– Technical Information –

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Membrane Technology

Introduction

A variety of industries are finding that it makes sense to reevaluate the way they treat industrial process water, both to improve the quality of their products and increase the efficiency of their processes. Purification systems utilizing crossflow membrane filtration, such as reverse osmosis, nanofiltration or ultrafiltration can be a good alternative to traditional filtration and chemical treatment systems. Reverse osmosis crossflow filtration systems produce water similar in quality to demineralized or distilled water. This makes reverse osmosis the filtration method of choice for the ***medical, semiconductor, beverage, pharmaceutical, food and chemical industries*** where water quality is of paramount importance.

Although the basic scientific principles behind membrane technology had been developed by the 1950s, it was not until the 1970s that crossflow membrane technology began to be recognized as an efficient, economical and reliable separation process. Reverse osmosis was first used primarily for ***desalting brackish and sea water***. In the last six to eight years the technology has gained industry acceptance as a viable water treatment option for many different fluid separation applications. Low operating costs and the ability to remove organic contaminants and 95-99% of inorganic salts with minimal chemical requirements make reverse osmosis an attractive technology for many industrial applications.

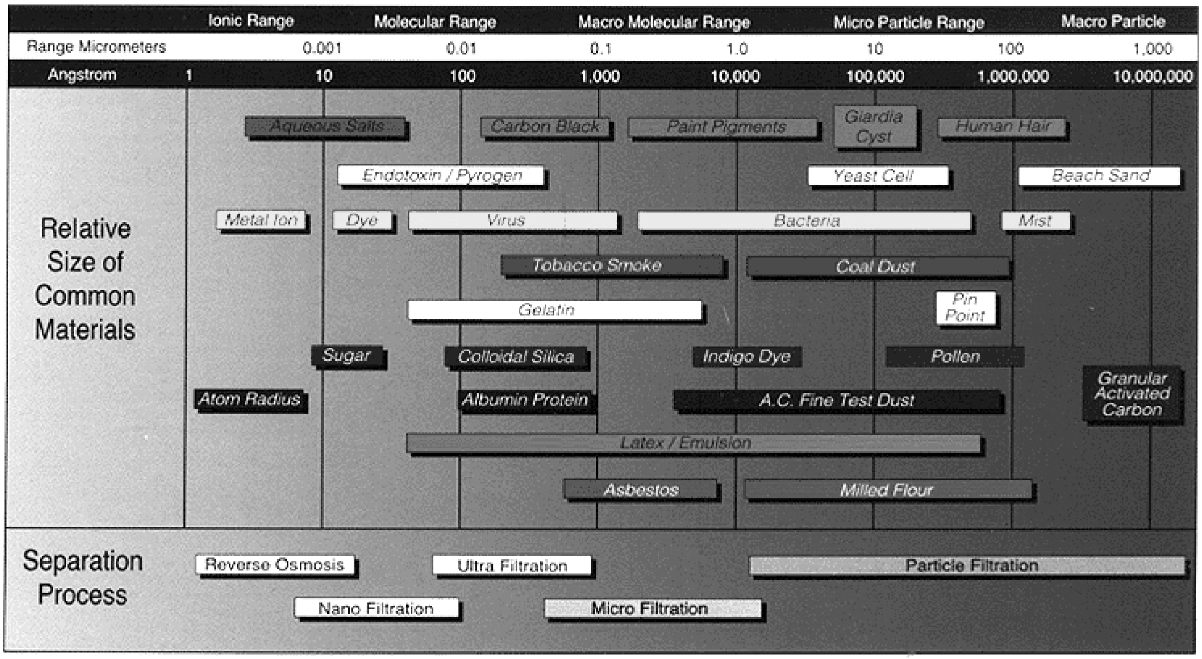
Basic principles

A membrane is a selective barrier that permits the separation of certain species in a fluid by a combination of sieving and sorption diffusion mechanisms. In terms of energy, membrane separations have an important advantage in that, unlike evaporation and distillation, no change of phase is involved in the process, thus avoiding latent heat requirements. No heat is required with membranes, thus it is possible to produce products with functional properties superior in some respects to those produced by conventional processes. Membrane technology also enables to simultaneously concentrate, fractionate, and purify the products.

Membranes can selectively separate components over a wide range of particle sizes and molecular weights, from macromolecular materials such as starch and protein to monovalent ions. Membrane should be selected such that the size of the pores is smaller than the size of the smallest particle in the feed stream that is to be retained by the membrane.

Membranes are available in several different configurations – tubular, hollow-fiber, plate-and-frame, and spiral-wound. Some of these designs may work better than others for a particular application, depending on such factors as viscosity, concentration of suspended solids, particle size, and temperature.

The process of cross-flow pressure-driven membrane filtration is very simple, requiring only the pumping of the feed-stream tangentially across the appropriate membrane, i.e., parallel to the membrane surface. Crossflow membrane filtration is generally divided into four groups: reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF) and microfiltration (MF). The filtration spectrum (Figure 1).



The Filtration Spectrum

Figure 1

The membrane splits the feed stream into two streams: one stream is the ***permeate***, consisting of components small enough to pass through the membrane pores; the other stream is the ***concentrate (retentate)*** consisting of components large enough to be retained by the membrane. The retentate stream is usually recirculated through the membrane module because one passage through the membrane may not deplete the feed significantly. Important operating variables are applied ***transmembrane pressure*** and ***cross-flow velocity*** through the membrane module. Cross-flow velocity is the average rate at which the process fluid flows parallel to the membrane surface. Velocity has a major effect on the permeate flux. The permeate flux depends on the applied transmembrane pressure for a given surface area up to a threshold transmembrane pressure. Above this pressure, which has to be experimentally determined for each application, higher pressures have little or no effect. In fact, too high a pressure may aggravate fouling of the membrane.

Within these broad categories, a system can be engineered to meet most process requirements. The ongoing evolution of membrane technology allows greater flexibility in designing systems that function under a variety of operating conditions. The development of new membranes continues to expand both the range of ***chemical compatibilities*** and ***physical operating conditions*** (including pressure, temperature and pH) of membrane systems. There are four major configurations for membrane modules: plate and frame units, hollow fiber, tubular and spiral-wound.

Although there are advantages to each depending upon the application, this discussion will focus on the most popular spiral-wound configuration. This configuration offers several advantages to industrial users, including higher membrane area per unit volume, which allows greater flows, and spacers between membranes to promote turbulent flow, a feature that reduces fouling and lengthens membrane life.

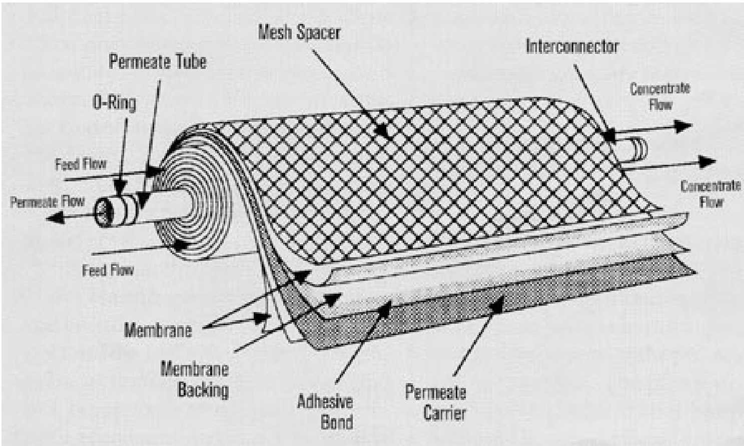


Figure 2

Spiral-wound elements are constructed with several "pairs" or "envelopes" of flat sheet membrane wrapped around a central permeate collection tube (Figure 2). The membrane envelopes are comprised of two flat sheets of membrane with the active surface placed outside, separated by a thin support mesh and glued together along three sides. The open end of the envelope is glued to a perforated collection tube.

Microfiltration (MF)

MF is a form of filtration that has two common forms. One form is crossflow separation. In crossflow separation, a fluid stream runs parallel to a membrane. There is a pressure differential across the membrane. This causes some of the fluid to pass through the membrane, while the remainder continues across the membrane, cleaning it. The other form of filtration is called dead-end filtration or perpendicular filtration. In dead-end filtration, all of the fluid passes through the membrane, and all of the particles that cannot fit through the pores of the membrane are stopped. Pore sizes of MF membranes are in the range of 0.05 to 3 mm. Thus, MF typically operates at low transmembrane pressures to minimize build-up of the suspended solids at the membrane surface. ***Pressures of 0.3 to 3.5 bar*** and cross-flow ***velocities of up to 3-6 m/s*** in tubular modules are common. On an industrial scale, MF is usually carried as a multistage (stages-in-series) operation in a feed-and-bleed mode of operation. MF is the most open membrane and separates macro-materials and suspended solids. Crossflow MF is used in a number of applications, as either a prefiltration step or as a process to separate a fluid from a process stream. ***Dead-end*** MF is used commonly in stopping particles in either prefiltration or final filtration before a fluid is to be used. Cartridge filters are typically composed of MF media.

Ultrafiltrationsanlage

Ultrafiltration (UF)

UF is a form of filtration that uses membranes to preferentially separate different fluids or ions. UF is a ***low-pressure fractionation*** of selected components by size. UF is not as fine a filtration process as nanofiltration, but it also does not require the same energy to perform the separation. UF also uses a membrane that is partially permeable to perform the separation, but the membrane's pores are typically much larger than the membrane pores that are used in nanofiltration.

UF is most commonly used to separate a solution that has a mixture of some desirable components and some that are not desirable. One of the uses that demonstrates the usefulness of UF is electrodeposition paint recovery. In this instance the paint, composed of a resin, a pigment and water are separated into two streams that can be reused. The first stream includes the water and a small amount of the paint resin, which can be used to rinse the parts later in the process. The paint pigment is separated from that stream and can be reused in the paint bath, allowing the bath to be concentrated to a usable level.

UF is capable of concentrating bacteria, some proteins, some dyes, and constituents that have a larger molecular weight of ***greater than 10,000 daltons***. Depending on the molecular weight cutoff selected, the membrane will concentrate high molecular weight species while allowing dissolved salts and lower molecular weight materials to pass through the membrane. UF is typically not effective at separating organic streams. UF membranes are used in numerous industries for concentration and clarification of large process streams.

Nanofiltration (NF)

NF is a form of filtration that uses membranes to preferentially separate different fluids or ions. NF is not as fine a filtration process as reverse osmosis (RO), but it also does not require the same energy to perform the separation. NF also uses a membrane that is partially permeable to perform the separation, but the membrane's pores are typically much larger than the membrane pores that are used in RO. NF is a membrane technology on the rise because it is more cost effective than RO membranes in certain applications. NF is most commonly used to separate a solution that has a mixture of some desirable components and some that are not desirable. An example of this is the concentration of corn syrup. The NF membrane will allow the water to pass through the membrane while holding the sugar back, concentrating the solution. As the concentration of the fluid being rejected increases, the driving force required to continue concentrating the fluid increases. NF is capable of concentrating sugars, divalent salts, bacteria, proteins, particles, dyes, and other constituents that have a molecular weight ***greater than 1000 daltons***. NF, like RO, is affected by the charge of the particles being rejected. Thus, particles with larger charges are more likely to be rejected than others. NF is not effective on small molecular weight organics, such as methanol.

The ***largest users of the NF technology are municipal drinking water plants***. A future trend is for NF to replace lime softening to achieve an industry standard of 50 parts per million (ppm) of alkalinity plus meet the federal THM limits. NF is well established in the dairy industry for cheese-whey desalting. Other growing markets are in RO pretreatment; pharmaceutical concentration; kidney dialysis units; and maple sugar concentration.

Reverse Osmosis (RO)

RO, also known as ***hyperfiltration***, is the finest filtration known. RO is the most complex technique in membrane separation. This process will allow the removal of particles as small as ions from a solution. High pressures of about ***15.0 to 70.0 bar*** are required in order to overcome the high osmotic pressures across the membrane. This permits water to flow from the concentrated feed stream to the dilute permeate - a direction that is just the reverse of what would occur naturally during osmosis. RO is used to purify water and remove salts and other impurities in order to improve the color, taste or properties of the fluid. It can be used to purify fluids such as ethanol and glycol, which will pass through the RO membrane, while rejecting other ions and contaminants from passing. The most common use for RO is in purifying water. It is used to produce water that meets the most demanding specifications that are currently in place.

RO uses a membrane that is semi-permeable, allowing the fluid that is being purified to pass through it, while rejecting the contaminants that remain. Most RO technology uses a process known as crossflow to allow the membrane to continually clean itself. As some of the fluid passes through the membrane the rest continues downstream, sweeping the rejected species away from the membrane. The process of RO requires a driving force to push the fluid through the membrane, and the most common force is pressure from a pump. The higher the pressure, the larger the driving force. As the concentration of the fluid being rejected increases, the driving force required to continue concentrating the fluid increases. RO is capable of rejecting bacteria, salts, sugars, proteins, particles, dyes, and other constituents that have a molecular weight of ***greater than 150-250 daltons***. The separation of ions with RO is aided by charged particles. This means that dissolved ions that carry a charge, such as salts, are more likely to be rejected by the membrane than those that are not charged, such as organics. The larger the charge and the larger the particle, the more likely it will be rejected.

Process	**Components Retained**	**Transmembrane Pressure**	**Process Applications**
RO	greater than 150-250 daltons	circa 15.0 - 70.0 bar	Brackish sea water, Desalting, boiler feed purification, blowdown reclamation, pretreatment to ion exchange, ultrapure water production.
NF	greater than 1000 daltons	circa 9.0 - 16.0 bar	Hardness removal, organic and microbiological removal, dye desalting, color removal
UF	greater than 10,000 daltons	circa 1.5 – 7.0 bar	Pre- and post-treatment to ion exchange, beverage clarification, concentration of industrial organics and dilute suspended oils, removal of pyrogens, bacteria, viruses, and colloids.
MF	Small suspended particles greater than 0.1 m	circa 0.3 – 3.5 bar	High volume removal of small suspended solids.

Application-Matrix

As show membrane technologies are suitable for a great variety of applications. The following table gives examples for successful application:

Industry	Application	RO	NF	UF	MF
Agriculture Industry	Seawater Desalination for the Irrigation of a golf course	X			
Airline Industry	Fire fight training waste water recycling, zero discharge UF/RO			X	
	Propylen glycol cleaning/concentration (De-Icing)	X	X		
Automobil Industry	ED Paint recovery	X		X	X
	Oil removal in waste water			X	X
	polishing of UF permeate from oil emulsion treatment.	X			
	Ethylen Glycol (Anti Freeze) Reclamation		X		
Beverage (beer)	Dealcoholization of beer	X			
	Make up water for beer production	X			
Beverage (coffee)	Coffee extract concentration	X			
Beverage (Cola)	MF Pretreatment before CA/RO				X
	Make up water	X	X		
	Soft drink water purification			X	
Beverage general	Bottle washing, waste water from	X			
Beverage (juice)	Apple juice clarification & Acivated Carbon removal				X
	Apple juice decolorisation			X	
	Passion fruit concentration 50 Brix	X			
	Passion fruit MF				X
Beverage (wine)	Grape juice concentration	X			
	Tartaric acid removal from wine	X			
	Vinegar concentration	X			
	Wine clarification				X
	Wine production, secondary waste water				X

BioPharm& Chemical	Acetic acid concentration up to 20%	X			
	Acetic acid purification		X		
	Caprolactam Polymer, concentration of. From 5% to 22%	X			
	Cephalosporine, concentration		X		
	Clavulanic acid concentration		X		
	Hexamethyleneformamide, recovery from waste water	X			
	Methanol purification		X		
	Methanol, 65%, from extraction of low Dalton organics	X			
	Optical Brightener, concentration of		X		
	Sodium phosphate (Na3PO4) removal		X		
	Tannic acid concentration		X		
	Dye desalting			X	
	X-Ray contrast liquid, Concentration of		X		
Chemical Processing (Plastic production)	"Adipic" acid; removal of oil from			X	
	Catalyst (Fe) recovery in PVC production		X		
Dairy	Cheese brine clarification				X
	Cheese whey concentration	X			
	Cheese whey concentration and partial desalting (NF)		X		
	Cheese whey fractionation (WPC)			X	
	Cheese whey fractionation (WPI)			X	
	Milk, Dilute, Concentration	X			
	Whole milk, stabilization			X	
	Polisher, RO of NF permeate	X			
Drinking Water Production (Domestic)	Brackish water desalination	X			
	Drinking water, NO3 removal	X			
	Humic acid (color) removal	X	X		X
	Spring Water, Iron Removal from				X
	Seawater Desalination	X			
	Seawater softening		X		
	Drinking water, Softening by NF		X		

Electronic	Production of >18 Meg Ohm rinse water by RO upfront Mixed Bed	X			
Fertilizer	Evaporator condensate, NH4NO3 recovery	X			
	Phosphoric acid; heavy metal separation of		X		
Food	Boiler feed water	X			
	Egg white, concentration from 12% to 20%	X			
	Evaporator condensate, water recovery from	X			
	Jelly concentration			X	
	Maple syrup concentration	X			
	Olive production				X
	Potatoe starch derivation	X			
	Vegetable rinse water recovery			X	
	Vinegar clarification				X
	Raisin rinse water, Sugar recovery	X			
Landfill	Landfill leachate waste water, Ultrahigh pressure RO	X			
Manufactering	Optical lenses production, rinse water for		X		
	PVA recovery from waste water from TV display tube washing		X		
Medical	Dialysis water. Hot water sanitazion	X			
	Dialysis Water. Standard	X			
	Water for Injection (WFI), still pretreatment	X			
Metal Finishing	Aluminium electroplating facility, recycling of rinse water	X			
	H2SO4, 0.5-5%. Concentration of Pickling Rinse	X			
	H3PO4, pH 2.3, 2-3% acid, separation of Al from Al foil production		X		
	Washwater from aluminium cans production	X			
	Oil emulsion treatment (cutting oil)			X	
	Penetrant oil emulsion UF & NF		X	X	
Mining Industry	Evaporator pond from Zn refinery, NF &RO	X	X		
	Pregnant leach solution (PLS), open pit Cu mine		X		
Petroleum	Boiler feed water	X			
	Produced Water			X	

Pharmaceutical	Dextran purification			X	
	Fructose concentration		X		
	Ultra pure water (UPW) Polishing			X	
	Urea Purification from protein and Oil before chromatography (Insulin production)Insulin				X
	USP23 water	X			
Photo Finishing	purification of photographic liquid waste		X		
Power Industry	Boiler feed water	X			
	cooling water for rectifiers	X			
	Seawater desalination, power steam production	X			
Pulp, Paper, Wood	Cork cooking water recycling		X		
	MDF(Medium density fiberboard) Production, Secondary WW	X			
	MDF, Medium density fiberboard, waste water, zero discharge	X	X		
	Spent sulphite liquor, Ca-base	X			
	White water, water recovery for recycling		X		
Sugar production	Cooling Tower blown down NF/RO	X			
	Boiler feed water	X			
	Brine recovery. Ion exchange eluate from sugar decolorization		X		
	Purification of Dextrose Syrups		X		
Textile	Laundry waste water		X		X
	Polyester dying; Dye house waste water.(high temp)	X			
	Rinse water recovery after activated Koks treatment	X			
	Secondary Waste Water	X	X		
	Wool dyeing. Waste water. High temperature	X			
	Wool wash water			X	
	Secondary waste water / Lagoon water /DOC reduction				X