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Comparision of cellulose acetate and nanofiltration membranes for color removal from a Norwegian lake

K. Majamaa[a,*], M. Lehtinen[b], P. Pilipenko[c]

[a]*Dow Water & Process Solutions, Dow Deutschland Anlagengesellschaft mbH, Industriestraße 1, 77836 Rheinmünster, Germany Tel. +49-7227 91 37 65; Fax. +49-7227 91 37 08; email: kmajamaa@dow.com*
[b]*Dow Water & Process Solutions, Dow Suomi Oy, PO Box 117, 0010 Helsinki, Finland Tel. +358 9 5845 5316; Fax. +358 9 5845 5330; email: mlehtinen@dow.com*
[c]*Goodtech Environment Sorumsand AS (former Fluidtec AS), PO Box 148, 1921 Sorumsand, Norway Tel. +47 63 86 6460; Fax. +47 63 866461; email: polina.pilipenko@goodtech.no*

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ABSTRACT

Norwegian lake water treatment is dominated by cellulose acetate (CA) membranes, which serve approximately 3% of the population. The quality requirements for potable water are becoming stringent and Dow Water & Process Solutions has suggested nanofiltration (NF) as a suitable technology replacement in cases where CA membranes fail to meet the quality limits. This paper discusses the operating experience of the first CA plant retrofit trial in Norway, where the treatment goal was to remove color, organic matter and bacteria from surface lake water to produce potable water for the community. The project has shown that nanofiltration membranes can provide excellent water quality in terms of color, bacteria and an overall TOC rejection (98%). The end user reports a clear improvement in the water quality compared to CA membranes. The trial was executed with minimal modifications to the existing plant. This paper focuses on evaluating the feasibility of the current set up and gives recommendations on further process optimization in terms of improving pre-treatment and cleaning, as well as the cost evaluation of the recommended modifications.

Keywords: NF; Potable water; Color removal; TOC removal

1. Introduction

Norwegian lake water treatment is dominated by cellulose acetate (CA) membranes, which serve approximately 3% of the population. The current trend of increasing potable water requirements (especially in terms of color and TOC) increases the attractiveness of nanofiltration (NF) membranes as they offer higher overall rejection.

Fluidtec's Stranda plant was the first existing CA installation to be retrofitted with high productivity, high area nanofiltration membranes. The site treats lake water with high color (45–55 mgPt/L) content and a *E. Coli* contamination. The total dissolved solids (TDS) concentration is very low and the treatment goal is to produce potable water by removing color, organic matter and bacteria with a minimal change in the ionic content. For this application a loose NF membrane is the best choice.

The plant was started up in 1h997 using CA membranes and they were producing water of sufficient quality until the recent increase in quality requirements. As a result, the Drangedal community required the following guaranties for its water: color < 5 mgPt/L and TOC < 1.5 mg/L. Based on the experience from more than 80 plants, Fluidtec could not give such guaranties with CA membranes and nanofiltration was chosen instead. The membrane properties of CA and NF membranes according the manufacturer's

*Corresponding author.

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Table 1
CA and NF membrane properties.

Parameter	Unit	Membrane	
		CA	NF
Type	–	Ultrafiltration	Nanofiltration
Construction	–	Spiral Wound	Spiral Wound
Material	_	Cellulose Acetate	Poly Piperazine Amide
Permeate flow	m^3/d	49.2[1]	55.6[2]
Membrane area	m^2	48.3	37
Salt Rejection	%	30*	40–60[2]
pH range—continuous operation		3–7	3– 10
pH range—cleaning		2.5–8	1–12
Free chlorine tolerance	ppm	1	<0.1

Where permeate flow and salt passage are based on following test conditions:
[1]Mixed feed with 700 mg/L TDS of which at least 45% is monovalent, 3.4 bar, 25°C pH 7.5 and 20% recovery.
[2]500 mg/L $CaCl_2$, 4.8 bar, 25°C and 15% recovery.

information are presented in the . The benefit of NF membrane compared to CA is the increased overall rejection and the wider allowable pH range, both in continuous operation and short term cleaning. The drawback of the NF is the lower tolerance for free chlorine.

2. Plant configuration and modifications for retrofit

In its previous configuration, water from the lake was pumped through a 50 µm self-cleaning screen filter directly to the CA membranes. The plant had 25 pressure vessels in operation and each of them was housing four "mega" elements, which are the equivalent to six NF elements. A part of the concentrate was then being recycled to the feed in order to increase the overall system recovery. A flow scheme of the plant is described in .

The nominal production capacity of the plant was 50 m^3/h and it was important for Fluidtec that the plant is flexible enough to operate even with smaller production flows, depending on the final water demand. The plant sizing was re-evaluated to fulfil these requirements. Based on simulations with a system analysis simulation program, it was realised that the same water quantity could be achieved with only 15 pressure vessels loaded with NF membranes. This configuration was also verified to run successfully in the three different situations, as described in .

Downstream of the membranes, the product water is chlorinated before sending it to a reservoir. In the original design the chemical dosing was placed directly in the permeate collection line but as a part of the retrofit, it was recommended to change the chlorination inlet to avoid chlorine suck back and membrane degradation during shut down. In addition, it was suggested that a vacuum breaker be installed due to air in the system.

One of the main concerns in the project was the inadequate pre-treatment of the source water. The existing set up included only 50 µm of pre-filtration, which is considered minimal for NF. Adsorption of the natural organic substances on the membrane surface can cause flux loss, which is irreversible in serious cases. Therefore these organic are usually removed in pretreatment.

While the day-to-day operation of the plant was handled by the community itself, the general service including membrane cleanings was outsourced to Fluidtec. The current contract covered only one annual clean in place (CIP) and between them, the performance of the CA membranes was maintained with a daily preventive cleaning. The preventivse cleaning was a 1-h procedure where the plant was isolated and chemicals (soap (sodium salt of citric acid) and NaOCl) were added and recirculated in the system followed by a raw water flushing. The daily cleaning was continued after the NF retrofit with the exception of removing the NaOCl dosing due its incompatibility with polyamide membrane. The effect of the flush was not expected to be as efficient and Fluidtec was informed that the required cleaning frequency with NF membranes is most likely going to be higher than they were used to with CA membranes.

Table 2
Production variations.

Situation	Recovery (%)	Permeate production (m^3/h)	Concentrate recirculation (m^3/h)
High flow	75	50	100
Normal flow	75	38	100
Low production	75	22	100

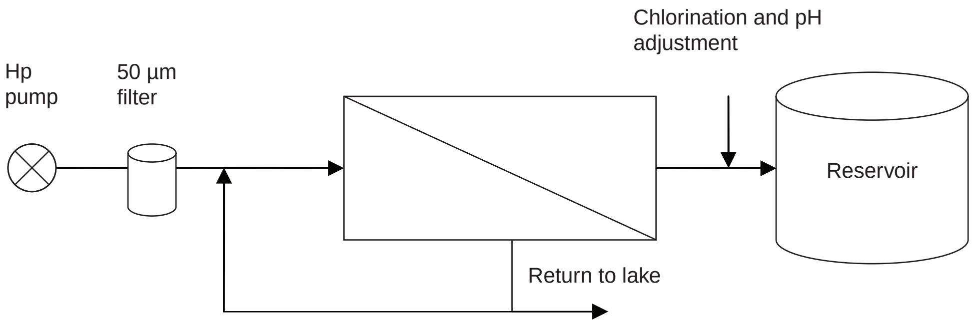

Fig. 1. Flow schema of the plant.

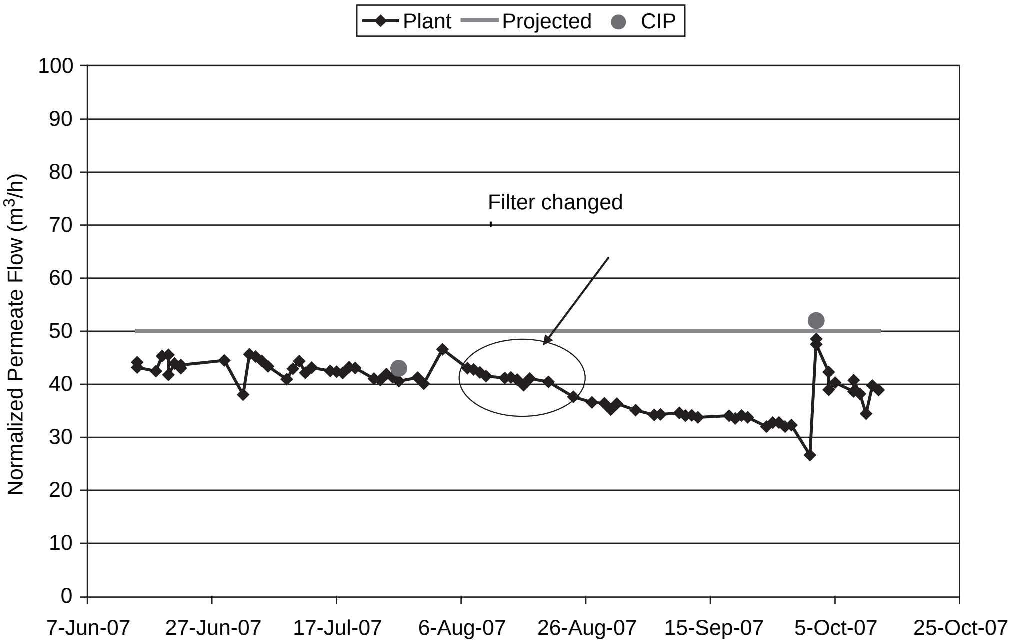

Fig. 2. Normalized permeate flow.

3. Results

The plant was started up with NF elements in June 2007. The operational data was collected daily and the data was normalized by using a normalization program with a reference to expected plant performance at 5°C. Soon after the start up it was clear that the recycling pump of the plant was not capable to pump the required recycling flow to assure high cross flow velocities. This lead to slight adjustments in the operating conditions.

3.1. Normalized permeate flow and normalized pressure drop (Δp)

The normalized permeate flow over time is presented in the . The initial permeate production was slightly lower than predicted by the simulation software, as a result of the permeate backpressure caused by the air in the system. The permeate flow was stable for the first 60 days, but soon after that the pretreatment screen filter was changed to a slotted-tube type filter. After the filter change, a gradual performance decline was observed until full restoration after CIP.

The normalized pressure drop over time is presented in the . The normalized Δp stayed stable for the first weeks of operation. A gradual increase due the membrane fouling started after 20 days of operation until the performance was restored with a cleaning.

3.2. Performed cleanings

As seen in Fig. 3, the normalized pressure drop increased gradually after some weeks of operation and

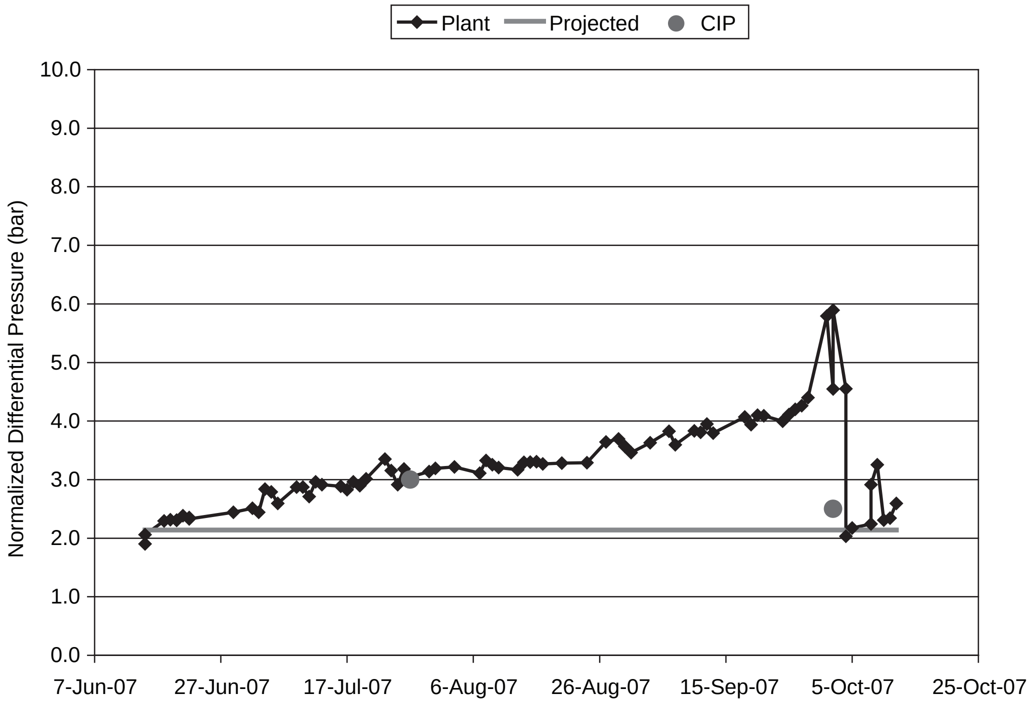

Fig. 3. Normalized pressure drop during operation.

after 40 days, Fluidtec performed the first CIP at the plant. The plant has no cleaning tanks or other CIP equipments in place and as a result the cleaning solutions were prepared directly in the system by using raw water as a make up solution. The experience has shown that this can reduce the cleaning efficiency significantly and thus clean permeate water should be used when ever possible. In the first cleaning, the cleaning solution was prepared in raw water and contained 0.025% Na-DSS (Sodium Laurel Sulfate) and NaOH at pH 11.7 (T = 35ºC). The cleaning solution was observed to be transparent dark brown but not black, as operators were used to seeing with CA membranes. This indicated that the cleaning was not successful and as seen in Figs. 2 and 3, the cleaning did not show any drastic effect on the performance.

After 100 days of operation, the normalized permeate flow was decreased by 30–40% from the initial level, and a second, harsh cleaning was done. For this, a separate cleaning tank was attached to the system and filled with NF permeate. The tank had an approximate size of 5 m^3, which was sufficient to fill the system twice. The cleaning was done in two steps. The first step was a high flow re-circulation with 20% caustic (flush). Operation was stopped when the concentrate water turned black, as shown in the . At this time, the solution pH was 13.2 at 10.5ºC. The system was drained and re-filled with permeate water and the put back into recirculation. No further caustic addition was needed, since the pH was 11.8.

Fig. 4. Sample of the cleaning solution.

The solution was heated up to 32ºC by high circulation flow, and the membranes were left for overnight soaking with a very low flow to maintain the temperature. The next day, the system was flushed with raw water and the operation was slowly brought up to normal levels.

From and 3 we can see that cleaning had a positive effect and the permeate flow was fully restored and the *Δp* was returned to start up level. Measurements taken directly after the cleaning showed an 11% increase in flow, compared to the initial start up, which is attributed to the reversible swelling effect of the membrane. The membrane soon stabilized and the production remained at the initial levels. The performed cleaning

Table 3
Water samples analyzed by the community.

Date	Color (mgPt/L)	Turbidity (FTU)	E. Coli (bact/100 mL)	Total coliforms	Total bacteria count 22ºC (CFU/mL)
Jun-07	<2	<0.1	<1	<1	<3

Fig. 5. Permeate, feed and concentrate sample.

Table 4
TOC rejection.

TOC rejection		
	After 4 months	
Start up	Before cleaning	After Cleaning
98.50%	97.00%	96.20%

was harsh and exceeded the manufacturer's guidelines for NF membranes. The conductivity of each pressure vessel was measured individually to control if the cleaning had damaged any of the membranes. Every vessel showed values which were similar in nature to those prior to the harsh cleaning. It is assumed that the fouling layer protected the membrane from damage. The full restoration of the membrane performance indicates that no irreversible fouling had yet occurred. Based on this data, a quarterly CIP would be required for NF elements.

3.3. Quality of the permeate

During the first four months of plant operation, water samples of feed, permeate and concentrate were taken and analyzed for TOC three separate times. The first set after the start up, the second sampling after four months with fouled membranes prior to cleaning, and the third set of samples was taken directly after a harsh cleaning.

In addition, the Drangedahl community analyzed the water for color, turbidity and total bacteria count in an external laboratory twice a month, in accordance with Norwegian legislation calling for a minimum of 24 samples each year.

Permeate quality was reported to be "perfect", and it exceeded the end user's expectations in terms of color, TOC and bacteria rejection. An example of the water sample analysis by the community is presented in . There were no variations in the water quality throughout the project. The color removal can easily be seen with bare eye as shown in .

The initial TOC rejection was very good (98.5%), but it was reduced slightly once the membranes were fouled (97%). The sample taken directly after the cleaning showed further rejection decrease (96.2%), but this can be explained by the reversible swelling of the membrane (Table 4).

4. Economical evaluation

For this implementation, the cost for 90 NF membranes was 478,000 NOK, and the cost for equivalent amount of new CA membranes (approximately 80 pieces) would have been 488,000 NOK, both prices including the VAT. The largest individual operational cost in a membrane plant is linked to the energy required to run the feed pump. With NF membranes, the required feed pressure at design conditions of 75% recovery and 50 m^3/h permeate production, is four bars. With CA membranes at design conditions of 70% recovery and 53 m^3/h permeate production, the required feed pressure is three bars.

Cost estimation for the cleaning optimization was done and the price was approximately 70,000 NOK. This included a CIP tank, piping including valves, labor costs and programming. Based on the experience, the annual cleaning chemical costs were approximately 25,000 NOK for the soap and disinfection agent used in the daily cleanings and an annual CIP with CA membranes. With the nanofiltration membranes, the annual cost for NaOH was calculated for quarterly cleanings and was approximately 5,000 NOK. Therefore, the return on investment of the CIP unit would be around 3.5 years just by savings in the cleaning chemicals.

5. Summary and conclusions

The project has shown that NF is a suitable low energy membrane for removing color, organic matter and bacteria from lake water at Stranda plant. The end user reports clear improvements in the permeate quality after the CA replacement, and the color, bacteria and TOC rejection (97–98.5%) has proven to be very good.

As expected, the main issue is the faster fouling rate of the NF membranes compared to CA membranes. After four months of operation, data shows that more frequent, probably quarterly, cleanings are needed to keep the average flux stable. To enable successful long term operation, some modifications are needed in the existing plant and its operations. Through improvement of the pre-treatment, including the use of a sand filtration or tighter cartridge filter in front and having a high enough concentrate flow; the cleaning frequency may be lowered. Once a drop in the normalized permeate flow or an increase in the Δp is seen, it is critical that adequate cleaning be performed on time. Therefore, it is also recommended that a proper CIP unit is installed at the site. The cost of the CIP unit will be covered shortly (3.5 years) by the cost reduction in the cleaning chemicals.