CERAMIC MICROFILTRATION FOR TREATING SECONDARY WASTEWATER EFFLUENT: INFLUENCE OF PRE-TREATMENT ON THE OPERATIONAL PERFORMANCE

Jumeng Zheng, PWN Technologies, Dijkweg 12, 1619 HA, Andijk, The Netherlands
Email: jzheng@pwntechnologies.nl, Phone: +31 6 8320 9023
Holly Shorney-Darby, PWN Technologies, Dijkweg 12, 1619 HA, Andijk, The Netherlands
Gilbert Galjaard, PWN Technologies, Dijkweg 12, 1619 HA, Andijk, The Netherlands

Abstract

This paper summarizes the performance of ceramic microfiltration (MF) for treating secondary wastewater effluent, with and without pre-chlorination. Because of a high organic concentration in the feed water, coagulation was needed to control membrane fouling. Pre-treatment with pre-ozone alone and pre-ozone combined with coagulation were also evaluated to learn the potential benefits, as well as to understand the impact on cost if ozone was highly beneficial, or necessary, for ceramic membrane filtration. For the in-line coagulation/ceramic MF process with chlorinated feed water, operation at a flux of 189 lmh, backwash (BW) interval of 32 minutes, enhanced BW (EBW) every 24 hours, and coagulation with 2 to 6 mg/L as $Al3+$ using PACl is deemed sustainable, with a low fouling rate that would yield a CIP interval of > 30 days. The membrane permeate had an average silt density index (SDI) of 2.5, and the SDI was < 3, 100 percent of time which meets the quality criteria as RO feed. The ceramic MF with in-line coagulation as pre-treatment was also sustainable for treating un-chlorinated feed water, but required a slightly lower flux, and resulted in higher aluminum and SDI in the filtrate. Pre-treatment with pre-ozone alone did not lead to a sustainable membrane operation. But pre-treatment with combined pre-ozone and in-line coagulation greatly improved the performance of the ceramic MF, with an operating flux of 300 lmh being possible. It also improved the water quality of the membrane permeate. The secondary effluent, however, had a high ozone demand, and the cost of ozone application rendered it non-competitive.

Introduction

Reclamation of wastewater for reuse is getting more and more important. A state-of-the-art approach is to use the treatment train comprising microfiltration/ultrafiltration (MF/UF), reverse osmosis (RO) and UV disinfection. Most of the current MF/UF processes are with polymeric membraness; however, ceramic membranes can be an alternative after its merits have been demonstrated: less fragile than polymers with a much longer life time, ability to withstand heavy pollutant loads and a vigorous backwash, resistant to strong chemicals and easily cleaned.

This work is about a pilot study of ceramic MF for treating secondary effluent at a wastewater treatment plant (WWTP) to investigate possible advantages compared to state of the art microfiltration. The current process in the WWTP is straining, MF, RO and UV-disinfection. The existing MF process employs a polymeric membrane system.

The feed water to the WWTP has high organic concentration (typically 14 mg/l TOC and a maximum TOC of 25 mg/l). To control the organic fouling, coagulation was thought to be needed as a pre-treatment for the ceramic MF. Coagulation allows negatively charged organics to adsorb into the positively charged hydrolysis products of the coagulant, within the desired pH range. Having organics adsorbed to micro-flocs minimizes fouling on the membrane surface, and the solids are backwashed easily from the membrane surface.

Ozone is an excellent disinfectant and a strong oxidant. The combination of ozone, coagulation and membrane filtration has shown to be very effective in treating secondary effluent in a number of studies [Lehman and Liu (2009), Duke et al. (2013), Noguchi and Tegane (2013), and Gerringer et al. (2013)]. Therefore, ozone as a pre-treatment process (in combination with coagulation or not) was also evaluated during the pilot study to learn the potential benefits, and resulting impact on cost if ozone proved highly beneficial or necessary for ceramic membrane filtration.

Objectives

The aim of this pilot study was to evaluate the following design parameters for a variety of pre-treatment conditions. The ultimate aim was to identify the pre-treatment design parameters as well as the membrane operating parameters for treating secondary effluent.

The specific objectives included:

1. evaluate different pre-treatments (i.e., direct filtration, in-line coagulation, pre-ozone and combined pre-ozone and coagulation) for ceramic membrane filtration of secondary wastewater;
2. select a pre-treatment which yields the maximum sustainable flux, while achieving the goals for enhanced backwash (EBW) and clean-in-place (CIP) frequency;
3. conduct a two-week trial of the selected pre-treatment with ceramic membrane filtration;
4. evaluate the difference in performance when treating chlorinated strained versus un-chlorinated unstrained secondary effluent feed water;
5. evaluate alum versus polyaluminum chloride (PACl) as a coagulant;
6. determine the filtrate silt density index (SDI)

Methodology

The pilot installation

The pilot plant was a simple and small pilot (l x w x h = 120 x 150 x 210 cm). It contained an aquarium ozone generator with a maximum production of 1.2 g/h, a simple ozone contactor, an injection point for a coagulant, a static mixer, two, stirred coagulation contactors, and a 0.4 m2 Metawater ceramic membrane (1000x30mm). It was a microfiltration membrane with a nominal pore size of 0.1 micron. The installation could monitor and log five signals: the feed flow, the residual ozone concentration near the membrane, feed pressure, permeate pressure, and the temperature. The installation could automatically perform a backwash, but an enhanced backwash was performed manually. Figure 1 is a simple process diagram of this pilot.

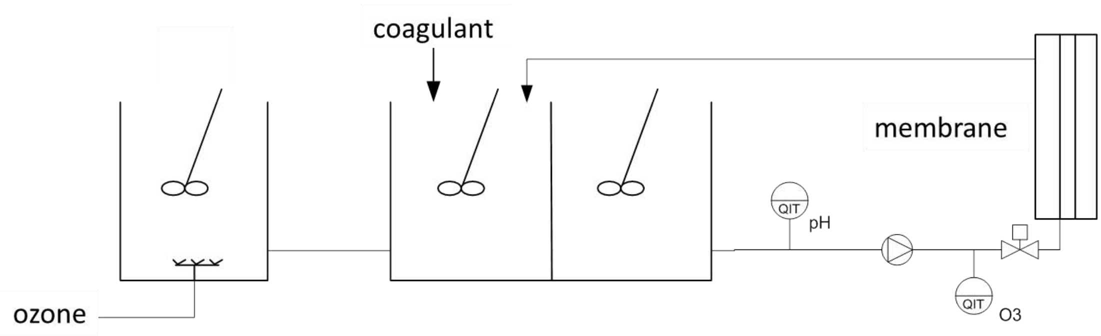


Figure 1. Process Diagram of the Ceramic MF Pilot

The maximum flow through the installation was 140 L/h, and the minimum was about 40 L/h. Each coagulation contactor had a volume of 2 L leading to a contact time of 1.6 minute per contactor at a flux of 189 lmh. The coagulant used for pilot testing was Sachtoklar (Sachtleben Wasserchemie GmbH; Duisburg, Germany). This is a liquid PACl with a density of 1.21 g/cm3 and an aluminum content of 5.35%. This coagulant was used for treating both chlorinated water and un-chlorinated water. During the testing with un-chlorinated water, two other coagulants were used from a local supplier; aluminium sulphate (8 wt % as Al_2O_3) and PACl (density of 1.2 g /cm3 and an aluminum content of 10%).

Ozone decay experiments

A preliminary assessment of the ozone decay in the secondary effluent was made. Samples were sent to the University of Arizona, and tests were performed by the Shane Snyder group. Nitrite and nitrate were also measured in the same lab.

Water analysis

The SDI of the membrane permeate was measured in the field. Other water analyses that were performed in the field were done with a Hach Lange DR6000 photospectrometer, and included free chlorine, ozone, TOC, DOC, UVT254, Al, Fe and Mn. The natural organic matter (NOM) was analyzed via SEC-LC-OCD method (size-exclusion chromatography followed by online organic carbon detection). The samples were collected during the pilot test and shipped to a laboratory in the Netherlands (Het Water Labortorium; HWL) for analysis. Zeta potential of the liquid samples was measured by a Malvern Zetasizer nano in the University of Twente.

Pilot experimental set-up

To find the optimum operation conditions under the different pre-treatments, the experiments were initially divided into four categories and were conducted in this order:

1) in-line coagulation;
2) direct filtrating (no pre-treatment);
3) combined pre-ozone and coagulation; and
4) pre-ozone

Membrane runs within these categories were performed in two main sets:

1) critical flux determination;
2) optimization of the BW frequency

The EBW condition was fixed throughout the testing, with one EBW per day.

One of the main objectives was to determine the critical flux for treating chlorinated secondary effluent with in-line coagulation and ceramic MF. During the experiments, the flux through the membrane was increased in steps. The run time of each step (referred to in this study as a 'run') was defined by the total volume of water that was produced per square meter of membrane surface. This total filtrate volume was the same for each of the initial runs. This protocol allowed for a comparison of the membrane performance at different feed flux. Membrane performance was quantified by evaluating the mean normalized flux (or permeability), fouling rate, irreversible fouling and the permeate quality. These characteristics are specific for the feed water and the pre-treatment.

After four runs with in-line coagulation, the fouling potential of the secondary effluent could be evaluated and the filtration conditions for other pre-treatment methods were determined. After these runs, the pre-treatment method was selected and the filtration conditions under the selected pre-treatment method were determined for a two-week trial. With this method, the pilot was operated with the following test runs:

1) in-line coagulation pre-treatment (runs 1 to 4);
2) no pre-treatment (run 5);
3) ozone and in-line coagulation (runs 6 and 7);
4) two-week operation at selected parameters (run 9)

The basic input parameters for these runs are shown in Table 1, and the specific operating set-points are shown in Tables 2.

Table 1. Input Parameters for Critical Flux Experiment

Parameter	Unit	Value
membrane surface per element	[m2]	0.4
total number of elements	[n]	1
total volume to filtrate	[m3/m2]	5
total volume until backwash	[l/m2]	75
total volume until enhanced backwash	[l/m2]	>2400
total volume used for backwash	[l/m2]	3
total volume used for enhanced backwash	[l/m2]	6

After the two-week trial treating the chlorinated water, but before starting the testing with un-chlorinated water, tests were performed to optimize the dosage of Sachtoklar PACl coagulant when treating chlorinated water. Three runs were proposed and the details of the operational parameters of these runs are outlined in Table 3.

For treating the un-chlorinated and un-strained water, only in-line coagulation as the pre-treatment was used. The focus was to determine the critical flux and to test different coagulants. The first three runs (13, 14, and 15) were to determine the critical flux by continuously using the Sachtoklar PACl. After that, two coagulants both alum and PACl from local suppliers were tested. The operating parameters for these runs were shown in Table 3.

Table 2. Process Parameters for Runs 1 to 9

Run	1	2	3	4	5	6	7	8	9
Coag dose (mg Al/L)	2	3	6	6	0	6	6	0	6
Contact time (min)	6	4	3.5	3	-	3	2	-	3
Ozone (mg/L)	-	-	-	-	-	0.8	0.8	0.8	-
Flux (lmh)	100	150	173	200	100	200	300	200	189
Filtration time (min)	45	30	26	22.5	45	22.5	15	22.5	32

Table 3. Process Parameters for Runs 10 to 20

Run	10	11	12	13	14	15	16	17	18	19	20
Feed water	chlorinated			un-chlorinated							
Coag type	Sachtoklar PACl						alum			local PACl	
Coag dose (mg Al/L)	3	1.5	2	2	2	2	2	4	4	4	4
Contact time (min)	3	3	3	4	3.5	3	3	3	4	4	3.5
Flux (lmh)	189	189	189	150	173	189	189	189	150	150	173
Filtration time (min)	32	32	32	30	26	32	32	32	30	30	32

Clean-in-Place (CIP)

After each run, the membranes were cleaned before beginning the next run. The membrane was put into recirculation (permeate was fed back to the first coagulant tank). NaOCl was added at a concentration of 500 ppm, and this was recirculated at a low flow of 20 L/h over the membrane for 60 minutes. This cleaning solution was then flushed out and then a recirculation was started with H2SO4 solution at pH 3. As this solution recirculated, H2O2 was added to a concentration between 50 and 100 ppm as a reducer for metal oxides. This solution was also recirculated for an hour at a flow of 20 L/h and then flushed out before the next run started.

Results and discussion

Organic information of the raw water

Figure 2 shows the LC-OCD chromatograms of the wastewater effluent. It can be seen that the secondary effluent has high DOC concentration, high content of the biopolymers fraction and the LMW fraction, but low content of humics (as shown on the organic carbon detection, OCD, curve). Although the organic concentration is high, there was not strong UV adsorbing properties, indicating low aromaticity (as shown by the ultraviolet detection, UVD, curve). The wastewater had a high organic nitrogen concentration (the peaks corresponding 25 and 45 minutes retention time on the organic nitrogen detection, OND, curve) but it also had a high inorganic nitrogen concentration (the peak corresponding ca. 75 minutes retention time, on the OND curve, the organic nitrogen detector can also detect inorganic nitrogen indeed).

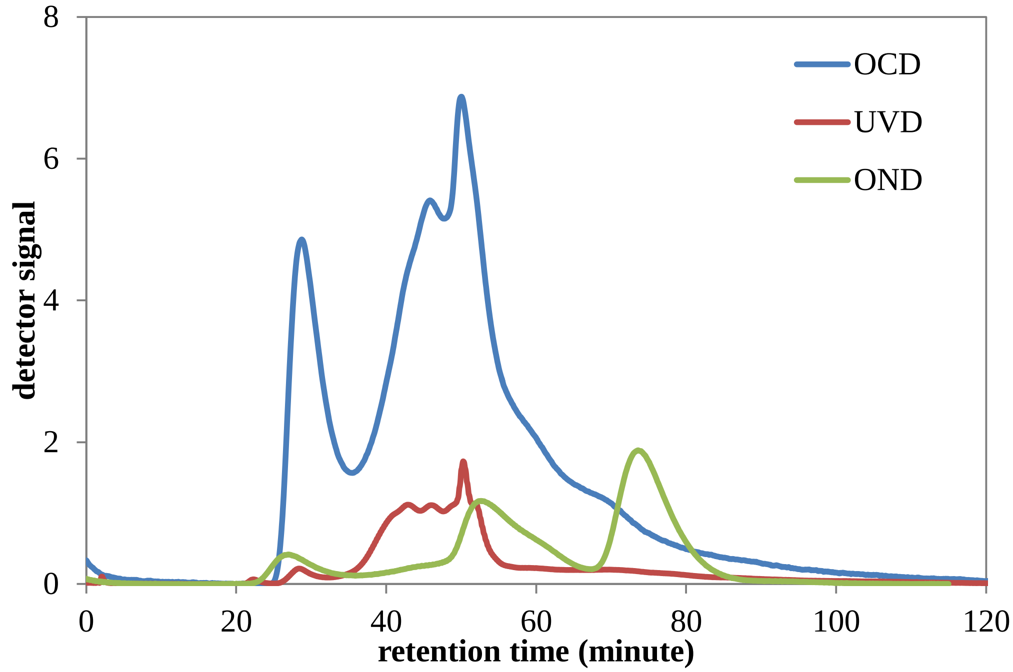


Figure 2. LC-OCD Chromatograms of Secondary Effluent Wastewater

Results of ozone decay experiment
Figure 3 shows the ozone decay at different initial applied ozone doses. The secondary effluent wastewater had a high ozone demand. At an initial ozone dose of 8 ppm, the residual ozone concentration was 0.8 ppm after 3 minutes.

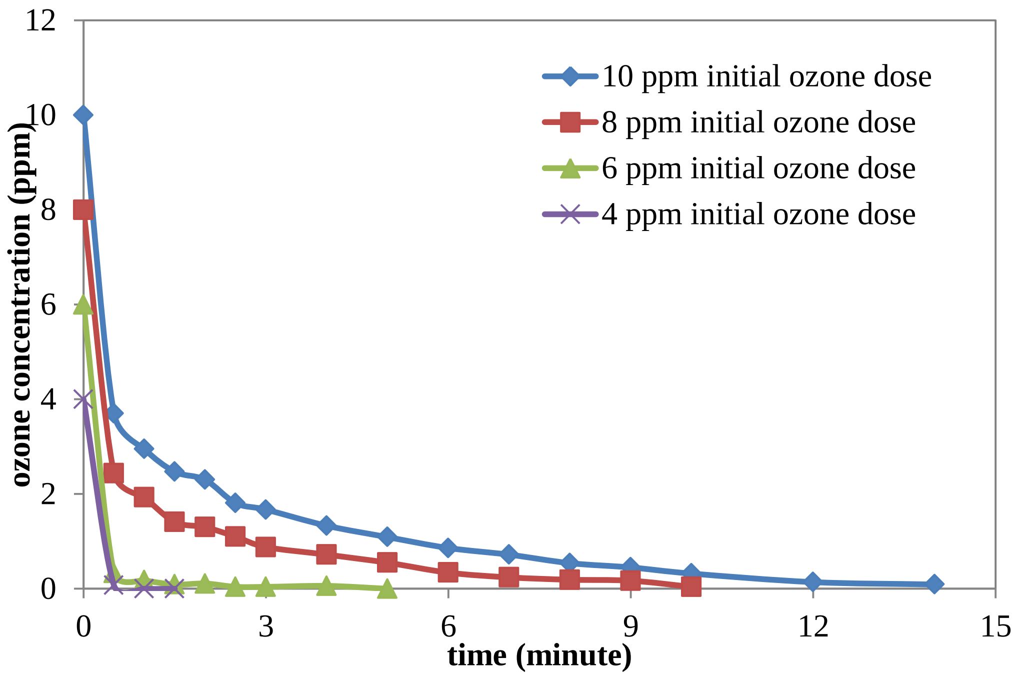


Figure 3. Ozone decay of the Secondary Effluent Wastewater

Nitrogen/nitrate analysis was performed during the ozone experiments. It indicated that increasing ozone dose converted nitrite to nitrate. This is because nitrite is known to inhibit ozone reactions by scavenging molecular ozone. It also shows the advantage of ozone by converting nitrite into nitrate for treating wastewater.

Table 4. Nitrite and Nitrate Concentration at Different Applied Ozone Doses

sample	nitrite-N (µg/L)	nitrate-N (µg/L)
wastewater effluent	1220	357
ozone 2 mg/L	927	619
ozone 4 mg/L	171	1110
ozone 6 mg/L	<21	1150
ozone 8 mg/L	<21	1220
ozone 10 mg/L	<21	1260

Membrane operational performance

The membrane operation started with coagulation as the pre-treatment. The flux was increased from 100 to 150, 173 and then 200 lmh; the filtration time between BWs decreased from 45, 30, 26.5 to 22.55 minutes at these different fluxes. This arrangement for testing allows for a direct comparison at the same volume load until a BW (i.e., 75 liter per m2 membrane surface area in this trial). Figure 4 illustrates the TMP build-up at different feed fluxes. For run 2 at 150 lmh, the TMP was high because of a feed pump malfunction and air getting into the pipeline. But the overall impression is that the in-line coagulation can control the membrane fouling. The fouling rate at 100 lmh was very low, at 0.5 kPa/day and the fouling rate at 200 lmh was acceptable at 9.3 kPa/day.

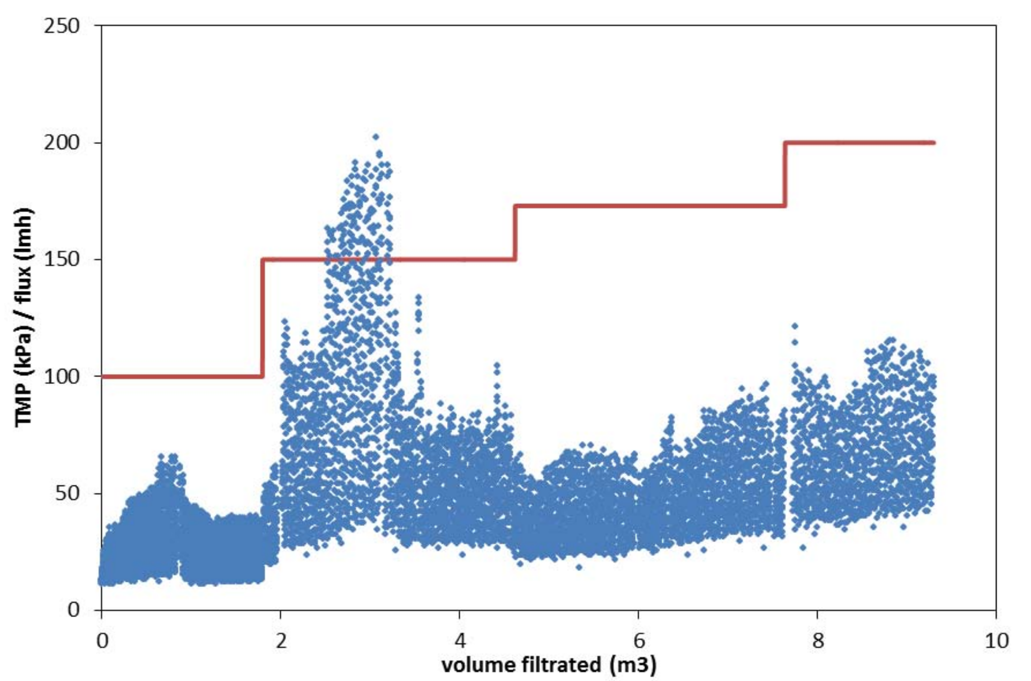


Figure 4. TMP Profile at Different Feed Flux with In-line Coagulation Pre-treatment

After the first four runs with pre-coagulation, other pre-treatment methods were tested. The results are shown in Figures 5 and 6. Because of different fouling potential of the membrane feed after different pre-treatments, the membrane filtration conditions were varied, i.e., 100 lmh for direct filtrating (no pre-treatment), 200 lmh for in-line coagulation pre-treatment or pre-ozone pre-treatments, and 300 lmh for the combined pre-ozone and coagulation pre-treatment. The filtration load until a BW was kept as a constant at 75 l/m2.

The data presented in Figures 5 and 6 were obtained from the last two filtration terms (a filtration term is defined as the filtration between two BWs) at the end of each run. From Figure 5, it can be seen that the TMP was very high when there was no pre-treatment or when using the pre-ozone pre-treatment. The TMP was much lower when having in-line coagulation pre-treatment and when operating with a combined pre-ozone and in-line coagulation pre-treatment.

Figure 6 shows the influence of pre-treatment on the specific flux. Without any pre-treatment or with pre-ozone alone, the membranes experienced a serious specific flux reduction. A higher specific flux could be maintained with in-line coagulation pre-treatment and with a combined pre-ozone and in-line coagulation pre-treatment.

The advantage of the combined pre-ozone and in-line coagulation pre-treatment as compared to in-line coagulation alone was also clear. By introducing ozone, it could be operated at high flux (i.e., 300 lmh), and at same time with high specific flux.

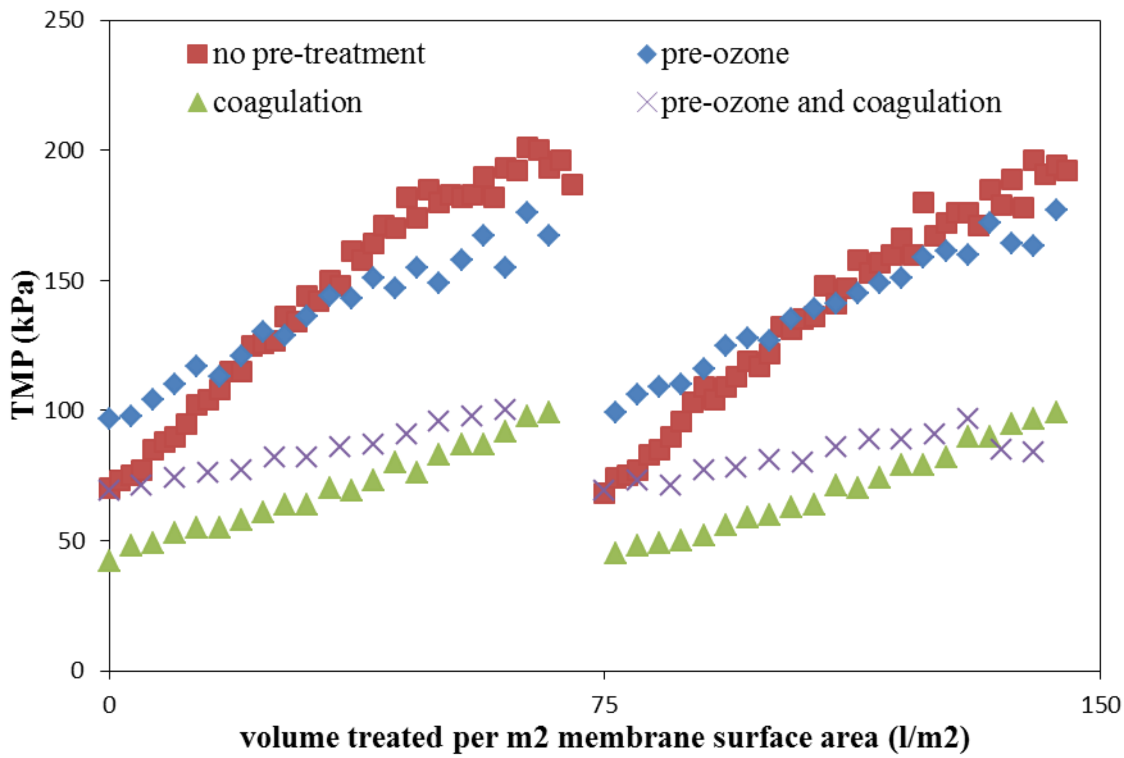


Figure 5. TMP Build-upwith Different Pre-treatment Conditions, Feed Flux 100 LMH for Direct Filtration, 200 LMH for In-line coagulation or Pre-Ozone alone, and 300 LMH for Combined Pre-Ozone and Coagulation Pre-treatment

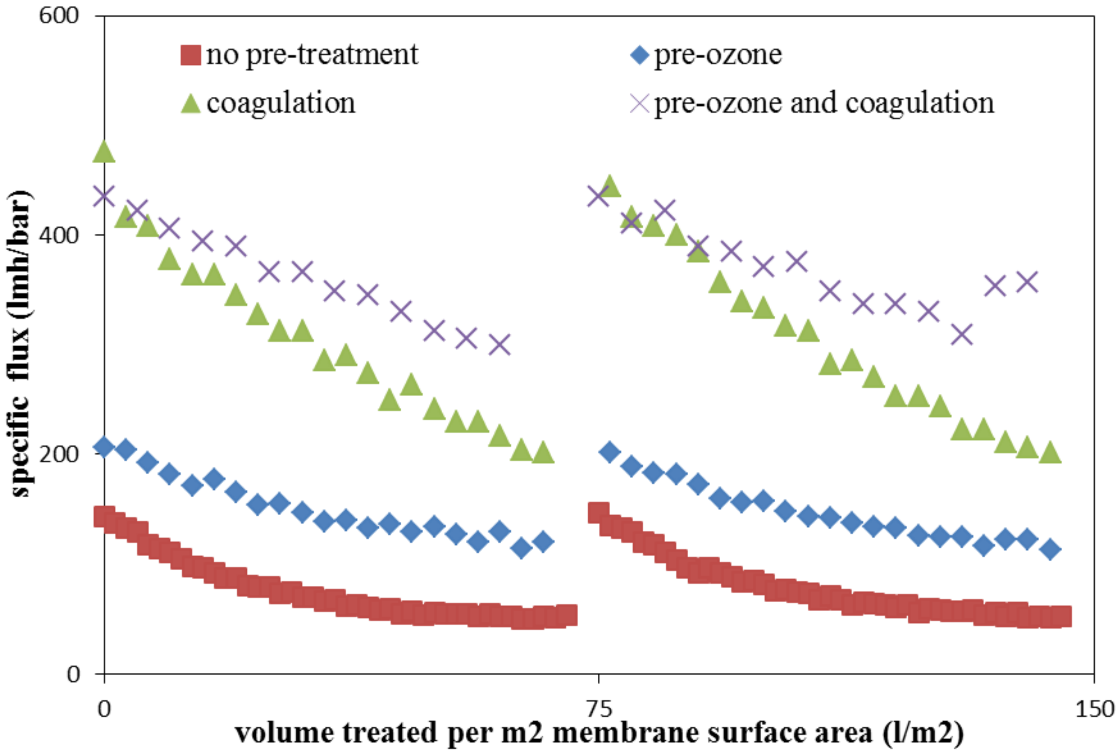


Figure 6. Specific Flux with Different Pre-treatment Conditions, Feed Flux 100 LMH for Direct Filtration, 200 LMH for In-line coagulation or Pre-Ozone alone, and 300 LMH for Combined Pre-Ozone and Coagulation Pre-treatment

After the first eight runs, it became clear that a pre-treatment was required to obtain stable membrane operation. Pre-treatment with pre-ozone alone could not control the membrane fouling. But both in-line coagulation and the combined pre-ozone with in-line coagulation pre-treatments stabilized the membrane operation. Combined pre-ozone and in-line coagulation yielded the best membrane operational performance, which was a stable performance at a very high flux (300 LMH). The cost, however, of ozone application to this wastewater rendered it non-competitive.

In-line coagulation also provided a stable membrane operation at quite a high feed flux (up to 200 LMH) and the fouling rate was acceptable for achieving the goal for a CIP frequency. Based on these results, in-line coagulation was selected as the pre-treatment for the ceramic MF and a two-week trial was carried out.

Based to pilot observations from the first four test runs, and achieving the target CIP frequency of every 30 days, it was decided to operate the pilot at 189 lmh with a filtration time of 32 minutes until a BW, and a daily EBW as required. The coagulant dose was 6 ppm Al3+. The TMP profile obtained in the two-week trial is shown in Figure 7. There were some start/stop issues with the pilot plant, because of a membrane feed pump failure and shortage of feed water supply. The pilot operation was very stable during the first three days with a fouling rate of 2.1 kPa/day (before the first stop). The overall fouling rate was found to be 3.7 kPa/day. With the maximum TMP until CIP set at 200 kPa, the CIP frequency would be ((200-30)/3.7=) 46 days. The 30 kPa is the target starting TMP at 189 LMH after a CIP.

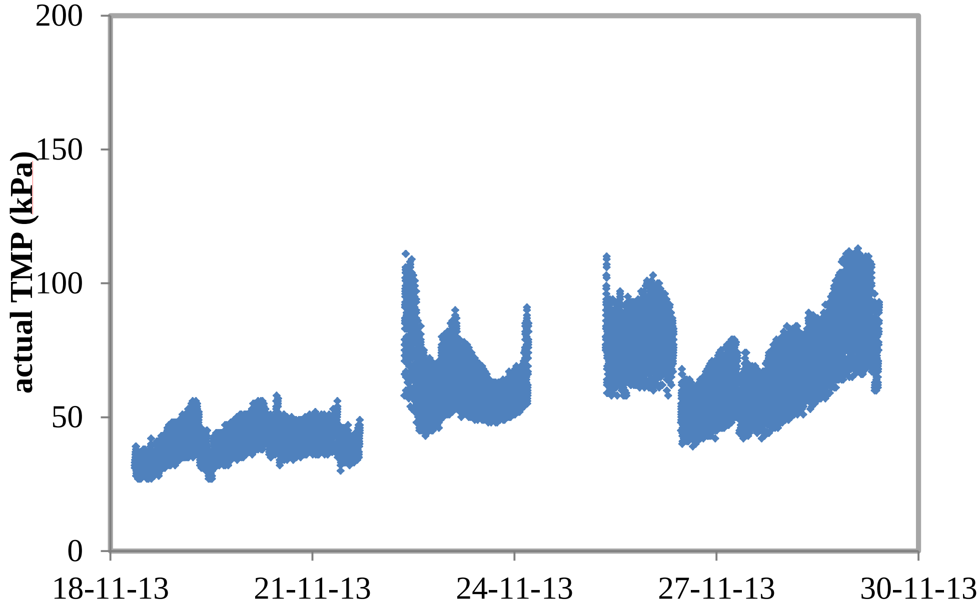


Figure 7. TMP Profile for the Two-Week Trial with In-Line Coagulation Pre-treatment

After the two-week trial, additional tests were performed with chlorinated feed water for optimizing the coagulant dose. Test runs 10 through 12 were conducted with different coagulant dosages of Sachtoklar PACl, (i.e., 4, 2 and 1.5 ppm). The dosage of 2 ppm was able to obtain a sustainable operation.

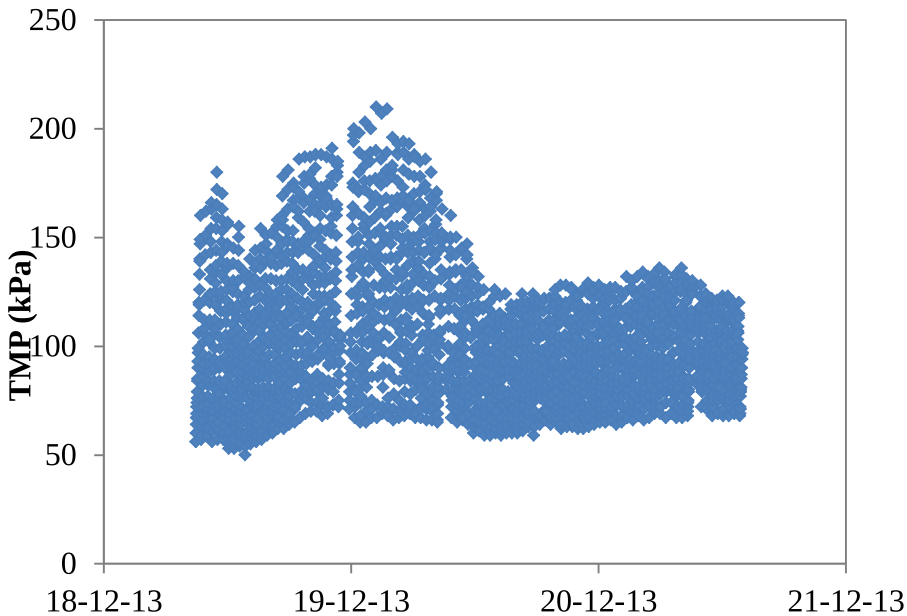


Figure 8. TMP Profile for Treating Un-chlorinated and Unstrained Feed

Additional tests were performed with un-chlorinated un-strained feed water. Test runs were conducted at 150, 173 and 189 lmh (filtration time 30, 26 and 32 minutes respectively). The coagulant dose was 2 mg/L as Al3+ (Sachtoklar PACl). Stable results were observed for all three runs. Figure 8 shows the results from run 15 at 189 LMH. In this graph, the TMP during the first part of the run was high because of air getting into the system (i.e., a feed pump malfunction). At the same feed flux, the operational pressure was higher for treating un-chlorinated un-strained feed as compared to treating chlorinated and strained feed water (Figures 7 and 8).

In the last stage of testing, aluminum sulphate coagulant and a different PACl (from local supplier) were trialed when treating un-chlorinated water. These coagulants were not as good as Sachtoklar PACl for reducing fouling tendencies of the feed water, and neither coagulant was able to yield stable operation at the coagulation dose up to 4 ppm Al3+ at 150, 173 and 189 lmh feed fluxes. This suggests that the coagulant type has an important role in fouling control, and it should be carefully selected.

Water quality of membrane permeate

Figure 10 shows the values of silt density index (SDI) of the membrane permeate at different times throughout the test. The SDI was of particular importance, because the ceramic membrane permeate would feed a downstream RO process. When treating chlorinated water, the membrane permeate had a low SDI, most of time below 3. Different pre-treatments also had an impact on the permeate SDI. The lowest SDI values were found when using pre-ozone pre-treatment or a combination of pre-ozone and in-line coagulation. The SDI of membrane permeate was higher when treating un-chlorinated water, often above the SDI was 3. Mostly likely, this was caused by NOM, but not by suspended solids. Lab analysis revealed that the TSS of the membrane permeate was < 10 mg/L (under the detection limit).

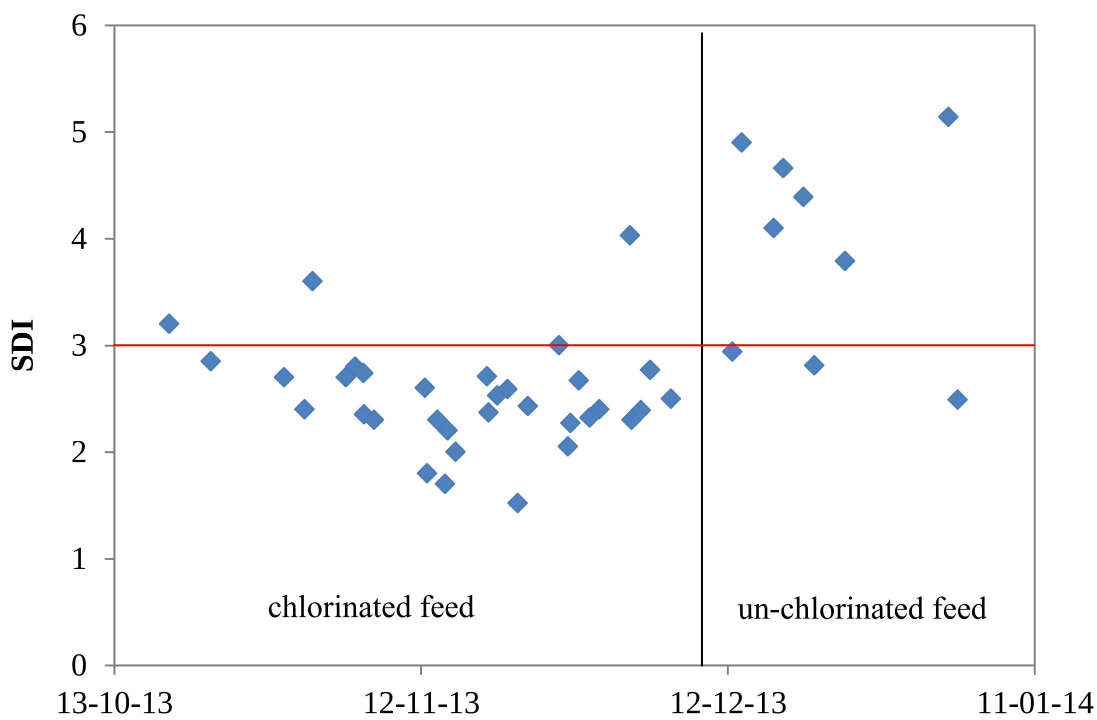


Figure 9. SDI of Membrane Permeate

Organic change and removal during the process
It has been demonstrated that different pre-treatments led to different membrane operational performance or fouling behavior. This was caused by the organic alteration and removal with different pre-treatment methods and the change in organic/membrane interaction.

Figure 10 shows the NOM removal through the pre-ozone, in-line coagulation and ceramic MF treatment process. It can be seen that ozonation did not remove much organics. But it is visible that ozone slightly reduced the amount of the high molecular weight fractions and slightly increased the amount of low molecular weight fractions. During coagulation, a large part of biopolymer was adsorbed to the coagulant flocs (and thus removed by sample filtration for the LC-OCD analysis) , together with a small portion of humics. The ceramic MF rejected some of the remaining biopolymers and also a very small amount of organics. For this type of water, it is logical to consider the biopolymer as the main foulant.

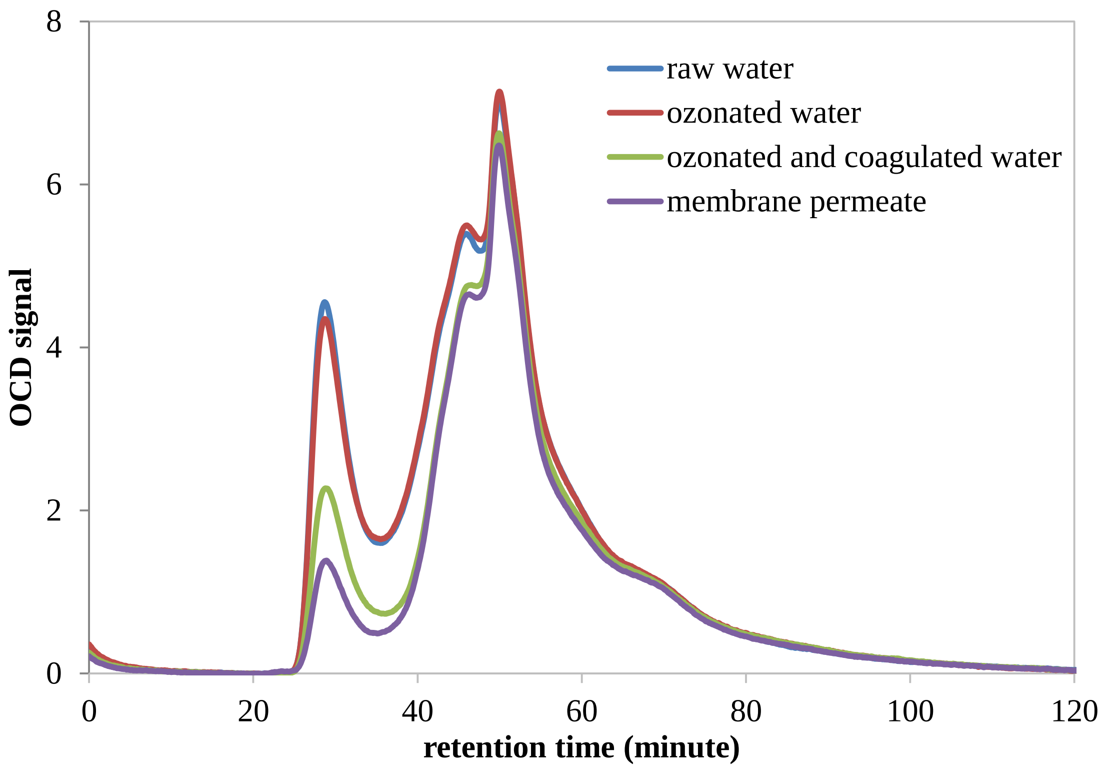


Figure 10. NOM Change and Removal by Pre-Ozone and Coagulation followed by Ceramic MF

Table 5 outlines the change of the biopolymer concentration throughout the processes. For direct filtration (i.e., no pre-treatment), the biopolymer load was high and the membrane also showed a very high rejection towards the biopolymer (78 percent). Consequently, rapid fouling occurred. Pre-ozone did not alter or significantly reduce of the amount of biopolymer, and it also did not change the biopolymer rejection by the ceramic membrane (78 percent rejection of biopolymer with the ceramic when treating pre-ozonated water). Therefore pre-ozone alone is not a useful tool for control the fouling for this feed water. Coagulation pre-treatment lowered the biopolymer load to the membrane, although not as much as expected, but coagulation also changed the biopolymer/membrane interaction. After the coagulation pre-treatment, less biopolymer was rejected (i.e., the rejection was 50 percent) than in other tests.

The results also suggested that pre-ozonation enhanced the efficiency of coagulation. More biopolymer was removed during coagulation when it was pre-ozonated, and the membrane showed a "bad" rejection of biopolymer after the pre-ozone and coagulation pre-treatment. Only 39 percent biopolymer was rejected. Hence, the key for fouling control with the coagulation and with combined pre-ozone and coagulation pre-treatments seems to be: 1) reduce the biopolymer concentration; and 2) promote the exclusion at the membrane interface.

Table 6 presents the results of zeta potential measurement. A significant change of zeta potential after membrane filtration was observed when direct filtration the secondary effluent or the water after pre-ozone alone. Interesting, high biopolymer rejection was observed in these two cases as discussed previously. On the other hand, the zeta potential change after membrane filtration is minor when having coagulation or combined pre-ozone and coagulation as the pre-treatments. This was linked to the observation that the biopolymer rejection was rather low. This may suggest an electrostatic exclusion between the membrane and the biopolymer after the coagulation pre-treatment. Consequently, the fouling was less. The electrostatic interaction could also explain how the ozone enhanced coagulation. After the ozone treatment, zeta potential became more negatively charged. This promoted the adsorption of organics into the positively charged hydrolysis products of the coagulant.

Table 5. Biopolymer Concentration Change during the Processes

biopolymer (ppb)	no pre-treatment	pre-ozone	coagulation	ozone & coag.
raw water	1338	1381	1794	1647
ozonated		1365		1683
coagulated			1362	
ozonated and coagulated				922
membrane permeate	291	300	677	561

Table 6. Zeta Potential Change during the Processes

zeta potential (mV)	no pre-treatment	pre-ozone	coagulation	ozone & coag.
raw water	-16.9	-18.1	-20.9	-16.9
ozonated		-18.2		-20.7
coagulated			-17.1	
ozonated and coagulated				-15.1
membrane permeate	-9.84	-12.1	-16.6	-14.7

Conclusion

This pilot study evaluated different pre-treatments to ceramic microfiltration for treating secondary effluent that was chlorinated in some tests, and un-chlorinated in other tests. It was concluded that direct filtration of chlorinated secondary effluent was not viable. Pre-ozone alone was also not a feasible pre-treatment option. In-line coagulation pre-treatment yielded a stable membrane operation when treating both chlorinated stained and un-chlorinated un-stained secondary effluent; however coagulant type was important. Sachtoklar PACl worked well but alum and a different PACl did not. Pre-chlorination of secondary effluent led to low SDIs of membrane permeate (SDI<3) whereas un-chlorinated feed often resulted in higher SDIs of membrane permeate (SDI>3).

A combined pre-ozone and coagulation pre-treatment led to best membrane operational performance. It also improved the water quality of the membrane permeate. The secondary effluent had a high ozone demand and, as a result, the cost of ozone application rendered it non-competitive.

Organics (especially biopolymers) were the contributors to fouling. The key for fouling control seems to be reducing the organics (especially biopolymers) load and promoting electrostatic exclusion between the organics (i.e., the biopolymers) and the membrane.

Acknowledgements

The authors are thankful to Dr. Shane Snyder from University of Arizona, Dr. Mieke Luiten-Olieman from University of Twente, and Het Waterlaboratorium (HWL) for their supports.

References

S. Geno Lehman and Li Liu (2009), "Application of Ceramic Membranes with Pre-ozonation for Treatment of Secondary Wastewater Effluent", Water Research, 43, pp.2020-2028.

Noel Dow, Danny Murphy, Jonathan Clement and Mikel Duke (2013), Outcomes of the Austrlian Ozone/Ceramic Membrane Trial on Secondary Effluent, Water, 40, 45-51.

Motoharu Noguchi and Hiroshi Tegane (2013), "Reclaimed Wastewater Facility Using Ozone and Ceramic Membranes", Proceedings AWWA AMTA Conference, San Antonio.

Fredrick W. Gerringer, Rajen Budhia, Teresa Venezia, Marc A. Serna and R. Shane Trussell (2013), Optimizing MF Performance after Ozone Pre-treatment in a Water Reuse Treatment Train, Proceedings AWWA AMTA Conference, San Antonio.

2015 Membrane Technology
CONFERENCE & EXPOSITION

Ceramic microfiltration for treating secondary wastewater effluent: influence of pre-treatment on the operational performance

Jumeng Zheng, Gilbert Galjaard, Holly Shorney-Darby
PWN Technologies

America's Authority in Membrane Treatment
AMTA
American Membrane Technology Association
Improving America's Waters Through Membrane Treatment and Desalting

American Water Works Association
Dedicated to the World's Most Important Resource™

acknowledgement

- PWNT – Harry Scheerman, Isaac Ng, Vincent Lam
- Metawater
- Het Waterlaboratorium
- Dr. Shane Snyder, University of Arizona
- Dr. Mieke Luiten-Oliman, University of Twente

agenda

- background
- objectives
- experimental
- results
- discussion
- conclusions

TECHNOLOGIES

background

- microfiltration pre-treatment to RO
- request for proposal
  - raw water: TOC 14 ppm; TSS 6 ppm
  - EBW frequency: one EBW per day
  - CIP interval: > 30 days
- proposed method
  - proposed inline coagulation and ceramic MF
  - ozone tested in pilot study

objectives

- evaluate different pre-treatment methods
  - direct filtration (no pre-treatment)
  - in-line coagulantion
  - pre-ozone
  - combined pre-ozone and coagulation
- select a pre-treatment and determine the critical flux
- conduct a two-week trial
- observe the difference when treating chlorinated strained versus un-chlorinated un-strained feed water
- evaluate alum versus PACl as coagulant
- determine the filtrate silt density index (SDI)

TECHNOLOGIES

the pilot plant

- several pre-treatment options
- Metawater membrane
  - dimension 30x1000 mm
  - surface area 0.4 m^2
  - nominal pore size 0.1 µm
- treatment capacity
  - 40-140 l/h

test plan

- in-line coagulation
- direct filtration
- combined pre-ozone and in-line coagulation
- pre-ozone alone
- two-week trial at optimum settings
- PACl coagulant dosage optimization and testing different coagulants
- treating un-chlorinated un-strained feed

settings runs 1 to 9

run	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
alum dose (ppm Al)	2	3	6	6	0	6	6	0	6
contact time (min)	6	4	3.5	3	/	3	2	/	3
ozone (ppm)	0	0	0	0	0	0.8	0.8	0.8	0
flux (lmh)	100	150	173	200	100	200	300	200	189
filtr time btwn BWs (min)	45	30	26	22.5	45	22.5	15	22.5	32
recovery (%)	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9	96.9
basic run test design	runs 1 to 8, equally 2 m^3 water treated per run; run 9 two-week trial								
EBW	100 ppm NaOCl or pH 3 (H_2SO_4) solution, once per day								
CIP	500 ppm NaOCl recirculation, and pH 3 solution recirculation; after each run								

TECHNOLOGIES

settings runs 9 to 20

Run	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
water source	chlorinated feed				un-chlorinated feed							
coagulant type	Sachtoklar PACl							alum			“PACl”	
alum dose (ppm Al)	6	3	1.5	2	2	2	2	2	4	4	4	4
contact time (min)	3	3	3	3	4	3.5	3	3	3	4	4	3.5
flux (lmh)	189	189	189	189	150	173	189	189	189	150	150	173
filtr time btwn BWs (min)	32	32	32	32	30	26	32	32	32	30	30	32
recovery (%)	96.9	96.9	96.9	96.9	95.9	95.9	96.9	96.9	96.9	95.9	95.9	96.7
EBW	100 ppm NaOCl or pH 3 (H_2SO_4) solution, once per day											
CIP	500 ppm NaOCl recirculation, and pH 3 solution recirculation; after each run											

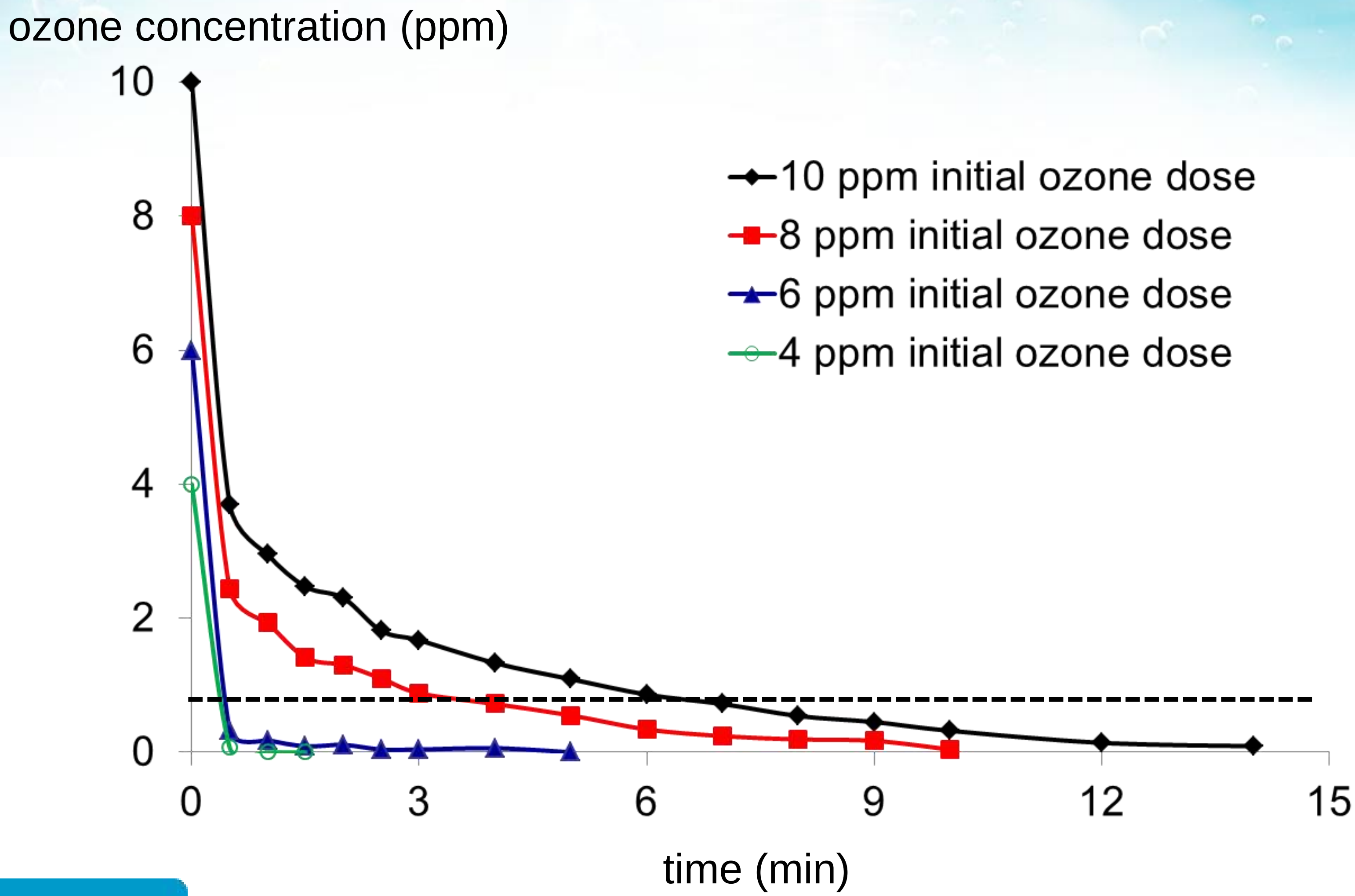
TECHNOLOGIES

water analysis

- field analysis
  - silt density index (SDI)
  - TOC,UVT, Al etc. *via* photospectrometer
- BOD, COD, TSS, TDS etc – local lab
- raw water ozone demanding – UA, USA
- zeta potential measurement – UT, NL
- NOM analysis – HWL, NL

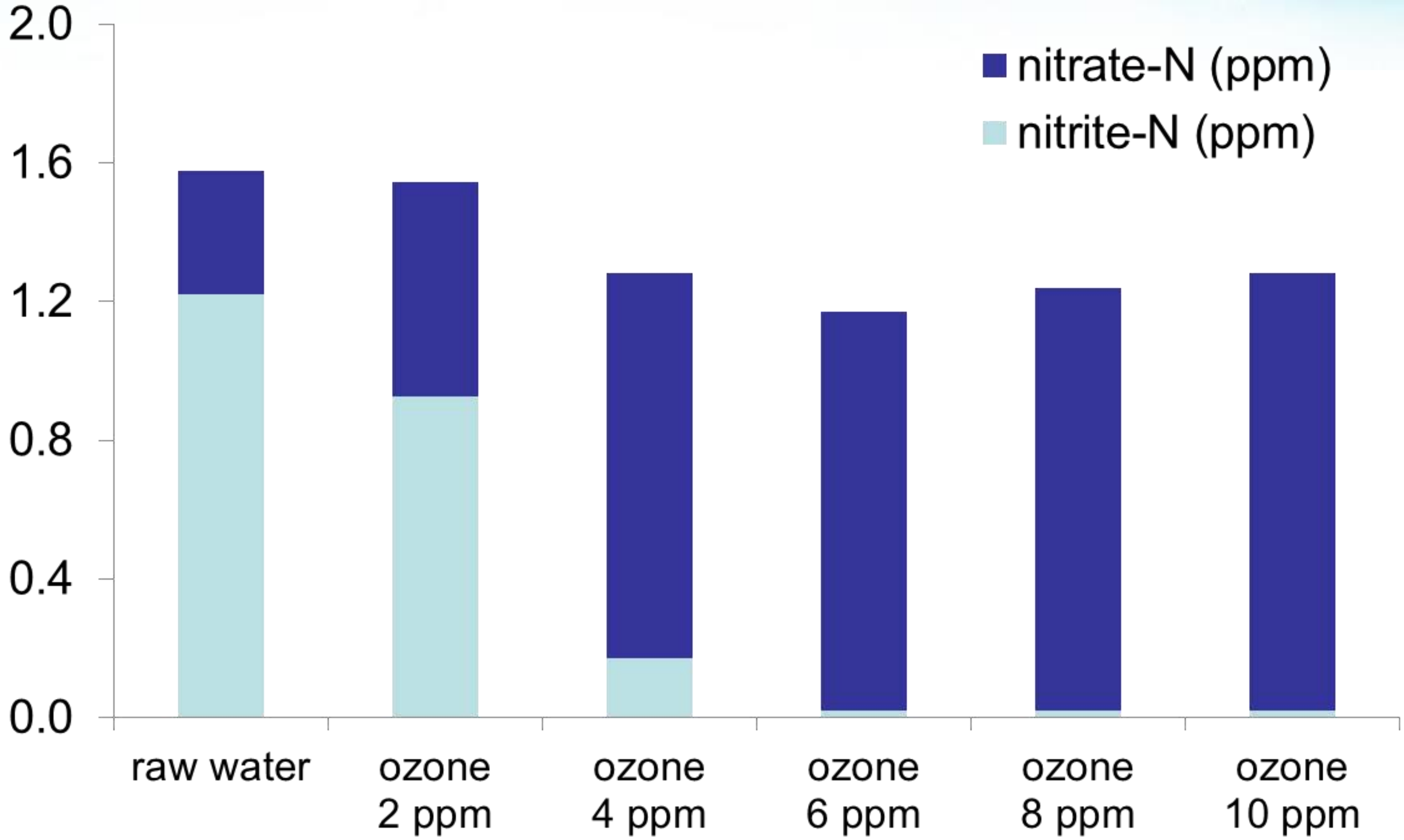
TECHNOLOGIES

raw water – ozone decay

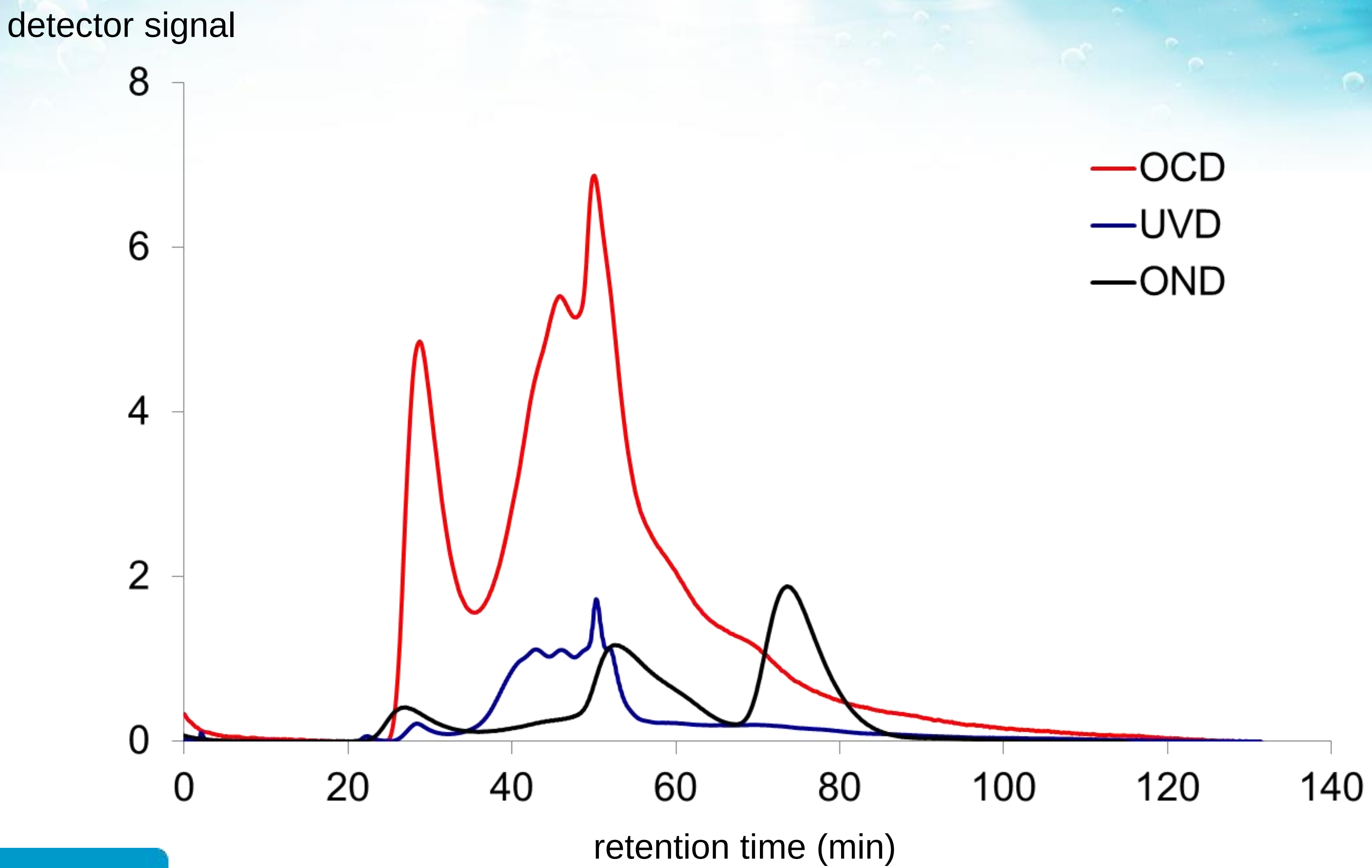


nitrite/nitrate conversion

nitrite/nitrate concentration (ppm)

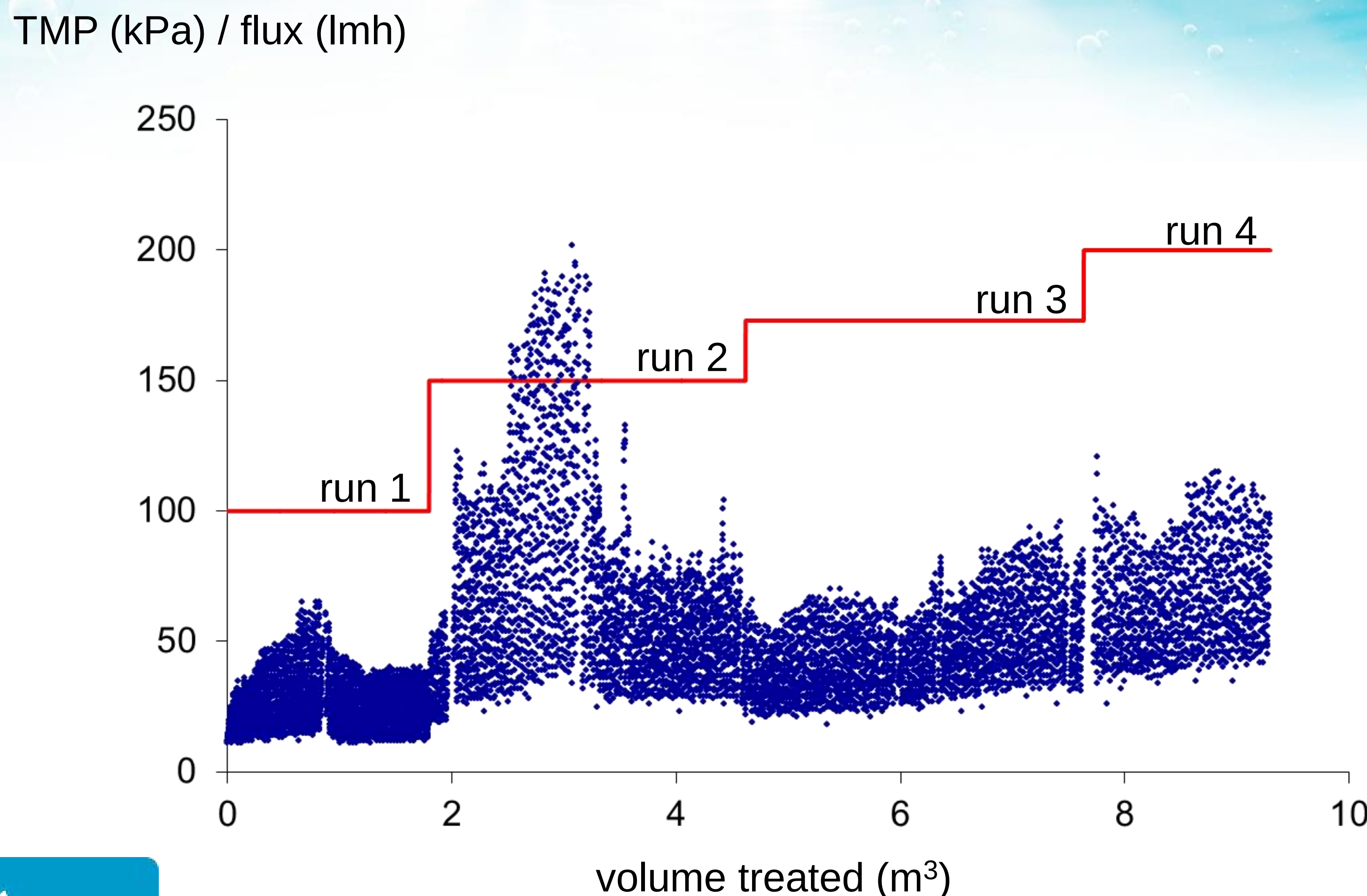


raw water - NOM

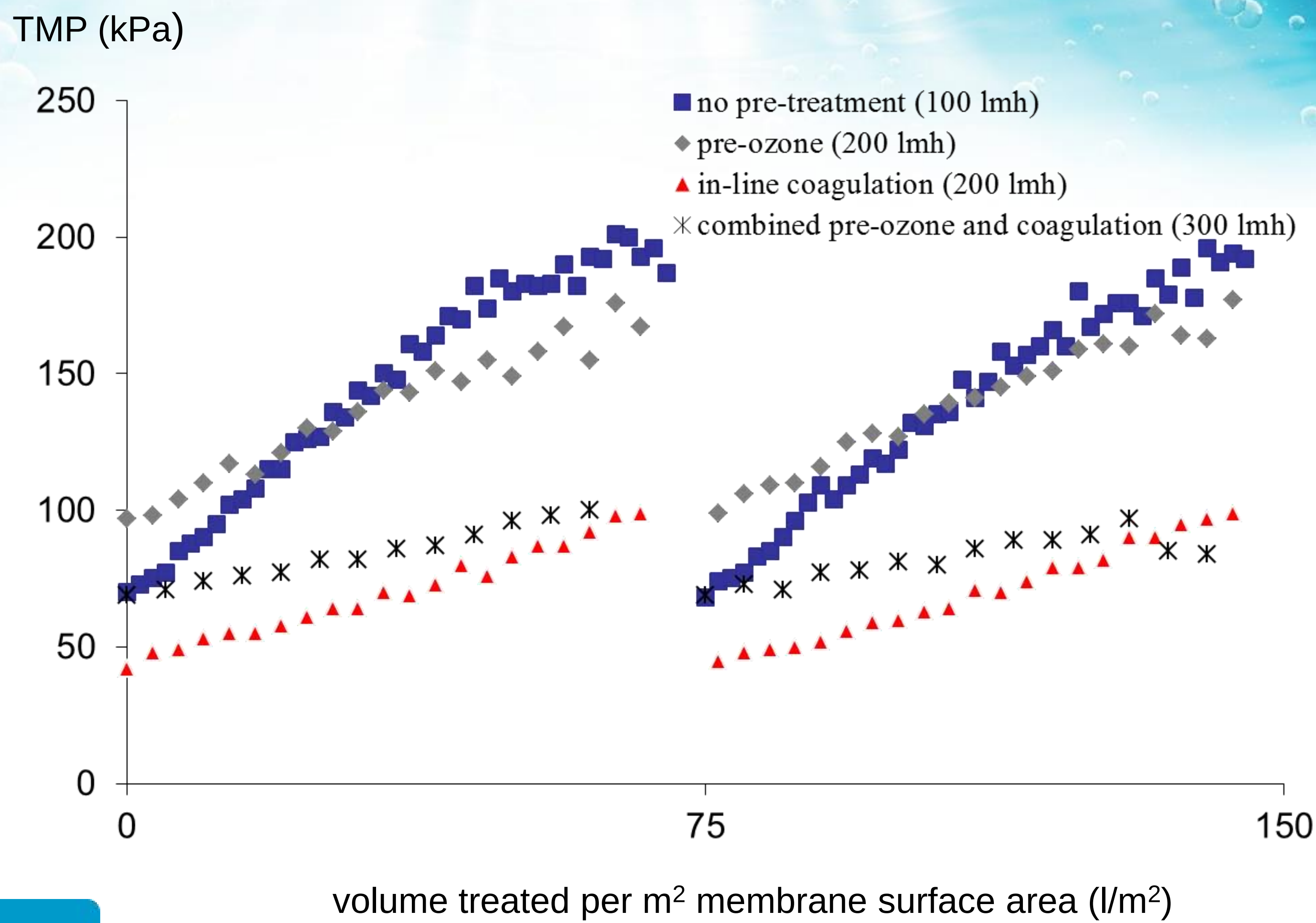


TECHNOLOGIES

in-line coagulation/ceramic MF

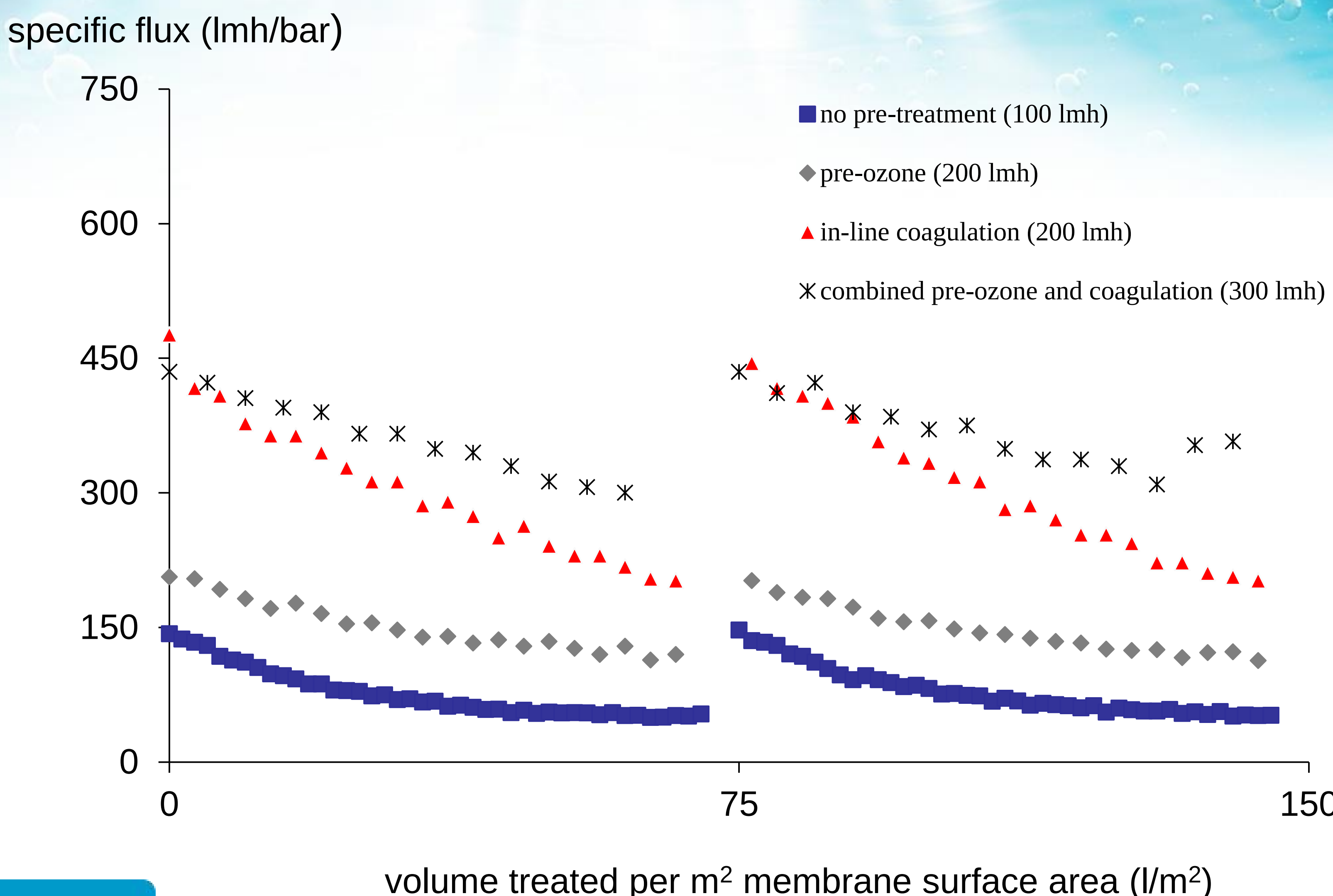


comparing different pre-treatments



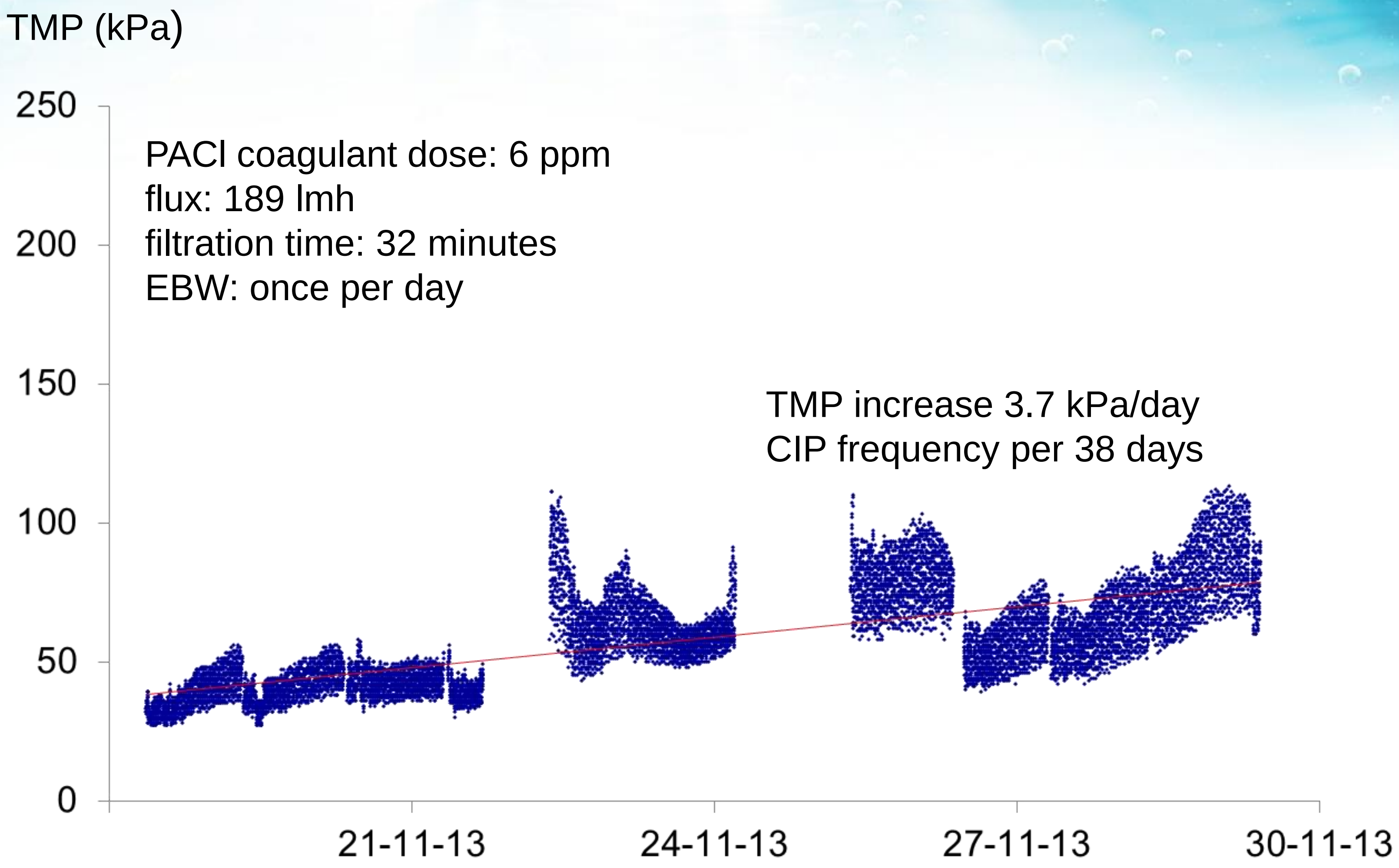
TECHNOLOGIES

comparing different pre-treatments

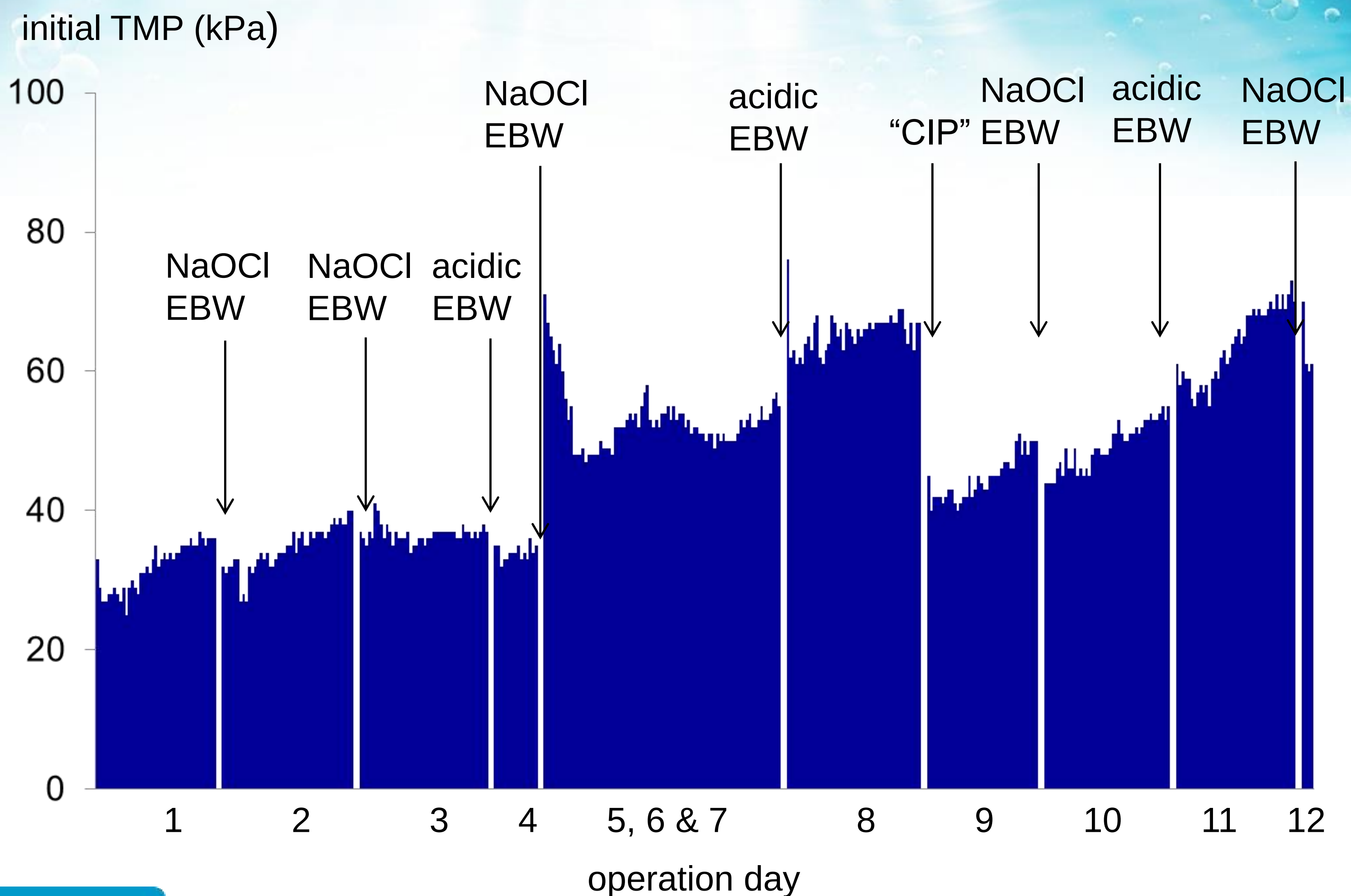


TECHNOLOGIES

the two-week trial (run 9): overview

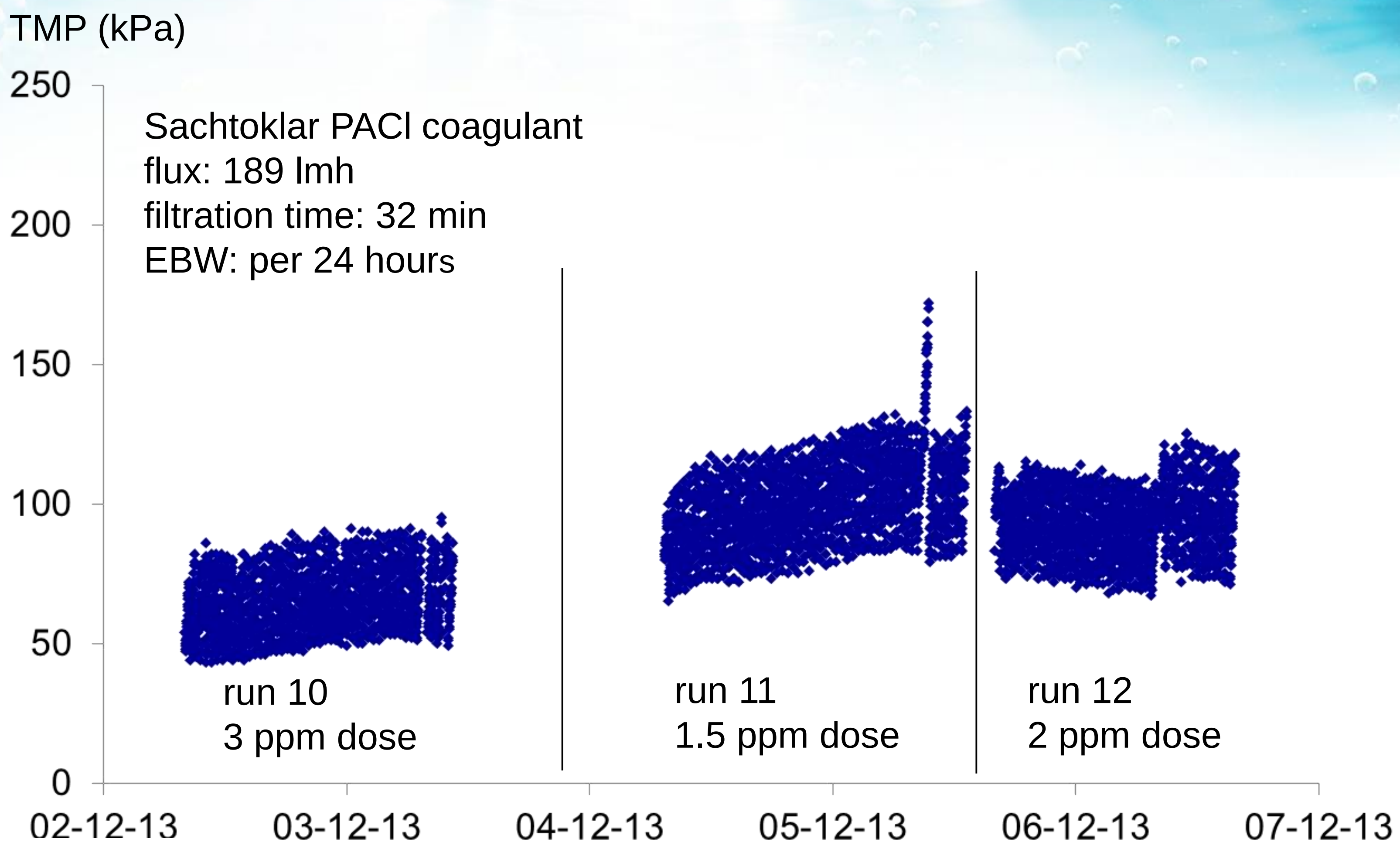


the two-week trial (run 9): initial TMP

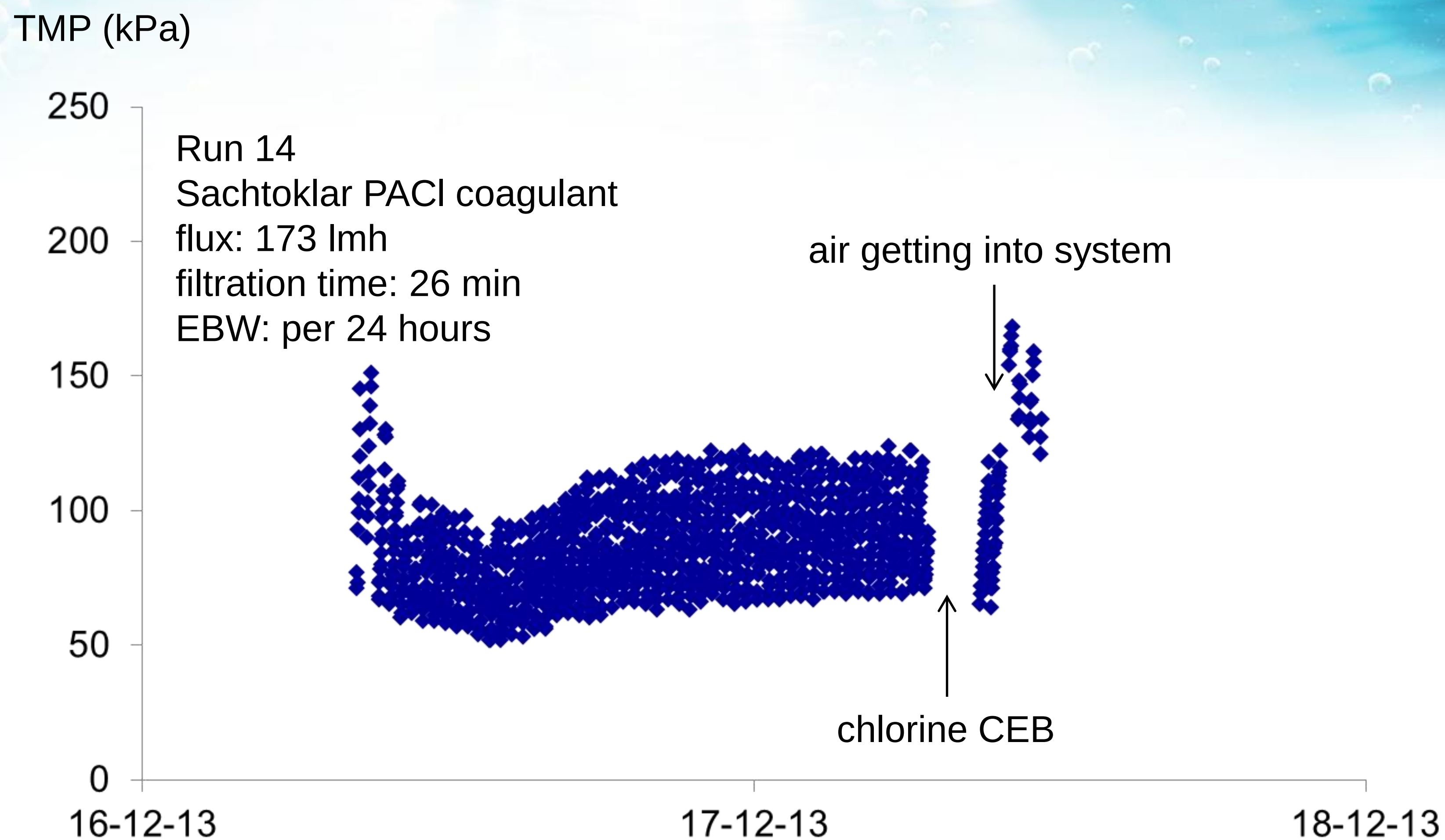


"CIP": 1) 500 ppm NaOCl recirculation 30 minutes; and 2) pH 3.0 recirculation 30 minutes

optimizing Sachtoklar PACl dose

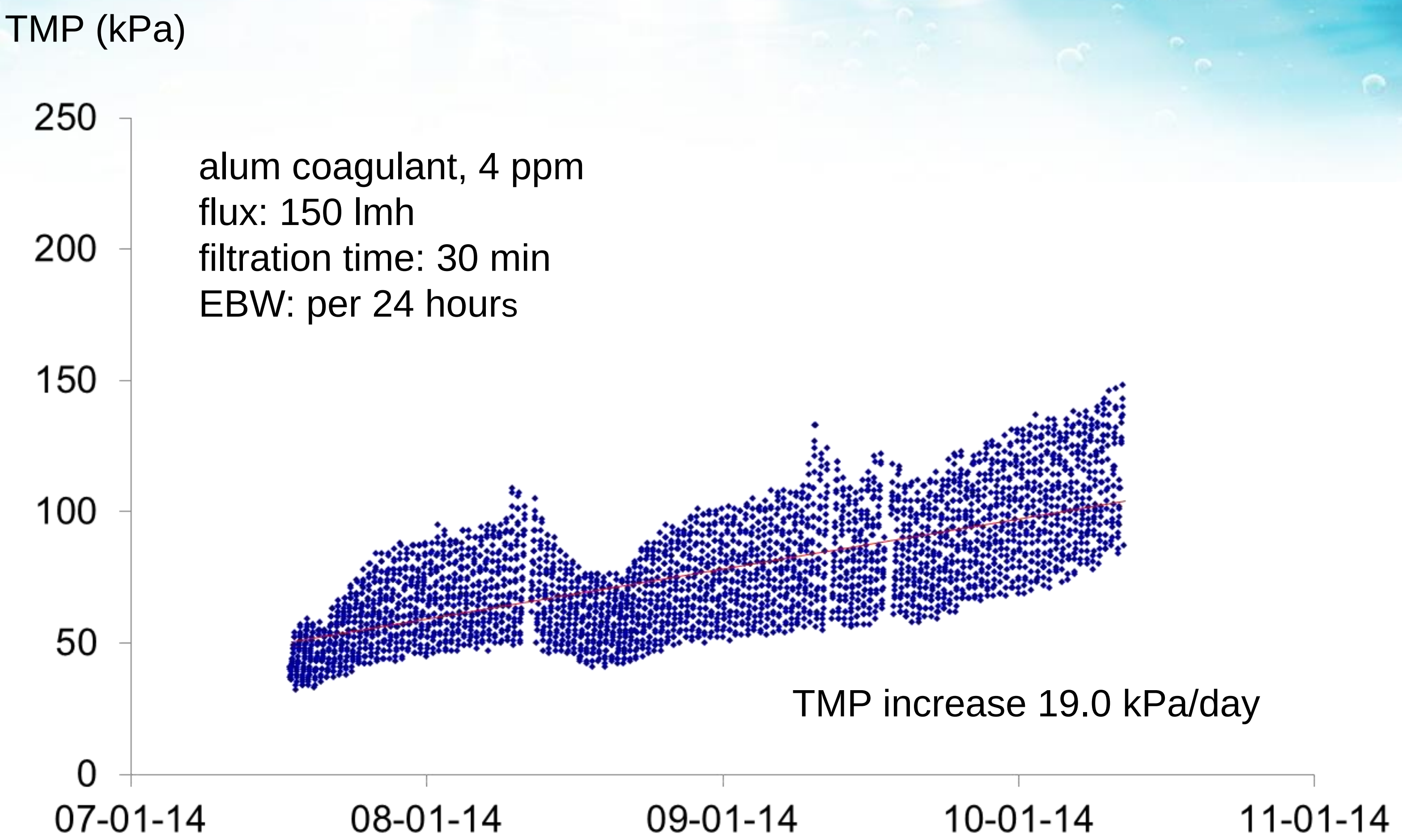


treating un-chlorinated un-strained feed

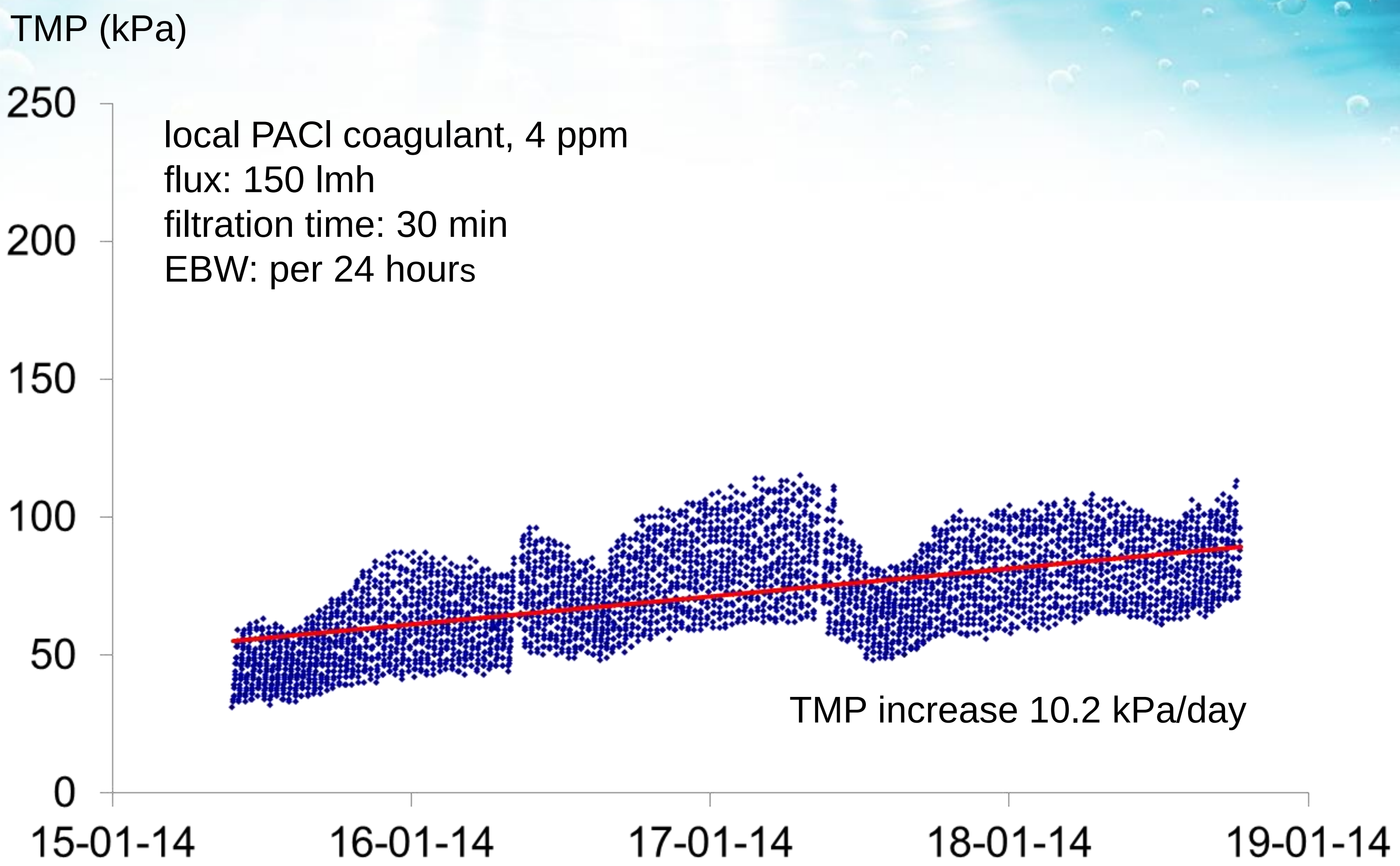


TECHNOLOGIES

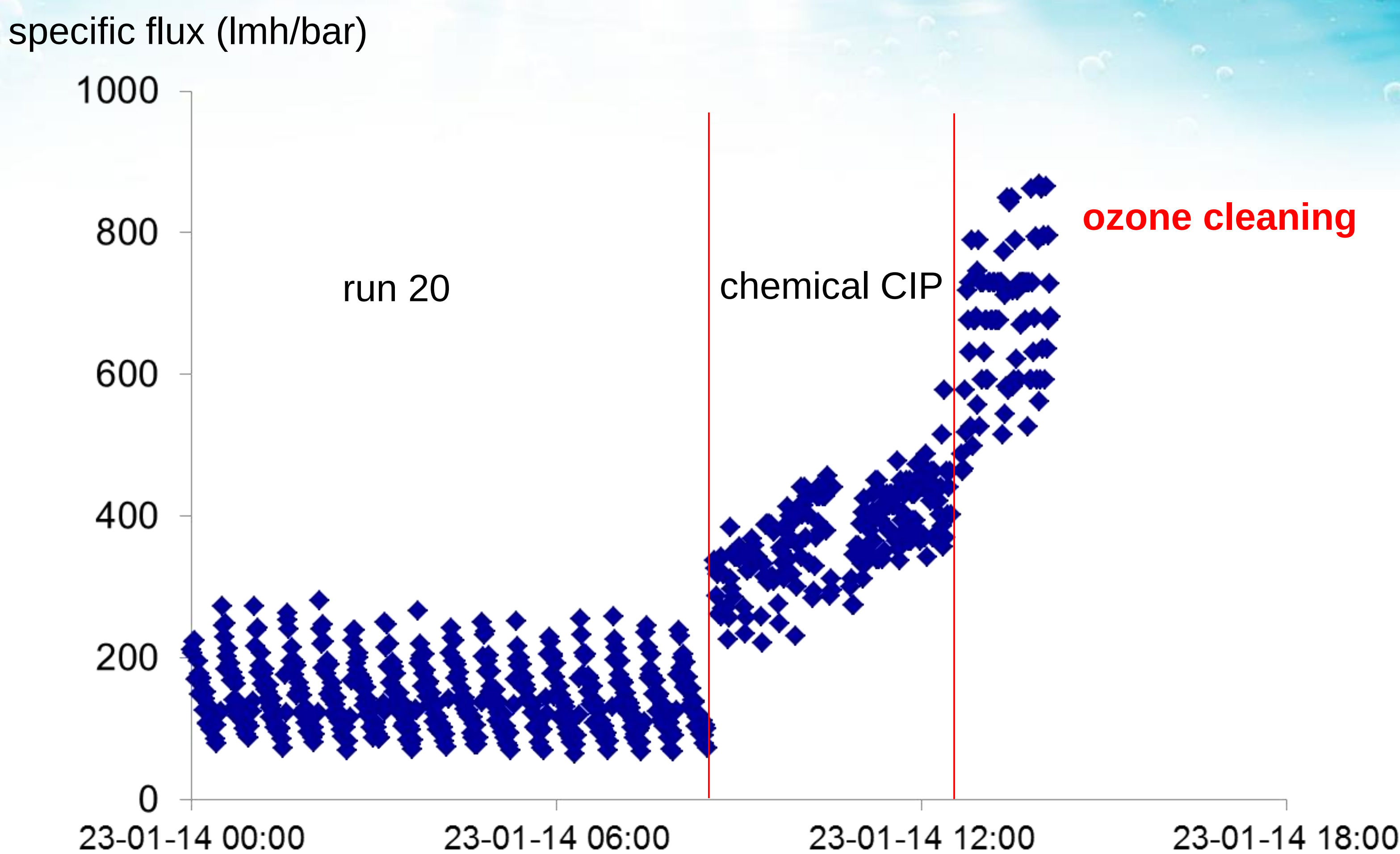
alum coagulant (run 18)



local PACl coagulant (run 19)

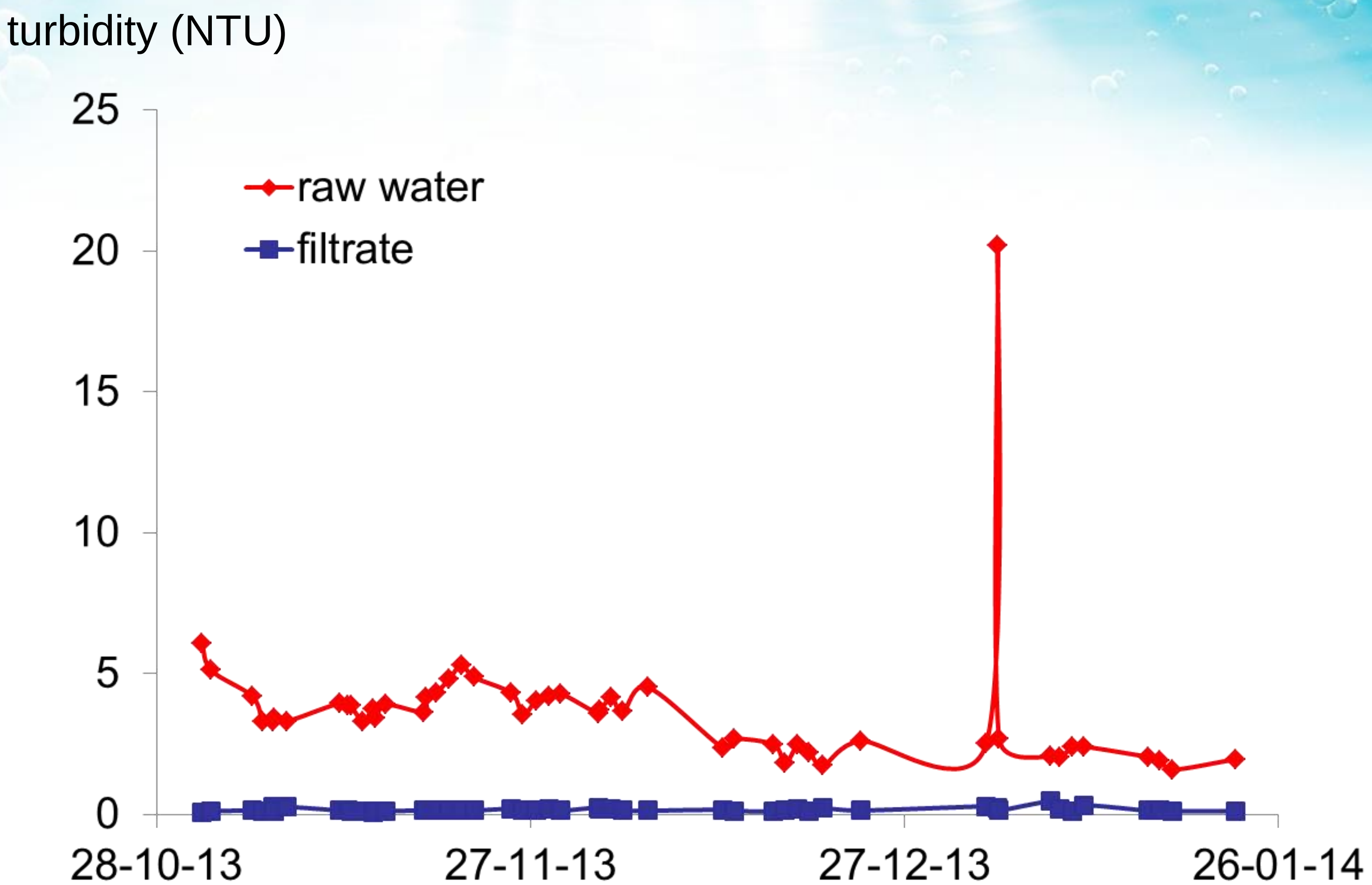


a happy end with ozone cleaning



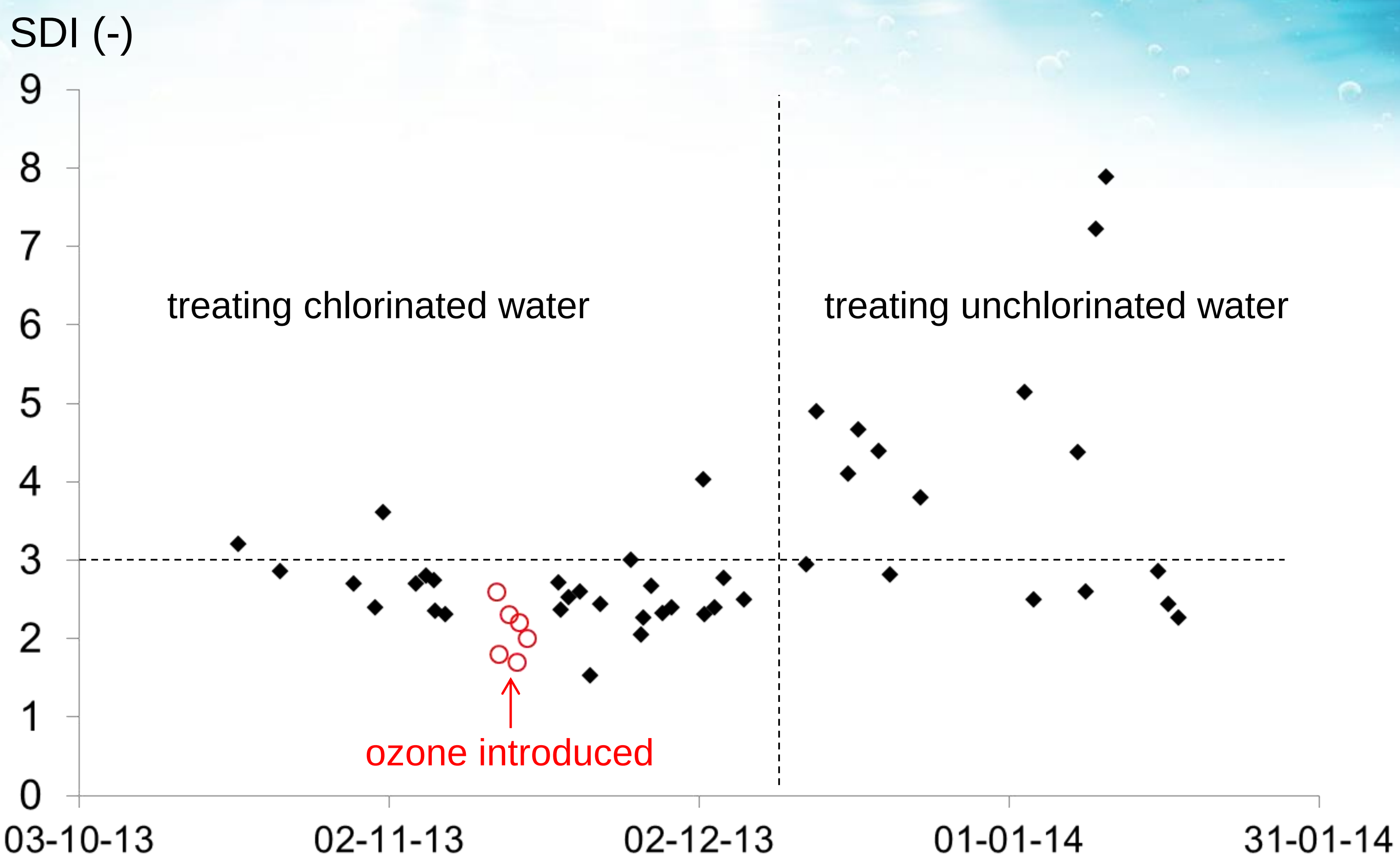
AMTA/AWWA © 23

turbidity control



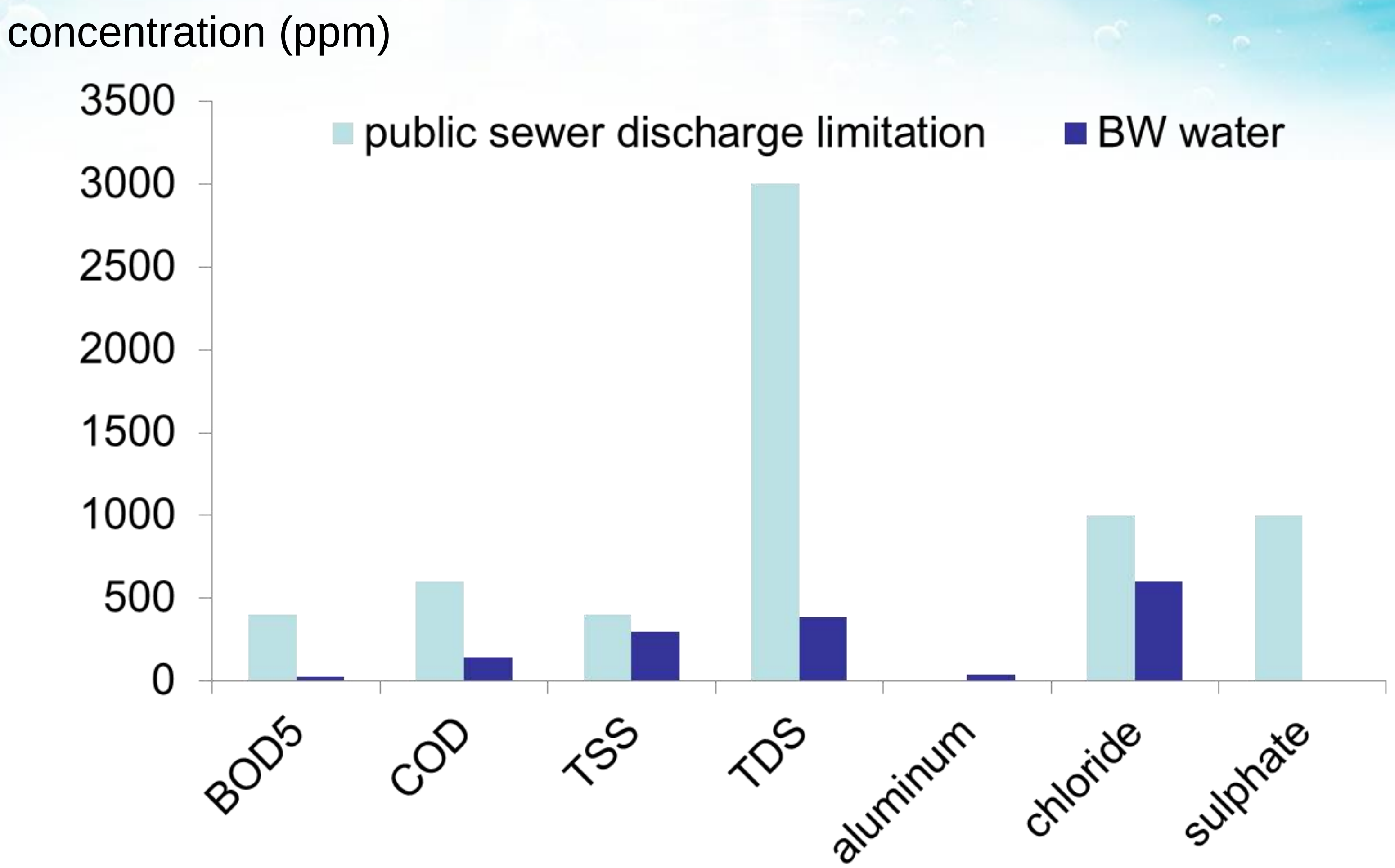
TECHNOLOGIES

filtrate SDI

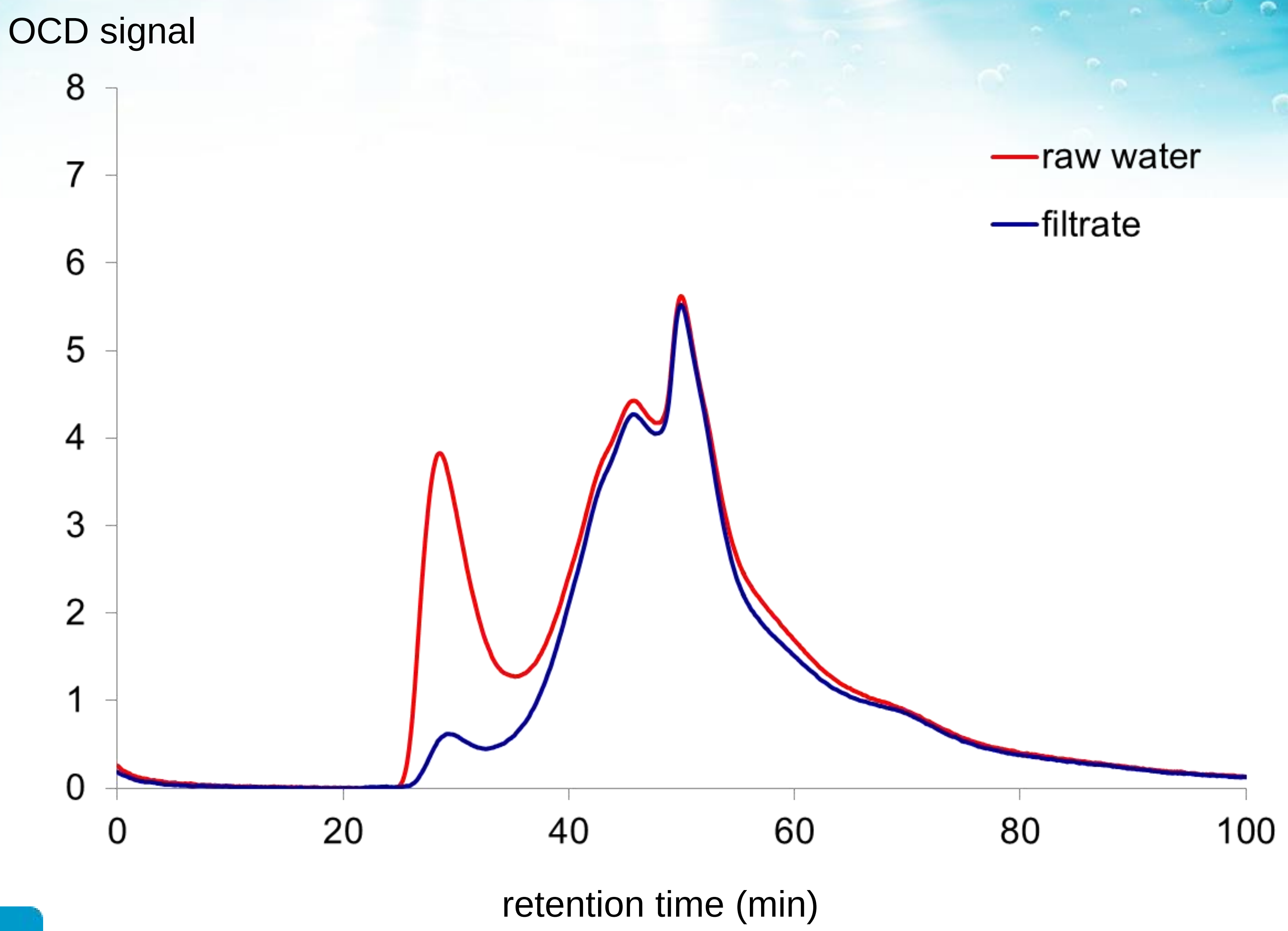


TECHNOLOGIES

quality of BW water (run 9 sample)

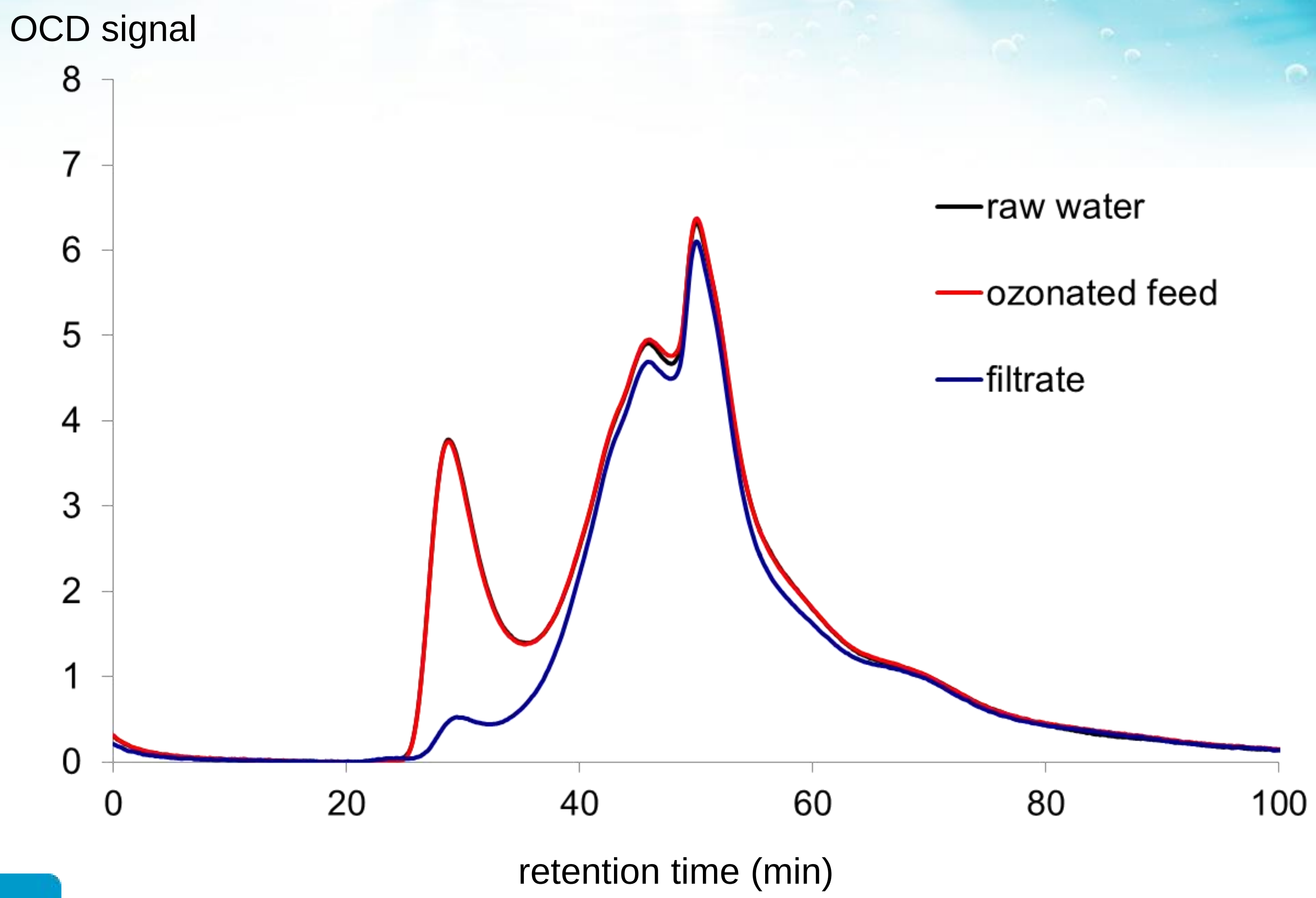


NOM discussion – no pre-treatment

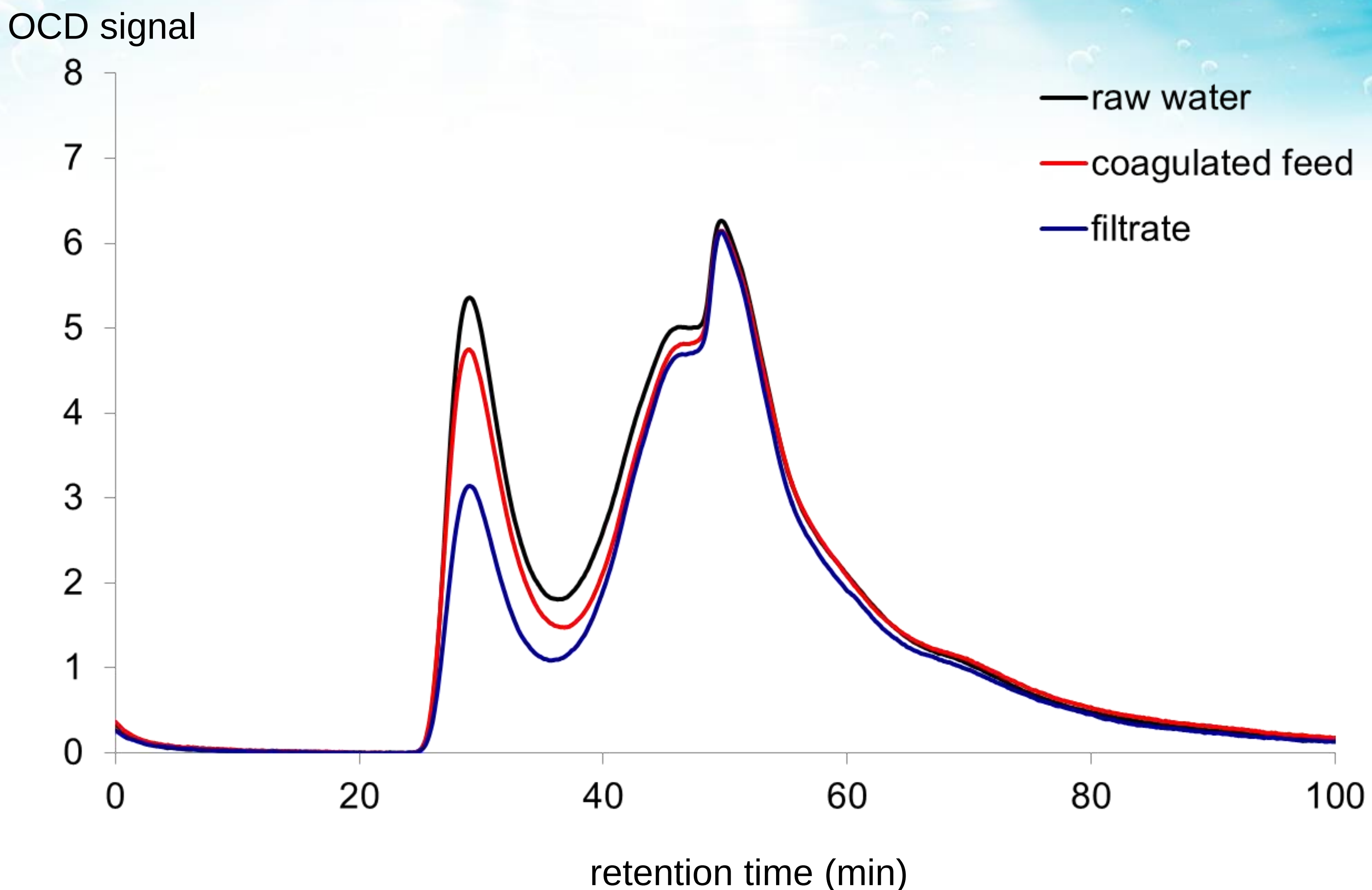


TECHNOLOGIES

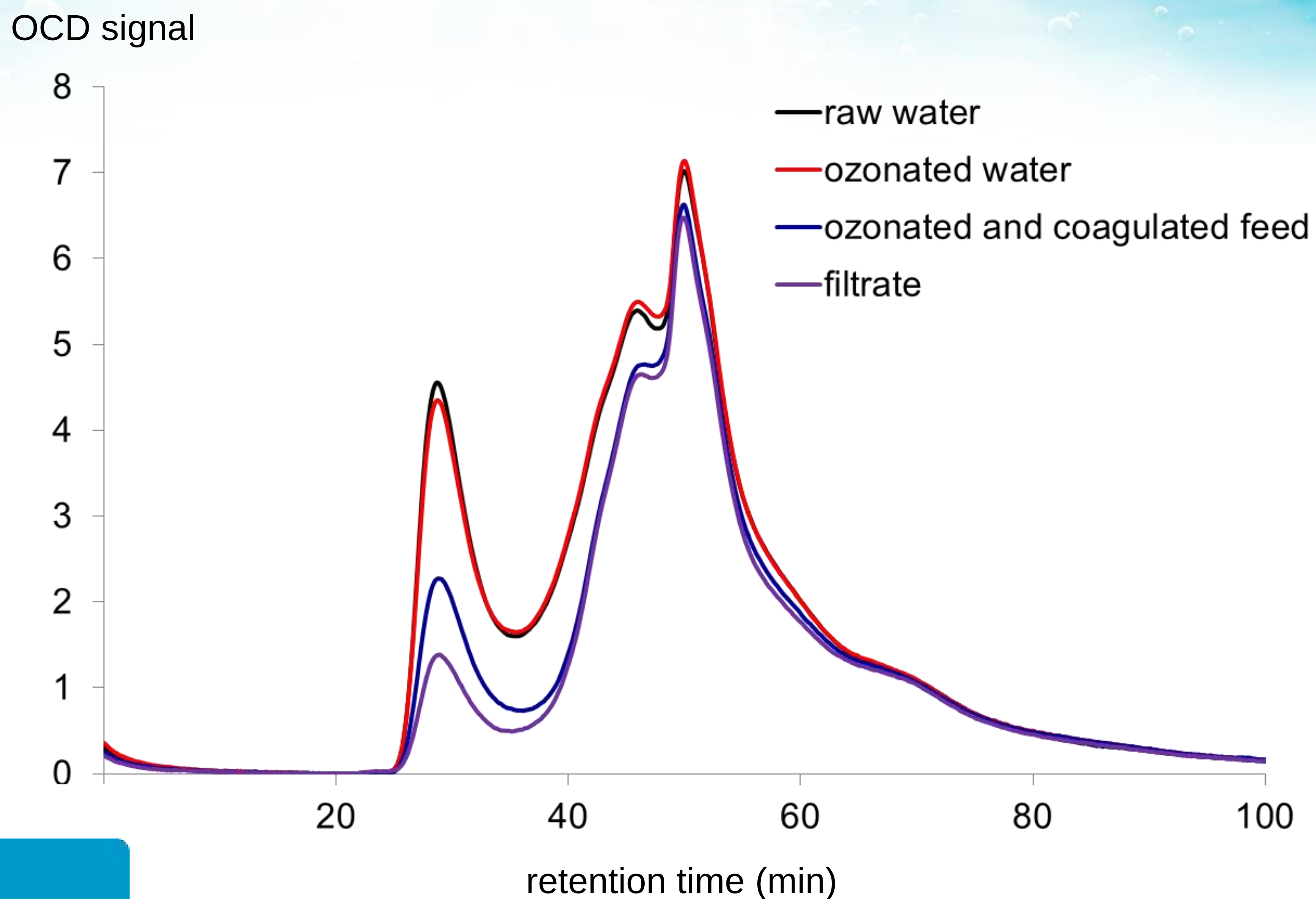
NOM discussion – pre-ozone alone



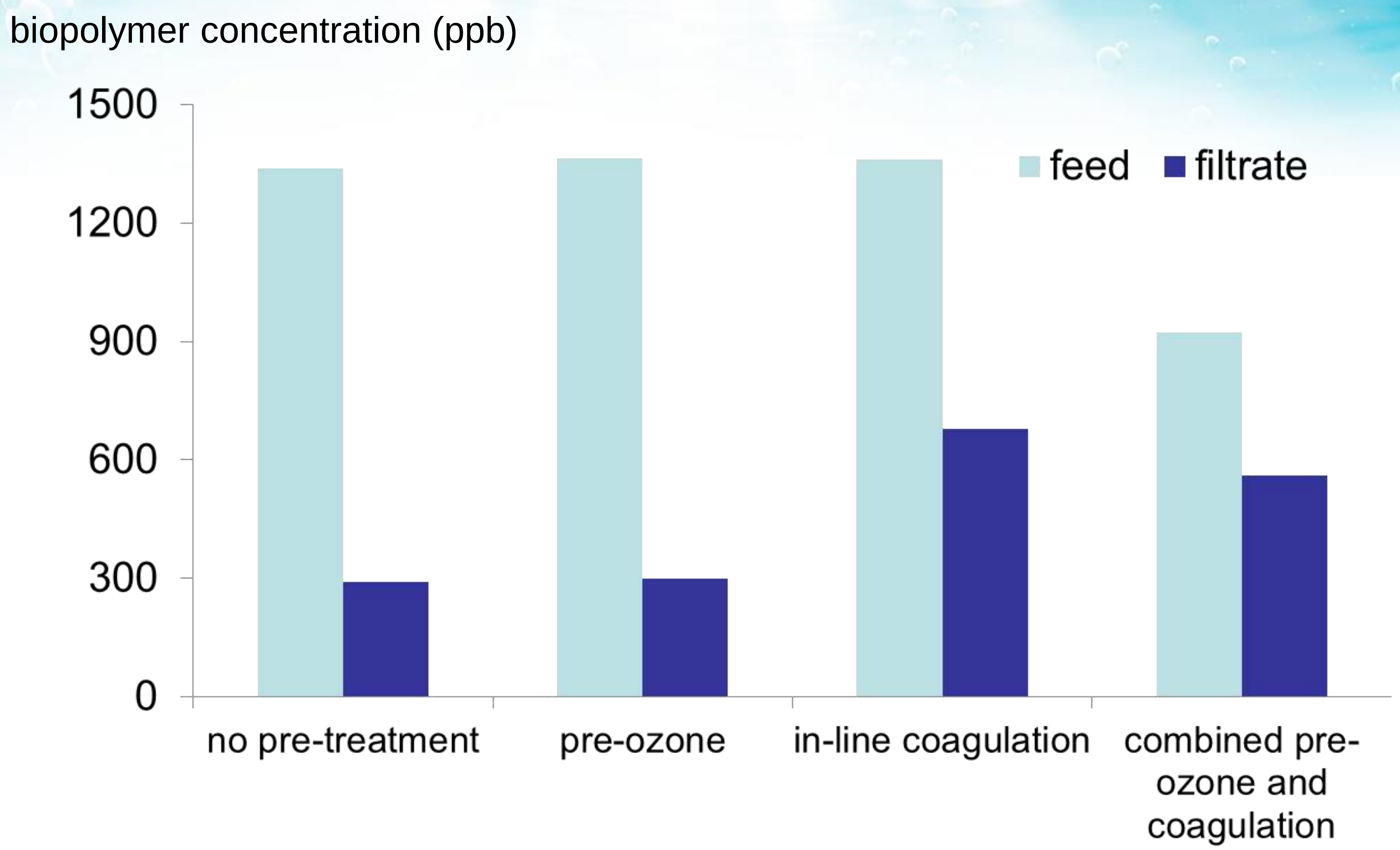
NOM discussion – in-line coagulation



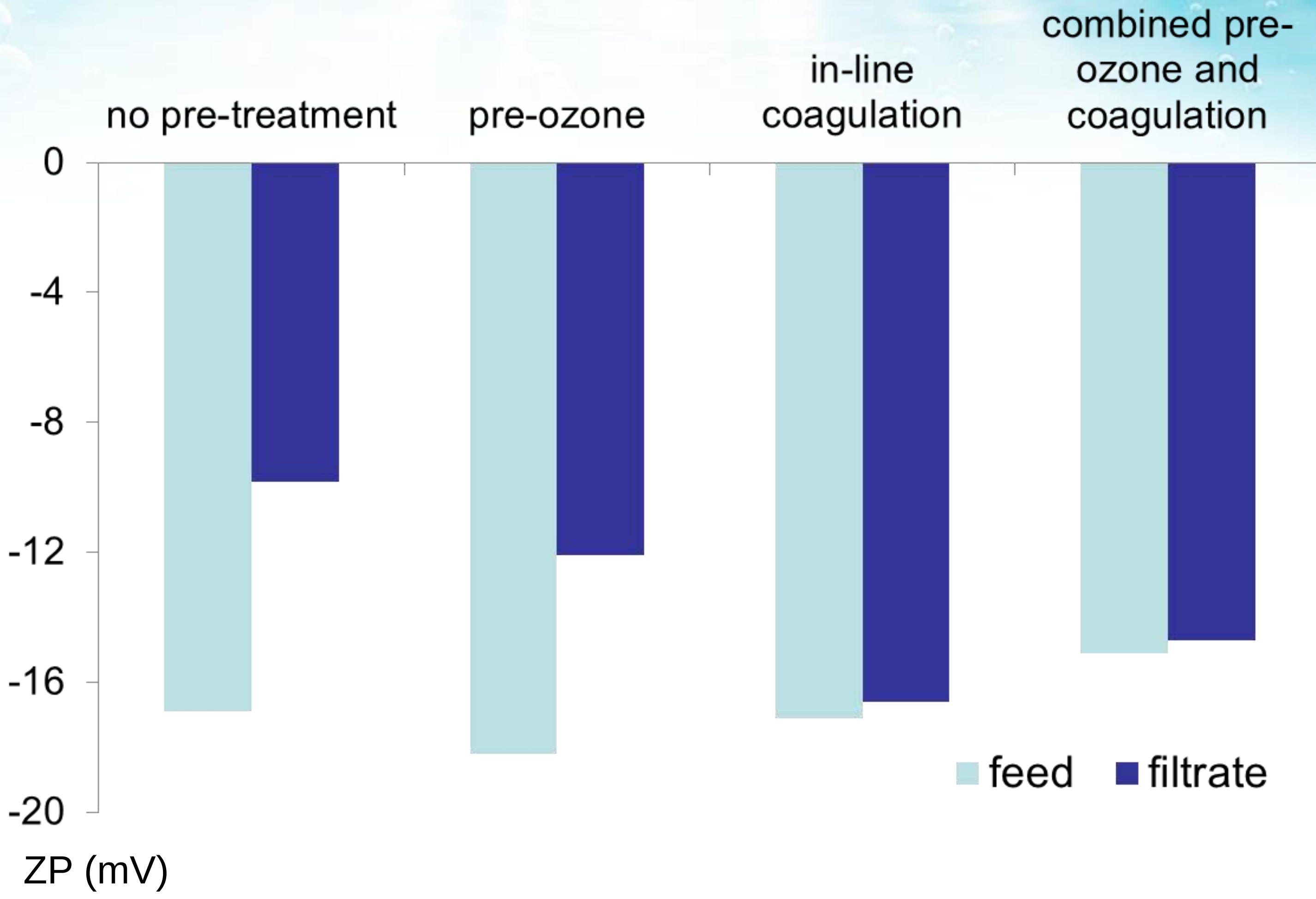
NOM analysis – pre-ozone and coag.



biopolymer change



zeta potential change



conclusions

- in-line coagulation and ceramic MF feasible for treating secondary effluent wastewater
- flux of 189 lmh with 2 to 5 ppm as Al using PACl deemed sustainable, allowing a CIP interval of > 30 days when treating chlorinated strained water
- treating unchlorinated unstrained feed possible but at lower flux and higher CIP frequency
- SDI target <3 can be achieved when treating chlorinated feed but not for treating unchlorinated feed

TECHNOLOGIES

other findings – the pre-treatments

- direct filtration of chlorinated secondary effluent not feasible
- pre-treatment with pre-ozone alone not feasible
- pre-treatment with combined pre-ozone and in-line coagulation yielding best performance but not economically viable

TECHNOLOGIES

other findings – using of ozone

- promoted the coagulation
- improved the water quality
  - converted nitrite into nitrate
  - lowered the filtrate SDI
- efficient cleaning with ozone

TECHNOLOGIES

other findings – fouling control

- biopolymer primary foulant
- biopolymer rejection caused fouling
- biopolymer rejection associated with zeta potential change
- fouling control
  - reduce biopolymer concentration
  - promote electrostatic exclusion