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Performance and operating experiences of the first Scandinavian full-scale Discfilter installation for tertiary phosphorus polishing with preceding coagulation and flocculation

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Abstract

Microscreening (using Discfilters) is a widely used technology for suspended solids removal in tertiary effluent streams of wastewater treatment plants. Several pilot studies have shown the feasibility of using coagulation and flocculation in combination with microscreens for advanced phosphorus removal, but the number of full-scale references is still limited. In summer 2014, the first Scandinavian full-scale Discfilter installation with 2-stage chemical pre-treatment (coagulation and flocculation) was started up at the Arvidstorp wastewater treatment plant in Trollhättan (Sweden). The results obtained during the first year of operation proved that low suspended solids and total phosphorus effluent values could be achieved (<5 and <0.2 mg/l, respectively). These results were obtained even during heavy rainfall, when biologically and primary treated water were mixed at the influent of the Discfilter installation, before the coagulation and flocculation tanks. Further analysis of the results showed that Discfilter in combination with coagulant and polymer pre-treatment is a robust and reliable technology with low energy demand (34 Wh/m^3) and a high recovery (1.9 $\pm$ 0.4% of influent flow discharged as reject).

Key words: coagulation, filter, flocculation, micro-screen, treatment plant, wastewater

INTRODUCTION

Discharge of eutrophying substances in the environment has significantly decreased in recent decades. However, wastewater treatment plants (WWTPs) are still the source of 15% of the anthropogenic phosphorus (P) released in Swedish water bodies (SEPA 2014). Consequently, more stringent effluent requirements on total phosphorus (TP) are expected in the future.

Microscreening (using Discfilters) is a widely used technology for total suspended solids (TSS) removal in tertiary effluent streams of WWTPs. Previous studies conducted at the Rya WWTP in Gothenburg (Mattsson *et al.* 2009; Wilén *et al.* 2012; Nunes *et al.* 2013a; Wilén *et al.* 2015) have shown the possibility to achieve very low concentrations of TSS (<5 mg/l) and TP (<0.3 mg/l) based on a treatment configuration with simultaneous precipitation and filtration by Discfilters as the final solids separation method.

Several pilot studies have been conducted in order to investigate the feasibility of using coagulation and flocculation (as a 2-stage chemical pre-treatment) in combination with microscreens (10 micron in pore size) for advanced P removal to reach very low TP effluent concentrations (Langer *et al.* 2012;

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Tooker *et al.* 2012; Väänänen 2014). This treatment line in practice corresponds to post-precipitation with floc separation in Discfilters. Based on careful design of the coagulation and flocculation processes, including control of dosing, retention times and mixing intensities, TP concentrations <0.1 mg/l could be consistently achieved. Such low TP concentrations in the filtrate could be achieved irrespectively of flow and temperature fluctuations. Microsieves performing this process have a smaller footprint than conventional dual media filters (Persson *et al.* 2006) and display a lower energy demand and carbon footprint than other membrane processes (Remy 2013).

In summer 2014, the Arvidstorp WWTP in Trollhättan (Sweden) implemented Discfilters preceded by 2-stage chemical treatment with metal-based coagulant and polymer to achieve monthly average effluent TP concentrations below 0.3 mg/l. The present paper summarizes the start-up, results and operational experience of the first Scandinavian Discfilter facility featuring advanced P removal. Furthermore, it gives an insight to chemical and energy consumption and proposes strategies to optimize operation and improve results.

MATERIALS AND METHODS

Arvidstorp WWTP

The Arvidstorp WWTP is designed for 62,000 population equivalents and treats the wastewater from residents living in the Trollhättan municipality, where about 52,000 inhabitants are connected to the municipal sewage network today (Walleback 2015).

The mechanical pre-treatment at the site features fine screens (3 mm) and sand and grit removal (Figure 1). Ferric chloride is dosed before the screens for pre-precipitation. The created flocs are strengthened by adding a polymer in the aerated sand trap and finally settled in the primary clarification step. The subsequent secondary biological treatment aims for BOD and N removal with an activated sludge system (Kraus process).

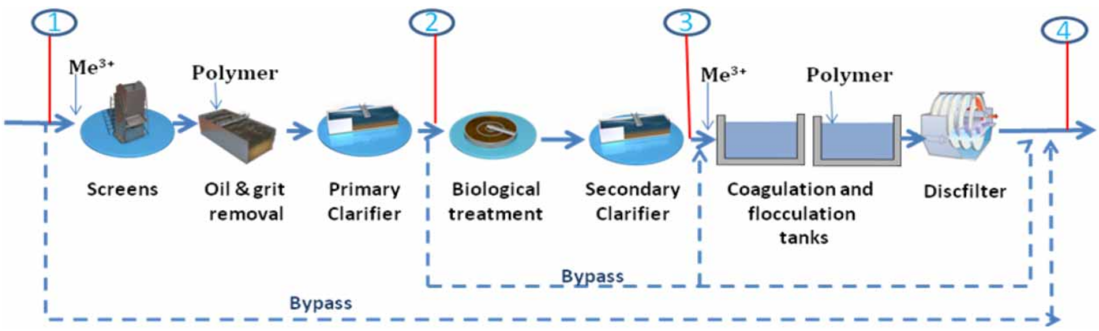

Figure 1 | Schematic layout of Arvidstorp WWTP (numbers 1–4 are sampling points).

A new polishing step consisting of coagulation and flocculation chambers (2 lines in parallel) and six Discfilters (HSF2626/18-2F, Hydrotech, Sweden) was installed in 2013 to achieve monthly average effluent TP concentrations below 0.3 mg/l. The WWTP is located 35 m underground, but 12 m above sea level, with limited expansion possibilities. Discfilters were selected due to their small footprint compared to other technologies (e.g. dual media sand filters).

Each Discfilter has 18 vertically mounted discs with 10 micron filter cloth panels offering a total filtration area of 821 m^2. It is possible to mount 8 additional discs on each filter for an eventual increase of the plant's capacity. The installation was commissioned in summer 2014. Detailed description of the Discfilter operation is available elsewhere (Ljunggren 2006). The installation was dimensioned for a maximum flow of 2,700 m^3/h, of which 1,800 m^3/h is effluent from the biological treatment and up to

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900 m^3/h can be by-passed after the primary clarification tank during heavy rainfall. Both streams are mixed at the influent of the Discfilter installation, before the coagulation and flocculation tanks.

Previous experiences have shown the importance of the chemical pre-treatment design to optimize plant operation (Väänänen *et al.* 2013). In the Arvidstorp WWTP the coagulant is dosed in a separate flash mixing tank, thereafter water is directed to a coagulation tank where flocs are allowed to grow and react. Between the coagulation and flocculation tank there is a set of baffles that avoid short-circuiting and promote the increase of the water velocity to ensure proper polymer dispersion.

The present paper summarizes operation data from the period June 2014 to June 2015.

Applied chemicals

During the first three months of operation (June-September 2014), the Discfilter installation was operated without chemical pre-treatment. Thereafter the 2-stage chemical pre-treatment was started up by sequentially adding coagulant and polymer for P precipitation prior to the Discfilters. Dosage of Polyaluminum chloride (PAX-XL360, Kemira Ltd., Finland), was 2 mg Al^{3+}/l throughout the monitored period. The dose of anionic polymer (Flopam An 923SH, SNF Nordic, Sweden) was reduced from 1 mg/l (Dosing 1) to 0.7 mg/l (Dosing 2) in November 2014.

Chemical cleaning of the filter panels was routinely carried out with hydrochloric acid (HCl, 9%) to remove mineral precipitates (*e.g.* aluminum and carbonated compounds). Thereafter, the panels were washed with filtered water at 0.8 MPa. After that, sodium hypochlorite (NaClO) was diluted to 3%, and applied on the filter panels for biofouling remediation. The chemical cleaning sequence concluded with a final rinse with water at 0.8 MPa. In order to decrease the risk of forming chlorine gas (Cl_2), two separate pipes with spraying nozzles facing the filter panels were mounted under the cover of each filter for separate acid and NaClO dosage. Chemical cleaning was performed in semiautomatic fashion, by using the installed nozzles and manual activation of each cleaning sequence described above.

Water quality analyses

Daily average samples were collected by autosamplers (Efcon®, the Netherlands) in the WWTP influent, the primary clarifier effluent, and the WWTP effluent. The effluent from the Discfilter installation, the combined sewer overflow, the water bypassing the biological treatment and the Discfilters (if any) are combined and discharged to the Göta Älv River (Figure 1). Therefore, the WWTP effluent concentrations presented here represent an average quality of these water streams.

Determination of TP, orthophosphate (PO_4-P), biological oxygen demand (BOD_7), TSS, and total nitrogen (TN) in these samples were performed at the Arvidstorp WWTP laboratory according to national standard methods.

VisoLid® 700 IQ (WTW, Germany) was used for online determination of TSS in the influent and effluent of the Discfilter installation. P700 lQ analyser (WTW, Germany) allowed for online monitoring of PO_4-P in the influent of the Discfilter installation. TresCon analysers OP210 and OP510 (WTW, Germany) were additionally installed for online determination of PO_4-P and TP in the effluent samples of the WWTP.

RESULTS AND DISCUSSION

Impact of the Discfilter installation on the overall WWTP performance

The stricter annual effluent limits for TP from 0.5 to 0.3 mg/l as flow proportional annual average were coming into force after the 1st of July 2013. The Discfilter installation was delayed until June

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2014. Consequently, the average TP concentrations for quarters 1 and 2 of 2014 were higher than allowed in this period (0.40 and 0.56 mg/l). TP concentrations below 0.3 mg/l were achieved consistently after the start-up of the Discfilter installation for tertiary P removal (Table 1).

Table 1 | Effluent quality of the WWTP during 2013–2014 (Örning 2014; Wallebäck 2015)

	BOD_7 (mg/l)		TN (mg/l)		TP (mg/l)	
	2013	2014	2013	2014	2013	2014
Effluent of WWTP						
Quarter						
1	12	12	15	11	0.43	0.4
2	9	14	12	13	0.36	0.56
3	4	7	11	10	0.32	0.25
4	9	7	10	9	0.45	0.16
Annual average						
Half year 1 average	9	10	12	11	0.46	0.46
Half year 2 average					0.41	0.2
Effluent requirements						
Annual average						
Half year 1 average	10		15		0.5	0.3
Half year 2 average					0.3	

Effluent requirements for TN and BOD at the treatment plant were 15 mg/l and 10 mg/l, (respectively) as flow proportional annual average. Despite of slightly elevated BOD levels (higher than 10 mg/l) during the first quarter of 2013 and first two quarters of 2014, the requirements on the effluent annual average were fulfilled throughout 2013 and 2014 (Table 1).

Performance of Discfilter installation

Online measurements of TSS and PO_4-P

TSS measurements are not included in effluent quality permits, however TSS online measurement was installed in order to monitor the performance of the Discfilter installation and to help to discover any deviations in the filtration process. Without chemical pre-treatment prior to the Discfilter, the installed online measurement equipment recorded an average of 3.9 ± 2.0 mg TSS/l in the Discfilter effluent (Table 2). An average value of 5.4 ± 3.6 mg TSS/l was obtained by analysing the WWTP effluent daily composite samples in the laboratory (Figure 2(b)) during the same period, which included

Table 2 | PO_4-P and TSS removal at the Discfilter installation with and without chemical pre-treatment (Online measurements)

	PO_4-P			TSS		
	Without chemicals	Dosing 1*	Dosing 2**	Without chemicals	Dosing 1*	Dosing 2**
Influent	0.31 ± 0.12	0.41 ± 0.13	0.43 ± 0.10	18.1 ± 10.8	31.9 ± 16.6	17.7 ± 12.5
Effluent	0.20 ± 0.09	0.14 ± 0.10	0.13 ± 0.08	3.9 ± 2.0	2.3 ± 1.1	2.7 ± 1.2
% removal	22 ± 60	66 ± 18	70 ± 16	75 ± 11	92 ± 4	80 ± 9
n	30	10	26	31	10	53

*__Dosing 1__: 2 mg Al^{3+}/l (PAX-XL360) and 1 mg/l anionic polymer (Flopam An 923SH).
**__Dosing 2__: 2 mg Al^{3+}/l (PAX-XL360) and 0.7 mg/l anionic polymer (Flopam An 923SH).
n – number of daily average results.

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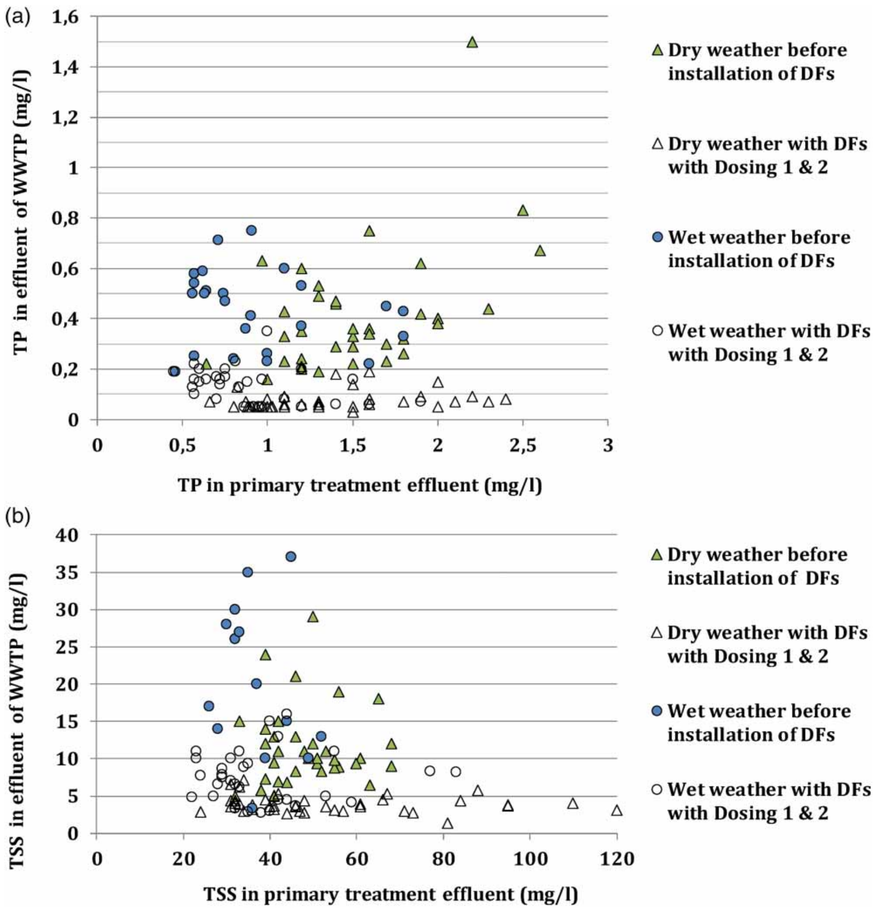

Figure 2 | TP (a) and TSS (b) concentrations in the effluent of primary treatment and WWTP (daily composite samples) before and after installation of the Discfilter plant during different weather conditions.

effluent from the Discfilter installation, the combined sewer overflow, the water bypassing the biological treatment and the Discfilters. Therefore a higher TSS absolute value and variation can be expected from daily composites. However, both type of measurements indicate that reliable TSS removals by the discfilter installation leading low effluent TSS values in the WWTP.

Wilén *et al.* (2012) reported average TSS concentration of 4.2 mg/l in the effluent from a similar full-scale Discfilter installation (with 15 μm filter media) at the Rya WWTP (Gothenburg). In addition, a pilot test for water reclamation of secondary effluent at WWTP Castellón de la Plana (in Spain) showed that ACTIDisc® process (a combination of the process Actiflo with Discfilter) can provide an effluent similar in TSS (<5 mg/l), for similar influent TSS concentrations (24 mg TSS/l) (Sanz *et al.* 2007).

Higher TSS removals were achieved with chemical pre-treatment compared to filtration without chemical additions despite the higher influent concentrations to the Discfilters (Table 2). When chemical pre-treatment was applied an average online TSS concentrations of 2.3 ± 1.1 and 2.7 ± 1.2 mg/l in the Discfilter effluent (with Dosing 1 and 2) were achieved. Average TSS concentrations of 3.7 ± 2.4 and 5.8 ± 3.1 mg TSS/l (with Dosing 1 and 2) were determined in the composite grab samples of the WWTP effluent (Figure 2(b)). However, it remains unclear if the higher polymer dosage (Dosing 1 compared to Dosing 2) or higher TSS concentrations in the influent are the reason for the increased removal.

The removal of dissolved phosphorous (PO_4-P) by the Discfilter with the 2-stage chemical pre-treatment was close to 70%. Removal of PO_4-P by the Discfilter without chemical pre-treatment was around 22%. This value was much higher than expected and could be explained by analytical errors of the online measurement equipment at such low P concentrations.

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Performance during wet and dry weather conditions

During dry weather, TP and TSS concentrations in the WWTP effluent were between 0.16–1.5 mg TP/l and 5–29 mg TSS/l prior to the Discfilter installation, whereas concentration values in the WWTP effluent were much lower (0.03–0.2 mg TP/l and 1–7 mg TSS/l) after the Discfilter installation with Dosing 1 and 2 (Figure 2). Previous studies conducted at the largest WWTP in Berlin (Langer *et al.* 2012) have also shown the possibility to achieve very low concentrations of TSS ($<$5 mg/l) and TP ($<$0.1 mg/l) with similar chemical dosing and secondary effluent quality (0.3 mg TP/l). TP values under 0.05 mg/l have been reported in Discfilter tertiary effluent with the similar upstream coagulation/flocculation process, but with a higher chemical dose (Langer *et al.* 2012; Väänänen 2014).

A similar trend was also recorded during high flow situations (*i.e.* wet-weather events). While the WWTP effluents contained 0.2–0.8 TP/l and 3–37 mg TSS /l before the Discfilter installation during these high flow conditions, effluents 0.05–0.35 mg TP/l and 3–16 mg TSS/l were recorded during Discfilter operation with Dosing 1 and 2. During 2014, 12% of the total influent flow bypassed the biological treatment and as much as 50% of the incoming flow could be bypassed during a single wet-weather event and treated in the Discfilter installation. The collected data shows higher TSS concentrations in the WWTP effluent when biologically and primary treated water were mixed before the coagulation and flocculation tanks (the higher the by-passed flow, the worse the effluent quality). However, the overall performance of the WWTP became less sensitive to limited capacity of the biological treatment or the influent flow variations after installation of the Discfilter plant.

All 6 Discfilters were equally loaded. Bypassing of the Discfilters occurred only during 2.6% of the total operational period described here (periods where the design capacity was surpassed). The operation expenses of the plant could be lowered by adjusting the number of units in operation depending on the actual mass loading into the Discfilter installation. Since the Discfilter installation is designed for treating peak flows and peak TSS, during the dry weather conditions, not all the filters need to be in operation. Reducing the number of filter units in operation during dry weather conditions would lead to a slight increase of the backwash frequency of the installation, but a lower overall energy consumption due to a lower amount of units required treating the flow. Other advantages of this operation mode would be a lower clogging rate of the filters taken offline and a better management of chemical cleaning operations. The offline filter units would be required to restore normal operating conditions every 12–24 h in order to avoid biofouling of the filter panels and the filter walls.

Backwash water production

During Discfilter operation, a part of the effluent is reused for backwashing at a pressure of 0.8 MPa without interruption of the filtration process. Average backwash time during the reported operational period was 30% indicating that full capacity of the Discfilter plant was not utilised during average conditions. Backwash water (BWW) production oscillated between 0.4 and 2.5% (1.4 $\pm$ 0.5% in average) of the total influent flow to the Discfilter plant in periods without chemical pre-treatment. The BWW production increased with chemical pre-treatment (between 1.1 and 3.6%, 1.9 $\pm$ 0.4% in average). Values around 2–3% are expected in tertiary Discfilter installations like the one in Trollhättan (Väänänen 2014). Average TSS loading to the Discfilter was 28 g TSS/m^2/h without chemical pre-treatment, 48 g TSS/m^2/h with Dose 1, and 34 g TSS/m^2/h with Dose 2. Therefore, the higher TSS loading rates during the period with chemical pre-treatment could explain the higher BWW production during this period. The reported volumes are overall lower than for dual media filters with a reported consumption of 4% of the influent flow (Remy 2013).

The total solids (TS) content of the BWW varied between 0.11 and 0.75%. This flow was directed to a flotation unit, where it was thickened to 3% with polymer. The reject water from the thickening step was pumped back upstream the WWTP.

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Chemical cleaning

Long-term fouling, meaning fouling which is not removed by conventional backwash, is removed by chemical cleaning of filter panels whereby original filtration capacity is regained.

However, the formation of this type of fouling can lead to a lower nominal pore opening and a potential improvement of the TSS and TP removal efficiencies as indicated by Nunes *et al.* (2013a). However, this operating scenario also involves a more frequent backwash frequency and a higher energy consumption (backwash pump and drum rotation). Thus, the selection of frequencies for chemical cleaning becomes a trade-off between maintaining good filtration fluxes, maintaining a low particle content in the filtered water, and minimization of the energy consumption for backwashing.

During the first year of operation of the Arvidstorp WWTP, chemical cleaning of the filter panels with both HCl and NaClO took place approximately every 6th week. Given the low amount of water that bypassed the Discfilters (2.6% of the total WWTP flow) this cleaning frequency seems appropriate in terms of maintaining sufficient treatment capacity. Future studies would show whether this interval is appropriate in relation to increased specific treatment costs due to clogging (increasing BW time for the same loading), the cost for chemical cleaning, and the removal efficiencies.

Operational experiences

Chemical cost

The purchase of coagulant and flocculant was by far the highest cost related to chemical use. The plant had flow-proportional dosing of both coagulant and polymer. The online measurements indicate that the concentration of PO_4-P in the influent to the Discfilter installation varied from 0.06 to 0.60 mg/l (averaging 0.37 mg/l) during the first year of operation. In order to optimise chemical use in the pre-treatment stage, load proportional feed forward dosing relying on online monitoring of the influent PO_4-P concentration could be implemented instead. Moreover, this dosing strategy would avoid coagulant and polymer overdoses, which could impair the filtration fluxes. More stringent TP effluent requirements on WWTPs are expected to be enforced in the next decade. Therefore, implementation of dosing control at even lower PO_4-P levels in the polishing treatment steps will be dependent on availability of reliable and accurate online measurement equipment at low P concentrations.

Cost of chemical cleaning at the Arvidstorp WWTP was about 15,810 SEK/year (Table 3). The cost in terms of HCl and NaClO consumption amounted 14.9 and 4.3 SEK/year per m^2 of filter media, respectively. Overall, the cost of the chemicals used for chemical cleaning (0.0015 SEK/m^3) was insignificant compared to the chemical cost associated to the chemical pre-treatment (0.07 SEK/m^3).

Table 3 | Amount of chemicals used in conjunction with chemical pre-treatment prior to the Discfilters and chemical cleaning of Discfilter panels

	Consumption L/year (or kg/year‡)	Cost SEK/year
Chemical cleaning		
HCl	5,200	12,250
NaClO	312	3,560
Chemical pre-treatment*		
Coagulant**	240,000‡	550,800
Anionic polymer**	8,040‡	168,840
Total		735,450

*It was assumed that the pre-treatment was continuously in operation at Dose 1 (maximum annual chemical consumption).
**The coagulant PAX-XL360 costs 2,295 SEK/ton and the polymer 21 SEK/kg.
‡Annual chemical consumption is in kg/year.

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Maintenance work

About 38 min/year/m^2 were used in total in the Arvidstorp WWTP for maintenance work. Chemical cleaning was the most time consuming maintenance procedure, as it was performed semi-automatically. Installation of a fully automated system would impact positively the maintenance costs of the plant. Inspection and cleaning of the 1,512 backwash nozzles was the second most time consuming activity (Table 4). The backwash strainer (200 μm), which protects the backwash nozzles from big particles, was also cleaned manually when pressure decreased below 0.8 MPa. Maintenance costs could be decreased further by installing self-cleaning nozzles and self-cleaning strainers.

Table 4 | Maintenance work for the operation of Discfilter installation

Maintenance work	Interval	Hours/year	Min/year/m^2
Chemical cleaning of filter panels	Every 6th week	208	15.2
Cleaning of BW water filter	Every week	52	3.8
Inspection and cleaning the nozzles and lubrication	Every second week	156	11.4
Cleaning of on-line measurement and analysis equipment	Every week	104	7.6
Total		520	38

The manpower needs for maintenance in the Arvidstorp WWTP contrasts with the 21.6 min/year/m^2 spent for maintenance work at the Rya WWTP in Gothenburg (Nunes *et al.* 2013b). The installation in Gothenburg is designed for tertiary treatment without P precipitation (Mattsson *et al.* 2009). The lower maintenance time needed in Gothenburg could be related to the lack of chemical pre-treatment, the centralized backwash pumping circuit, and the centralized automated chemical cleaning system.

Table 5 | Energy demand for the Discfilter installation and for equipment used for chemical pre-treatment step

Process	Used instrument	Rated power kW	Quantity	Energy consumption kWh/day	Energy consumption Wh/m^3
Coagulation	Pumps	0.55	1	13.2	0.5
	Motors for dispersion	3	1	72.0	2.5
	Motors for mixers	1.5	2	72.0	2.5
Flocculation	Pumps	0.2	2	9.6	0.3
	Mixers	2.2	2	106	3.7
6× Discfilter	BW pump	15	6	648	23
	Drive motor	1.1	6	47.5	1.7
	Total			968	34

Consumption of spare parts

Two out of six backwash strainers were exchanged in late January 2015. During one year operation, 12 filter panels out of 3,024 were exchanged.

Energy demand

The average energy consumption for the chemical pre-treatment and the Discfilter installation was estimated to be 34 Wh/m^3 filtrated water (Table 5). During high flow conditions, the energy

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demand per m^3 is lowered to 27 Wh/m^3 due to fact that the energy consumption for the mixing equipment in the coagulation and flocculation stage is the same and not dependent on the flow variation in the WWTP. The measured energy consumption was 13 Wh/m^3 for the Discfilter installation (without chemical pre-treatment) in the Rya WWTP in Gothenburg. (Nunes *et al.* 2013a). If chemical dosing is only periodical then the energy consumption will be expected to be in the range of 13–34 Wh/m^3.

The energy consumption estimated in the Arvidstorp WWTP can also be compared to the 30 Wh/m^3 estimated from a pilot-scale study conducted at the Ruhleben WWTP, Berlin, Germany (Langer & Schermann 2013). In comparison Remy (2013) reported 41 Wh/m^3 for dual media filters and about 70 Wh/m^3 for UF membranes in tertiary treatment for advanced phosphorus removal.

The energy consumption in WWTPs varies from country to country, but mostly depends on the treatment processes, WWTP size, pumping requirements, treated wastewater quality requirements, and operation and maintenance practices (Silva & Rosa 2015). Average energy consumption for treatment of municipal wastewater in Sweden is 750 Wh/m^3 (Lingsten & Lundkvist 2008). Thus, the estimated energy consumption (based on total installed power of the drive motors) for Discfilter installation with chemical pre-treatment corresponds to 5% of total energy demand of Swedish WWTPs. In comparison, it has been reported that a sandfilter requires about 10% of total WWTPs energy demand (De Gussem *et al.* 2011).

More in detail, the present assessment indicates that, similarly to the Rya WWTP (Nunes *et al.* 2013a), the energy for maintaining 0.8 MPa in the backwash was higher compared to the cost of chemical cleaning. Therefore, the frequency for chemical cleaning of the filters should be optimized as previously mentioned in order to keep clogging at a low level and achieve higher filtration fluxes over time at the lowest energy use.

Annual discfilter plant operation expenses

Annual operation expenses of the Arvidstorp Discfilter installation with chemical pre-treatment are estimated to be about 1.4 million SEK. The proportions between the main costs for annual operation expenses were evaluated to be as following: about 51% for the chemicals used for chemical pre-treatment, 22% for the maintenance work, 18% for the backwashing of six Discfilters, 7% for energy consumption for equipment in the coagulation-flocculation step and 1% for the chemicals used for chemical cleaning.

CONCLUSIONS

The results obtained during the first year of operation of the Arvidstorp Discfilter plant with 2-stage chemical pre-treatment proved that reliable TSS and TP removal effluent values can be consistently achieved (<5 mg/l and <0.2 mg/l, respectively). The installation of Discfilters with 2-stage chemical pre-treatment has avoided the release of over 3 tones of P/year into Göta Älv River. The installed tertiary treatment stage proved to be robust, reliable, and with a low energy use of about 34 Wh/m^3 filtrated water while generating minimal reject volumes (about 2% of influent flow).

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