# New ASD Feed Spacer Geometry Reduces Power Consumption and Bioaccumulation

DR. CARSTEN SCHELLENBER AND DR. STEFAN LEHMANN
Lanxess Deutschland GmbH
Bitterfeld, Germany

ALAN D. SHARPE
Lanxess Sybron Chemicals, Inc.
Birmingham, NJ

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## ABSTRACT

Reverse Osmosis (RO) technology is commonly employed in industrial water applications. This desalination technique is often considered energy intensive. Improvements in feed spacer geometry have been shown to reduce the overall RO system energy consumption, reducing the operational costs on the order of 2 -5%. Further, changes in feed spacer geometry have been shown to reduce the incidence of bioaccumulation, reducing cleaning frequency, and possibly improving membrane lifetime.

## FEED SPACERS IN RO APPLICATION

RO membrane elements are typically offered in spiral wound configuration, consisting of three distinct sheets that carry the feed/ brine, transmembrane, and permeate. These sheets are common to all spiral wound RO membrane elements, and consist of: a feed channel spacer material, an RO membrane flat sheet (incorporating a PA barrier layer, polysulfone substrate, and a non-woven textile sheet), and a permeate carrier sheet (also called tricot). The feed spacer, or netting, provides vital separation between the membrane surfaces in a membrane envelop, or leaf, promoting turbulence and allowing feed water to flow through the membrane element, contacting the membrane surface. An RO element may have 20 to 30 leafs. Figure 1 shows a typical RO spiral wound element.

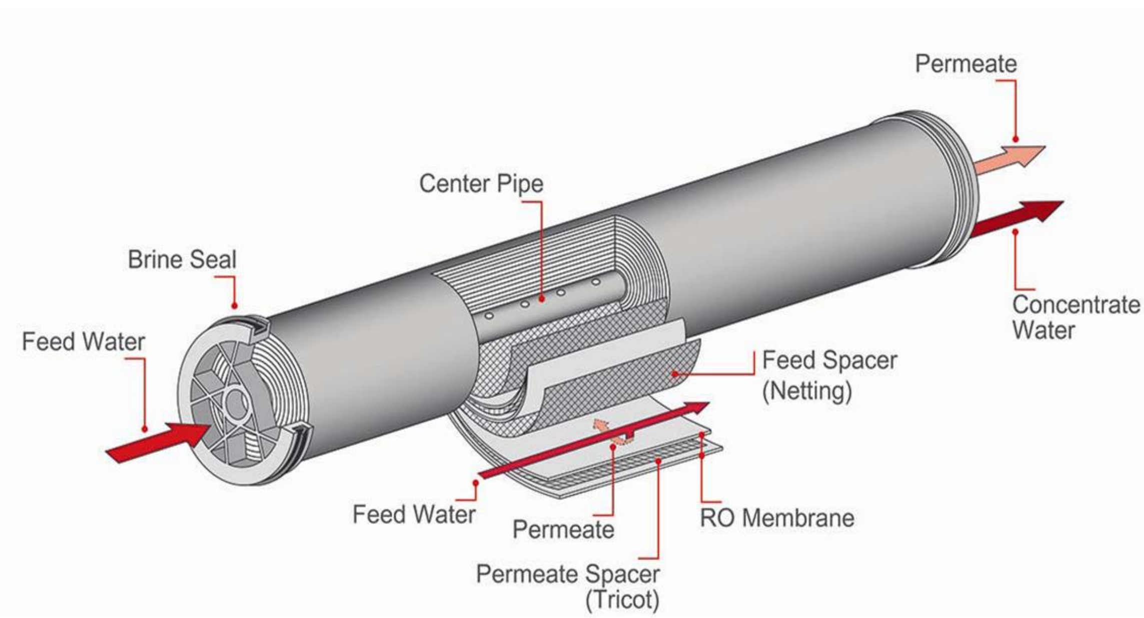


Figure 1: General construction of an RO element, showing the feed spacer

Most would agree that the development of new feed spacer technology has lagged the improvements in fundamental membrane performance. However, more recently, there has been a greater emphasis on improvements to the feed spacer within the RO element. Spacers have been introduced with, e.g. lower strands per inch, shapes more approximating rhomboids, strands prepared with biostatic agents as well as strands with a "bottleneck" spatial configuration.

## RO PROCESS AND ENERGY

RO is essentially a pressure-driven separation process. The pressure to drive the process is usually supplied via a high pressure pump. The pressures necessary to overcome the natural osmotic pressure of a solution can be quite high, for example, 60-70 bar in seawater application, and 10-15 bar in brackish water application. The power consumption to drive the RO process can amount to more than 30-45% of the total overall operating cost of the treatment process.

It is also important to recognize that innate membrane permeability plays a role in overall power consumption, and this is reflected in the feed pressure to the RO system. However, frictional pressure losses also play a role in the overall efficiency of the RO process. The frictional losses that occur in the piping from the high pressure pump to the inlet of the 1$^{st}$ stage of the RO system are pressure losses in the overall RO system. In addition, the pressure drop through the feed channel of each RO membrane element are also frictional pressure losses, and have a direct impact on the overall power consumption of the RO process.

It is well known that very clean feed water with low concentration of suspended matter is required for stable operation of RO membrane units. If the feed channel is clean, without particles that could block the feed water flow, the pressure drop across a single RO element is typically about 0.1 – 0.2 bar. In spiral 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 from 0.6 – 1.5 bar. In brackish applications, the RO systems are mainly configured as two stage systems, such that the combined pressure drop will be frequently in the range of 1.5 – 3 bar.

## FEED SPACERS, PRESSURE DROP, AND POWER CONSUMPTION

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 a feed channel with standard feed spacer are shown schematically on Figure 2. The feed channel is usually a rectangular opening of typically 0.7 – 0.86 mm in height. The presence of spacer or netting strands in the feed channel means that the actual cross section area open to the feed flow is smaller than the geometric cross section.

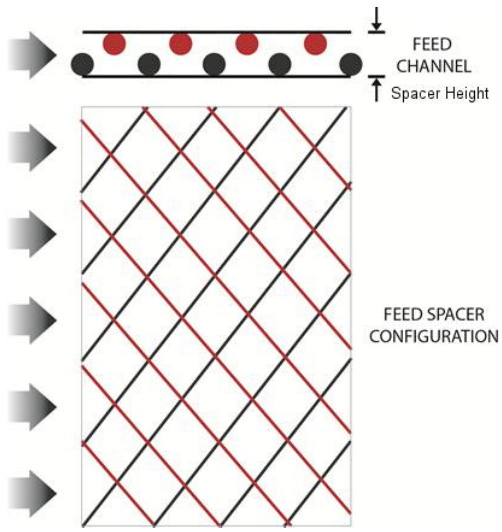


Figure 2: Flow through a standard feed spacer

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

The feed spacer has filaments or strands positioned in a bi-planar orientation. The bi-planar characteristic causes the feed stream to change flow direction, both above and below the subsequent filaments, promoting turbulence of the feed stream. The need for turbulence in the feed stream is related to a phenomenon known as concentration polarization which is common to all cross-flow membrane processes. This phenomenon occurs because the feed water and dissolved salts flow parallel to the membrane surface and only a fraction of the feed water passes through the membrane as permeate, leaving dissolved ions to accumulate at the membrane surface that form a kind of barrier to permeation and limit membrane performance. The feed spacer-induced turbulence reduces the extent of concentrate polarization. However, the induced turbulence increases friction in the feed channel, which is translated into pressure drop of the feed stream between the element feed and exit points.

The friction losses (or pressure drop) 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 typical efficiencies of feed pumps and motors). Accordingly, 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.

# OPTIMIZED FEED SPACER GEOMETRY USING ALTERNATING STRAND DESIGN (ASD)

Given the importance of power consumption in RO process, a project was initiated to develop a novel feed spacer configuration, reducing pressure losses. In a first step, basic feed spacer geometries were evaluated, using 3D printed samples and detailed CFD (computational fluid dynamics) calculations towards decreasing pressure drop and minimized low flow areas. Feed spacers using equal strands, alternating strands and bottleneck type strands were evaluated. The basic results of these calculations are summarized in Figure 3 and show that a structure of alternating (thick-thin) strand type feed spacers are well balanced with regard to pressure drop, with the added benefit of minimizing areas of low flow (discussed later). This research confirmed the enhanced pressure drop performance of feed spacer material based on the new alternating (thick thin) strand design. This technology is now designated “ASD”, standing for Alternating Strand Design.

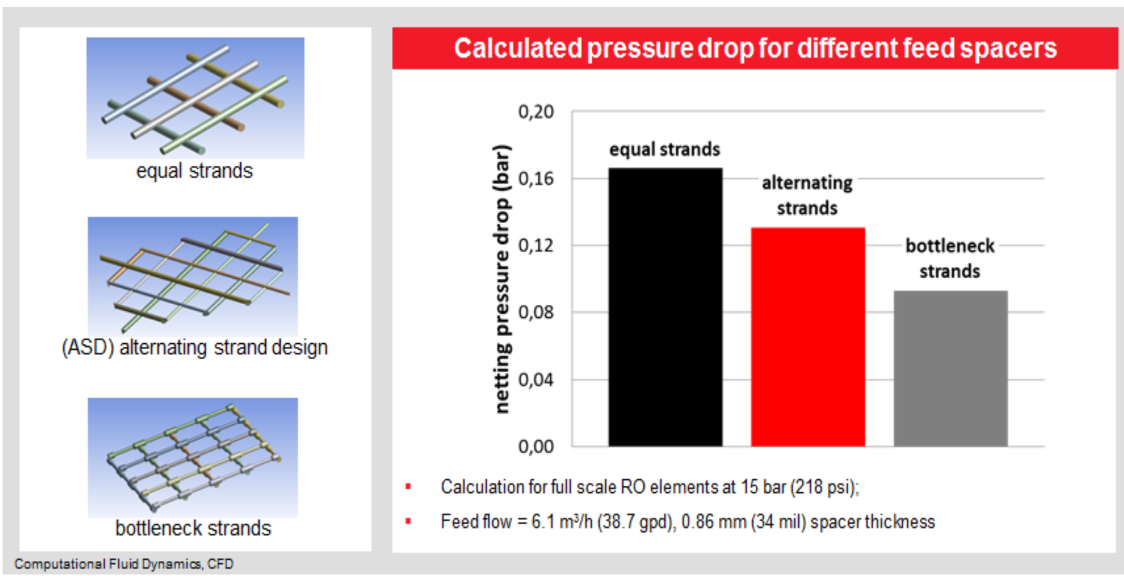


Figure 3: Calculated pressure drop for various spacer geometries by CFD

It has been found that the RO elements constructed with the alternating strand geometry do achieve a lower pressure drop than most other commercially available feed spacers. The performance for pressure drop was conducted on a variety of RO elements in process scale equipment, and suggests a reduction of approximately 0.05 to 0.15 bar per element at nominal flow rates. This comparison is presented in Figure 4. This lower pressure drop translates to an approximate 5% reduction in specific energy consumption. In addition, new ASD type spacer shows a finely tuned flow pattern resulting in reduced low flow areas (expected to reduce biofouling tendency). This reduced biofouling tendency can be seen as an improvement towards increased membrane life and lower cleaning frequency of RO membrane elements.

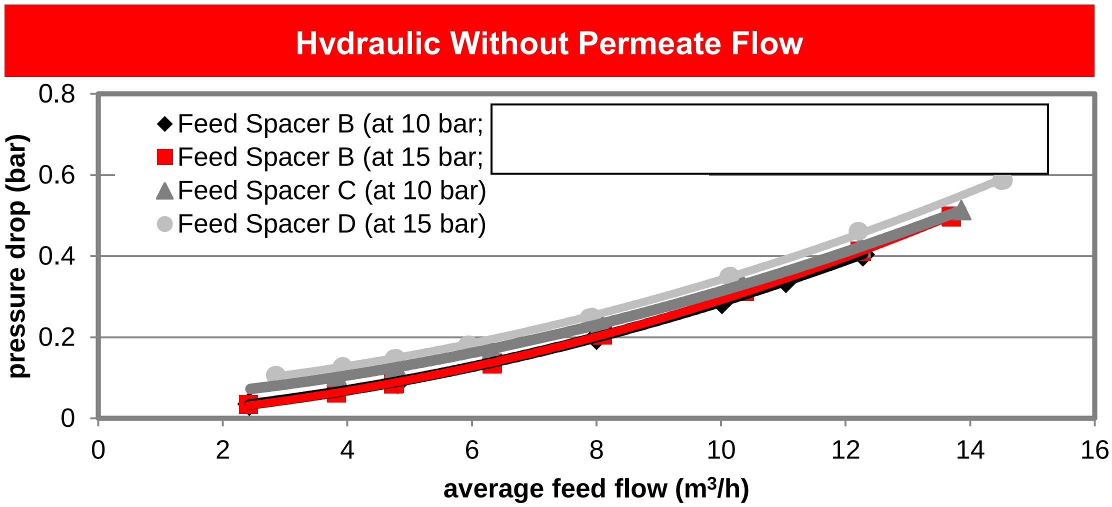


Figure 4: Comparison of pressure drop for elements using process scale equipment

## COST SAVINGS PROJECTIONS WITH ASD SPACERS AT A GERMAN TEST FACILITY

In October, 2015, the piloting of a prototype ASD membrane element was started at an industrial facility on the Elbe River in Germany. The piloting was conducted at a client using surface water (Elbe River) with a TDS of approximately 487 ppm. This facility uses flocculation and media filtration with sand as pretreatment feeding seven side by side trains producing approximately 385 $m^3$/day each of permeate. The RO system has a 2 stage system configuration using a 38:17 array with 7 elements per vessel and a 78% recovery.

The client was particularly inclined to pilot ASD technology as the energy saving projection suggested approximately 5% savings on power consumption with the change to ASD elements. This translated into an overall energy savings for the facility of approximately 2% and a cost savings of approximately 40,000 Euro/ yr. In addition, the switch to ASD elements also offered a small increase in overall permeate quality. The feed water analysis and cost savings detail are summarized in Figure 5.

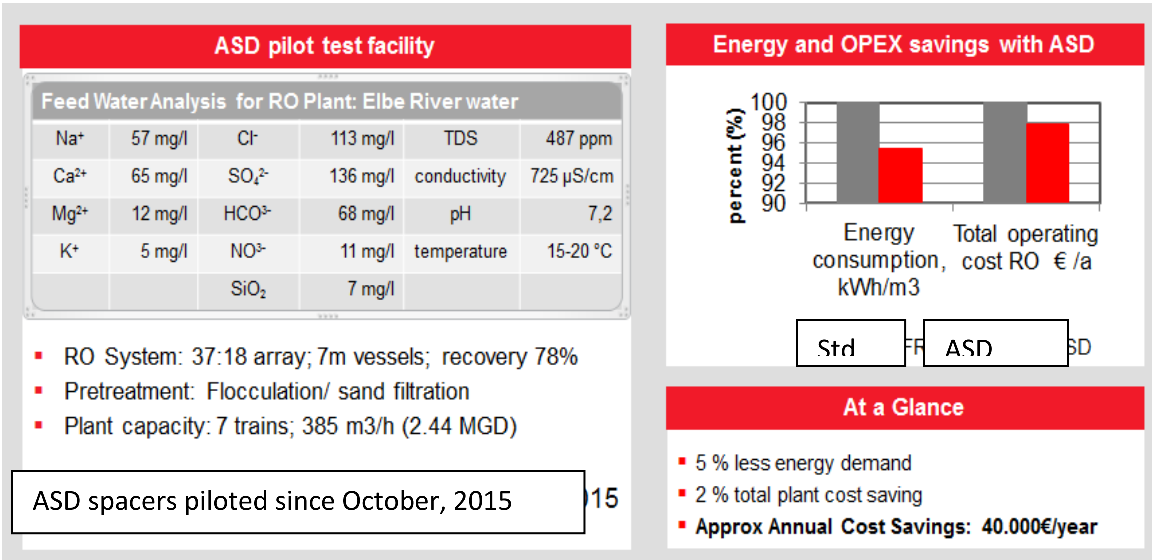


Figure 5: Cost savings projection using ASD spacer

The performance of the RO elements were checked periodically and confirmed the projection by the LewaPlus calculation software. This permeate quality meets the requirements for the downstream processes, and convinced the client in the performance of the ASD spacer and standard pressure RO elements.  Figure 6 represents the performance after six months in operation under real conditions of RO treatment.

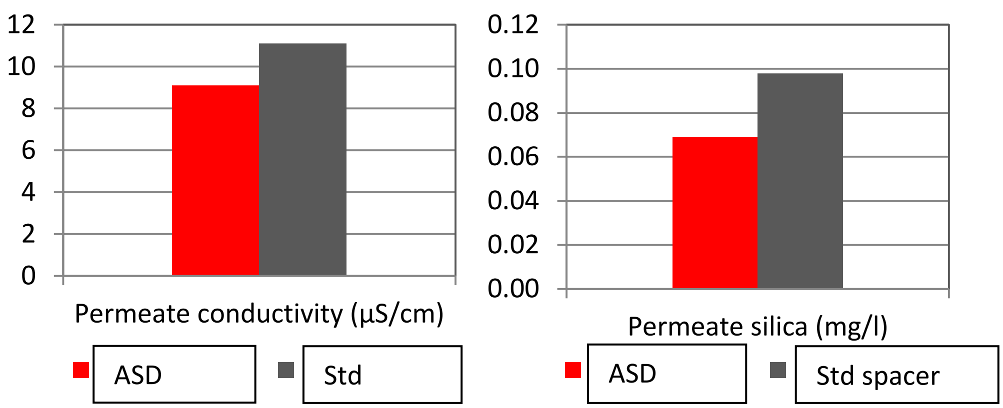


Figure 6: Performance of RO-elements regarding existing water analysis

## ADDITIONAL BENEFITS BEYOND LOWER PRESSURE DROP

It has been found that ASD type feed spacers offer lower pressure losses than most commercially available feed spacers, translating to lower power consumption in most RO systems. The savings were estimated at typically 2 -3 percent of the operating cost per annum. Additionally, it has been found that the unique spatial configuration of the ASD spacer minimizes areas of low flow in the feed channel, leading to less bioaccumulation and an improved fouling resistance.

## MINIMIZATION OF LOW FLOW AREAS

A recent study presented in the Journal of Membrane Science investigated several of the more common feed spacer configurations, and concluded that spatial configuration plays an important role in biofouling of the membrane element. In fact, this research concludes that the amount of biofilm correlates with pressure drop, and that feed spacer geometry has a direct impact on the structure and distribution of the biofilm in the spacer (1). The paper also concludes that the use of biostatic and metal coated materials were not effective in biofouling control (2).

Further, it is well known, especially in the ultra-pure water industry, that low flow, or stagnant, areas in process piping are a common source of biogrowth, and that reduction of low flow areas should reduce these mechanisms of bioaccumulation. To this end, the project conducted CFD analysis to study the distribution of low flow areas with differing spatial configurations of the feed spacer. The CFD analysis (Figure 7) confirms that the concept that alternating thick-thin strands, especially thin strands, within the spacer does minimize the extent of low flow areas.

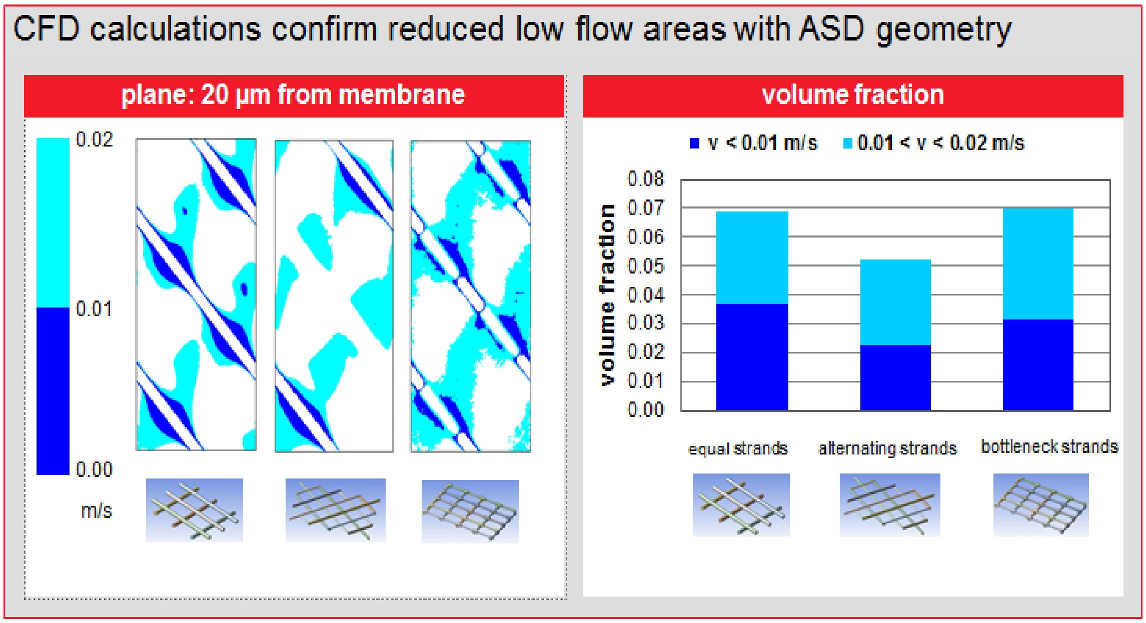


Figure 7: CFD calculation of low flow areas

## LOWER BIOACCUMULATION

The tendency for lower bioaccumulation can be seen using a newly developed, novel test method which is described in Reference 1. This method employs a dynamic flow-through test environment using a membrane cell tester with spacer, wherein a specific nutrient is dosed over a certain time period. After a defined period of time, the spacer is removed and tested for ATP (adenosine triphosphate) as biomass. ATP is considered a tracer for bioaccumulation, as it is a metabolite, and only present if secreted by living organisms. In this way, ATP measurement is a good proxy for assessing the bioaccumulation development over time.

In our tests, we compared the ATP development for five commercially available spacers over a 9- day incubation period. As can be seen from Figure 8, the ASD type spacer (Spacer C) exhibited the lowest amount of biomass accumulation over the 9-day period. In addition, spacers A and B, equal size strand spacers, exhibited higher levels of ATP development. Spacer B with fewer strands per inch was better than Spacer A in this test. Further, competitive spacers with either bottleneck strands or rhomboid strands (Spacers D and E) also performed with higher ATP development than the ASD type spacer.

**Biogrowth**

| feed spacer code | ATP ($10^{-5}$ pg/cm²) |
|---|---|
| A | 2.41 |
| B | 1.37 |
| C | 1.12 |
| D | 1.97 |
| E | 1.88 |

- lowest biofouling tendency for feed spacer C
- measuring biomass after nutrient dosing for 9 days (ATP adenosine triphosphate)

Lit.: The potential of standard and modified feed spacers for biofouling control, Araújo, P.; Kruithof, J.; Loosdrecht, M. V. & Vrouwenvelder J., Journal of Membrane Science , 2012, 403 - 404, 58 - 70

Figure 8: ATP development over a 9-day incubation with various spacers

Finally, the project also conducted additional tests for biomass accumulation. This time, the incubation period was increased to 90 days, the time for +15 percent pressure drop increase was measured, and the overall increase in pressure drop over the 90-day period was determined (see Figure 9). In all cases, the ASD type spacer offered the lowest pressure drop development, and the longest time for +15 percent pressure drop increase to occur. Again, it is thought that the minimization of low flow areas reduce, or inhibit the development of biomass.

**Pressure drop increase due to bioaccumulation**

| Feed Spacer Code | Δp increase after 90 days | Duration for Δp increase of 15 % |
|---|---|---|
| A (standard) | 54 % | 45 days |
| B (standard) | 60 % | 30 days |
| C (ASD) | 30 % | 65 days |
| D | 40 % | 45 days |
| E | 42 % | 30 days |

Figure 9: ATP development over 90 day incubation with various spacers

A WORD ABOUT POROSITY AND SMOOTHNESS

A separate analysis was conducted to evaluate the given porosity of certain feed spacers. The porosity is reasonably easy to calculate knowing the spacer height (34 mil), spacer length (40 inches), strand size and strand frequency (strands per inch). That is, each spacer has a fixed specification for the number of strands per inch, and average strand diameter which allows calculation of the inherent channel porosity, ε, by the equation presented in Figure 10.

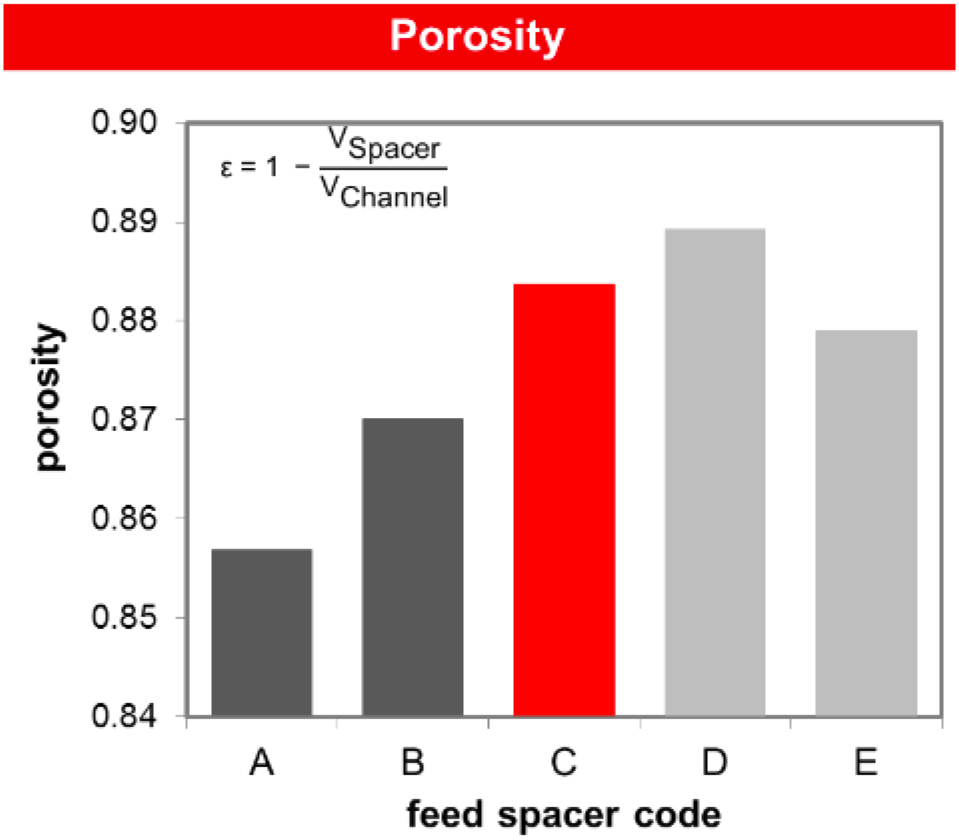


Figure 10: Calculated porosity of various feed spacers

The smaller strand diameter in the ASD type spacers increases the channel porosity vs. standard, equal type strand spacers. Further, the thin strand creates a more open structure at the membrane/ spacer interface allowing more effective movement of cleaning chemicals to critical areas, and movement of the foulants through the spacer to drain. The openness of this channel can be compared to equal strand type spacers in the microscopy presented in Figure 11. Note that the side view through the ASD channel shows high areas of grey – where polymer strands are not present in the spacer channel.

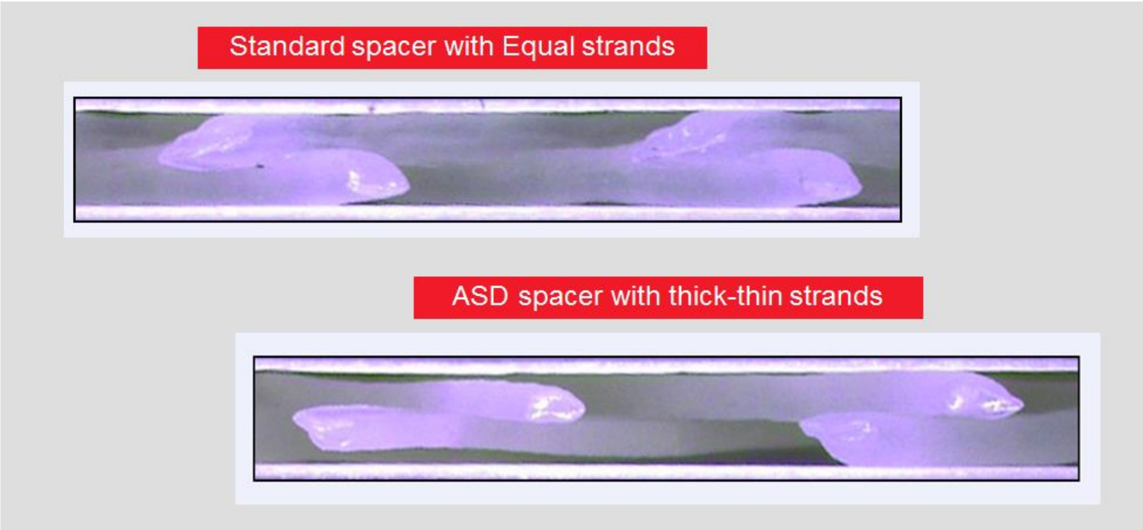


Figure 11: Side view of feed channel for ASD type and Equal strand type spacers

It is also useful to consider the importance of strand smoothness. This dimensionless property of the strand has impact in two important ways. First, a smooth strand improves the spacer to membrane surface contact which is important for maintaining membrane surface integrity during manufacturing. Finally, the smoothness of the spacer is often considered important to minimize the unintended capture of particles, dissolved organics, etc. in the bulk solution. Again, the smoother the spacer strand, the less tendency for capture, and the subsequent clogging of the feed spacer channel.

## SUMMARY

The ASD (Alternating Strand Design) feed spacer has demonstrated a lower pressure drop vs. more conventional spacer configurations, lowering power consumption and reducing operating cost in typical RO plants. The savings in power consumption is estimated at approximately 0.1 bar per RO element, and approximately 5% reduction in specific energy consumption. Additionally, the data suggests that the alternating (think-thin) strand design also minimize low flow areas within the feed channel, reducing bioaccumulation over time. The data suggest that ASD type spacers offer longer run times to a fixed increase in pressure drop, and slower pressure drop development. Further, the spatial orientation, porosity, and smoothness of the ASD strands may increase the time between periodic cleaning processes to recover performance.

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