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Commercial RO membranes and modules

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12.1 Introduction

The semipermeable membranes for nanofiltration and reverse osmosis applications consist of a film of polymeric material composed of a skin layer several thousands angstroms thick and spongy supporting layer approximately 0.025–0.050 mm (0.001–0.002″) thick, cast on a polyester non woven fabric support. The overall thickness of membrane is 0.15–0.20 mm (0.06–0.08″). The schematic configuration of membrane layers is shown in Fig. 12.1. Scanning electron microscopy (SEM) picture of cross section of composite polyamide membrane is shown in Fig. 12.2.

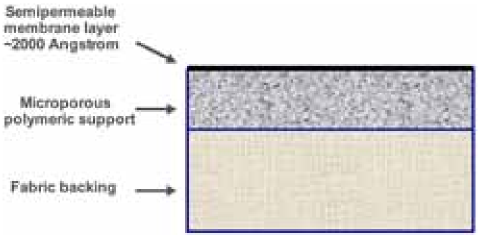

FIG. 12.1 Schematic diagram of cross section of flat sheet RO membrane.

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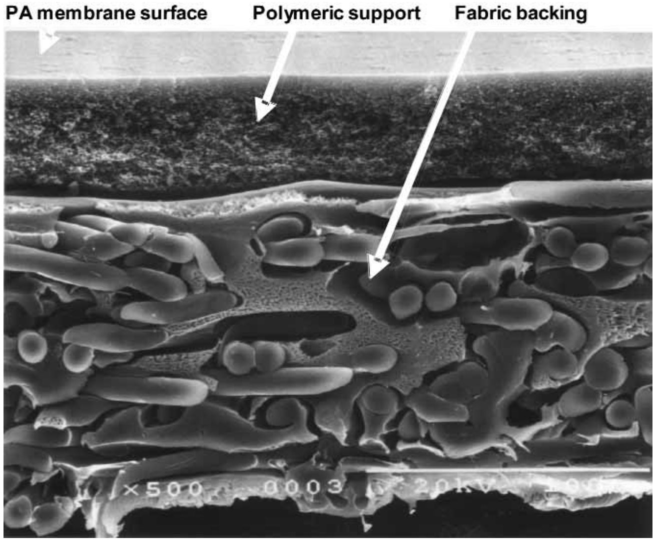

FIG. 12.2 SEM picture of cross section of cross section of commercial flat sheet composite RO membrane.

The commercial grade RO membrane must have high water permeability and a high degree of semipermeability; that is, the rate of water transport must be much higher than the rate of transport of dissolved ions. The membrane material must be stable over a wide range of pH and temperature, and have good mechanical integrity. The stability of membrane performance: permeability and salt rejection, over a period of operation at field conditions defines the commercially useful membrane life, which is, for the current commercial membranes, in the range of 5 to 10 years.

The reverse osmosis technology started in 1950's with cellulose acetate developed by Loeb and Sourirajan (1). Latter on, a composite membrane, based on aromatic polyamide, has been introduced by Cadotte in early eighties (2). The performance of composite membrane gradually improved and the composite polyamide membrane eventually replaced cellulose acetate products in majority of all commercial applications, due to significantly higher permeability and higher salt rejection. Evolution of performance of performance of brackish RO membranes is shown in Fig. 12.3.

Another reason for replacing cellulose acetate membranes with composite polyamide product was its ability to tolerate wide range of pH. Compared to cellulose acetate material, the aromatic polyamide membrane is very durable

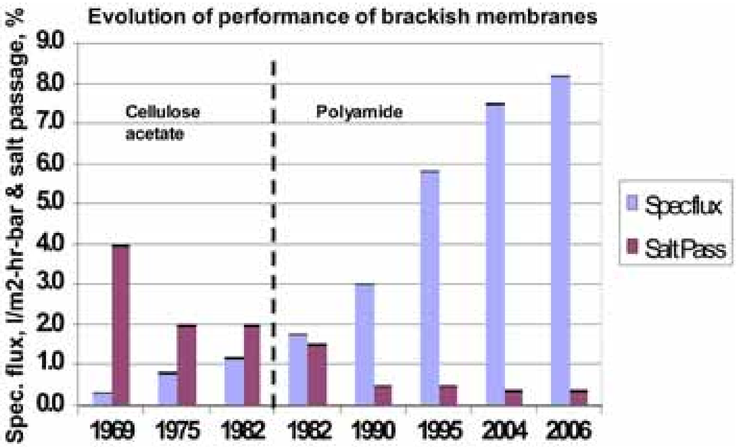

FIG. 12.3 Evolution of water permeability and salt passage of commercial brackish RO membranes.

and has much higher tolerance for exposure to acidic and basic solutions. Therefore, cleaning solutions, at extreme pH, could be applied for effective foulants removal. Chemical structure of aromatic polyamide is shown in Fig. 12.4.

The tolerance of polyamide membrane barrier material to exposure of oxidants is much lower than the cellulose acetate membranes. Therefore in applications that require presence of free chlorine in feed water (some application in pharmaceutical and food industry), composite polyamide membranes can not be used. For the above niche applications, cellulose acetate membranes are still being utilized. In applications involving reduction of salinity levels in municipal effluents, RO systems equipped with polyamide membranes, employ low level of chloramines to control biological activity. Details of this procedure are provided in subsequent chapters discussing design and operation of RO units in wastewater reclamation systems.

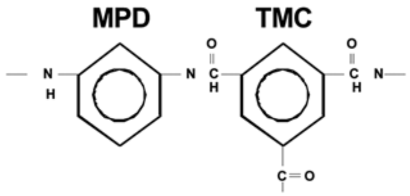

FIG. 12.4 Chemical structure of aromatic polyamide membrane barrier polymer.

12.2 Manufacturing of composite polyamide membranes

The manufacturing process of composite polyamide membranes consists of two distinct steps (Fig. 12.5). First, a polysulfone support layer is cast onto a non-woven polyester fabric. The process of application of polysulfone and formation of ultrafiltration membrane (UF) is shown schematically on Fig. 12.6. The polysulfone polymer solution is applied from a trough onto a moving polyester backing fabric. After polysulfone application and formation of UF membrane layer the fabric travels through water bath to remove solvent and is collected on a drum.

The polysulfone membrane layer is very porous and is not semipermeable; i.e., it does not have the ability to separate water from solution of dissolved ions. However, it has high water permeability (low resistance to permeate cross flow). It serves as structural support for the semipermeable polyamide membrane barrier.

In the next process step, the drum with polysulfone membrane is moved to the second machine where interfacial polarization takes place (Fig. 12.7). There, a semipermeable membrane skin is formed on the polysulfone substrate by interfacial polymerization of two monomers, one: metaphenylenediamine (MPD) containing amine groups and the other: trimesoyl chloride (TMC) provides carboxylic acid chloride functional groups. The polymerization reaction is

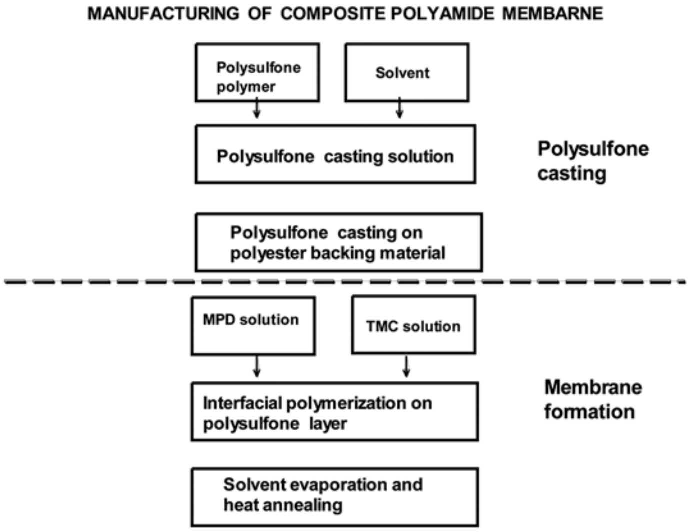

FIG. 12.5 Manufacturing sequence of flat sheet composite polyamide membrane.

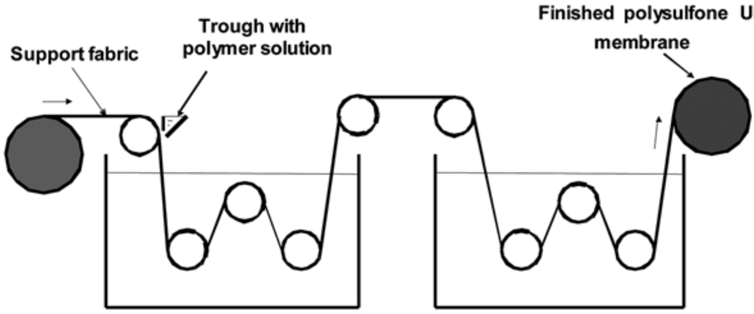

FIG. 12.6 Schematic diagram of manufacturing of polysulfone membrane support.

very rapid and takes place on the surface of the polysulfone support forming a barrier, 1000–2000 angstrom thick. This barrier is responsible for the semipermeable property: passage of water and rejection of dissolved species. Following polymerization zone, membrane web enters a rinse bath. The membrane is rinsed to remove excess reagents and passed trough the oven to dry (2).

This manufacturing procedure enables independent optimization of the distinct properties of the membrane support and salt rejecting barrier. The resulting composite membrane is characterized by higher specific water flux and low salt passage.

The polyamide membrane formed has very rough surface (Fig. 12.8), it is slightly negatively charged and has hydrophobic character. Some membrane manufacturers apply coating of hydrophilic compounds, such as derivatives of polyvinyl alcohol, to increase hydrophilic property of membrane surface.

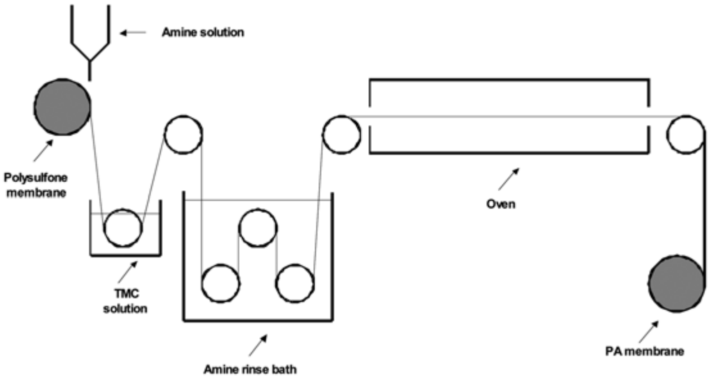

FIG. 12.7 Schematic diagram of manufacturing process of formation of polyamide membrane barrier on a polysulfone support.

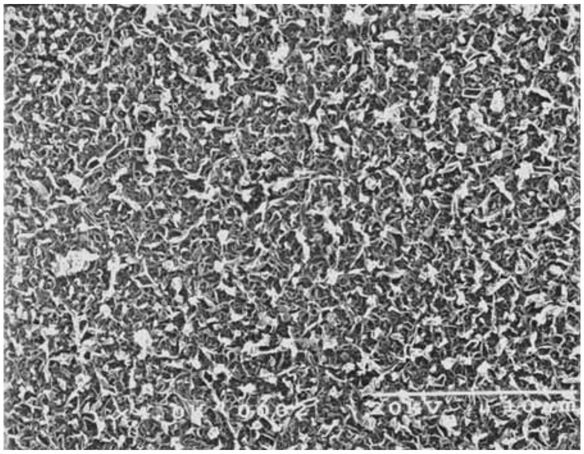

FIG. 12.8 SEM picture of surface of aromatic polyamide membrane.

The offering of commercial membranes made of composite aromatic polyamide includes seawater, brackish and nanofiltration membrane elements. Composite membranes are used in all areas of applications: seawater and brackish water desalting, potable water softening, wastewater reclamation, food processing and other industrial applications.

12.3 Other membrane materials

Membranes made of aromatic polyamide are characterized by high salt rejection. For some applications, which involve partial salinity reduction and/or removal of selective contaminants, membranes with low rejection rate and high water permeability are preferred. These membranes, called "loose RO or nanofiltration (NF) membranes, utilize sometimes different type of membrane barrier polymer. In some cases, the aromatic 1,3-benzenediamine is being replaced by cyclic piperazine to react with trimesoyl chloride. The structure of the membrane barrier polymer formed in such reaction is shown in Fig. 12.9. The piperazine based membrane can be manufactured as high permeability membrane in wide range of salt rejection. In some cases the salt rejection property of these membranes can be tailor to preferentially reject a group of contaminants.

Another type of high permeability, low rejection membrane is based on polyether sulfone polymer. The membrane surface of this type of membrane is relatively smooth (Fig. 12.10) and has strong negative charges

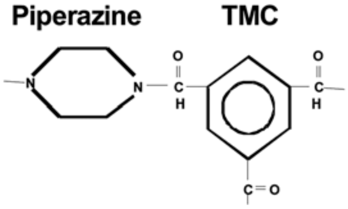

FIG. 12.9 Chemical structure of semi-aromaticpolyamide membrane barrier polymer.

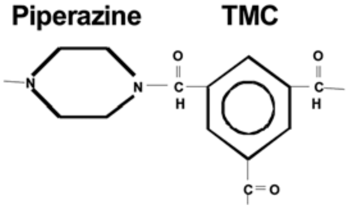

FIG. 12.9 Chemical structure of semi-aromaticpolyamide membrane barrier polymer.

The PES membrane, offered by Hydranautics as NTR- 7450 or HydraCore, has very low salt rejection but very high rate of removal of color forming organic compounds (3).

Both the piperazine and PES based membranes can be exposed to free chlorine, or other strong oxidants, for significant period of time, without affecting their performance.

12.4 Plate and frame configuration

Application of reverse osmosis process requires packaging of membrane into a device that would provide high membrane area packing rate and allow for convenient separation of feed, permeate and concentrate streams. The configuration of the membrane device should facilitate high turbulence in the feed channels allow application of high feed pressure without damaging membrane barrier. The reverse osmosis technology started with tubular and plate and frame configurations. Due to low packing density, these initial module configurations were gradually phased out of potable applications and at present are being very seldom used in conventional reverse osmosis applications. However, new configurations of plate and frame modules are still being used in industrial applications such as food processing, recovery of valuable chemicals and for treatment of waste streams including land fill leaches. In the past, the two major membrane module configurations used for reverse osmosis applications were hollow fiber and spiral wound. At present, majority of RO membrane manufactures offer elements in spiral wound configuration only.

The plate and frame configuration has been introduced at the early stages of development of reverse osmosis technology (8) and latter on almost abandon in favor of higher packing density spiral wound and hollow fiber configurations. Today the plate and frame modules are still used in applications where spiral wound and hollow fiber modules cannot provide sufficient reliability or performance. These include treatment of streams with high concentration of suspended solids. One of such applications is reduction of volume of land fill leachate (4). In modern plate and frame configuration, the flow regime provides turbulent flow and short feed flow path. Therefore, the propensity for membrane scaling or fouling is significantly reduced in this type of membrane element configuration, allows operation at very high recovery rate (5). Another variation of plate and frame configuration is vibratory shear enhanced device (6). In this configuration stack of plate and frame cells is continuously vibrated during separation process. Vibration of the device substitutes for high cross flow rate reducing formation of foulant layer on the membrane surface. This approach reduces energy consumption and enables operation with very low hold up volume. This property is very important in processing high value constituents, conditions common in biotechnology industry. Due to high cost of membrane module and low membrane packing rate, the plate and frame configurations are not used in commercial potable applications.

12.5 Hollow fine fiber membrane elements

The concept of hollow fine fiber (HFF) configuration module has been introduced by Mahon (7) in early sixties. The HFF configuration utilizes semipermeable membrane in the form of hollow fibers which have been extruded from cellulosic or non-cellulosic materials. The fiber is asymmetric in structure and is as fine as a human hair, about 40–80 micron (0.0016–0.0030 inch) I.D. and 85–150 micron (0.0033–0.060 inch) O.D. Millions of these fibers are formed into a bundle. Because of very close packed fibers and tortuous feed flow inside the module, hollow fiber modules require feed water of better quality (lower concentration of suspended solids) than the spiral wound module configuration.

In the past, the hollow fiber modules were used mainly for desalting of seawater. Today number of system using hollow fiber RO modules is very limited. Due to fouling susceptibility of the conventional hollow fiber configuration, these module types are not used for desalting of municipal wastewater.

12.6 Spiral wound elements configuration

The concept of spiral wound membrane element device was introduced shortly after the invention of the hollow fiber configuration (8). In a spiral wound configuration two flat sheets of membrane are separated with a permeate collector channel material to form a leaf. The leaf assembly is sealed on three sides with the fourth side left open for permeate to exit (Fig. 12.11). A feed/brine spacer material sheet is added to the leaf assembly. A number of these assemblies or leaves are wind around a central plastic permeate tube. The permeate tube is perforated to collect the permeate from the multiple leaf assemblies (Fig. 12.11). During the element assembly process membrane leaves are rolled around the permeate tube in a spiral configuration (Fig. 12.12). The membrane leaves are kept in this form with a tape wrapped around the element. Additional structural strength is provided by the outer shell, which is usually made of fiber reinforced epoxy resin.

The typical commercial spiral wound membrane elements are approximately 1000 or 1500 mm (40 or 60 inches) long and 200 mm (8 inches) in diameter. (Fig. 12.13). The feed/brine flow through an element is in a straight

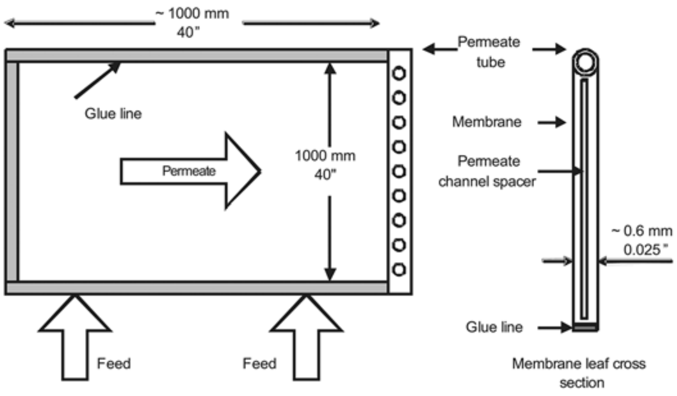

FIG. 12.11 Configuration of flat sheet membrane leaf.

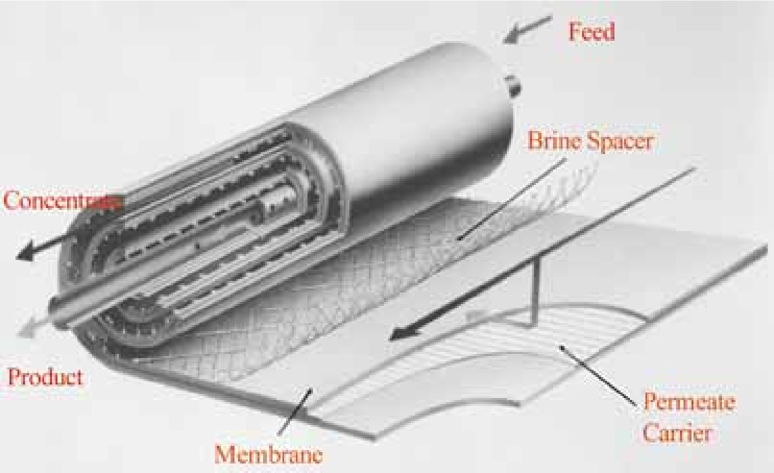

FIG. 12.12 Configuration of spiral wound membrane element.

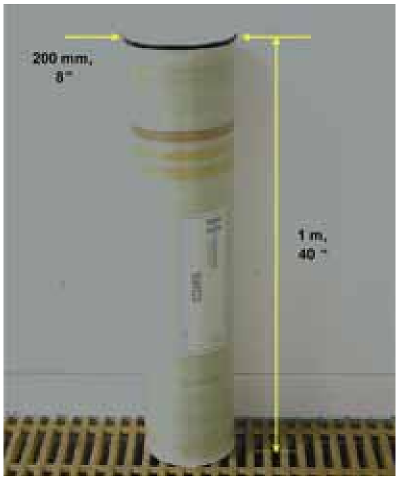

FIG. 12.13 Commercial spiral wound membrane element, 200 mm diameter, 1000 mm long (8″ × 40″).

axial path from the feed end to the opposite brine end, running parallel to the membrane surface. Fraction of the feed permeates through the membrane and flows through the permeate carrier fabrics to the central permeate tube. The remaining fraction of feed water continue to flow through the feed channel and becomes a concentrate (Fig. 12.12). The feed channel spacer is in the form of a

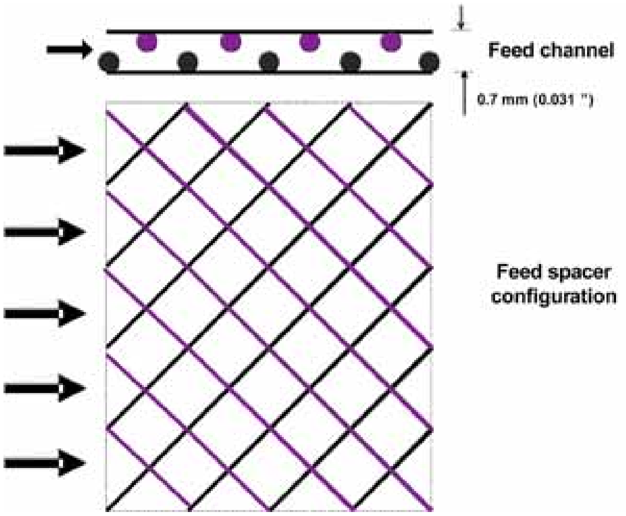

FIG. 12.14 Configuration of feed-brine spacer in a spiral wound element.

two level (biplanar) net. The strands in each level are parallel and crossing at about 90 degree strands in the other level (Fig. 12.14). This two level net separates membranes from adjacent leaves and induces turbulence in the feed stream to reduce concentration polarization. The thickness of the feed channel is in the range of 0.7–09 mm (0.028–0.034″). However, the cross section of feed channel open to flow is much smaller, due to the presence of feed spacer.

Membrane manufacturers specify feed–concentrate flow rate requirements to control concentration polarization by limiting permeate recovery rate (conversion rate) per element to 10–20 percent. Therefore, the recovery rate is a function of the feed-brine path length.

In order to operate at acceptable recoveries, spiral systems are usually staged with six to eight membrane elements connected in series in a pressure vessel (Fig. 12.15). The concentrate stream from the first element becomes the feed to the following element, and so on for each element within the pressure vessel.

Each element contains brine seal, which is in the form of flexible u-cup ring, usually position at the front end of element. The brine seal seals the space between the element outer wall and inner wall of the pressure tube. Brine seal prevents feed water to bypass the element, which would otherwise result in low flow through element and high recovery rate. Concentrate stream from the last element exits the pressure tube to the next processing stage or to waste. The

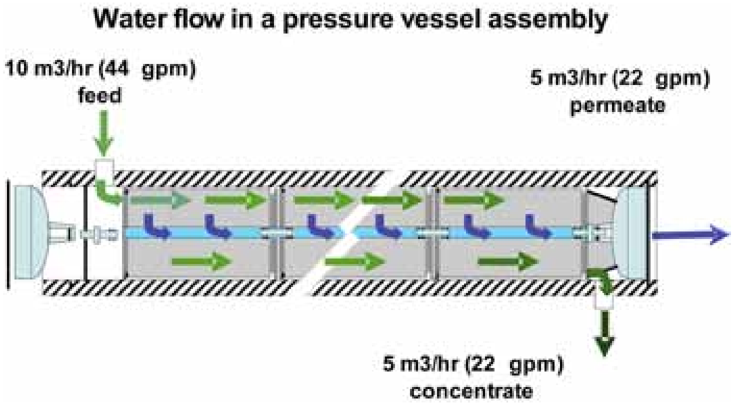

FIG. 12.15 Schematics of configuration and hydraulic operation of a pressure vessel (courtesy R. Chmielewski–SPI).

permeate tubes of each element are connected to adjacent element through permeate interconnector, forming a common permeate tube. The first and the last element in the pressure vessel is connected through an adaptor to the pressure vessel permeate outlet. Permeate from all elements in the pressure vessel exits the vessel as a common permeate stream. A single pressure vessel with six to eight membrane elements connected in series can be operated at up to 50–70 percent recovery under normal design conditions.

The dimensions and geometry of spiral wound membrane elements is highly standardized. Spiral wound membrane elements produced by various manufacturers are of very similar configuration and outer dimensions. They could be operated in the same pressure vessels and are easily interchangeable. More recently a committee composed of representatives of major manufacturers of spiral wound elements has been evaluating feasibility of large scale commercial production of large diameter (> 200 mm, 8″) elements (9). The conclusion of the evaluation was that the optimum size of the future large elements should be 406 mm diameter by 1016 mm long (16″ Φ by 40″ L). Compared to 200 mm (8″) diameter elements, that have between 37–41 m^2 (400–440 ft^2) membrane area, the 406 mm (16″) diameter elements could be manufactured with 125–165 m^2 (1350–1800 ft^2) membrane area. In wastewater applications, 200 mm diameter membrane element, operating at an average flux rate of 19 $l/m^2/hr$ would provide permeate output of about 17 m^3/day. (4500 gpd). At the same conditions a 406 mm diameter element would produce 67 m^3/day (17,500 gpd).

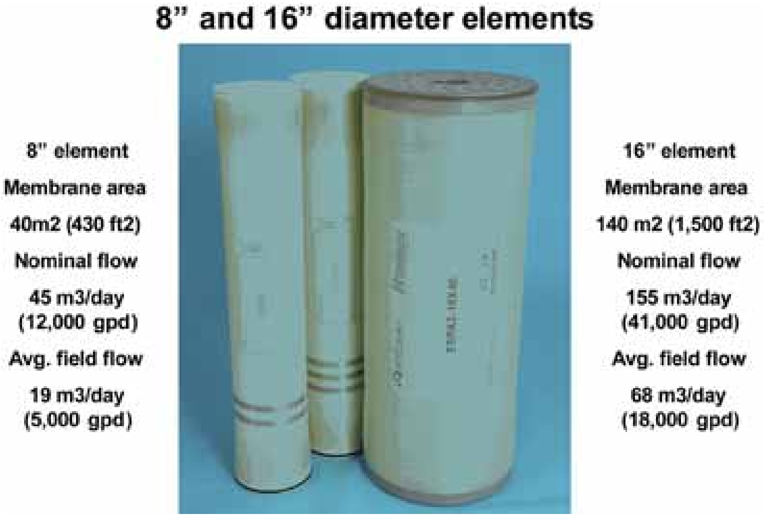

FIG. 12.16 Spiral wound 1000 mm (40″) long 200 mm and 406 mm (8″ and 16″) diameter elements.

Presently, number of major membrane manufacturers offer large diameter membrane elements, which are used in small to medium size RO units in wastewater reclamation (10) and seawater applications (11).

12.7 Spiral wound element categories

The three main application categories, listed in the order of increasing feed salinity and operating pressure range, are nanofiltration, brackish and seawater desalination. Membrane elements in a spiral wound configuration, designated for different application categories, have the same external dimensions and are manufactured from the same materials of construction, including chemistry of membrane polymer. The major differentiators are intrinsic membrane performance: water permeability and salt passage, which are the highest for nanofitration membranes and lowest for seawater elements. Difference of properties of water and salt transport are mainly result of adjustment of manufacturing process parameters, during formation of polyamide membrane barrier.

Membranes that belong to different categories differ in their nominal performances that are determine at standardized test conditions. The representative test conditions for determination of nominal membrane performance are listed

TABLE 12.1
Test condition for determination of nominal membrane elements performance

Membrane type	Nanofiltration	Low pressure brackish	Regular pressure brackish	Seawater
Feed salinity, ppm NaCl	500–2000[1]	500–2000	1500–2000	32000
Feed water temperature °C	25	25	25	25
Feed pressure, bar (psi)	3–5 (45–75)	5–10 (75–150)	15.5 (225)	56 (800)
Recovery rate, %	15–25	15	15	8–10

[1] 2000 ppm of $MgSO_4$ feed solution is used for testing of some types of nanofiltration elements.

in Table 12.1. The nominal element performance are used as reference data for projecting system performance at field conditions. Testing at standard test conditions are applied as part of manufacturing QC procedure and also for determination elements performance level after period of field operation.

Membranes used for wastewater reclamation applications belong mainly to brackish categories, either regular brackish elements or so called "low fouling" type. The low fouling type elements have permeability and salt transport property similar to brackish products. The "low fouling" designation usually refers to condition of membrane surface that is either smother, more hydrophilic or less negatively charged as compared to regular brackish membranes. The "fouling resistant" designation usually indicates that surface of membrane or feed spacer contains compounds that contains biogrow suppression property.

According to technical information published by membrane manufacturers (12) and results of pilot and commercial plants operation, such modifications of membrane surface properties result in lower fouling rate during treatment of effluents with high concentration of organic matter (13, 14). Application of additional coating on the membrane surface usually results in some decrease of water permeability, as compared to uncoated membrane (15).

The representative properties and nominal performance of nanofiltration, brackish and low fouling membrane elements are listed in Table 12.2, 12.3 and 12.4.

At present, nanofiltration membranes are used very infrequently for treatment of tertiary municipal effluent. Salt rejection of nanofiltration membranes is usually not sufficient to provide required reduction of salinity. However, it

TABLE 12.2

Representative nominal performance of nanofiltration (softening) membrane elements.

Element model	HydraCore	ESNA-LF	SU620F	NF-90	NF-270
Element dimensions	1m L × 0.2 m Φ (40″ × 8″)	1m L × 0.2 m Φ (40″ × 8″)	1m L × 0.2 m Φ (40″ × 8″)	1m L × 0.2 m Φ (40″ × 8″)	1m L × 0.2 m (40″ × 8″)
Membrane area, m^2 (ft^2)	36.8 (400)	36.8 (400)	36.8 (400)	36.8 (400)	35 (380)
Permeate flow, m^3/d (gpd)	31.0 (8,200)	29.5 (7,800)	22.0 (5,800)	38.8 (10,000)	47.3 (12,500)
Salt rejection, %	50.0	80.0	55.0	97.0*	97.0*
Test feed pressure, bar (psi)	5.2 (75)	5.2 (75)	3.4 (50)	4.8 (70)	4.8 (70)
Test feed salinity, ppm NaCl	500	500	500	2000*	2000*
Test recovery rate, %	15	15	15	15	15
Test flux rate, l/m^2/hr (gfd)	34.9 (20.5)	33.2 (19.5)	24.7 (14.5)	42.5 (25)	55.9 (32.9)
Permeability, l/m^2/hr/bar (gfd/psi)	7.6 (0.31)	7.3 (0.29)	8.6 (0.35)	11.9 (0.48)	15.8 (0.63)
Relative salt transport value (Flux × SP)	17.4 (10.2)	6.6 (3.9)	11.1 (6.5)	1.3 (0.8)	1.7 (1.0)

*Na_2SO_4 used as a test solution

could be expected that in the future use of nanofiltration membranes in this application may increase. There is growing concern about presence in wastewater effluents of trace concentrations of micropolutants, including pharmaceutical and personal care compounds. Membrane separation processes could be applied for reduction of the above contaminants, and for treatment of low salinity wastewater effluents, nanofiltration would be a suitable technology.

The membrane elements that are commonly applied for treatment of wastewater effluents are high water permeability brackish membranes or low fouling type. The primary objective of applying RO technology is reduction of salinity. The RO process could provide additional benefits of general reduction of all dissolved constituents. However, if the treated effluent has low salinity and only reduction of specific constituents is required, usually other treatment methods

TABLE 12.3

Representative nominal performance of brackish membrane elements.

Element model	ESPA2+	ESPA4+	TMG20-430	BW30LE440	BW30LE-440
Element dimensions	1m L × 0.2 m Φ (40″ × 8″)	1m L × 0.2 m Φ (40″ × 8″)	1m L × 0.2 m Φ (40″ × 8″)	1m L × 0.2 m Φ (40″ × 8″)	1m L × 0.2 m Φ (40″ × 8″)
Membrane area, m^2 (ft^2)	39.5 (430)	39.5 (430)	39.5 (430)	40.5 (440)	40.5 (440)
Permeate flow, m^3/d (gpd)	41.6 (11,000)	49.2 (13,000)	41.6 (11,000)	48.0 (12,700)	48.0 (12,700)
Salt rejection, %	99.60	99.20	99.50	99.0	99.3
Test feed pressure, bar (psi)	10.3 (150)	6.7 (100)	7.6 (110)	6.7 (100)	10.3 (150)
Test feed salinity, ppm NaCl	1500	500	500	500	2000
Test recovery rate, %	15	15	15	15	15
Test flux rate, l/m^2/hr (gfd)	43.5 (25.6)	51.4 (30.2)	43.5 (25.6)	49.1 (28.9)	49.1 (28.9)
Permeability, l/m^2/hr/bar (gfd/psi)	4.9 (0.20)	8.2 (0.33)	6.2 (0.25)	7.8 (0.31)	5.9 (0.24)
Relative salt transport value (Flux × SP)value	0.174 (0.102)	0.205 (0.121)	0.218 (0.128)	0.491 (0.289)	0.344 (0.202)

rather than RO are capable to achieve treatment objectives at a lower cost then it is possible with RO technology.

The nominal performances are determined during testing of individual elements at nominal test conditions (Table 12.1). The nominal test conditions include feed salinity (as NaCl solution), feed pressure, recovery rate and temperature (25°C). At field conditions, where operating parameters are significantly different then the conditions during the factory tests, the elements are operating at a different performance level. However there is a direct relation between the nominal performance of individual elements and performance of RO unit. RO industry developed relations that enable accurate prediction of performance of RO unit based on nominal element data. In subsequent chapters method of calculations will be explained and illustrate through calculation examples.

TABLE 12.4

Representative nominal performance of low fouling (LF) and fouling resistant (FR) membrane elements.

Element model	LFC1	LFC3	BW30-400-FR	BW30-400-FR	TML20-400
Element dimensions	1m L × 0.2 m Φ (40″ × 8″)	1m L × 0.2 m Φ (40″ × 8″)	1m L × 0.2 m Φ (40″ × 8″)	1m L × 0.2 m Φ (40″ × 8″)	1m L × 0.2 m Φ (40″ × 8″)
Membrane area, m^2 (ft^2)	36.8 (400)	36.8 (400)	36.8 (400)	33.9 (365)	36.8 (400)
Permeate flow, m^3/d (gpd)	41.6 (11,000)	36.0 (9,500)	39.7 (10,500)	36.0 (9,500)	38.6 (10,200)
Salt rejection, %	99.5	99.7	99.5	99.5	99.70
Test feed pressure, bar (psi)	15.5 (225)	15.5 (225)	10.3 (150)	10.3 (150)	15.5 (225)
Test feed salinity, ppm NaCl	1,500	1,500	2,000	2,000	2,000
Test recovery rate, %	15	15	15	15	15
Test flux rate, l/m^2/hr (gfd)	46.8 (27.5)	40.5 (23.8)	44.5 (26.2)	44.2 (26.0)	43.3 (25.5)
Permeability, l/m^2/hr/bar (gfd/psi)	3.3 (0.13)	2.9 (0.12)	5.4 (0.22)	5.3 (0.21)	3.2 (0.13)
Relative salt transport value	3.3 (0.13)	2.9 (0.12)	5.4 (0.22)	5.3 (0.21)	3.2 (0.13)

The nominal performances of membrane elements listed in table 12.2 through 12.4 are difficult to compare directly. The one reason being is that the nominal test conditions are somewhat different for different model elements. The test conditions differ even for the elements listed in the same application category. The membrane performance parameters that provide some insight into expected performance of membrane elements in field conditions are water permeability (specific flux) and relative salt transport value. Method of calculation of specific flux is illustrated in Example 11.10. The permeability is indicative of the required feed operating pressure of RO unit. High permeability will results in low feed pressure required for a given flux rate during the initial system operation period. During the course of field operation, the permeability usually would change due to fouling and/or membrane compaction.

Results of specific permeability listed in Tables 12.3 and 12.4 indicate that nominal values are lower for low fouling membrane than for the regular brackish, most likely due to additional resistivity of the hydrophilic surface coating. However, if the coating will result in lower absorption of organics and lower rate of permeability decline, the end result could be lower operating pressure for systems equipped with low fouling membranes. Usually, verification of low fouling property requires operation of pilot unit.

Relative salt transport value (RSTV), listed in Table 12.2–12.4, is calculated as a product of flux rate (l/m^2/hr) and salt passage (%). The result actually expresses solute transport but through a simpler calculations then the conventional approach. RSTV provides indication what would be relative permeate salinity produced by different membrane elements if operate at the same conditions. Membranes with low RSTV value will produce permeate of low salinity. The RSTV value could be used as an indicator for selection of high rejecting brackish membranes.

For low rejecting nanofiltration membranes, the situation is more complicated. In addition to nominal salt rejection, due to high passage rate, the actual permeate salinity will depend strongly on the ions composition in the feed water. Presence in feed water of high concentration of ions that are poorly rejected (bicarbonate) will result in high permeate salinity, as the more mobile ions pull the counter ions through the membrane to maintain neutral charge balance at the both sides of the membrane (16). On the other hand, high fraction of highly rejected ions (sulfate) in feed water will result in lower permeate salinity then it could be expected according to the nominal salt rejection. Projecting of permeate composition in nanofiltration systems is rather complex process, heavily based on empirical results and extrapolations.

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