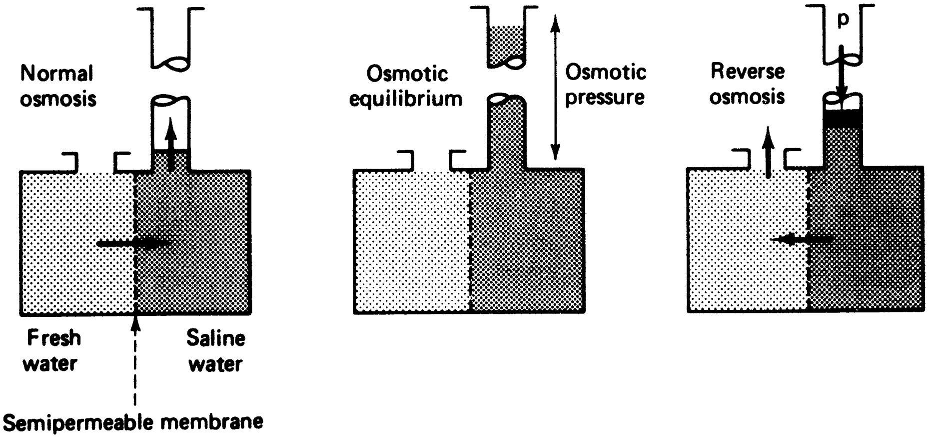

Figure 11.19. Osmotic flows across a membrane separating fresh water and saline water. (With permission, from D. W. Sundstrom and H. E. Klei, *Wastewater Treatment*, Pearson Education, Upper Saddle River, NJ, 1979, p. 281.)

In some reverse osmosis applications, membranes may allow the passage of solute molecules along with solvent. Solute transport can be by diffusion or convection. A *reflection coefficient* (σ) for each solute can be defined as the fraction of solute molecules retained on one side of the membrane in the presence of a solvent flux. Therefore, for $\sigma = 0$, complete solute passage is obtained, and for $\sigma = 1$, no solute passage is achieved (that is, perfect reflection). Solvent and solute fluxes in reverse osmosis can be expressed as

$$\text{Solvent:} \quad N_1 = K_p(\Delta P - \pi) \tag{11.57}$$

$$\text{Solute:} \quad N_2 = C(1-\sigma)N_1 + K_{p'}\ \Delta C \tag{11.58}$$

where K_p and $K_{p'}$ are permeability coefficients for solvent and solute, respectively, C is the average solute concentration in solution, and ΔC is the solute concentration difference across the membrane.

The magnitude of the required pressure varies with the concentration of solutions. Pressures on the order of 30 to 40 atm are required for a 0.6 M salt solution. The salt level in fermentation fluids may be much higher than 0.6 M, requiring high pressures for RO separations. The applications of RO in bioseparations are limited, since the method requires high pressures and is based on solvent removal. RO membranes are usually used for dewatering and concentration purposes, but not for protein separations.

Another problem with RO membranes is the deposition of solute molecules on membrane surfaces, resulting in large resistances for solvent flow. This phenomenon, known as *concentration polarization,* can be overcome by increasing the degree of turbulence on the membrane surface.

The osmotic pressure for multicomponent systems is equal to the sum of the individual osmotic pressures:

$$\pi = \sum_i \pi_i = \sum_i C_i RT(1 + B_{2i}C_i + B_{3i}C_i^2 + \cdots) \tag{11.59}$$