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Large scale tertiary filtration – results and experiences from the discfilter plant at the Rya WWTP in Sweden

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Abstract

This paper summarizes the results and experiences from the full-scale discfilter plant at the Rya WWTP. In 2010 the WWTP was extended with post-denitrification and a discfilter plant for tertiary filtration of the effluent in order to meet the new discharge limits of 10 mg total nitrogen and 0.3 mg/l of total phosphorus. The disc filters receive effluent from both the moving bed biofilm reactor (MBBR) and the secondary settlers. The disc filters are equipped with filter cloths with 15 μm pore openings. The concentration of suspended solids was generally kept below 5 mg/l and total phosphorus was <0.2 mg/l for approximately 60% of the days during the experimental period, with generally lower concentration of particles in the effluent from the disc filters during the summer. The mass load of suspended solids from the MBBR was higher compared to the load from the secondary settlers but this did not influence the concentration of suspended solids in the effluent from the disc filters. The particles in the MBBR effluent are larger and easier to filter compared to the secondary settler effluent which contain a larger number of small particles. During passage through the disc filters, some particles break-up leaving a larger number of particles (1–5 μm) in the effluent. Due to their small mass, this does not affect the effluent suspended solids concentration significantly. The removal of indicator and pathogenic microorganisms was only marginal. Since the discfilter plant has been placed in operation, the operational strategies have improved (e.g. more frequent cleaning of the filter cloths) which has increased the treatment capacity. The study demonstrates successful operation of a large discfilter plant with large variation in flow and particle loading.

Key words: discfilter, particle size analysis, tertiary filtration

INTRODUCTION

In 2010 the Rya wastewater treatment plant in Gothenburg was extended with a moving bed biofilm reactor (MBBR) for post-denitrification and a discfilter plant for tertiary filtration of the effluent in order to be able to meet the new discharge limits of 10 mg/l total nitrogen and 0.3 mg/l of total phosphorus. The disc filters receive effluent from both the MBBR and the secondary settlers. The design of the disc filter plant was preceded by extensive pilot tests where disc filters with a cloth pore diameter of 15 μm was found most suitable for suspended solids (SS) removal (Mattsson *et al.* 2009).

Microscreens have been used for tertiary filtration since the 1950's when the first drum filters were installed in the UK (Isaac & Hibberd 1972). Since the late 1990's disc filters, rather than drum filters, have been increasingly applied for tertiary treatment, mainly due to small foot-print and low operational head loss. Recent studies have also demonstrated the possibility to combine the technology

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Table 1 | Operational conditions for the discfilter plant at the Rya WWTP 2011–2013

Period	To disc filters	From disc filters	Capacity	Particle load	Particle reduction		Filters in operation	Rotation speed
	mg SS/l		m/h	g SS/ m^2*h	g SS/ m^2*h	%	Average No	rpm
2011	17	4	5.8	92	71	73	21	1.5
2012 Jan–Oct	17	3	6.5	115	92	81	19	1.5
Nov 2012–May 2013	21	4	7.5	152	122	79	16	3.0

with preceding coagulation/flocculation in order to achieve <0.1 mg/l of total phosphorus (Tooker *et al.* 2010; Langer *et al.* 2012; Väänänen 2014).

The Rya WWTP serves about 830,000 pe with an average flow of about 350,000 m^3/d which makes it one of the largest treatment plants in Scandinavia. After screening, grit removal and primary clarification water is treated in a high-loaded activated sludge plant with possibilities for pre-denitrification and simultaneous precipitation. Trickling filters are utilized for subsequent nitrification and the newly installed MBBR for nitrogen removal in a post-denitrification process. Water is finally treated in the disc filter plant before being released into the recipient. The 32 disc filters with a total filtration area of 3,584 m^2 (Hydrotech HSF 2220-2FN) and with 15 μm pore openings are designed for a flow of 8 m^3/s. The filter media is made of a twill weave monofilament polyester filter cloth (Persson *et al.* 2006). Backwashing requires in the order of 3% of filtered water at design conditions. The streams from the secondary settlers and from the post-denitrifying MBBR are mixed before entering the disc filter plant. However half of the filter units (those to the north) receive mainly effluent from the MBBR whereas the other half (to the south) receive mainly effluent from the secondary settlers. This enables studies of the efficiency of removing particles from the two process steps. Depending on the flow and mass load of SS from the secondary settler and post-denitrification MBBR the operational conditions of the disc filter plant vary; the mass load of SS determines the number of filters in operation and the flow to each filter depends on the resistance over the filter cloth (Table 1). At regular intervals the filters are cleaned with hydrochloric acid (once a month) and hypochlorite (once every three months). The degree of fouling of the filter cloth is measured as the time it takes for tap water to pass the filter cloth compared to passage through cleaned or new filter cloths. The separated sludge flocs are brought back to the inlet channel of the activated sludge tanks.

The objective of this paper is to summarize full-scale results from the first years of operation. In addition, detailed investigations of removal of organic material and nutrients as well as pathogenic microorganisms over specific disc filters receiving mainly effluent from either the secondary settlers or the post-denitrification effluent were performed.

MATERIALS AND METHODS

Figure 1 illustrates the process layout of the Rya WWTP including sampling points for evaluation of the disc filter plant. The concentration of SS, N_{tot}, and P_{tot} was analysed daily in the effluent from the discfilters. On-line sensors for SS concentration were located at sampling points 1, 2 and 4 (Figure 1). Process data was collected between January 2011 and March 2013. Detailed assessment of specific filters were made during 2011 including particle size analysis (1–400 μm, Art Instr. Inc.) and removal of SS, P_{tot}, $N_{tot,}$ total organic carbon (TOC), and Chemical Oxygen Demand (COD). Fractionation of the MBBR and secondary settler effluent was performed by filtration through test filter cloths with nominal pore sizes of 10, 15, 20 and 40 μm as well as filter papers with 1.2 and 0.45 μm pore size to assess the potential for removal efficiency.

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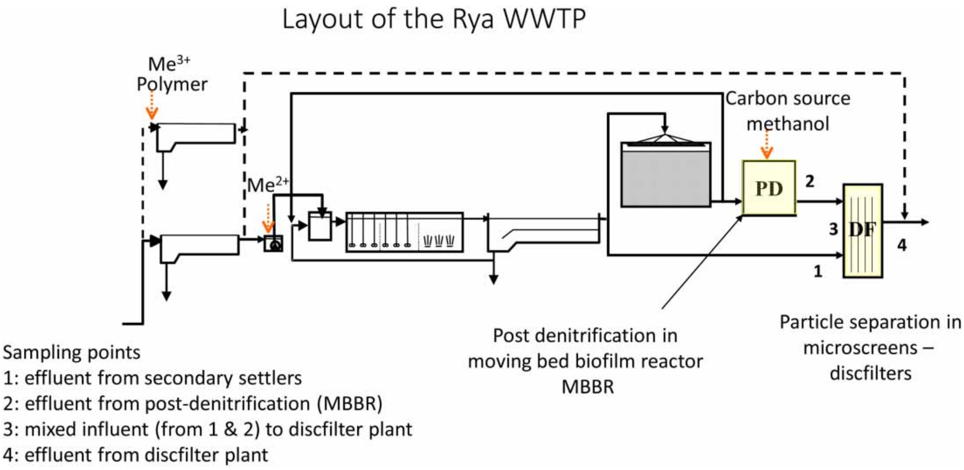

Figure 1 | Process layout of the Rya WWTP.

In 2012 removal efficiencies of a series of indicator organisms, including the faecal indicator bacteria *E. coli* and total coliforms (Colilert-18 Quantitray/2000, IDEXX), and enterococci (membrane filtration ISO 7899-2:2000), were analysed. Besides Somatic coliphages (ISO 10705-2), *Clostridium Perfringens* (spore forming bacteria, ISOP/CD 6471-2) and the pathogenic virus *Norovirus* (qPCR) were analysed. Sampling was performed during normal operational conditions. Before the first sampling occasion (6–8 March 2012) each filter was cleaned with acid the day before so that the biofilm build-up was limited. The second sampling occasion (28–30 May 2012) was performed two weeks after the last acid cleaning to see if this would lead to higher removal efficiency due to biofilm build-up. During both sampling occasions the removal of SS over the disc filters were monitored, and during the first sampling occasion also total phosphorus, total nitrogen as well as particle number and size were analysed.

RESULTS AND DISCUSSION

The concentration of SS was generally kept below 5 mg/l and P_{tot} was <0.2 mg/l for approximately 60% of the days during the experimental period (Figure 2). Generally the particle concentration in the effluent from the disc filters were lower during the summer. The mass load of SS from the MBBR was higher compared to the load from the secondary settler, 42 ± 16 and 29 ± 25 g/s, respectively. Particle size analysis of the effluent from sampling points 1, 2 and 4 showed that the number of smaller particles (<20–30 μm) was larger in the effluent from the secondary settlers compared to the MBBR effluent (Figure 3). After passage through the disc filters the larger particles in both the secondary settler and MBBR effluent had a tendency to break-up due to high shear forces leaving the effluent from the disc filters with a larger number of particles <2–5 μm. However, these small particles contribute little to the SS, leaving generally lower SS concentration after disc filtration (Table 2). The particles in the MBBR effluent are easier to filter due to their larger size.

Fractionation of the MBBR and secondary settler effluent showed that approximately 0.1 mg P_{tot}/l is in a dissolved fraction and cannot be removed by disc filtration (Figure 4). There was no large difference in P_{tot} between filtration through 10 and 15 μm filter cloths which confirms the appropriate choice of filter cloth pore size as assessed previously (Mattsson *et al.* 2009). The removal of nitrogen was only marginal.

The removal of indicator microorganisms was different depending on type of microorganism. In most samples, the numbers of indicator microorganisms were larger in the effluent from the secondary settler compared to the MBBR effluent (Table 3). There was a slight reduction in numbers of total

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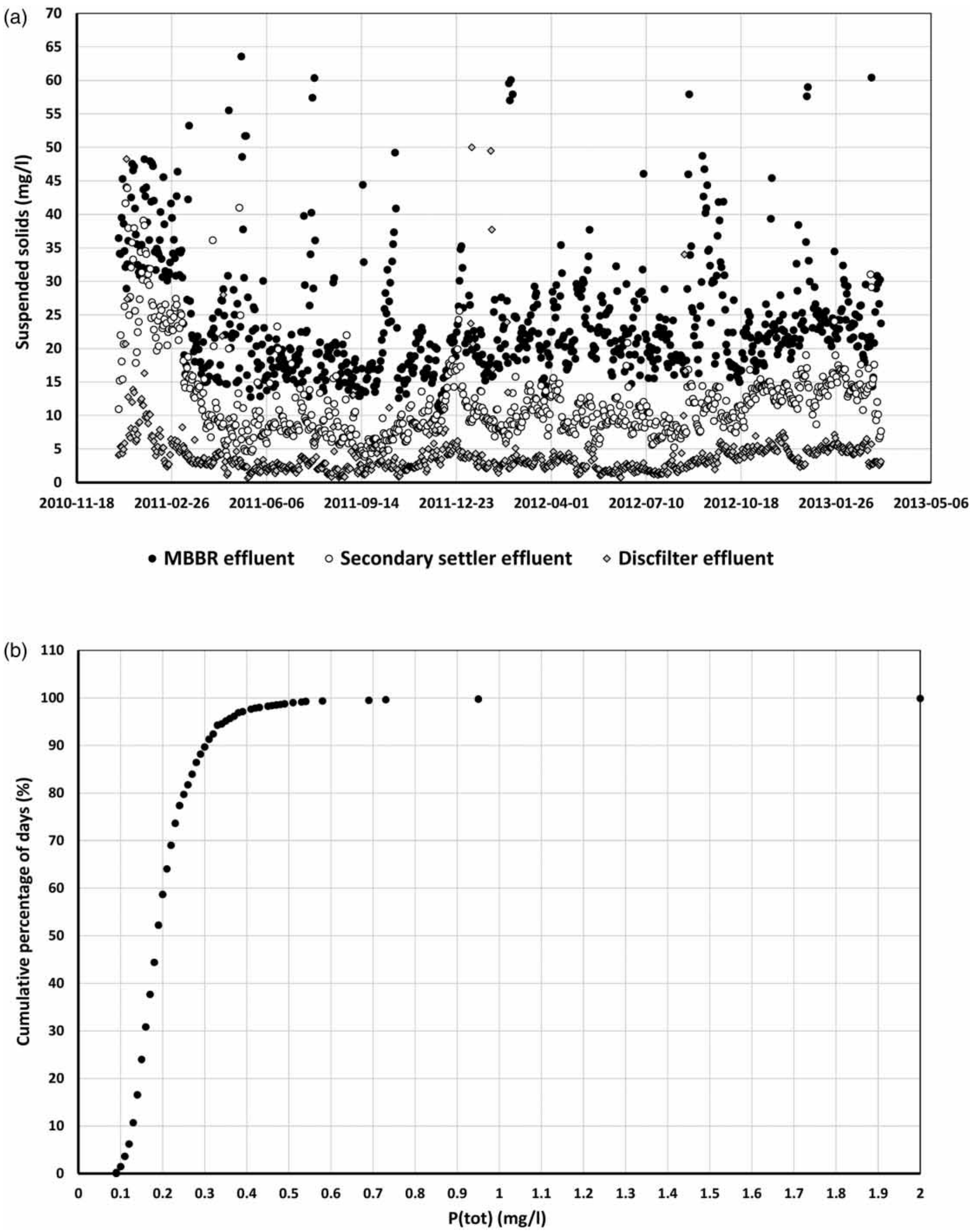

Figure 2 | Effluent concentrations of SS (a); and cumulative percentage of days with a certain P_{tot} concentration (b).

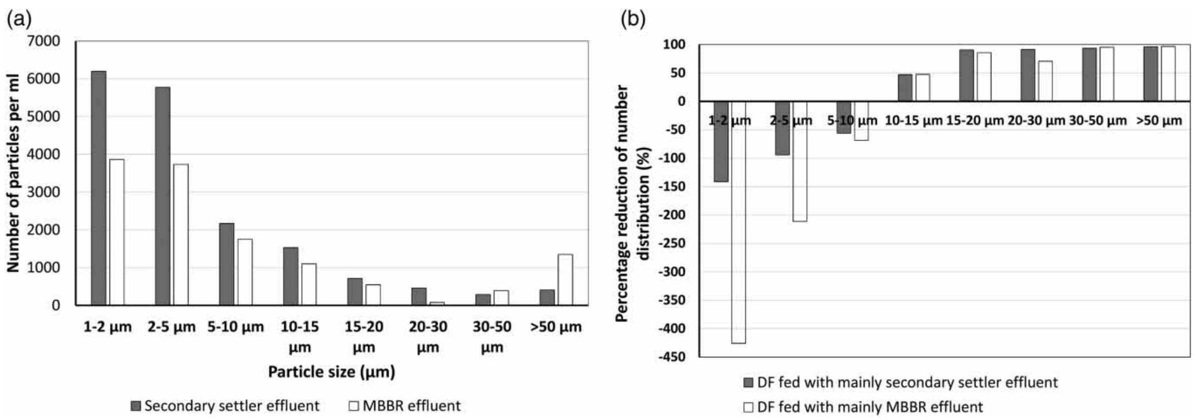

Figure 3 | Particle size analysis of MBBR and secondary settler effluent (a) number size distribution, and (b) percentage reduction in number of particles of different sizes.

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Table 2 | Removal of different components over disc filters (DF) receiving either mainly effluent from MBBR or from secondary settler (each data is an average of two analyses performed at one sampling occasion)

Component (mg/L)	In-DF receiving secondary settler effluent	Out-DF receiving secondary settler effluent	Removal efficiency (%)	In-DF receiving MBBR effluent	Out-DF receiving MBBR effluent	Removal efficiency (%)
SS	20.6	3.5	83.0	22.1	2.8	87.6
N_{tot}	15.8	14.8	6.3	10.4	10.2	2.0
TOC	19.2	17	11.6	16.0	15.6	2.8
COD	40	25	37.5	34	28	17.9
P_{tot}	0.53	0.16	69.8	0.58	0.11	81.0
P_{tot}/SS	0.026	0.046		0.026	0.040	

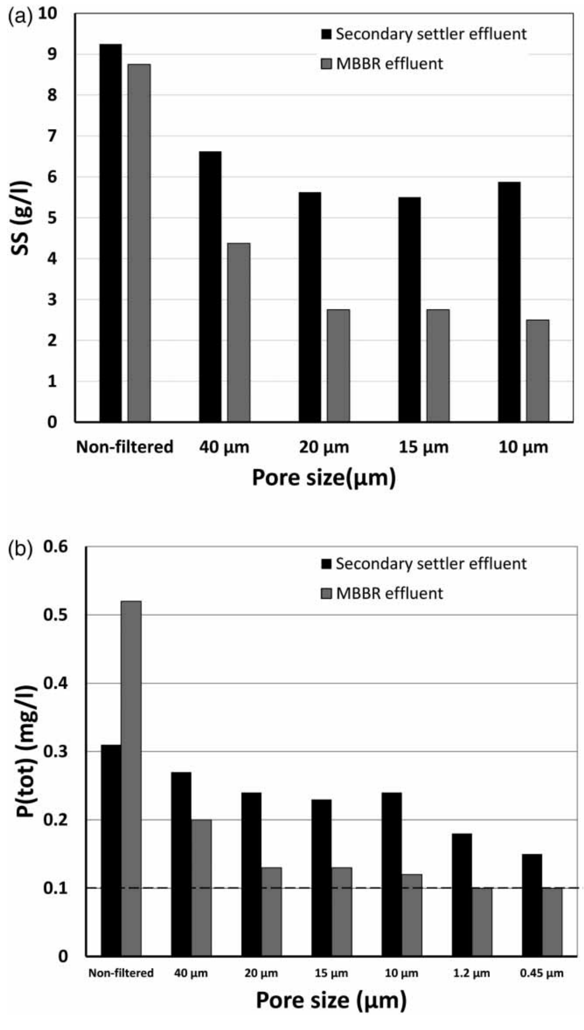

Figure 4 | Concentration of (a) SS and (b) P_{tot} in different fractions of the MBBR, secondary settler and disc filter effluents.

coliforms and *E. coli* in the 24-h samples in both measurements for the disc filter receiving mainly MBBR effluent (Table 3). However, less good removal was observed for the grab sample measurement. For the disc filter receiving mainly secondary settler effluent the removal was less good or even negative, with the exception of the enterococci measured with grab samples with an 82% removal efficiency. For *Noroviruses* and Somatic coliphages, negative removal efficiencies were

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Table 3 | Numbers and removal efficiencies of indicator and pathogenic microorganisms

Parameter	DF receiving MBBR effluent[a]	DF receiving secondary settler effluent[a]	DF receiving MBBR effluent[b]	DF receiving secondary settler effluent[b]	Entire DF unit[c]
Total coliforms (numbers/100 ml)					
Removal (6–8 March)	36%	−76%	16%	–	
Influent (6–8 March)	9.30E + 02 ± 3.20E + 02	9.07E + 05 ± 8.73E + 04	1.90E + 04	–	
Effluent (6–8 March)	6.0E + 02 ± 1.40E + 02	1.60E + 06 ($n = 1$)	1.60E + 04	1.60E + 06	
Removal (8 March)					63%[d]
Influent (8 March)	1.67E + 04 ± 1.67E + 03[c]	1.40E + 06 ± 8.17E + 04[c]			
Effluent (8 March)					1.93E + 05 ± 3.39E + 04[c]
E. coli (numbers/100 ml)					
Removal (6–8 March)	26%	31%	−35%	−33%	
Influent (6–8 March)	4.04E + 04 ± 1.55E + 04	1.61E + 05 ± 1.41E + 04	2.90E + 03	1.20E + 05	
Effluent (6–8 March)	3.0E + 04 ± 4.30E + 02	1.11E + 05 ± 1.55E + 04	3.90E + 03	1.69E + 05	
Removal (8 March)					63%[d]
Influent (8 March)	3.40E + 03 ± 4.10E + 02[c]	1.93E + 05 ± 3.30E + 04[c]			
Effluent (8 March)					2.36E + 04 ± 3.70E + 03[c]
Removal (28–30 May)			64%	−7%	
Influent (28–30 May)			1.40E + 03	1.40E + 04	
Effluent (28–30 may)			5.0E + 02	1.50E + 04	
Enterococci (cfu/100 ml)					
Removal (6–8 March)	–	35%	−11%	82%	
Influent (6–8 March)	–	1.23E + 04 ± 2.05E + 03	1.80E + 03	4.0E + 04	
Effluent (6–8 March)	–	8.0E + 03 ± 8.30E + 02	2.0E + 03	7.30E + 03	
Removal (8 March)					65%[d]
Influent (8 March)	1.60E + 03 ± 4.30E + 02[c]	3.0E + 04 ± 8.20E + 03[c]			
Effluent (8 March)					4.20E + 03 ± 1.0E + 03[c]
Norovirus (numbers/100 ml)					–
Removal (6–8 March)	−14%	−76%			
Influent (6–8 March)	1.0E + 04 ± 2.80E + 03	8.60E + 03 ± 1.62E + 03			
Effluent (6–8 March)	1.14E + 04 ± 2.29E + 03	1.52E + 04 ± 2.34E + 03			
Removal (28–30 May)			−230%	−92%	
Influent (28–30 May)			8.50E + 03	2.91E + 04	
Effluent (28–30 may)			2.81E + 04	5.56E + 04	
Clostridium Perfringens (cfu/100 ml)					–
Removal (28–30 May)			78%	17%	
Influent (28–30 May)			3.80E + 03	2.30E + 03	

(*Continued.*)

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Table 3 | Continued

Parameter	DF receiving MBBR effluent[a]	DF receiving secondary settler effluent[a]	DF receiving MBBR effluent[b]	DF receiving secondary settler effluent[b]	Entire DF unit[c]
Effluent (28–30 may)			7.70E + 02	1.90E + 03	
Somatic coliphages (cfu/100 ml)					–
Removal (28–30 May)			−67%	−100%	
Influent (28–30 May)			9.0E + 03	1.40E + 04	
Effluent (28–30 may)			1.50E + 04	2.80E + 04	
Suspended solids (SS) (mg/l)					
Removal (6–8March)					82.1% (6–8 March)[a]
Influent (6–8 March)					17.6
Effluent (6–8 March)					3.1
Removal (8 March)					78.5% (8 March)[c]
Influent (8 March)					16.3
Effluent (8 March)					3.5
Removal (28–30 May)					93.3% (28–30 May)[a]
Influent (28–30 May)					17.7
Effluent (28–30 May)					1.2
Total P (mg/l)					
Removal (8 March)					60% (8 March)[c]
Influent (8 March)					0.35
Effluent (8 March)					0.14
Total N (mg/l)					
Removal (8 March)					18% (8 March)[c]
Influent (8 March)					9.40
Effluent (8 March)					7.72
Total particle volume (μm^3)					
Removal			96% (8 March)[b]	89% (8 March)[b]	
Influent (8 March)			22.4E−6	7.8E−6	
Influent (8 March)			0.8E−6	0.9E−6	

[a]Composite 24-h sample; [b]Grab samples; [c]Composite 1-h sample; [d]Inflow concentration calculated as numbers in mixed water from all disc filters receiving effluent from MBBR and secondary settlers multiplied with the corresponding flow.

observed. *Clostridium Perfringens* were removed in the discfilter receiving both mainly MBBR and secondary settler effluent with removal efficiencies of 78 and 17%, respectively. The removal efficiency over the entire discfilter plant was calculated from the numbers in the part of the disc filters receiving mainly MBBR and secondary settler effluents, respectively, multiplied with the corresponding flows and compared with the effluent concentration from all filters multiplied with the total flow. This showed a substantially higher number of indicator organisms in the secondary settler effluent compared to in the MBBR effluent but that that concentrations in the total effluent was much lower with removal efficiencies >60% (Table 3). One possible cause for the large variation in results for the different sampling occasions can be problems with sample homogenisation considering the large variation in particle size distribution of the different waters. Some larger particles break up during the passage of the filter cloth leaving a larger number of small particles which are easier analysed for indicator and pathogenic microorganisms, especially when colony counting methods are

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applied. Considering the large variation in data between sampling occasions, disc filters cannot be considered suitable technique for removal of pathogens. Wilén *et al.* (2012) showed that the reduction of indicator organisms is substantially reduced in the activated sludge process, which indicates that the potential for further removal in disc filters is limited.

Since the discfilter plant was placed in operation 2010, the operational strategies have been improved. From 2012 the filter clothes have been cleaned regularly as opposed to previously when they were cleaned when the hydraulic resistance reached a certain level. The rotational speed of the filters has been increased and hence the frequency of backwashing (Table 1). This has increased the hydraulic capacity of the discfilter plant and allows a higher load of SS which also leads to increased capacity of the secondary settlers.

The hydraulic capacity, expressed as maximum flow divided by total filtration area, decreases with increasing SS concentration (Figure 5). This explains the somewhat lower capacity when filtrating water from the MBBR-process. Differences in hydraulic capacity, especially for comparable influent SS concentrations, could be attributed to differences in particle size distribution. Water from the activated sludge contains fewer large particles since these are, ideally, separated in the settling process. Consequently, operational parameters like sludge age could affect the particle size distribution and thereby also disc filter capacity. The particle size distribution from MBBRs is influenced by process parameters such as COD-loading (Ødegaard *et al.* 2010) which in turn could influence both removal efficiency and hydraulic capacity. For the MBBR-process the disc filters serve as the only process for biomass separation. The shift in particle size distribution to relatively larger particles seems favourable for separation by disc filtration (Persson *et al.* 2006; Mattsson *et al.* 2009; Gustavsson & Cimbritz 2013).

Frequent cleaning of the filter cloth is important not only for maintaining the capacity (and thereby avoiding bypass) but also to minimize energy consumption. The energy consumption is mainly related to pressurization of filtered water to approximately 7 bar. With reduced capacity, as a result of long-term fouling of the filter cloths, backwashing frequency increases, which in practice means that more filters are needed to treat the same flow. Thus, by keeping the filter cloths clean the production of pressurized filtered water for backwash can be minimized and thereby also the energy consumption. Energy consumption is 0.013 kWh/m^3 (Nunes *et al.* 2013), which is a minor contribution to the overall energy consumption at the plant. From the same study it can be concluded that the cost for chemical cleaning, on a yearly basis, is very small in comparison to the cost for electricity for the backwash pumps. Therefore regular and frequent backwashing is of outmost importance to keep backwashing at minimum and to maintain the design capacity.

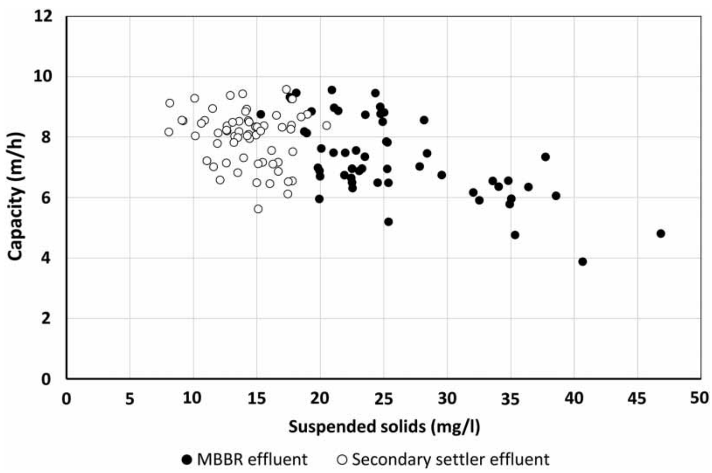

Figure 5 | Hydraulic capacity versus SS concentration (Nov 2012–May 2013). Data corresponds to occasions when the flow from the secondary settler and MBBR made up at least 60% of the total flow.

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CONCLUSIONS

In conclusion, the discfilter plant has performed well since start-up maintaining phosphorus concentrations below 0.3 mg P_{tot}/l and SS below 5 mg/l. Also the secondary settlers can be loaded a bit higher due to the efficient particle separation in the discfilters which increases the efficiency of the whole plant. This study demonstrates successful operation of a large discfilter plant with large variations in flow and particle loading.

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REFERENCES

Gustavsson, D. & Cimbritz, M. 2013 Biomass separation following MBBR for post denitrification – assessment of microscreening. In: *The Nordic wastewater conference NORDIWA*, October 8–10, Malmö, Sweden.
Isaac, P. C. G. & Hibberd, R. L. 1972 The use of microstrainers and sand filters for tertiary treatment. *Water Research* **6** (4–5), 465–474.
Langer, M., Boulestreau, M., Väänänen, J., Bourdon, C. & Lesjean, B. 2012 Advanced phosphorus removal via microsieve filtration in tertiary treatment: performance and operation. In: *Proceedings of 6th IWA Specialised Conference on Particle Separation*, June 18–20, Berlin, Germany.
Mattsson, A., Ljunggren, M., Fredriksson, O. & Persson,, E. 2009 Particle size analysis used for design of large scale tertiary microscreen. In: *Proceedings of 2nd IWA Specialised Conference on Nutrient Management in Wastewater Treatment Processes*, September 6–9, Krakow.
Nunes, J., Fredriksson, O., Lindqvist, P. & Mattsson, A. 2013 Experiences of full scale operation of discfilter as a final treatment step at Gryaab. In: *The Nordic wastewater conference NORDIWA*, October 8–10, Malmö, Sweden.
Ødegaard, H., Cimbritz, M., Christensson, M. & Dahl, C.-P. 2010 Separation of biomass from moving bed biofilm reactors (MBBRs). In: *WEF/IWA Biofilm reactor technology conference*, August 15–18, Portland, OR, USA.
Persson, E., Ljunggren, M., Jansen, J. C., Strube, R. & Jönsson, L. 2006 Disc filtration for separation of flocs from a moving bed bio-film reactor. *Water Science and Technology* **53**(12), 139–147.
Tooker, N., Guswa, S., Horton, J., Hastings, M. & Devalk, C. 2010 Pilot testing for low-level phosphorus removal: confronting non-reactive phosphorus challenges. In: *Proceedings of WEFTEC*, October 26, New Orleans, LA, USA.
Väänänen, J. 2014 Applying coagulation, flocculation and discfiltration in tertiary treatment. Licentiate Thesis, Dept. of Chemical Engineering, Water and Environmental Engineering, Lund University, ISBN 978-91-7422-373-6.
Wilén, B.-M., Johansen, A. & Mattson, A. 2012 Assessment of sludge particle removal from wastewater by disc filtration. *Water Practice and Technology* **7** (2), 1–8.