Performance advancement in the spiral wound RO/NF element design

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Abstract

New spiral wound element improvements have been made so that RO/NF products are more robust. One improvement is the design of vents in the seal carrier or ATD's on the ends of the elements. This feature has proven to quickly equalize the pressure on the inside of and outside of the element and prevent rupture of the FRP shell. A second improvement is the development of feed spacers which have lower pressure drop. Thicker spacers with a unique geometry have been shown to have less pressure drop and reduce the frequency of chemical cleaning when treating water of poor feed quality.

Introduction

Spiral wound elements have become the most popular and economical form of packaging reverse osmosis (RO) and nanofiltration (NF) membranes. The reason is a result of the high membrane packing area that can be achieved, the efficient water flow and mass transfer in the element, and the low-cost of the materials that are used to construct the element.

The basic components of a spiral wound element are the flat sheet membrane, the feed-brine spacer, the permeate carrier, the leaf adhesives, the seal carrier (also called the anti-telescoping device [ATD]), the product water tube, and the epoxy outer shell. Over the past twenty years, the design and materials of the spiral wound element have slowly been optimized to enhance the performance and lower the cost. Some of the improvements include specialized feed spacer designs to improve mixing and vary thickness to optimize feed flow through the element. Also, various weaves and materials have been used for the permeate carriers to reduce pressure drop when transmitting the permeate to the product water tube. Also, improved adhesives have been developed which allow easier processing of the element, improved chemical resistance at higher and lower pH, as well as stability at higher temperatures.

Two items have recently received more attention to give better performance of the spiral wound element. One item is the seal carrier or ATD. Historically, this part, which is placed at both ends of the spiral wound element, has had two roles – one being to carry the u-cup brine seal which prevents feed liquid by-passing the membrane. The other function is to support the back face of the element and prevent the membrane leaves from telescoping due to the pressure differential across the element. The former function is provided on the upstream side of the element, while the latter is provided on the down-stream side.

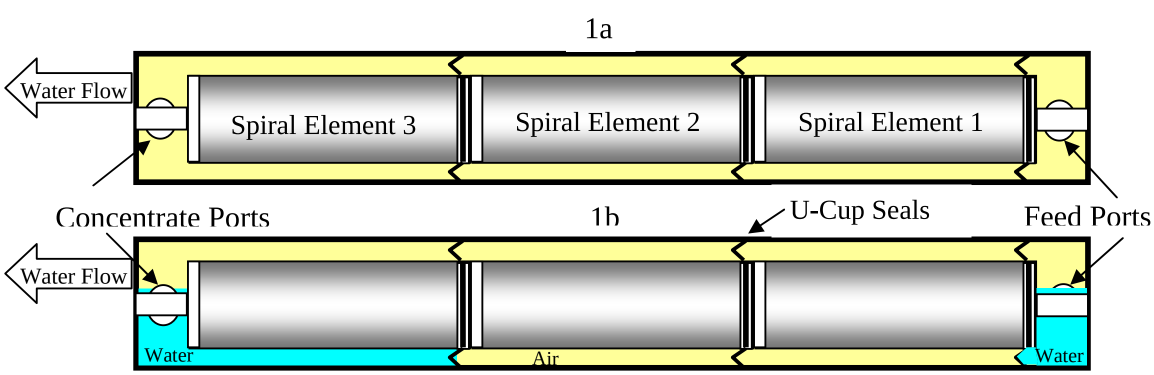
One role of the seal carrier has been little understood, which is the venting of the air from the pressure vessel. In a commercial RO/NF system, there are usually 6-8 elements in a pressure vessel. Due to the presence of the u-cup brine seal, water does not readily flow around the outside of the spiral wound element. As the water flows on the inside of the element, it becomes pressurized to the feed pressure, which can be 60 to 80 bar for seawater applications. In some cases, especially when starting a new system, there can be air on the outside of the element, in the annular gap between the element and the vessel. This annular gap can also be partially full of water, which is common if there is some drain down of liquid when an operating plant is stopped. In either case, the air in this gap must be purged from the system. Since there is no flow path for water around the outside of the element, the air must be removed and displaced with water where the two elements contact the face of each other or by-passing the u-cup seal. This venting can be difficult due to the differential pressure across the elements in the vessel which forces the two seal carriers tightly together. For systems that ramp pressure up too quickly, the air in the annular gap may not be quickly removed. This results in a large pressure differential across the epoxy fiberglass shell. In some cases this pressure differential can rupture the shell and irreversibly damage the element. This paper will discuss the issues associated with poor versus effective venting of air at this position.

The other item which has received attention is the design of the feed spacer. This material is responsible for maintaining a flow channel between the two faces of membrane in the spiral wound element. The feed spacer must provide a clear path for flow of the water, promote turbulence to keep the saline solution mixed and should have minimal pressure drop for water traveling tangentially to the membrane. For a system with good pretreatment, the feed spacer can be quite narrow and function well. This allows the element designer to pack the maximum area in the element. However, for poor quality feedwater, the fouling tendency of the water is much higher and can rapidly plug the channels created by the feed spacer. This results in a higher operating pressure and more frequent cleaning. With the use of RO/NF technology for more surface water applications, there is a need to optimize the feed spacer design for more difficult applications.

Seal Carrier Improvements

A detailed analysis of pressures and water flow in a multi-element vessel has revealed that there are issues related to purging air from a pressure vessel due to the U-cup seals preventing the natural flushing of the annular gap. Figure 1 shows a schematic diagram of a pressure vessel with RO elements. In Figure 1a, the vessel does not contain any water, while in Figure 1b, the schematic shows water in the vessel immediately after the first addition of water.

Figure 1 Schematic of spiral elements in a pressure vessel, 1a After loaded and before water introduced, 1b Just after water first starts to enter the vessel.



It can be seen that the water easily floods the vessel in front of the first element by displacing the air down through the elements. Also, the water fills the back of the vessel all the way to the U-cup seal of the last element. The air is displaced out of the vessel. However, the U-cup seal prevents the water from going to the next to last element. The only way to get the air out of the annular gap of elements 1 and 2 is to pressurize the water so it will flow past the u-cup seal; however, the air would then have to go against the seal to escape or go forward in the vessel to the next element position. Alternatively, the water may flood the annular gap by pressurizing the feedwater so it will separate the two facing seal carriers between 1 and 2 or 2 and 3. This would allow water into the annular gap and air to go out through the element. Either of these mechanisms are not very effective for venting the air from the system.

This issue is particularly problematic for seawater systems. In a seawater system the feed in the element is being pressurized to 60-80 bar of pressure. Until the water fully floods the annular gap, the pressure in the gap will be much lower than in the element. This pressure differential can lead to catastrophic damage. Figure 2 shows an element which has a ruptured fiberglass outerwrap. This element, from an operating plant, saw failure of the fiberglass reinforced plastic (FRP) epoxy outerwrap. It takes very high pressure differentials to cause this to happen. Such pressure can be generated when pressure ramps up quickly, and the air cannot be removed as rapidly.

Figure 2 Elements with cracked FRP shells.

This issue has recently been addressed in the development of a new seal carrier which can allow rapid venting of the air from the annular gap. The new design incorporates a number of recessed areas in the seal carrier which act as vents (Figure 3). When two opposing seal carriers are face to face, these small gaps provide an opening which allows the water to flow through (usually at the bottom of the seal carrier) and the air to pass through (usually through the top of the seal carrier). Since each element has this feature, the annular gaps can rapidly fill with water and the air can be expelled.

Laboratory Evaluation of Pressure Distribution

An experiment was performed to measure the pressures as a function of time during a typical start-up. The experimental set-up is shown in Figure 4. A variety of pressure gauges were installed to measure pressure at different points in the vessel. To visually

Figure 3 New seal carrier design with recessed vents

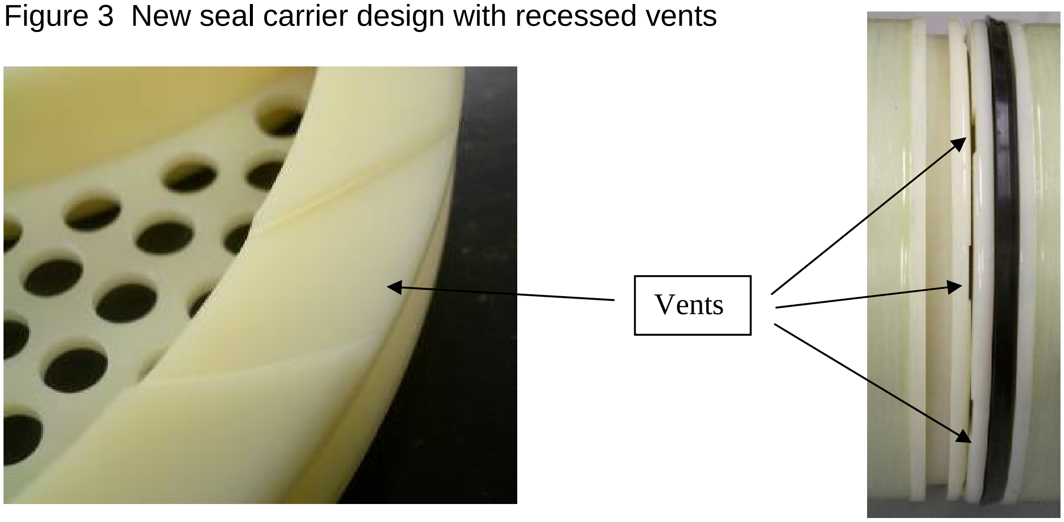
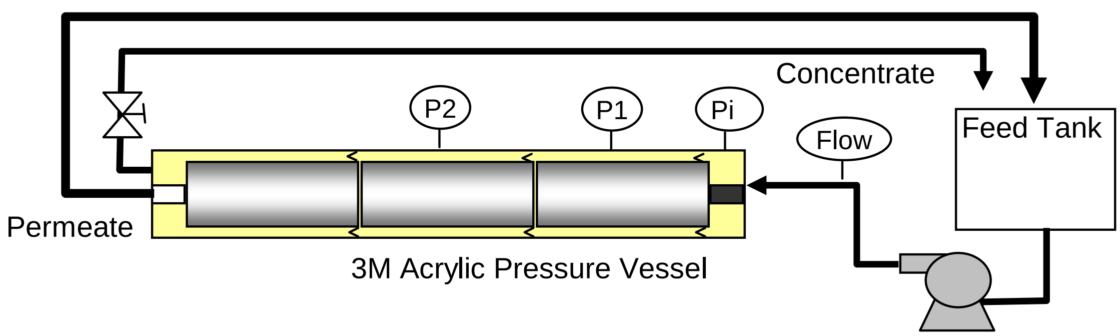


Figure 4 Design of the 2-element vessel for pressure differential measurements



observe the water flow, a pressure vessel was made of acrylic plastic so that the water in the vessel could be seen. A photograph of this experimental rig is shown in Figure 5.

A picture of the edge of a new seal carrier is shown in Figure 3. This shows the recessed portion of the edge of the seal carrier that acts as a vent to allow air and water to pass between the seal carriers. There are six of these evenly dispersed on the edge of the seal carrier. As these are only a few mm deep, they do not compromise the strength of the part.

Figure 5 Photograph of experimental rig

The test unit was then run to pass water to the two elements that are in series. The water entered from right to left. The pressure was measured at the inlet to the vessel, at the annular gap next to the first element, and the annular gap of the second element. From Figure 6, it can be seen that the inlet pressure rises at around 40 seconds. At about 60 seconds, the inlet pressure has risen to about 10.0 bar while the pressure at P1 and P2 are still nearly zero. Thus the pressure differential across the element shell will be 10 bar. At about 80 seconds of operation, the pressure at P1 has nearly equaled the inlet pressure, but P2 is still about 5 bar less than Pin. Thus, elements in the middle of the vessel may be at a greater risk of damage. Although this pressure differential did not damage the FRP shell in this case, the much larger pressure differentials in seawater applications may lead to element failure. Naturally, many other factors will also determine if the element FRP shell will be damaged, such as how much dP there is, and the ramp up speed of the high pressure pumps. This is one of the key reasons why it is good to have a pump ramp-up speed that does not exceed 0.7 bar per second.

Figure 6 Pressure distribution in a vessel with conventional seal carrier design

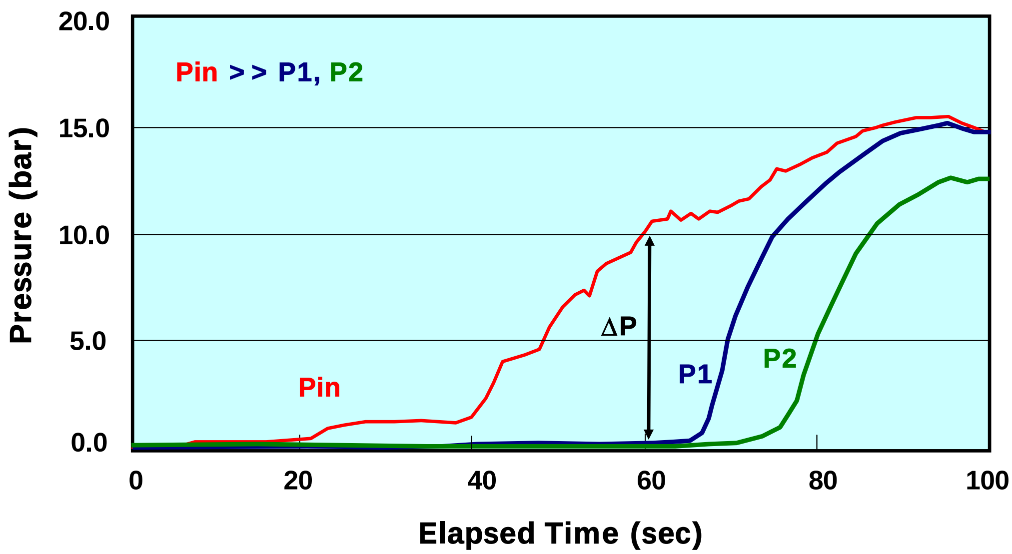
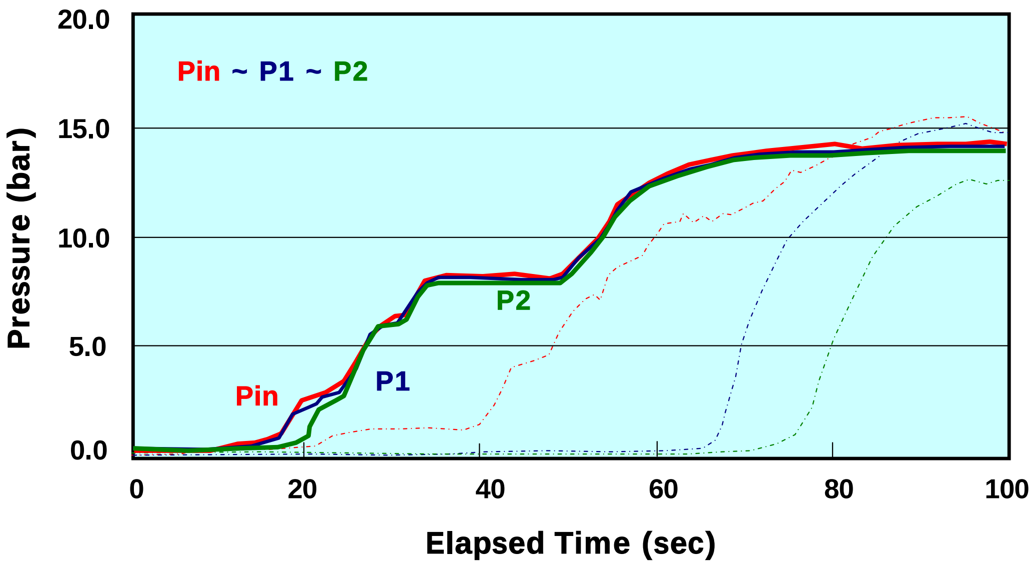


Figure 7 Pressure profile in a vessel using vented seal carriers



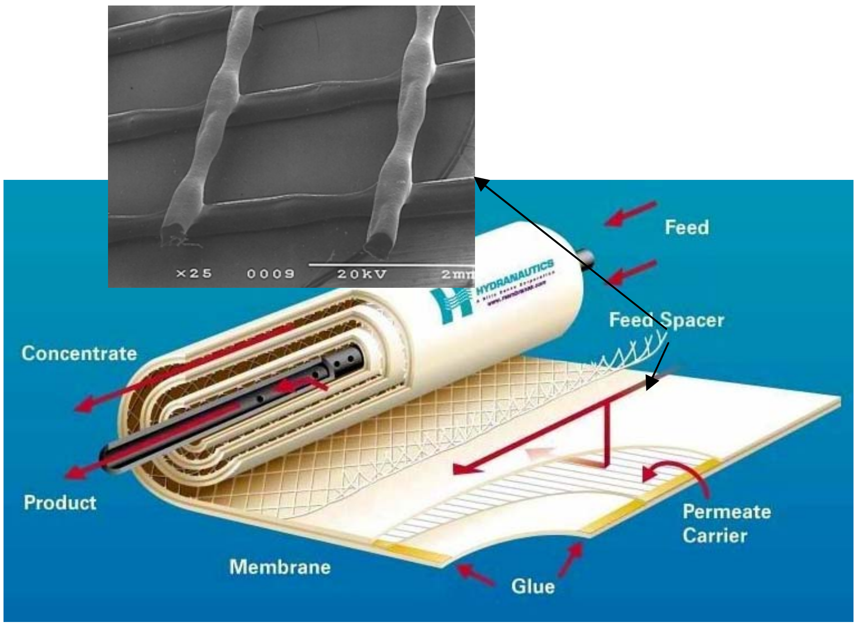
In contrast Figure 7 shows the pressure profile in a three element experiment where the new vented seal carrier of Figure 3 was used. In this case the pressure profile is very balanced. The pressure at the inlet, P1 and P2 are approximately equal at all times. This is due to the seal carriers allowing the air to quickly vent from the annular gap and be replaced by water. This new design will prevent the large pressure differential across the shell and prevent element damage.

Feed Spacer Improvements

Spiral wound RO and NF elements have traditionally used feed spacers that range between 0.66 and 0.81 mm thick. Significant research has been done to model and improve these spacers and understand the flow dynamics in elements using such spacers.[1] Figure 8 shows the schematic design of a spiral wound element, with a magnified electron microscope view of the feed spacer. The narrower (less height) the feed spacer the more membrane area can be designed into the element. For this thickness range, the difference in area would be about a 13% reduction in area if everything else remained constant. In most cases, RO/NF feedwater is of high quality, and it is the most optimum condition to use the narrower feed spacer to achieve the higher area. Figure 9 shows the pressure drop in a plant where a standard 0.66 mm spacer is used. It can be seen that the pressure drop in the system has been fairly stable and little plugging of the channels has occurred. No cleaning has been done on this system over the 2 years of operation.

In contrast, membranes are being used more frequently to treat feedwaters of poor quality. In these cases, the pressure rises more quickly than desired due to channel plugging. For this scenario, it would be more advantageous to use a feed spacer that is more open. This would provide lower pressure drop, less rapid plugging and more effective cleaning. Such feed spacers are being used in special products for high fouling applications, including the CPA3-LD, LFC3-LD and the CPA5 RO elements. The former two use a 0.79 mm (31 mil) spacer, while the latter uses a 0.86 mm (34 mil) spacer. To overcome the problem of lost area, automation has been utilized to control glue line placement, as well as some other element design changes. These changes have allowed these elements with thicker feed spacers to be made with the standard 37.2 sq m (400 sq ft) membrane area. In addition to using thicker feed spacers, the geometry of the spacer has also been optimized. This has resulted in additional reduction of the pressure drop. Figure 10 shows the pressure drop measured for a variety of elements using different feed spacers. It can be seen that these

Figure 8 Schematic design of a spiral wound element and SEM view of feed spacer



result in about 50% pressure drop reduction when compared to a standard 0.66 mm (26 mil spacer). The newly designed 0.81 mm (34 mil) spacer used in CPA5 has 16% less pressure drop than an element made with standard 34 mil spacer.

As a result, these new 37.2 sq m (400 sq) elements can save additional energy. In a two stage brackish RO system, the pressure drop will be about 2-3 bar. For example, a two stage system operating at 25 lmh (15 gfd) and 80% recovery at 25 C, will have about 2.6

Figure 9 Pressure drop in a NF system operating on low turbidity feed water

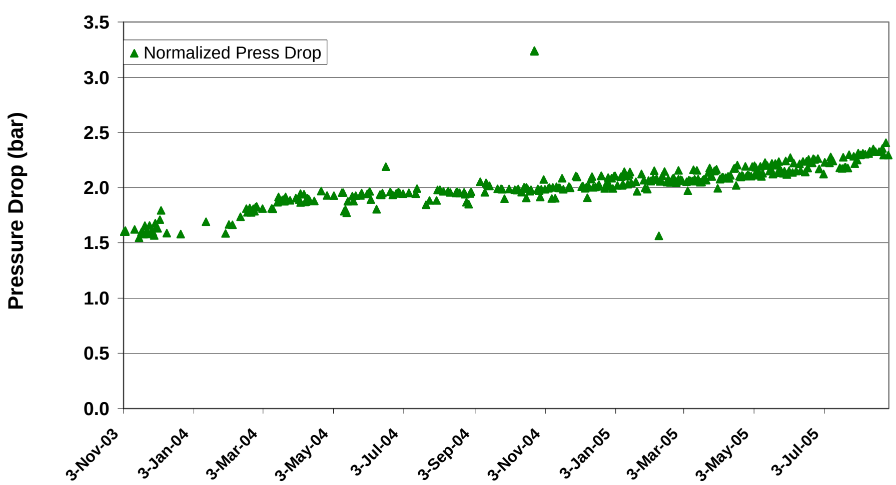
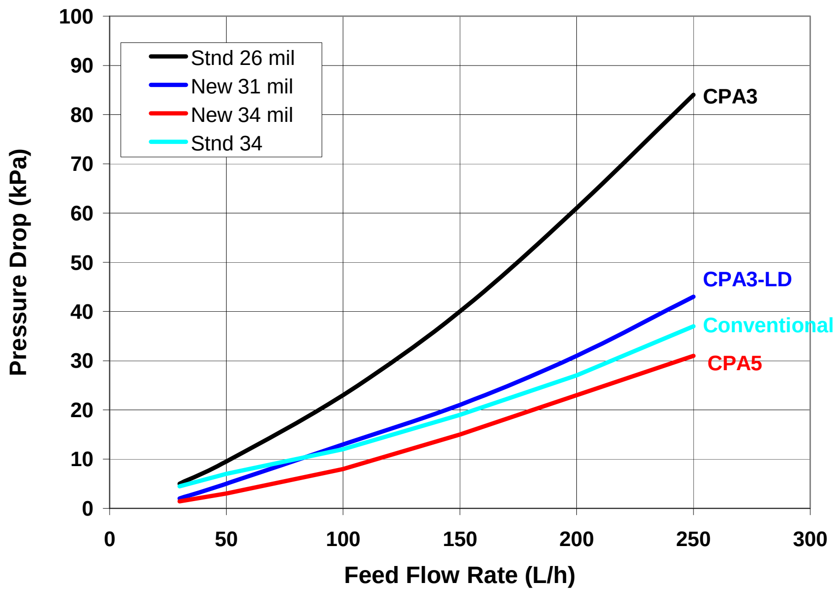
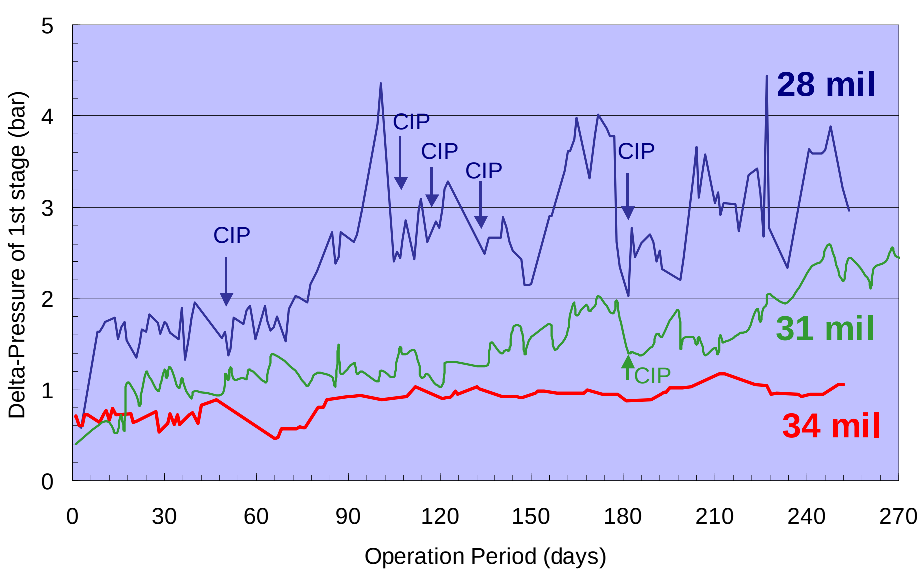


Figure 10 Pressure drop as a function of feed flow rate measured for 4 different spiral wound elements



bar of pressure drop with a CPA3 element using 0.66 mm feed spacer. For CPA3-LD, this would be 1.6 bar (39% less) and 1.3 bar (49% less) for CPA5. Again more importantly for poor feedwater quality, these elements will not have channel plugging as rapidly, and are more readily cleaned. As evidence of this, Figure 11 shows the performance of a RO system running on surface water feed. The operation was done in three phases, first with a standard 0.71 mm (28 mil) spacer, then a new geometry 0.79 (31 mil) spacer, and finally the new geometry 0.86 (34 mil) spacer. The most stable operation was achieved with the last 2 types, and the lowest dP was achieved with the 34 mil spacer. It is also seen that the conventional 0.71 mm spacer element ha numerous clean-in-place (CIP) events to maintain the acceptable pressure drop in the vessel.

Figure 11 Comparison of element performance on surface water feed using different feed spacer thicknesses.



Conclusion

The spiral wound element design improvements described here will ensure that the elements maintain good physical integrity over a long period of time and will also reduce the operating cost. The added feature of vents provided in the new seal carrier designs will ensure that air can be readily removed from the annular gap between the outside of the element and the pressure vessel wall. This ensures rapid pressure equalization between the inside and outside of the spiral element. As a result, aggressive operation will be much less likely to cause damage, such as bursting of the FRP shell.

The new, thicker brine spacers will be advantageous for more consistent operation when treating poor quality feedwaters. The lower pressure drop will reduce cleaning frequency, allow cleaning to be more effective, and reduce the potential for element damage caused by high dP. Due to improved automation, these new brine spacers can be implemented without reducing membrane surface area.

References

1. “Spiral wound modules and spacers, Review and analysis”, J. Schwinge, D.E.Neal, Wiley, D.F. Fletcher, and A.G. Fane, JMS 242 (2004) 129-153.