Enhanced pre-coat engineering (EPCE) for micro- and ultrafiltration: the solution for fouling?

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Abstract The feasibility of ultra- and microfiltration depends strongly on the achieved net flux. Direct treatment of surface water frequently results in low net fluxes and high cleaning frequencies. Experiments have been conducted at constant flux on surface water with an ultrafiltration pilot plant with direct filtration, in-line coagulation and pre-coating (EPCE) with ferric hydroxide flocs. The aim was to control and reduce the rate of fouling. With the use of a pre-coat at the beginning of the filtration cycle a stable ultrafiltration process was obtained. This is contrary to the use of in-line coagulation and direct filtration which resulted, due to a very high fouling potential of the feed water, in high fouling rates at low fluxes. The result of this exploratory research is an important step towards a higher feasibility of micro- and ultrafiltration.

Keywords Ultrafiltration; enhanced pre-coat engineering; fouling; cake filtration

Introduction Cost and therefore feasibility of ultra- and microfiltration depends strongly on the achieved net flux and cleaning frequency. The productivity (net flux) is largely determined by the quality of the feed water and the mechanisms that determine the fouling and fouling rate of the membranes. The feasibility and therefore the application of MF/UF depends on controlling those mechanisms. Controlling and preferably reducing the rate of fouling is a major challenge. Operating the systems in crossflow mode is not a realistic option due to high-energy consumption. Two promising options are:

• in line coagulation
• pre-coating.

In-line coagulation In-line coagulation comprises a continuous addition of a flocculent to the feed stream of the membrane. The formatted flocs consist partly out of agglomerated particles or meshed particles. As a solution to control membrane fouling in-line coagulation is applied with varying success. The improvement of the membrane performance is often ascribed to the coagulation of colloids, which reduces the pore blockage (Bos et al., 1998; Galjaard et al., 1999). Another possible mechanism is the formation of a permeable cake on the membrane surface, which consists of the suspended matter and the continuous feed of flocs. The followed suspended matter in the feed water is then trapped on and within this cake instead of on and in the pores of the membrane (van der Velde et al., 1998; Vos et al., 1995). The cake protects the permeable surface area of the membrane. Possibly both processes, coagulation and cake formation, happen at the same time.

Pre-coating A similar cake, as formed during in-line coagulation, can be applied on a membrane before the start of a filtration cycle. Such a cake or coating is already well known in other types of
industry on conventional filters. However it has never been done deliberately on hollow fibre micro- or ultrafiltration membranes.

Ultrafiltration is successfully applied in the re-use of backwash water from conventional treatment plants. The membrane fouling on this type of feed water is more controllable at higher flux rates compared to the direct treatment of surface water despite the much higher content of suspended matter (Chang et al., 1998; Vos et al., 1996). Also in the treatment of backwash water with ultrafiltration the responsible mechanism is thought to be the formation of a permeable, incompressible and easily removable cake.

To investigate the possibilities of pre-coating a pre-coat method has been developed. This method has been called Enhanced Pre-Coat Engineering (EPCE).

In Figure 1 a theoretical diagram of this method is given. At the start of each filtration cycle a selected particle suspension is dosed on the membrane over a very short period. These particles form an easily removable, permeable and incompressible layer on the membrane (Figure 1A). After the dose the filtration cycle starts. Colloids, algae and other suspended matter will be trapped or adsorbed by the pre-coat (Figure 1B). When the trans-membrane pressure reaches a certain threshold the membrane is backwashed. The pre-coat with the filter cake detaches from the membrane and is flushed out of the membrane fibre (Figure 1C). Depending on the characteristics of the used pre-coat particles the flushed out pre-coat can be separated from the concentrate re-generated and re-used. This method has been applied for a patent (Dutch patent application: NL 1013263).

Objectives
The Watersupply Company Overrijssel (in the Netherlands) has done exploratory ultrafiltration experiments on water from the Twente Canal. The results showed that the fouling potential of this surface water was spectacularly high. The achieved net flux with direct treatment was low (25 l/(m².h)) which made direct treatment with ultrafiltration not feasible for this location. The purpose of the underlying study was to increase the membrane performance by evaluating the effect of in-line coagulation and pre-coating.

Experimental
Materials
Water from the Twente Canal in Enschede (Netherlands) was used as the feed water. This water is high in turbid surface water (maximum turbidity 42 NTU) with a known tendency to foul UF-membranes quickly at low flux rates.
For the in-line coagulation, ferric chloride (FeCl₃) was dosed as a flocculent. The ferric chloride dosage in the feed stream was in the range of 2–4 mg Fe/l with a floc formation time of 4 minutes.

The used pre-coat particles were ferric hydroxide flocs. These flocs were prepared in advance by adding sodium hydroxide to, in distilled water diluted, ferric chloride solution. The materialised suspension was dosed to the feed stream of the membrane.

**Equipment**

A semi-pilot scale UF unit known as the Quick-Scan (Galjaard et al., 1998) was used to carry out the UF-experiments. This installation can test up to four membrane elements simultaneously (parallel or in series). The controls and the data acquisition are fully automated which ensures reproducibility. The used UF-membranes were Stork Superfill capillary membranes integrated in a 3 × 40” module, each with a membrane area of 2.1 m². The fibres have an internal diameter of 1.5 mm and are made from polyethersulfone. For this study, three membranes were placed parallel in the Quick-Scan unit.

In the feed line of the first membrane (membrane 1: in-line coagulation) an injection point was placed for the flocculent followed by a variable length of pipe to create the desired floc formation time.

In the feed line of the second membrane (membrane 2: pre-coat) an injection point was made for the pre-coat suspension.

The third membrane (membrane 3: blank) was used for the direct treatment of the surface water.

**Methods**

The experiments were divided into three sets. The operation conditions for all the membranes were exactly the same. The backwash flux was three times as high as the filtration flux and was followed by a forward flush. The backwash frequency was determined by a constant total volume of water that had been produced per square metre of membrane surface (12.5 l/m²) and the length of the backwash was determined by a total fixed volume. The membranes were enhanced by being backwashed with chemicals (HCl pH = 2 and NaOCl 100 ppm) every 200 l/m².

**First set of experiments (in-line coagulation versus floc filtration).** In the first set of experiments the membrane performances of in-line coagulation, floc filtration (continuous dosage of the ferric hydroxide microflocs) and direct treatment (no dose) are compared in parallel under the same conditions. This is to compare the effect of coagulation and cake formation solely with cake formation. The total amount of iron dosed on membrane 2 as ferric hydroxide was exactly the same as on membrane 1 as ferric chloride (2–4 mg Fe/l). The controlled gross flux for all 3 membranes was 25 l/(m².h).

**Second set of experiments (in-line coagulation versus pre-coating).** In the second set of experiments the membrane performances of in-line coagulation, pre-coating (continuous dosage of the ferric hydroxide microflocs) and direct treatment (no dose) are compared in parallel under the same conditions. This is to compare the effect of coagulation and cake formation solely with cake formation. The total amount of iron added was equivalent to the first set. The controlled gross flux for all 3 membranes was 25 l/(m².h).

**Third set of experiments (increased gross flux).** This set of experiments was almost exactly the same as the second set. Only the controlled gross flux was increased to 50 l/(m².h).
Results and discussion

In Table 1 the most relevant measured parameters of the used surface water are given. Remarkable is the fact that the averages and the maximum values measured during this short period are higher then the average of the historical values based on monthly samples from 1985–1999.

First set of experiments (in-line coagulation versus floc filtration)

In Figure 2 the TMP (Trans Membrane Pressure) is given at the time of the three parallel tested membranes during the first and the second set of experiments. The first set of experiments stops after 20 hours caused by the high TMP of membrane 1 (in-line coagulation). The fouling rate of the membrane with the continuous floc dosage (membrane 2) did not differ significantly from the blank. The fouling rate of membrane 1 with the in-line coagulation is slightly higher than the other two. However all fouling rates were too high to obtain a stable process between two backwashes even at relatively low fluxes (25 l/(h.m²)). Also, the enhanced backwashes with chemicals every 8 hours did not seem to restore the membranes enough.

Because of these high fouling rates it became impossible to find an unambiguous difference between coagulation and floc filtration.

Second set of experiments (in-line coagulation versus pre-coating)

In Figure 3, after 20 hours, the TMP in time is also given during the second set of experiments. Membrane 1 (in-line coagulation) was not restarted because it was impossible to restore the membrane. The effect of pre-coating membrane 2 is remarkable: a stable process occurs between two enhanced backwashes.

Table 1 Measured values of parameters in the feed water compared to the historical values

<table>
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<th>Parameter</th>
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<th>Historical values</th>
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<td>DOC</td>
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</table>

Figure 2  TMP in time at a constant flux of 25 l/(h.m²), after 20 hours the continuous floc filtration with Fe(OH)₃ is replaced by EPCE with Fe(OH)₃₃
After 120 hours the enhanced backwash interval was altered from 200 to 400 l/m² (at this flux rate from 8 to 16 hours). This seemed to have no effect on the regularity of the TMP-pattern. Furthermore the stability of the pattern and the average TMP of about 0.2 bar created the possibility to increase the flux for the third experiment.

**Third set of experiments (increased gross flux)**

Experiment 2 was stopped and restarted at a higher flux, i.e. 50 l/(h.m²), with an alternation in the pre-coat dosage (shorter dosing time, from 2 to 1 minutes, and double the concentration of the suspension). The first membrane with the continuous dosage of ferric chloride was also not restarted during this experiment because the permeability of this membrane could not be restored sufficiently after an intensive cleaning. In Figure 3 the TMP in time is given of membrane 2, with the pre-coat, and of membrane 3, for the blank.

Already after 11 hours the TMP of the blank reached the maximum allowed TMP of 1 bar. The pre-coated membrane now ran stably between two flushes instead of two enhanced backwashes, still at an average TMP of 0.2 bar.

Even though further research is necessary to optimise conditions the results indicate that pre-coating the membrane resulted in a substantial improvement of the membrane performance, compared to direct treatment and in-line coagulation.

**Conclusions**

Out of this exploratory research the following can be concluded:

- The observed rate of fouling in ultrafiltration treating turbid surface water was high, notwithstanding a low gross flux (25 l/(h.m²)).
- In-line coagulation with ferric chloride did not result in a reduced fouling rate. On the contrary the rate of fouling was even higher.
- Applying frequent pre-coating (EPCE) with ferric hydroxide flocs reduced the fouling rate drastically. A stable operation at double gross flux (50 l/(h.m²)) could be demonstrated combined with a lower cleaning frequency. Continuous dosage (same total amount between two backwashes) of ferric hydroxide flocs (floc filtration) did not give any improvement.
- Optimisation of the pre-coating process (EPCE) opens the possibility to achieve high flux rates in treatment of surface waters with a high fouling potential.
- General applicability of this new approach needs to be verified with different water sources and pre-coat materials.

![Figure 3](https://iwaponline.com/ws/article-pdf/1/5-6/151/477265/151.pdf)  
**Figure 3** TMP in time of the blank and EPCE with Fe(OH)₃ at a stable flux of 50 l/(h.m²)
Acknowledgements
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References
Dutch patent application: NL 1 013 263.