REVERSE OSMOSIS

THEORY

Principles of Reverse Osmosis Membrane Separation

Lewabrane®

LANXESS

Energizing Chemistry

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1. Basics and Principle of Reverse Osmosis

1.1 Overview of RO application

Reverse Osmosis (RO) is a separation technique that is suitable for a wide range of applications, especially when salt and/or dissolved solids need to be removed from a solution. Accordingly, RO can be used for seawater and brackish water desalination, to produce both water for industrial application, and drinking water. It can also be applied for the production of ultrapure water (e.g. semi-conductor, pharmaceutical industries) and boiler feed water. In addition, RO membrane systems are used for wastewater and water reuse treatments.

RO is currently considered one of the most economic and effective process for water desalination. Accordingly, it is often the appropriate technique to treat solutions having salt concentrations from 100 to over 50,000 mg/ liter. Solutions with salinity from surface water to sea water, and even brines, can be treated by RO.

Cross flow is the configuration applied for membrane separation using RO membrane. As shown in Figure 1.1 the feed water stream flows tangentially to the membrane surface. A fraction of the water in this feed stream passes through the membrane, whereas the majority of the feed flow travels along the surface. Thus, two streams are collected:

- permeate, almost pure water containing low concentration of ions
- concentrate, having high concentration of small particles and dissolved ions

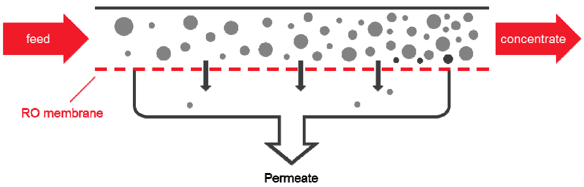

Figure 1.1: Schematic flow of RO membrane

In operation, the RO membrane system is continuously supplied with feedwater which produces a constant water movement from feed to concentrate. When in cross-flow operation, there is little accumulation of the rejected solutes, and fouling or scaling can be minimized.

1.2 Principle of Reverse Osmosis

Osmosis is a natural phenomenon which can be defined as the movement of pure water through a semi permeable membrane from a low to a high concentration solution (see Figure 1.2). The membrane is permeable to water and some ions but rejects almost all ions and dissolved solids. This process (movement of water) occurs until the osmotic equilibrium is reached, or until the chemical potential is equal on both sides of the membrane.

A difference of height is observed between both compartments when the chemical potential is equalized. The difference in height expresses the osmotic pressure difference between the two solutions.

Reverse osmosis is a process which occurs when pressure, greater than the osmotic pressure, is applied to the concentrated solution. Water is forced to flow from the concentrated to the diluted side, and solutes are retained by the membrane (see Figure 1.2).

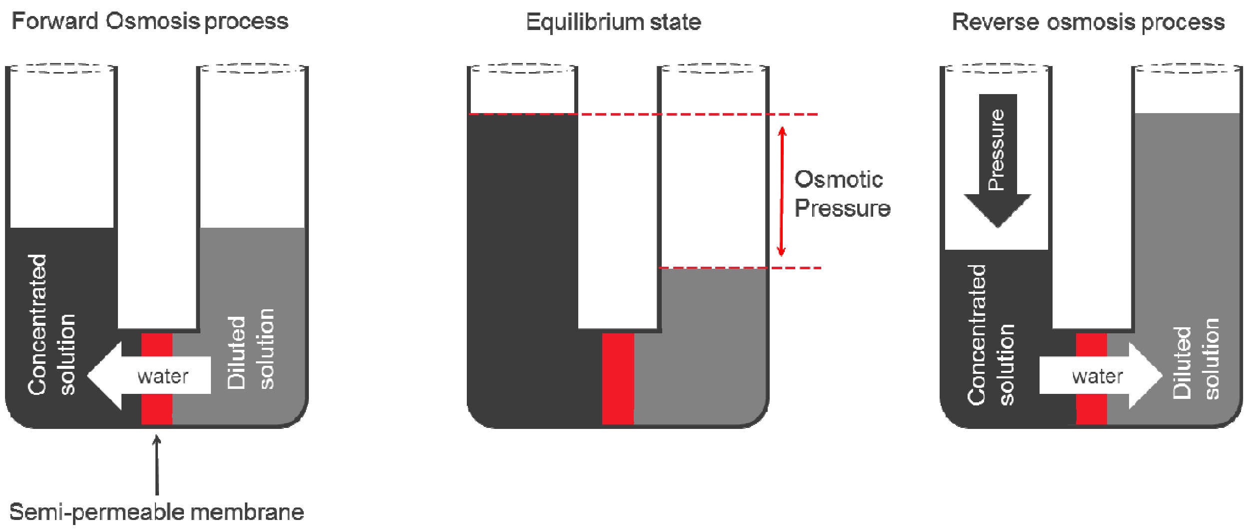

Figure 1.2: Principle Osmosis and of Reverse Osmosis (RO)

1.3 RO membrane description

RO membranes can be supplied in both flat sheet and HFF (Hollow Fine Fiber) structural formats. The flat sheet RO membrane is composed of three layers.

As shown in Figure 1.3, there is a non-woven polyester support layer, a polysulfone layer, and on top the polyamide barrier layer. The barrier layer is formed by the polyamide layer of which the molecular structure is shown in Figure 1.3.

1.4 RO membrane performance

The performance of an RO membrane is defined by various parameters. The important parameters are defined below.

1.4.1 Flow Rate

Three types of flows are present when cross-flow configuration is used. These flows are usually expressed in cubic meters per hour (m^3/h) or in gallons per minute (gpm). Feed flow is defined as the rate of water entering the RO system. Permeate flow is defined as the rate of water passing through the RO membrane, and concentrate flow is defined as the rate of flow which has not passed through the RO membrane, and comes out from the RO system with rejected ions.

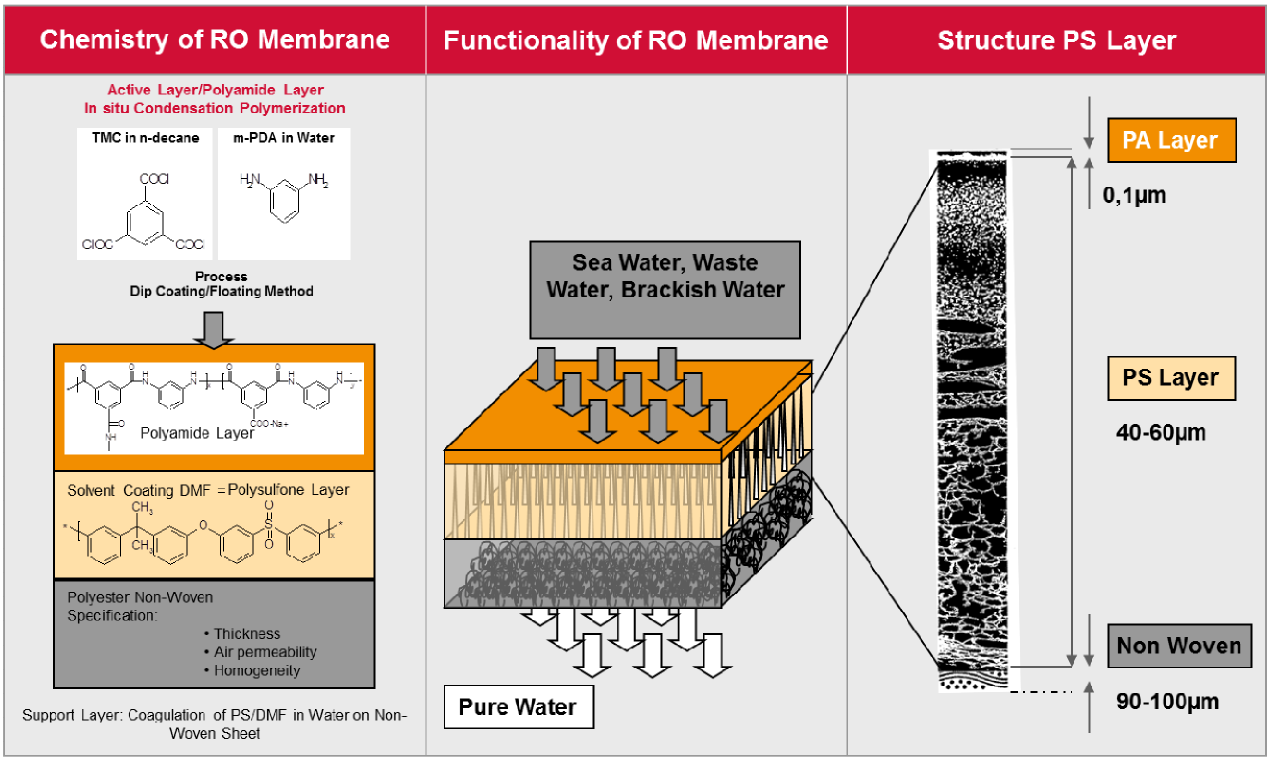

Figure 1.3: Structure of RO membrane

1.4.2 Permeate Flux

Permeate flux describes the quantity of permeate produced during membrane separation per unit of time and RO membrane area. The flux is measured in liters per square meters per hour (lmh) or in gallons per square feet per day (gfd).

The flux is defined by:

$$Jv = \frac{Q_p}{S} \qquad (1.1)$$

In which: JV, permeate flux, S, area of the membrane, Qp, permeate flow rate

1.4.3 Salt Rejection

Salt rejection is a percentage which describes the amount of solute retained by the RO membrane. The retention rate is given by:

$$R = \left(1 - \frac{C_p}{C_{ave}}\right) * 100 \qquad (1.2)$$

In which: R, rejection, Cp, permeate concentration, Cave, average feed concentration; $C_{ave} = (C_f + C_c)/2$

1.4.4 Recovery Rate

The recovery rate is defined as the fraction of the feed flow which passes through the membrane. It is usually expressed in percentage.

$$Y = \frac{Q_p}{Q_f} \qquad (1.3)$$

In which: Y, recovery rate, Qp, permeate flow rate, Qf, feed flow rate

1.4.5 Differential Pressure (Pressure Drop)

The pressure drop is the difference between the feed and concentrate pressure during water flow through one or more RO membrane elements. The pressure drop (dp) is defined by:

$$dp = P_f - P_c \qquad (1.4)$$

In which: Pf, feed pressure, Pc, concentrate pressure

1.4.6 Transmembrane Pressure

Transmembrane pressure (TMP or ΔP) is defined as the difference in pressure between the feed side and the permeate side of the membrane. This pressure is usually measured in bar, and is the driving force for membrane separation and permeate production. In general, an increase in the transmembrane pressure increases the flux across the membrane.

The transmembrane pressure (TMP) is defined by:

$$TMP = \frac{P_f + P_c}{2} - P_p \qquad (1.5)$$

In which: Pp, permeate pressure, Pf, feed pressure, Pc, concentrate pressure

1.4.7 Tendency of RO Performance

The main parameters are the flux which evaluates the permeate production and the salt rejection which determines the quality of permeate. These two parameters can be influenced by operating condition factors such as feed pressure, feed concentration, temperature, etc. These factors influence the RO membrane system performance, and are summarized in the following Table 1.1.

When considering changes in feed concentration, the salt rejection increases with the increase of the concentration first, the rejection reaches a peak, and afterwards, decreases as the feed concentration increases. This can be seen from Figure 1.4.

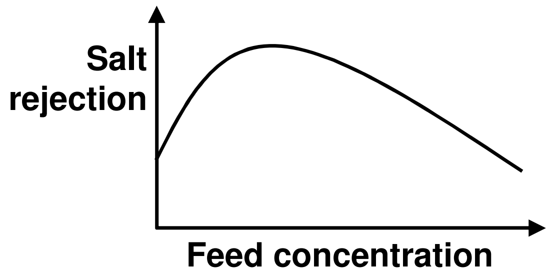

Figure 1.4: Feed concentration effect on RO membrane rejection

The influence of the pH of the feed solution on the rejection of solutes is complex because the pH fluctuations modify the charge of membrane surface as well as dissociation and state of the solutes. However, the following trends of rejection can be shown in Table 1.2.

Increase of Conditions	Tendency		Reason for Membrane Performances Change
	Flux	Rejection	
Feed Pressure	↗	↗	Permeate flux is proportional to net driving pressure. Solute permeation rate does not increase with pressure. As a result, the flux and the salt rejection increase.
Feed Concentration	↘	↘ ↗	Net driving pressure decreases by osmotic pressure. At lower salinity (ex. < 400 mg/l), the salt rejection decreases due to charged effect of RO membrane.
Temperature	↗	↘	Permeate flux increases with temperature (3%/degC) mainly owing to decrease of water viscosity. Solute permeation rate increases with temperature more than permeate flux.
Concentrate Flow Rate	↗	↗	At low flow rate, concentration polarization is occurred, so the concentration at the membrane surface becomes higher, and osmotic pressure increases.

Table 1.1: Operating conditions and effect on RO system performance

Chemicals	pH Range (Acidty)	pH Range (Alka-linity)	Reason of Membrane Rejection Change
Acidic Compounds	low	high	The dissociation of acids at alkaline pH enhances the rejection because of the charge repulsion occurring between compounds and membrane surface.
Basic Compounds	high	low	The dissociation of alkaline compounds at acidic pH enhances the rejection because of the charge repulsion occurring between compounds and membrane surface.
SiO2	low	high	An increase of pH modifies the ionization of silica from silica acid to silicate, therefore increasing the rejection.
Boron	low	high	An increase of pH modifies the ionization of boron from boric to borate, therefore increasing the rejection.

Table 1.2: Feed pH effect on RO membrane rejection

1.4.8 Element Construction

Several designs are available for making RO membrane and elements. These membrane devices are available in tubular, hollow fiber, and plate and frame membrane formats. The Lewabrane® RO membrane elements from LANXESS are manufactured as “spiral wound RO membrane elements”.

The most common element device for RO membrane application is assembled according to spiral-wound configuration.

This format provides the highest degree of packing density. The spiral-wound module uses flat sheets wound around a centre pipe. The membranes are glued along three sides to form membrane leaves attached to a permeate channel (centre pipe) placed along the unsealed edge of the membrane leaf. The internal side of the leaf contains a permeate spacer designed to support the membrane sheet without collapsing under pressure.

This permeate spacer is porous and conducts permeate to the centre pipe. A feed channel spacer (a net-like sheet) is placed between the leaves to define the feed channel height (typically round 1 mm) and provide mass transfer benefits. The membrane leaves are wound around the centre pipe and given an outer casing (Figure 1.5). This design provides a high packing density (300-1000 m^2/m^3).

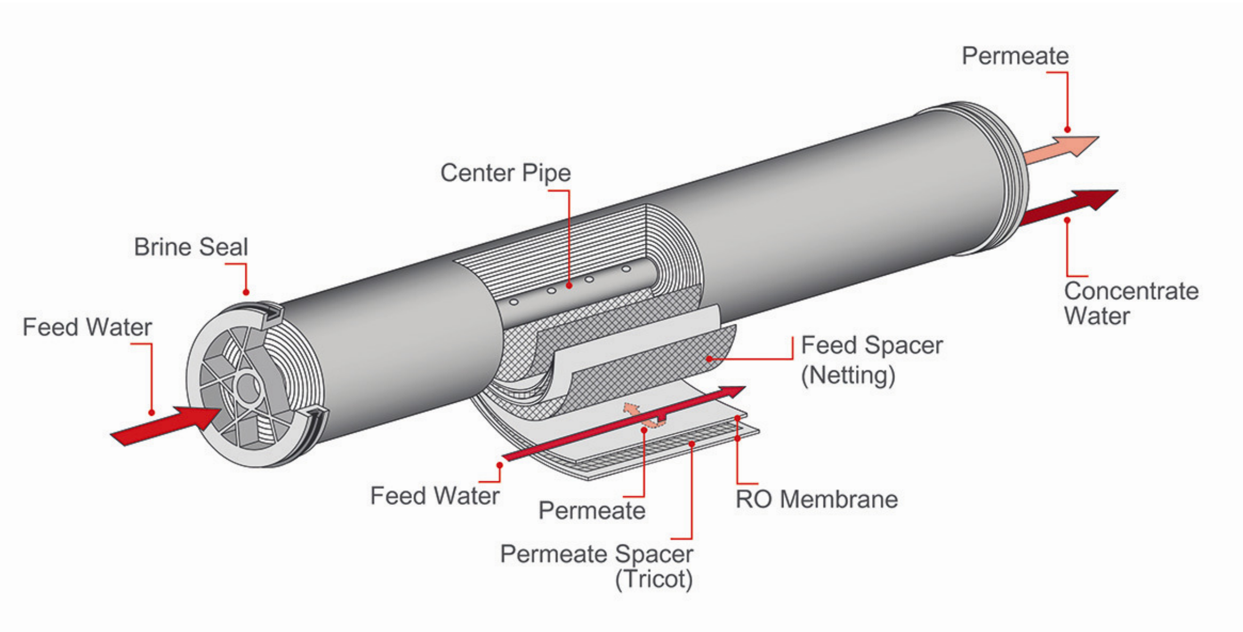

Figure 1.5: Typical spiral-wound element construction

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