stock.adobe.com / verticalarray

PES Membrane Separation

By Hiroyasu Yamauchi

Specifying the engineering for thermoplastic polyethersulfone for separation membranes

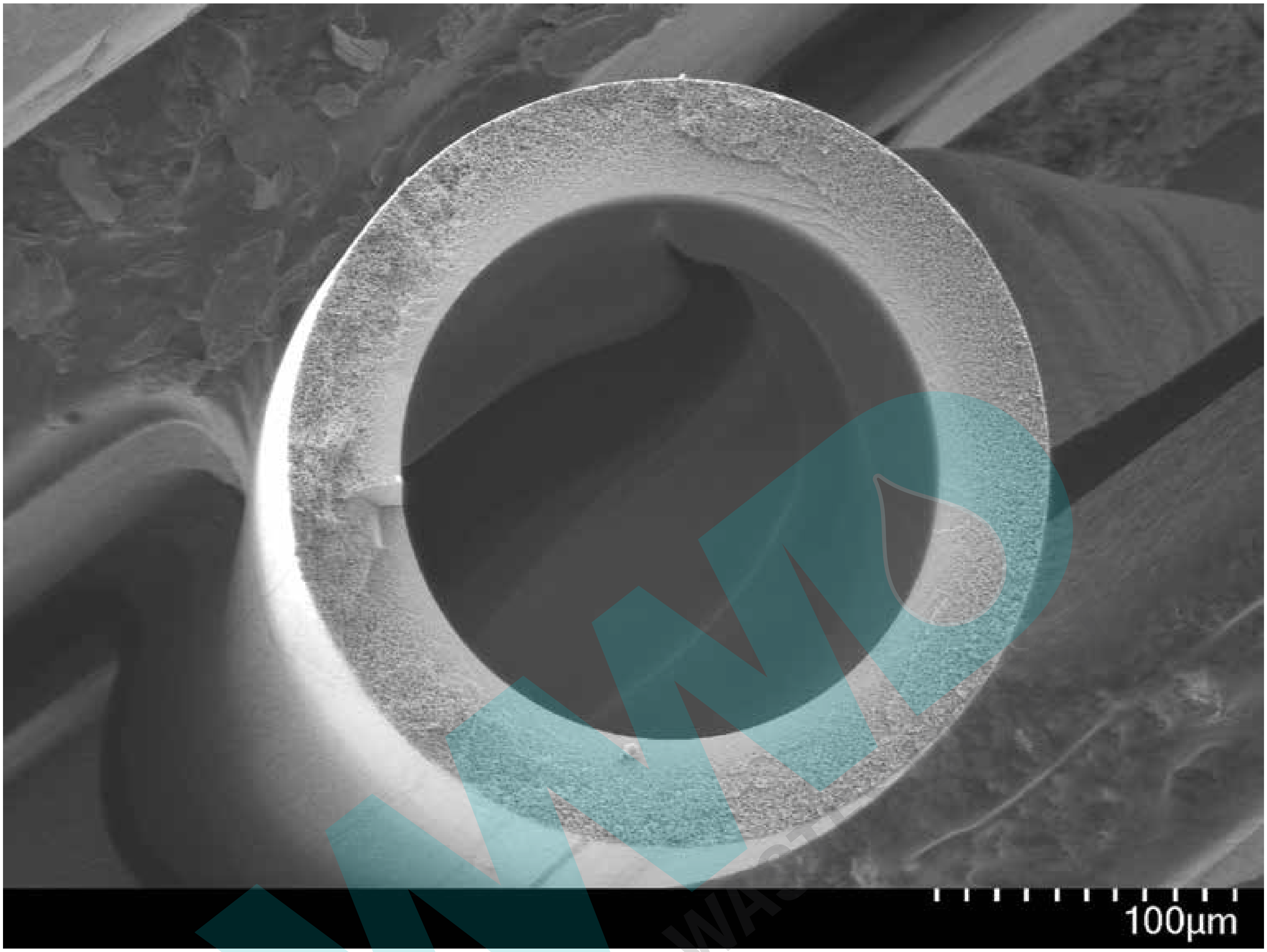
Designers of high-performance filtration applications are increasingly specifying the engineering thermoplastic polyethersulfone (PES) for separation membranes owing to the polymer's performance and its microporous structure, which make PES an effective filter medium.

Separation Membranes

Separation membranes are widely used to remove contaminants in filtration applications. These include producing industrial or potable water from seawater; performing dialysis or separating plasma from other blood components during medical procedures; filtering a variety of food and beverage products to improve color, odor and taste; and industrial uses to separate out a gas, such as carbon dioxide. These membranes often are used in place of or in conjunction with other filtration processes including sand, clay, filter presses and sedimentation.

Depending on the size of particles, liquids, or gases to be separated, different types of separation membranes are used in industry:

- Microfiltration (MF) membranes have pore sizes of approximately 0.1 µm. In the case of water, MF will remove protozoa and many bacteria, however, it will not

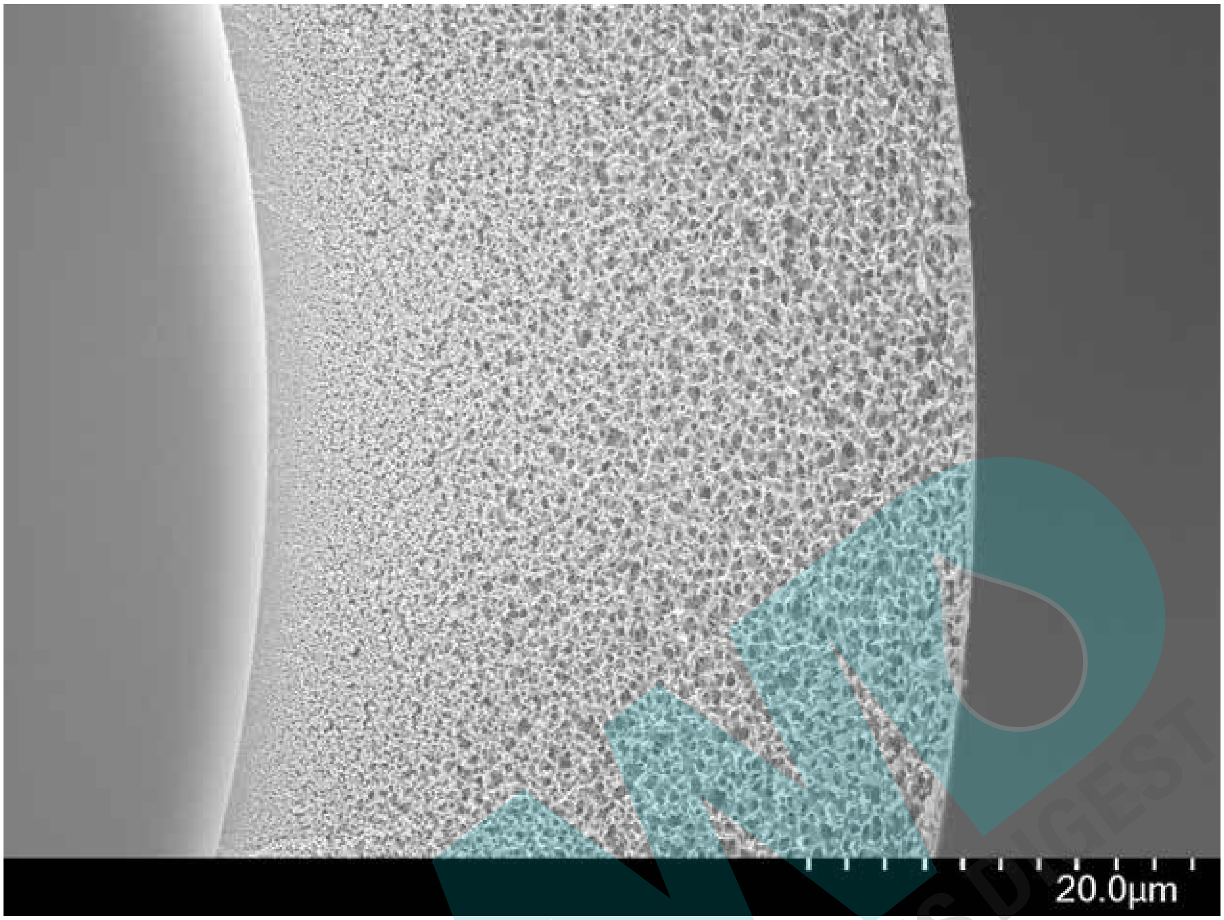


A hollow-fiber membrane in PES polymer.

filter out viruses or chemicals.

- Ultrafiltration (UF) membranes have pore sizes of approximately 0.01 µm, making them effective at removing protozoa and bacteria as well as some viruses, but they cannot remove chemical contaminants. Neither MF nor UF filters can remove dissolved substances until or unless they are adsorbed with activated carbon or are coagulated using alum or iron salts.
- Nanofiltration (NF) membranes have pore sizes of approximately 0.001 µm, meaning they can remove protozoa, bacteria and most viruses from water. Additionally, NF membranes can remove some chemicals, including most organic molecules and natural organic matter and many salts from water. NF filters also can remove divalent ions, which is what makes water hard, so nanofiltration softens water.
- Reverse osmosis (RO) membranes have pore sizes of approximately 0.0001 µm, meaning they can remove all organic molecules and viruses from water as well as most dissolved minerals and monovalent ions, thereby desalinating the liquid and leaving pure water. Typically, water will be subjected to MF and UF processes before RO because this helps reduce fouling of RO membranes. Pretreatment also can eliminate the need for costly steps, such as clarification or sand filtration and can reduce the need for chemical additives like coagulants and flocculants.

Depending on the structure of the filter module in which they will be mounted, separation membranes may take the form of hollow tubes or flat membranes. Hollow tubes commonly are used when filtering liquids with low solids, and can be kept clean and running efficiently with occasional backwashing and clean-in-place (CIP) procedures.



The microporosity in the walls of the tubes shown in greater magnification.

Separation Membrane Materials

Various materials are used to produce separation membranes, the most common being polymeric. Examples include polyvinylidene fluoride (PVDF), polytetrafluoroethylene (PTFE), cellulose acetate (CA), polysulfone (PSU) and PES. Ceramics like aluminum oxide (Al_2O_3) or metals like titanium dioxide (TiO_2) or stainless steel also can be used, however. Polymers generally are preferred owing to their flexibility and chemical compatibility. However, for the most demanding filtration processes—aggressive chemicals, temperature extremes, or high solids, for instance—ceramic or metallic materials may be necessary.

Technical requirements for separation-membrane materials include:

- Good chemical resistance, particularly to sodium hypochlorite, a chlorinated compound used as a bleach or disinfecting agent to clean membranes;
- High mechanical strength, especially resistance to the high pressures applied to filters to separate solids, liquids or gases;
- Low fouling, so filters can operate efficiently over a long period of time; and
- Permeability, which is functionally necessary to provide separation operations.

Among polymers, both PVDF and PTFE offer high thermal and mechanical performance and broad chemical resistance. However, both polymers are hydrophobic so membranes made from them require frequent cleanings owing to a high tendency to foul.

CA often is made from plant pulp, which can be a greener alternative. It also is hydrophilic, which can reduce the need to clean membranes as often. However, it has poor abrasion resistance, it rapidly loses strength when wet, and has limited chemical resistance and thermal performance.

PSU is chemically related to PES but with a lower glass-transition temperature (Tg). PES offers higher mechanical and thermal performance, and higher chemical resistance than PSU. Theoretically, PES also has a more polar moiety, making it slightly more hydrophilic.

PES Polymer

PES is known for its high strength and impact resistance; its creep resistance even at elevated temperatures and loads; and its dimensional stability and low coefficient of linear thermal expansion (CLTE) over a broad temperature range up to the glass transition temperature of 225°C.

PES also provides stress-crack and broad chemical resistance, particularly for an amorphous thermoplastic. The material is resistant to hot water (to 160°C), to both strong and weak acids and bases, and to aromatic hydrocarbons like gasoline, ethanol, oil, and grease. It has acid and alkali tolerance over a broad pH range. However, PES is affected by polar solvents like acetone and chloroform.

PES has the highest thermal resistance among amorphous thermoplastics. Depending on grade selected, properties can include: Tg of 225 to 230°C, continuous-use temperature to 190°C, and distortion temperature under load to 203°C at 1.8 MPa. Although not important for most filtration applications, PES also is characterized by inherent flame retardance (UL94 V-0 down to 0.41 mm), low smoke and minimal outgasing.

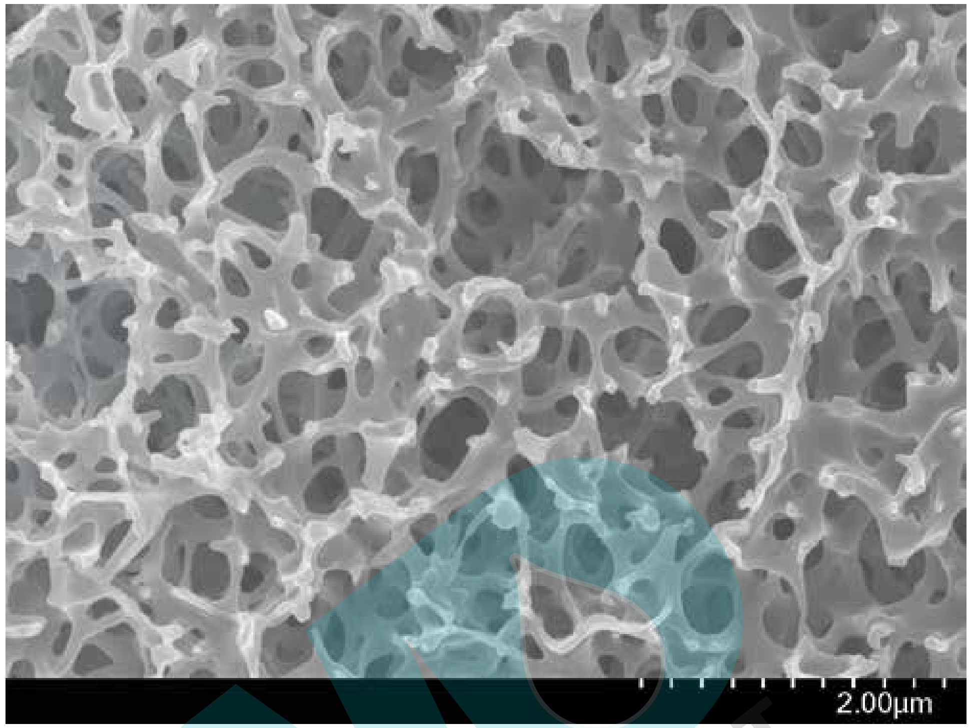
Common form factors for PES include pellets for injection molding, extrusion and film processes; and powders for cast films, filtration membranes, and as an epoxy additive for composites, high-temperature paints and coatings, and adhesives.

PES is well suited for use in separation membranes because of its high mechanical properties and broad chemical stability. Both of these functions derive from the polymer's chemical structure. In the case of water filtration, the hydrophilic nature of PES contributes superior water permeability and wettability to separation membranes. The polymer also shows low protein-binding and low fouling properties.

A characteristic of PES is that it produces controllable pore sizes and pore distribution, both of which are controlled by changing parameters, such as the concentration of PES solution and the temperature of the coagulation bath. Pores also are asymmetric and microporous, controllable features that are a function of non-solvent-induced phase separation. These features help increase the flow rate and the efficiency of filtration operations in PES separation membranes.

The walls of hollow-fiber membranes are microporous and asymmetrical. The latter means pores are larger at the top or front face of a flat membrane, becoming smaller toward the bottom or back side of the membrane or, in the case of hollow tubes, pores are larger on the outside wall and become smaller on the inside wall.

Combined, these properties enable PES hollow fibers and cast membranes to withstand high-pressure cleaning processes like gas backwashing, as well as super-heated steam, e-beam radiation and ethylene-oxide sterilization, and exposure to sodium hydroxide, sodium hypochlorite and surfactants. That helps ensure high flow, long use-life and low fouling in critical filtration media.



Pore-size asymmetry is shown above. Pores are larger on the outside wall and smaller/finer on the inside wall.

PES Membrane Processing

PES powder is dissolved in an organic solvent—such as N-methyl pyrrolidone (NMP) in conjunction with polyvinylpyrrolidone (PVP)—and then it is spun into hollow fibers or cast into a membrane. In the case of hollow fibers, the PES and solvent solution—plus a bore fluid or inner coagulant, which produces the hollow center of each fiber—are injected through a bi-annular spinning nozzle and into a series of coagulation baths to induce phase separation and form the fibers. These fibers have outer diameters of approximately 0.2 mm and micropore sizes of 0.1 to 0.5 µm. Fibers then are removed, wound onto a bobbin, and washed a final time to remove residual solvent. Bundles of tens-of-thousands of fibers are used to produce a membrane module.

Flat or cast membranes are produced via plastic extrusion. The polymer is dissolved in a solvent, and that low-viscosity solution then passes through filter and die and then is applied to a mold film that determines its surface finish and thickness. As the membrane moves forward, it passes through a coagulation bath and eventually through heat treatment via heated rollers that help evaporate the solvent and dry the film. During this process, the film is dried (via solvent evaporation), cured, quenched and cooled, and a thin, flexible membrane is formed and wound onto a roller.

Water Filtration Benefits

Typical water filtration applications for PES membranes include particle filtration for wastewater treatment, precision filtration of ultrapure water in the electronics industry, MF, UF, and NF drinking water decontamination, and RO seawater desalination or drinking water purification. WWD

Hiroyasu Yamauchi is senior manager of the Advanced Polymers Division of Sumitomo Chemical Advanced Technologies LLC. Yamauchi can be reached at hyamauchi@sumichem-at.com.