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Water Talk

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Water Reuse with Membrane Technologies

The emphasis of government and industry on green initiatives and the search for opportunities for water recycling has resulted in new applications for membrane technology. Membrane manufacturers are working diligently in developing fouling resistant membranes and systems for the treatment of industrial waste that can be recycled into the plan operation. This water talk reviews these technologies.

Membrane technologies were created based on a process known as cross flow or tangential-flow filtration which uses water pressure to force water through a membrane to minimize the accumulation of particulate matter.

There are several cross flow membrane separation technologies: Microfiltration (MF), Ultra filtration (UF), Nanofiltration (NF) and Reverse Osmosis (RO).

- MF is utilized to remove submicron suspended materials on a continuous basis, but it does not remove dissolved materials. The size range is about 0.01 to 1 micron.
- UF is the membrane process which removes dissolved non-ionic solute, such as organic materials. The maximum molecular weight of the dissolved organic compound that will pass through the membrane into the permeate stream is the molecular weight cut-off. Pore sizes are usually smaller than 0.01 micron.
- NF can be considered loose RO because it rejects dissolved ionic contaminants, but to a lesser degree than RO. These membranes have molecular weight cut-offs for non-ionic solids below 1,000 Daltons (1.66 x 10^{-24} grams).

- RO produces the highest quality permeate of any pressure driven membrane technology; many will reject over 99% of all ionic solids and have molecular weight cut-offs in the range of 50-100 Daltons.

Both NF and RO membranes reject salts utilizing a mechanism that is not fully understood. In all cases, the greater the range of contaminant removal, the higher the pressure requirement to allow for the separation which is why RO requires a higher pressure, typically an order of magnitude higher, than microfiltration because it separates the widest range of contaminants.

The water passage rate through a membrane is the flux rate, which is a function of applied pressure, water temperature, and in the case of NF and RO, the osmotic pressure. Flux rate is usually measured as gallons per square foot per day (GFD).

Increasing the applied pressure will increase the permeate rate, but high flow of water through the membrane will promote more rapid fouling.

Table 1 summarizes the various properties of these technologies.

Features	**Microfiltration**	**Ultra filtration**	**Nanofiltration**	**Reverse Osmosis**
Polymers	Ceramics Polypropylene Polysulfone Polyvinylidine fluoride Polytetrafluoroethylene Polyacrylonitrile	Ceramics Cellulosics Polysulfone Polyvinyldine fluoride	Thin film composites	Thin film composites Polysulfonated Polysulfone
Pore size range (micrometers)	0.01-1	0.001-0.01	0.0001-0.001	<0.0001
Molecular Weight cut-off range (Daltons)	>100,000	2,000-100,000	300-1,000	100-300
Operating	<30	20-100	50-300	225-1,000

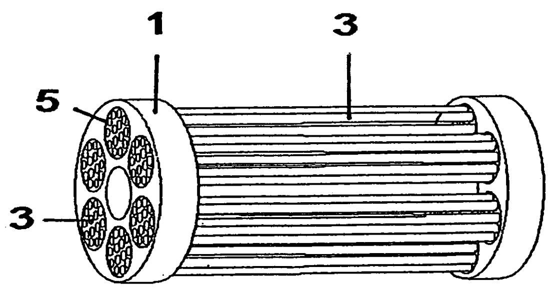
pressure range (psi)				
Suspended solids removal	Yes	Yes	Yes	Yes
Dissolved organics removal	None	Yes	Yes	Yes
Dissolved inorganics removal	None	None	20-75% rejection	95-99% rejection
Micro organism removal	Protozoan cysts, algae and bacteria*	Protozoan cysts, algae, bacteria* and viruses	All*	All*
Osmotic pressure effects	None	Slight	Moderate	High
Concentration capabilities	High	High	Moderate	Moderate
Permeate purity	High	High	Moderate	Moderate
Energy usage	Low	Low	Low to moderate	Moderate
Membrane stability	High	High	Moderate	Moderate
*Under certain conditions, bacteria will grow through the membrane				

DEVICE CONFIGURATIONS

To be effective, membrane polymers must be packaged into a configuration commonly called a device or element. The most common element configurations are tubular, capillary fiber, spiral wound, and plate and frame.

- Tubular devices are usually manufactured from ceramics, carbon, stainless steel, or a number of thermoplastics which have a diameter ranging from ¼ inch up to one inch. The feed solution flow through the interior (lumen) from one end to the other, with the permeate passing through the wall and collected on the outside of the tube.

- Capillary (Hollow fiber) are similar to tubular but they are smaller and require rigid support on each end which is provided by an epoxy potting of a bundle of fibers inside a cylinder. Feed flow is either down the interior of the fiber (lumen feed) or around the outside of the fiber.



- Spiral wound elements are the most common elements and are constructed from an envelope of sheet membrane wound around a permeate tube that is perforated to allow collection of permeate. Water is purified by passing through one layer of the membrane and flowing into the permeate tube.

- Plate and frame elements incorporate sheet membrane stretched over a frame to separate the layers and facilitate collection of permeate which is directed to a center tube.

From a cost and convenience perspective, it is best to have a high packing density because the greater the density, the greater the membrane area enclosed, the lower the cost of the membrane element. The downside of high density membrane elements is the greater likelihood of fouling.

Table 2 compares the element configurations with regards to their packing densities.

Element Configuration	**Packing Density**	**Fouling Resistance**
Capillary fiber	Medium	High
Plate and frame	Low	High
Spiral wound	Medium	Moderate
Tubular	Low	High

SYSTEM PERFORMANCE

The majority of membrane system failures occur as a result of membrane fouling which is usually caused by:

- Suspended solids in the feed stream resulting from incomplete feed water filtration,
- Precipitation of insoluble salts or oxides resulting from concentration effects within the membrane device, and/or
- Biofilms resulting from microbiological activity.

These mechanisms cause the membrane surface to become coated with fouling materials that build up in layers. As the layer thickness increases, the flow rate is reduced which causes more settling of suspended solids and increasing fouling layer-thickness.

With NF and RO membranes, fouling usually creates concentration polarization where the fouling layers inhibit the free movement of the feed stream away from the membrane surface. As salts are rejected from the membrane, their concentration at the surface is higher than in the bulk solution. The increased salt concentration at the membrane surface promotes precipitation of those salts whose solubility limit is exceeded. The percentage of feed stream flow that becomes permeate is recovery. The contaminant-laden stream that exits the element is known as brine, or reject.

Recovery can be changed by varying the feed flow rate to the element; the effect of recovery on system performance is important because the flow rate of the concentrate stream diminishes as recovery is increased. For wastewater treatment and water reuse applications, the minimum recovery is usually at least 80%.

The advantage of operating systems at high recoveries is that the volume of concentrate is small and the flow rate of the feed pump is smaller; the potential disadvantages are numerous:

- Higher concentration of contaminants is more likely to result in fouling.
- In NF and RO applications, the concentrated salts solution results in high osmotic pressure, requiring a higher-pressure pump and a more pressure resistant system.
- As higher recoveries reduce the quantity of concentrate to be discharged, the higher concentration of the concentrate stream may present discharge problems.

The issue of recovery is definitely application specific: most water purification applications-those treating water to be purified for some down-stream application (drinking, product manufacturing, rinsing, etc.)-generally operate at relatively low recoveries, not exceeding 85% even for the largest applications.

Membrane technologies represent some of the most successful processes to switch to water recovery and reuse. As the need increases and the costs become more acceptable, these technologies will become the focus of the water reuse and recovery movement.