Recent operational experiences of FILMTEC™ NF270 membrane in Europe
Katariina Majamaa, Justyna Warczok and Martti Lehtinen

ABSTRACT
Nanofiltration (NF) is an attractive technology for potable and industrial water treatment because NF operates between ultrafiltration (UF) and reverse osmosis (RO) membranes. NF is designed to remove a high percentage of organic contaminants (humic acids, pesticides, color bodies) while passing a medium to high percentage of salt. Compared to UF membranes, the NF product water quality is significantly better; compared to comparable RO treatment systems NF systems require lower operating pressures. Due to these features, NF is increasingly used in a broad range of water treatment applications. The general applications include softening, as well as color, organics and micro-organism removal. DOW FILMTEC™ NF270-400 is one the most frequently used elements in water treatment and this paper presents examples of three recent NF270-400 installations in Europe. The first two plants, Eupen and Stembert, are located in Belgium and produce potable water from surface water. The third one is a Scandinavian plant which purifies groundwater for a brewery and soft drink production. The presented operation results prove NF to be a highly competitive technique for low cost water treatment.

Key words | beverage, nanofiltration, NF270, plant operation, potable water

INTRODUCTION
Nanofiltration (NF) rejects solutes in the range between the capabilities of ultrafiltration and reverse osmosis (RO). NF combines low pressure demand with high rejection of particles in the 200–1,000 molecular weight range and polyvalent ions. NF is used in a broad range of applications, i.e. potable water treatment, commercial/industrial treatments and food & dairy processes (Mänttäri et al. 2004; Boussu et al. 2007; Luo et al. 2009). Due to the removal of organics such as humic acid, pesticides and color bodies, NF is increasingly applied in the treatment of surface water. Rejection of polyvalent salts makes it suitable for removal of hardness ions (membrane softening) and sulfate (Gorenflo et al. 2003). The NF membranes have a high pure water permeation coefficient, thus they can be operated at a lower operating pressure than RO membranes, resulting in reduction of the operational costs of the plant. The selection of the NF membrane type is dependent upon the application specific needs.

The construction of both RO and NF thin-film composite membranes is similar. Both types consist of three layers: a polyester support web, a microporous polysulfone interlayer, and an ultra-thin polyamide barrier layer at the top surface. Each layer is adapted to specific requirements (Anon 2010) and the final barrier layer is responsible for defining the membrane productivity of solute removal properties. NF270-400 has a barrier layer made from aromatic/aliphatic polyamide with amine and carboxylate end groups, while RO membranes and the tighter NF membrane called NF90 have an aromatic polyamide barrier layer. In terms of MWCO, no specific values or ranges are assigned. As a whole, they are considered to be MWCO 200-400 Da, with NF270 as the loosest (higher MWCO) and NF90 being the tightest (lower MWCO). Park et al. (2005) determined the MWCO of NF270 as 270 Da, using fractional rejection method with non-charged PEG solutes. Lin et al. (2007) estimated the NF270 MWCO as 300 Da. For NF90, data gathered by Yangali-Quintanilla et al. (2010) confirm the MWCO to be 200 Da.

The NF270-400 membrane element was developed to remove a high percentage of TOC and trihalomethane (THM) precursors with medium to high salt passage and

doi: 10.2166/wst.2011.583
medium hardness passage, while operating at a low feed pressure. The specified element performance at standard test conditions is permeate flow of 12,500 gpd (47.3 m³/day) with MgSO₄ rejection of >97% and permeate flow of 14,700 gpd (55.6 m³/day) with CaCl₂ rejection of 40–60% (NF270-400 element permeate flow and salt passage based on the following test conditions: 500 mg/L CaCl₂, 70 psi (0.48 MPa), 77 °F (25 °C) and 15% recovery 2,000 mg/L MgSO₄, 70 psi (0.48 MPa), 77 °F (25 °C) and 15% recovery). Thus, it is a good choice for surface water and groundwater where good organic removal is desired with partial softening. One of the applications of this membrane is color removal. This application is common especially for cold climate areas where the water is soft, but has high a concentration of natural organic matter (NOM) with significant color content (Thorsen & Flogstad 2006). NF270 for high color, bacteria and overall TOC rejection (98%) was applied successfully in a potable water plant in Norway (Majamaa et al. 2009). In Sweden an NF270 precursor (NF255) was applied to purify surface lake water (to remove color and iron, and to reduce COD demand) to obtain potable water (Anon 2001). Lin et al. (2007) demonstrated the usefulness of NF270 to eliminate THM precursors (THMPs). The authors obtained over 70% rejection of small THMPs at neutral pH and over 80% rejection for pH above 9, indicating charge exclusion as the prevailing mechanism for removal of small THMPs. de la Rubia et al. (2008) confirmed THMPs can be significantly removed by NF270 membrane, but also concluded hydrophilic THMPs are better removed by NF90. These findings are in good agreement with the physical characteristics of both membranes.

The NF90-400 membrane element provides high membrane productivity while removing a high percentage of salts, nitrate, iron and organic compounds such as pesticides, herbicides and THM precursors. The specified element performance in standard test conditions is permeate flow of 9,500 gpd (36 m³/day) with MgSO₄ rejection of >97% and permeate flow of 7,500 gpd (28.4 m³/day) with NaCl rejection of 85–90% (NF90-400 element permeate flow and salt passage based on the following test conditions: 2,000 mg/L NaCl, 70 psi (0.48 MPa), 77 °F (25 °C) and 15% recovery 2,000 mg/L MgSO₄, 70 psi (0.48 MPa), 77 °F (25 °C) and 15% recovery). Compared to the NF270-400, higher rejection of monovalent ions is achieved with NF90-400, but the productivity is accordingly lower. Ahmad et al. (2008) indicated NF90 to be the best element for pesticides elimination among the four NF membranes tested. NF90 showed over 90 and 95% rejection of atrazine and dimethoate, respectively, while permeate flux was good. This membrane also showed very good results in arsenic removal (above 91%) for a broad range of operating conditions such as temperature, transmembrane pressure, pH and feedwater concentration (Figoli et al. 2010). Santafé-Moros et al. (2007) indicated NF90 as a suitable membrane to reduce nitrate concentration to the limits of potable water. They studied binary and ternary mixtures and the influence of different ions and pH on the nitrate rejection. At all of the tested conditions the membrane showed very good performance.

Another NF membrane type, NF200B, specifically designed for the largest NF plant at Méry Sur Oise (140,000 m³/day) was installed and successfully used to remove organic matter and pesticides. Moreover, the organoleptical characteristics of the water have been improved (chlorine taste and calcium concentration are reduced) compared with the conventional plant which operates in parallel. The NF plant is thoroughly controlled resulting in long-term efficient operation since 1999 (Ventresque et al. 2000; Cyna et al. 2002; Plottu et al. 2003).

Compared to conventional water purification methods, the application of membrane treatment is usually criticized due its high energy demand and fouling tendencies. Proper plant design, correct selection of membrane type, well adjusted pre-treatment and correct plant control are the key elements to diminish the development of fouling and achieve operation at the lowest possible energy consumption. The objective of this paper is to show the latest examples of NF plants that are meeting treatment goals with minimal energy consumption. The first two plants, Eupen and Stembert, are located in Belgium and produce potable water from surface water. The third one is a Scandinavian plant which purifies groundwater for a brewery and soft drink production.

All the presented results – permeate flow, differential pressure and rejection – are normalized using FTNORM, which is based on ASTM standard D 4516. The objective of the normalization is to compare the actual performance to a given reference performance (e.g. start-up, design) taking into account fluctuations of operational parameters. Parameters as temperature, pressure or feed salt concentration strongly affect both permeate flow and salt rejection. Since the mentioned operation parameters are difficult to keep constant, correction factors have to be applied. Through normalization one can obtain realistic information about plant performance and identify potential problems such as fouling, chemical damage, etc.
EUPEN AND STEMBERT, BELGIUM

The Eupen plant, with a design capacity of 50,000 m$^3$/day, and the Stembert plant, with a design capacity of 36,000 m$^3$/day, are the second and third largest potable NF plants in Europe after the Méry Sur Oise plant. The plants were built by Degrémont and are operated by SWDE. Located in Western Belgium, next to the Vesdre and La Gilleppe barrages, respectively, the plants are treating reservoir water after conventional drinking water treatment. The NF units were added as a final treatment step to reduce the level of organics in the drinking water. The potable water is chlorinated prior to discharge to the distribution line and the treatment goal is to remove THM precursors in order to reduce the formation of disinfection byproducts. The feedwater total organic carbon (TOC) concentration is at the level of 4 mg/L in the NF feedwater and always below 0.4 mg/L in the permeate water. The removal efficiency is high enough to allow blending part of the conventionally treated drinking water with NF permeate. Blending of the permeate and the feedwater in order to obtain a product of desired quality minimizes the size of the plant, therefore lowering the capital costs of the plant. The TOC levels are continuously monitored and the blending ratio can be adjusted based on the inlet TOC levels. Based on successful pilot trials, the NF270-400 membrane was selected due to its high capability to remove NOM with the lowest achievable feed pressure. The units are designed to reach maximum output as can be seen in the details of the design conditions presented in Table 1.

Commissioning and start up of the five NF trains of the Eupen plant were done between March and September 2009. Currently two trains are operating at the same time and the operating units are alternated. An example of operation is shown with train 2 data, which has been operating the longest (Figure 1). The performance has been stable and has met expectations. The increase of normalized differential pressure (Figure 1) indicates that some degree of fouling occurs in the first stage, but it can be well controlled with a proper cleaning regimen.

The Stembert plant was commissioned and started up during September and October 2009. Currently one train is operating at one time, and the operating unit is alternated. An example of operation is shown with train 2 data in Figure 2.

<table>
<thead>
<tr>
<th>Design parameter</th>
<th>Unit</th>
<th>Eupen – Vesdre</th>
<th>Stembert – La Gilleppe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average flux</td>
<td>l/m$^2$/h 19.43</td>
<td>19.74</td>
<td></td>
</tr>
<tr>
<td>System recovery</td>
<td>%</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Permeate flow per train</td>
<td>m$^3$/h 433</td>
<td>515</td>
<td></td>
</tr>
<tr>
<td>Number of trains</td>
<td>–</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Number of stages</td>
<td>–</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Pressure vessel staging</td>
<td>–</td>
<td>60:28:12</td>
<td>68:34:15</td>
</tr>
<tr>
<td>Elements/pressure vessel</td>
<td>–</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Element type</td>
<td>–</td>
<td>NF270-400</td>
<td>NF270-400</td>
</tr>
<tr>
<td>Total amount of elements</td>
<td>–</td>
<td>3,000</td>
<td>2,106</td>
</tr>
<tr>
<td>Design temperature</td>
<td>°C</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Feed TDS</td>
<td>mg/L</td>
<td>96</td>
<td>74</td>
</tr>
<tr>
<td>Permeate TDS</td>
<td>mg/L</td>
<td>52</td>
<td>41</td>
</tr>
<tr>
<td>Feed pressure (max)$^a$</td>
<td>bar</td>
<td>7.03</td>
<td>6.45</td>
</tr>
<tr>
<td>Specific energy (max)$^a$</td>
<td>kWh/m$^3$</td>
<td>0.27</td>
<td>0.25</td>
</tr>
</tbody>
</table>

$^a$Calculated at design temperature and long-term flow factor of 0.7.
Since the start up, the membrane performance has been good and is meeting expectations. Stable normalized pressure drop indicates that no fouling took place during the first month of operation.

**BREWERY PLANT, SCANDINAVIA**

The majority of references using NF membranes relate to the treatment of potable water (Gaid et al. 1998; Wittmann et al. 1998; Hilal et al. 2004), but NF can also be utilized in industrial applications. Veolia Water Solution’s plant in a brewery application is a good example of a process where high productivity and selective removal NF membranes are an optimal technology choice. The site treats groundwater from a well and the treatment goal is to produce high quality production water for a brewery and soft drink production. The main objective of NF treatment is to remove suspended and colloidal matter and organics, mainly humic acids, from the pretreated raw water. Concurrently, the membrane forms an absolute barrier for any micro-organisms present in the raw water. Ionic content of brewery water has a high impact on the final taste of the product. Typical of Nordic waters, the total dissolved solids (TDS) content of the raw water is already naturally low (159 mg/L) and therefore large reduction in salt content was not desired; only slight alkalinity removal was preferred. NF membranes were considered to offer the best energy/quality solution and both loose NF270 and tight NF90 membranes were piloted. The results of a pilot sampling are presented in Table 2. The NF270 membranes were demonstrated to reduce the feedwater alkalinity to an optimal level, 28 mg/L, for the process and were selected for the large plant.

The NF plant configuration is the following: water intake is from a large groundwater reservoir through a well. The NF plant pre-treatment scheme consists of active carbon filtration and 5 μm safety filters. There are two identical NF units installed, but operated in alternating mode. The design capacities of the units were 110 m³/h at 80% recovery. Currently the units are operated at a production level of 90 m³/h and at 75% recovery. Operational flux is 27 L/m²/h. The units are 2-stage systems with a 12:6 staging, each pressure vessel housing 5 elements. In total, 180 pieces of NF270-400 membranes are installed. Temperature of the raw water are very stable between 7 and 11 °C. At the design conditions with lowest temperature, the maximum energy consumption of one unit is 0.31 kWh/m³.

The plant was started up in 2007 and the end user has been very satisfied with the operation. Preventative cleaning is performed once or twice a year to minimize operational variances in the process. The most important factor for the end user is reliability. To maximize reliability, roughly 15% of the membranes are changed on a yearly basis as a preventative procedure.

<table>
<thead>
<tr>
<th>Water Sample</th>
<th>Turbidity (FTU)</th>
<th>Conductivity (μS/cm)</th>
<th>Total Hardness (d)</th>
<th>Alkalinity (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed to NF270</td>
<td>0.1</td>
<td>243</td>
<td>4.0</td>
<td>62</td>
</tr>
<tr>
<td>NF270 permeate</td>
<td>0.0</td>
<td>106.3</td>
<td>1.1</td>
<td>28</td>
</tr>
<tr>
<td>Feed to NF90</td>
<td>0.0</td>
<td>245</td>
<td>4.4</td>
<td>62</td>
</tr>
<tr>
<td>NF90 permeate</td>
<td>0.0</td>
<td>33.6</td>
<td>1.2</td>
<td>13</td>
</tr>
</tbody>
</table>

Figure 3 | Normalized permeate flow (left axis) and differential pressure (right axis) of the two NF270-400 units.

Figure 4 | Normalized salt rejection of the two NF270-400 units.
preventative measure. The operational results over the last 1.5 years are presented in Figures 3 and 4. As can be seen, the units are constantly operating in a very stable manner.

**SUMMARY**

The examples shown in the present paper place NF as a highly competitive technique compared to traditional methods which are not always effective in the removal of a broad range of contaminants. The operation results obtained for the three presented plants prove NF can be used successfully for potable water production, as well as in industrial applications. The selection of the highest productivity membrane, NF270-400, has ensured operation at very low energy consumption (0.25–0.31 kWh/m³). Proper plant design, well adjusted pre-treatment and correct plant control have been key elements to diminish the development of fouling.

**REFERENCES**


ASTM D4516-00: Standard Practice for Standardizing Reverse Osmosis Performance Data.


Thorsen, A. & Flogstad, H. 2006 Nanofiltration in Drinking Water Treatment. Literature Review. Technue, D5.3.4B.


First received 5 January 2011; accepted in revised form 3 March 2011