DEMONSTRATING IMPROVED RO SYSTEM PERFORMANCE WITH NEW LOW DIFFERENTIAL (LD) TECHNOLOGY

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Abstract

A new low differential (LD) pressure brine spacer technology has been developed for the spiral wound element which reduces fouling and improves RO system performance. The new technology uses a chemically enhanced, thicker feed/brine spacer with a unique geometry to reduce biogrowth and colloidal fouling. The use of the new brine spacer leads to less fouling, fewer cleanings, a reduction in differential pressures losses, and lower operating cost.

The ability of the new spacer to improve performance and reduce fouling has been demonstrated in the laboratory and in several full scale RO systems. Laboratory testing compared the accumulation of foulants on the conventional spacer and the enhanced spacer in both static and dynamic tests. The conventional spacer accumulated heavier fouling while the improved spacer accumulated less particulate foulants and suppressed biogrowth.

The improved spacer was also tested in full scale RO systems and compared to elements with conventional spacer technology. When fouling occurred and differential pressures increased, the systems with the conventional spacer displayed a greater increase in the differential pressure than the systems with the improved spacer technology. To further investigate the benefits of the improved spacer, the elements were removed from these RO systems and analyzed after several months of operation. Elements with the conventional spacer were found to have heavier fouling than elements manufactured with the improved spacer.

Both the laboratory testing and the field studies clearly demonstrate the advantage of the improved spacer. The new technology can be used in RO systems to reduce operating cost by reducing fouling and the rate of differential pressure increase and by increasing the effectiveness of chemical cleanings and the time between chemical cleanings.

Introduction

Fouling is a common aspect of operating an RO system. Successfully designed and operated RO systems with proper pretreatment typically require cleaning four to six times per year. However, as RO membranes are being used to treat more challenging feed waters, there is an increase in the frequency and severity of membrane fouling. Foulants from challenging feed waters come in different forms including colloidal/particulate fouling and biological fouling. A combination of these different foulants makes stable RO operation even more challenging.

The potential for colloidal or particulate fouling is measured using the Silt Density Index (SDI) and turbidity. Though membrane manufacturers allow a maximum SDI of 5.0 and a maximum turbidity of 1.0 NTU, lower levels, such as SDI less than 3.0 and turbidity less than 0.1, are more conducive to stable RO operation. The potential for colloidal or particulate fouling is significantly reduced if microfilter or ultrafilter membranes are used as pretreatment ahead of the RO. Unfortunately, the initial capital cost sometimes deters the use of membrane pretreatment.

The most difficult type of fouling to mitigate is biological fouling. This stems from the incompatibility of the polyamdie RO membrane with oxidants, such as chlorine, which are commonly used to control biofouling. Alternatives to chlorine for the control of biofouling in an RO system, such as DBNPA or chloramines, are sometimes used. However, their use may be limited by cost, environmental regulations, or ineffectiveness.

The development of new Low Differential (LD) pressure brine spacer technology addresses fouling associated with treating challenging feedwaters. The LD technology uses a thicker, 34 mil brine spacer while still maintaining 400 sq ft of active surface area in the eight inch RO element. The thicker spacer reduces the tendency for colloidal material to accumulate in the spacer mesh. The use of a thicker spacer, along with the modified geometry, also reduces hydraulic pressure losses and thus saves energy. Additionally, the new spacer is chemically enhanced to reduce biofouling. Studies done in the laboratory and in the field have proven the spacer's effectiveness at reducing biogrowth on and around the spacer and thus mitigating the increase in system differential pressures associated with biofouling. This leads to a reduction in the number of required cleanings. The improved spacer technology is best utilized in treating any feeds with high colloidal and/or biological fouling potential

Thicker Brine Spacer With Improved Geometry

When manufacturing the spiral wound RO element, a trade off is made between the thickness of the feed/brine spacer and the amount of active membrane surface area that can be packaged into the element. The conventional spiral wound element, with a diameter of eight inches, is manufactured with 400 square feet of membrane when using a 26 or 28 mil spacer. Historically, if a thicker 31 mil or 34 mil spacer was selected, the membrane surface area would be reduced to 365 square feet. However, due to advances in materials and automated manufacturing, including using robotics for the precise placement of the glue lines, today's element can be constructed with a thicker 34 mil spacer while maintaining 400 square feet of active membrane area. The use of a thicker spacer offers several advantages including lower differential pressures, lower fouling potential, improved membrane cleanings, and better flux distribution between the lead and tail elements of an RO system.

By going from a 28 mil spacer to a 34 mil spacer, the thickness of the channel through which the feed flows is increased by 20%. A thicker channel means that less pressure is lost as water travels from the feed to the brine end of the element. In a low pressure RO or NF system with two or three stages and six elements per vessel, the water travels through twelve to eighteen elements before exiting on the brine end of the system. The viscous flow through these 18 element leads to a substantial loss in pressure. Using a thicker spacer, however, can reduce this hydraulic pressure loss. This reduction in differential pressure loss is a significant percentage of the net driving pressure and will result in a reduction in overall system feed pressure. Using a three stage nano filtration plant as an example, a system loaded with 28 mil spacer elements and operating at 85% recovery would require water to travel through 18 elements in series. Feed pressure would be 6.9 bar and differential pressure loss would be 2.0 bar. By increasing spacer thickness to 34 mil, the same system would experience half of the differential pressure loss and operate at a feed pressure of 6.1 bar – a 12% reduction in feed pressure and associated energy cost.

The thicker spacer also has the advantage of reducing particulate fouling. The thicker channel allows particulate matter to move more freely from the feed to brine end of the element without becoming trapped in the spacer mesh. For those particulates that do become trapped, the thicker channel allows the foulant to be more easily removed during chemical cleanings.

A field study done using elements of varying thicknesses illustrates the advantages of the thicker brine spacer. The study was done on high fouling surface water with an average SDI of 4.5 and SDI spikes as high as 6.0. Three separate runs were completed during the study. Each of the three runs lasted more than 250 days and used different spiral elements with brine spacer thicknesses of 28 mil, 31mil, and 34 mil. Performance parameters were monitored and a periodic clean in place (CIP) was initiated as necessary. **Figure 1** below shows more stable differential pressures and fewer CIPs when using the thicker 34 mil spacer. In the case of the 34 mil spacer, there was almost no increase in differential pressure and no cleanings were required during the 250 day test period.

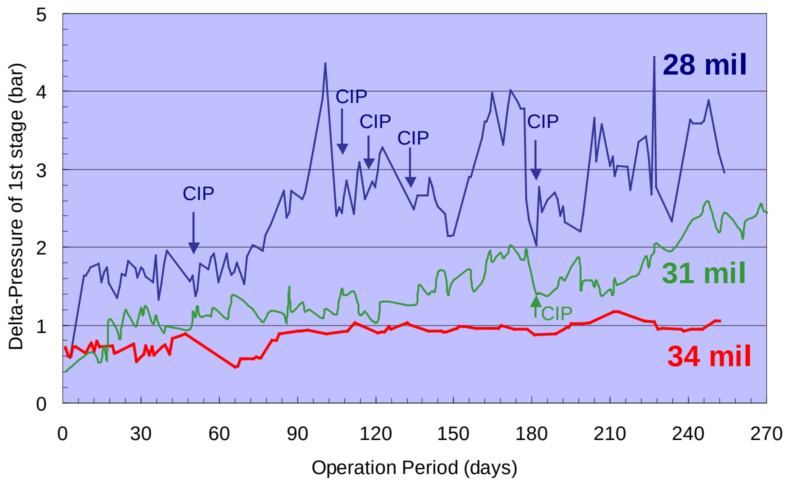


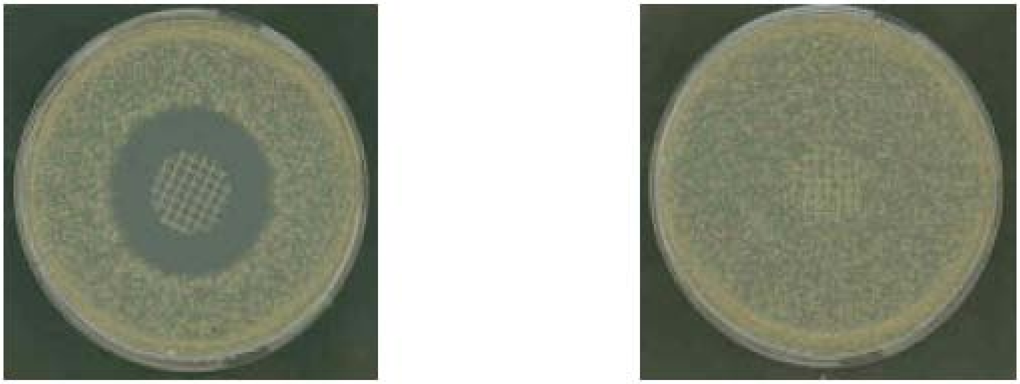
Figure 1. Performance of RO elements with different brine spacer thickness operating on high fouling feed water with SDI between 4 and 5.

Chemically Enhanced Brine Spacer Technology

Chemically Enhanced Spacer Technology Demonstrated in Laboratory

In addition to an increase in thickness to reduce particulate fouling, the improved spacer is chemically enhanced with a biostatic agent to reduce biofouling. The effectiveness of the biospacer was first demonstrated in the laboratory in static tests. Samples of the conventional spacer and the chemically enhanced spacer were placed in Petri dishes containing bacteria cultured on a 100 ul nutrient. After a five day incubation period, the samples were visually inspected. The biospacer consistently showed minimal growth while the conventional spacer showed heavy growth. **Figure 2**, for example, shows the difference in growth on the conventional spacer compared to the biospacer after five days of incubation using the colon bacillus bacteria. Similar results were found with a variety of different bacteria tested, including Escherichia coli and Staphylococcus aureus.

It is important to note that the inhibition of biogrowth occurs not only on the chemically enhanced spacer itself, but also on the area surrounding the spacer. This would suggest that biogrowth would be inhibited on the membrane surface as well. The reduction of biogrowth on the spacer and on the membrane surface surrounding the spacer is confirmed in field studies discussed in more detail below.



A **B**

Figure 2. Bacterial growth after five days of incubation in colon bacillus on A) chemically enhanced spacer B) conventional spacer

Dynamic studies were also conducted in the laboratory using cell testing with a conventional spacer in parallel with a chemically enhanced spacer (**Figure 3**). The two cells were exposed to a continuous 0.5 L/min (0.13 gpm) flow of wastewater for a period of one month. Visual inspection of the two brine spacers revealed less fouling on the chemically enhanced spacer than on the conventional spacer.

A B

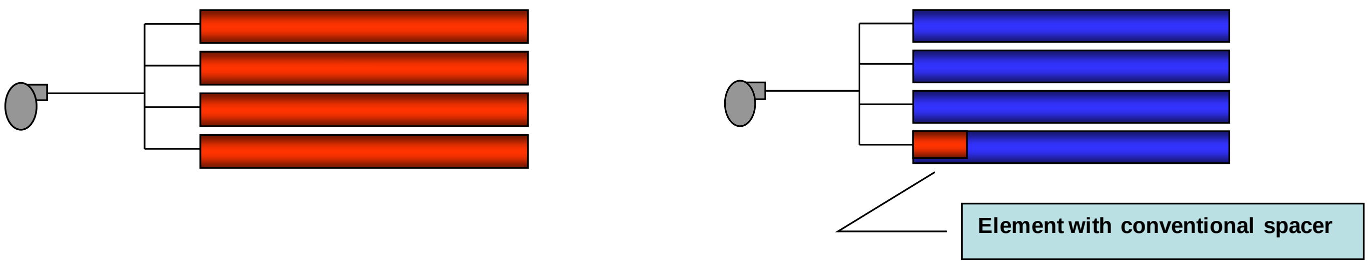
Figure 3. Biofouling on A) conventional spacer and B) biospacer after one month of continuous exposure to 0.5 L/min stream of waste water.

Chemically Enhanced Spacer Technology Demonstrated in RO Systems

The new spacer technology was also tested in several full scale RO systems alongside conventional spacer technology. When biofouling occurred in these systems and differential pressures increased, the elements with the conventional spacer were found to have greater biofouling than elements manufactured with chemically enhanced feed spacer.

One RO system in which the chemically enhanced feed spacer was tested alongside the conventional spacer was treating municipal effluent for use in cooling towers at a natural gas power plant in Southern California. The RO system consisted of two trains, Train A and Train B. Each train operated as a single stage with six parallel pressure vessels. Each pressure vessel housed six spiral wound elements in series. System average flux was 10 gfd. Because the trains were single stage running at only 55% recovery, no acid or antiscalant was injected.   Due to the absence of chloramines, the trains were routinely flushed with DBNPA twice each week. Pretreatment before the trains consisted of hollow fiber ultrafiltration producing filtrate with an SDI less than 3.0.

On February 1, 2009, Train A was loaded with elements containing 32 mil conventional spacer. Train B was loaded with elements containing 32 mil chemically enhanced feed spacer. A single element with conventional spacer was loaded in the lead position of the bottom vessel to act as the control for Train B (**Figure 4**). Both trains started with similar performance including similar feed pressures of 130 psi and similar differential pressures of 14 psi to 16 psi.



Train A with conventional spacer   Train B with chemically enhanced spacer + single element with conventional spacer

Figure 4. Two single stage trains with four vessels and six elements per vessel. Each train is running at 55% recovery and flux of 10 gfd. Train A is loaded with elements with 32 mil conventional spacer. Train B is loaded with elements with 32 mil chemically enhanced feed spacer spacer and a single element with conventional spacer.

After startup, both trains experienced an initial 15% loss in permeability within the first week due to organic fouling. This is typical of an RO system treating municipal wastewater. After the initial loss in permeability, both trains stabilized. The two trains operated stably for a period of two months. Neither train experienced a significant increase in differential pressure due to DBNPA soaking two times per week. Then, starting in the first week of May, 2009, the DBNPA soaking was mistakenly neglected for several weeks. The absence of DBNPA soaking set off a severe biofouling event which caued a rise in differential pressure (dP) in both trains and a loss of normalized flux. **Figure 5** shows that the increase in dP was gradual in both trains at first, however, after three or four days, the differential pressure in Train A with conventional spacer began an exponential increase in differential pressure while Train B, with chemically enhanced feed spacer continued a more gradual increase in differential pressure. Fifteen days into the biofoulng event and the differential pressure of the conventional spacer system had increased by 90% from its stable dP value. The system with chemically enhanced feed spacer elements increased in dP by only 30% during the same period.

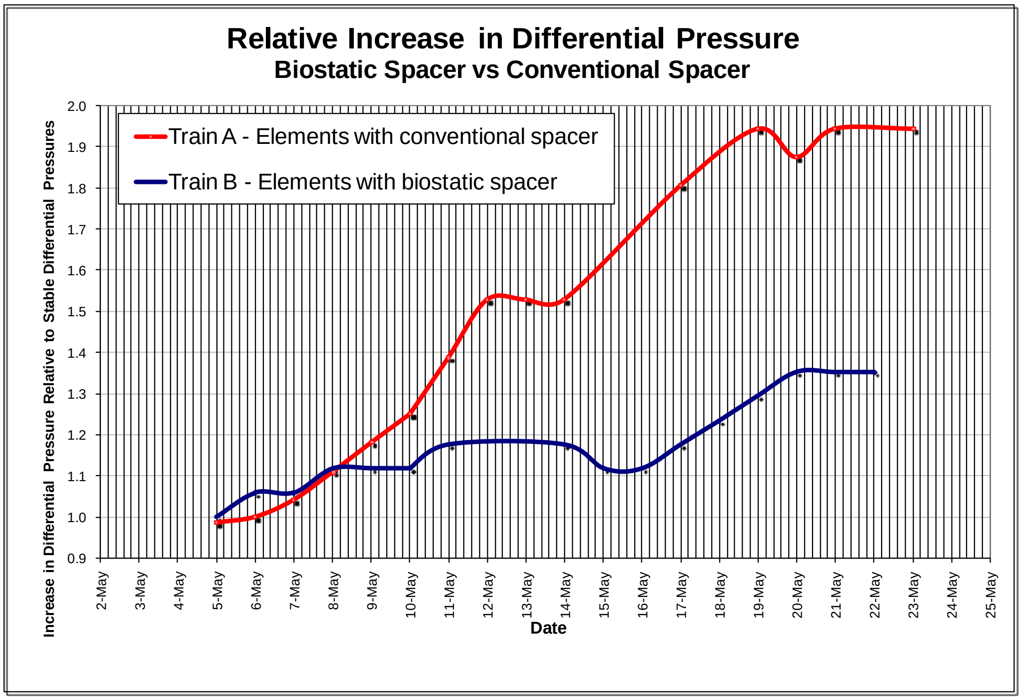


Figure 5. Relative increase in differential pressure of two RO trains running side by side during a severe biofouling event. Train A (red) operated with conventional spacer elements while Train B (blue) operated with a chemically enhanced spacer elements.

Fifteen days after the biofouling event began, the DBNPA flushes were reinstated, but had little effect on recovering performance. A high pH clean was performed on both trains, but had little effect. The biofouling had become too severe. At this point, the four lead elements (three with chemically enhanced spacer and one with conventional spacer) were removed from Train B and returned to the manufacturer for retest, autopsy, and analysis.

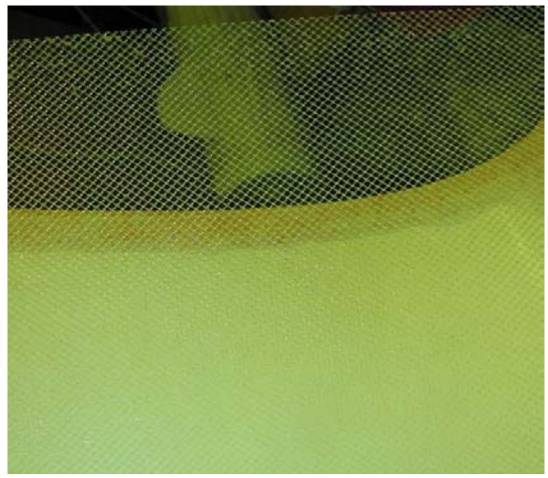
After draining off excess water, the elements were weighed to determine the mass of any biogrowth that may have accumulated in the elements. The typical weight of an unfouled, wet element is 35 lbs. The weight of the element operating in Train B containing chemically enhanced feed spacer was 36.2 lbs, indicating 1.2 lbs of biomass. The element with the conventional spacer weighed 41.5 lbs, suggesting that 6.5 lbs of biomass had accumulated in the element.

The returned lead elements were tested at a standard test condition of 225 psi and 15% recovery on a 1500 ppm NaCl feed solution. Flow, rejection and differential pressure losses were compared to their original performance. As expected, all elements increased in differential pressure, but the increase in dP of the element with the standard spacer was greater than the increase in dP of the element with the chemically enhanced feed spacer. The conventional spacer element had increased from 3.5 psid to 8.8 psid. The element with advanced spacer had increased from a 3.5 psid to 7.3 psid.

A similar side by side study was conducted on a system treating high fouling surface water. Two lead elements (one with conventional spacer and one with chemically enhanced feed spacer) were returned after six months of operation. The elements were autopsied and visually inspected. An examination of the brine spacer and the membrane surface of the element with conventional spacer revealed a slimy biofilm. More biofilm coated the lead portion of the element compared to the tail portion. **Figure 6 A** shows the lead portion of the autopsied element with conventional spacer as the spacer is being lifted away from the membrane surface. The biofilm is clearly seen in the membrane mesh.

In contrast, the element with chemically enhanced feed spacer was found to have very little biofilm. Both the membrane surface and the spacer mesh were free of significant biogrowth. As seen in **Figure 6 B**, the mesh is clear and the membrane surface below the mesh can be easily viewed through the mesh.

A



B

Figure 6. Autopsied membrane and from lead elements that had been operating side by side treating high biofouling surface water. One element A) with conventional spacer and one element B) with chemically enhanced spacer.

Conclusion

Fouling and cleaning are a common aspect of RO system operation. As more challenging waters are treated by RO and less capital is available for robust pretreatment, fouling becomes more severe and cleanings become more frequent. A new brine spacer has been developed to specifically reduce colloidal fouling and biological fouling. The thickness of the spacer has been increased from the standard 28 mil to a thicker 34 mil. The spacer has also been chemically enhanced with a biostatic agent. This combination of properties is important because fouling is often a complex event. It often has components that relate both to colloidal and to biologically active fouling mechanisms. This new advanced spacer has improvements in thickness, geometry and chemistry to help minimize the impact of complex fouling events. Both laboratory testing and field studies demonstrate the ability of the new brine spacer to reduce fouling, reduce differential pressure losses, and reduce the number of cleanings. Though the advanced spacer does not completely solve the fouling challenges associated with treating very difficult feedwaters, it can be used as one of several strategies in an effort to achieve more stable RO performance and reduce RO operating costs.