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A nanofiltration membrane for the removal of color from surface water to meet Norwegian standards

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ABSTRACT

The color removal from a lake on the border between Engerdal municipality in Norway and Älvdalen municipality in Sweden by a Norwegian water treatment plant using a new nanofiltration (NF) membrane is demonstrated in this study. This water source has low turbidity but a high concentration of natural organic matter (NOM), which gives the water undesired color, smell and taste. In order to fulfill the Norwegian Drinking Water Regulations, this plant installed new NF membranes, the sulfonated polyethersulfone HYDRACoRe 50. The typical Norwegian water treatment design was used for the water treatment, which consisted of a screen filter of 50 μm, the NF membrane rig, a UV unit and an alkaline filter treatment. The initial flux, 14 L/m²·h, was recovered to around 90% after all the main cleanings were applied during 4 years of service. This effort helped to maintain a good performance of the plant. Each year, the normalized flux declined 7%, suggesting the formation of the common fouling layer over the membrane surface. This performance loss is normal after 4 years of continuous operation with NF membranes. In fact, there have been no membrane replacements during the time under study. The color and infectious microorganisms removal with this selected process was higher than the 90% that shows its adequacy to treat the typical high colored Norwegian water sources. This paper presents the successful application of the NF membranes in the typical Norwegian water treatment design.

Keywords: HYDRACoRe; Color; NOM; Nanofiltration membranes

1. Introduction

Norwegian water supply is largely based on the use of surface sources, which have a high content of natural organic matter (NOM). The main component of NOM in Norway is the humic substances, also called “humus”, which gives the water undesired color, smell and taste [1]. Since this high NOM content in the raw water can cause problems during the water treatment and disinfection, such as producing undesirable by-products of chlorination and producing some fouling and bacterial growth in the distribution systems, its removal is becoming more important at water treatment plants [2]. In fact, in the last decade, there has been an increase in the color content of the surface water due to an increase in the amount of NOM. This issue is described in the report from the organization Norsk Vann B14 by its link to the climate change, with the consequent increase of NOM in the raw water sources (Southern and Eastern Norway) [3]. The increased rainfall in spring and late autumn can provide prolonged deterioration of the raw water source, which causes higher color concentrations in the feed water and need for upgraded water treatment, which leads to financial and operational consequences.

In Norway, there are about 1,600 waterworks supplying more than 4.3 million people, according to the report about the waterworks registry in Norway for 2009 and 2010 [4]. Approximately 300 of these waterworks plants are built for the removal of humus to fulfill the Norwegian Drinking

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Water Regulations, supplying 2.1 million people. The main treatment processes used for this purpose are coagulation and direct filtration, which represents 87% of these plants, while membrane filtration represents 9%, and the remaining 4% of plants utilize techniques such as ozone–biofilter or ion exchange [2].

The number of waterworks that have failed in the disinfection of drinking water has decreased significantly with the application of these techniques. However, by the end of 2008, there were still an 8% of registered waterworks with problems in the disinfection of the water supplied [4]. Therefore, there is an increased interest in the development and improvement of new compact, automated technologies such as ultrafiltration (UF) and nanofiltration (NF) that can ensure a satisfactory hygienic barrier effect for the production of drinking water without addition of chemical additives during routine operation. In fact, the number of waterworks that use membranes is increasing and in 2008, there were around 120 plants. These membrane filtration systems, with a nominal pore size of 20 nm or less, can remove more than 90% of the bacteria, bacterial spores, parasites and viruses from the raw water, making them an acceptable hygienic barrier according to the Norwegian Drinking Water Regulations [5]. However, there is still room for improvement of these techniques with respect to both design and operational issues. Indeed, Norsk Vann rapport 160/2008, has reported some operational problems experienced at membrane filtration plants [6], as follows:

- Fouling/scaling on the pre-filter or insufficient hydraulic pre-filter capacity (46% of the plants).
- Membrane fouling (40% of the plants). The particles in the range 0.1–2 μm have been shown to have the highest fouling potential. Existing screen filter types are not suitable to reduce the particles at this size, due to being really expensive, or requiring a lot of manual work. Some investigations regarding this issue are being conducted to develop an economically acceptable pre-filter.
- Failure of the treatment barrier efficiency (27% of the plants).
- High plate count numbers (HPC) numbers in permeate (30% of the plants). This high plate count number is caused by microbiological regrowth at the treated water side of the membranes, and is related to the biofilm formation potential in the water.

Biovac Environmental Technology AS has designed and installed around 100 membrane plants in Norway and Sweden in the last 20 years. The membranes used were cellulose acetate UF membranes (Koch, 8133 UF Magnum®) with a pore size of 8,000 Da. However, in the last 4 years, Biovac has introduced in Norway a new NF type of membrane, the HYDRACoRe 50 with 1,000 Da pore size. The NF membranes are a very promising technology that is replacing more and more the reverse osmosis and UF membranes due to its rejection and operation characteristics [7]. These membranes offer a low pressure operation compared with the reverse osmosis membranes what makes it suitable to treat surface water that has low osmotic pressure. In comparison with the UF membranes, it gives better permeate quality independent of the raw water quality and greater tolerance toward chemicals, which improves their cleanability. Moreover, it combines two different mechanisms to remove pollutants from surface waters: a sieving mechanism and a charge effect due to these membranes normally have charged properties. In the case of the NOM, its rejection is produced by its molecular size, while the inorganic salts are removed by the charge effect of the membrane surface and ions [8,9]. Moreover, the new NF membranes produced by Hydranautics offer a negatively charged surface that helps to repel organic pollutants from the treated water, reducing the fouling effect by these organic compounds.

This study will show the results of scientific studies and subsequent performance improvements that Biovac, in collaboration with Hydranautics, has achieved using new NF HYDRACoRe 50 membranes.

2. Materials and methods

2.1. Feed source and permeate quality requirements

The feed water to the water treatment plant is taken from a lake called Grøvelsjøen, which is situated on the border between Engerdal municipality in Norway and Älvdalen municipality in Sweden. Water quality for this plant is given in Table 1.

As it can be seen in Table 1, the raw water quality of this plant is high in color, although low in turbidity, what makes the Norwegian source waters a special type of water for its treatment. Moreover, the pH of these waters is around 6 being corrosive for the pipe systems, so a post-treatment to increase the water pH is normally necessary after the membrane treatment plant.

In Norway, the drinking water regulations state that all water supply systems must contain at least to hygienic (safety) barriers. For a water treatment process to be credited as one barrier, the required removal or inactivation rate is defined as 99.9% (3log) for viruses and bacteria and 99% (2log) for protozoa. Table 2 shows the results obtained with different membrane methodologies that can be find in the literature. These results show that NF membranes act as hygienic barrier against virus, bacteria and protozoa.

Table 1
Feed and drinking water quality

Parameter	Drinking water regulations	Raw water
Turbidity, NTU	<1	0.6
Color, mg Pt/L	20	157
pH	6.5–9.5	6.5
Total organic carbon, mg/L	5.0	10
Iron, mg/L	0.2	3.5
Manganese, mg/L	0.05	0.4
Aluminum, mg/L	0.2	0.8
Coliform bacteria, pr. 100 mL	0	23
E. coli, pr. 100 mL	0	1
Plate count, pr. mL (22°C)	<100	47

However, the UF membranes will have some limitations to remove virus depending on its pore size.

2.2. Water treatment plant description

A water treatment plant called Sør-Odal was selected to study the performance of the nanofiltration membrane HYDRACoRe 50 to act as a hygienic barrier and remove color from the selected Norwegian water source. The feed water is taken at a depth of 9–11 m, and it is carried by gravity to the treatment plant with a capacity of approximately 500 m^3/h.

The treatment plant was designed following the typical structure of the membrane plants in Norway, which is shown in Fig. 1. First, the pressure of the raw water is boosted by a pump to the operating pressure needed or in some cases, as in this plant, the water arrives at the plant by gravity and the pressure is adjusted with a valve. Then, the water reaches a pre-treatment unit, a screen filter with an opening of 50 µm. Some plants have a sand filter unit before the micro-sieve, but it is not common because of the investment involved, as in this case. A cross-flow filtration takes place in the membrane unit resulting in a cleaned water stream (the permeate) that crosses the membrane surface and a dirty water stream (the concentrate). Some of the concentrate is recycled in order to increase the recovery, which is normally 70%. After the membrane system, the water is treated with UV radiation before holding it in a clean water basin, which in this plant is situated at 3 m above the floor level. Since the filtration process will reduce the water alkalinity making it corrosive for the distribution systems, an alkaline filter (calcium carbonate) is often included in order to increase the level of calcium and bicarbonate to stabilize the product water.

In order to prevent reduction in the capacity of the plant over time because of membrane fouling, the membranes are cleaned by two different cleaning procedures: a frequent (daily) cleaning and a main cleaning that is carried out once or twice a year.

The membrane system consists of three rigs that treat a flow of 500 m^3/h. The rigs 1 and 3 have 56 pressure vessels of 6 m long, containing 6 membranes of HYDRACoRe 50 and rig 2 has 70 pressure vessels of 6 m long, containing 6 membranes of HYDRACoRe 50. The membrane used before installation of the HYDRACoRe 50 was a cellulose acetate UF membrane from Koch Membrane Systems, which had an element length approximately of 1.5 m. The replacement of these membranes was conducted without modifications to the existing plant.

This study focused on rig 1 from Sør-Odal treatment plant, which has a production capacity of 168 m^3/h during 23 h between each daily wash. As it was mentioned before,

Table 2
Reported pathogenic reduction (log reduction) with different membrane filtration methods [10–13]

Method	Virus	Bacteria			Protozoa	
	Bacteriophages	Total coliform	*E. coli*/fecal coliform	Clostridium perfringens, clostridium sulfate reducing bacteria	Giardia	Cryptosporidium
Reverse osmosis /nanofiltration	3–4, 6[7]	–	–	>6[8]	>6[8]	–
Ultrafiltration	1.5–> 6[8]	7[9]	–	>6[8]	>6[8]	–
Microfiltration	0.05–3.3[7]	–	0.1–3[10]	–	>5[7]	>5[7]

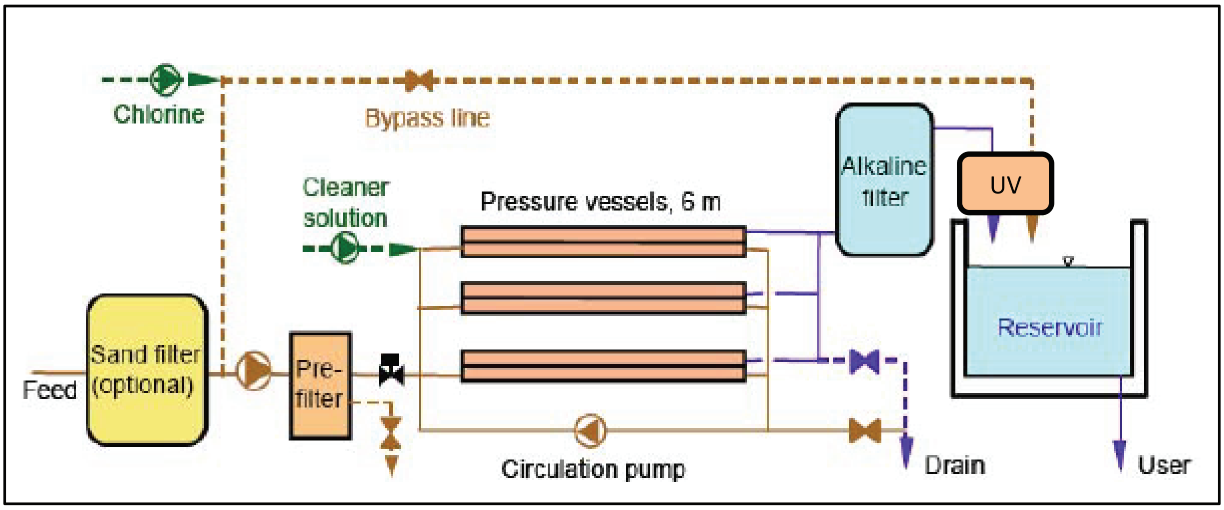

Fig. 1. Typical flow diagram of a Norwegian NF membrane treatment plant. Taken from Ødegaard et al. [2].

the rig has 56 pressure vessels with6, 40 inch length NF membranes per vessel, a screening pre-filtration of 50 µm and a post-treatment with UV radiation. After UV radiation, the water is treated with an alkaline filter to increase its pH. Sodium hypochlorite is dosed before the treated water reaches the distribution network, which prevents bacterial growth.

2.3. *HydraCoRe NF Membrane*

A nanofiltration membrane treatment plant was chosen by this municipality due to its relative ease of operation, small footprint, minimal chemical requirements and effectiveness at removing color and TOC regardless of its concentration in the feed solution. Acetate cellulose UF membranes with a nominal molecular weight of 8,000 Da were used previously at this plant with relatively good performance. However, after being experienced some episodes with high concentration of color in the produced water, these membranes were changed to nanofiltration elements. In that way, a good barrier efficiency against color, TOC and pathogens could be assured. In fact, the replacement was conducted without modifications to the existing plant. Specifically, the HYDRACoRe 50 membrane was considered due to its high rejection of color and large organics relative to its high passage of dissolved salts. The HYDRACoRe membrane consists of a sulfonated polyether sulfone polymer with a typical thickness of 0.3 µm. The surface charge of the HYDRACoRe membrane is strongly negative due to the presence of the sulfonate functional groups. Streaming potential measurements (Fig. 2) show the anionic HYDRACoRe to have a constant surface zeta potential of −85 mV over a pH range of 3–11. In contrast, the conventional amphoteric polyamide RO membrane (CPA2) varies in charge from +10 mV at pH 3 to −20 mV above pH 6. The same amphoteric pattern can be found in the literature for the acetate cellulose membranes [14]. The strong negative charge of the HYDRACoRe can be advantageous in that it will repel negatively charged organics present in certain waters and thus minimize membrane fouling by organic adsorption.

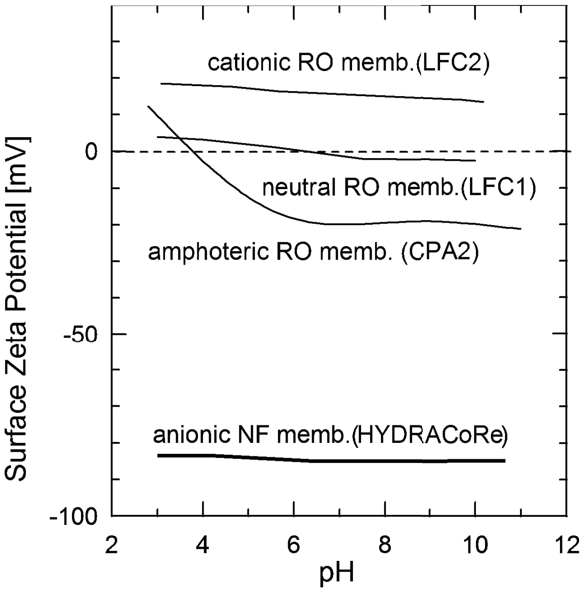

Fig. 2. Surface zeta potential measurement for typical polyamide membranes and the HYDRACoRe membrane.

HydraCoRe 50 product is a chemical and oxidant-resistant composite nanofiltration element that is designed to reject organic species with a nominal molecular weight of 1,000 or greater. Estimated NaCl rejection is 50%. Applications include color separations and adjustments in juices, sauces, and food extracts; amino acid production; concentration of fish, meat and vegetable extracts for seasoning manufacturing and concentration of oligosaccharides.

Another important characteristic of the HYDRACoRe membrane is its smooth surface relative to a typical polyamide membrane surface. Figs. 3 and 4 compare a scanning electron microscope image and an AMF image of a polyamide membrane (a) with that of the HYDRACoRe membrane (b). The surface roughness for the polyamide is clearly greater than that of the HYDRACoRe. The smooth surface can reduce the potential for colloidal fouling and biofouling by reducing the number of sites for the deposition of colloids or microbial cells.

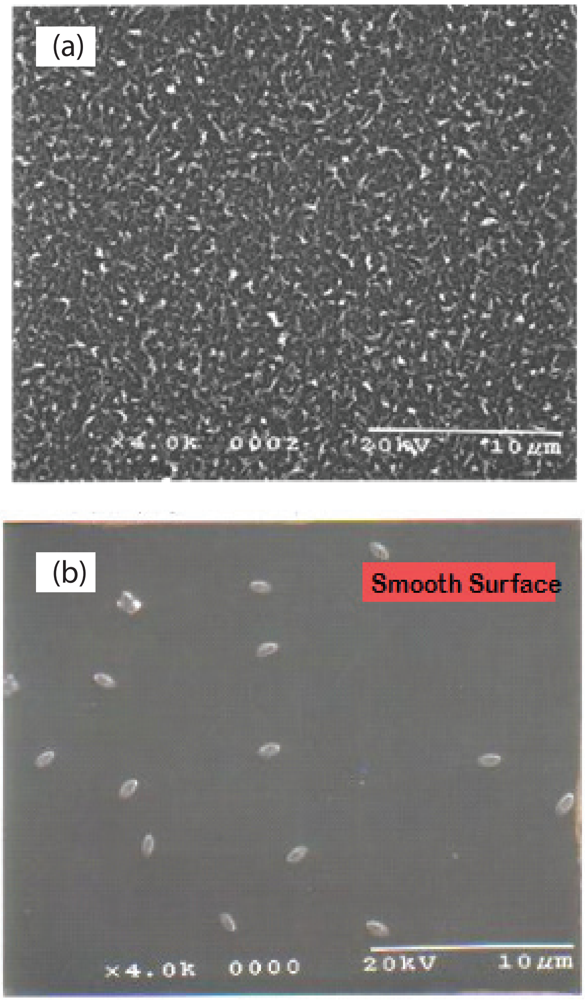

Fig. 3. Characterization of surface roughness of (a) a typical polyamide membrane and (b) the HYDRACoRe membrane.

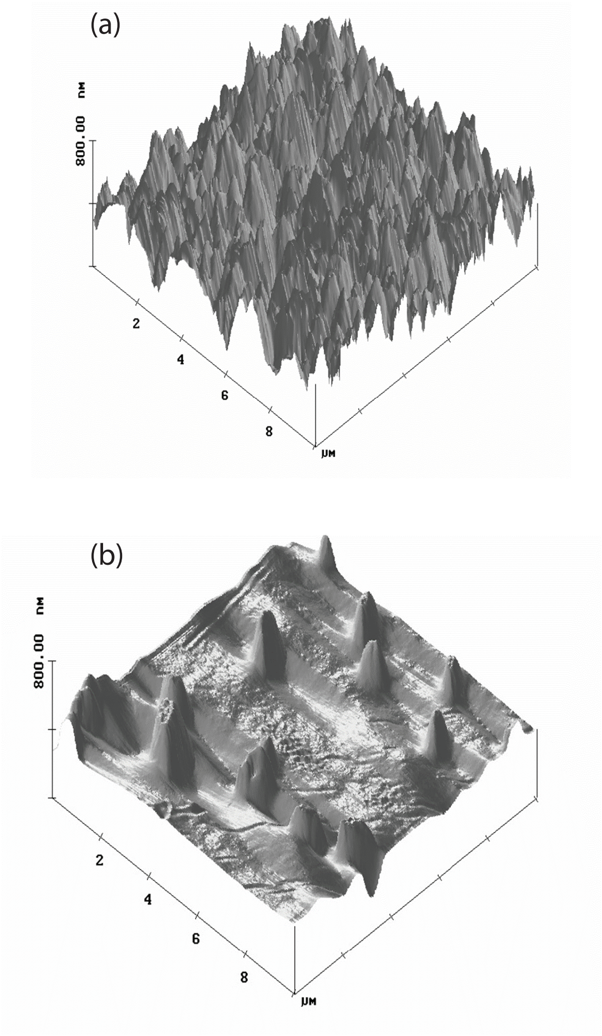

Fig. 4. AFM image of (a) polyamide membrane and (b) HYDRACoRe membrane.

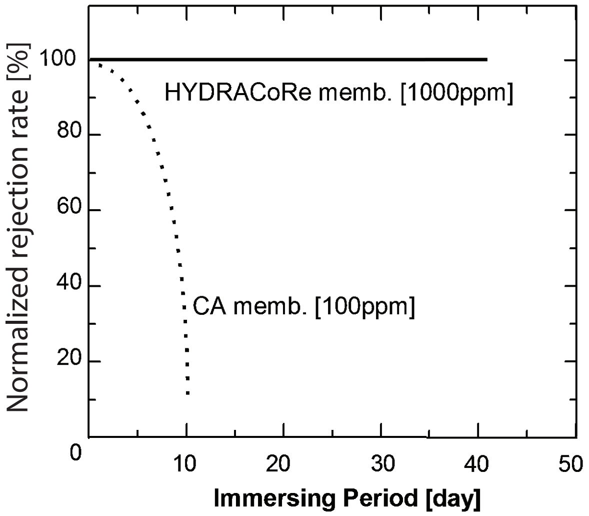

Fig. 5. Chlorine tolerance of the HYDRACoRe membrane as compared to cellulose acetate membrane.

Another advantage of the HYDRACoRe membrane is its greater stability toward pH and chlorine compared with conventional polyamide membranes. Chlorine is especially harmful to polyamide membranes at concentrations above 0.01 ppm due to the hydrolysis of the polyamide that leads to an increase in salt passage. A general rule is that the salt passage of a polyamide membrane will double after an exposure of 2,000 ppm-hours of free chlorine. As a result, even low doses of free chlorine cannot be used to control or clean biogrowth on polyamide membranes. Though not as severe, chlorine can have a detrimental effect on cellulose acetate membrane as well.

In contrast to the polyamide and cellulose acetate membranes, the HYDRACoRe is tolerant to chlorine. Fig. 5 demonstrates the chlorine tolerance of the HYDRACoRe relative to the cellulose acetate membrane. A sample of HYDRACoRe membrane was soaked in a 1,000 ppm sodium hypochlorite solution. After 50 d (1,200,000 ppm-hours), the HYDRACoRe membrane maintained a stable sodium chloride rejection. In contrast, a cellulose acetate (CA) membrane was exposed to a 100 ppm sodium hypochlorite solution for 10 d (24,000 ppm-hours) and showed a doubling in salt passage. Thus, the HYDRACoRe is ideally suited for low doses of chlorine to control biofouling and higher doses to enhance the removal of organic foulants.

3. Results

3.1. HYDRACoRe 50 membrane performance results

Sør-Odal water treatment plant has been working with UF membranes about for 10 years, until 2012 when they changed to the new NF membranes. During this time, the membranes has been working well, recovering its performance after the periodical cleanings. However, higher color concentrations were observed in the permeate analysis during the last years, which indicated that the water source used by this plant experienced a change in its natural organic matter concentration, apart from the seasonal normal changes. Thus, this plant decided to use a tighter type of membranes to replace the old membranes when its replacement was needed. In that way the produced water is less affected by these changes in NOM concentration of the source water, maintaining a good concentration of minerals naturally present in the source water used.

Table 3 lists a summary of the average ranges and concentrations obtained with the old UF membranes and the new NF membranes for the raw and permeate water. In addition, it includes the concentrations required to fulfill the drinking water regulations in Norway.

As analysis of data in Table 3 demonstrates that the raw water contains a high concentration of color and total organic carbon (TOC), which can produce an organic type of fouling on the membrane surface. In addition, as it has been mentioned before the 50 µm screen filter used in this plant cannot remove the particles reported to have the highest fouling potential (from 0.1 to 2 µm), resulting in the creation of a fouling layer that is difficult to remove. Nevertheless, thanks to the use of the HYDRACoRe 50 NF membranes, which have the capacity to tolerate a wide range of pH, it is possible to apply a more

Table 3
Average ranges and concentrations of feed and permeate water treated in Sør-Odal plant

Parameter	Raw water	Permeate water with UF membrane	Permeate water with NF membrane	Drinking water regulations
Turbidity, NTU	0.6	<0.1	<0.1	<1
Color, mg Pt/L	157	5–15	<2	20
pH	6.5	6.5	6.4	6.5–9.5
Total organic carbon, mg/L	10	5.0	1.0	5.0
Iron, mg/L	3.5	0.17	<0.01	0.2
Manganese, mg/L	0.4	0.05	<0.01	0.05
Aluminum, mg/L	0.8	0.05	<0.05	0.2
Coliform bacteria, cfu/100 mL	23	0	0	0
E. coli, cfu/100 mL	1	0	0	0
Plate count, cfu/mL (22°C)	47	<100	<100	<100

aggressive cleaning relative to the old UF cellulose acetate membranes. Therefore, a better cleaning can be achieved, leading to a better performance of the plant during the years in operation.

Further analysis of the data presented in Table 3 shows that the new NF membrane is able to produce an improved water quality relative to the previously used UF membranes. The NF membrane is clearly superior at removing color, organics and iron, which gives a better performance with seasonal changes in concentration of these compounds in the source water.

After six months since the new NF membranes were installed in this plant, an increase in the operation pressure was experienced, mainly caused by the formation of a fouling layer on the membrane surface. A summary with all the results and technical information of the plant during these 4 years in operation can be found in the Appendix 1. However, the permeate water quality was not affected by these operational problems, as it can be seen in the Appendix 2. This fact shows the great capacity of these new membranes to maintain a good permeate quality independently to the feed water changes in concentration.

In order to reduce the effect of the fouling layer created in the surface of the membranes two different cleanings were implemented in the plant:

- A daily cleaning with 50 ppm sodium hypochlorite and an organic salt, 1,500 ppm of trisodium citrate, at pH around 7–8. This cleaning were conducted for 1 h at room temperature (in Norway, this could be at a temperature between 5°C and 15°C at nights).
- A main cleaning which uses two different solutions:
  - Basic solution with sodium hypochlorite and sodium hydroxide at pH 12. During this cleaning, there was a soaking time before flushing the cleaning solution from the membranes to improve the cleaning effect. The chemicals were in the membranes approximately 2 h at 35°C.
  - Acid solution with citric acid at pH 2. The same procedure for the basic cleaning was used and the chemicals were in the membranes approximately 2 h at room temperature.

The main cleaning is used in the plant twice per year and it is conducted by the technicians from Biovac. During these services, the operational data are collected before and after the plant inspection and cleaning in order to evaluate the cleaning efficiency and its performance. Fig. 6 compares water quality of the raw water with the quality of the permeate and concentrate during one of these services.

To investigate the performance of this plant, the recovery of the flux before and after each of these cleanings, compared with its designed value of 14 L/m^2/h were studied. This information compiled since the plant start-up until the time of this study is showed in Fig. 7. As it can be seen in Fig. 7, the flux experienced a reduction of 6% and 14% after first and second years of operation, respectively. Nevertheless, a stabilization of the flux can be observed after the third year of experience showing a reduction of 8% and 13% after the third and fourth year of operation, respectively. This performance loss is normal for 4 years of continuous operation on surface water. In fact, there have been no membrane replacements during the period studied. Indeed, as a result of the cleanings, 87% of the design flux has been maintained and recovered, showing the efficiency and durability for these types of membranes.

Regarding the permeate flow produced after these 4 years of operation; it has been decreased by 13%, now producing 147 m^3/h (Fig. 8). In contrast, the inlet pressure has increased from 3.7 to 5.8 bar, which shows that an irreversible fouling layer has been formed over the membrane surface.

It can be also pointed out from Fig. 8 that there was a big change in the permeate and inlet pressure, slightly more pronounced in the case of the inlet pressure, during the initial months of operation. This issue could be related with a fast formation of a fouling layer on the surface of the new membrane, due to the high NOM concentration in the source solution. Nevertheless, these parameters seem to stabilize with the time, indicating that the fouling layer is increasing to a lesser extent when it reaches equilibrium.

This fact has been widely reported in the literature showing that this organic fouling created by NOM can act as a

Fig. 6. Water quality comparison of the different streams obtained during the membrane filtration process.

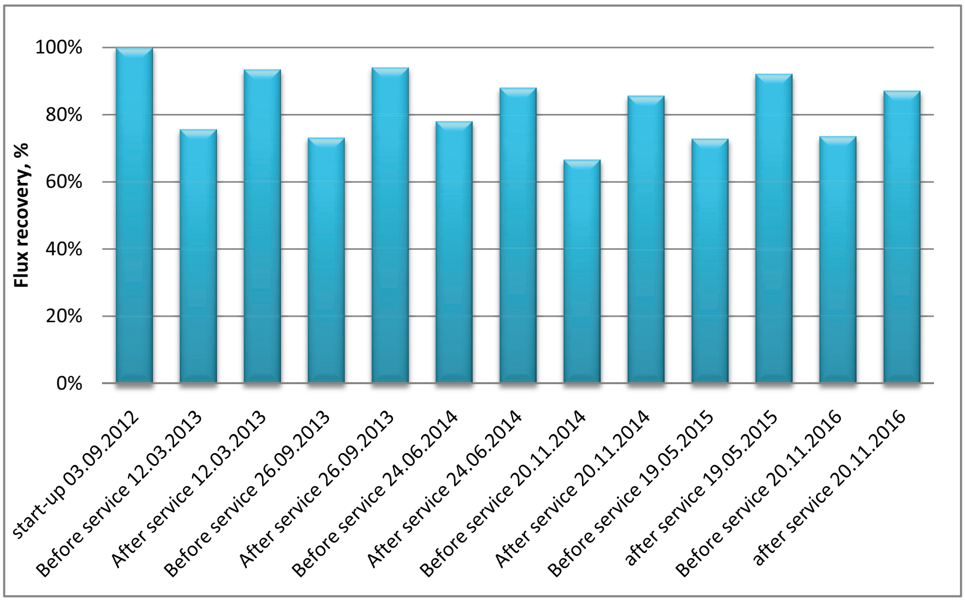

Fig. 7. Flux recovery before and after the services done in the plant from its starting-up until nowadays.

nutrient source for the microorganisms naturally present in the raw water facilitating biofouling [15]. Moreover, cations in feed solution, such as iron or calcium, may cause intermolecular bridging between the organic foulants and the membrane surface, what produces a foulant type difficult to remove in nanofiltration membranes [16].

Producing new type of membranes that reduces these operational problems experienced with the Norwegian type of source waters is the main task for Biovac in cooperation with Hydranautics. Therefore, the new NF membranes HydraCoRe 10 with a nominal cut-off of 3,000 Da and the hybrid systems, which combines both of them, the HydraCoRe 50 and HydraCoRe 10 are under study now.

4. Conclusion

A scientific study of the new HYDRACoRe membranes to remove color and act as a good disinfection barrier for the Norwegian surface waters has been conducted. The color and infectious microorganisms content has been reduced from the feed water at a greater level compared with previously installed UF membranes, demonstrating the NF membrane's adequacy to accomplish the Norwegian Water Regulations. The replacement of these membranes was conducted without modifications to the existing plant. In fact, a good permeate quality was maintained during the 4 years of study, suggesting that it is independent of the changes in the raw water color contents during the seasons. The improved

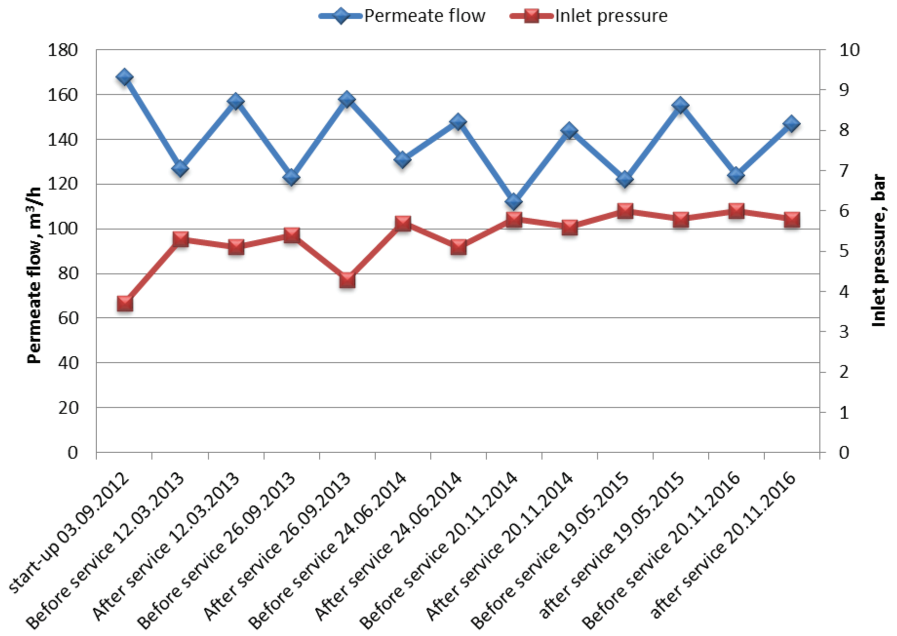

Fig. 8. Permeate flow and inlet pressure data before and after the services done in the plant from its starting-up until present.

performance of the plant was achieved after the systematic analysis and subsequent modification of the cleaning procedures which enhanced the cleaning efficiency and reduced the cleaning frequency to twice per year. In fact, 87% of the membrane design flux was recovered after the cleaning modifications were implemented. Nevertheless, a fast formation of a fouling layer on the membrane surface was suspected due to the acute increase of the feed pressure during the first months of operation. The increase in feed pressure stabilizes with time, which is evidence that the fouling layer is decreasing its formation rate. This performance loss that the plant has experienced is totally normal after 4 years of continuous operation with nanofiltration membranes. In fact, there has not been any replacement of the membranes during the time under study.

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Appendix

Appendix 1
Summary of the results and technical information of Sør-Odal nanofiltration water plant

Date		03.09.2012		12.03.2013		26.09.2013		24.06.2014		20.11.2014	
		Before NF installation (UF)	NF installation	Before service	After service	Before service	After service	Before service	After service	Before service	After service
Configuration	PV × M	56 × 6	56 × 6	56 × 6	56 × 6	56 × 6	56 × 6	56 × 6	56 × 6	56 × 6	56 × 6
Membranes number		336	336	336	336	336	336	336	336	336	336
Membrane area	m^2	35.8	35.8	35.8	35.8	35.8	35.8	35.8	35.8	35.8	35.8
Permeate flow	m^3/h	168.0	168.0	127.0	157.0	123.0	158.0	131.0	148.0	112.0	144.0
Flux	$L/m^2/h$	14.0	14.0	10.6	13.1	10.2	13.1	10.9	12.3	9.3	12.0
Recirculation flow	m^3/h	414.0	414.0	284.0	262.0	140.9	216.0	180.0	180.0	234.0	203.0
Recirculation rate	$m^3/h/PV$	7.4	7.4	5.1	4.7	2.5	3.9	3.2	3.2	4.2	3.6
Concentrate flow	m^3/h	68.0	68.0	68.0	68.0	86.5	80.0	81.6	83.0	51.4	49.7
Recovery	%	71	71	65	70	59	66	62	64	69	74
Pretreatment		50 µ		50 µ		50 µ		50 µ		50 µ	
Feed pressure	bar	3.7	3.7	5.3	5.1	5.4	4.3	5.7	5.1	5.8	5.6
Permeate pressure	bar	2.1	2.1	2.7	2.9	3.4	2.0	2.9	2.4	2.5	1.8
ΔP		1.6	1.6	2.6	2.2	2.0	2.3	2.8	2.7	3.3	3.8
Post-treatment		UV + alkalinity filter		UV + alkalinity filter		UV + alkalinity filter		UV + alkalinity filter		UV + alkalinity filter	
Daily cleaning		Sodium hypochlorite + organic salt pH 7		Sodium hypochlorite + organic salt pH 7		Sodium hypochlorite + organic salt pH 7		Sodium hypochlorite + organic salt pH 7		Sodium hypochlorite + organic salt pH 7	
Main cleaning		Ultrasil53 + organic salt + UfacidK pH 8.5		Sodium hydroxide + sodium hypochlorite pH 12; Citric acid pH 2		Sodium hydroxide + sodium hypochlorite pH 12; Citric acid pH 2		Sodium hydroxide + sodium hypochlorite pH 12; Citric acid pH 2		Sodium hydroxide + sodium hypochlorite pH 12; Citric acid pH 2	
CIP frequency	CIP/year	2		2		2		2		2	
Temperature	°C	9.5		2.2		11.6		7.7		7.7	

Appendix 2
Analysis results for the raw and permeate water of Sør-Odal nanofiltration water plant from 2012 to 2015

Parameter		UF membranes		NF membranes		NF membranes		NF membranes		NF membranes	
Date		15.08.2012		24.10.2012		20.11.2013		10.09.2014		14.01.2015	
		Feed	Permeate	Feed	Permeate	Feed	Permeate	Feed	Permeate	Feed	Permeate
pH		6.5	6.5	6.5	6.4	6.5	6.4	6.5	6.4	6.5	6.4
Feed temperature range	°C	1–12	1–12	1–12	1–12	1–12	1–12	1–12	1–12	1–12	1–12
Coliform bacteria	col/100 mL	55	<1	78	<1	10	<1	<1	<1	<1	<1
E. coli	col/100 mL	< 1	<1	1	<1	<1	<1	<1	<1	<1	<1
Plate count 2°C	col/mL	41	3	70	4	44	4	32	<1	43	<1
Turbidity	FNU	0.62	<0.1	0.43	<0.1	0.9	<0.1	0.58	<0.1	0.54	<0.1
Color	mg Pt/L	145	13	199	4	156	2	109	<2	163	<2