Commercial RO Technology

The semipermeable membrane for reverse osmosis applications consists of a thin film of polymeric material several thousand Angstroms thick cast on a fabric support. The commercial grade 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 must be stable over a wide range of pH and temperature, and have good mechanical integrity. The stability of these properties over a period of time at field conditions defines the commercially useful membrane life, which is in the range of 3 to 5 years. There are two major groups of polymeric materials which can be used to produce satisfactory reverse osmosis membranes: Cellulose Acetate (CAB) and Composite Polyamide (CPA). Membrane manufacturing, operating conditions, and performance differ significantly for each group of polymeric material.

CELLULOSE ACETATE MEMBRANE

The original cellulose acetate membrane, developed in the late 1950's by Loeb and Sourirajan, was made from cellulose diacetate polymer. Current CA membrane is usually made from a blend of cellulose diacetate and triacetate. The membrane is formed by casting a thin film acetone-based solution of cellulose acetate polymer with swelling additives onto a non-woven polyester fabric. Two additional steps, a cold bath followed by high temperature annealing, complete the casting process.

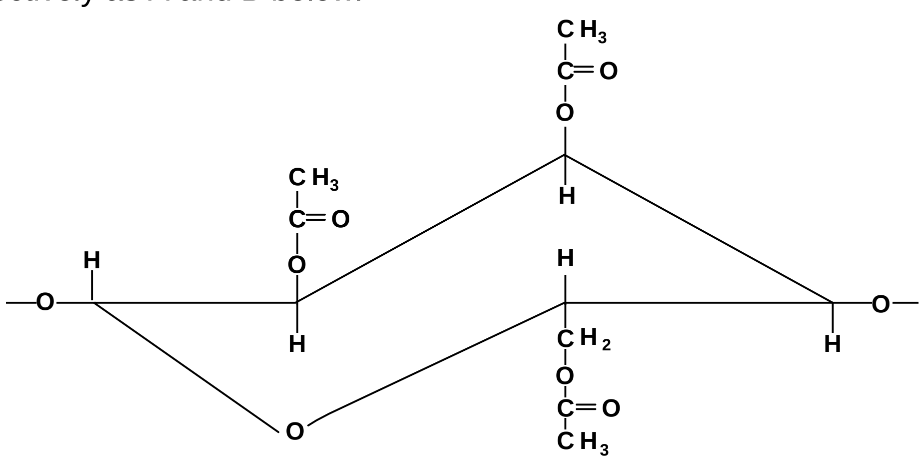
During casting, the solvent is partially removed by evaporation. After the casting step, the membrane is immersed into a cold water bath which removes the remaining acetone and other leachable compounds. Following the cold bath step, the membrane is annealed in a hot water bath at a temperature of 60 - 90° C. The annealing step improves the semipermeability of the membrane with a decrease of water transport and a significant decrease of salt passage. After processing, the cellulose membrane has an asymmetric structure with a dense surface layer of about 1000 - 2000 A (0.1 - 0.2 micron) which is responsible for the salt rejection property. The rest of the membrane film is spongy and porous and has high water permeability. Salt rejection and water flux of a cellulose acetate membrane can be controlled by variations in temperature and duration of the annealing step.

COMPOSITE POLYAMIDE MEMBRANES

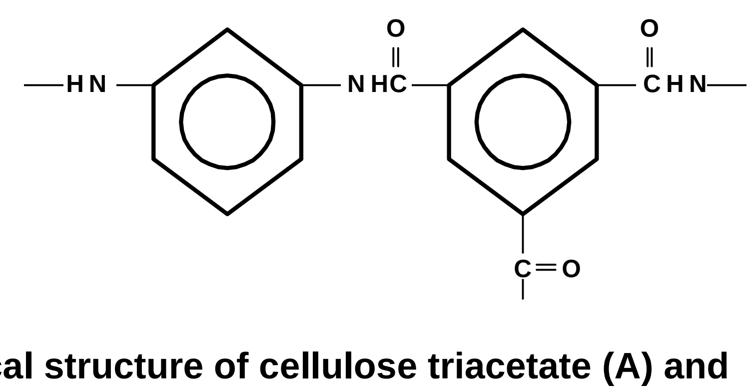
Composite polyamide membranes are manufactured in two distinct steps. First, a polysulfone support layer is cast onto a non-woven polyester fabric. The polysulfone layer is very porous and is not semipermeable; that is it does not have the ability to separate water from dissolved ions. In a second, separate manufacturing step, a semipermeable membrane skin is formed on the polysulfone substrate by interfacial polymerization of monomers containing amine and carboxylic acid chloride functional groups. This manufacturing procedure enables independent optimization of the distinct properties of the membrane support and salt rejecting skin. The resulting composite membrane is characterized by higher specific water flux and lower salt passage than cellulose acetate membranes. Polyamide composite membranes are stable over a wider pH range than cellulose acetate membranes. However, polyamide membranes are susceptible to oxidative degradation by free chlorine, while cellulose acetate membranes can tolerate limited levels of exposure to free chlorine. Compared to a polyamide membrane, the surface of cellulose acetate membrane is smooth and has little surface charge. Because of the neutral surface and tolerance to free chlorine, cellulose acetate membranes will usually have a more stable performance than polyamide membranes in applications where the feed water has a high fouling potential, such as with municipal effluent and surface water supplies.

The structures of cellulose acetate and polyamide polymer are shown respectively as A and B below.

A



B



Chemical structure of cellulose triacetate (A) and polyamide (B) membrane material

MEMBRANE MODULE CONFIGURATIONS

The two major membrane module configurations used for reverse osmosis applications are hollow fiber and spiral wound. Two other configurations, tubular and plate and frame, have found good acceptance in the food and dairy industry and in some special applications, but modules of this configuration have been less frequently used in reverse osmosis applications.

HOLLOW FINE FIBER (HFF) MEMBRANES

This configuration uses membrane in the form of hollow fibers which have been extruded from cellulosic or non-cellulosic material. The fiber is asymmetric in structure and is as fine as a human hair, about 42 micron (0.0016 inch) I.D. and 85 micron (0.0033) inch) O.D. Millions of these fibers are formed into a bundle and folded in half to a length of approximately 120 cm (4 ft). A perforated plastic tube, serving as a feed water distributor is inserted in the center and extends the full length of the bundle. The bundle is wrapped and both ends are epoxy sealed to form a sheet-like permeate tube end and a terminal end which prevents the feed stream from bypassing to the brine outlet.

The hollow fiber membrane bundle, 10 cm to 20 cm (4 to 8 inches) in diameter, is contained in a cylindrical housing or shell approximately 137 cm (54 inches) long and 15 - 30 cm (6 - 12 inches) in diameter. The assembly is called a permeator. The pressurized feed water enters the permeator feed end through the center distributor tube, passes through the tube wall, and flows radially around the fiber bundle toward the outer permeator pressure shell. Water permeates through the outside wall of the fibers into the hollow core or fiber bore, through the bore to the tube sheet or product end of the fiber bundle, and exits through the product connection on the feed end of the permeator.

In a hollow fiber module, the permeate water flow per unit area of membrane is low, and therefore, the concentration polarization is not high at the membrane surface. The net result is that hollow fiber units operate in a non-turbulent or laminar flow regime. The HFF membrane must operate above a minimum reject flow to minimize concentration polarization and maintain even flow distribution through the fiber bundle. Typically, a single hollow fiber permeator can be operated at up to 50-percent recovery and meet the minimum reject flow required. The hollow fiber unit allows a large membrane area per unit volume of permeator which results in compact systems. Hollow fiber perimeters are available for brackish and seawater applications.

Membrane materials are cellulose acetate blends and aramid (a proprietary polyamide type material in an anisotropic form). 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.

SPIRAL WOUND MEMBRANES

In a spiral wound configuration two flat sheets of membrane are separated with a permeate collector channel material to form a leaf. This assembly is sealed on three sides with the fourth side left open for permeate to exit. A feed/brine spacer material sheet is added to the leaf assembly. A number of these assemblies or leaves are wound around a central plastic permeate tube. This tube is perforated to collect the permeate from the multiple leaf assemblies. The typical industrial spiral wound membrane element is approximately 100 or 150 cm (40 or 60 inches) long and 10 or 20 cm (4 or 8) inches in diameter.

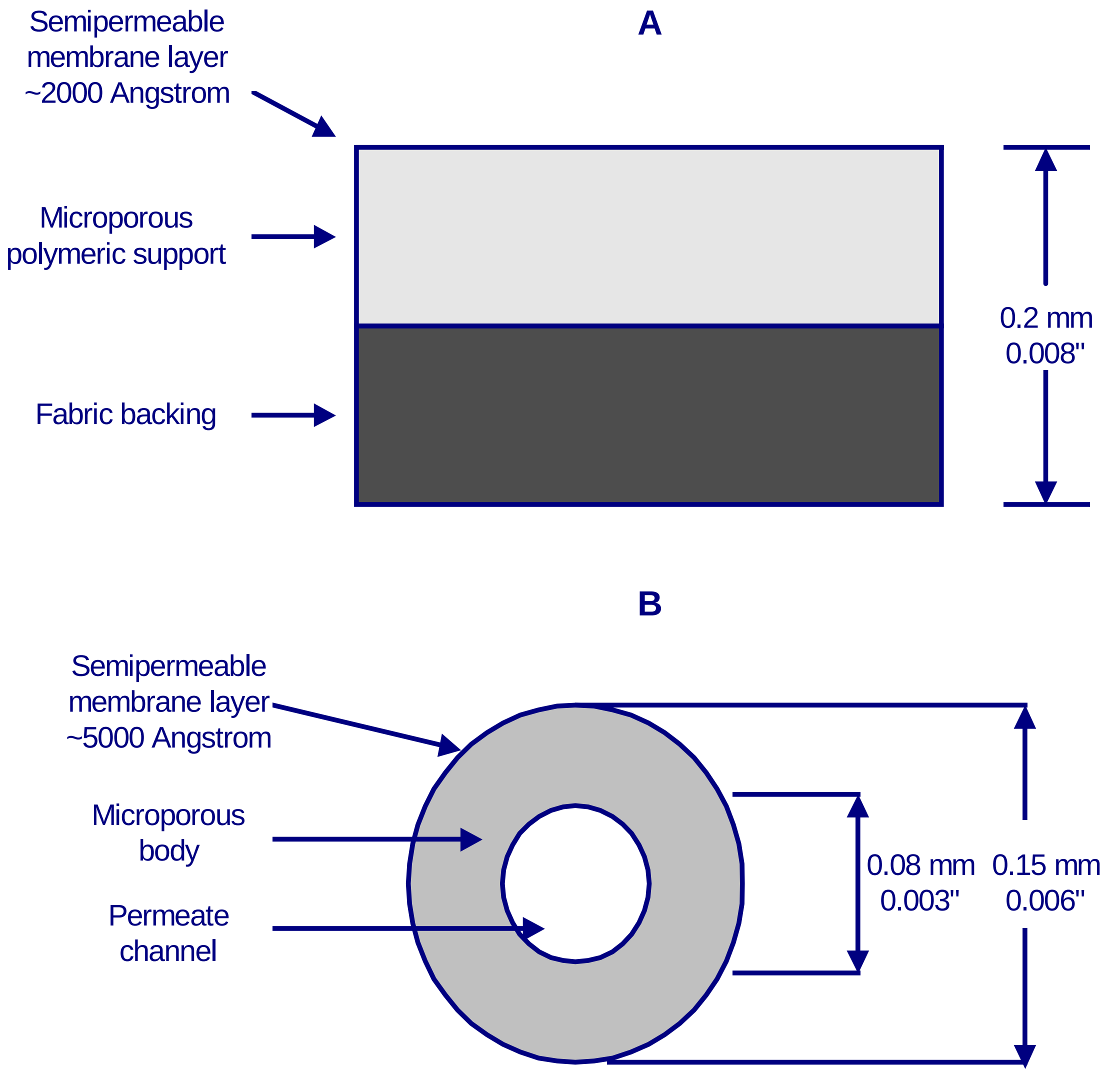
The feed/brine flow through the element is a straight axial path from the feed end to the opposite brine end, running parallel to the membrane surface. The feed channel spacer induces turbulence and reduces concentration polarization. Manufacturers specify brine flow requirements to control concentration polarization by limiting recovery (or conversion) per element to 10 - 20 percent.

Therefore, recovery (or conversion) is a function of the feed-brine path length. In order to operate at acceptable recoveries, spiral systems are usually staged with three to six membrane elements connected in series in a pressure tube. The brine stream from the first element becomes the feed to the following element, and so on for each element within the pressure tube.

The brine stream from the last element exits the pressure tube to waste. The permeate from each element enters the permeate collector tube and exits the vessel as a common permeate stream. A single pressure vessel with four to six membrane elements connected in series can be operated at up to 50-percent recovery under normal design conditions. The brine seal on the element feed end seal carrier prevents the feed/brine stream from bypassing the following element.

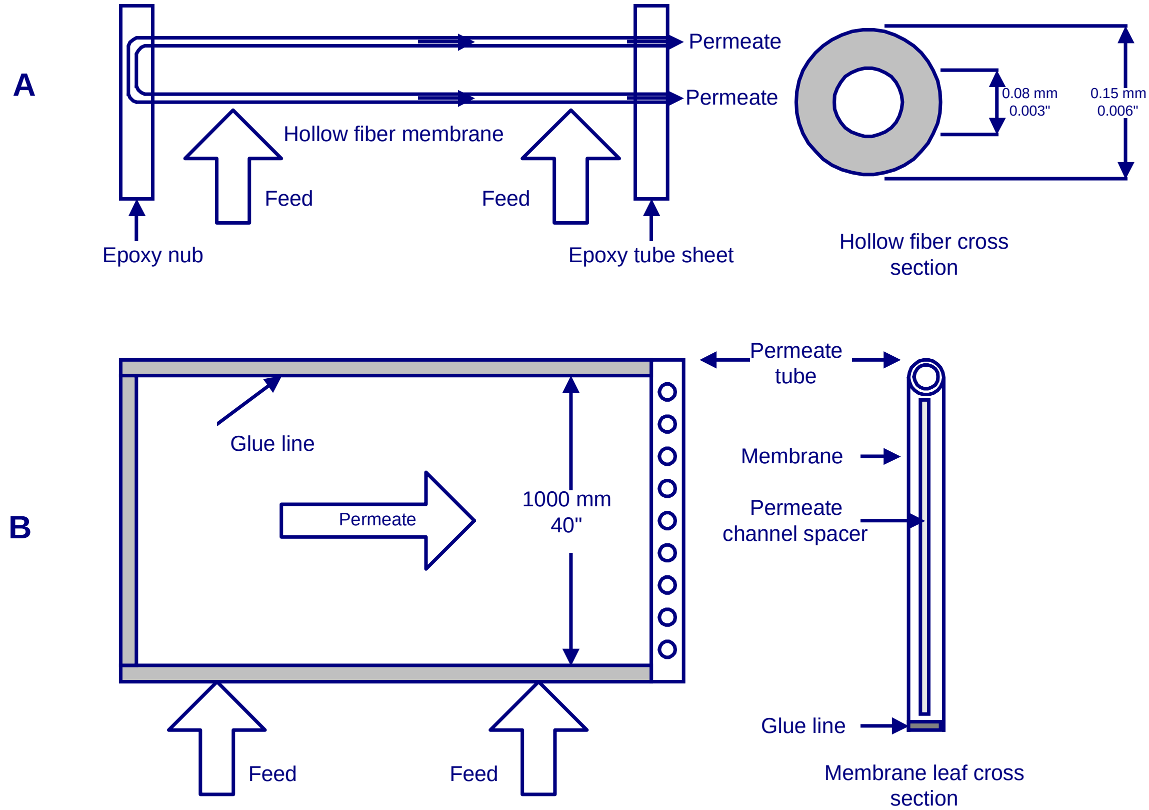
Spiral wound elements are most commonly manufactured with flat sheet membrane of either a cellulose diacetate and triacetate (CA) blend or a thin film composite. A thin film composite membrane consists of a thin active layer of one polymer cast on a thicker supporting layer of a different polymer. The composite membranes usually exhibit higher rejection at lower operating pressures than the cellulose acetate blends. The composite membrane materials may be polyamide, polysulfone, polyurea, or other polymers.

The structure of composite and hollow fiber membrane is shown below.



Cross section of flat (A) and hollow fiber (B) membranes

Corresponding modules configurations are shown below.



Hollow fiber (A) and Spiral wound (B) module configuration