FILMTEC Membranes

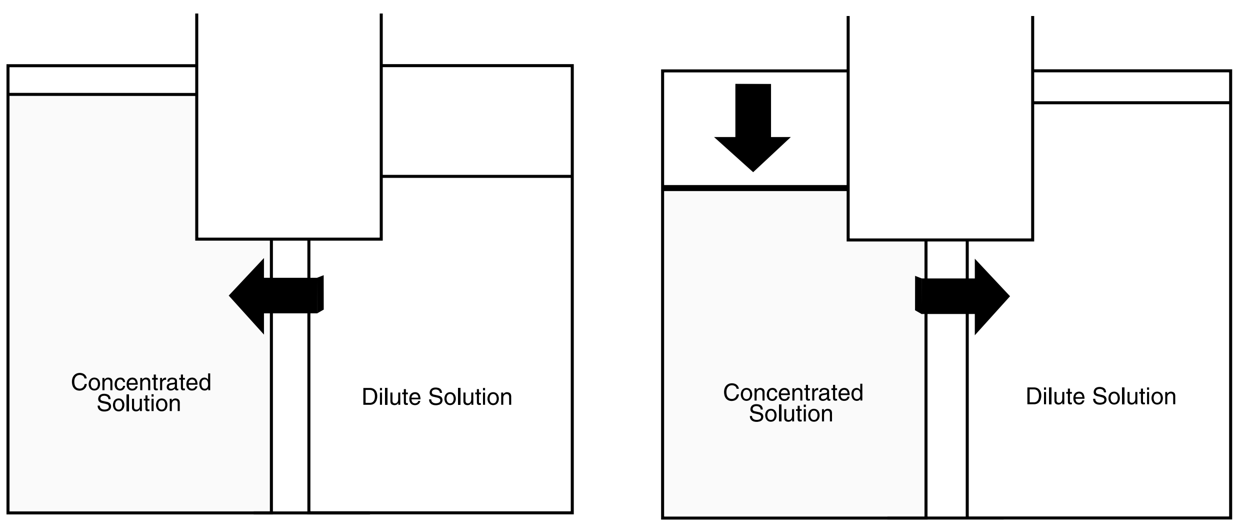
Principle of Reverse Osmosis

How Reverse Osmosis Works
The phenomenon of osmosis occurs when pure water flows from a dilute saline solution through a membrane into a higher concentrated saline solution.

The phenomenon of osmosis is illustrated in Figure 1. A semipermeable membrane is placed between two compartments. “Semipermeable” means that the membrane is permeable to some species, and not permeable to others. Assume that this membrane is permeable to water, but not to salt. Then, place a salt solution in one compartment and pure water in the other compartment. The membrane will allow water to permeate through it to either side. But salt cannot pass through the membrane.

As a fundamental rule of nature, this system will try to reach equilibrium. That is, it will try to reach the same concentration on both sides of the membrane. The only possible way to reach equilibrium is for water to pass from the pure water compartment to the salt-containing compartment, to dilute the salt solution.
Figure 1 also shows that osmosis can cause a rise in the height of the salt solution. This height will increase until the pressure of the column of water (salt solution) is so high that the force of this water column stops the water flow. The equilibrium point of this water column height in terms of water pressure against the membrane is called osmotic pressure.

If a force is applied to this column of water, the direction of water flow through the membrane can be reversed. This is the basis of the term reverse osmosis. Note that this reversed flow produces a pure water from the salt solution, since the membrane is not permeable to salt.



Osmosis

Water diffuses through a semi-permeable membrane toward region of higher concentration to equalize solution strength. Ultimate height difference between columns is “osmotic” pressure.

Reverse Osmosis

Applied pressure in excess of osmotic pressure reverses water flow direction. Hence the term “reverse osmosis.”

Figure 1: Overview of Osmosis / Reverse Osmosis

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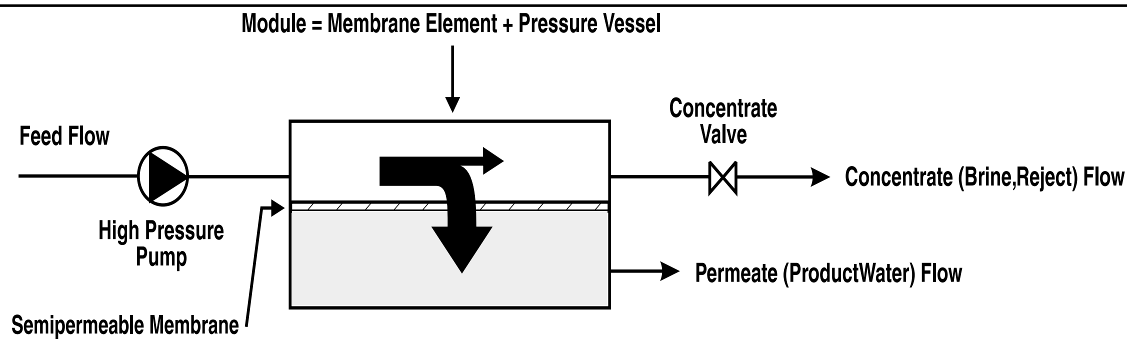
How to Use Reverse Osmosis In Practice

The simplified reverse osmosis process is shown in Figure 2.

With a high pressure pump, pressurized saline feed water is continuously pumped to the module system. Within the module, consisting of a pressure vessel (housing) and a membrane element, the feed water will be split into a low saline product, called permeate and a high saline brine, called concentrate or reject. A flow regulating valve, called concentrate valve, controls the percentage of feedwater that is going to the concentrate stream and the permeate which will be obtained from the feed.

In the case of a spiral wound module consisting of a pressure vessel and several spiral wound elements, pressurized water flows into the vessel and through the channels between the spiral windings of the element. Up to seven elements are connected together within a pressure vessel. The feedwater becomes more and more concentrated and will enter the next element, and at last exits from the last element to the concentrate valve where the applied pressure will be released. The permeate of each element will be collected in the common permeate tube installed in the center of each spiral wound element and flows to a permeate collecting pipe outside of the pressure vessel.



$$\text{Recovery (\%)} = \frac{\text{Permeate Flow} \cdot 100}{\text{Feed Flow}}$$

$$\text{Salt Passage (\%)} = \frac{\text{Permeate Salt Concentration} \cdot 100}{\text{Feed Salt Concentration}}$$

$$\text{Salt Rejection (\%)} = 100 - \text{Salt Passage}$$

Figure 2: Reverse Osmosis Process

Reverse Osmosis Module Designs

Four basic types of RO module designs are in commercial use: tubular, plate-and-frame, spiral wound, and hollow fiber modules.

The tubular and the plate-and-frame devices date back to the early days of RO membrane technology. Both of these designs involve a high initial capital cost and a low membrane packing density (very low for the tubular design). However, these designs can operate on highly fouling feedwaters. Thus, these designs find use in the food industry (examples: milk concentration for cheese manufacture, tomato juice concentration), and in concentration/treatment of wastewaters. They seldom compete with spirals and hollow fiber modules in desalination and water purification applications.

The design of spiral wound elements contains two layers of membrane glued back-to-back onto a permeate collector fabric (permeate channel spacer). This membrane envelope is wrapped around a perforated tube into which the permeate empties from the permeate channel spacer. A plastic netting is wound into the device, and maintains the feed-stream channel spacing. It also promotes mixing of the feedstream to minimize concentration polarization.

Comparisons of Reverse Osmosis System Types

System Costs:
Tubular, plate & frame >> hollow fiber, spiral

Flexibility in Design:
Spiral >> hollow fiber > plate & frame > tubular

Cleaning Behaviour:
Plate & frame > tubular > spiral > hollow fiber

System Space Requirements:
Tubular >> plate & frame > spiral > hollow fiber

Susceptibility to Fouling:
Hollow fiber >> spiral > plate & frame > tubular

Energy Requirement:
Tubular > plate & frame > hollow fiber > spiral

The design of a hollow fiber permeator can package a tremendous amount of membrane area into a small volume. The difficulty in this approach, however, is that these fibers act almost like a string filter. This design requires a high level of feedwater pretreatment to minimize the fouling potential of the feedwater. And when they are fouled, they are very difficult to regenerate by cleaning methods. Another aspect of hollow fiber permeators is that abrasion through fiber-fiber contact or via fiber contact with trapped particles appears to occur during RO operation. This results in gradual fall-off of salt rejection with time.

Above is a set of comparisons between the four basic module designs. Comparing their susceptibility to fouling for example, hollow fiber devices are much worse than spiral wound devices, which in turn are much worse than tubular devices and plate-and-frame devices.

Referring to system costs, spiral wound and hollow fiber systems are relatively equal on well water sources. For surface water sources, pretreatment costs tend to be higher for hollow fiber systems because of their fouling potential. Tubular and plate-and-frame systems are far more expensive than hollow fiber and spiral wound devices, and are relatively cost competitive to each other. As for system space requirements, tubular modules require the most space, hollow fiber and spiral modules require the least space.

One specific advantage of spiral wound units is that they can be linked together into series of two to seven elements within a single pressure vessel. Thus, up to seven times the flow of product water can be handled with only a single set of plumbing connections for feed, concentrate and permeate to a pressure vessel. In the case of hollow fiber modules, each hollow fiber unit requires installation of one feedwater inlet, one concentrate outlet, and one permeate outlet. For large modular systems for field application, a significant percentage of the system cost will be in the plumbing connections.

Factors In Influencing Reverse Osmosis Performance
Permeate Flux[1] and salt rejection
are the key performance parameters of a reverse osmosis process. They are mainly influenced by variable parameters which are as follows:

- pressure
- temperature
- recovery
- feed water salt concentration

The following graphs show the impact of each of those parameters when the other three parameters are kept constant. In practice, there is normally an overlap of two or more effects.

Not to be neglected are several main factors which cannot be seen directly in membrane performance. These are maintenance and operation of the plant as well as proper pretreatment design. Consideration of these three ‘parameters’, which have very strong impact on the performance of a reverse osmosis system, is a must for each OEM (original equipment manufacturer) and end user of such a system.

Pressure
With increasing effective feed pressure, the permeate TDS will decrease while the permeate flux will increase as shown in Figure 3.

Temperature
If the temperature increases and all other parameters are kept constant, the permeate flux and the salt passage will increase (see Figure 4).

Recovery
The recovery is the ratio of permeate flow to feed flow. In the case of increasing recovery, the permeate flux will decrease and stop if the salt concentration reaches a value where the osmotic pressure of the concentrate is as high as the applied feed pressure. The salt rejection will drop with increasing recovery (see Figure 5).

Feedwater Salt Concentration
Figure 6 shows the impact of the feedwater salt concentration on the permeate flux and the salt rejection.
Table 1 shows a summary of the impacts influencing reverse osmosis plant performance.

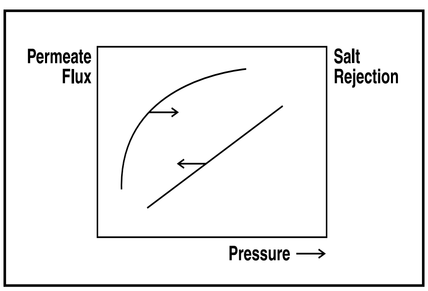


Figure 3: Performance vs. Pressure

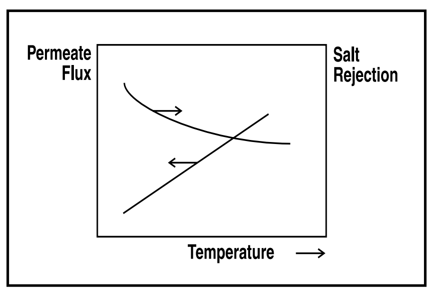


Figure 4: Performance vs. Temperature

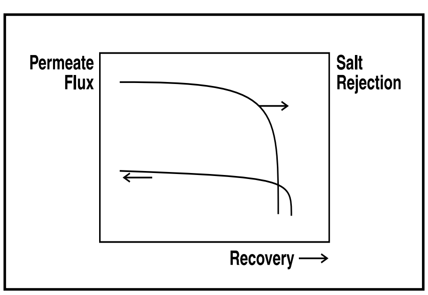


Figure 5: Performance vs. Recovery

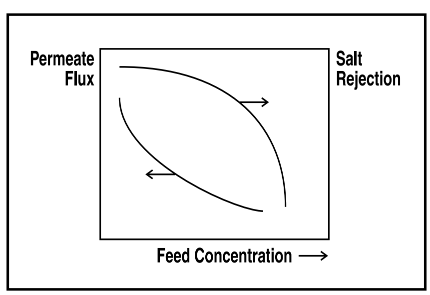


Figure 6: Performance vs. Feedwater Salt Concentration

FILMTEC Membranes

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Table 1: Factors Influencing Reverse Osmosis Performance

Increasing	Permeate Flow	Salt Passage
Effective Pressure	↑	↓
Temperature	↑	↑
Recovery	↓	↑
Feed Salt Concentration	↓	↑

increasing ↑ decreasing ↓

[1] Permeate flow through unit membrane area (in l/m^{2}h or GFD)

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