Reverse Osmosis & Nanofiltration

How Membranes Work

Reverse osmosis and nanofiltration membranes are used to remove a large majority of contaminants from water and process feed streams. This bulletin explains the basics behind reverse osmosis and nanofiltration technology, how they work and their various applications.

WHAT IS A MEMBRANE & HOW DO THEY WORK?

What is a membrane?

A membrane is a semi-permeable barrier that allows some molecules to pass through while retaining (or rejecting) others.

Osmosis

Osmosis is the natural migration of pure water across a membrane. Figure 1 illustrates this phenomenon. A semi-permeable membrane is placed between two compartments in a tank; the left side containing water of high purity (low salt content) and the right side containing water of lower purity (high salt content). Assuming the membrane is only permeable to water and not dissolved salts, the system will naturally try to achieve equilibrium resulting in two compartments of equal salt concentration. To accomplish this, pure water from the dilute solution naturally travels through the membrane (which retains salts) towards the concentrated solution.

As water from the dilute solution passes through the membrane to the concentrated solution, the liquid levels change. The dilute solution loses water so the liquid level drops, whereas the compartment containing the concentrated solution gains water allowing the liquid level to rise. The concentrated solution's liquid level continues to rise until enough pressure (caused by the difference in levels between the two compartments) is generated to stop the process of osmosis. This pressure is referred to as osmotic pressure and is equivalent to the force that osmosis exerts in order to equalize concentrations on both sides of the membrane.

FORM NO.: TB-016
REVISION DATE: 07/01/2021

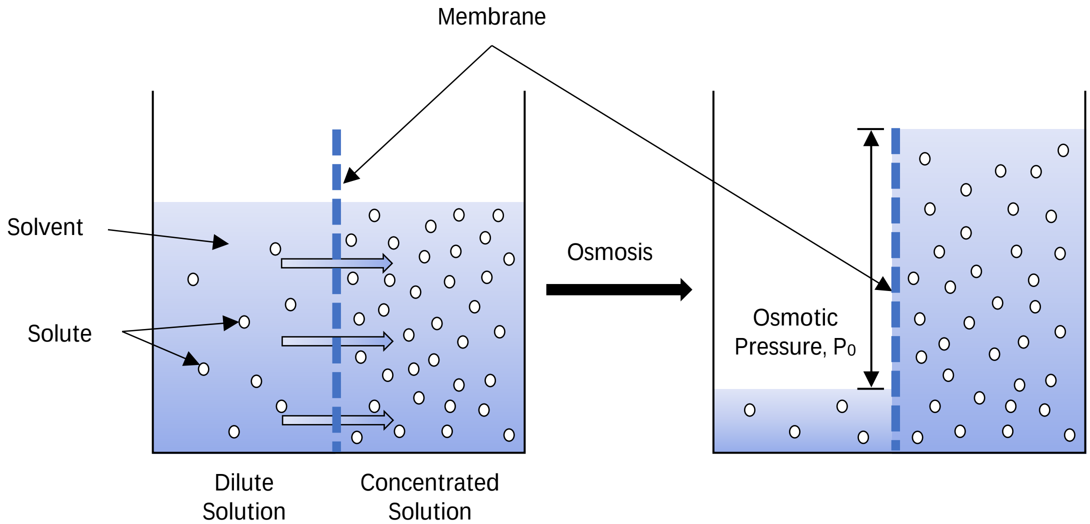

Figure 1. Osmosis is the natural migration of pure water (of a region of low solute concentration) across a semi-permeable membrane to a region of higher solute concentration.

Reverse Osmosis
Reverse osmosis (RO) on the other hand, is when pressure (greater than the solution's osmotic pressure) is applied to the highly concentrated solution forcing pure water to flow through the membrane in the opposite direction towards the compartment of lower concentration. This process is illustrated in Figure 2.

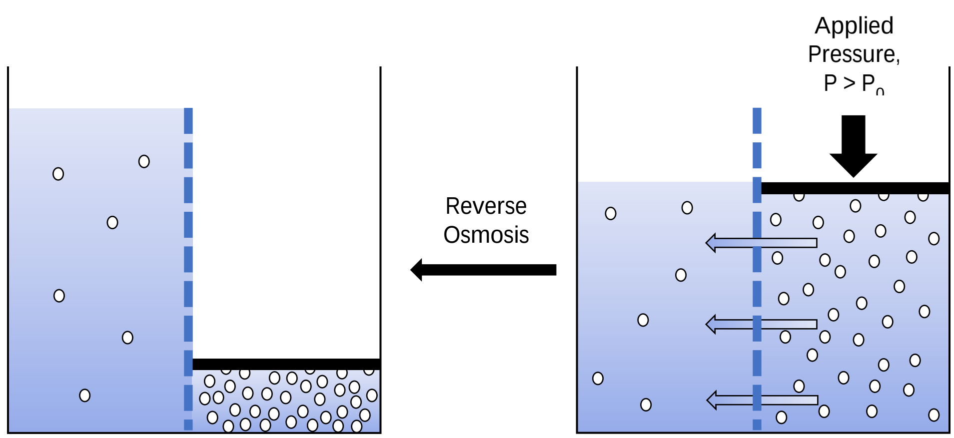

Figure 2. Reverse osmosis is when an applied pressure forces pure water from a region of high solute concentration to travel across a membrane to a region of lower solute concentration.

THE HISTORY OF MEMBRANES

Microfiltration (MF) was developed in the early 1900s – the first of the membranes – and has become increasingly essential in medicine, pharmaceutical production and microbiology.

RO was the next class of membranes to be invented in 1959 by Loeb and Sourirajan at the University of California, Los Angeles with an initial purpose of producing drinking water from brackish water and seawater. They succeeded in producing a functional synthetic RO membrane from cellulose acetate which behaved much like a filter, allowing only water molecules to pass through while rejecting NaCl and TDS (total dissolved solids).

Not much later, ultrafiltration (UF) was born and fit nicely between the salt-rejecting RO and salt-passing, particle-retaining MF. RO and UF membranes worked well for many applications, but there was an increasing need for a membrane with performance characteristics between those of RO and UF membranes.

NF membranes were developed years after RO, and were initially developed as "loose RO" and "RO/UF hybrid" membranes in order to bridge the gap between RO which essentially rejects all salt ions and most uncharged organic solutes, and UF which allows complete passage of ionic species, but retains uncharged solutes above as small as several thousand Daltons. New applications required the development of a new membrane since neither RO nor UF membranes could perform the necessary separations.

The earliest documented application being a water softening application in Florida in the late 1970s and the first documented process NF membrane was commercialized for the purpose of desalting a small food-grade dye in 1983. In 1984, FilmTec Corporation coined the term "nanofiltration" based on the estimated size of the pores in a NF membrane, queuing the birth of the fourth class of pressure-driven membranes.

REVERSE OSMOSIS & NANOFILTRATION MEMBRANES

In a cross-flow membrane system, three types of streams exist: feed, permeate and concentrate (Figure 3). The feed stream is the water that enters the membrane system. The permeate stream consists of the "clean" water where the majority of contaminants and dissolved salts have been removed. The permeate is also sometimes referred to as the product water. The concentrate stream consists of the "reject" water that exits a system; it contains most of the contaminants and dissolved salts that were unable to pass through the membrane. It is also often referred to as the retentate, reject or brine.

Figure 3 is a simple schematic illustrating how a membrane system works. As the feed water enters the membrane element under pressure (a feed pressure higher than the solution's osmotic pressure, P > P0), the water molecules pass through the semi-permeable membrane. The salts and other contaminants are not allowed to pass and are discharged through the concentrate stream, which goes to drain or can be fed back into the feed water supply as a recycle stream to save water. The water that makes it through the membrane is called permeate or product water.

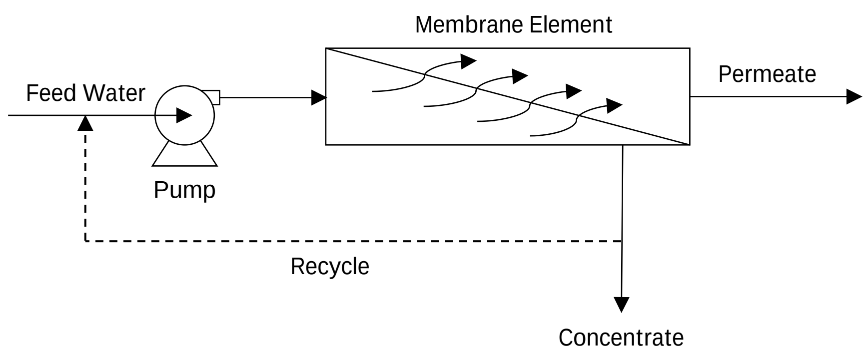

Figure 3. A schematic of a cross-flow membrane system.

Reverse Osmosis

Reverse osmosis (RO) is capable of rejecting over 99% dissolved salts (ions), particles, colloids, sugars, organics, pesticides/herbicides and endotoxins/pyrogens from the feed water. An RO membrane rejects contaminants based on both their size and charge. Any contaminant in the feed that has a molecular weight greater than 100 Da is likely to be rejected by an RO membrane. Likewise, the greater the ionic charge of the contaminant, the more likely it will be unable to pass through the RO membrane. For example, an RO membrane easily rejects magnesium and sulfate ions which have a 2+ and 2- charge (divalent), whereas sodium or chloride ions are not as easily rejected because they have a 1+ and 1- charge (monovalent).

RO is very effective in treating brackish, surface and ground water for both large and small flow applications. Some examples of industries that use RO water include municipal drinking water, pharmaceutical, boiler feed water, food and beverage, metal finishing and semiconductor manufacturing. Some of the above process applications use RO membranes to concentrate proteins and sugars. In these types of applications, the concentrate becomes the valuable product and the permeate is the unwanted stream.

MANN+HUMMEL

Nanofiltration
Similar to RO, NF is a pressure-driven membrane filtration process that utilizes a semi-permeable membrane and cross-flow filtration to separate a feed into a purified permeate stream and a concentrate stream containing a high percentage of the impurities found in the raw water.

NF requires lower operating pressures than RO and has a slightly more open structure allowing predominantly monovalent ions to pass through the membrane, while largely rejecting divalent ions. This has been especially relevant in the application of water softening where NF membrane technology is used to reduce hardness (calcium and magnesium) and remove organics, color, bacteria, THM (trihalomethane) precursors and other impurities from the raw water supply. This has also been especially relevant in process applications including divalent ion concentration, dextrose purification, food and dairy applications where piperazine NF membranes are typically used to pass 50 to 90% monovalent ions while still rejecting the majority of divalent ions.

Although RO is necessary for seawater desalination and brackish water treatment containing very high levels of dissolved solids (TDS), many water supplies do not require the almost total salt removal provided by RO. NF membranes partially demineralize water, removing between 10 to 90% of dissolved salts compared to >99% for RO.

Contact

Europe
Germany: +49 611 962 6001
Italy: +39 0721 1796201
info@microdyn-nadir.com

Americas
USA: +1 805 964 8003
sales.mnus@microdyn-nadir.com

Asia
Singapore: +65 6457 7533
China: +86 10 8413 9860
waterchina@mann-hummel.com

FORM NO.: TB-016
REVISION DATE: 07/01/2021

MANN+HUMMEL