4-9. Important Parameters for System Design

The performance of an RO system is usually defined by its feed pressure, its permeate flow and its salt passage (salt rejection). Two simple equations show the relationship among the parameters.

$$Q = A \times S \times \left(P_f - \frac{\Delta P_{fc}}{2} - P_p - \pi_{ave} \right) \quad (1)$$

where Q = permeate flow
A = membrane permeability coefficient
S = membrane surface area
P_f = feed pressure
ΔP_{fc} = concentrate side pressure drop
P_p = permeate pressure
π_{ave} = average osmotic pressure

Equation 1 indicates that the permeate flow Q is directly proportional to the surface area S times a net permeation driving force.

$$\left(P_f - \frac{\Delta P_{fc}}{2} - P_p - \pi_{ave} \right)$$

On the other hand, the salt passage is by diffusion and thus the salt flux N is proportional to the difference in salt concentration between both sides of the membrane as shown in equation 2.

$$N = B \times \left(C_{fc} - C_p \right) \quad (2)$$

where B = salt diffusion coefficient
C_{fc} = feed - concentrate average concentration
C_P = permeate concentration

The equations 1 and 2 can be used to calculate the performance of a single RO element and also of a multi RO element system if average values for

$\left(P_f - \Delta P_{fc}/2 - P_p - \pi_{ave} \right)$, $\left(C_{fc} - C_p \right)$, temperature, and number of elements are known.

When a large number of elements are combined in a system with a complex series-parallel-series configuration and only inlet operating variables are known, system performance calculation becomes more complex and tedious. Feed pressures and salt concentration for each element is the feed to the following element. However, it is possible to do the complex element to element calculation by a computer simulation program.

The first step is to guess the applied pressure P_f needed to produce the water flow rate (Q) required. Equation 1 can be converted to equation 3.

$$P_f = \frac{Q}{A \times S} + \pi_{ave} + \frac{\Delta P_{fc}}{2} + P_p \tag{3}$$

To solve equation 3 for the feed pressure, the total area of the membrane from the total number of elements is summed to give S. The average osmotic pressure (π_{ave}) is calculated from the average concentration of the feed and the concentrate which is obtained from the nominal recovery and salt rejection of the element. The differential pressure ΔP_{fc} may be estimated from the average of ΔP_{fc} calculated from flow to the first element in series and the last element in the array.

The membrane permeability coefficient (A) is provided by the manufacturer or obtained from the slope of the curve of the permeate flow (Q) versus the operating pressure (P_f - π_{ave}).

Now using the guessed applied pressure (P_f), the computer calculates feed flow rates, permeate flow rates and salt concentrations on an element by element basis through the system. The total calculated permeate flow (Q) is lower than the target flow, then the pressure is raised proportionally and if Q is higher than the target flow, then the pressure is lowered proportionally.

The analysis of the concentrate exiting the last array is then checked for solubility and pH limits for various scaling salts. If the solubility limits are exceeded, Q or the pressure may be decreased, but not so low to drop below the minimum concentrate flow rate. If it does, then more staging (number of arrays) is required.

Another limiting factor is that in any event, the maximum feed flow rate and permeate flow rate of the first element in the first array must not be exceeded. If they do, then a physical damage to the element and fouling would occur. Controlling the feed pressure or adding more elements may be necessary to avoid such problems.

To be accurate and closer to the real situation, equation 1 could have several additional variables as shown in equation 4.

$$Q = A \times S \times TCF \times FF \times \left(P_f - \frac{\Delta P_{fc}}{2} - P_p - \Delta\pi \right) \tag{4}$$

$$C_p = B \times C_{fc} \times Pf \times TCF \times \frac{S}{Q} \tag{5}$$

$$TCF = \exp\left[U \times \left(\frac{1}{298} - \frac{1}{273+T}\right)\right] \quad (6)$$

$$\Delta\pi = \pi - \pi_p \quad (7)$$

$$\pi = \pi_f \times \frac{C_{fc}}{C_f} \times Pf \quad (8)$$

$$Pf = \exp\left[0.7 \times Y\right] \quad (9)$$

where	Q	= permeate flow
	A	= membrane permeability coefficient
	S	= effective membrane area
	TCF	= temperature correction factor which is verified in equation 6.
	FF	= fouling factor, about 0.8
	P_f	= feed pressure
	ΔP_{fc}	= feed-concentrate side pressure drop
	P_p	= permeate pressure
	$\Delta\pi$	= driving osmotic pressure
	C_p	= permeate concentration
	B	= salt diffusion coefficient
	C_{fc}	= average concentration of feed-concentrate side
	C_f	= concentration of feed side
	Pf	= concentration polarization
	U	= temperature correction factor coefficient which depends on membrane sheet
	T	= temperature, (℃)
	π	= average osmotic pressure of feed-concentrate side
	π p	= permeate osmotic pressure
	π f	= feed osmotic pressure
	Y	= recovery of the element

Woongjin Chemical Co., Ltd. CSMPRO v3.0 computer program utilizes equations 4 and 9. Using iterative trial and error solution, it projects the performance of given systems, and optimizes the design of the system.