Desalination by Osmosis–Reverse Osmosis Couple

Abstract. *Water is separated from brines by a semipermeable membrane. Water flows by osmosis across the membrane into a sealed chamber where it creates pressure. This pressure is transmitted by a water-immiscible liquid piston to a second chamber where it effects reverse osmosis. Water-removal rates are calculated.*

Removal of solutes from water requires considerable energy. The thermodynamic minimum energy for desalting water equals the product πV of the osmotic pressure of the solution and the volume of pure water obtained from it; for seawater, this amounts to about 2.65 kw-hour per 4000 liters of desalted water (*1*). This energy must be purchased in some commercial form—say electrical power at one end of the cost spectrum or green wood at the other—when thermal or electrical processes are considered (*2*).

When cheap conventional energy is available, water can be desalted by distillation or electrically powered reverse osmosis or electrodialysis. Distillation especially has been optimized for reduction of energy losses, but the inefficiencies inherent in a thermal process result in use of many times the thermodynamic minimum energy necessary to separate solutes and water. Multipurpose installations, such as a nuclear reactor, that may provide cheaper by-product energy constitute further optimization. In some instances, especially in fuel-poor countries, purchase of as little as the generally accepted 2.65 kw-hour of energy in any form per 4000 liters would make desalination unacceptable.

A few concepts, however, use naturally available energy to avoid purchase of fuel or power; the cost of desalted water is then primarily the capital and depreciation costs of the equipment. Optimization of equipment may be simplified at the expense of waste of some of the freely available energy.

These concepts using freely available energy include recoverable, athermic, regenerant ion-exchange (*3*), osmionic demineralization (*4*), solar stills (*5*), use of geodesic energy (*6*), and our proposal of an osmosis–reverse osmosis couple.

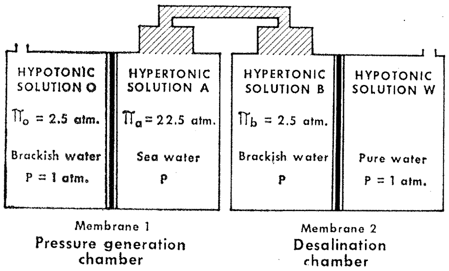

Fig. 1. Model assembly for osmosis–reverse osmosis desalination.

Desalination according to our proposal is achieved by reverse osmosis (*7*). Hydrostatic pressure exerted on a solution accelerates flux of water through a semipermeable membrane (*8*); the pressure is generated by transfer of water, into a closed container by direct osmosis through a second semipermeable membrane, from a hypotonic solution to a hypertonic solution.

A model assembly (Fig. 1) consists of two chambers, each containing a solution of low osmotic pressure separated from a solution of higher osmotic pressure by a membrane that passes water but not solutes. Pressure is generated as water flows by direct osmosis from solution *O*, which is vented to the atmosphere, into solution *A*, which is contained in a sealed compartment; this pressure can be transmitted to the hypertonic solution *B* in the second chamber. If the osmotic pressure π_B of solution *B* is less than the difference in osmotic pressures ($\pi_A - \pi_O$) of the solutions in the first chamber, then desalted water will be produced through membrane *2*. The pressure may be transmitted between the two chambers in various ways, such as by a tight mechanical piston, a diaphragm, or a piston of a water-immiscible liquid.

As an example, let us consider desalination of brackish water by use of cellulose acetate membranes and a brackish water–seawater osmosis couple to produce the pressure; data for such an example appear in Fig. 1 and Table 1. The rate of water permeation through semipermeable cellulose acetate membranes can be described (*9*) by

$$dQ/dt = KA\ (\Delta P - \Delta\pi) \qquad (1)$$

where *Q* is the volume of water transported in time *t*, *A* is the area of the membrane, ΔP and $\Delta\pi$ are the differences in hydrostatic and osmotic pressures across the membrane, respectively, and *K* is an empirical constant characteristic of the membrane. In the scheme depicted (Fig. 1) water will pass through membrane *1* at a rate given by

$$dQ_1/dt = KA_1\ (1 - P + \pi_a - \pi_o) \qquad (2)$$

and through membrane *2* according to

$$dQ_2/dt = KA_2\ (P - 1 - \pi_b) \qquad (3)$$

Pressure *P* in these equations is time-dependent and can be calculated from the equation of state for the liquids:

$$P = 1 + (1/\beta V)\ (Q_1 - Q_2) \qquad (4)$$

where β is the compressibility, and *V* is the volume of the liquids under pressure (the seawater–piston–brackish water volume contained between membranes *1* and *2* in Fig. 1).

We can predict the pressure and the amount of water produced at any time by differentiating Eq. 4 with respect to time, substituting for dQ_1/dt and dQ_2/dt from Eqs. 2 and 3, and finally integrating with the initial conditions that *t* is zero when Q_1 and Q_2 are zero and *P* is 1 atm.

If for the moment we consider π_a, π_o, and π_b, the osmotic pressures in Eqs. 2 and 3, to be independent of time, the results are

$$P = 1 + \left[\frac{A_1(\pi_a - \pi_o) + A_2\pi_b}{A_1 + A_2}\right] \times \left\{1 - \exp\left[-\frac{K}{\beta V}\ (A_1 + A_2)t\right]\right\} \qquad (5)$$

$$Q_2 = \frac{KA_1A_2}{A_1+A_2}\ (\pi_a - \pi_o - \pi_B)t - \frac{A_2\beta V}{(A_1 + A_2)^2}\left[A_1(\pi_a - \pi_o) + A_2\pi_b\right] \times \left\{1 - \exp\left[-\frac{K}{\beta V}\ (A_1 + A_2)t\right]\right\} \qquad (6)$$

Equations 5 and 6 are obviously only approximations, because no account is taken of the dilution of the sea water or the concentration of the brackish water as pure water passes through the membranes. However at small values of *t* they should be nearly true, and they do exhibit some of the features of the system. An example (Fig. 2) shows

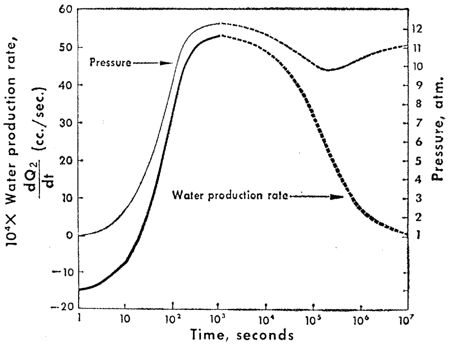

Fig. 2. Calculated couple performance; see Table 1.

Table 1. Data for the brackish water–seawater example (Fig. 2).

Item	Value
Volume of the liquid under pressure	$V = 2000\ \text{cm}^3$
Volume of water charged	$V_a = V_b = 1000\ \text{cm}^3$
Area of membranes	$A_1 = A_2 = 100\ \text{cm}^2$
Original osmotic pressures	$\begin{cases} \pi_a(O) = 22.5\ \text{atm} \\ \pi_o = \pi_b(O) = 2.5\ \text{atm} \end{cases}$
Compressibility of the liquid under pressure	$\beta = 48 \times 10^{-6}/\text{atm}$
Membrane constant	$K = 6 \times 10^{-6}\ \text{cm}^3/(\text{cm}^2\ \text{sec atm})$*

*Corresponds to a rate of production of water by reverse osmosis of 40 liter/(0.1 m²/day) from seawater at an operating pressure of 102 atm (gauge).

that during the first few seconds the water-production rate is negative as water flows back through membrane *2* into the brackish water. Influx of water by normal osmosis (Q_1 and Q_2) quickly raises the pressure in the closed system until the osmotic pressure of the brackish water is overcome. In the example (Fig. 2) hydrostatic pressure rises 2.5 atm, equalling the osmotic pressure of the brackish water, in 20 seconds. At this point, the rate of water production becomes positive and rises to a level controlled by the osmotic pressure of the seawater; meanwhile very little dilution or concentration has occurred in the chambers, and the exponential terms in Eqs. 5 and 6 have fallen to zero. If the osmotic pressures were constants, the pressure and production rate would remain constant at their maximum values.

However, the osmotic pressures are not constants, varying with time. If one assumes the osmotic pressure of seawater solutions to be linearly proportional to the molal concentrations, the osmotic pressures are

$$\pi_o = \pi_o$$

$$\pi_a = \pi_a(t) = \frac{\pi_a(O)}{1 + \dfrac{Q_1}{V_a}}$$

$$\pi_b = \pi_b(t) = \frac{\pi_b(O)}{1 - \dfrac{Q_2}{V_b}} \qquad (7)$$

where π_o is assumed to be maintained constant, either by circulation past the membrane or by adequate stirring in a very large volume; $\pi_a(O)$ is the original osmotic pressure of the seawater; and V_a is the volume of water in the original charge of seawater; $\pi_b(O)$ and V_b are defined similarly.

To account vigorously for changes in osmotic pressures, we should substitute Eqs. 7 into Eqs. 2–4. The resultant differential equation is quite complex. A very approximate indication can be obtained by substitution of Eqs. 7 directly into Eqs. 5 and 6, as was done for the dashed portion of the curves in Fig. 2. As the brackish water under pressure becomes concentrated the rate of water production gradually falls to zero. About 75 percent of the water in the original charge of brackish water can be ultimately desalted; this operation requires nearly 2000 hours. However, 50 percent of the water can be recovered in only 62 hours, so that optimization of the cycle time should be possible.

Although the example presented refers to the seawater–brackish water system, it should be understood that the process is applicable to any couple in which a net difference of osmotic pressures exists and where the solute is rejected by the membrane. So, for example, processing effluents of the food or chemical industry may be concentrated to the point where they may be treated with a view to reclamation of valuable constituents. Low concentrations of thermolabile solutes also may be conveniently concentrated. The system tends to show particular merit when one contemplates concentrations of marine waste products such as stick water and whale blood; in such instances the method does with a loss in efficiency what can be achieved directly by either osmotic dehydration (*10*) or reverse osmosis (*8*); the advantage is, however, the safety factor of guarding against rupture of the membrane and contamination in the former instance, and economy of energy in the latter.

For straightforward desalination of seawater it is quite possible to couple this system with a solar-still brine or distillation-blowdown brine and effect additional desalting. Coupling with a solar still may be of substantial benefit, especially in view of the relatively high cost of the still superstructure (*11*), because the capacity of the still will be at least doubled.

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Ribonucleic Acid Control of Steroid Synthesis in Human Adrenals and Testes

Abstract. *The pattern of steroid synthesis in human fetal testes and adrenals was altered by prior exposure, in organ culture of the explants, of one gland to the ribonucleic acid extracted from the other gland. The new pattern reflected the origin of the RNA.*

Preparations of ribonucleic acid from adrenals of human fetuses altered the pattern of steroid synthesis in explants of testes of the same fetus in organ culture. The new pattern resembled that of human fetal adrenals. The reverse phenomenon could be demonstrated with explants from human fetal adrenals and with ribonucleic acid from mouse testis.

Ribonucleic acid was extracted from adrenals of human fetuses (*1*). Testes from three human fetuses were maintained in organ culture for 24 hours in a chemically defined medium (Parkers 1066). Control tissues were cultured in medium alone. Experimental tissues were cultured in medium that contained preparations of ribonucleic acid from adrenals of the same fetus. After 24 hours in organ culture in 95 percent oxygen and 5 percent carbon dioxide at 26°C, the explants were removed and