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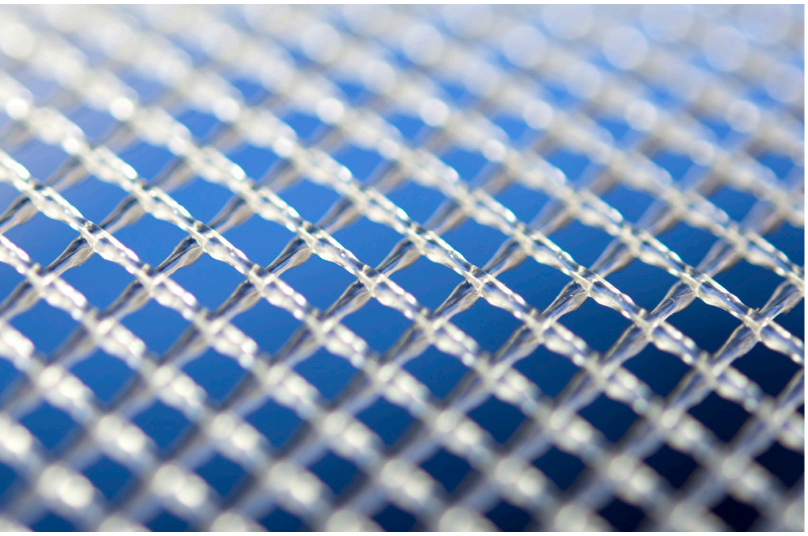

Effect of feed spacer on pressure drop and mass transfer.

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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 on Figure 1. The feed channel, shown here in unwrapped configuration, forms a rectangular opening of about 0.7 – 0.9 mm high. Due to the presence of spacer filaments (netting strands) in the feed channel, the actual cross section area open to the feed flow is smaller than the geometric cross section.[1]

The length of the feed channel is about 1 m (3.3 ft). The feed spacer net, filling the feed channel, has filaments or strands positioned biplanarly. The biplanar 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.

During operation of RO systems, the feed flow velocity in the feed channel is quite low, in the range of 1 – 3 cm/sec (0.4 – 1.2 inch/sec). This flow velocity falls into a laminar flow range and the required turbulence is facilitated by the presence of feed spacer net filaments.

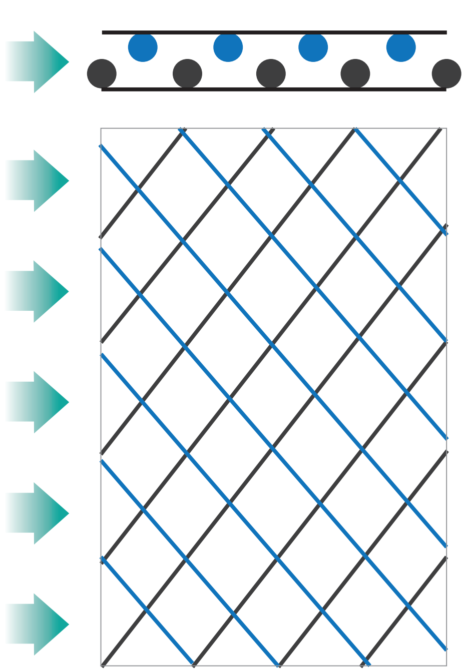

Figure 1. Configuration of a feed channel and a feed spacer net

The need for turbulence in the feed stream is related to the nature of the RO desalination process. The feed water and dissolve salts flow parallel to the membrane surface with fraction of the feed water passing through the membrane as a 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 extend 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 pressure drop over feed channel length (dp/dl) is a function of flow velocity (u), water density (ρ), hydraulic radius (d_h) and friction coefficient (f), according to Equation 1.

Equation 1

$$dp/dl = 2u^2 * \rho * f / d_h$$

The hydraulic radius of an empty feed channel is:

Equation 2

$$d_h = 4 * \text{cross section of flow channel/wetted circumference}$$

For a flat channel where height (h) is much smaller than width (b) the channel hydraulic radius can be approximate as:

Equation 3

$$d_h = 4 * b * h/(2 * (b + h)) \approx 2h$$

The value of the friction coefficient depends on the flow characteristics (Reynolds number) and the hydrodynamics of the feed spacer.[1, 2] The values of Reynolds numbers, calculated for flow velocity prevailing in RO applications are very low. Therefore, proper hydrodynamic configuration of feed spacer, that would promote mixing, at minimum increase of pressure drop, is very important for effective reduction of excess concentration at the membrane surface.[3]

The current configurations of feed spacers, used for construction of RO spiral wound elements, have been developed based on practical experimentation and fundamental studies.[4] The objective was to create condition of "mixing flow" even at the low flow velocities existing in the feed channels of the spiral wound membrane elements. Subsequent R&D works demonstrated importance of feed spacer filaments' geometry, and angular configuration as well as alignment of feed spacer with the direction of feed flow.[5]

Based on experimental results and hydraulic modeling, the configuration of feed spacer for RO applications evolved in to a biplanar 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 1). This configuration results in acceptable tradeoff 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 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 significantly 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 the membrane units.

If the feed channel is in clean condition, without particles that could block feed water flow, the pressure drop across a single element is about 0.1 – 0.2 bar (1.5 – 3 psi). 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 (9 – 22 psi). Seawater RO systems are configured as single stage units. RO systems for brackish applications are mainly configured as two stage units or even three stage units. Consequently, the combined pressure drop in brackish RO systems will be higher, frequently in the range of 1.5 – 3 bar (22 – 44 psi).

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.

Friction losses in the membrane element feed channels contribute to overall energy usage of the RO unit. Based on the common efficiencies of feed pumps and motors, each bar of pressure drop is equivalent to additional energy usage of about 0.025 kwhr/m^3 of product water produced (0.09 kwhr/kgallon). At the power rate of $0.1/kwhr, this translates to annual cost of $0.9/$m^3$ ($3.4/kgallon).

During system operation some feed born particles will deposit in the feed channels of the RO elements, contributing to increase of the pressure drop. The RO elements can be damaged by operation at very high pressure drop. Still, some RO systems will operate for long periods of time (between membrane elements cleanings) with pressure drop 50% to 100% higher than the initial pressure drop on system startup.

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.[6] Therefore, the use of feed spacer will develop lower pressure drop and result in smaller power usage of the RO plant over the length of the RO system operation.

SUMMARY

I. Feed spacer is an essential part of the spiral wound element configuration. The feed spacer's purpose is to maintain constant height of the feed channels and promote turbulence of the feed stream at the membrane surface.

II. Presence of spacer net filaments or strands in the feed channel constitutes obstruction to the feed flow inside the channel, which contributes to increase of pressure drop and increase of power usage of the RO desalination system.

III. Optimized configuration of feed spacer should result in effective mixing of the feed stream and maintaining low pressure drop during RO system operation.

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