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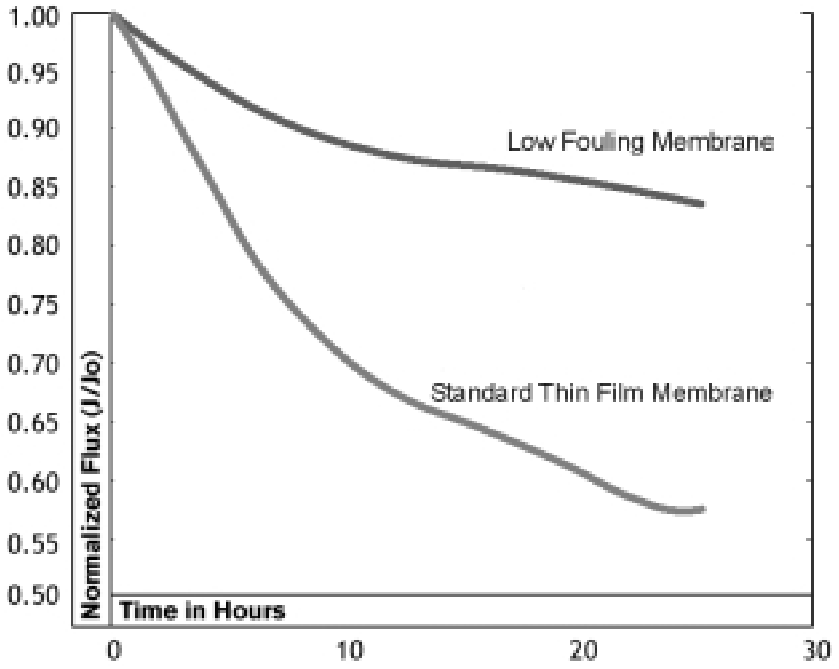
Membranes

Fouling and Cleaning

Membrane technology is widely accepted as a means of producing various qualities of water from surface water, well water, brackish water and seawater. Membrane technology also is used in industrial processes and industrial wastewater treatment, and lately membrane technology has moved into the area of treating secondary and tertiary municipal wastewater and oil field-produced water. In many cases one membrane process is followed by another with the purpose of producing water of increasing purity and quality for various purposes. Thus, one type of membrane may enhance the function of another to meet goals ranging from disposal of wastewater to production of drinking water from unexpected sources. In this way membrane technology offers the possibility of managing total water resources. The spiral wound membrane element configuration is the most widely used due to its high packing density and relatively low price. This article will describe some technological advances in the area of innovative new membranes and application concepts for spiral wound membrane elements.

Figure 1:
Occurence of Fouling in Membranes



Spiral Wound Elements

Spiral wound elements span the four commonly defined membrane technologies, which are microfiltration (0.01 to 10 microns), ultrafiltration (500 to 100,000 Dalton), nanofiltration (100 to 500 Dalton) and reverse osmosis (up to 100 Dalton). A sandwich consisting of two membrane sheets with an inserted permeate carrier is glued together and a feed spacer is inserted between the opposing membrane surfaces to complete the membrane package. The membrane package is wound around a perforated central tube through which the permeate exits the element. The physical shape of a membrane element is secured by applying a suitable outer wrap. The physical and chemical properties of the various materials including the membrane are chosen according to the operating parameters. The typical reverse osmosis elements have limitations with respect to temperature (45° C), pH value (2 to 10), silt density index (less than 3 SDI), chlorine (dechlorination mandatory) and several other parameters. This generally is acceptable for conventional pure water applications, but for more complex membrane applications these limitations must be diminished or removed.

Advanced materials and material science have been applied to the membranes, materials and construction of spiral wound elements. This effort has resulted in elements with improved operating parameters and wider areas of applications. Various new membrane applications have been made possible and there is no limit in sight, except that new applications must rest on a profitable foundation for the user. Scarcity of water, environmental requirements and the simple logic of reusing water instead of discharging it are conditions that call for increased use of membrane technology in a multitude of applications.

Membrane Fouling

Fouling of the membrane surface during operation diminishes the productivity of the membrane and, in the case of a continued fouling condition, causes the salt rejection to suffer. Fouling mainly stems from three sources, namely particles in the feed water, buildup of sparsely soluble minerals and byproducts of microorganism growth. All of these conditions require frequent cleaning, which is expensive and leads to shorter service life of the membrane elements. Especially when more than one fouling condition prevails, the membrane can be irreversibly fouled, in which case correction of the condition and replacement of the membrane elements is the only solution.

In general, the feed to membranes should not contain suspended solids, and adequate pretreatment of the feed is mandatory to a well-functioning membrane plant. The most common sparsely soluble minerals include silica, barium and contributors to hardness. Growth of microorganisms is most pronounced in the temperature range of 30 to 45° C, which ironically is the prevailing operating temperature for membrane plants in areas with warm climates.

There is only one way to avoid membrane fouling and resulting frequent cleaning procedures—to ensure adequate pretreatment of the feed and operate the membrane filtration equipment using parameters that do not produce fouling. Pretreatment needs to be designed to remove suspended solids in the feed. Normally, the combination of sand filters and depth filters will accomplish this goal. The water recovery and flux per area unit of membrane must be chosen to ensure that the crossflow over the membrane can remove the boundary layer—which forms at the surface of the membrane—at a rate faster than it is formed. Last but not least, the bacteriological conditions of the feed and in the plant must be controlled to prevent growth of microorganisms

Reverse Osmosis Membranes

Reverse osmosis membranes are sensitive to mineral fouling, which occurs when the solubility product of a material is exceeded in the boundary layer formed on the membrane surface during operation. The concentration in this boundary layer can be twice as high as in the bulk solution, if the crossflow of the feed stream is inadequate. Several ways have been suggested to diminish mineral fouling including various post-treatment methods to change the electrical charge of the membrane surface, which is then believed to repel certain species. However, only moderate success has been achieved following this avenue. The cellulose acetate membrane, which has largely been replaced by thin-film polyamide membrane, still seems to offer the best fouling resistance.[1] A recent study[2] suggests that the single most important factor in preventing mineral fouling, as well as fouling caused by microorganisms, is the smoothness of the membrane surface. The conclusion is that if there are no crevices in the surface of the membrane, no material will be deposited there, because the boundary layer formation becomes less pronounced, and the crossflow will be able to remove it at a faster rate than it can be deposited (see Figures 1 and 2).

Most reverse osmosis membranes in use today are thin-film polyamide membranes formed on top of another membrane, usually a polysulfone ultrafiltration or microfiltration membrane called a substrate. The surface morphology of the substrate determines the smoothness of the resulting membrane sandwich. A smoother and less fouling-prone membrane can be made by inserting an additional membrane layer between the polysulfone and thin-film layers or by designing a polysulfone membrane with a smooth surface to begin with. Both methods have proved their value through results in practical applications.

In some cases, naturally occurring water—for instance from artesian wells—has a temperature exceeding that which normally is considered feasible for reverse osmosis membranes. The water can be cooled down, often at great expense, to allow reverse osmosis treatment, but in most cases such projects fall by the wayside for economical reasons in areas where water is much needed. Lately, reverse osmosis elements tolerating operating temperatures up to 80° C have been developed and commercialized. Operating a reverse osmosis plant at temperatures in the 50° C to 80° C range also alleviates the risk of microorganism growth, which can cause severe fouling of the membrane surface. High temperature compatible elements offer the capability of operating a membrane plant at high temperature or sanitizing a plant occasionally at 90° C to keep microorganism growth under control.

Membrane Cleaning

Even if all possible measures have been taken to prevent membrane fouling, changes in the composition of the feed, breakthrough in the sand filter, production upsets and a host of other irregular operating conditions may result in membrane fouling. The fouling will, in most cases, be detectable as a gradual decrease in plant productivity and later as a gradual increase in the salt content of the permeate. If biofouling is the culprit, there almost always will be a marked increase in bacterial count in the concentrate and, in severe cases, the permeate will show unacceptably high bacterial counts. It is important to recognize the symptoms and to take action at the earliest possible time. A detailed log of the plant operation and analysis of the production parameters helps to identify a problem situation at an early stage before the problems become severe. If fouling is allowed to develop, cleaning becomes much more difficult.

If fouling occurs in a membrane filtration plant, regularly or as an exception, two goals must be accomplished. The cause of the problem must be identified and corrected, or the same fouling situation simply will reoccur. Then there is the problem of choosing a suitable cleaning regimen to bring the plant back on line, operating at or close to the design capacity.

The most effective cleaning method in the case of biofouling is an oxidizing agent such as chlorine, hydrogen peroxide and peracetic acid. Cellulose acetate membranes tolerate oxidizing agents, but the more popular thin-film polyamide reverse osmosis membranes do not. Of nonoxydizing cleaners for biofouling situations formaldehyde, glutaraldehyde and quaternary ammonium compounds may be used for polyamide membranes. If the fouling is caused by intracellular byproducts from microorganisms, various enzymatic cleaning agents have proved to be effective.

In the case of mineral fouling, chemical cleaning agents are used. Acid generally will remove inorganic salts. Cellulose acetate membranes do not tolerate low or high pH values, whereas polyamide membranes generally can be cleaned down

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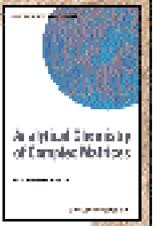
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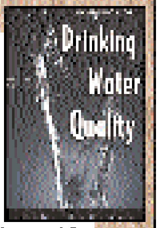
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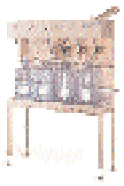
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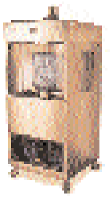
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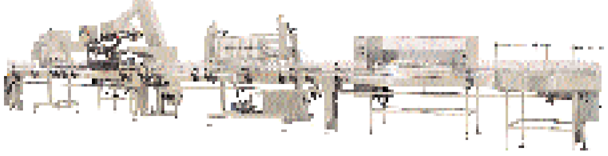
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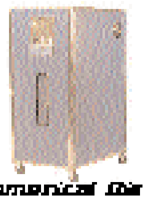
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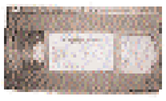
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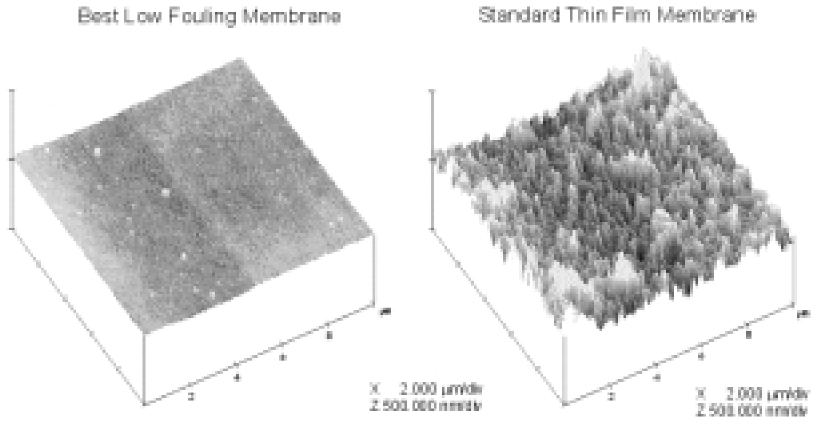
Figure 2:
Membrane Design Helps Prevent Fouling



to pH 2. Acetic acid, which also is a complexing agent for some metals, often is used with good results. Complexing agents like quaternary ammonium compound operate better at elevated pH values, which renders them of little use for cellulose acetate membranes.

Membrane technology has undergone a rapid development as it pertains to most applications, in particular, as it pertains to water purification. The last 20 years have witnessed new membranes working at ever lower pressures and with increasing salt rejection from the original cellulose acetate membrane requiring 400 psi (28 bar) to modern polyamide thin-film membranes requiring only 100 psi (7 bar) net driving pressure. Salt rejection of the reverse osmosis membranes has increased from 97.0 to 99.5 percent with some special membrane types exhibiting even higher salt rejections. Are we nearing the end of the possible, and will we have to accept today's standards in the future?

The answer is that membrane technology will continue to develop with huge benefits for the user of membrane filtration equipment for water purification. Material science and molecular modeling are some of the tools that are used in the advancement of membrane technology. Net driving pressures will continue to decrease. Salt rejection will continue to increase, although it already is close to 100 percent. Resistance of membrane materials to oxidizing agents will increase to the point that cleaning with chlorine is possible. The tolerance for solvents and other aggressive chemicals will be improved. In short, the end is not in sight, and membranes will claim an increasing role in water purification to the advantage of the thirsty humanity. **WQP**

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