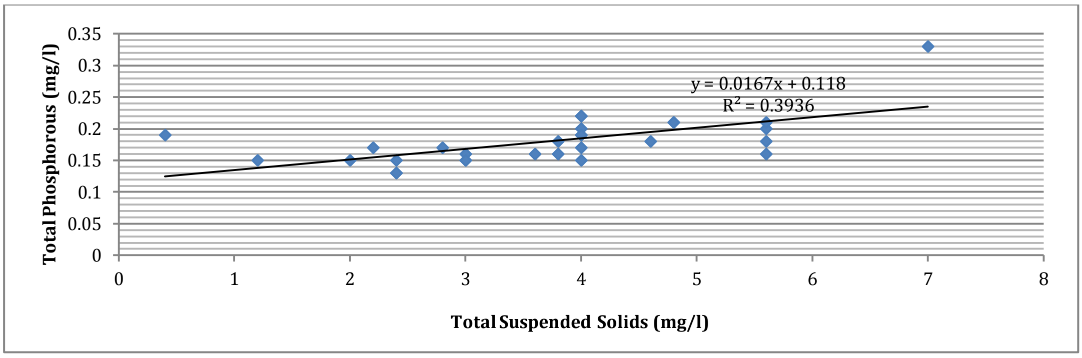

Figure 15 The correlation between total suspended solid and total phosphorous in the effluent of WWTP in Apr 2011

4.1.3 Correlations between Total Suspended Solids and Chemical Oxygen Demand

Finding the correlations between total suspended solids and chemical oxygen demand can explain if the organic matters in the wastewater are in particulate form or in the dissolved form and the importance of removing particles for treating organic matters. The correlation between total suspended solids and chemical oxygen demand was checked from June 2010 to August 2011in the effluent of discfilters. Good correlations were found in some months as Figure 16 and 17 whereas worse correlations were found for other months, they are presented in appendix (B). It can be seen from the figures that organic matters are related to suspended solids and particles removals plays an important role for removing organic matters in the wastewater at the Rya WWTP.

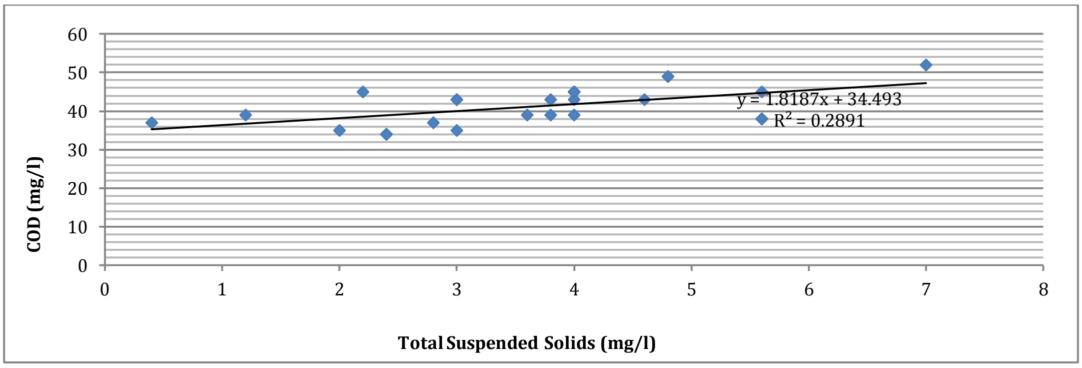

Figure 16 The correlation between total suspended solids and chemical oxygen demand in April 2011

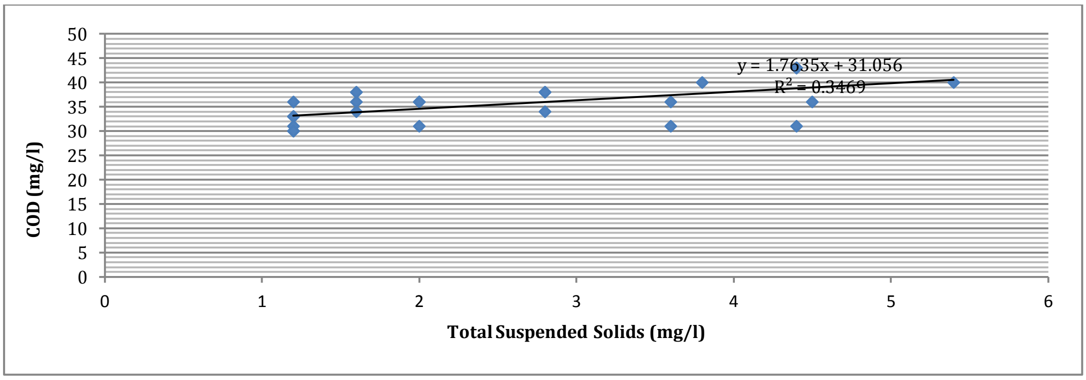

Figure 17 The correlation between total suspended solids and chemical oxygen demand in Augest 2011

4.1.4 Correlations between Total Suspended Solids and Stirred Sludge Volume Index (SSVI)

The correlation between total suspended solids and stirred sludge volume index was checked from June 2010 to August 2011. Good correlations were found in some months as July 2010 and November 2011. It can be seen the correlations that TSS in the effluent of the treatment plant is related to sludge settling ability in the wastewater at the Rya WWTP. In summary, the correlation between SSVI and TSS varies during the year and SSVI does not seem to influence the operation of the discfilters to a large extent.

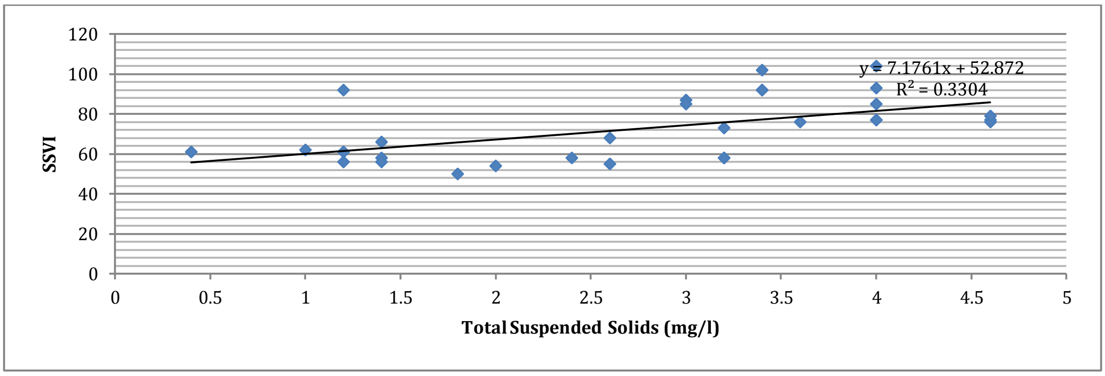

Figure 18 The correlation between total suspended solids and stirred sludge volume index in the effluent of WWTP in July 2010

Figure 19 Correlation the between total suspended solids and stirred sludge volume index in the effluent of WWTP in November 2010

4.2 Particle Distribution Analysis (PDA)

Samples were taken from the inlet and outlet of two specific discfilters in the South and North parts of the disc filter building (DFB). The discfilters in the South part are mainly fed with wastewater from the ES-channel; the discfilters in the North part are mainly fed with the wastewater from the MBBR.

Figure 20 and 21 show the removal efficiency of two specific discfilters for big particles in size ranges 15 to >50µm. Both discfilters showed high efficiency for removing big particles.

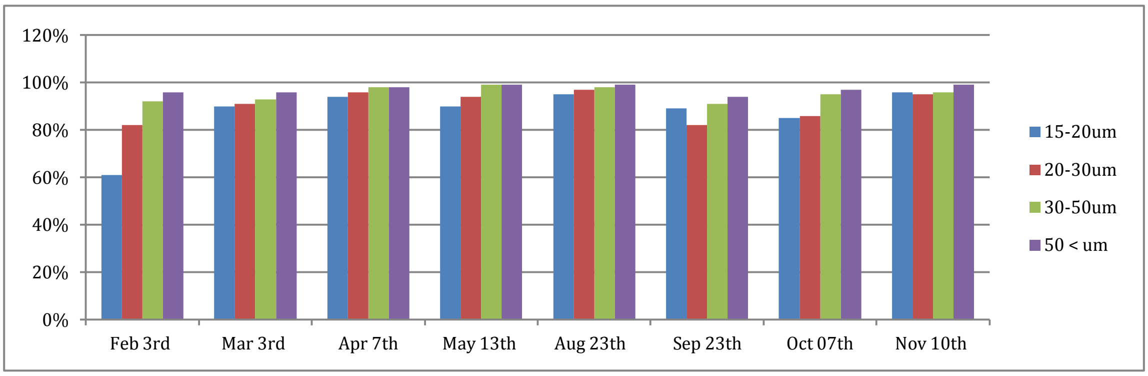

Figure 20 The removal efficiency of a specific discfilter, located in the South part of the DFB (receiving water from ES-channel), for the big particles.

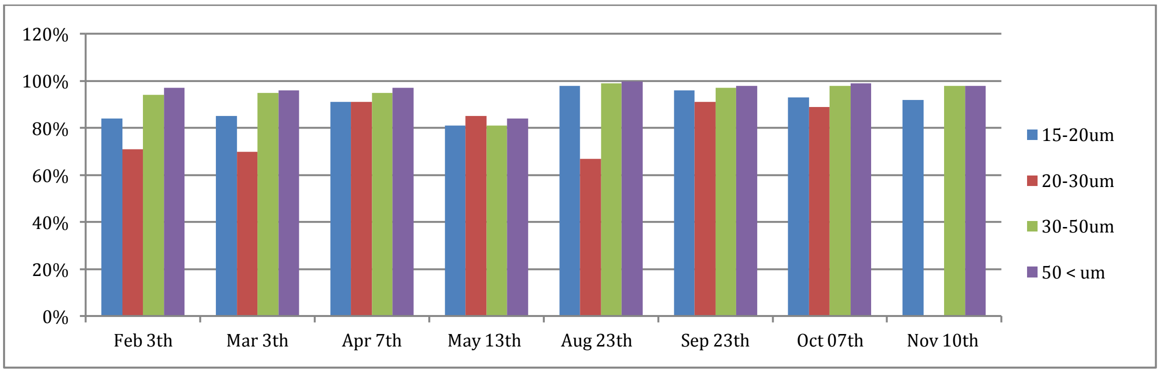

Figure 21 The removal efficiency of a specific discfilter, located in the North part of the DFB (receiving water from MBBR), for the bigger particles.

Figure 22 and 23 show the removal efficiency of two specific discfilters for the small particles in size ranges 1- 15µm. Both discfilters showed negative efficiency for removing particles 1-2, 2-5 and 5-10µm and showed good efficiency for removing particles 10-15µm. Negative efficiency means there were more particles in the effluent than in the influent. The possible explanation would be that the discfilters might break the big particles, which is bigger than the discfilters pore size 15µm, into small ones when wastewater is being filtered.

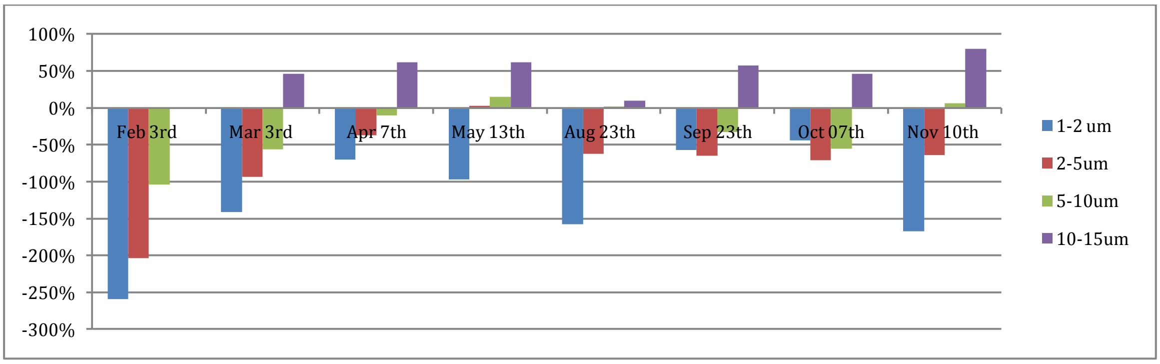

Figure 22 The removal efficiency of a specific discfilter, located in the South part of the DFB, for the smaller particles.

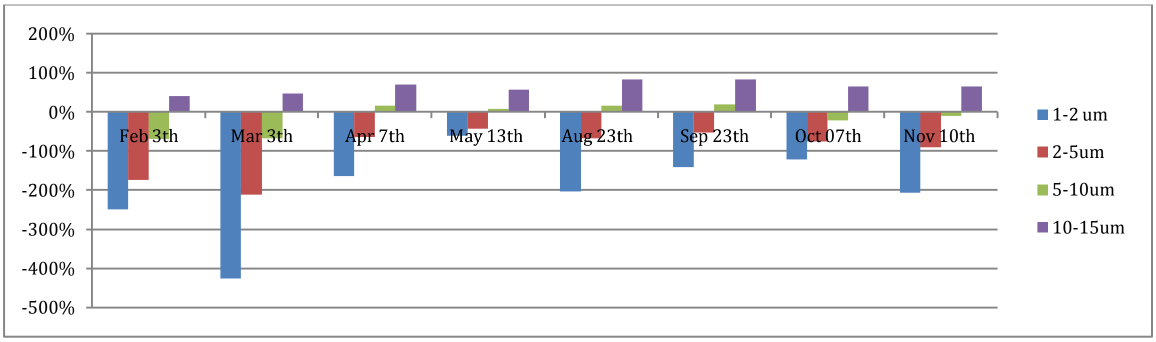

Figure 23 The removal efficiency of a specific discfilter, located in the North part of the DFB, for the smaller particles.

Figure 24 and 25 show the number of particles in size rage 1-2, 2-5µm and 20-30, 30-50, >50µm in the wastewater from the influent of a specific discfilter at the South part of discfilter building. An opposite trend can be found between the number of small particles (1-2, 2-5µm) and big particles (20-30, 30-50 and >50µm) as shown in the figures. As shown in Figure 24 the particle numbers in size range 1-2µm in September and October increased to the highest level, this may be due to the sampling was made during rainy days. In the same sampling time as shown in Figure 25, the number of particles in size range 15-20,20-30 and >50µm decreased to very few in October 7th . Similarly, with decreasing number of small particle in November the number of big particles was increased. The same trend has also been found for the wastewater from a specific discfilter in the North part of discfilter building as shown in Figure 26 and 27. The high number of small particles and less number of big particles in the wastewater from some sampling periods indicates that the big particles might disrupt into small ones. The increased numbers of small particles in the wastewater are less favorable for removal efficiency of discfilters since the pore sizes of discfilters are 15µm.

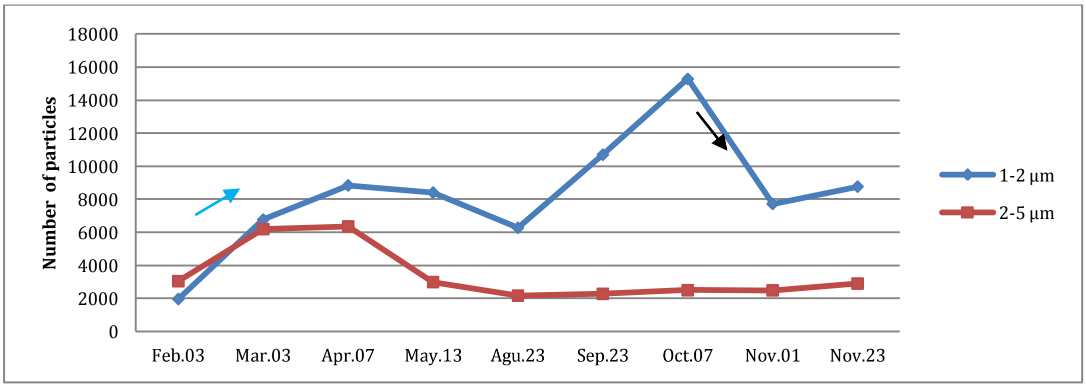

Figure 24 The number of smaller particles in the influent of a specific discfilter in the South part of DFB

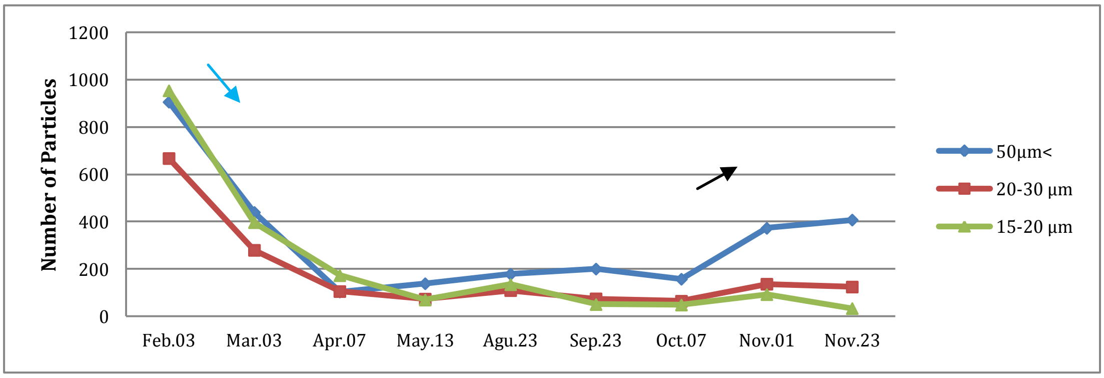

Figure 25 The number of bigger particles in the influent of a specific discfilter in the South part of DFB

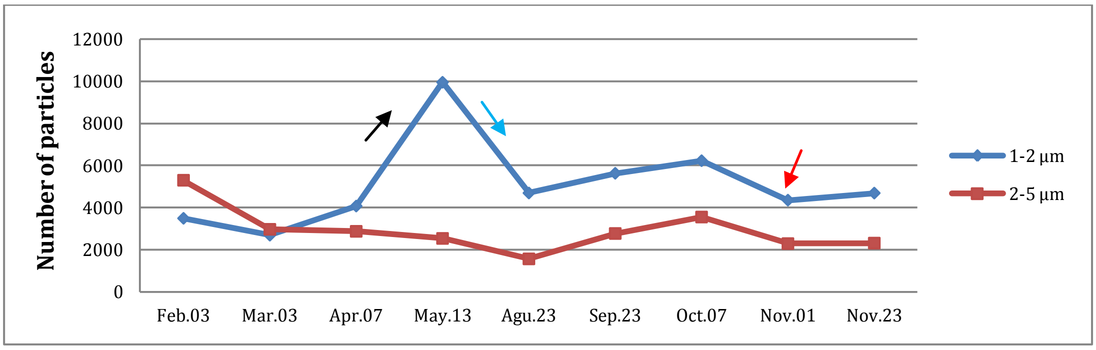

Figure 26 The number of smaller particles in the influent a specific discfilter in the North part of DFB

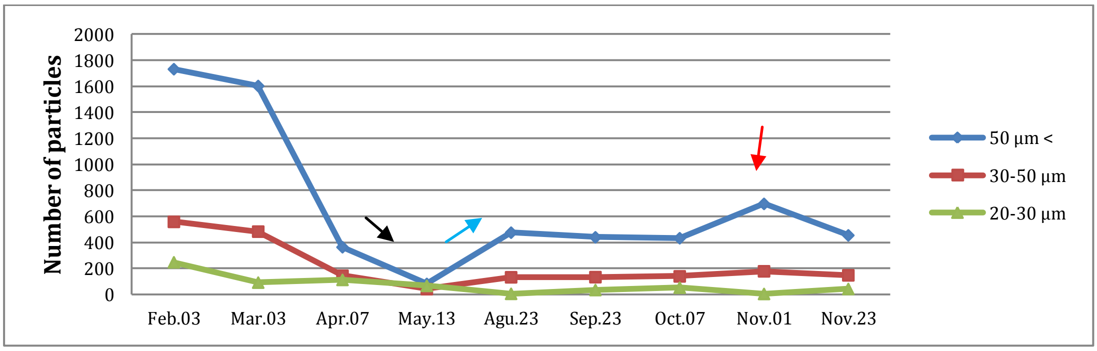

Figure 27 The number of bigger particles in the influent of a specific discfilter in the North part of DFB

4.3Wastewater Fractionation Analysis

Fractionation analysis was performed for characterization of the effluent wastewater from the secondary settlers as well as the effluent from the post-denitrification unit (MBBR). The samples from the effluent of secondary settling channel (ES-channel), MBBR, and discfilter building (DFB) were fractionated through different sized cloth filters (40, 20, 15, 10) and filter papers (1.2, 0.45 µm).

4.3.1 Total Phosphorous (P_{tot}) Analysis

As shown in Figure 28 the cloth filters were more efficient for removing P_{tot} from the wastewater of the MBBR. The phosphorous compounds in the wastewater from the MBBR might be more in particulate form than dissolved form compared with the wastewater from other sampling points. Another possible reason might be the high number of big particles (20-30, 30-50 and >50 µm) in the MBBR. It can be seen from Figure 29 that there were higher number of big particles in the MBBR than the other sampling points. This contributes to more P_{tot} removal in the wastewater from the

MBBR and the phosphorous bound to the small particles might not be removed by the fractionations in the wastewater from the ES-channel and the DFB.

As shown in Figure 28, the concentration of P_{tot} was higher in the fractionation of 10µm cloth filter than the fractionations of 15 and 20 µm cloth filters. The cloth filter 10µm should give lower values than cloth filters 15 and 20µm since smaller opening size filters can remove more P_{tot}. The lab error or mixture of samples might have happened during the fractionations and analysis.

The low concentration of total phosphorous in the non-filtered sample might be the reason for insignificant decreases in the total phosphorous concentration during the fractionations. Therefore, dry climate period is recommended for avoiding dilutions of the total phosphorous with high-flow when performing fractionation analysis.

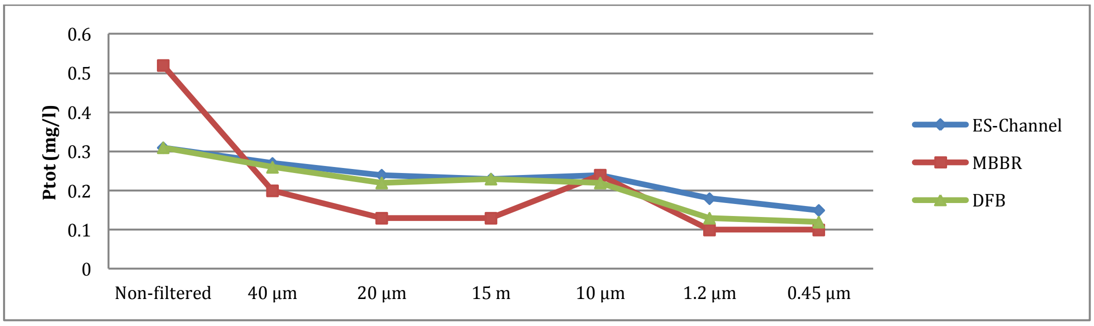

Figure 28 The concentration of total phosphorous in the effluent of ES-channel, MBBR and DFB after fractionation analysis

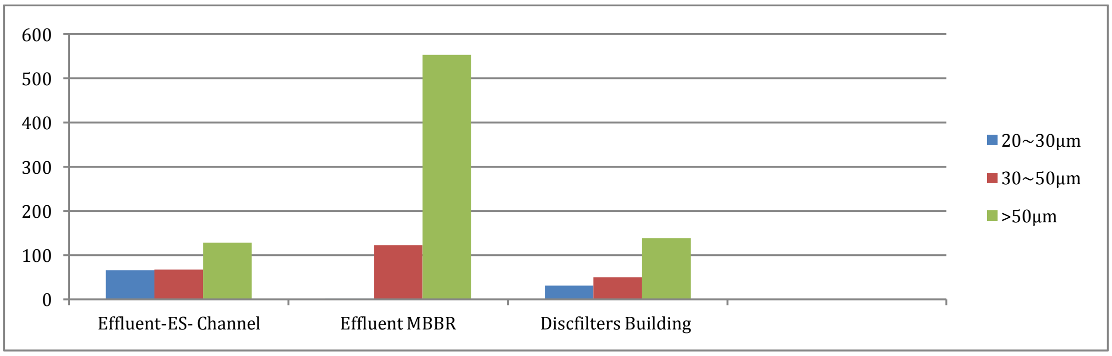

Figure 29 The average number of big particles in the effluent of ES-Channel, MBBR and DFB

The concentration of P_{tot} from the influent and effluent from two specific discfilters from the South and North part of discfilter building is given in Figure 30. Compared with the sampling from the mixed effluent from the DFB, the individual discfilters showed better removal performance where the concentrations of total phosphorous were decreased to 0.16 and 0.1 mg/l.

The concentration of total phosphorous in non-filtered sample in the effluent of discfilter building is 0.3 mg/l. This meets the discharge limit of total phosphorous. The discfilters worked efficiently in this sampling time.

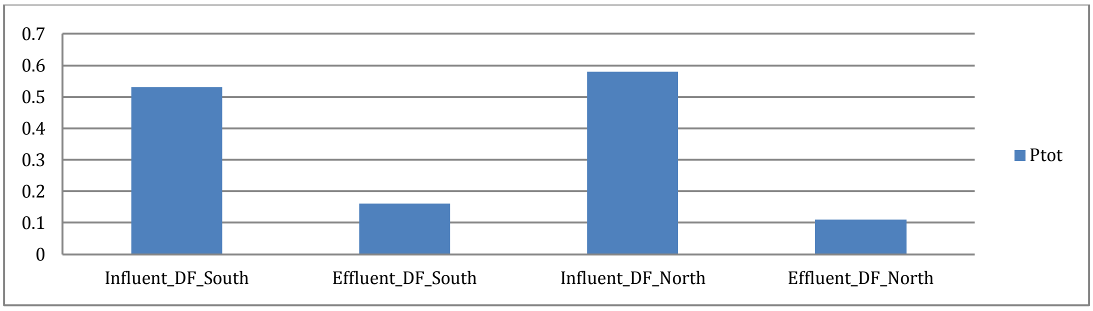

Figure 30 The concentration of total phosphorous in the influent and effluent of a specific discfilter in the South and North part of the DFB

4.3.2 Total Suspended Solid (TSS) Analysis

The fractionated samples were analyzed for TSS except for the 1.2µm and 0.45µm filters papers fractionations since 1.2µm filter paper is used for analyzing TSS. As shown in Figure 31 the cloth filters showed good TSS separation efficiency for the wastewater from the MBBR. This is similar with good P_{tot} separations efficiency of the cloth filters for the wastewater from the MBBR. There were good correlations mentioned between TSS and P_{tot} as shown in the 4.1.2 section of this paper. The reason for high TSS removal efficiency of the cloth filters for the wastewater from the MBBR might correspond to with high removal of Ptot efficiency of discfilters for the wastewater from the MBBR. As shown in Figure 29 that there are higher number of big particles in the MBBR than the ES-channel and the DFB. The high number of big particles in the MBBR may contribute more to TSS removals during the fractionations.

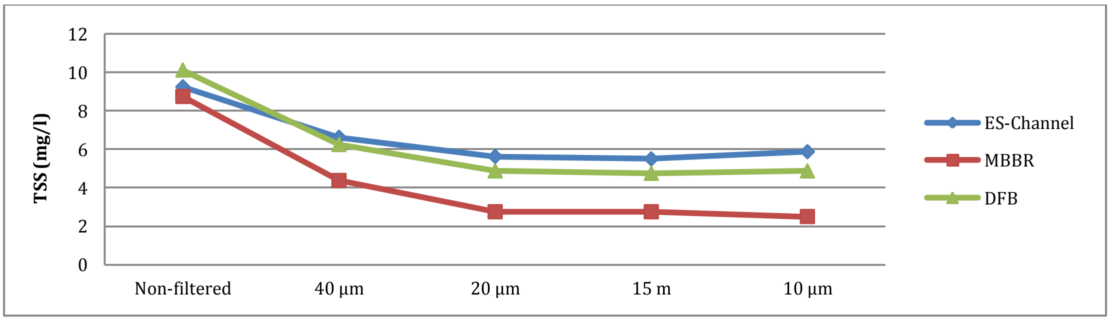

Figure 31 The removed percentage of total suspended solids in different cloth filters.

The concentration of TSS in non-filtered sample in the effluent from the discfilter building (DFB) was 10 mg /l as shown in Figure 31. This was the wastewater that had been filtered by discfilters, i.e. a mixed sample from all discfilters. It should be below than the discharge limit 5mg/l. Furthermore, the concentration of TSS was below than the discharge limit in the effluent of specific discfilters as shown in Figure 32. The samples from the effluent of specific discfilters were taken just after the filtration from inside the discfilters while the mixed effluent from the DFB was taken from the end of the plant where the filtered wastewater was transported in a tube for some time. The possible reason for high concentrations of TSS in the effluent of DFB might be the particles smaller than 1.2µm re-coagulated during the transportation. Particles might also accumulate in the transportation tubes to the sample point in the DFB.

The concentration of TSS from the influent and effluent of two specific discfilters from the South and North part of DFB is given in Figure 32. Both discfilters showed good performance for removing total suspended solid so that the concentrations of TSS were decreased to 3.5 and 2.7 mg/l, respectively.

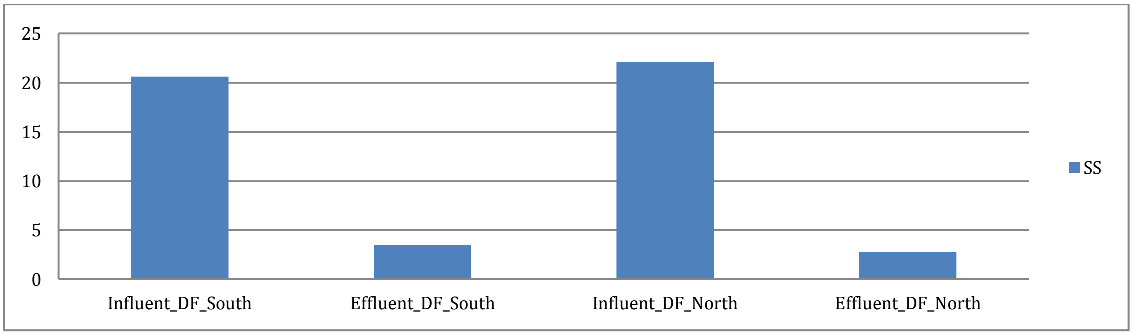

Figure 32 The concentration of total suspended solids in the influent and effluent of a specific discfilter in the South and North part of DFB

4.3.3 Chemical Oxygen Demand (COD) Analysis

It can be seen from Figure 33 that the concentrations of COD were marginally decreased in filter papers 1.2 and 0.45µm after the fractionation analysis. The concentrations of COD were almost the same in the fractionations 15 and 10 µm cloth filters in the wastewater from the MBBR and DFB. The low concentration of COD in the non-filtered sample might result in insignificant decreases during the fractionations analysis. Therefore, dry climate is recommended for the analysis to avoid the low concentration of COD by high-flows.

In the fractionation of 15µm cloth filter, the concentration of COD was expected to be higher than the fractionations of 10, 1.2µm since 10 and 1.2µm filter papers can block more COD. Lab error might be happened in the fractionation of 15µm cloth filter.

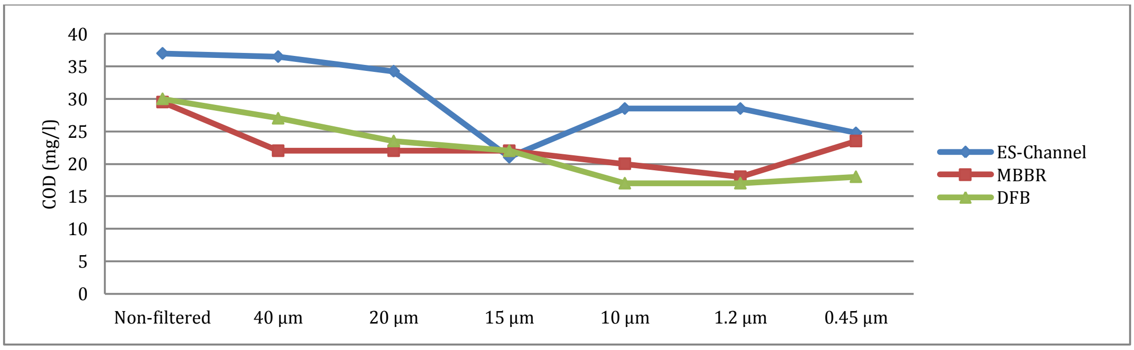

Figure 33 The concentration of chemical oxygen demand in the effluent of ES-channel, MBBR and DFB after fractionation analysis

Figure 34 shows the concentration of COD in two specific discfilters in the North and South part of the DFB. In both discfilters, the concentrations of COD were marginally decreased, the reason might be low concentration of COD did not provide good removal efficiency for the discfilters.

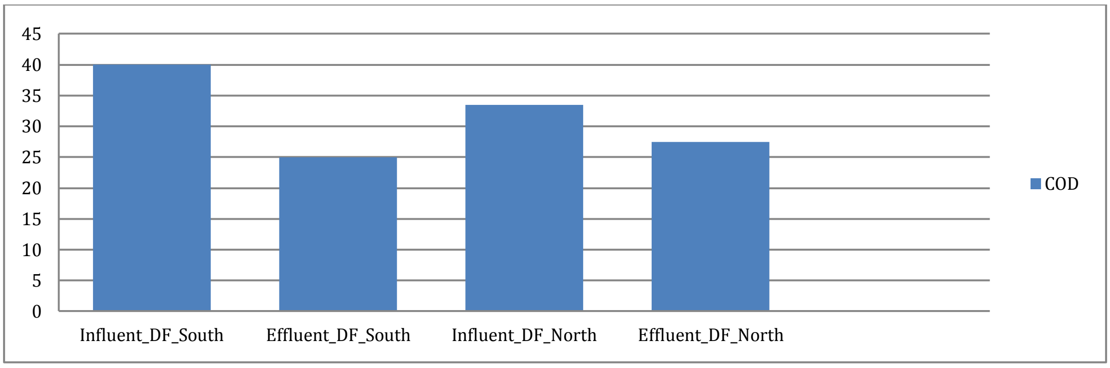

Figure 34 The concentration of chemical oxygen demand in the influent and effluent of a specific discfilter in the South and North part of DFB

4.3.4 Particle Distribution Analysis

Particle distribution analysis was also made for the wastewater from the fractionations of 10, 15, 20 and 40µm cloth filters. The wastewater from the fractionations of 1.2 and 0.45µm filter papers were not analyzed for particle distribution analysis since the filter papers 1.2 and 0.45µm block almost all particles in size ranges 1-50µm.

The efficiency of cloth filters (E) was calculated by the formula below:

$E = (x1 - x2)/x1 \times 100$

$x1 =$ Number of particle in non-filtered water

$x1 =$ Number of particles in filtered water

The cloth filters 20, 15, 10 µm showed similar separations efficiencies for the big particles (10-15, 15-20, 20-30, 30-50, >50µm) from the wastewater of three sampling points. The separation efficiencies are positive. The cloth filter 40 µm only showed positive efficiencies for separating particles in size ranges 30-50µm and >50µm and showed negative values for separating particles in other size ranges. The values are presented in the Figures 35, 36 and 37. The cloth filter 20 µm showed very negative separations values for the particles 20-30µm and 5-10µm from the wastewater of the MBBR as shown in Figure 36. The possible explanation is that there were re-flocculation of small particles happened after the fractionation analysis. This resulted in more particles in these size ranges in the fractionated sample of 20µm cloth filter than the non-filtered samples.

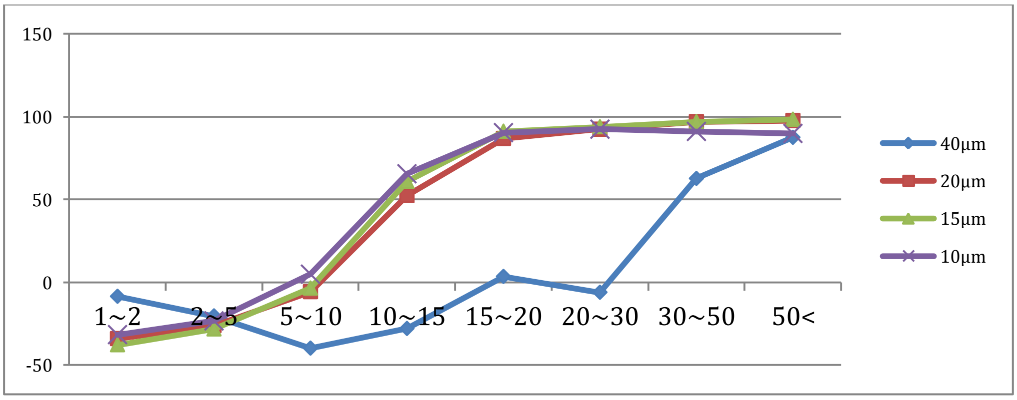

Figure 35 Particle removal efficiency of different sized cloth filters for the wastewater from the effluent of ES-channel

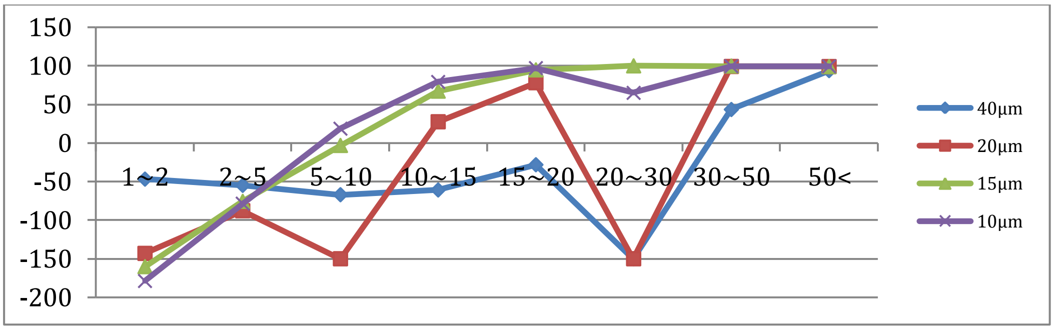

Figure 36 Particle removal efficiency of different cloth filters for the wastewater from the effluent of the MBBR.

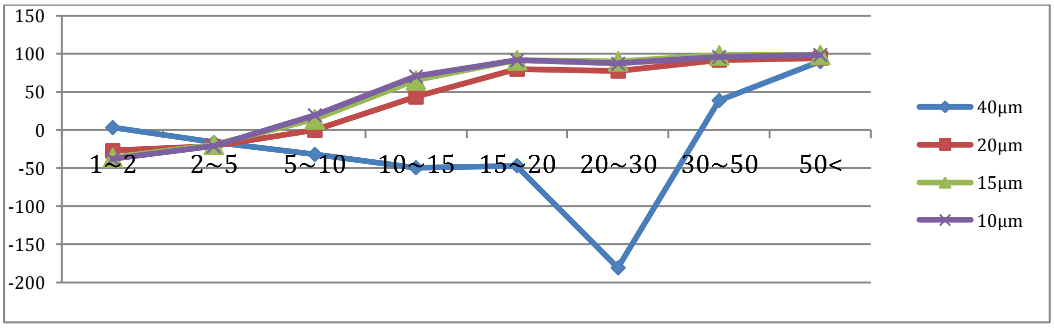

Figure 37 Particle removal efficiency of different cloth filters for the wastewater from the mixed effluent of discfilter building.

The Table 1, 2 and 3 show the separation efficiencies of cloth filters for small particles (1-2, 2-5 and 5-10µm) from the wastewater of the ES-channel, the MBBR, and the DFB. It can be seen from the tables that the separation efficiencies are negative. This means there are more particles in these size ranges in the fractionated samples than the raw samples. The possible reason might be some big particle break-up by the high shear forces of cloth filters.

size	40µm	20µm	15µm	10µm
1~2	-8.48501	-34.0462	-37.7448	-31.6423
2~5	-20.3375	-26.1359	-28.1913	-23.3665
5~10	-39.7993	-5.68562	-3.51171	4.849498

Table 1 Separation efficiency of cloth filter for the small particles in ES-channel

size	40µm	20µm	15µm	10µm
1~2	-46.7875	-143.06	-160.194	-178.83
2~5	-54.8756	-87.7612	-75.6219	-78.5572
5~10	-66.9983	-150	-3.15091	18.5738

Table 2 Separation efficiency of cloth filter for the small particles MBBR

size	40µm	20µm	15µm	10µm
1~2	3.212191	-27.3201	-36.4852	-38.031
2~5	-16.2871	-21.3366	-19.4307	-21.3366
5~10	-31.9444	-0.27778	14.16667	19.44444

Table 3 Separation efficiency of cloth filter for the small particles DFB

It can be seen from the tables that the separation efficiency of cloth filters for the small particles from wastewater of the MBBR are more negative than for the other sampling points. The reason can also be contributed to the number of big and small particles in the MBBR and the other sampling points. As shown in Figure 38, 39 (compare with figure 29), there are higher number of big particles (20-30, 30-50 and >50µm) and less number of small particles (1-2, 2-5, 5-10µm) in the MBBR than other sampling points. During the fractionation analysis, the big particles break-up by high shear forces. The higher number of big particles contributes more to the breaking-up of the particles that there are more small particles produced after the filtrations. This resulted in very negative values for the separations efficiency of cloth filters for small particles from the wastewater of the MBBR.

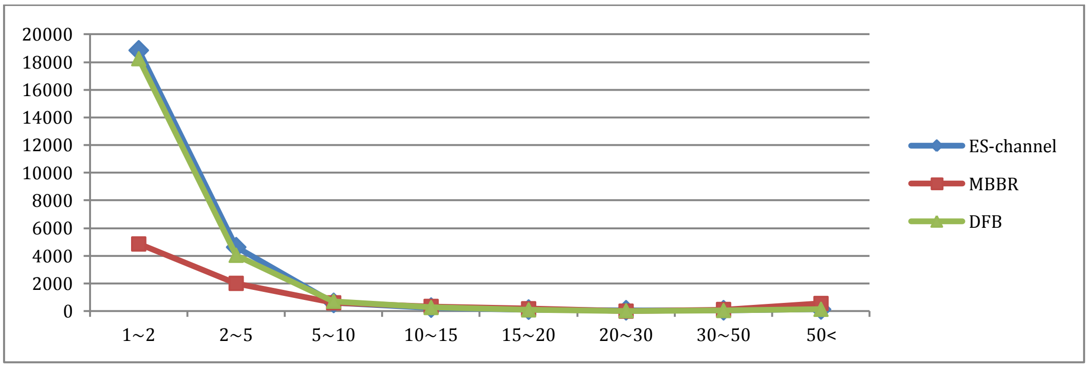

Figure 38 The number of particles in different size ranges in the wastewater from the ES-channel, MBBR and DFB

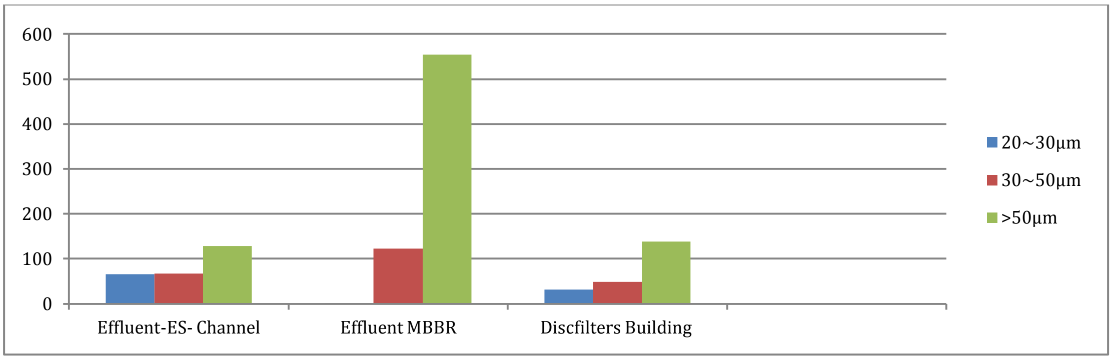

Figure 39 The number of big particles in the effluent of ES-Channel, MBBR and DFB (same as Figure 29)

4.3.5 Total Nitrogen (N_{tot}) Analysis

The same fractionated samples from the ES-channel, the MBBR and the DFB effluents were also analyzed for total nitrogen. The result is presented in Figure 40. It can be seen from the figure that the concentration of N_{tot} does not change during the fractionation. It is reasonable that there was not much removal during the fractionation analysis since nitrogen in the wastewater is mainly soluble and cannot be removed by filtrations.

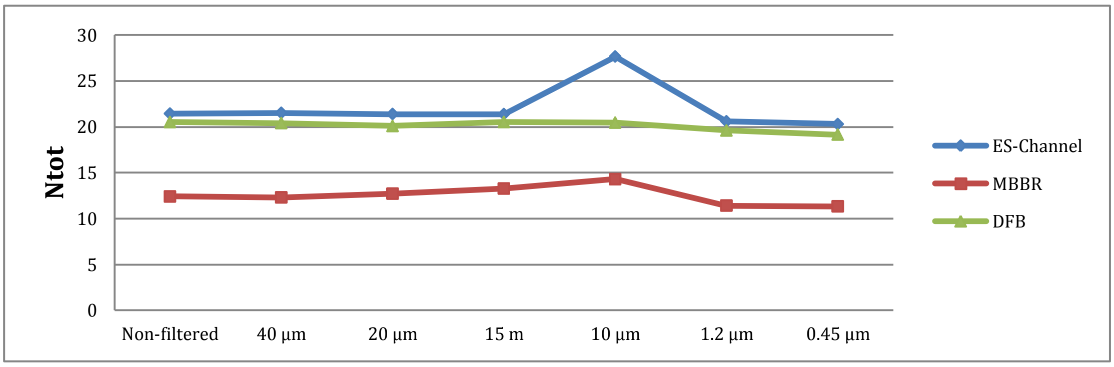

Figure 40 The concentration of total nitrogen in the effluent of ES-channel, MBBR and DFB after fractionation analysis

There were no significant differences in the concentration of total nitrogen in the influent and effluent of the specific discfilters as shown in Figure 41.The discfilters have shown low removal efficiency because nitrogen is water soluble after treatment. Also, the wastewater leaving the post-denitrification unit (the MBBR), contains low nitrogen concentrations as most nitrogen gas has been converted into nitrogen gas. The fraction that is removed by the discfilters is therefore particle bound.

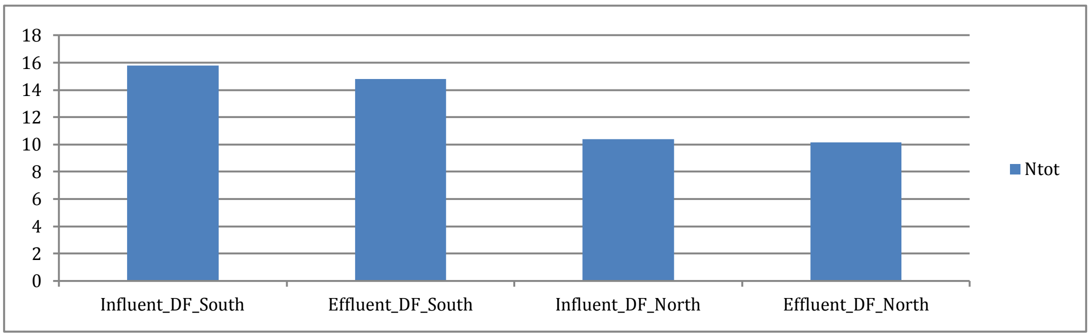

Figure 41 The concentration of total nitrogen in the influent and effluent of a specific discfilter in the South and North part of DFB

4.3.6 Total Organic Carbon (TOC) Analysis

The concentrations of total organic carbon through every fractionation analysis are given in Figure 42. The concentrations of total organic carbon were not changed after the fractionations. Organic carbon can be oxidized in the wastewater. There were marginal changes in the concentration of chemical oxygen demand in all sampling points during the fractionations. The results from the fractionations of COD and TOC were similar. The minor removal of TOC compared to COD might be due to the sampling equipment. The TOC instrument sucks up a very small volume of sample through a relatively small opening and there is a risk that particles containing organic carbon are not analyzed properly.

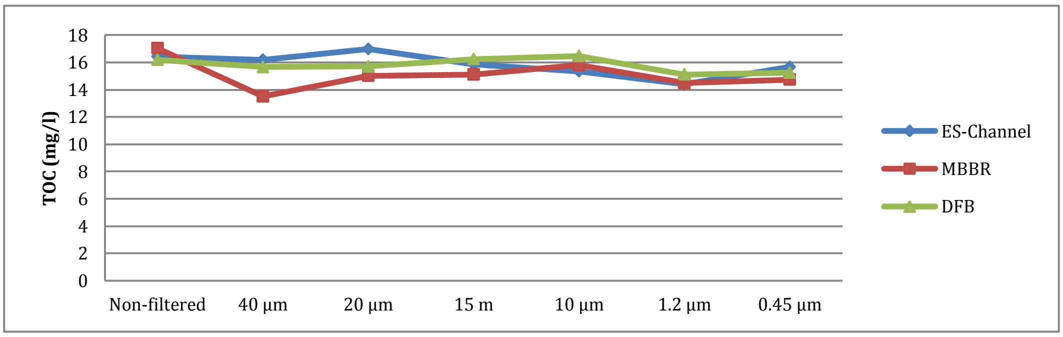

Figure 42 The concentration of total organic carbon in the effluent of ES-channel, MBBR and DFB after fractionation analysis

The concentration of total organic carbon from specific discfilters in the North and South of the DFB is given in Figure 43. The same findings were observed in the performance of the discfilters for removing TOC with the fractionation analysis of TOC that there were not significant changed in the concentrations of TOC.

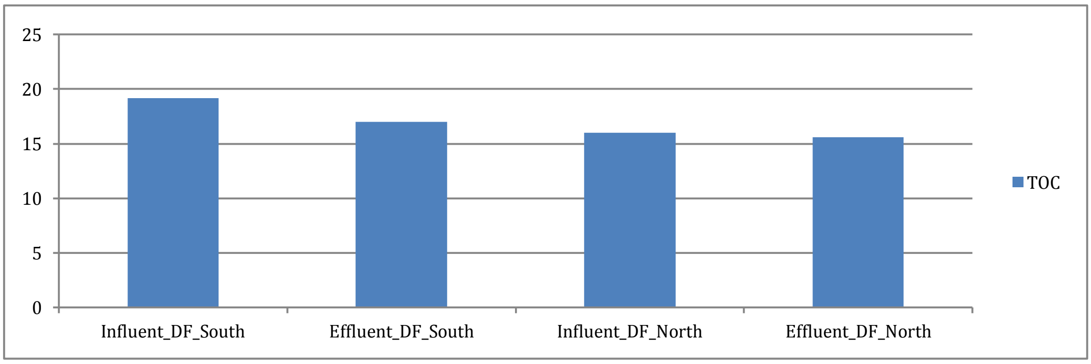

Figure 43 The concentration of total organic carbon in influent and effluent of a specific discfilter in the South and North part of DFB

4.3.7 Characterizations of Wastewater from Secondary Settling Channel and Moving Bed Biofim Reactor

The discfilters in the North part of discfilter building receive wastewater from the moving bed biofilm reactor (post-denitrification unit) and the discfilters in the South part of discfilter building receive wastewater from the secondary settling channel. The performance of discfilters for removing pollutants from two different sources was different. Therefore, characterizations of the wastewater from these two sources might give good information for improving treatment processes.

Figure 44 and 45 shows the number of small particles (1-2µm) and big particles (>50µm) during eight sampling periods in 2011. It can be seen from these two figures that there were higher number of small particles in the ES-channel than the MBBR. And, there were higher number of big particles in the MBBR than the ES-channel. The particles in size ranges 2-5, 5-10, 10-15, 15-20, 20-30 and 30-50µm were also analyzed; the same conclusion was drawn from the particles in these size ranges. They are presented in appendix D.

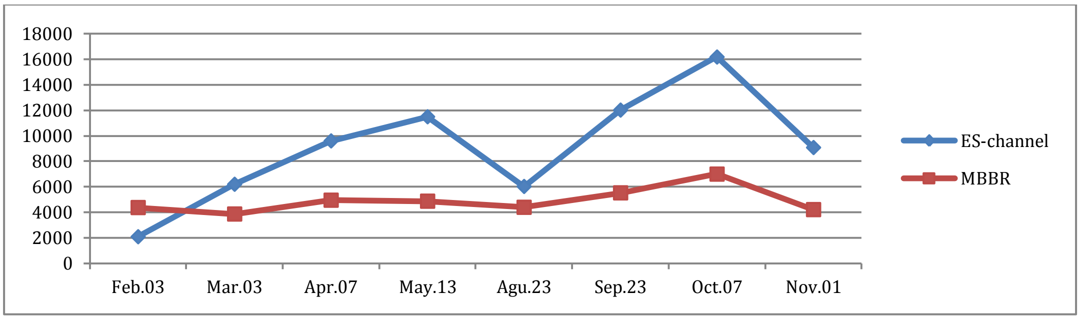

Figure 44 The number of small particles in size ranges 1-2µm in eight sampling periods in 2011.

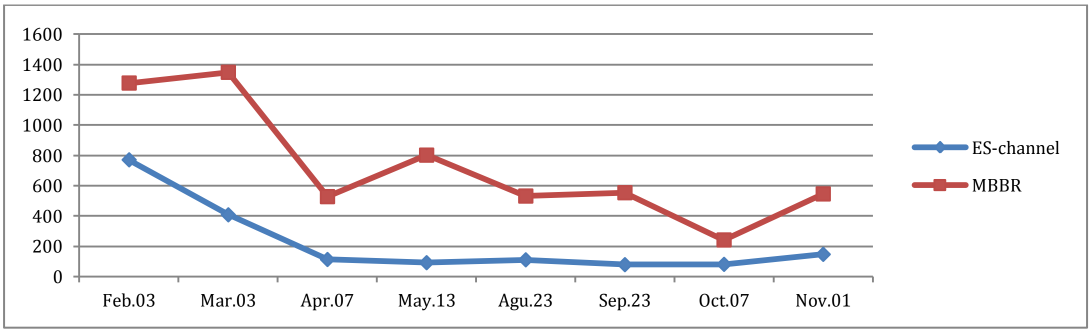

Figure 45 The number of big particles (>50µm) in eight sampling periods in 2011

Table 4 shows the removal efficiencies of two specific discfilters for different parameters. It can be seen from the table that the discfilter receives water from the MBBR showed slightly higher efficiency for removing total suspended solids and total phosphorous. This might also relate to the higher number of big particles in the wastewater from the MBBR as mentioned earlier parts of the study. The discfilters were more efficient for removing big particles.

The discfilters showed high and similar efficiency for removing total suspended solids and total phosphorous and showed lower efficiency for removing total nitrogen, TOC and COD.

	Removal Efficiency (%)	
Component	Discfilters receiving ES-channel water	Discfilters receiving MBBR water
TSS	83	88
$P_{(tot)}$	79	81
$N_{(tot)}$	6	14
TOC	11	3
COD	38	18

Table 4 The removing efficiency of discfilters over all the parameters.

Conclusion

It can be concluded from the full scale data that the discfilters operation has improved the removal efficiency of the WWTP for total phosphorous and total suspended solids. The number of days when the concentration of total phosphorous and total suspended solids below the limit (0.3 mg P/l and 5 mg SS/l) have increased compare to the same months before the application of discfilters. In January, February, March and April 2011, the concentrations of total phosphorous and total suspended solids were above the discharge limit in the most of the days even if with the discfilters in operation. However, the concentrations of total phosphorous and total suspended solids have decreased to lower level.

Good correlations were found between total suspended solids and total phosphorous, total suspended solids and COD. The correlations support the importance of particles separations in domestic wastewater treatment. Phosphorous and organic matters are mostly bond to particles and the ideal reduction of phosphorous and COD can be reached by better separations of particles in the domestic wastewater.

It can seen from the particle size distribution analysis that the discfilters showed good separation efficiency for the big particles in size range 15-50 and >50µm. However, there were more small particles in the effluent of discfilters. The reason for this phenomenon might be that the discfilters break big particles into small ones. However, it can be concluded from the concentration of total phosphorous and total suspended solids from full scale data analysis that even if the discfilters showed negative efficiency for removing smaller particles, the days where discharge limits were met for total phosphorous and total suspended solids were increased.

An interesting opposite trend was found between the number of big and small particles in the both wastewater from the ES-channel and the MBBR. The high number of small particles and less number of big particles in the wastewater from some sampling periods indicates that the big particles might be disrupted into small ones with high-flow. The increased number of small particles in the wastewater is less favorable for the removal efficiency of discfilters since the pore sizes of discfilters are 15µm.

Wastewater fractionation analysis supports us with good information for characterization of different wastewater. In the fractionation analysis of this study, cloth filters are more efficient for removing TSS and P_{tot} in the wastewater from the MBBR than the ES-channel and the DFB.

In the particle size analysis of fractionated samples, the cloth filters 20, 15 and 10µm showed similar efficiency for separating big particles (15-50µm) from the wastewater of the ES-channel, the MBBR and the DFB. The cloth filters 20, 15 and 10µm showed negative efficiencies for separating small particles (1-2, 2-5 and 5-10µm) from the wastewater of the ES-channel, the MBBR, and the DFB. Furthermore, the separation efficiency of cloth filters for the small particles from wastewater of the MBBR were more negative than other sampling points. The possible reason can also be contributed to the high number of big particles in the wastewater of the MBBR than other sampling points. The higher number of big particles contributed more to the breaking-up of particles that there were more small particles produced after the filtrations.

The concentrations of COD and total organic carbon were not significantly decreased in small filter papers 1.2 and 0.45µm; the concentrations are almost the same with 15 and 10 µm cloth filters. The reason would be the low concentration of COD in the samples that it cannot be decreased to even lower level. Better comparison can be found if the concentrations of pollutants are higher in the non-filtered sample. Therefore, dry climate period is recommended for fractionation analysis so that pollutants in the wastewater are not diluted from high-flow from rain events. The concentration of total nitrogen was kept in the same level during the fractionation analysis. The reason would be nitrogen is water soluble and the concentration did not decrease during the fractionations.

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Appendix

A: Correlations between SS and P_{tot}

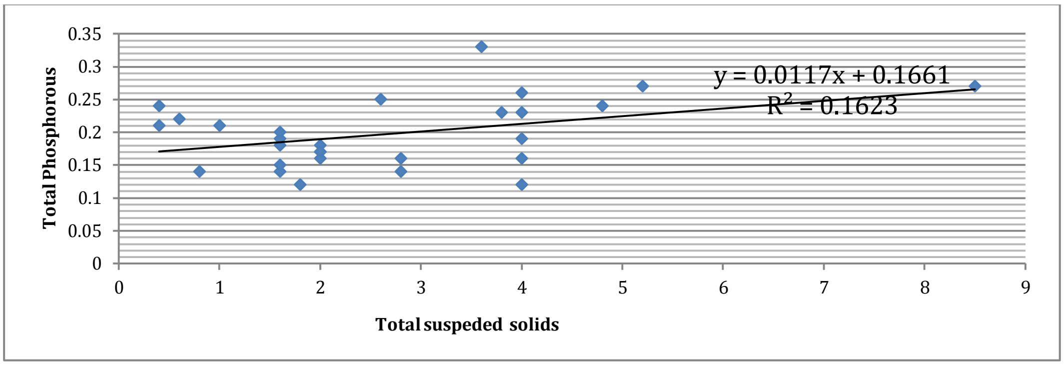

Figure 46 The correlation between total phosphorous and total suspended solids in June 2010

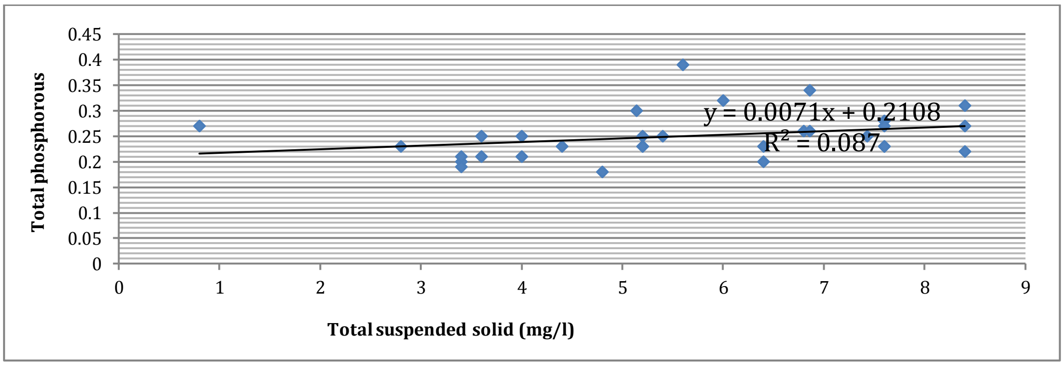

Figure 47 The correlation between total phosphorous and total suspended solids in December 2010

B: Correlations between TSS and COD

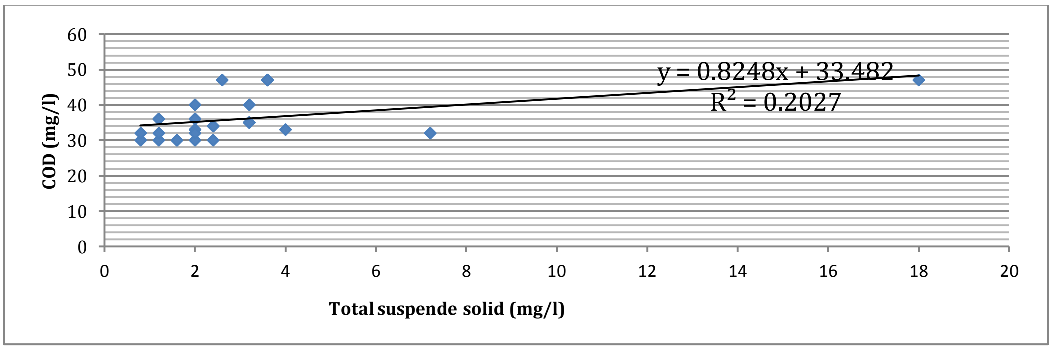

Figure 48 The correlation between total suspended solids and chemical oxygen demand in July 2011

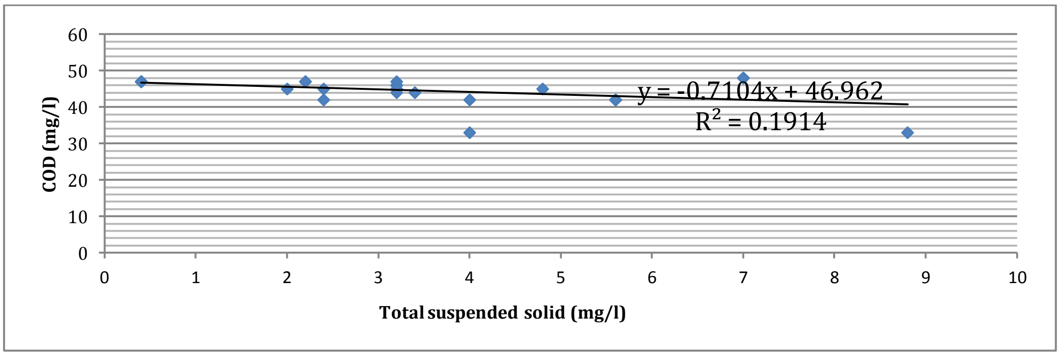

Figure 49 The correlation between total suspended solids and chemical oxygen demand in June 2011

C: Correlations between TSS and SSVI

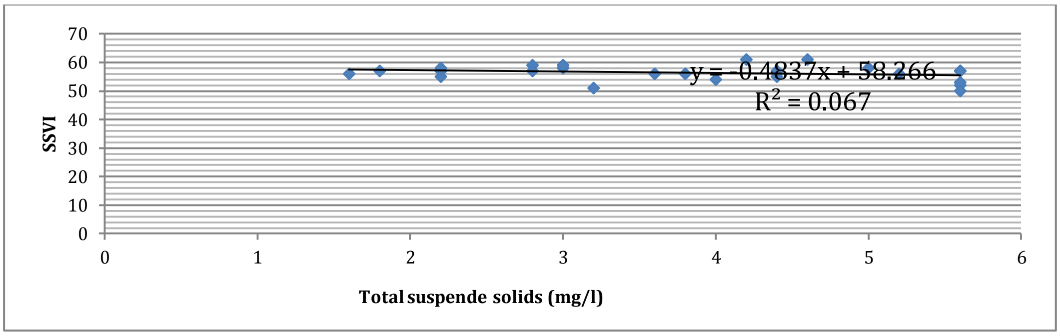

Figure 50 The correlations between total suspended solids and stirred sludge volume index October 2010

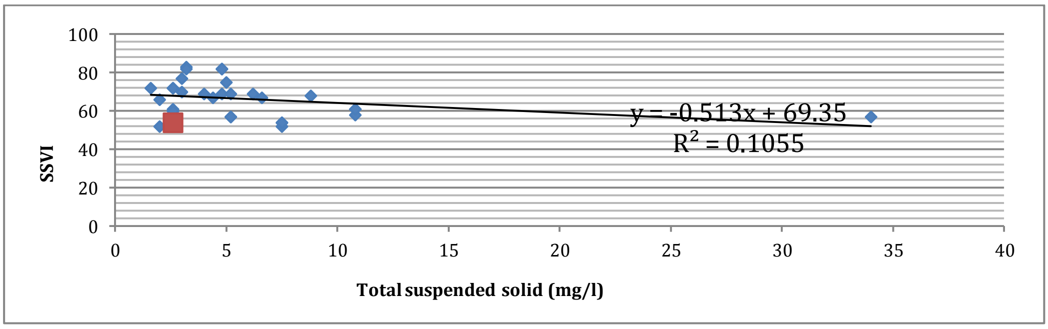

Figure 51 Correlations between total suspended solids and stirred sludge volume index November 2010

D: Characterizations of Wastewater from Secondary Settling Channel and Moving Bed Biofilm Reactor

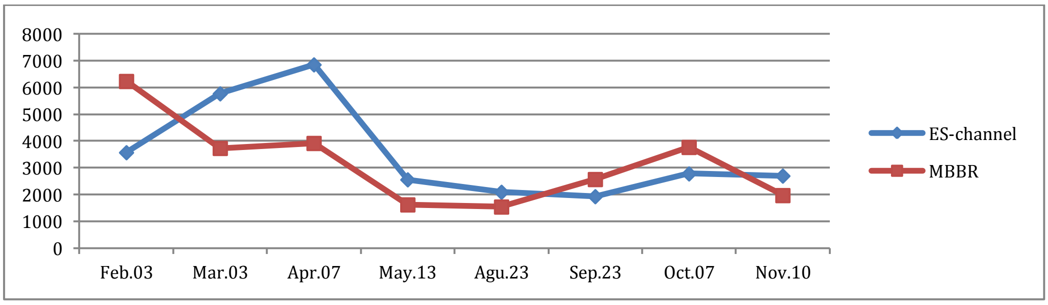

Figure 52 The number of particles in size range 2-5μm in the wastewater from secondary settling channel and moving bed biofilm reactor

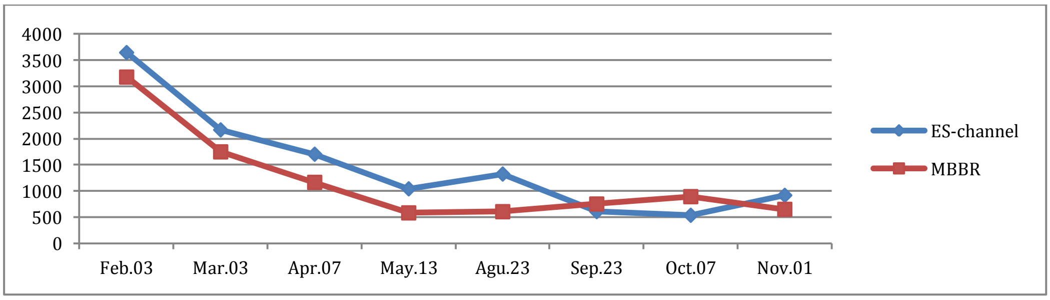

Figure 53 The number of particles in size range 5-10μm in the wastewater from secondary settling channel and moving bed biofilm reactor

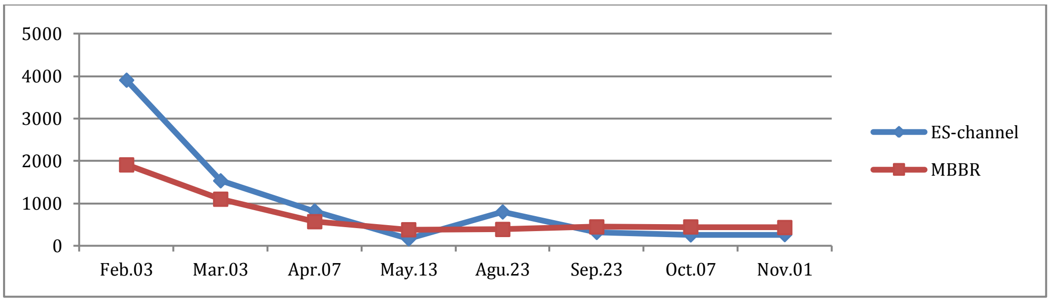

Figure 54 The number of particles in size range 10-15μm in the wastewater from secondary settling channel and moving bed biofilm reactor

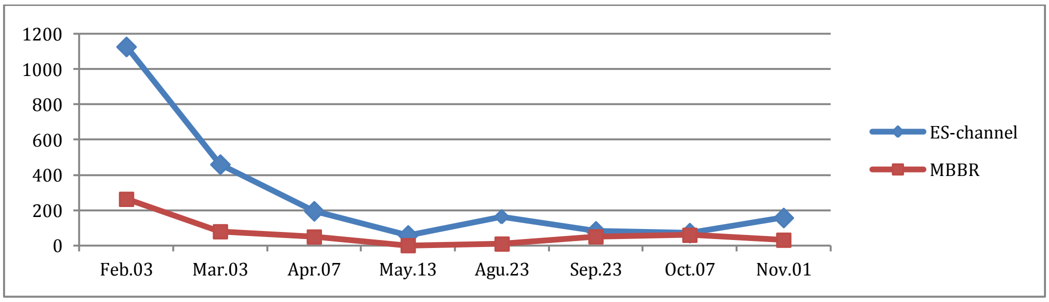

Figure 55 The number of particles in size range 20-30μm in the wastewater from secondary settling channel and moving bed biofilm reactor

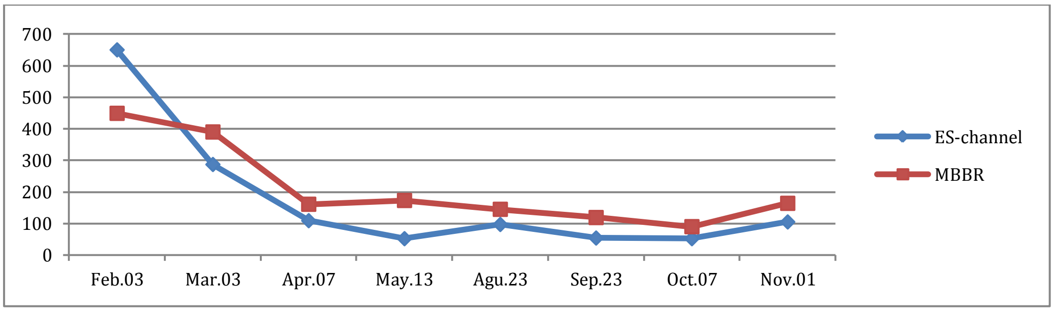

Figure 56 The number of particles in size range 30-50μm in the wastewater from secondary settling channel and moving bed biofilm reactor

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