PAC retention by Mecana pile cloth filter

Piloting at Viikinmäki WWTP
Part of the CWPharma project

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1 Introduction

1.1 Background

CWPharma (Clear Waters from Pharmaceuticals) is a project funded by EU's Interreg Baltic Sea Region Programme. CWPharma will give tools and recommendations to policy makers, authorities and municipalities on the best ways to reduce emissions of pharmaceuticals in the Baltic Sea Region. In the work package (WP) 3 of CWPharma, advanced wastewater treatment to remove pharmaceuticals from wastewater is studied.

Primarily ozonation and activated carbon treatment can be considered as mature technologies for removing pharmaceuticals from municipal wastewater. Even though ozonation is effective in removing pharmaceuticals, it produces by-products with potential ecotoxicological effects. WP3 explores the alternatives for post-treatment after ozonation to reduce ecotoxicity. The most well-known method for removing ozonation by-products from wastewater is treatment by powdered activated carbon (PAC). The removal capacity of PAC is well-known in literature, but the separation of PAC from wastewater requires further study.

Helsinki Region Enviromental Services Authority (HSY) has studied the separation of PAC from wastewater at Viikinmäki WWTP with three different technologies. The focus of the study has been in process operation and optimization, not in the removal of pharmaceuticals. The performance of PAC in removing pharmaceuticals and the effects of PAC dosage and residence time on micropollutant removal from wastewater have been previously studied at Viikinmäki WWTP in laboratory scale in 2015 (Castrén 2016).

In this study, the applicability of pile cloth filtration was tested for PAC retention in pilot-scale. A small-scale piloting unit of the Mecana disc filter by Mecana Umwelttechnik GmbH was applied for trial runs at Viikinmäki WWTP.

1.2 Objectives of study

The main objective of the pilot was to examine the retention of PAC by pile cloth filtration. The focus of the pilot was on PAC retention by the Mecana disc filter, without using other chemicals. Two different PAC products with different particle sizes were used and their operational applicability compared.

Research questions:

- How well can PAC be separated with a pile cloth filter?
- What are the effects of PAC on the pile cloth filter?
- Does PAC particle size affect the results?
- How can the amount of PAC breakthrough be assessed?

2 Material and methods

2.1 Piloting arrangements

2.1.1 Piloting equipment

The suitability of pile cloth filtration in the removal of powdered activated carbon was tested with the Minifilter piloting equipment by Mecana Umwelttechnik GmbH. The Minifilter was rented for the period of August and September 2018. The filter area of the Minifilter was 0.04 m^2, and the flow rate was kept at 0.5 m^3/h, in accordance with the manufacturer’s instructions. Water used in the pilot was effluent wastewater from Viikinmäki WWTP, which is further described in Chapter 0.

The Mecana Minifilter piloting equipment is illustrated in Figures 1 and 2. Powdered activated carbon (PAC) was added straight to the filtration chamber, dosed from a stock solution using a peristaltic pump. PAC dosing point was above the inlet, so that PAC could mix with the influent flow. A separate maturation tank would have been needed before the Minifilter if the removal of pharmaceuticals was a research objective. However, this study focused on the separation of PAC from wastewater using the Mecana Minifilter, and therefore PAC maturation was not included.

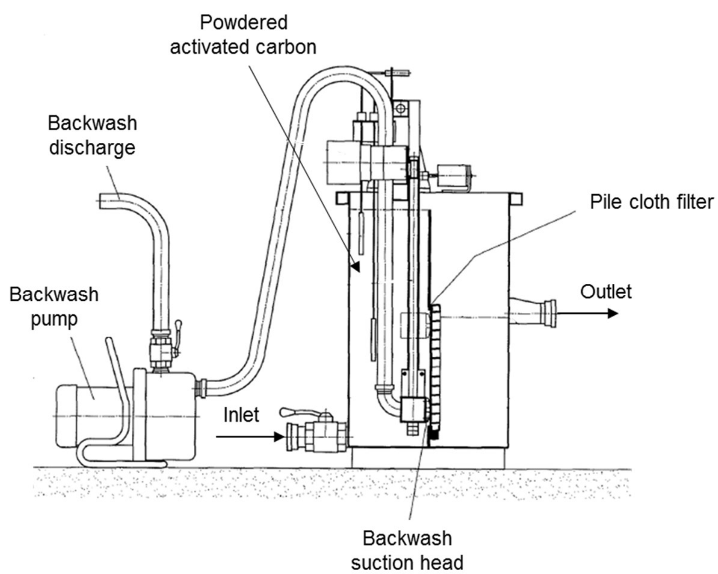

Figure 1. Process configuration of the Mecana Minifilter pilot

Figure 2. Mecana Minifilter piloting unit

The filter cloth used in the pilot was the PES-14 OptiFiber® Pile Cloth Media (Figure 3). This pile fabric is made of polyester and has the nominal cut-off size of 5 µm. The cut-off size corresponds with the pore size in different types of filters. However, the actual width of the gaps between fibres becomes less than 5 µm, when the fibres go flat against the water flow. Backwash sucks the filter cake and combs the fibres up. Removing the filter cake increases the gaps between the fibres, and filtration results can therefore be temporarily reduced. Filtration is continuous i.e. backwash does not interrupt filtration.

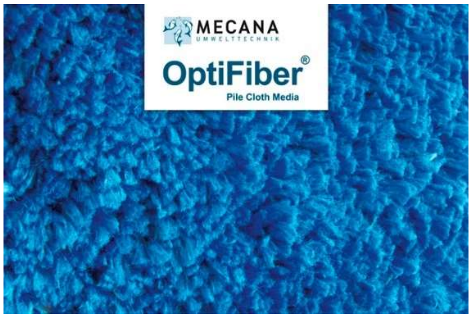

Figure 3. Filter cloth used in the pilot (picture by Mecana Umwelttechnik GmbH)

Full-scale Mecana disk filters have fully immersed, slowly rotating pile cloth filters, with stationary suction heads to remove solid cake from the filter. By contrast, the Minifilter has a square filter cloth, and the suction head ascends to the top of the filter when water level rises in the filtration chamber (see Figure 1). Sludge and activated carbon are only removed by the suction head in the Minifilter. Full-scale Mecana disk filters suck also the settled sludge from the bottom of the filtration chamber. These differences between the set-up of the Minifilter and the full-scale disk filter allow only for certain conclusions to be made about the suitability of the Mecana disc filter for PAC removal. Mainly the properties of the pile cloth fabric can therefore be evaluated.

2.1.2 Chemicals

The only chemicals used in the pilot were two types of powdered activated carbon. The properties of the two PAC products used are listed in Table 1. Both PAC products were tested with concentrations of 10 mg/L, 20 mg/L, 30 mg/L and 50 mg/L. PAC was dosed straight to the filtration chamber with a peristaltic pump. Both carbon types were doses from continually mixed stock solutions with the concentration 50 g/L.

Table 1. Properties of PAC products used

	AquaSorb® MP25 PAC-C	Norit SAE Super
Supplier	Jacobi	Cabot
Raw material base	Mineral coal	Mineral coal
d50	35-50 µm	15 µm
Total surface area (BET)	1150 m^2/g	1150 m^2/g

The particle size of PAC affects the removal of pharmaceuticals. Finer PAC is able to adsorb pharmaceuticals more efficiently, and therefore smaller dosing or shorter contact time can be sufficient, depending on what is the goal for pharmaceuticals removal. For PAC retention, the particle size distribution is significant. For Norit SAE Super, the particle size distribution is shown in Figure 4. The graph shows that approximately 20% of the particles in Norit SAE Super are smaller than 5 µm, and therefore below the pore size of the Mecana pile cloth filter. Although the average particle size of AquaSorb® PAC-C is larger than that of Norit SAE Super, it is likely that there is also a significant portion of particles smaller than 5 µm in PAC-C.

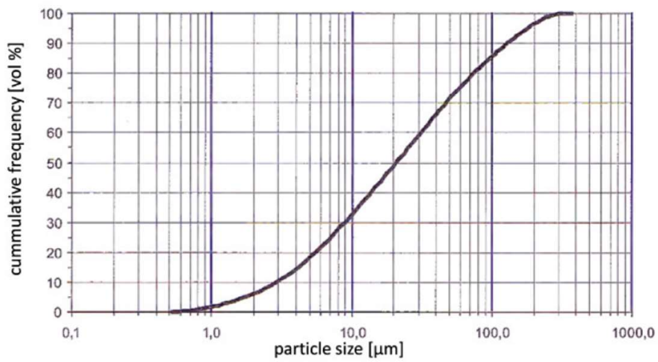

Figure 4. Particle size distribution in Norit SAE Super powdered activated carbon.

2.1.3 Influent

Water used as the influent for the Mecana pile cloth filter came from the technical water system of Viikinmäki WWTP. Technical water is treated wastewater, which is collected from the effluent tunnel. Technical water is collected for various uses at the plant, such as the dilution of polymer used for sludge dewatering. The quality of water pumped from the technical water system is essentially equivalent to the quality of Viikinmäki WWTP effluent.

Piloting with PAC took place from 11 July to 9 August 2018. The quality of the Viikinmäki WWTP effluent during this time is listed below in Table 2, for biological oxygen demand (BOD), chemical oxygen demand (COD_{Cr}) and suspended solids (SS).

Table 2. Viikinmäki WWTP average effluent quality during during August and September 2018

	BOD (mg/L)	COD (mg/L)	SS (mg/L)
Average	4.22	39	2.9
Maximum	5.81	57	3.9
Minimum	3.08	30	1.9

2.2 Analyses

2.2.1 Laboratory analyses and sampling

The breakthrough of PAC through the pile cloth filter was monitored by laboratory analyses to evaluate the performance of the pilot. Two parallel 1 L samples were taken from both the influent and the effluent after changes in PAC dosing. The sampling points were the inlet pipe before chemicals, and the outlet pipe after the Minifilter. The effluent samples were taken first, and then the inlet pipe was disconnected to get influent samples. Samples were taken after at least one hour of successful PAC dosing.

The samples were sent to an external laboratory (MetropoliLab Oy) to be analysed for turbidity, suspended solids (SS) and chemical oxygen demand (COD_{Cr}). The methods used by MetropoliLab Oy are listed in Table 3.

Table 3. Laboratory analyses performed by Metropolilab Oy

Parameter	Method	Uncertainty	Unit
Turbidity	SFS-EN ISO 7027	15%	FNU
Suspended solids	SFS-EN 872:2005	10%	mg/L
COD_{Cr}	ISO 15705:2002	15%	mg/L

2.2.2 Other analyses

Turbidity of influent and effluent were monitored on-site with a portable turbidity meter (Hach 2100Q IS Portable Turbidimeter). Additionally, the amount of PAC breakthrough was assessed by filtrating samples through glass fibre filters as in the studies by Langer (2013) and Isgaard & Thörnqvist (2016). A fixed volume of sample was filtrated through 0.5 µm glass fibre filter (MN GF-2) to visually compare the amount of PAC in the effluent.

The concentrations of pharmaceuticals in the pilot influent and effluent were analysed at Aarhus University, which is a project partner in CWPharma. Although the removal of pharmaceuticals was not optimised in this study, samples were sent to Aarhus University to get comparable results between different CWPharma pilots. No other analyses were made to determine the removal of pharmaceuticals.

2.3 Trial planning

Trial runs with the Mecana Minifilter with PAC lasted for approximately three weeks, from 16 August to 4 September 2018. Trial runs were conducted only during office hours, on weekdays. Operation was started with an unused pile cloth filter. First, samples were taken without any addition of PAC. The remaining time was divided between trial runs first with Aquasorb PAC-C and then with Norit SAE Super. Four different doses of PAC were tested with each PAC type: 10 mg/L, 20 mg/L, 30 mg/L and 50 mg/L. In between the trial runs with each PAC type, the filter was cleaned with water as thoroughly as possible without removing the filter panel.

3 Results

3.1 Assessing the amount of PAC breakthrough

3.1.1 Effluent quality

Figures 5-7 present the changes in influent and effluent quality during the course of piloting, measured by turbidity, suspended solids and chemical oxygen demand. The dosing of each carbon type is marked with grey. The average results of each sampling time (average results of duplicate samples) are presented.

Figure 5 shows that the influent turbidity was stable at around 1.2 FNU. Without any PAC addition, effluent turbidity was smaller than influent turbidity or the same. With PAC addition, effluent turbidity increased roughly in relation to the PAC concentration. The scale of changes in effluent turbidity corresponds with the results of the filtration tests (see Chapter 3.1.3).

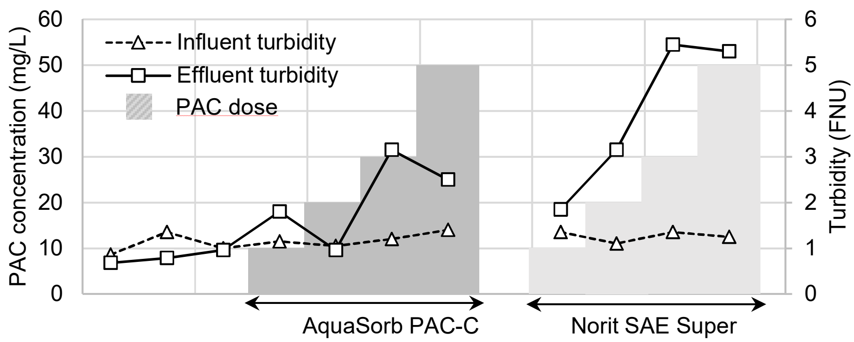

Figure 5. Changes in turbidity during the PAC trial runs with the pile cloth filter.

The analysis of suspended solids has the detection limit of 2 mg/L. Several samples of the influent fall below the detection limit, and their values in Figure 6 are represented as zero. Figure 6 shows that without PAC addition, the concentration of suspended solids in the effluent was below detection limit. With increasing PAC concentrations, effluent SS however increases, apart from the 20 mg/L dosing of AquaSorb® PAC-C.

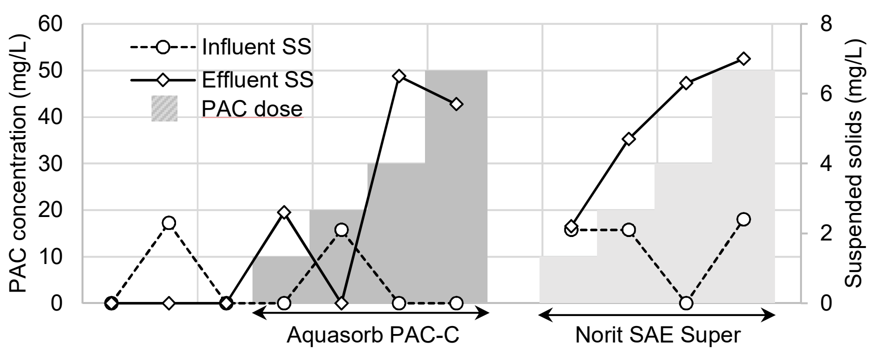

Figure 6. Changes in suspended solids during the PAC trial runs with the pile cloth filter. SS values below detection limit are shown as zero.

The average chemical oxygen demand of Viikinmäki effluent was 39 mg COD/L during the piloting period (see Table 2). Figure 7 shows that the COD_{Cr} results reflect mainly the influent quality and are therefore unsuitable in detecting the amount of PAC in the effluent.

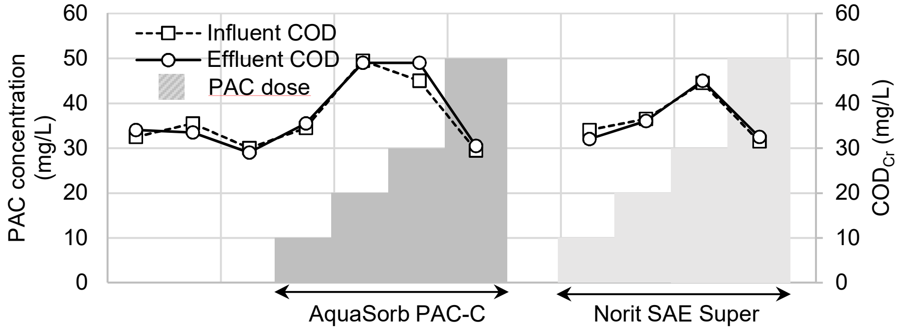

Figure 7. Changes in COD during the PAC trial runs with the pile cloth filter.

3.1.2 Correlation between analyses

The correlation between turbidity and suspended solids in the effluent is shown in Figure 8. The figure shows that suspended solids correlate with turbidity, although a difference can be seen between the carbon types. With the finer Norit SAE Super, turbidity seems to better reveal the excess breakthrough of carbon. With the coarser AquaSorb® PAC-C, a narrower range of turbidity can indicate that less PAC breakthrough happened, or that turbidity does not work as well detecting PAC-C compared to SAE Super.

Figure 9 clearly demonstrates that COD_{Cr} reflects poorly the amount of PAC in the effluent. The COD_{Cr} results vary little from the 39 mg COD_{Cr}/L average in pilot influent.

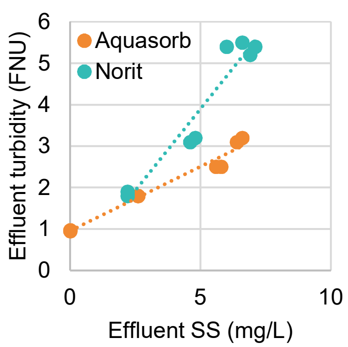

Figure 8. Correlation between effluent turbidity and suspended solids.

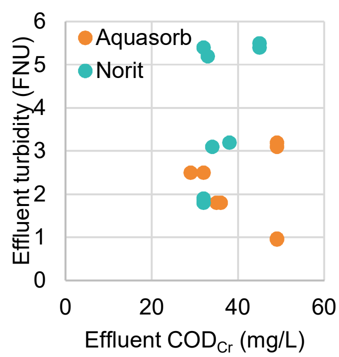

Figure 9. Correlation between effluent turbidity and COD_{Cr}.

3.1.3 Filtration tests

Filtration of samples with 0.5 µm glass fibre filters (MN GF-2) was done to further estimate the amount of PAC breakthrough. The 0.5 µm glass fibre filters retain finer solids than the 1.6 µm filters (GF/A) used in the analysis of suspended solids by Metropolilab Oy. The purpose of the filtration tests was mainly to visually compare PAC breakthrough between different chemical dosages. The results largely support the results of laboratory analyses for turbidity and SS.

Figure 10 combines the results of filtration tests for the effluent for each PAC type and dose. The figure shows that the higher the PAC dose, the higher the PAC breakthrough. More PAC breakthrough is also visible for Norit SAE Super than AquaSorb® PAC-C. The darkness of the glass fibre filters roughly corresponds with the results of laboratory analyses for turbidity and SS. It seems that with the coarse AquaSorb® PAC-C, the effluent SS fits the filtration results better than effluent turbidity. With the fine Norit SAE Super, the effluent turbidity matches the filtration results better. The darkest filter is the Norit SAE Super dosing at 30 mg/L, which corresponds with the highest effluent turbidity at 5.5 FNU. The highest level of effluent SS was 7.0 mg/L with Norit SAE Super dosing at 50 mg/L, which is not as dark as the filter for the 30 mg/L dose.

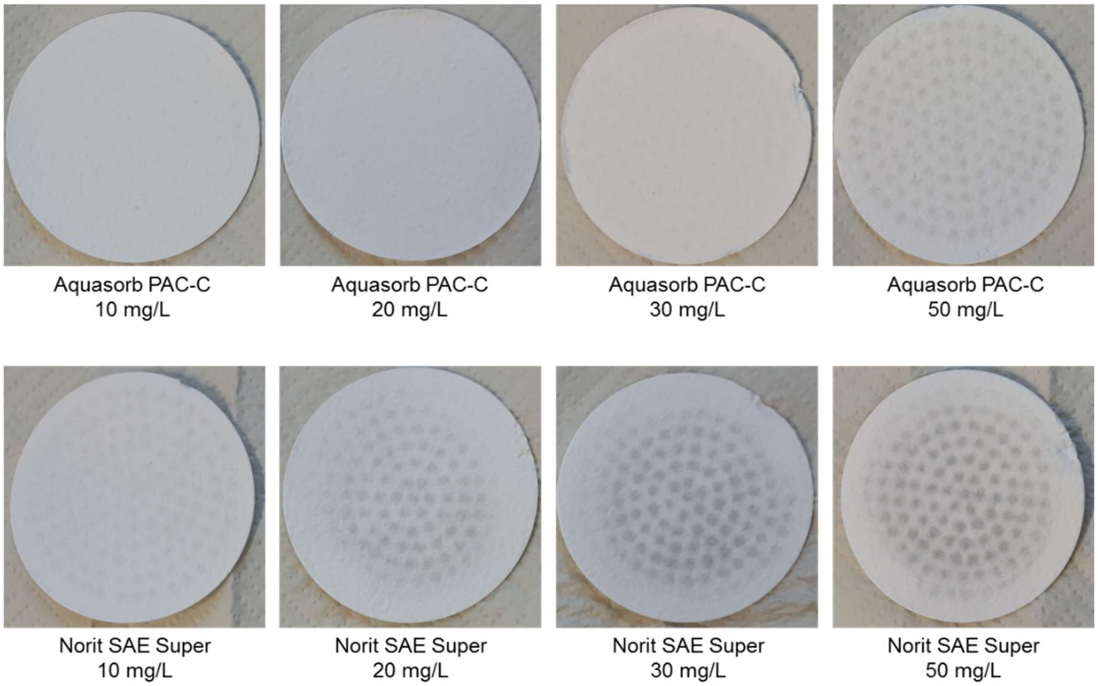

Figure 10. Comparison of the results of filtration tests for the Minifilter effluent with different doses of AquaSorb® PAC-C and Norit SAE Super carbons.

3.2 Effect of PAC on pile cloth filter

The pile cloth filter accumulated PAC during the trial runs, especially when 50 mg/L doses of PAC were applied. The filter was washed with water after trial runs with both carbon types. The filter was washed within the Minifilter piloting set-up, and not removed until after the end of trial runs with PAC. PAC stuck to the filter cloth even after thorough washing, as shown in Figure 11.

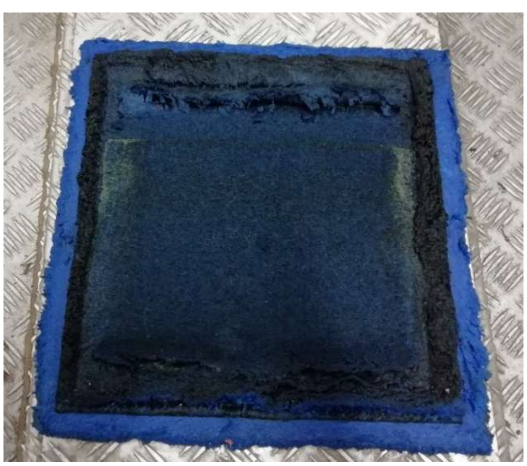

Figure 11. Pile cloth filter after the end of piloting with PAC, after thorough washing with water.

During the trial runs, it was noticed that large amounts of PAC escaped through the pile cloth filter after backwash when high PAC doses were applied. This phenomenon began when AquaSorb® PAC-C was dosed at 50 mg/L. Even though the filter cloth was washed before changing the carbon to Norit SAE Super, the phenomenon continued until the end of piloting. Backwash disturbed the filter cake and caused PAC to pass through the filter, as illustrated in Figure 12. To ensure that this phenomenon did not influence laboratory results, all samples were taken before initiating the backwash sequence. The results therefore represent normal operation, with accumulated filter cake intact.

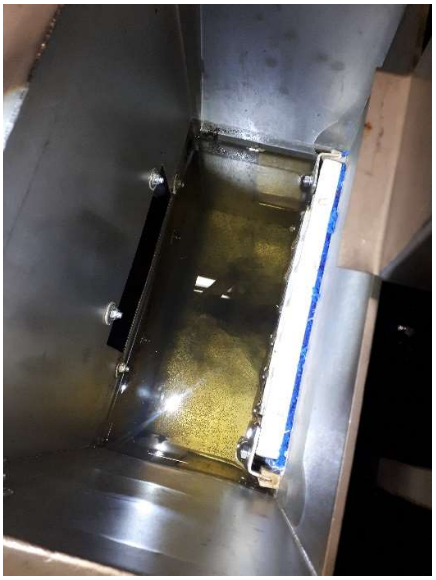

Figure 12. PAC escaping through the pile cloth filter after backwash.

The amount of PAC breakthrough seemed to roughly correspond with the PAC dose. Additional samples were taken during the events of heaviest PAC breakthrough to find out the scale of PAC breakthrough. Dosing of AquaSorb® PAC-C at the concentration 50 mg/L resulted in effluent turbidity at 2.5 FNU sampled before backwash, but right after backwash the effluent turbidity was 17 FNU. The corresponding results for effluent SS were 5.7 mg/L before backwash, and 70 mg/L after. Dosing of Norit SAE Super at the concentration 50 mg/L resulted in effluent turbidity 7.0 FNU before backwash, and 15 FNU right after backwash. The effluent SS was 5.6 mg/L before backwash, and 22 mg/L after. The higher SS with AquaSorb® PAC-C could be caused simply by the timing of sampling, or high pass-through of the finer Norit SAE Super during the trial runs, resulting in less PAC build-up.

4 Discussion

4.1 Amount of PAC breakthrough

4.1.1 Effect of PAC particle size

From the results it is clear that PAC particle size had an effect on PAC breakthrough. The pile cloth filter was better able to retain the coarse AquaSorb® PAC-C (d50 35-50 µm) compared to the finer Norit SAE Super (d50 15 µm). However, also PAC-C escaped through the filter, especially at higher concentrations (30 and 50 mg/L). Both PAC types formed a filter cake that was easily disturbed during backwash, causing significant breakthrough of PAC after backwash. The fine SAE Super seemed to be more easily disturbed than PAC-C: SAE Super was noticed to escape after backwash with all PAC concentrations, while PAC-C mainly escaped with the highest concentration at 50 mg/L.

PAC breakthrough can mostly be explained by the wide range of particle sizes in PAC. The particle size distribution graph for SAE Super (Figure 4) reveals that 20% of the particles in Norit SAE Super are smaller than 5 µm (see Chapter 2.1.2), which is the width of the gaps between fibres. No particle size distribution graph was available for PAC-C from the manufacturer. However, it can be assumed that also PAC-C and most likely every other PAC type contains some portion of particles smaller than 5 µm.

During filtration, the gap becomes smaller, when the fibres go flat against the water flow. Backwash removes most of the filter cake and lifts the fibres up, increasing the gaps between the fibres up to 5 µm. The difference between the filtration properties explains the temporarily reduced effluent quality after backwash. This phenomenon would be less noticeable in a full-scale Mecana disc filter, which backwashes in 2-3 stages. The peak in PAC breakthrough would therefore be blended. Furthermore, the manufacturer recommends PAC separation after coagulation to decrease the peak of PAC breakthrough.

4.1.2 Comparison to other studies

Mecana pile cloth filtration has mostly been studied for PAC separation combined with coagulation and flocculation. For coagulant, the recommended dose would be e.g. 2-3 mg Fe/L. Polymer may not be added, because it will affect the fibres and require more frequent backwashing. The recommended dose of polymer would be only 0.1-0.2 mg/L in maximum.

In other pilot-scale PAC studies using Mecana pile cloth filters, comparable results to this study were achieved. Platz et al (2012) tested a pile cloth drum filter by Mecana for the separation of PAC from wastewater. Filtration was preceded by coagulation using ferric chloride (dosing 2.0-2.5 mg Fe/L). PAC separation also without any coagulant was tested. PAC concentrations of 10 mg/L and 20 mg/L were applied, using two types of PAC (Norit SAE Super as the other). The results showed that when dosing 10-20 mg/L of Norit SAE Super without coagulant, the effluent SS was 2-3 mg/L. The addition of coagulant decreased the effluent SS to 1-2 mg/L.

Hodel (2017) studied the separation of ultra-fine and standard PAC with the Minifilter. Ferric chloride (dosing 1-2 mg Fe/L) and very low doses of polymer (dosing 0-0.02 mg/L) were used to coagulate and flocculate PAC from treated wastewater. PAC separation was also tested without coagulant. PAC concentrations of 10 mg/L was applied, using two very fine PAC types as well as Norit SAE Super. With the ultra-fine PAC, effluent turbidity <0.5 NTU was achieved with coagulant, and effluent SS <1.5 mg/L. Without coagulant, the effluent turbidity was 5 NTU, and effluent SS 2.4 mg/L. The effluent quality achieved in the HSY study was better: with 10 mg/L dosing of Norit SAE Super, the effluent turbidity was 1.9 FNU and the effluent SS 2.2 mg/L.

4.2 Practical experiences

4.2.1 PAC dosing

The dosing of PAC turned out to be challenging. A peristaltic pump was used for dosing carbon from a concentrated PAC suspension (50 g/L). The high concentration in the stock was selected for practical reasons (equipment available during the trial runs). The high concentration however resulted in very small volumes of stock solution dosed, especially when the PAC concentration 10 mg/L was applied. With the peristaltic pump, it was difficult to dose these small volumes, because the dosing pipe was easily filled with water, flowing upwards from the inlet. Although this issue was mostly solved by adjusting the position of the dosing pipe upwards and away from the inlet point, PAC dosing was still unreliable, because there was no flow measurement in the pump.

4.2.2 Assessment of PAC breakthrough

It is challenging to estimate the amount of PAC breakthrough. A particle counter could best monitor the amount of PAC in the effluent, but this kind of equipment was not available for the trial runs. It was also desired to test low-technology alternatives to assess PAC breakthrough that are easily available to WWTPs of all sizes. In the study by Langer (2013), turbidity was found to correlate with particle counts, so it was selected as one of the parameters to follow.

Three types of laboratory analyses were applied: turbidity, suspended solids and chemical oxygen demand. Of these, COD_{Cr} was the least informative. Between turbidity and suspended solids, turbidity seemed to better represent the breakthrough of Norit SAE Super, and suspended solids the breakthrough of AquaSorb® PAC-C. This observation is supported by the results of the filtration tests (see Chapter 3.1.3). When no PAC was added, turbidity worked better than suspended solids at monitoring the effectiveness of filtration, because suspended solids often fell below the detection limit of 2 mg/L.

5 Conclusions

In this study, the separation of PAC from wastewater was tested with a Mecana pile cloth filter. Two types of PAC were applied: the finer Norit SAE Super and the coarse AquaSorb® PAC-C. The separation of each PAC type was tested at different PAC concentrations by the Mecana Minifilter.

The results of the trial runs show that the Minifilter retained most of the PAC, even without any coagulant or polymer. The effluent turbidity was <6 FNU and the effluent SS was at the most 7 mg/L, even when PAC concentrations up to 50 mg/L were applied. Typically, PAC concentrations up to 30 mg/L are applied. The results from testing 50 mg/L PAC concentration are therefore not as representative as the results from testing lower PAC concentrations.

A clear difference could be seen in the retention of the two PAC types. The pile cloth filter was better able to retain the coarse PAC-C better than the fine SAE Super. The nominal cut-off size of the pile cloth fabric is 5 µm, while approximately 20% of PAC particles in SAE Super are smaller than 5 µm. The actual width of the gaps between the fibres becomes less than 5 µm during filtration when the fibres go flat against the fabric. Backwash removes the filter cake and lifts the fibres back up. During the trial runs, backwash could be seen to cause a clear peak in PAC breakthrough. Effluent suspended solids up to 70 mg/L were measured right after backwash.

The assessment of PAC breakthrough turned out to be challenging. Turbidity seemed to better reveal the breakthrough of SAE Super, while suspended solids seemed to work better with PAC-C. The amount of PAC breakthrough could also be monitored with the filtration tests, which were useful in comparing the breakthrough with different PAC concentrations.

According to literature, PAC breakthrough could be reduced by adding coagulant prior to pile cloth filtration. The results by Platz et al. (2012) and Hodel (2017) showed that coagulation by ferric chloride improved PAC retention. Otherwise, these studies showed similar results for PAC breakthrough without coagulant.

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