17

System operation

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Reverse osmosis system is a water manufacturing facility, which operates with the objectives to produce effluents (product water and concentrate) at the required quality and to deliver consistently flow rate at the planned schedule. To maintain operating cost within the budget, membrane elements have to perform within the limits projected during the design stage. Stability of performance of membrane elements is affected by system operating parameters and membrane fouling phenomena. Changes of performance of membrane elements, caused by operation outside the design limits or by membrane fouling, are usually reversible if detected at the early stages of the fouling process. Regular monitoring and evaluation of system operating parameters is integral part of system operation.

Monitoring of system operating parameters provides information that enables maintaining operation of desalination system within the design limits. Performance monitoring is necessary to achieve operational objectives.

Same of the major objectives are:

- Maintaining regulatory compliance of system operation.
- Enable early detection of membrane performance changes and determination of performance trend.
- Determination of the requirements and scheduling of equipment maintenance.

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- Compliance with warranty conditions of membrane elements and major equipment.
- Determination of operating cost and projecting future expenses
- Maintaining proper level of consumables (treatment chemicals, filtration cartridges, etc..)

17.1 Monitoring system operation

control and monitoring in commercial RO desalination systems utilizes almost exclusively computer based Supervisory Control AND Data Acquisition (SCADA) system. The SCADA is connected through data highway with a distributed network of process monitoring and controlling microprocessors–programmable logic controllers (PLC's). The local microprocessors evaluate process parameters of designated system unit and control its operation within determined limits. Local PLC's communicate with the central control unit usually through fiber optics cables that provide connection free of electric noises. Process control is achieved through evaluating the output signal from sensors, installed in the plant, and controlling operation of pumps and valves.

The following process parameters are being monitored in RO plants:

- Raw water conductivity
- Raw water temperature
- Raw water flow
- Raw water pump suction and discharged pressure
- Raw water turbidity
- Dosing rates of pretreatment chemicals
- Raw water free (or combined) chlorine
- Membrane filtration system effluent turbidity
- Membrane filtration system effluent particle count
- Membrane filtration system effluent SDI (MFI)
- Cartridge filters pressure drop
- High pressure pump suction and discharged pressure
- Feed water pressure

- Feed water pH
- Feed water free (or combined) chlorine
- RO permeate flow
- RO permeate pressure
- RO permeate conductivity
- RO permeate temperature
- RO permeate pH
- RO concentrate flow
- RO concentrate pressure
- Dosing rate of post-treatment chemicals
- Product water turbidity
- Product water free (combined) chlorine
- RO permeate storage tank level

The monitoring activity conducted to protect plant equipment includes monitoring operating parameters of major equipment. This activity includes setting alarms and shut off switches to indicate off limit conditions of the following parameters:

- Levels in water storage tanks
- Levels in chemical storage tanks
- Flow of treatment chemicals
- Water temperature
- Water pH
- Water turbidity
- Free (combined) chlorine concentration
- Pressure drop in cartridge filters
- Pumps suction pressure
- Pumps discharged pressure
- Feed pressure
- Permeate pH

- Permeate conductivity
- Permeate temperature
- Permeate pressure
- Concentrate flow
- Concentrate pressure
- Pressure drop in RO system
- Temperature of electric motors

Process information delivered to SCADA system are stored in a database format and are accessible for display, reporting and performance normalization. Through the monitoring station operational; data is available in the form of flow diagrams and performance graphs.

In addition to automatic data monitoring, it is quite common that plant operators collect operational data on a predetermined schedule (once per shift or more frequently). Plant data are collected during the scheduled walk through the system. Operators presence on the floor helps identify potential operational issues, that are still too small to affect system performance and be detected by the automatic monitoring system, but eventually could evolve into large problems.

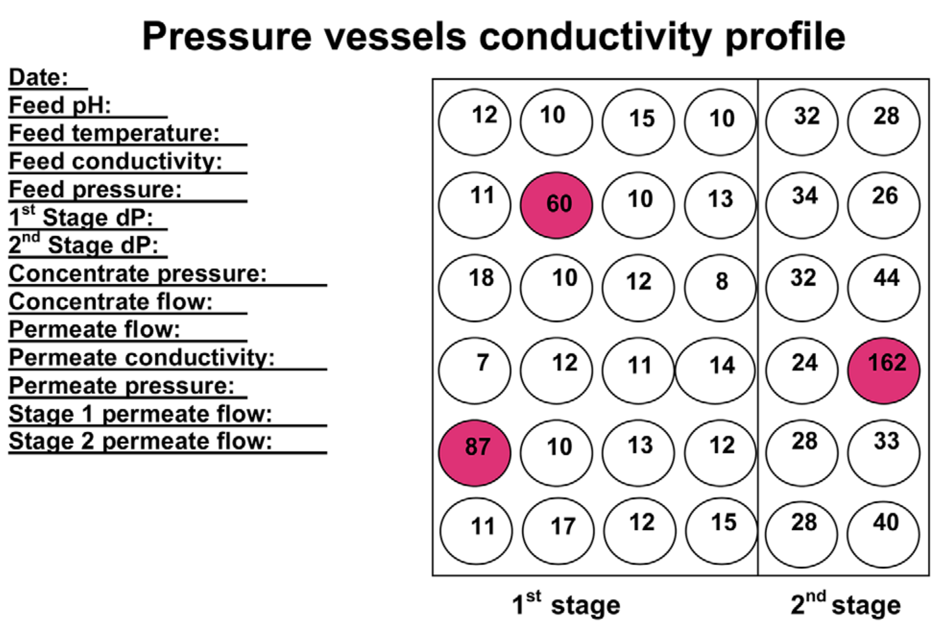

FIG. 17.1 Example of permeate conductivity measurement in a two stage membrane unit.

During system startup permeate conductivity from individual vessel is measured to assure that all pressure vessel produce uniform permeate salinity. If permeate conductivity from some of the vessels are significantly higher that the from the rest of the pressure vessels on a given desalting stage. The common culprit for higher permeate conductivity is leakage through misplaced or broken o-ring. It is also possible that that the high conductivity is caused by a defective element.

Conductivity "probing" procedure is usually applied to indentify location of the leak and to associate source of the leak with defective o-ring or with membrane element, which has high salt passage. Probing procedure involves inserting about 6mm (0.25") diameter tubing through the pressure vessel permeate port that is not connected to the product water manifold. The tubing is pushed to the very end of permeate tubes of connected elements. Then it is pulled back with sampling and measuring of conductivity every 500 mm (20"). The membrane elements are 1000 mm (40") long. Therefore the alternate positions, every 500 mm (20") represents either interconnector between elements or a middle of membrane element. Measurements of conductivity form "conductivity profile", which is compared with conductivity results calculated for given operating conditions, using computer projection program. The results of permeate conductivity measurements will be effected by the relative flow directions of feed and permeate streams, as demonstrated in Figs. 17.2 and 17.3

Fig. 17.2 illustrates accumulation of permeate flow along the pressure vessel for concurrent and countercurrent flow of feed and permeate. The direction

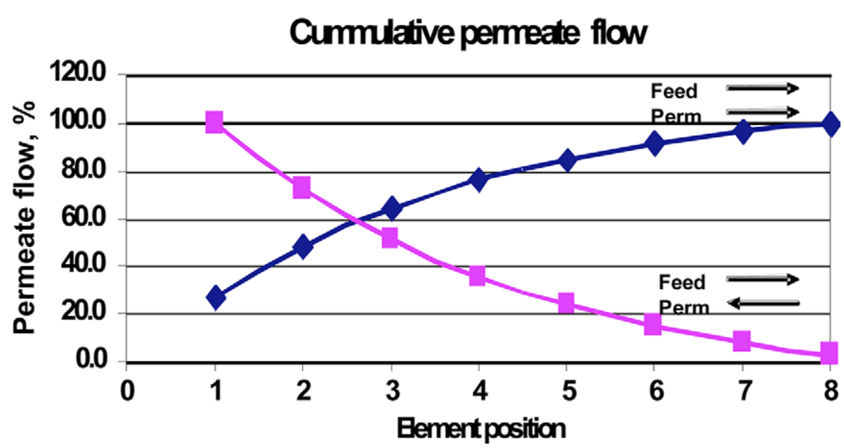

FIG. 17.2 Cumulative permeate flow in pressure vessel as a function of relative flow directions.

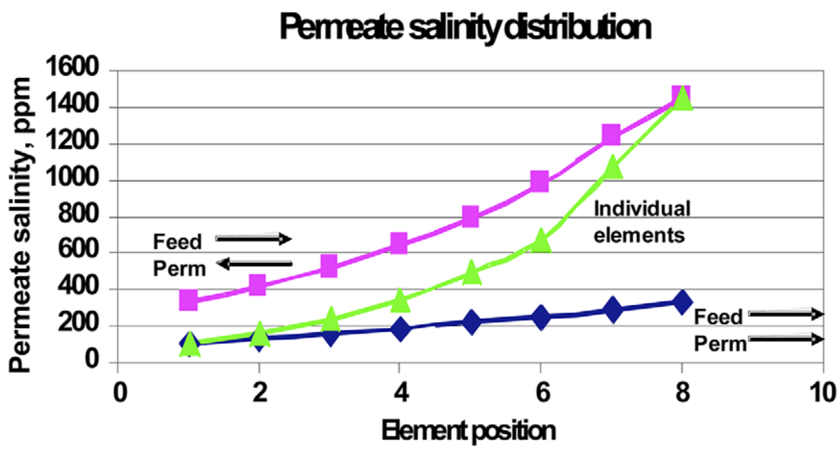

FIG. 17.3 Cumulative conductivity profile in pressure vessel as a function of relative flow directions.

of feed is always from feed port to the concentrate port. The direction of permeate flow is according to permeate manifold configuration. If the permeate collecting manifold is located at the concentrate end of pressure vessel, then the permeate flow will be concurrent with the feed flow direction. Otherwise, the feed and permeate flow directions will be opposite.

In a similar way permeate conductivity profile along the pressure vessel is determined by the relative directions of feed and permeate flows. For the concurrent flows, permeate conductivity starts with a very low values and increases along the vessel, till it reaches the maximum conductivity at the concentrate end of the vessel.

In countercurrent flow directions, the permeate port is connected to the permeate manifold at the feed end of the pressure vessel. The permeate conductivity starts at the relatively high conductivity, which the conductivity of the combined permeate at the exit from the pressure vessel. Moving in the direction of the concentrate port, the conductivity increases, till it reaches the highest conductivity at the concentrate end. When conducting conductivity probing, and comparing with projected values, relative flow directions have to be considered during performance evaluation.

After correcting potential leaks, the conductivity readings of permeate from individual vessels are taken periodically, usually after observed increase of conductivity from membrane train. In necessary conductivity probing is being conducted for pressure vessels with high permeate conductivity. Conductivity probing is a useful tool for targeting membrane elements in case of partial membrane replacement. Identifying membrane elements with high salt passage and selective replacement is significantly more effective in reduction of overall permeate salinity than replacement of group of elements based on their location in the membrane unit.

17.2 Normalization of membrane performance

Performances of RO membranes are affected by composition and physical parameters of feed water (temperature and pH) and system operating parameters (feed pressure, pressure drop, product pressure and settings of product recovery. As the conditions of feed water and operating parameters fluctuates, it is sometimes difficult to distinguish between performance changes that are result of changes of operating parameters and performance changes resulting from modification of intrinsic transport properties of membrane: changes of water permeability and salt transport.

In order to identify changes of intrinsic membrane performance such as permeability or salt passage, at the early stages of membrane deterioration process [2], system operational data are recorded at frequency at least once per day and normalized performance are calculated. The generic method of normalization of RO membrane performance is described in the ASTM procedure [1]. During operation of commercial RO plants, the following normalization approaches are adopted:

1. Normalization to the reference (initial) operating conditions of the plant.
2. Calculation of water transport and salt transport values for the membrane elements in operation
3. Normalization to the nominal element(s) test conditions

In the first normalization approach, one full set of basic operating parameters (flows, pressures, salinities and temperature) is collected and designated as a reference set of system operating data. In subsequent readings, system performances are corrected for changes of feed salinity, temperature and recovery rate and compared with the reference set of performances.

In the second normalization approach, operating data are transformed into values of average net driving pressure and average salt gradient. Average permeate flow and system salt passage is used to calculate average values of salt transport and water permeability.

In the Third normalization approach, readings of system (or stage) performances are reduced to a performance of an average element. These values are compared with nominal performance of membrane elements as provided by membrane manufacturer.

The common approach applied in commercial systems is normalization approach one and two.

In a multistage RO units, common in wastewater desalination plants, membrane element at different stages operate at significantly different conditions of feed salinity, flux rate and average cross flow rate. Therefore, it is recommend calculating normalized performance for each stage in a train separately.

In the normalization calculations process each set of plant (or desalting stage) flows, pressures and salinities data is initially reduced to the average values. These average values are assumed to be representative for an element positioned somewhere in the middle of the system, on the feed–concentrate cross section line: i.e. element that process an average feed salinity at an average applied feed pressure and produces average permeate flow. The averages are calculated based on feed–concentrate values. Then based on this data the water and salt permeability are calculated. In the normalization approach #1 every set of the performance data of the system are being recalculated to the initial operating conditions: temperature, average feed salinity and NDP.

Any of the above performance normalization method will provide good presentation of membrane unit performance trend. Some advantage of the first method is that, in addition to normalized permeate flow and salt passage, it usually also provides trend of the pressure drop. Pressure drop is an important indicator of early stage of fouling, which results in blockage of the element feed channels. In the normalization approach #2 the performance of the system are calculated and presented as a performance of an average element, it would perform, if tested at the nominal test conditions. The normalization approach #3 is very similar to the first one. In this calculations performance of RO system is reduced to performance of an average element. Then based on this data the water and salt permeability are calculated.

The set of operating parameters required for performance normalization includes:

- Date (and cumulative operating time)
- Membrane elements array and number of elements in operation
- Feed temperature (or permeate temperature if available)

- Feed pressure
- Interstage pressure (for each stage)
- Concentrate pressure
- Permeate pressure (for each stage if different)
- Feed conductivity
- Interstage conductivity (if available)
- Concentrate conductivity
- Permeate conductivity
- Permeate flow
- Concentrate flow
- Interstage flows (if available)

If the relevant data is available, calculation of normalized performance should be conducted for each stage separately.

Assuming that the number of elements in system is the same (constant membrane area), the normalization involves correcting measured performance for changes of feed water temperature, feed water salinity and/or changes of recovery rate.

The outline of different approach to performance normalization is provided in Table 17.1.

As discussed already in Chapter 11.8, temperature affects both the water permeability and salt transport. Temperature correction factor (TCF) for water permeability is given by Eq. 11.20:

$$TCF = 1/\exp(C \times (1/(273 + t) - 1/298)) \tag{11.20}$$

It is assumed that changes of temperature (t) have similar effect on salt passage as on water transport and similar value of constant (C) could be used in both calculations. However, this value could differ for different membrane materials. Therefore, the relation for TFC, and corresponding constants for water and salt transport, should be provided by membrane manufacturer or membrane supplier. In lack of specific information from membrane manufacturer, Eq. 11.20 could be used with value of constant C = 3000. The values of TCF for temperature range of 15–40°C (59–104) are shown in Fig. 11.7. To correct readings for temperature changes and to normalize to feed water temperature of 25°C (77°F), the readings are multiplied by the TCF. The temperature values

TABLE 17.1
Outline of the performance normalization procedures.

Collect relevant system operating data and information on nominal test condition (NTC) for element type used in the system		
Normalization to reference operating conditions	Normalization to nominal test conditions	Calculation of average water and salt transport values
Calculate the following parameters: 1. Recovery rate 2. Concentration factor 3. Average feed salinity 4. Average osmotic pressure 5. Net driving pressure 6. Average permeate flux 7. Temperature correction factor 8. Specific flux 9. Salt passage 10. Normalized salt passage 11. Normalized pressure drop	Calculate the following parameters: 1. Parameters 1–7 from column 1 2. Permeate flux at NTC 3. Concentration factor at NTC 4. Average feed salinity at NTC 5. Osmotic pressure at NTC 6. Net driving pressure at NTC 7. Average permeate flux in the system 8. Average element normalized permeate flow 9. Average normalized salt passage (rejection)	Calculate the following parameters: 1. Parameters 1–7 from column 1 2. Average permeate flux 3. Water transport 4. Salt transport

used for normalization are of feed water temperature, preferably measured after the discharge from high pressure pump. If available, temperature of permeate should be used, which is usually 1–1.5°C higher than the temperature of feed water.

Feed salinity is directly related to osmotic pressure. Osmotic pressure corresponding to average feed salinity is part of Eq. 11.16 applied for calculation of NDP.

$$NDP = P_f – P_{os} – P_p – 0.5 \times P_d \qquad (11.16)$$

The NDP values are used to calculate specific permeability or specific flux (SF) according to Eq. 11.22.

$$SF = APF/NDP \qquad (11.22)$$

The SF is multiplied by the corresponding TCF to correct for temperature effect on water permeability.

Changes of feed salinity would result in parallel changes of permeate salinity.

The recovery ratio affects average feed salinity (AFS) through the concentration factor as expressed in Eqs. 11.12 and 11.13.

$$AFS = Cf \times 0.5 \times (1 + 1/(1 - R)) \qquad (11.12)$$

$$AFS = C_f \times Ln\ (1/(1 - R))/R \qquad (11.13)$$

The value of apparent salt passage, calculated from the ratio of permeate salinity to the average feed salinity, is affected by temperature and permeate flux rate. Higher temperature will increase salt passage. Higher flux rate will result in decrease of apparent sat passage due to higher dilution of species passing through the membrane.

The normalized salt passage (NSP), in respect of temperature and permeate flux, is calculated according to Eq. 17.1.

$$NSP = SP \times APF/APF_r \times TCF \qquad (17.1)$$

where SP is salt passage, APF is average permeate flux at current conditions, APF_r is average permeate flux at reference conditions and TCF is temperature correction factor for current feed water temperature.

Eq. 17.1 will provide value of salt passage corrected to reference flux conditions and the temperature of 25°C (77°F). If temperature correction to reference a temperature is required, than TCF_r for reference temperature should be incorporated into calculations as shown in Eq. 17.2.

$$NSP = SP \times APF/APF_r \times TCF/TCF_r \qquad (17.2)$$

The relation for calculation of pressure drop is provided by Eq. 15.24

$$P_d = A \times Q_{fb}^B \qquad (15.24)$$

where P_d is pressure drop, A and B are constants specific for element configuration (provided by membrane manufacturer), Q_{fb} is an average flow rates of feed–concentrate streams

Normalized pressure drop is calculated according to Eq. 17.3

$$NP_d = Pd \times (Q_{fbr} / Q_{fb})^B \tag{17.3}$$

where NP_d is normalized pressure drop, Q_{fbr} is an average flow rates of feed–concentrate streams at the reference conditions.

If feed water temperature is significantly below 25°C, then normalization of pressure drop should include applying correction for increased viscosity of water at reduced feed water temperature.

In all methods of normalization, outlined in Table 17.1, to first step is collection of relevant operating parameters and calculation of average representative parameters for the system: average feed salinity, average net driving pressure and average permeate flux. These parameters, together with temperature correction factor, enable normalization of system performance data as shown in the following examples.

Table 17.2 includes information on relevant system configuration and sets of "initial" and "current" operating parameters, required for system normalization. Following examples 17.1–17.3 illustrate calculation of normalized values.

Example # 17.1

Normalization of system performance to the initial operating conditions according to performance data included in Table 17.2.

Recovery rate – R
$R = Q_p/(Q_p + Q_c)$
$R(1) = 200/(200 + 50) = 0.80$
$R(2) = 180/(180 + 60) = 0.75$

Concentration factor – CF
$CF = \ln(1/(1 - R))/R$
$CF(1) = \ln(1/(1 - 0.80))/0.80 = 2.01$
$CF(2) = \ln(1/(1 - 0.75))/0.75 = 1.85$

Average feed salinity, ppm – C_{favg}
$Cfavg = C_f \times CF$
$C_{favg}(1) = 2000 \times 2.01 = 4020$
$C_{favg}(2) = 2500 \times 1.85 = 4625$

TABLE 17.2
Example of system configuration and two sets of operating parameters.

Brackish RO unit. Array 20:10. Number elements per vessel–7			
		Initial values of operating parameters, conditions 1	Current values of operating parameters, conditions 2
Feed salinity (C_f)	ppm TDS	2000	2500
Permeate salinity (C_p)	ppm TDS	30	50
Feed pressure, (P_f)	bar (psi)	14 (203)	16 (232)
Concentrate pressure (P_c)	bar (psi)	10.5 (152)	11 (160)
Feed– concentrate pressure drop (P_d)	Bar (psi)	3.5 (51)	5 (72)
Permeate pressure (P_p)	bar (psi)	1.5 (22)	1.5 (22)
Feed temperature (t)	C	18	22
Permeate flow (Q_p)	m^3/hr (gpm)	200 (880)	180 (792)
Concentrate flow (Q_c)	m^3/hr (gpm)	50 (220)	60 (264)
Element type		8040 ESPA2	8040 ESPA2
Number of elements (NE)		210	210
Membrane area per element (MA)	m^2 (ft^2)	37 (400)	37 (400)

Average osmotic pressure, bar (psi) – P_{osmavg}
$P_{osmavg} = 0.77\ C_{favg}/1000$
$P_{osmavg}(1) = 0.77(4020/1000) = 3.1\ (45\ )$
$P_{osmavg}(2) = 0.77(4625/1000) = 3.5\ (51\ )$

Average permeate flux, l/m^2/hr (gfd) – APF
$APF = Qp \times 1000/(EN \times MA)$
$APF(1) = 200 \times 1000/(37 \times 210) = 25.7\ (15.1\ )$
$APF(2) = 180 \times 1000/(37 \times 210) = 23.2\ (13.6)$

Temperature correction factor – TCF
$TCF = 1/\exp(2700(1/(273 + t) - 1/298))$
$TC\ F(1) = 1/\exp(2700(1/(273 + 18) - 1/298) = 0.805$
$TC\ F(2) = 1/\exp(2700(1/(273 + 22) - 1/298) = 0.778$

Net driving pressure bar (psi) – NDP
$NDP = Pf - 0.5(P_f - P_c) - P_p - P_{osmavg}$
$NDP(1) = 14.0 - 0.5(14.0 - 10.5) - 1.5 - 3.1 = 7.65$ (111)
$NDP(2) = 16.0 - 0.5(16.0 - 11.0) - 1.5 - 3.5 = 8.50$ (123)

Specific flux L/m^2/hr/bar (gfd/psi)–SF
$SF = APF/(NDP \times TCF)$
$SF(1) = 25.7/(7.65 \times 0.778) = 4.31$ (0.172)
$SF(2) = 23.2/(8.50 \times 0.805) = 3.39$ (0.136)

Salt passage, % – SP
$SP = 100 \times C_p/C_{favg}$
$SP(1) = 100 \times 30/4020 = 0.74$
$SP(2) = 100 \times 50/4625 = 1.08$

Normalized salt passage, % – NSP
$NSP(2) = SP(2) \times APF(2)/APF(1) \times TCF(2)/TCF(1)$
$NSP(2) = 1.08 \times 23.2/25.7 \times 0.778/0.805 = 0.94\%$

Average feed flow m^3/hr (gpm) – Q_{favg}
$Q_{favg} = (Q_f + Q_c)/2 = (Q_p + 2Q_c)/2$
$Q_{favg}(1) = (200 + 2 \times 50)/2 = 150$ (660)
$Q_{favg}(2) = (180 + 2 \times 60)/2 = 150$ (660)

Normalized pressure drop, bar (psi) – NP_d
$NP_d = P_d\ (Qfavg1/Qfavg2)^{1.4}$
$NP_d = 5.0\ (150/150)^{1.4} = 5.0$ (73)

Example # 17.2

Normalization of system performance (Table 17.2, conditions 2) according to the nominal test conditions

Element membrane area:	37 m^2 (400 ft^2)
Nominal permeate flow:	34 m^3/day (9000 gpd)
Nominal salt rejection:	99.5%
Test pressure:	10.3 bar (150 psi)
Pressure drop	0.3 bar (4 psi)
Feed salinity	1500 ppm NaCl
Recovery rate	15%
Temperature	25°C

Permeate flux at nominal test conditions, l/m^2/hr (gfd)

TABLE 17.3
Summary operating parameters normalized to initial performances.

Normalized value	Initial values	Current values	Difference, %
Specific flux, l/m^2-hr-bar (gfd/psi)	4.31 (0.172)	3.39 (0.136)	–21
Salt passage, %	0.74	0.94	+27
Pressure drop, bar (psi)	3.5 (51)	5.0 (73)	+42

$PF_n = 34 \times 1000/(37 \times 24) = 38.2$ (22.5)

Concentration factor at nominal test conditions
$CF_n = \ln(1/(1-0.15))/0.15 = 1.083$

Average feed salinity at nominal test conditions
$C_{favgn} = 1500 \times 1.083 = 1624$ ppm

Osmotic pressure at nominal test conditions, bar (psi)
$P_{osmn} = 0.77 \times 1624/1000 = 1.2$ (17)

Net driving pressure at nominal test conditions, bar (psi)
$NDP_n = 10.3 - 0.5 \times 0.3 - 1.2 = 8.9$ (129)

Average element permeate flux in the system (Table 17.2), $l/m^2/hr$ (gfd)
$APF(1) = 200 \times 1000 /(210 \times 37) = 25.7$ (15.1)
$APF(2) = 180 \times 1000 /(210 \times 37) = 23.2$ (13.6)

Average element permeate flow in the system (Table 17.2), m^3/day (gpd)
$Q_{pavg}(1) = 200 \times 24 /210 = 22.85$ (6036)
$Q_{pavg}(2) = 180 \times 24 /210 = 20.57$ (5434)

Average element permeate flow normalized to nominal test conditions (NDP and TCF from Example 17.1), m^3/day (gpd)
$Q_{pavgn}(1) = 22.85 \times 8.9/(7.65 \times 0.778) = 34.13$ (9018)
$Q_{pavgn}(2) = 20.57 \times 8.9/(8.50 \times 0.805) = 26.77$ (7072)
Change of permeate flow between conditions 1 and 2: – 22%

Average element salt passage normalized to nominal test conditions (SP(1) and SP(2) from Example 17.1)
$SP_n(1) = 0.74 \times (25.7/38.2)/0.778 = 0.64$
$SP_n(2) = 1.08 \times (23.2/38.2)/0.805 = 0.81$
Salt passage change: + 27%

Average element salt rejection normalized to nominal test conditions, %
Rej (1) = 100 – 0.64 = 99.26
Rej (2) = 100 – 0.81 = 99.19

Example # 17.3

Calculation of water transport and salt transport values for the membrane elements in operation.

Calculations of water transport value (A) are conducted according to Eq. 11.3 using values of average permeate flux and net driving pressure, calculated in Example # 17.1. According to Eq. 11.3 water flow Q_w is a product of specific permeability – A, membrane area – MA and net driving pressure – NDP. Rearranging Eq. 11.3, the relation for calculation of A is given below:

$$Q_w = A \times MA \times NDP \tag{11.3}$$

$$A = APF/NDP$$

The units of A are sec-1

$$A(1) = 25.7\ (1000/\ 10000 \times 3600)/(7.65 \times 1000) = 9.3E-8$$

$$A(2) = 23.2\ (1000/\ 10000 \times 3600)/(8.50 \times 1000) = 7.6E-8$$

Difference of water transport coefficients–19%

Calculations of salt transport value (B) are conducted according to equation 11.5 using values of average permeate flux and average feed salinity, calculated in Example # 17.1

$$Q_s = B \times MA \times DC \tag{11.5}$$

$$B = APF \times (Cp/\ DC)$$

The units of B are g/cm^2-sec

At low permeate salinity one can assume that DC equals average feed salinity: C_{favg}

$$B(1) = 25.7\ X30\ (1000/\ (10000 \times 3600))/4020 = 5.32E-6$$

$$B(2) = 23.2\ X50(1000/\ (10000 \times 3600))/4625 = 6.95E-6$$

Difference of salt transport coefficients + 30%

The calculation examples listed in Examples 17.1–17.3 illustrate three different methods of performance normalization calculation. All calculations are based on the same principles that permeate flow depends on net driving pressure and temperature, and salt passage is function of salinity gradient. In the above calculations, the same value of temperature correction factor has been used for normalization of water and salt transport. Most likely, the effect of temperature differs for each case, but for the purpose of performance normalization, it is sufficient, as the relative changes and performance trend is of importance.

The above methods of normalization are accurate enough for normalization of performance of brackish membrane elements. In normalization of performance of low rejection nanofiltration elements, salinity of permeate should be included in calculations of NDP and salinity gradient. In system operating with high salinity feed (seawater), concentration polarization has significant effect on permeate flow. This effect should be account for, especially in calculations of normalized permeability. Otherwise, comparison of performance results obtained at different feed salinities will not provide meaningful results [3].

In commercial desalination systems, normalization of membrane performance is conducted applying the above relations in the form of computer spreadsheet. Larger systems tend to utilize normalization programs that are part of PLC computer program. Some desalination plants use programs, developed especially for the specific configuration of membrane unit. Other use generic normalization programs that are available from majority of RO membrane manufacturers and could be downloaded from their internet home pages [4–8].

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11. Increasingly, water reuse facilities use UV light-based processes to perform a variety of water treatment objectives. Beyond its well-known ability to perform disinfection, UV light (either alone or in combination with hydrogen peroxide) is also able to destroy chemical micropollutants such as pharmaceuticals, pesticides, and industrial solvents pharmaceuticals present in water. This section provides an overview of UV light-based processes for both disinfection and environmental contaminant treatment (ECT) in water reuse applications.