REVERSE OSMOSIS: INTRODUCTION

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Summary

Historical Development

In the 1950s Reid conceived and with his colleagues demonstrated reverse osmosis desalination using cellulose acetate films (sheets), but he received a very low permeate flux. In 1959–1960 Loeb and Sourirajan (L–S) found that anisotropic cellulose acetate membranes, those possessing a skin surmounting a porous substructure, could have both good desalination and an adequate permeate flux. The L–S membranes obtained the anisotropic character by dividing the nascent membrane into a skin and a porous substructure, a process historically labeling the membranes as "asymmetric". Later, in the 1960s and 1970s, Francis and Cadotte, and separately Riley fabricated anisotropic membranes by adding the skin to the porous substructure, initially physically and later by interfacial polymerization at the upper surface of the porous substructure. Membranes thus fabricated are called composite. For application both of these sheet-type membranes are interlaced with flow spacers, rolled into a tight spiral, and inserted into a pressure cylinder. The housing assembly, invented by Westmoreland and Bray in the 1960s is called a spiral module.

Hollow fiber membranes were first fabricated by Mahon in the early 1960s but his permeate flux was very low, probably because the fiber was isotropic. Starting in 1965, DuPont developed very successful asymmetric polyamide hollow fibers and appropriate modules for both brackish and seawater desalination. In the latter 1970s, the Toyobo Company began marketing asymmetric cellulose triacetate hollow fibers and modules.

Principle of Reverse Osmosis

A solution is separated from its solvent by a semipermeable membrane, one permeable to the solvent but not the solute. The natural permeation from solvent to solution is called osmosis. If hydrostatic pressure is applied increasingly on the solution side the permeation rate will decrease accordingly, stop at a hydrostatic pressure called the osmotic pressure, and reverse direction at a greater hydrostatic pressure. This is reverse osmosis (RO).

Technical and Economical Relevance of Reverse Osmosis

Reverse osmosis has a number of innate advantages. Because it is all-liquid and uses hydrostatic pressure as an energy source, RO modules and plants can be very compact, operation is relatively simple, and modules are readily replaced. Furthermore, the energy input can be quite low because it can approach the free energy of separation. These advantages have been realized by the necessary development of membranes having an adequately high value of the water permeation constant, A, $m^3\ m^{-2}\ d^{-1}$ bar, thus combining relatively low hydrostatic pressures with minimization of required membrane area to obtain the lowest fresh water cost. An important and necessary factor in RO's success has been the development of customized pretreatment, suiting feed brines to membranes to increase membrane life.

Starting from zero in 1968 reverse osmosis now occupies a dominant position in desalination.

1. Introduction

Reverse osmosis (RO) water desalination was conceived and laboratory-demonstrated in the late 1950s. A quantum jump to practicality was made in 1960 with the discovery of the anisotropic RO membrane which combined good desalination with adequate permeate flux at a reasonable hydrostatic pressure. Since then there has been progressive improvement in these membranes and development of ingenious means for packaging them. As a result, present day RO plants are compact and simple to operate, and can take advantage of the fact that in RO there is no phase change required. Therefore, the required energy input can approach fairly closely to the thermodynamic minimum free energy of separation, an advantage no other desalination process can surpass, and usually cannot approach.

An important factor in the commercial success of reverse osmosis desalination has been the development of pretreatment methods appropriate for the particular feed brine being used.

For all of these reasons reverse osmosis enjoys a leading position today in the installation of commercial water desalination capacity and plants.

2. Historical Development

For comparison of various membranes several performance criteria are used. These include: volumetric permeate flux, J_v ($m^3\ m^{-2}\ d^{-1}\ bar^{-1}$) and per cent salt rejection =

$100\left(1-\frac{\text{salt concentration in product}}{\text{salt concentration in feed}}\right)$.

A frequently used term is:

$$A = J_v /(\Delta P - \Delta\Pi) \qquad (1)$$

or

$$A \cong J_v /(P - \Pi) \qquad (2)$$

where A is the water permeation constant ($m^3\ m^{-2}\ d^{-1}\ bar^{-1}$), ΔP and $\Delta\Pi$ are the hydrostatic and osmotic pressure differences across the membrane, and P and Π are the upstream hydrostatic and osmotic pressures. The water permeation constant, A, is a better criterion of membrane performance than J_v alone because A is independent of the driving pressure ($\Delta P - \Delta\Pi$) or ($P - \Pi$).

To illustrate technical ranking in the application of reverse osmosis desalination technology, definitions are given here on relevant parameters of representative modules. Membrane packing density, ρ_{mem}, is the ratio of membrane area in the module to module volume. Permeation rate density, ρ_{perm}, is the ratio of module permeation rate to module volume and is a measure of compactness in a reverse osmosis module and plant. The volumetric permeate flux, J_v, determines the membrane area required and the applied hydraulic pressure, P, is directly related to energy expenditure per unit of desalinized water produced. The term ρ_{perm} [= (J_v) (ρ_{mem})] indicates the desirability of high values of the right hand terms for plant compactness.

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