Innovative feed spacer technology leads to enhanced reverse osmosis element performance

Dr Carsten Schellenberg and Alan D. Sharpe

Innovations in feed spacer technology can enhance the performance of reverse osmosis technologies, say Conwed Plastics and LANXESS

THE WORLD IS RUNNING OUT of water. By 2025 nearly 1 billion people will lack access to fresh, drinkable water. Reverse Osmosis (RO) water treatment will play a major role in alleviating water scarcity, however, this desalination technique is energy intensive. Any improvement of the membrane or element technology that can increase the energy efficiency of the RO process will be important. In a co-research project, Conwed Plastics and LANXESS' Liquid Purification Technologies business unit have proven that innovations in feed spacer technology lead toward enhanced RO element performance.

The Reverse Osmosis process

Reverse Osmosis is a water purification technology to remove mainly monovalent ions (e.g. NaCl) that utilizes a semipermeable membrane. An applied pressure is used to overcome natural osmotic pressure. Such RO membranes are being offered as spiral wound elements for a huge variety of desalination applications. Frequently known as scrim, mesh, net, or netting, feed spacers act as one of the layers of spiral wound RO elements and provide vital separation between the membranes to achieve superior filter performance.

A spiral wound element refers to a membrane configuration which is comprised of "flat sheet membrane - permeate channel spacer - flat sheet membrane - feed channel spacer" combinations rolled up around a permeate collection tube. As shown on Figure 1, the membrane element structure contains the feed spacer that separates the surfaces of adjacent membrane envelopes. The feed spacer, configured as a net, keeps the feed channel open, allowing feed water to flow inside the feed channels, along the membrane element;

RO challenges

There are many challenges within the RO membrane water treatment process. With respect to feed spacers as a component in the overall RO element design, the critical issues are:

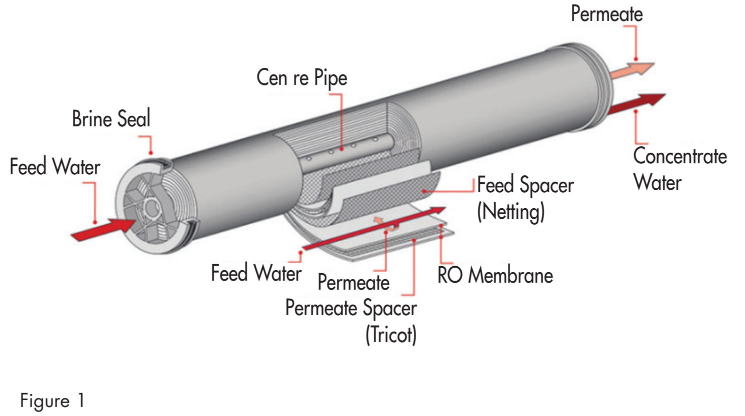

Figure 1

- Pressure drop – balancing turbulence promotion against frictional losses
- Membrane damage during winding
- Biofouling and scaling during operation.

These challenges have driven the combined technology efforts of Conwed Plastics and LANXESS to develop more efficient RO products.

Effect of feed spacer on pressure drop

The feed spacer is an essential component of spiral wound membrane elements. Feed spacers are manufactured from polymeric materials and optimized to maintain stable performance of membrane elements in a wide range of feed water composition and process parameters.

The configurations of feed channel and feed spacer net are shown schematically in Figure 2. The feed channel, shown here in unwrapped configuration, forms a rectangular opening of typically 0.7 – 0.9 mm in height. Due to the presence of spacer or netting strands in the feed channel, the actual cross section area open to the feed flow is smaller than the geometric cross section.

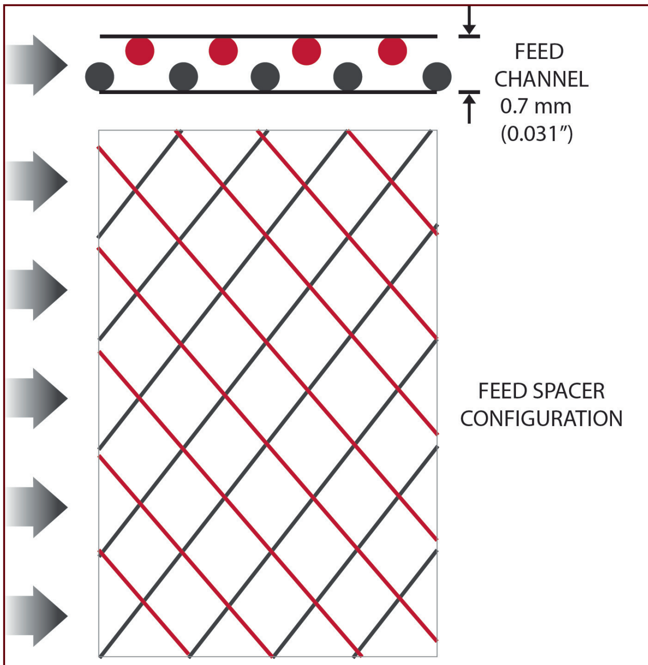

Figure 2

The length of the feed channel is about 1 m. The feed spacer net, filling the feed channel, has filaments or strands positioned bi-planarly. The bi-planar characteristic causes the feed stream to change flow direction as it flows above and below the subsequent filaments. The objective of the feed spacer, in addition to keeping the feed channel open, is to promote turbulence of the feed stream.

The need for turbulence in the feed stream is related to the nature of the RO desalination process. The feed water and dissolved salts flow parallel to the membrane surface, with a fraction of the feed water passing through the membrane as permeate, leaving the dissolved ions in the retained fraction of the feed water stream.

This process generates excess concentration of dissolved ions at the membrane surface, a phenomena known as concentration polarization. The feed spacer-induced turbulence reduces the extent of concentrate polarization, thus improving performance of the RO membranes. However, the feed spacer induced turbulence increases friction in the feed channel, which is translated into pressure drop of the feed stream between element feed and exit points.

The current configurations of feed spacers, used for construction of RO spiral wound elements, have been developed based on practical experimentation and fundamental studies. The objective was to create a condition of "mixing flow" even at the low flow velocities existing in the feed channels of the spiral wound membrane elements. Subsequent research and development work demonstrated the importance of feed spacer filaments' geometry, angular configuration as well as alignment of feed spacer with the direction of feed flow.

The configuration of feed spacer for RO applications evolved (after much experimentation and hydraulic modelling) into a bi-planar net with square or rhomboid openings. Rhomboid net configurations are commonly known as diamond netting. The spacer is positioned in the feed channel with net filaments at an angle of about 45° to the direction of the feed flow (shown on Figure 2). This configuration results in acceptable trade-off of sufficient turbulence and mixing of the feed stream without excessive pressure drop.

This orientation of the feed spacer net is applied in a vast majority of RO and NF (nanofiltration) membrane elements of spiral configuration. The above orientation of feed spacers, relative to direction of the feed stream, and the presence of high density membrane support nodes, result in significant blockage of the flow path in the feed channel. Therefore, very clean feed water with low concentration of suspended matter is required for a stable operation of RO membrane units.

If the feed channel is in clean condition, without particles that could block feed water flow, the pressure drop across a single RO element is about 0.1 – 0.2 bar. In RO systems, membrane elements operate while enclosed in a pressure vessel. A single pressure vessel usually contains 6 – 8 membrane elements, operating in series.

Therefore, the combined pressure drop along a pressure vessel is in the range of 0.6 – 1.5 bar. Seawater RO systems are typically configured as single stage units. RO systems for brackish applications are mainly configured as two stage, or even three stage units, each stage operating in series. Consequently, the combined pressure drop in brackish RO systems will be higher, frequently in the range of 1.5 – 3 bar.

The required increase of RO system feed pressure, due to feed-concentrate pressure drop, is approximately equal to half of the pressure drop value. Therefore, the configuration of the feed spacer has to provide sufficient turbulence and mixing in the area adjacent to the membrane surface without significant increase of pressure drop in the feed channel.

The friction losses in the membrane element feed channels contribute to overall energy usage of the RO unit. Each bar of pressure drop is equivalent to additional energy usage of about 0.025 kwh/m^3 of product water produced (based on the common efficiencies of feed pumps and motors). During system operation some feed born particles will deposit in the feed channels of the RO elements, contributing to an increase in system pressure drop. The RO elements can be damaged by operation at very high pressure drop. Still, some systems will operate for long periods of time (between membrane elements cleanings) with pressure drop 50 to 100 per cent higher than the initial pressure drop on system start-up. The rate of pressure drop increase mainly depends on quality of the feed water. However, feed spacers of lower initial feed pressure show lower rate of pressure drop increase.

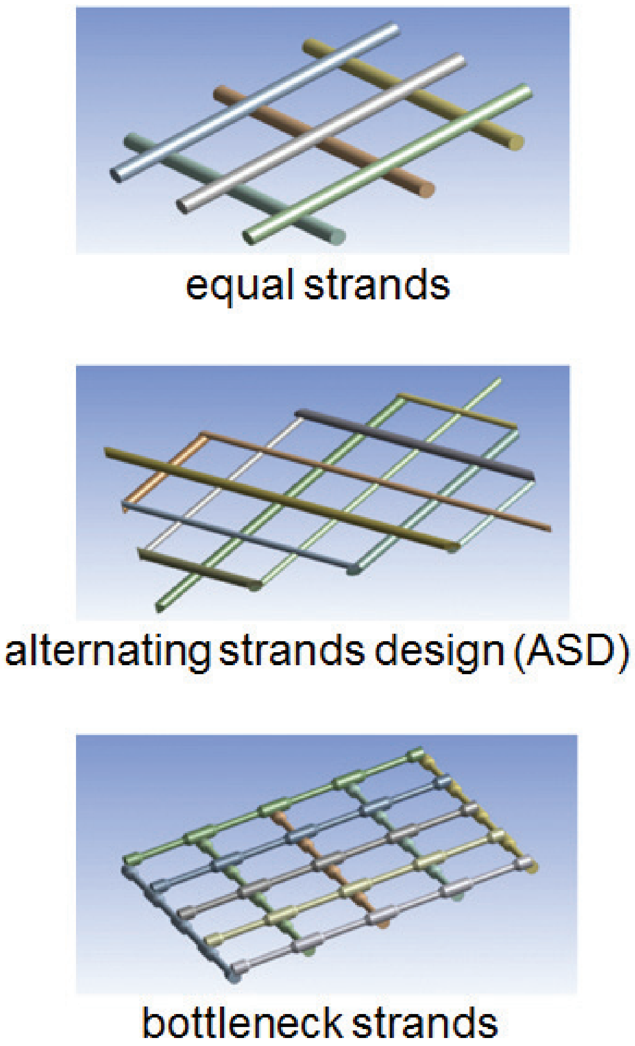

Figure 3

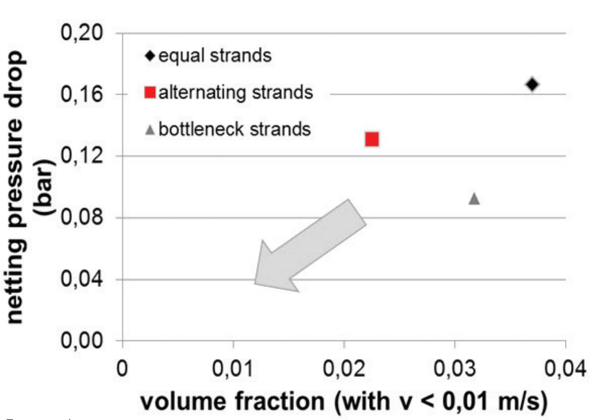

Figure 4

Co-research project leads to optimized feed spacer geometry called Alternating Strand Design (ASD)

Based on the above knowledge, a co-research project was initiated to develop a novel feed spacer technology addressing the outlined challenges. In a first step, basic feed spacer geometries were evaluated, using 3D printed samples. Next, detailed CFD (computational fluid dynamics) calculations towards decreasing pressure drop and minimized low flow areas were made. Low velocity areas, seen as the starting point for biofouling for example, were calculated, making use of feed spacers with equal strands, alternating strands and bottleneck type strands (Figure 3). The basic results of these calculations are summarized in Figure 4, and show that the system of alternating strand type feed spacers are well balanced with regard to pressure drop while minimizing areas of low feed water velocity.

To prove the performance of alternating strand design feed spacers, a number of different feed spacer types, produced using large scale netting production technology, were tested in a flow cell measurement program. The pressure drop performance was evaluated. The feed spacer samples were installed in a special flow cell and tested using different conditions (e.g. feed flow, time or fouling conditions). A selection of tested feed spacer materials is shown in Figure 5 along with corresponding pressure drop results in Figure 6 at a given flow rate of 20 l/h. This research confirmed the enhanced pressure drop performance of feed spacer material based on the new alternating strand design (ASD) technology.

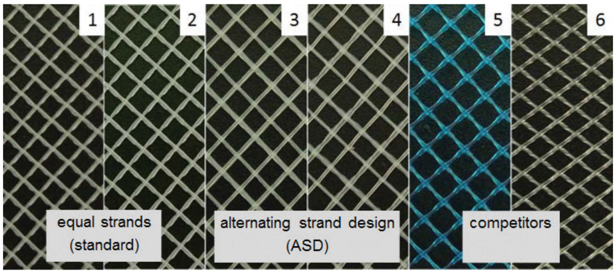

Figure 5

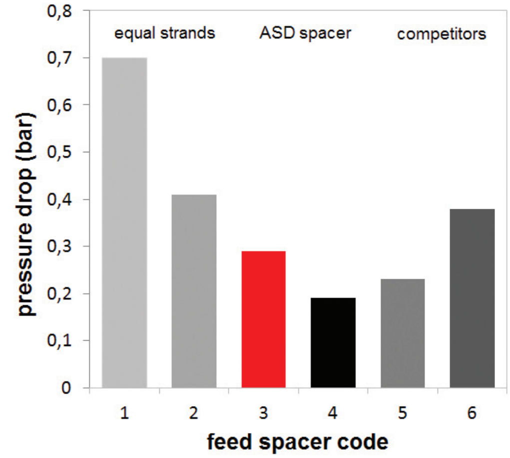

Figure 6

The RO elements constructed with such an innovative spacer geometry achieve a lower pressure drop than commercially available feed spacers based on equal strands. This leads to savings in energy consumption. In addition, the new ASD type spacer shows a finely tuned flow pattern resulting in reduced low flow areas, thought to reduce biofouling tendency. This reduced biofouling tendency can be seen as an improvement towards increased membrane life, and lower cleaning frequency, of such RO membrane elements.