# PAC retention by Actiflo® Carb

Piloting at Viikinmäki WWTP
Part of the CWPharma project

**Helsingin seudun ympäristöpalvelut -kuntayhtymä**
Samkommunen Helsingforsregionens miljötjänster
Helsinki Region Environmental Services Authority

**Helsinki Region Environmental Services Authority**
P.O. Box 100
FI-00066 HSY
phone +358 9 156 11
fax +358 9 1561 2011
**www.hsy.fi**

**Contact**
Paula Lindell, phone +358 50 412 3162
paula.lindell@hsy.fi

# Table of contents

# 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 ballasted sedimentation was tested for PAC retention in pilot-scale. A small-scale piloting unit of the Actiflo® Carb process by Veolia 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 ballasted sedimentation. The focus of the pilot was on PAC retention by coagulation, flocculation and ballasted sedimentation. Two different PAC products with different particle sizes were used and their operational applicability compared.

Research questions:

- How well can PAC be separated with ballasted sedimentation?
- Does PAC particle size affect the results?
- What doses of chemicals are required to achieve minimal PAC breakthrough?
- 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 ballasted sedimentation in the separation of powdered activated carbon was tested with an Actiflo® Carb Mini piloting system by Veolia. The containerised piloting system (Figures 1-2) was rented for trial runs, which were conducted during December 2018 and January 2019. The flow capacity of the system was 15 $m^3$/h without carbon, and 5 $m^3$/h with carbon added (surface load 33 m/h). Water used in the pilot was effluent wastewater from Viikinmäki WWTP, which is further described in Chapter 0.


*Figure 1. The containerised Actiflo® Mini Carb piloting system within Viikinmäki WWTP.*

*Figure 2. Actiflo® Mini Carb piloting unit.*

The flow diagram of the piloting unit is illustrated in Figure 3. In the process, powdered activated carbon was first dosed into contact tanks that gave the PAC sufficient retention time to remove pharmaceuticals. One or two contact tanks could be used, resulting in retention times of 17 or 34 minutes before other chemicals were added. Coagulant was dosed to the pipe after the contact tanks, and polymer to the injection tank, as illustrated in Figure 3. All chemicals were dosed using peristaltic pumps, with fixed dosing rates.

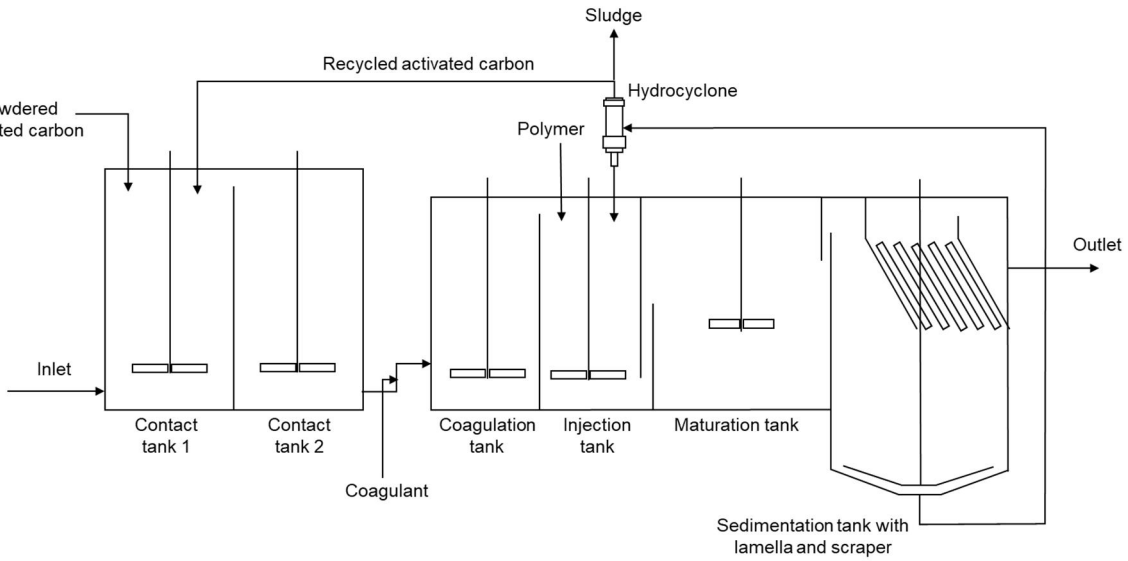


*Figure 3. Process configuration of the Actiflo® Mini Carb piloting system.*

With the Actiflo® Carb technology, carbon and sludge can be recycled in the process. Carbon and other solids are flocculated with the microsand in the maturation tank, and then separated from water in the sedimentation tank with lamella. The mix of carbon, sludge and microsand is pumped from the bottom of the sedimentation tank to the hydrocyclone, which separates the sand from carbon and sludge. Sand is discharged to the injection tank in the cyclone underflow. The amount of recycling for carbon and sludge back to the contact tanks can be adjusted in the recirculation box, which receives the cyclone overflow.

The recirculation flow rate applied in the pilot process was kept at 1.0-1.2 $m^3$/h. This accounted for 20-24% of the flow rate of the pilot. The recirculation flow rate had to be kept this high, because it was the minimum inlet flow to the hydrocyclone.

### 2.1.2 Chemicals

Prior to trial runs, different coagulants and polymers were tested in laboratory scale to find out which chemicals worked best with the water, PAC and Actiflo® microsand. The chemicals used in the pilot and their dosing are listed below.

Powdered activated carbon

- dose 10 mg/L and 30 mg/L
- stock solution concentration 10 g/L
- fixed dosing rate
- dosing to contact tank (1st or 2nd, depending on PAC retention time)

Coagulant

- polyaluminium chloride, Kemira PAX XL-100
- dose 5-20 mg Al/L
- fixed dosing rate
- dosing to the pipe leading from contact tanks to the coagulation tank

Flocculant

- cationic polymer, Kemira SUPERFLOC C-492VP
- dose 1.0-1.5 mg/L
- fixed dosing rate
- dosing to injection tank
- prepared using a Timsa Polymer Make-Up unit

Two different PAC products with different particle sizes were applied to compare their operational applicability. Norit SAE Super is a very fine PAC product, which is widely used in water treatment. AquaSorb® MP25 PAC-C is a coarser PAC product. The properties of the two PAC types are listed in Table 1. The two PAC types were selected to find out whether the coarse PAC-C could be better separated by ballasted sedimentation.

*Table 1. Properties of PAC products applied*

| | 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 over 30 % of the particles in Norit SAE Super are smaller than 10 µm, and therefore difficult to remove. 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 10 µm in PAC-C.

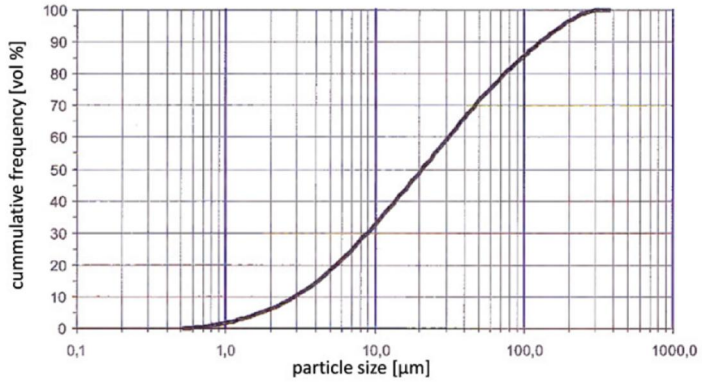


*Figure 4. Particle size distribution in Norit SAE Super powdered activated carbon.*

### 2.1.3 Influent

Water used as the influent for the pilot 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 December 2018 to January 2019. The quality of Viikinmäki WWTP effluent during this period 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 December 2018 and January 2019*

| | BOD (mg/L) | COD (mg/L) | SS (mg/L) |
|---|---|---|---|
| Average | 4.28 | 42 | 3.1 |
| Maximum | 5.07 | 58 | 4.2 |
| Minimum | 3.94 | 30 | 2.2 |

## 2.2 Analyses

### 2.2.1 Laboratory analyses and sampling

The breakthrough of PAC to the effluent 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 located in the pilot's inlet pipeline (visible in Figure 2), and the outlet pipeline from the lamella. Samples were taken at least one hour after making any changes in chemical doses.

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 |
| Ash content in solids | SFS 3008:1990 | 10% | 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 removal of pharmaceuticals in the piloting process was analysed at an external laboratory from four sets of samples (both influent and effluent tested). The four samples were taken from tests with long and short retention times for PAC (approximately 30 min and 15 min), and high and low PAC dosing (30 and 10 mg/L), when dosing the Norit SAE Super at 30 mg/L.

***List of pharmaceuticals analysed***

| | |
|---|---|
| amoxicillin | furosemide |
| atenolol | hydrochlorothiazide |
| bezafibrate | ibuprofen |
| bisoprolol | ketoprofen |
| carbamazepine | metaflumizone |
| ciprofloxacin | metoprolol |
| citalopram | metronidazole |
| diclofenac | naproxen |
| 17a-Ethylestradiol (EE2) | propranolol |
| 17b-estradiol (E2) | sotalol |
| estriol (E3) | sulfamethoxazole |
| estrone (E1) | trimethoprim |
| fluoxetine | warfarin |

Samples were also sent to Aarhus University to be analysed for the removal of selected pharmaceuticals. Aarhus University is a project partner in the CWPharma project, and the concentrations of pharmaceuticals in the pilot influent and effluent were analysed at Aarhus University to get comparable results between different CWPharma pilots. The samples were taken with long PAC retention time, dosing the Norit SAE Super PAC at 30 mg/L, simultaneously to the other samples for testing pharmaceuticals removal.

## 2.3 Trial planning

PAC trial runs with the Actiflo® Mini Carb pilot unit lasted for approximately four weeks between 3 December 2018 and 14 January 2019. Prior to this, the piloting system was tested without adding PAC. Trial runs were conducted only during office hours, on weekdays. Trial runs were divided between the two PAC types.

According to the manufacturer, PAC should be accumulated in the process to concentrations around 1-5 g/L by recycling most of the PAC added. In the piloting system, this would mean over 4 kg of PAC circulating in the process. Dosing of fresh PAC was kept at the most at 30 mg/L, so considerable time would have been needed to increase the PAC concentration up to 1 g/L. Therefore, trial runs were conducted with smaller amounts of PAC accumulated in the process.

During the trial runs, different doses of coagulant and polymer were tested with the PAC dosing at 30 mg/L with both PAC types. With the finer Norit SAE Super carbon, also PAC dosing at 10 mg/L was tested. The carbon type was switched in the middle. As much carbon was removed from the system as possible, before switching to the other PAC type. Long retention time for PAC was applied for the majority of the time, but in the end the shorter retention time was applied.

# 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 the ash content of solids. The points represent sampling points, often with the same chemical doses. Trials were replicated to see how stable the effluent quality was. The dosing of each carbon type is marked with grey. The dosing of PAC was mostly kept at 30 mg/L to increase the concentration of PAC circulating in the system (see Chapter 2.3), but PAC was also dosed at 10 mg/L. PAC retention time was kept long until the end of the trial runs, when the system was adapted for short retention time.

Figure 5 shows that the influent turbidity had some variation, with the range 0.73-2.4 FNU. An outlying value for influent turbidity at 28 FNU was left out of the figure. Contrary to the varying results for influent turbidity, the effluent turbidity was stable, with the range 0.70-1.1 FNU (average 0.85 FNU). No clear difference can be seen between the two PAC types applied, or between PAC doses. For two sampling points, the turbidity increased by 6% and 14%, but otherwise the turbidity reduced by approximately 32%.

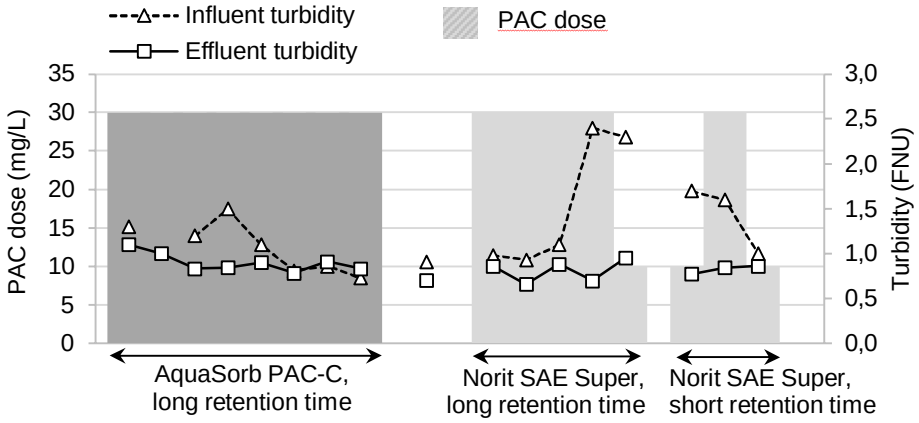


*Figure 5. Changes in turbidity during the PAC trial runs with Actiflo® Mini Carb.*

Figure 6 shows the corresponding results for suspended solids. The analysis of suspended solids has the detection limit of 2 mg/L. Several influent results fall below the detection limit, and their values in Figure 6 are represented as zero. Same as in Figure 5, an outlying value for the same sampling point was left out of Figure 6, with influent SS at 160 mg/L. Generally, the influent suspended solids varied according to the same pattern as the influent turbidity, indicating changing quality of the influent.

The effluent suspended solids also had varying concentrations, but not clearly linked to changes in influent quality. The effluent SS range was 2.3-7.4 mg/L. The lowest effluent SS concentrations were achieved with the lowest PAC dose, when Norit SAE Super was dosed at 10 mg/L. The highest effluent SS concentration resulted from the lowest coagulant dose applied. The effect of chemical dosing is further discussed in Chapter 3.2.

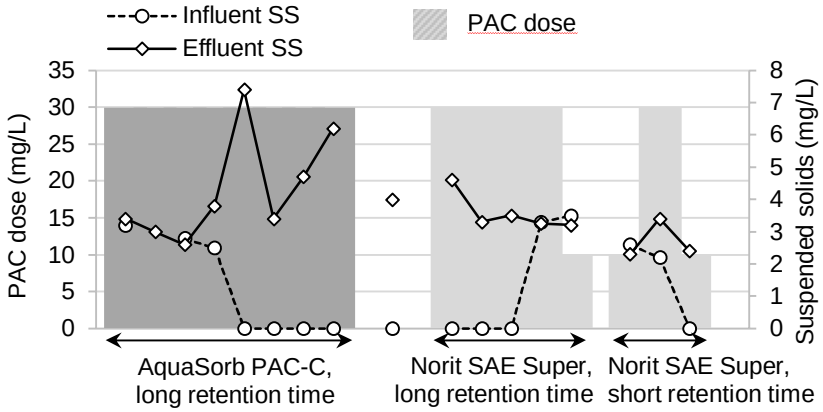


*Figure 6. Suspended solids during the PAC trial runs with Actiflo® Mini Carb. Influent SS results below detection limit are shown as zero.*

Figure 7 shows that the ash content in solids mostly reflects the influent quality. With some sampling points, the higher ash content in the effluent suggests that PAC could be detected. This parameter however seems unreliable in detecting PAC breakthrough.

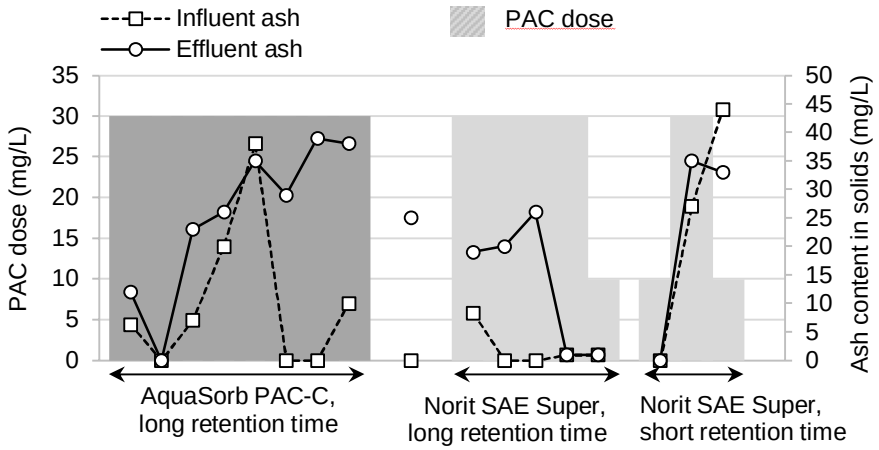


*Figure 7. Changes in the ash content in solids during the PAC trial runs with Actiflo® Mini Carb.*

The flocs formed in the maturation tank and the effluent quality are illustrated in Figures 8 and 9. The pictures demonstrate the pilot process when Norit SAE Super was dosed at 30 mg/L with short retention time, and coagulant dose was 10 mg Al/L and polymer dose 1.5 mg/L. Although heavy flocs were formed (Figure 8), not all carbon could be captured. Figure 9 demonstrates that the effluent was clear, but it contained small flocs containing carbon, not heavy enough to be separated.

*Figure 8. Sample grabbed from maturation tank.*

*Figure 9. Effluent sample grabbed from lamella outlet.*

### 3.1.2 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 mainly support the results of laboratory analyses for turbidity and SS.

Figure 10 compares the filtration test results for the influent to the effluent, with two different doses of Norit SAE Super. The effluent samples were taken from otherwise similar conditions (PAX 10 mg Al/L, polymer 1.5 mg/L, long retention time), with only differing PAC doses (10 and 30 mg/L). The filters show similar quantities of small PAC flocs as Figure 9 in the otherwise clear effluent. Although little difference can be seen between the two doses of PAC, it is difficult to make specific conclusions on the amount of PAC breakthrough based on the filtration tests.


*Figure 10. Comparison for the results of filtration tests for the Actiflo® Mini Carb influent, and the effluent with two doses of Norit SAE Super carbon.*

## 3.2 Response to chemical dosing

The effects of coagulant and polymer were tested by applying different chemical dosages. The average results for effluent quality are combined in Tables 4 and 5, for effluent turbidity and effluent SS, respectively. The tables give an overview of all test series conducted. Average results for reproduced test series are given, showing also the retention time given for PAC maturation.

Table 4 shows the effluent turbidity for each combination of chemical dosages, with both PAC types. The results show that the lowest effluent turbidities were achieved with coagulant dosed at 10 mg Al/L and polymer dosed at 1.5 mg/L. Increasing the coagulant dose did not improve the results. Overall, the effluent turbidity stayed very low with all chemical doses.

*Table 4. Average results for effluent turbidity for each combination of PAC, coagulant and polymer doses.*

| PAC retention time | Coagulant dose (mg Al/L) | Polymer dose (mg/L) | PAC dose (mg/L) | | |
|---|---|---|---|---|---|
| | | | AquaSorb® PAC-C | Norit SAE Super | |
| | | | 30 mg/L | 10 mg/L | 30 mg/L |
| 34 min | 5.0 | 1.5 | 0.90 FNU | - | - |
| | 10 | 1.0 | - | - | 0.88 FNU |
| | 10 | 1.5 | 0.88 FNU | 1.0 FNU | 0.68 FNU |
| | 20 | 1.0 | 0.83 FNU | - | - |
| | 20 | 1.5 | 0.94 FNU | - | 0.86 FNU |
| 17 min | 10 | 1.5 | - | 0.82 FNU | 0.84 FNU |

Table 5 shows the corresponding results for effluent suspended solids for each combination of chemical dosages. There is higher variation in the results for SS, although the values are overall low. Most of PAC was successfully separated in all test series. The best results were achieved with the same chemical doses of coagulant dosed at 10 mg Al/L and polymer at 1.5 mg/L. Increasing the coagulant dose did not improve the results.

*Table 5. Average results for effluent suspended solids for each combination of PAC, coagulant and polymer doses.*

| PAC retention time | Coagulant dose (mg Al/L) | Polymer dose (mg/L) | PAC dose (mg/L) | | |
|---|---|---|---|---|---|
| | | | AquaSorb® PAC-C | Norit SAE Super | |
| | | | 30 mg/L | 10 mg/L | 30 mg/L |
| 34 min | 5.0 | 1.5 | 7.4 mg SS/L | - | - |
| | 10 | 1.0 | - | - | 3.5 mg SS/L |
| | 10 | 1.5 | 4.3 mg SS/L | 3.2 mg SS/L | 3.3 mg SS/L |
| | 20 | 1.0 | 6.2 mg SS/L | - | - |
| | 20 | 1.5 | 3.6 mg SS/L | - | 4.6 mg SS/L |
| 17 min | 10 | 1.5 | - | 2.4 mg SS/L | 3.4 mg SS/L |

## 3.3 Removal of pharmaceuticals

The removal of pharmaceuticals using PAC dosages 30 and 10 mg/L and retention times 34 and 17 min, measured at an external laboratory, are presented in Table 6. Only substances where at least one sample had a concentration above the detection limit are included. The list of all analysed pharmaceuticals is in Chapter 2.2.2

*Table 6. Average results for effluent suspended solids for each combination of PAC, coagulant and polymer doses. Reductions marked with green font: the effluent concentration is below detection limit.*

| Pharmaceutical | PAC 30 mg/l, 34 min | | | PAC 30 mg/l, 17 min | | | PAC 10 mg/l, 34 min | | | PAC 10 mg/l, 17 min | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Infl. (µg/L) | Effl. (µg/L) | Red (%) | Infl. (µg/L) | Effl. (µg/L) | Red (%) | Infl. (µg/L) | Effl. (µg/L) | Red (%) | Infl. (µg/L) | Effl. (µg/L) | Red (%) |
| Atenolol | 0.157 | <0.100 | 36 % | 0.185 | <0.100 | 46 % | 0.158 | <0.100 | 37 % | 0.174 | <0.100 | 43 % |
| Ibuprofen | 0.068 | 0.038 | 44 % | 0.093 | 0.041 | 56 % | 0.038 | <0.030 | 21 % | 0.065 | 0.087 | -34 % |
| Azathioprine | <0.050 | <0.050 | N/A | 0.058 | <0.050 | 14 % | <0.050 | <0.050 | N/A | <0.050 | <0.050 | N/A |
| Carbamazepine | 0.276 | <0.050 | 82 % | 0.264 | <0.050 | 81 % | 0.258 | <0.050 | 81 % | 0.293 | <0.050 | 83 % |
| Citalopram | 0.246 | <0.050 | 80 % | 0.276 | <0.050 | 82 % | 0.255 | <0.050 | 80 % | 0.287 | <0.050 | 83 % |
| Diclofenac | 1.70 | <0.050 | 97 % | 1.97 | 0.364 | 82 % | 2.27 | 0.191 | 92 % | 2.49 | 0.867 | 65 % |
| Furosemide | 2.08 | 0.120 | 94 % | 1.72 | 0.197 | 89 % | 1.58 | 0.294 | 81 % | 1.74 | 0.508 | 71 % |
| Gabapentin | 19.8 | 17.3 | 13 % | 22.8 | 17.5 | 23 % | 21.1 | 16.7 | 21 % | 24.3 | 17.5 | 28 % |
| Hydrochlorothiazide | 2.76 | 0.229 | 92 % | 2.58 | 0.242 | 91 % | 2.27 | 0.359 | 84 % | 2.10 | 0.513 | 76 % |
| Iohexol | 55.3 | 30.2 | 45 % | 25.0 | 19.7 | 21 % | 64.9 | 39.4 | 39 % | 27.9 | 17.8 | 36 % |
| Ketoprofen | 0.104 | <0.050 | 52 % | 0.153 | <0.050 | 67 % | 0.129 | <0.050 | 61 % | 0.151 | 0.060 | 60 % |
| Metoprolol | 0.560 | <0.050 | 91 % | 0.446 | <0.050 | 89 % | 0.464 | <0.050 | 89 % | 0.490 | 0.076 | 84 % |
| Metronidazole | 0.273 | <0.050 | 82 % | 0.236 | <0.050 | 79 % | 0.219 | 0.060 | 73 % | 0.255 | 0.087 | 66 % |
| Naproxen | 0.400 | <0.100 | 75 % | 0.727 | <0.100 | 86 % | 0.351 | <0.100 | 72 % | 0.548 | <0.100 | 82 % |
| Oxazepam | 1.67 | 0.121 | 93 % | 1.33 | 0.192 | 86 % | 1.38 | 0.285 | 79 % | 1.51 | 0.426 | 72 % |
| Piroxicam | <0.050 | <0.050 | N/A | 0.059 | <0.050 | 15 % | 0.059 | <0.050 | 15 % | 0.071 | <0.050 | 30 % |
| Propranolol | 0.178 | <0.050 | 72 % | 0.142 | <0.050 | 65 % | 0.155 | <0.050 | 68 % | 0.156 | <0.050 | 68 % |
| Sotalol | 0.343 | <0.050 | 85 % | 0.275 | <0.050 | 82 % | 0.282 | <0.050 | 82 % | 0.313 | 0.069 | 78 % |
| Sulfamethoxazole | 0.081 | <0.050 | 38 % | 0.078 | <0.050 | 36 % | 0.081 | <0.050 | 38 % | 0.086 | <0.050 | 42 % |
| Tramadol | 0.368 | <0.050 | 86 % | 0.451 | <0.050 | 89 % | 0.292 | <0.050 | 83 % | 0.451 | 0.133 | 71 % |
| Trimethoprim | 0.309 | <0.050 | 84 % | 0.347 | <0.050 | 86 % | 0.338 | <0.050 | 85 % | 0.373 | <0.050 | 87 % |
| Valsartan | 5.94 | 2.21 | 63 % | 5.36 | 2.62 | 51 % | 5.21 | 2.87 | 45 % | 5.43 | 4.01 | 26 % |
| Bisoprolol | 1.1 | <0.050 | 95 % | 0.7 | 0.051 | 93 % | 0.71 | 0.1 | 86 % | 1.3 | 0.021 | 98 % |
| Estrone | 0.007 | <0.005 | 32 % | 0.008 | <0.005 | 35 % | 0.006 | <0.005 | 15 % | 0.008 | <0.005 | 40 % |

As for most pharmaceuticals the effluent concentrations were below detection limits, their reductions in Table 6 depend on the influent concentration and the impact of PAC dosage or contact time cannot be assessed.

The reductions of those pharmaceuticals, whose concentrations were above detection limit in all or in three of the four effluent samples (underlined in Table 6) are presented in Figure 11.

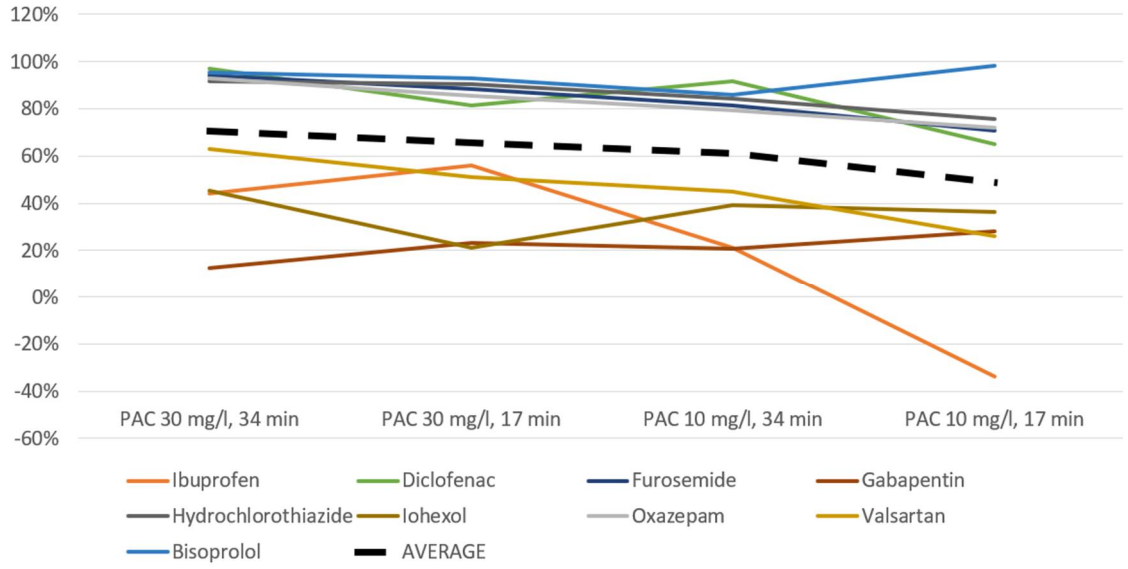


*Figure 11. Reductions of selected pharmaceuticals with different PAC dosages and contact times and the average of reductions.*

There were variations in the results but as average and for several pharmaceuticals and for the average, the reductions decreased systematically with decreasing PAC dosage and contact time. The reductions were mainly higher with a PAC dosage 30 mg/L with a 17 min contact time compared to 10 mg/L and 34 minutes (Figure 11).

It should be noted that the average reduction presented in Figure 11 is not representative for the total removal efficiency, as only those pharmaceuticals whose effluent concentration were above detection limits were included.

# 4 Discussion

## 4.1 Amount of PAC breakthrough

### 4.1.1 Effect of PAC particle size

Not a clear difference could be seen between the results of the two PAC types used. Measured by effluent turbidity, both PAC types could be removed to the same extent. Measured by effluent SS, better effluent quality was achieved with Norit SAE Super. When dosing each PAC type at 30 mg/L, coagulant at 10 mg Al/L and polymer at 1.5 mg/L, the average effluent turbidity was 0.88 FNU with AquaSorb® PAC-C, and 0.68 FNU with Norit SAE Super. The corresponding values for effluent SS were 4.3 mg/L with PAC-C, and 3.3 with SAE Super. Based on this, the finer carbon was better captured by ballasted sedimentation, although good results were achieved with both carbons.

### 4.1.2 Effect of coagulant and polymer dosing

During the trial runs, it became clear that PAC retention relied greatly on the success of coagulation and flocculation. Whenever problems were experienced either in coagulant dosing or polymer quality, PAC retention clearly reduced. PAC breakthrough could be seen by the fouling of the lamellas. Good effluent quality relied greatly on the settleability of flocs. Good settleability was only achieved when PAC attached properly to the sand by both coagulant and polymer. Just adding coagulant, or just adding polymer led to large-scale PAC breakthrough and a change in the colour of the flocs from black to brownish.

The best effluent quality was obtained for both PAC types when coagulant was dosed at 10 mg Al/L and polymer at 1.5 mg/L. Higher dosing of coagulant did not have a clear effect on effluent quality. Higher dosing of polymer was not tested.

Because PAC breakthrough could be so clearly seen from the lamellas and floc properties, samples were only taken when the coagulation and flocculation were working well. Whenever there was a problem in coagulation or flocculation, samples were not taken, and the problem was worked on. The results shown in Chapter 3 therefore represent good performance of ballasted sedimentation.

Blank samples were not taken before carbon addition was started. The reason for this is that flocculation did not work properly without PAC. The polymer was selected based on jar tests using Actiflo® microsand and the two PAC types. Although the polymer worked well with PAC, it was not suitable for just the water and the microsand. Therefore, it is difficult to compare the performance of the process with and without PAC addition.

## 4.2 Practical experiences

### 4.2.1 Issues with piloting equipment

The results were affected by some problems with the piloting equipment that were experienced during the trial runs. One of the main problems was the clogging of the hydrocyclone and the sand recirculation piping. This was partly caused by initially too high microsand concentration in the system, and further increased by accumulation of PAC in the system. Sand was removed from the system to reduce clogging, but in the process, unknown amounts of PAC were also removed. Due to this, the accumulated PAC concentration in the system was unknown for all the sampling points. The PAC amount in the system also varied, because sand was removed also between the sampling days.

Another problem with piloting equipment was experienced in the dosing of coagulant. All chemicals were dosed with peristaltic pumps. This is the ideal pump type for PAC, which is abrasive and can contains large particles that will other types of pumps. However, the dosing of coagulant with was challenging. Dosing was unreliable, because there was no flow measurement with the peristaltic pumps. The coagulant dosing pump was also too big for the small concentrations of PAX wanted in the process (1-2 mg Al/L). To ensure sufficient flow of coagulant, high dosing rates had to be applied (10-20 mg Al/L).

Other problems with the piloting equipment caused delays in the initial start-up of the pilot, causing the trial runs to be delayed. Modifications to the piloting equipment had to be done e.g. to improve sand recirculation and mixing in the maturation tank. These delays prevented more comprehensive tests to be done with different PAC, coagulant and polymer concentrations.

### 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 ash content in solids. Of these, ash content was the least informative. Between turbidity and suspended solids, both parameters seemed to work well with both PAC types. PAC breakthrough was minimal with both PAC types. However, higher PAC breakthrough seemed to be detected by turbidity for Norit SAE Super, while suspended solids showed higher variation for AquaSorb® PAC-C. This could indicate that turbidity is better suited to represent the breakthrough of SAE Super, and suspended solids the breakthrough of PAC-C.

## 4.3 Removal of pharmaceuticals

The removal of pharmaceuticals with PAC dosages 30 or 10 mg/L and contact times 34 or 17 minutes was mainly efficient. When using the higher dosage or the higher contact time, more than half of the effluent concentrations of those for pharmaceuticals that were detected in the influent were below detection limits.

The impact of PAC dosage and contact time on API removal could be assessed only for nine pharmaceuticals, whose effluent concentrations were above detection limit in all four tests or in three tests. In average the reductions were highest with a higher PAC dosage and with a higher contact time, as could be expected. The differences in reduction efficiencies were not high. There was also some variation in the result, and for gabapentin the reductions appeared higher with lower dosages and retention times. The reductions observed for the nine pharmaceuticals (Figure 11) varied from < 20 % (< -33 %) to > 90 %.

# 5 Conclusions

In this study, the separation of PAC from wastewater was tested with ballasted sedimentation. Two types of PAC were applied: the finer Norit SAE Super and the coarse AquaSorb® PAC-C. Different doses of coagulant and polymer were tested with each PAC type to see what doses are needed to separate PAC from wastewater, and to see if the PAC particle size has an effect on the results.

The results of the trial runs show that successful coagulation and flocculation are essential in PAC retention by ballasted sedimentation. Both coagulant and polymer are needed to integrate PAC into flocs and attach to microsand. The settleability of flocs is the main factor on which PAC retention by ballasted sedimentation depends.

Overall, good effluent quality could be achieved with the Actiflo® Carb pilot. The optimal dosing of chemicals was 10 mg Al/L for coagulant and 1.5 mg/L for polymer, with both PAC types and most PAC concentrations. No major difference could be seen in the results between the two PAC types. The finer Norit SAE Super was slightly better captured by ballasted sedimentation, although good results were achieved with both carbons.

High doses of coagulant had to be applied because of problems with the dosing pump. Lower doses of coagulant would probably have been as effective as the high doses tested. Not all chemical doses were tested, because issues with the piloting equipment delayed the trial runs.

The amount of PAC breakthrough can be difficult to detect. In this study, turbidity seemed to better detect the breakthrough of Norit SAE Super, while suspended solids showed higher variation for AquaSorb® PAC-C. Both parameters are however useful in determining the amount of PAC breakthrough.

The removal of pharmaceuticals with PAC dosages 30 and 10 mg/L and contact times 34 and 17 minutes was mainly efficient or very efficient particularly with the higher dosage or higher contact time, with some exceptions such as gabapentin, whose removal efficiency was below 30 % in all tests. The majority of the effluent concentrations in effluents were below detection limit.

# 6 References

Philip Isgaard and Elias Thörnqvist. 2016. Integration of powdered activated carbon in tertiary disc filtration of wastewater. Master's thesis, Lund University Department of Chemical Engineering. 48 p.

Margarethe Langer. 2013. Feasibility of the microsieve technology for advanced phosphorus removal – Additional trials. Project acronym: OXERAM 2b. Kompetenzzentrum Wasser Berlin gGmbh. 15 p.