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Application of Low and Ultra-Low Pressure Reverse Osmosis Membranes to Water Treatment

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Abstract The criteria of the effectiveness of Reverse Osmosis (RO) membranes are their permeability, driving pressure and salt rejection. In order to save energy and decrease the operating costs, RO membranes are required to possess high permeability and high salt rejection under low operating pressure.

In this paper the application of low and ultra-low pressure composite RO membranes, including CPA2 or NTR-759, ESPA and LF10 membranes, to water treatment has been studied.

These kinds of RO membranes have been characterized by high specific surface, low operating pressure, and high output and salt rejection. The low and ultra-low pressure composite RO membranes are ideal for the production of ultra-pure water. The main characteristics of ultra-low pressure ESPA composite membrane are discussed. The operating pressure, water permeability, salt rejection and the bacterial endotoxins elimination efficiency of CPA2 or NTR-759 low pressure membranes are compared with those of CA membrane.

CCACC: 1290B, 3310; **EEACC**: 8695

1 Introduction

It is well known that reverse osmosis (RO) is a pressure-driven process of water flowing across a semipermeable membrane from the solution of high solute concentration to that of lower concentration. In the area of ultra-pure water fabrication RO is used for removing anions, cations, bacteria, viruses, endotoxins, organics and colloid impurities from water in order to produce high-purity water. The criteria of the performance of membranes including cellulose acetate (CA), composite polyamide[1,2] and ultra-low pressue composite membranes[3~5] are their water permeate capacity and salt rejection. The water permeate capacity is proportional to the net driving pressure differential across the membrane

$$Q_w = (P - P_{osm}) K_w S / d \tag{1}$$

$$Q_w = A (NDP) \tag{2}$$

where Q_w is the water premeate flow through the membrane; P is the pressure differential

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across the membrane; P_{osm} is the osmotic pressure; K_w is the water permeate coefficient; S is the area of the membrane; d is the thickness of the membrane; A is the membrane constant, and NDP is the net driving pressure acting on the solution system. The salt rejection is equal to

$$SR = 100\% - SP \tag{3}$$

where SR is the salt rejection and SP is the salt passage relative to the salt content in feed water.

It is obvious that for the same water permeate flow, the decrease of driving pressure results in the decrease in energy consumption and capital cost of pumps, pressure vessels and pipes. For example, at 25℃ a water flux of 25.5 l/(m^2·h) and a salt rejection of around 92～97% can be reached by using a CA membrane under a net driving pressure (NDP) of 1.7 to 2.1MPa. A 25.5 l/(m^2·h) water flux and a salt rejection of 99～99.7% can be reached by using low pressure TFC membranes such as CPA2 or NTR-759, requiring a net driving pressure of 0.9MPa, whereas the same water permeate flow and a salt rejection of 99～99.7% can be obtained by using ultra-low pressure composite RO membranes such as ESPA, ES20, requiring only a net driving pressure of 0.4～0.7MPa. Obviously, under the same net driving pressure the low and ultra-low pressure RO membranes result in an increase of product water flow. For example, under a pressure of 1MPa, the water flow produced by a ESPA membrane is higher than other RO membranes by 40% or more.

2 Characteristics of low and ultra-low pressure RO membranes

A thin film composite (TFC) membrane is composed of an active layer of aromatic polyamide with a polysulfone support. The TFC membrane has high salt rejection rate, large water permeate flux and can be used in a wide range of pH. However, the TFC membrane is susceptible to oxidation degradation and has a high fouling tendency. Ultra-low pressure composite RO membrane is a kind of TFC membranes and has a large specific surface which is two times larger than that of a low pressure membrane.

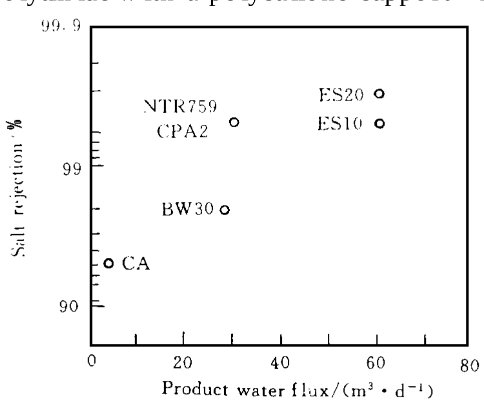

Fig.1 Comparisons of salt rejection rates and product water fluxes for CA, low pressure and ultra-low pressure composite membranes
Test condition:
feed water: 0.15% salt solution;
driving pressure: 1.5MPa, temperature: 25℃

2.1 Driving pressure and salt rejection

Compared with low pressure composite RO membrane, the ultra-low pressure spiral-wound RO membrane can have excellent salt rejection rate and water flux at lower operating pressure. Figure 1 shows the comparison among salt rejection rates and water fluxes for CA membrane, CPA 2, NTR-759 and BW 30 type low pressure composite membranes and ES10 and ES20 type ultra-low pressure composite membranes at the same driving pressure.

It can be seen from Fig. 1 that at a driving pressure of 1.5MPa the product water flux for ES10 and ES20 membranes is twice as much as that of CPA 2, NTR-759 or BW 30 membranes. Figure 1 also shows that the water flux for CPA 2, NTR-759 or BW 30 membranes is five times as much as that for CA membranes.

2.2 Removal of silica

The ESPA and NTR-759 type composite RO membranes possess good ability to remove silica from water and the silica rejection is above 97% as shown in Fig. 2.

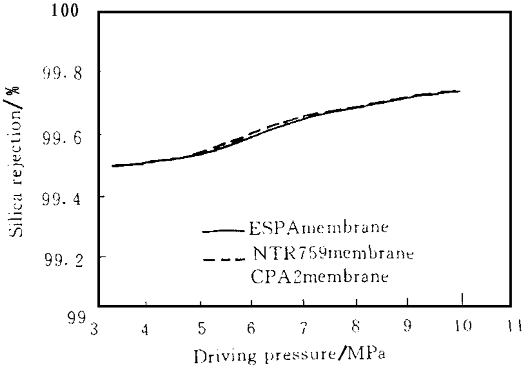

Fig. 2 Silica rejection versus driving pressure
Test condition: temperture: 18℃; feed water: water with 41 ppm SiO_2

2.3 Removal of bacterial endotoxins

2.3.1 Comparison of the removal of bacterial endotoxin among several kinds of RO membranes

The abilities of bacterial endotoxins removal for CPA 2 or NTR-759 type low pressure and ESPA type ultra-low pressure RO (TFC) membranes are determined and compared with that for CA membranes. The results are listed in Table 1.

Table 1 Comparison of the removal of bacterial endotoxin among several kinds of RO membranes

Kind of RO membranes	Bacterial endotoxin content after RO processing (EU/ml)
CA	> 0.03
NTR-759 or CPA 2 (TFC)	< 0.03
ESPA (TFC)	< 0.03

Table 1 shows that after RO processing by using low and ultra-low composite membranes the bacterial endotoxin content in high-purity water is less than 0.03 EU/ml, which meets the requirement of VLSI production or pharmaceutical industry. The CA membrane is not ideal for removal of bacterial endotoxins because it can be easily eroded by bacteria.

2.3.2 Comparison among other methods of removing bacterial endotoxins

There are many other methods of removing bacterial endotoxins, such as absorption by activated carbon, ion exchange, ultra-sonic and 254nm ultraviolet illumination method. The amounts of bacterial endotoxins after treatment by these methods are in the range of 0.03～3 EU/ml (Table 2). It is obvious that these methods are not satisfactory and the

RO with TFC membranes is the best for removing bacterial endotoxins (see Table 1).

Tabe 2 Comparison among methods of removing bacterial endotoxins

Methods	Amount of bacterial endotoxins (EU/ml)
Absorption by activated carbon	> 3
Ion exchange	0.25~0.5
Ultrasonic	0.25
254nm ultraviolet illumination	0.03~0.25

2.4 Chemical stability

The tolerance of low and ultra-low pressure composite RO membranes to chlorine affects their chemical stability, especially the degradation of salt rejection after a long time operation. Figure 3 shows the time dependence of salt rejection degradation for ESPA type ultra-low and CPA2 or NTR-759 type low pressure composite membranes.

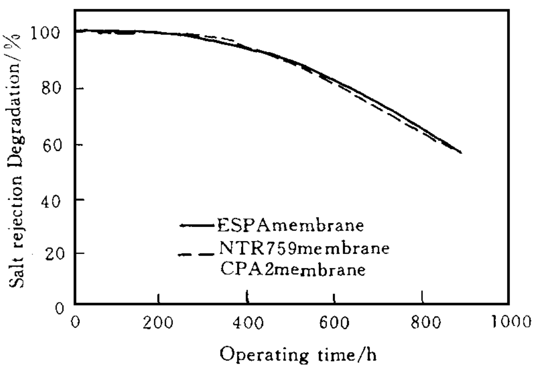

Fig. 3 Tolerance of low and ultra-low pressure composite RO membranes to chlorine
Working condition: feed water: water with 100ppm Cl_2, driving pressure: 1MPa, feed water: pH = 6
Test condition: feed water: water with 0.05wt% NaCl, driving pressure: 0.75MPa, feed water pH: 6.5, temperture: 25℃

It can be seen from Fig. 3 that the ESPA type ultra-low pressure composite membrane retains all the merits of composite membranes and continues to have the same chemical stability and salt rejection as low pressure membranes.

3 LF10 low pressure composite RO membrane[6]

LF10 is a kind of low pressure composite RO membranes. It has high salt rejection, high water flux and superior resistance to fouling and bacteria attack. LF10 also has a neutral charged surface and more hydrophilic property. As a result, it possesses a low fouling performance as compared with conventional RO membranes and is an ideal RO membrane for various waste water treatments.

3.1 Surface charge condition

The surface charge condition of LF10, ESPA and NTR-759HR type RO membranes at various pH values was compared (see Fig. 4). Figure 4

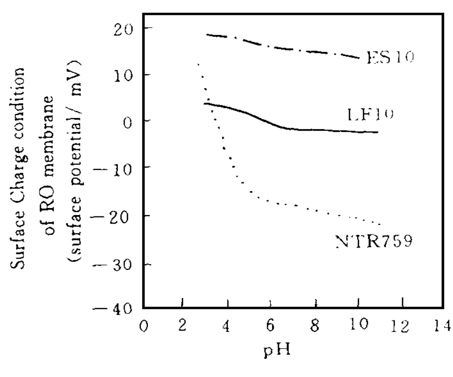

Fig. 4 Comparison among surface charge conditions of LF10, ESPA and NTR759 membranes at various pH values

shows that the LF10 membrane has a neutral surface charge.

3.2 Comparison of water flux stability of LF10 and NTR759 for treatment of waste water

LF10 membrane has a low fouling performance. As a result, the water flux of LF10 membrane does not decrease obviously as compared with coventional RO membranes when a waste water containing surfactants is treated (see Fig. 5).

4 Application

We have designed and built several pure water systems, each of which consists of a RO unit made of CPA2 type composite RO membrane elements, a multiple media filtration and an activated carbon unit for feed water pretreatment, an ion exchange mixed bed for post-treatement, an UV light or ozone sterilizer and a 0.2μm filter. The quality of water produced by the pure water systems meets the standard of ASTM E1 grade water. We have used the water for fabrication of space materials and accumulators of 1800 railroad wagons. In addition, the NTR-759 and ESPA type RO elements have been used for fabrication of water for chemicals and fiberboard production, respectively, The corrosion and scaling of moulding machines have been overcome. Thees pure water systems have high salt rejection, high product water flux with low energy consumption and low operation and capital costs.

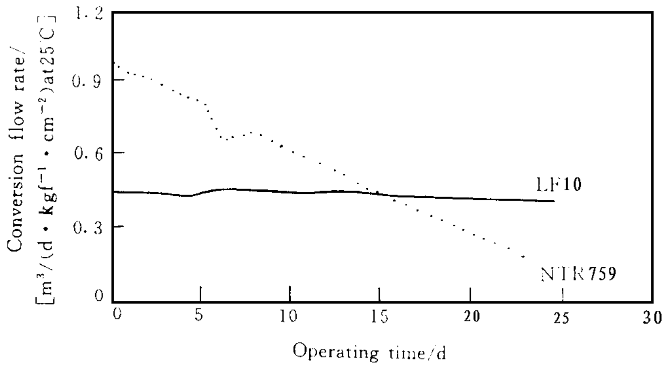

Fig. 5 Comparison between water flux stabilities of LF10 and NTR759 membrans in treatment of waste water

5 Conclusions

We have shown that low and ultra-low composite RO membranes have larger specific surface, lower driving pressure, larger product water flux, higher salt and silica rejection, lower operation and capital costs comparison with acetate cellulose membranes. The low and ultra-low composite RO membranes retain all the merits of composite membranes and have a good chemical stability. In addition, the endotoxin content in high-purity water purified by using low and ultra-low pressure RO membranes is less than 0.03EU/ml, which meets the requirement of VLSI or pharmaceutical industry.

LF10 membrane has the same salt rejection and water flux at a low pressure as compared with conventional RO membranes. Moreover, having a neutral-charged surface hydrophilic property, LF10 has a low fouling performance. Therefore, LF10 shows superior performance in the treatment of waste water containing membrane fouling substances such as surfactants.

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