FILMTEC™ Membranes

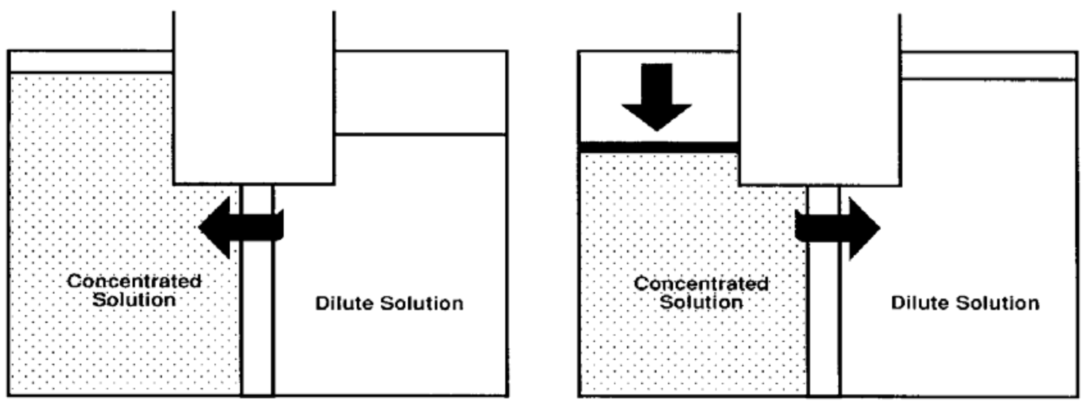
Basics of RO and NF: Principle of Reverse Omosis and Nanofiltration

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 1.4. A semi-permeable membrane is placed between two compartments. "Semi-permeable" 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.

Figure 1.4 Overview of osmosis



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".

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 1.4 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.

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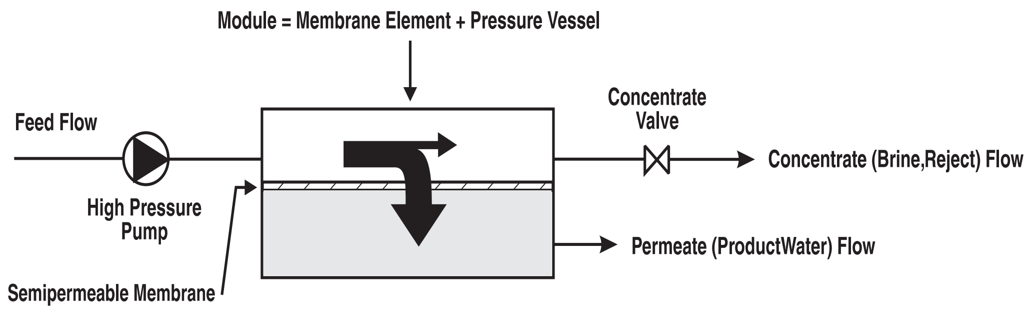
How Nanofiltration Works

The nanofiltration membrane is not a complete barrier to dissolved salts. Depending on the type of salt and the type of membrane, the salt permeability may be low or high. If the salt permeability is low, the osmotic pressure difference between the two compartments may become almost as high as in reverse osmosis. On the other hand, a high salt permeability of the membrane would not allow the salt concentrations in the two compartments to remain very different. Therefore the osmotic pressure plays a minor role if the salt permeability is high.

How to Use Reverse Osmosis and Nanofiltration in Practice

In practice, reverse osmosis and nanofiltration are applied as a crossflow filtration process. The simplified process is shown in Figure 1.5.

Figure 1.5 Reverse osmosis process



With a high pressure pump, feed water is continuously pumped at elevated pressure to the membrane system. Within the membrane system, the feed water will be split into a low-saline and/or purified product, called permeate, and a high saline or concentrated brine, called concentrate or reject. A flow regulating valve, called a concentrate valve, controls the percentage of feedwater that is going to the concentrate stream and the permeate which will be obtained from the feed.

The key terms used in the reverse osmosis / nanofiltration process are defined as follows.

Recovery - the percentage of membrane system feedwater that emerges from the system as product water or “permeate”. Membrane system design is based on expected feedwater quality and recovery is defined through initial adjustment of valves on the concentrate stream. Recovery is often fixed at the highest level that maximizes permeate flow while preventing precipitation of super-saturated salts within the membrane system.

Rejection - the percentage of solute concentration removed from system feedwater by the membrane. In reverse osmosis, a high rejection of total dissolved solids (TDS) is important, while in nanofiltration the solutes of interest are specific, e.g. low rejection for hardness and high rejection for organic matter.

Passage - the opposite of “rejection”, passage is the percentage of dissolved constituents (contaminants) in the feedwater allowed to pass through the membrane.

Permeate - the purified product water produced by a membrane system.

Flow - Feed flow is the rate of feedwater introduced to the membrane element or membrane system, usually measured in gallons per minute (gpm) or cubic meters per hour (m^3/h). Concentrate flow is the rate of flow of non-permeated feedwater that exits the membrane element or membrane system. This concentrate contains most of the dissolved constituents originally carried into the element or into the system from the feed source. It is usually measured in gallons per minute (gpm) or cubic meters per hour (m^3/h).

Flux - the rate of permeate transported per unit of membrane area, usually measured in gallons per square foot per day (gfd) or liters per square meter and hour (L/m^2h).

Factors Affecting Reverse Osmosis and Nanofiltration Performance

Permeate flux and salt rejection are the key performance parameters of a reverse osmosis or a nanofiltration process. Under specific reference conditions, flux and rejection are intrinsic properties of membrane performance. The flux and rejection of a membrane system are mainly influenced by variable parameters including:

- 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. Figure 1.6, Figure 1.7, Figure 1.8 and Figure 1.9 are qualitative examples of reverse osmosis performance. The functions can be understood with the Solution-Diffusion-Model, which is explained in more detail in *Design Equations and Parameters (Section 3.11.2)*. In nanofiltration, the salt rejection is less depending on the operating conditions.

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 1.6.

Temperature

If the temperature increases and all other parameters are kept constant, the permeate flux and the salt passage will increase (see Figure 1.7).

Recovery

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 1.8).

Feedwater Salt Concentration

Figure 1.9 shows the impact of the feedwater salt concentration on the permeate flux and the salt rejection.

Figure 1.6 Performance vs. pressure

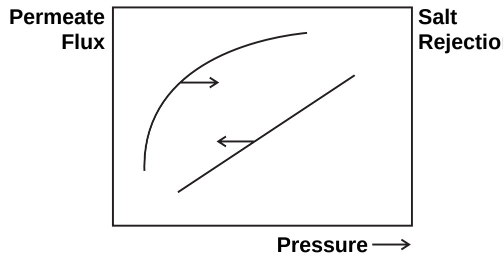


Figure 1.7 Performance vs. temperature

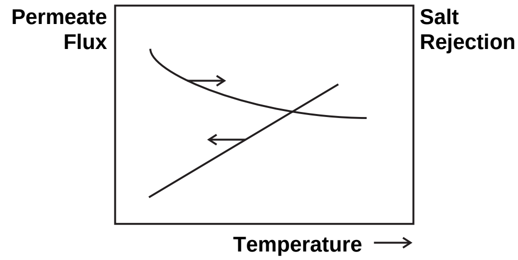


Figure 1.8 Performance vs. recovery

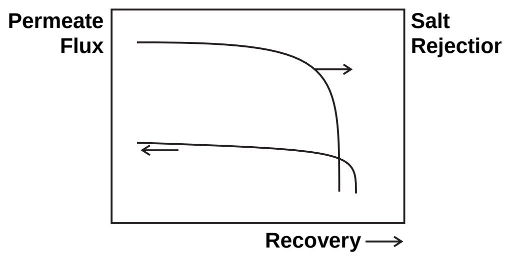


Figure 1.9 Performance vs. feedwater salt concentration

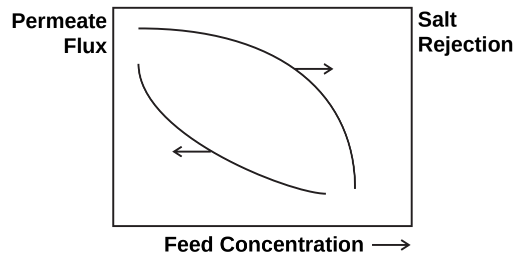


Table 1.1 shows a summary of the impacts influencing reverse osmosis plant performance.

Table 1.1 Factors influencing reverse osmosis performance

Increasing	Permeate Flow	Salt Passage
Effective pressure	↑	↓
Temperature	↑	↑
Recovery	↓	↑
Feed salt correction	↓	↑

Increasing ↑ Decreasing ↓

FILMTEC™ Membranes
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