Operation, Maintenance and Handling Manual for membrane elements

'TORAY'

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Introduction

Proper operation and maintenance of a Reverse Osmosis (RO) systems are key factors in maximizing long-term plant availability and efficiency with minimized fault-related down times.

These key factors must be considered starting from the design phase, and throughout manufacturing, erection and commissioning.

Selection RSU-400 (this section) presents checklists and procedures for commissioning and features useful information concerning operation monitoring methods applicable to all RO/NF systems using TORAY ROMEMBRA membrane elements.

Fitting RO elements into pressure vessels

1. Prior to installation – preparations

1) Before directing pre-treated feed water to elements, make sure inside of piping system and pressure vessels are free of dust, oil, metal residues etc. In case of severe pollution by foreign contaminations, it may be effective to clean inside of the pressure vessels by soft rotary brush flushing with pre-treated water. In no case the inside of the pressure vessels are damaged or scratched. This procedure also applies in case of element replacement or renewal.
2) Check feed water quality to meet recommendations for applied membrane elements. Flush RO system with pre-treated feed water at low feed pressure prior to start of high pressure pump for approx. 30 minutes.
3) Remove end plates from both ends of pressure vessel, check the inside of the vessel and if necessary clean mechanically.
4) Install permeate adapter with O-rings into the permeate port of brine side end plate. Lubricate both parts using only glycerin.

   Note: Do not install “thrust ring” if SU types will be fitted into pressure vessel. necessary only for TM element types.
5) Attach brine side end plate onto the brine side of the vessel and install retaining ring set according to instruction manual of the pressure vessels.
6) Prepare the necessary parts as shown in the following table:

Parts	**Required quantity**	
	SU type	**TM type**
Brine seals	m	m
O-rings	2×m	4×m
Permeate adapter open	n	n
Permeate adaptor closed	–	n
Interconnectors	m – n	m – n
Product tube caps	n	–

m: number of elements, n : number of pressure vessels

Note: The above parts except the vessel’s permeate adapter are shipped with each element package. Permeate adapters are shipped with pressure vessels. When ordering pressure vessels, please specify type of RO element to be installed.

7) Attach O-rings
   Apply glycerin to the O-ring. Attach O-rings to the interconnectors and product tube caps. We recommend that O-ring is adequately expanded to avoid twisting when it is put on interconnector.

2. Insertion of elements

1) Take an RO element out of the carton and the plastic bag.
   Note: The shipping bags are made of a material with extra high oxygen rejection, which improves lifetime of preservation solution. If bags are cleanly cut open at one end, some can be kept and re-used in case any RO elements must be conserved or sipped.
   The element is conserved in 0.5% to 1% sodium bisulfite solution! Protect eyes and skin.
2) Apply glycerin to outer (SU type) resp. inner (TM type) surface of the element's product tube. Install brine seal on the element as in Fig. 410.1 and 410.7. Be sure to attach the brine seal correctly.
   Note: Brine seal should be installed at feed end of each element.
3) Insert element from feed side end into the pressure vessel about 2/3 (see Fig. 410.2 and 410.8), after lubricating brine seals and vessel's inner surface with glycerin. Insert element carefully and smoothly, especially the first element.
4) Attach inter-connector to product tube at the feed end of the inserted element (see Fig. 410.3 and 410.10).
5) Attach brine seal to the second element as described for the first element. Connect the two elements at the interconnector, see Fig. 410.3 and 410.12. The partly inserted element is best held in place by a helper. Now push both elements smoothly and firmly into vessel, keeping them in line to avoid damages to inter-connector or brine seal.
6) Repeat procedures described in step (4) to (5) (see Fig.410.3 and 410.12). Insert elements one by one into the pressure vessel.
7) After inserting last element, attach tube cap resp. end plug to front end of permeate tube for SU types or the correct permeate adaptor for TM types (see Fig.410.4, 410.5, 410.11 and 410.12).
8) Push the last element home until the first (downstream) element's permeate tube is firmly connected.
9) Check distance "A" between product tube cap and plug installed in permeate adaptor of feed side end plate. If all elements are correctly inserted, the

distance “A” must be < 5mm, (see Fig.410.5). This procedure is only required if a tube cap or a plug is used.

10) Attach the feed side end plate of pressure vessel, and fit piping system to brine port of end plate.

3. Initial start-up checks

After finishing of piping and installation work, successively carry out initial start-up checks according to RSU-420.

4. Distance A (SU type)

After installing all membranes (see Fig.410.1 – 410.4), use shim rings provided by the pressure vessel manufacturer to make sure that the distance “A” (Fig.410.5) is < 5mm (0.2 inch). If distance “A” is too large, element stack will move too much, causing damage of O rings (interconnectors and / or permeate adapter) and disconnection of permeate adapter. In both cases brine / feed water will leak into permeate and spoil product quality. The risk of mechanical disconnection of permeate adapters is especially high if the permeate header is connected to feed side of pressure vessel. Therefore Toray highly recommends to install permeate system on the brine side of pressure vessels only.

On the feed side of element stack, use the product tube cap (Fig.410.4) supplied by Toray instead of the permeate adapter which may be supplied by the pressure vessel manufacturer. This provides best protection against “short-circuit” of permeate and brine. For end plate’s permeate port, use a correctly shimmed plug (available from pressure vessel manufacturer, to indicate when ordering).

For SU elements, do not install “thrust rings” supplied by vessel manufacturer. Construction of SU elements is such that axial forces (resulting from delta p) are absorbed by permeate tube. The fiberglass wrapping of SU is not suitable for absorbing axial forces. Use of thrust rings may result in damage to ATD (Anti-telescoping Device), fiberglass wrapping or the element itself.

5. Distance A (TM type)

After installing all membranes (see Fig.410.7 – 410.12), use shim rings provided by the pressure vessel manufacturer to make sure that the distance “A” is < 5mm (0.2 inch). If distance “A” is too large, element stack will move too much, causing damage of O-rings (interconnectors and / or permeate adapter) and disconnection of permeate adapter. In both cases brine / feed water will leak into permeate and spoil product quality. The risk of mechanical disconnection of permeate adapters is especially high if the permeate header is connected to feed side of pressure vessel. Therefore Toray highly recommends to install permeate system on the brine side of pressure vessels only.

6. Shimming Procedure

There are variations in length from vessel to vessel and from element to element. The acceptable variation is specified on the engineering drawings. The minimum distance between the inside faces of the installed end cap assemblies is normally designed to accommodate maximum length elements and adaptor pieces. If any of the internal components are of less than maximum length, there will be "free space" in the vessel. It is highly recommended to shim the elements to take up free space in the vessel.

The shimming process:

- Helps to minimize element movement inside the vessel when the system is shut down and restarted.
- Helps to minimize o-ring movement against the sealing surfaces, so reducing wear and possibility of "rolling" o-rings. This reduces leakage.

Shims are normally positioned on the upstream end of the vessel, between the endcap and the adaptor.

Shim material: Shims are plastic "washers" typically made of PVC material, though other hard plastics would also be suitable.

Shim diameter: Inside diameter should be sufficient to fit over adaptor stub (lead end), and outside diameter should be not less than diameter of adaptor shank. These dimensions are not critical dimensions.

Shim thickness: Shim thickness is not critical dimensions. It would be typical to have shims available in the following thickness, 1 – 5 mm.

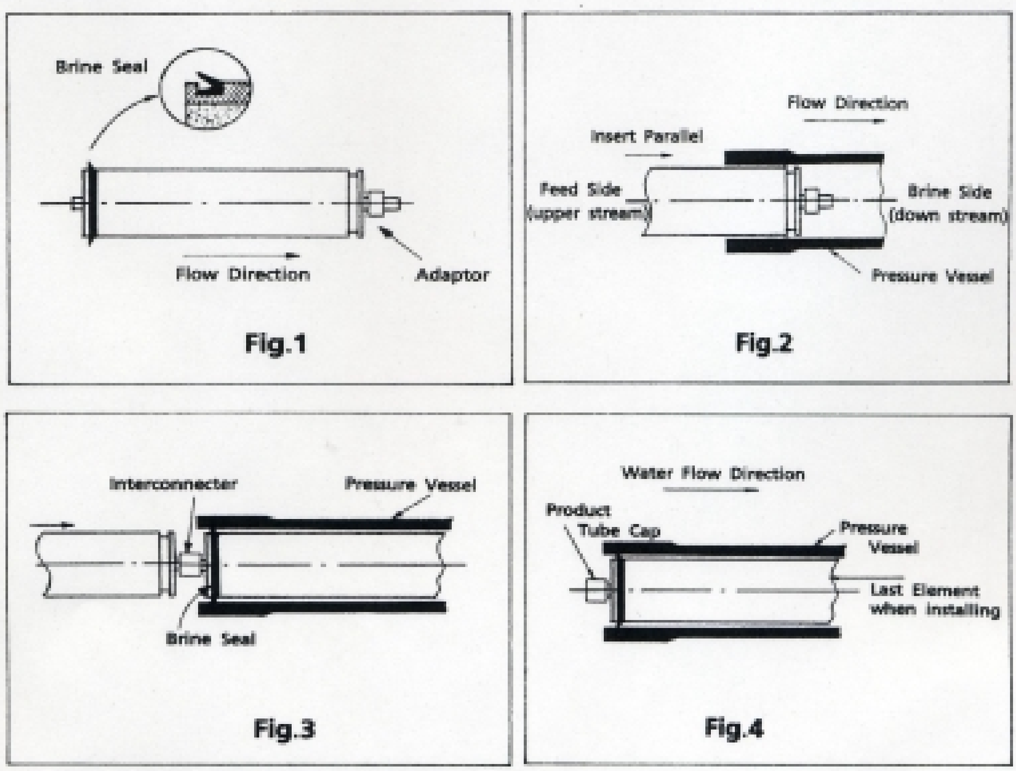


Fig. 410.1 to 410.4 : **Insertion of elements**

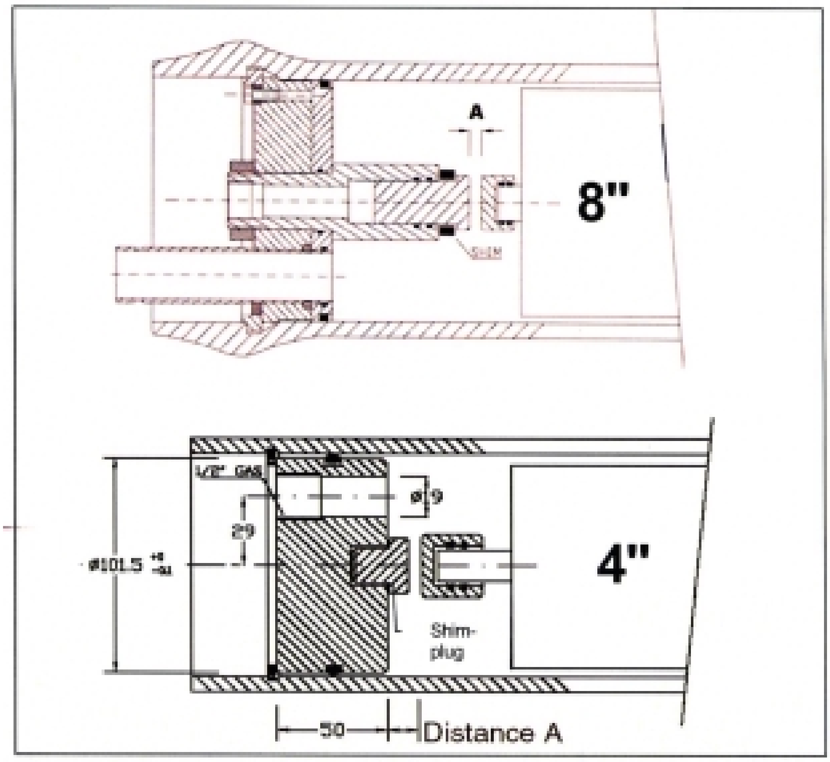


Fig. 410.5 : Distance A between end cap and shim plug

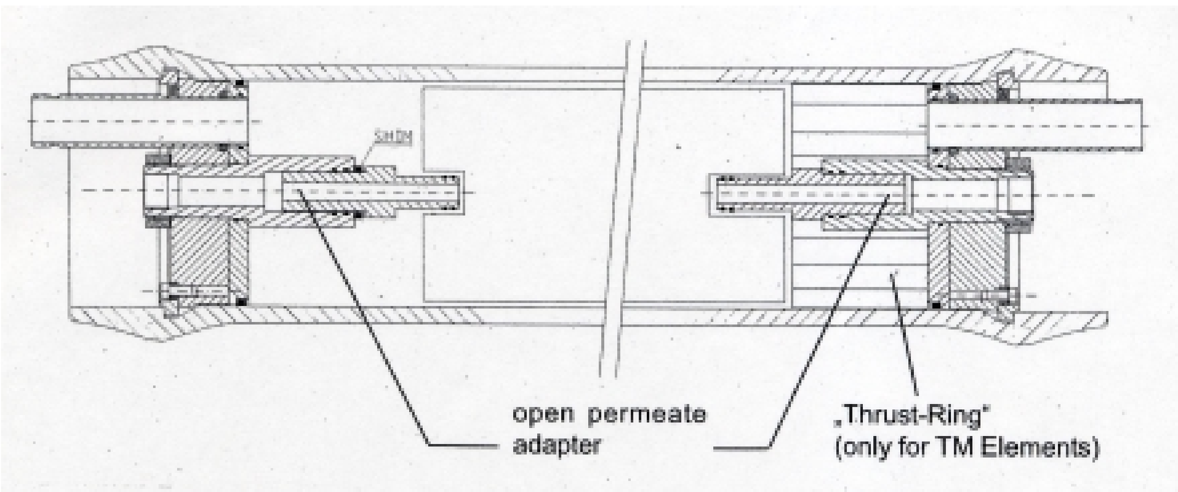


Fig. 410-6 : TM module 8 inch with thrust-ring on the concentrate side

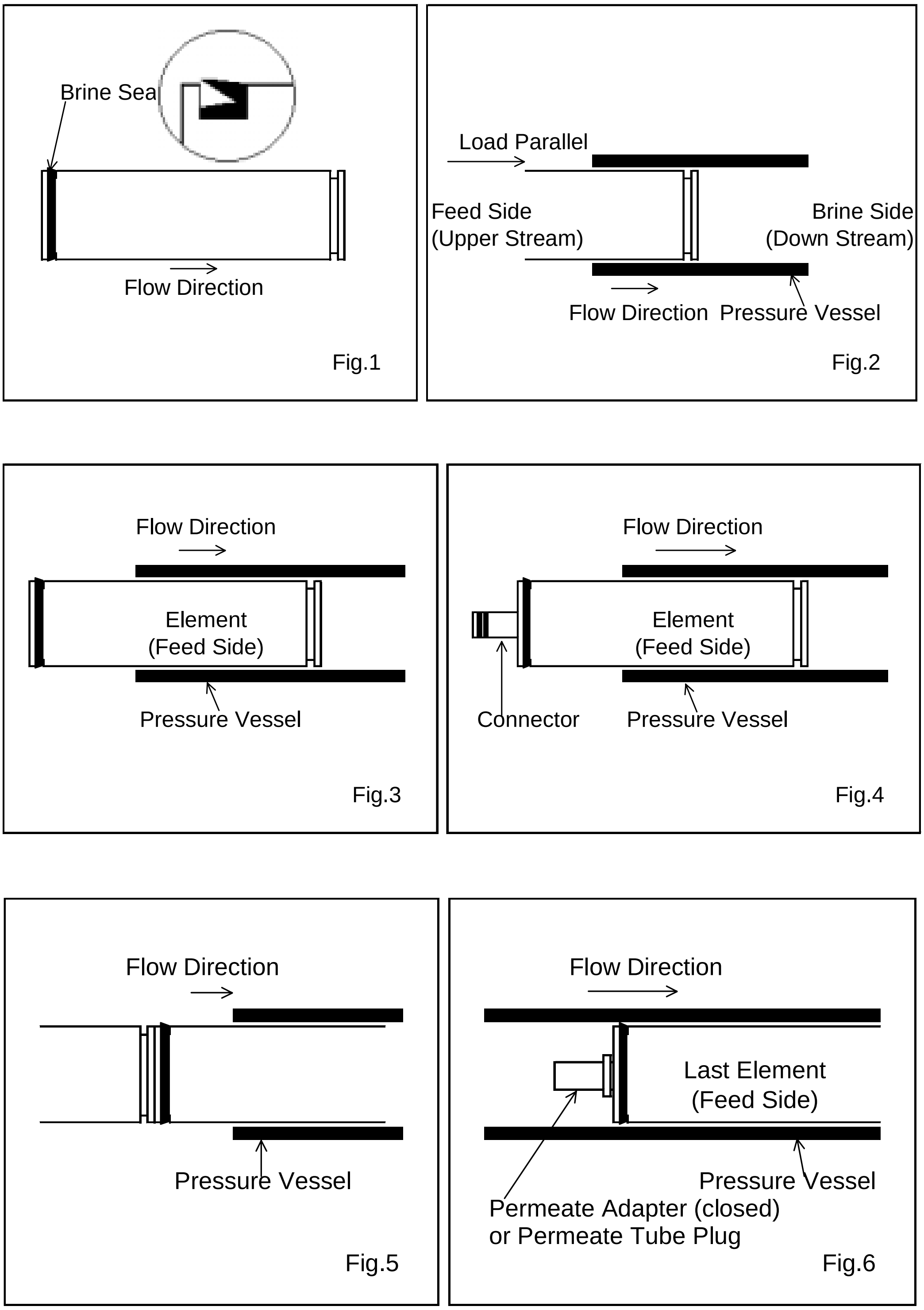


Fig. 410.7 to 410.12 : Insertion of elements (TM)

Removal of elements

If elements have to be removed from pressure vessels, e.g. for inspection, storage, shipment or replacement, proceed as following:

1) Disconnect feed, brine and permeate ports of pressure vessel, and remove connected fittings.
2) Remove end plates from both sides of the pressure vessel.
3) Push elements from the feed side until end of the downstream element appears at the brine side.
4) Pull out the element from the brine side slowly. Remove the interconnector from the next element.
5) Repeat this process, if necessary use e.g. a plastic pipe for pushing the elements through .
6) If re-installation of the elements is foreseen, they are to be packed directly into clean plastic bags, (see RSU-600). For re-fitting elements, proceed according to RSU-410.

Start-up check lists for RO system commissioning

1. Checks before commissioning

1) Prior to fitting membrane elements and directing water RO system, make sure all fittings are tight (in particular Victaulic joints and pressure vessel's end closures), all instruments and components are operating properly, and feed water matches requirements for RO elements to be installed, In particular, check the following items:

- Cleanliness of system; clean according to RSU-410 where necessary
- Fouling Index (SDI)
- Turbidity (NTU)
- Absence of chlorine and other oxidants
- Sufficient bisulphite surplus (if used for chlorine removal)
- Absence of flocculants, in particular cationic and nonionic compounds, originating from raw water pretreatment.

  Filter Cartridges must be free of surfactants, lubricants and textile aides. Either order them accordingly or, if unsure, flush them properly according to guidelines of cartridge manufacturer.

Before installing RO elements and pumping pre-treated water to pressure vessels, verify all dust, grease, oil, metal residues etc. have been removed from pipe installation. If necessary, clean and flush piping and pressure vessels before installation of elements. Then Install RO elements. Detaied instructions for installation and pre-commissioning system cleaning, see section RSU-410. And permeate back pressure is one of the most critical problem at start-up. It is necessary to write correct valve position setting before water feeding.

2) After elements installation, purge air from piping system, including headers and RO vessels for minimum one hour with pre-treated feed water at low feed pressure, with brine valve fully opened. Pay attention to not to exceed allowed ranges for low and differential pressure!
At the air venting, initial water velocity is very much high because of "air & water" flow condition. It is better to start from low flow rate to avoid any shock at air venting. After water coming from brine piping, it is recommended to increase flushing flow rate to remove air effectively.

And at the flushing for air venting, it is effective to repeat shut-down and start-up several times. Continuous pressurizing of flushing makes air volume smaller by pressure, however, during shut-down, air volume become normal and it is much easy to remove at next flushing.

Feed flow rate per vessel should be in the following:

8"vessel: 40 - 200 l/min
4"vessel: 10 - 50 l/min

Pressure drop (feed to brine) across a pressure vessel/ a single RO element must never exceed the following values:

Element type TM	**Per vessel**	**Per single element**
8"	0.4 MPa	0.15 MPa
4"	0.4 MPa	0.15 MPa
Element type SU	**Per vessel**	**Per single element**
8"	0.3 MPa	0.1 MPa
4"	0.3 MPa	0.1 MPa

3) After bleeding air from system, initial trial run can commence according to design operating parameters. In particular, check and adjust the following parameters to design value:
   - Permeate flow rate
   - Recovery ratio
   - Operation pressure

   Prior to final evaluation of trial run, operate for minimum two hours at design operating conditions. During trial run, dump permeate and brine. Operate smaller systems with internal concentrate recirculation at lower system recovery without using the recirculation.

4) Check quality of permeate and system performance as following:
   Check permeate conductivity for each vessel. If conductivity of permeate is found above specification, check O-rings, brine seals etc. of the vessel affected, and charge parts if necessary. Log all data and corrective measures taken.
   The data of 1, 24, 48 hour after start-up should be checked carefully. These data should be used for normalization standard data.

Data to be logged in particular:

- Feed: Feed pressure, temperature, TDS (conductivity), pH, fouling index (SDI), turbidity (NTU), chlorine (not detectable*)
- Differential pressure across each RO bank
- Brine: Brine flow, TDS (conductivity), pH
- Permeate: Permeate flow of each bank and total system, TDS (conductivity) from each vessel and total system.

*) In case of $NaHSO_3$ dosing, for chlorine removal, min. 0.5 mg/l HSO_3^- must be detectable in brine at any time.

It is recommended to take water samples for analysis of individual ions.
Compare operation results with projected data.
A typical data log sheet is shown in section RSU-430.

2. Regular start-up checks in daily operation

1) Check feed water quality to meet recommendations for applied membrane elements.
2) Flush RO system with pre-treated feed water at low feed pressure prior to start of high pressure pump.
3) Regulating valve between high-pressure pump discharge and membranes should be nearly closed at HPP start-up to avoid water hammer.
4) Gradually increase feed pressure (< 0.5 kg/cm2 increase per second) and feed flow rate to RO elements while throttling brine flow rate. Avoid excessive flow rates and differential pressures across RO banks during start up!

Note: At any time, maximum pressure drop across any vessel is 0.3 MPa for all SU, 0.4 MPa for TM-types. Details according to specification for each type of elements.

5) Adjust RO operating parameters to targeted permeate and brine flow rates. Do not exceed design recovery ratio (= permeate flow rate/feed water flow) during any stage of operation.
6) Dump permeate until required water quality is obtained.

3. High pressure pump (HPP) start-up procedures

This section describes typical start-up procedures, sorted by type of HPP.

RO systems will usually employ one of those four different types of high-pressure pumps:

1) Plunger (displacement) pump system with constant speed motor (fig.420.1)

1. Open brine control valve (V_B), to approx. 50%.
2. Open relief loop valve (V_R).
3. Close feed pressure control valve (V_F), if installed.
4. Start high pressure pump (HPP).
5. Slowly open V_F and close V_R until brine flow reaches design value.
6. Close V_B until brine flow starts decreasing. Feed pressure now starts to increase.
7. Check feed pressure, pressure drop and permeate flow.
8. Repeat procedure 5-7 step by step until permeate and brine flow match design.

2) Centrifugal pump system with constant speed motor (fig.420.2)

1. Open brine flow control valve (V_B), to approx. 50%.
2. Open minimum flow valve (V_M).
3. Close feed pressure control valve (V_F). If no V_M is installed, throttle to minimum flow.
4. Start high pressure pump (HPP).
5. Slowly open V_F until brine flow reaches design value (observe note!).
6. When minimum flow for HPP is reached, close V_M (if installed).
7. Close V_B until brine flow starts decreasing. Feed pressure now starts to increase.
8. Check feed pressure, pressure drop and permeate flow.
9. Repeat procedure 5-7 step by step until permeate and brine flow match design.

Note: In case excessive brine flow is obtained at point 4 (watch ΔP), brine flow control valve V_B must be throttled from step (1).

3) Centrifugal pump system with constant speed motor and soft start (fig.420.3)

1. Open brine flow control valve (V_B).
2. Throttle feed pressure control valve (V_F) to approx. 10% .
3. Start high pressure pump (HPP), (see note (A),(B)).

4. Slowly open V_F until design brine flow is reached.
5. Close V_B until brine flow starts decreasing. Feed pressure now starts to increase.
6. Check feed pressure, pressure drop and permeate flow.
7. Repeat procedures 4-6 step by step until permeate and brine flow match design.

   Note(A): In case excessive brine flow is obtained, (watch ΔP), brine flow control valve (V_B) should be set to throttled position in advance.

   Note(B): In order to avoid excessive feed flow, feed valve is to be throttled from the beginning.

4) Centrifugal pump system with frequency controlled motor (fig.420.4)

1. Open brine flow control valve (V_B).
2. Start high pressure pump (HPP) at minimum frequency (speed).
3. Increase speed of HPP until design brine flow is reached.
4. Close V_B until brine flow starts decreasing. Feed pressure now starts to increase.
5. Check feed pressure, pressure drop and permeate flow.
6. Repeat procedure 3-5 step by step until permeate and brine flow match design.

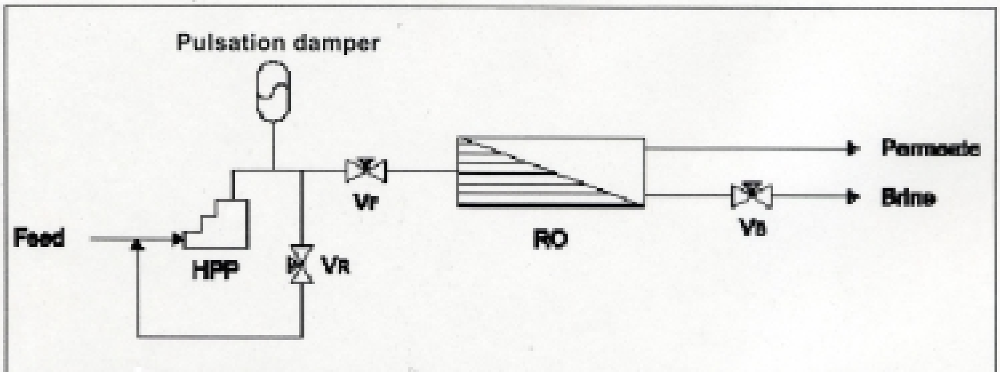


Fig. 420.1 : Plunger (displacement) pumps system with constant speed motor

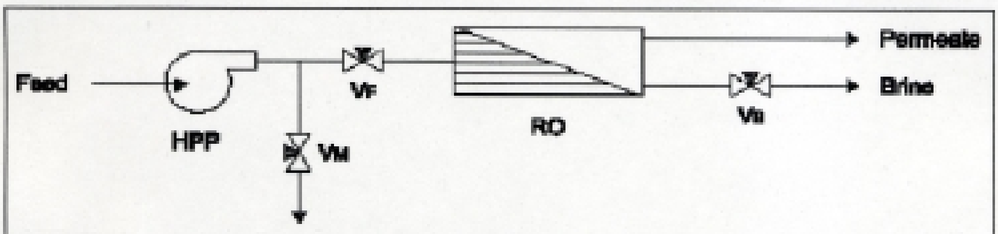


Fig. 420.2 : Centrifugal pump system with constant speed motor

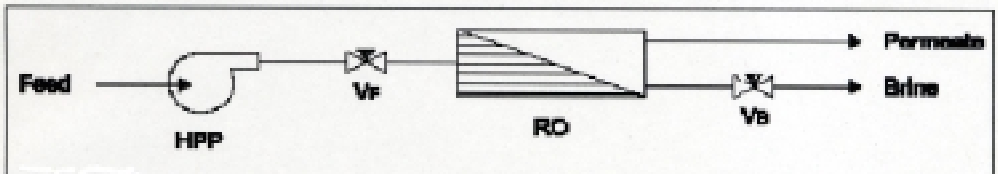


Fig. 420.3 : Centrifugal pump system with constant speed motor and soft start

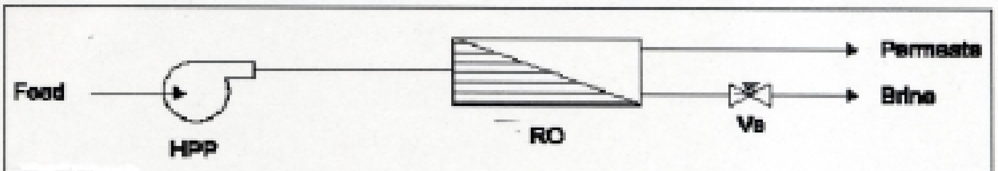


Fig. 420.4 : Centrifugal pump system with frequency controlled motor

Note: Above fig.420.1 – 420.4 are for general explanation of high-pressure pump start-up procedures, hence some of the necessary equipment and instruments are not shown.

Operation monitoring methods for RO System

Monitoring of RO performance is a fundamental prerequisite to ensure reliable, high-availability performance. Regular records will provide a solid basis for trouble shooting and handling of complaints.

1. Monitoring

Operating data to be logged and logging periods are listed in Tables A1 to A3.
Table B summarizes typical water analysis items for periodical check-up.
Table C summarizes items for scheduled or situation-related maintenance.

2. Regular monitoring and check points

When feed water quality and operating parameters: pressure, temperature, differential pressure and recovery, are constant, permeate flow rate and permeate quality should be within ±5% of their values intended, without substantial fluctuations or trends to change performance.
If a.m. parameters are subjected to change, perform regular "normalization" in order to enable a comparison of normal and actual values.
Frequency of normalizations will depend on extent and frequency of variations in feed quality and operating conditions.
This will also apply prior to any maintenance works affecting general operating parameters. If necessary, correct operating conditions.

3. Logbook

Log all operation relevant events will time and date, especially where the following "key factors" are involved or could change.

Parameters	Key factors affecting performance
Permeate quality	- Feed water quality (such as the total sum of the ions present) - Composition of feed water (such as monovalent and polyvalent ions) - Feed pH - Temperature - Pressure - Recovery (conversion) ratio
Permeate flow rate	- Feed water quality (total ions, colloids and suspended solids; fouling index (SDI_{15}) - Temperature - Pressure - Differential pressure - Recovery (conversion) ratio

4. Normalization of permeate quality

Normalization program which is provided from TORAY can be used. Following is the procedures of normalization calculation.

In order to effectively evaluate system performance it is necessary to “normalize” daily actual operating data obtained to a set of standard conditions (Normalization = efficiency comparison of the current measured values), and compare these data with:

a) Measured values at initial operation or
b) (upon commissioning) with projection data.

Normalized values will allow to determine if the system runs according to projection. If system performance deviates, they help in determining correct corrective measures (e.g. cleaning).

Salt rejection and **salt passage** are defined and calculated as follows:

Salt passage (%) = (permeate conc.) / (average feed water conc.)×100 (1)

Salt rejection (%) = 100 − salt passage (2)

(average feed water conc.) = (feed water conc.) / (recovery ratio)
× ln {(1 / (1−recovery ratio))} (3)

(or – somewhat less precisely –)

(average feed water conc.) = (feed water conc.+brine conc.) / 2 (3')

where

recovery ratio (%)*1 = (permeate flow rate) / (feed flow rate) (4)

and

concentration = TDS or conductivity*2 (5)

*1) Recovery results as decimal value

*2) It is simpler to use a summarized parameter instead of the chemical concentrations expression for the feed water. Most practically, use conductivity, (see Fig.430.1, Fig.430.1.1 and Fig.430.1.2).

Above calculation will compensate fluctuations of feed water concentration and recovery ratio. It is recommended, however, to maintain recovery ±2% of intended value for the system.

Further to this, the salt passage obtained through equation (1) must be normalized considering fluctuations or change of (treated) feed pH, temperature and operation pressure as follows:

normalized salt passage (%) = salt passage (%) $\times CC_H \times CC_T \times CC_P \times CC_C$ (6)

where

1. CC_H is a correction coefficients for feed water pH,
2. CC_T is a correction coefficients for feed water temperature,
3. CC_P is a correction coefficients for feed water pressure, and
4. CC_C is an additional correction coefficients for feed concentration.

The correction coefficients can be read from Fig.430.2 to Fig.430.5.2.

5. Normalization of permeate flow rate

Normalization program which is provided from TORAY can be used. Following is the procedures of normalization calculation.
The Normalized Permeate Flow Rate can be calculated according to the following equation:

$$NPFR = NDP_S / NDP_D \times TCF \times QP_D \quad (7)$$

where

$$NDP = (\text{feed pressure}) - 1/2 \times (\text{pressure drop}) - (\text{permeate pressure}) - \Phi P_{OSM} \quad (8)$$

and

NFPR = normalized permeate flow rate
NDP = net driving pressure
NDP_S = net driving pressure at standard or design conditions
NDP_D = actual net driving pressure
QP_D = current permeate flow rate
ΦP_{OSM} = average osmotic pressure
feed water osmotic pressure corresponding to average feed water
The graph for NaCl solution is shown in Fig.430.6
TCF = Temperature correction coefficient (characteristic of membrane type used in the system, shown in Fig.430.7)
This adjusts the current permeate flow rate to the value at 25℃.

As long as the RO system is operating under reasonably constant conditions, NDP calculation according to equation (8) may be replaced by the following equation (9):

$$NDP = (\text{feed pressure}) - (\text{constant value}) \quad (9)$$

where

$$(\text{constant value}) = 1/2 \times (\text{pressure drop}) + (\text{permeate pressure}) + \Phi P_{OSM} \quad (10)$$

For multi-bank systems, the normalization must be done for each bank separately. Multi-bank calculations in a single step can yield inaccurate results.

6. Sample Calculation

Our calculation example is based on the following:

Element:	SU-720
No. of PV with 6 elements each:	1st bank = 6
	2nd bank = 3
Feed water:	NaCl solution, 1,500ppm

Parameters		Design value	Daily Operation data
1. Date and time for data logging		Design	XX.YY
2. Total operating hours		Initial	ZZ
3. Number of vessels in operation		6/3	6/3
4. Feed water conductivity	µS/cm	3,000	2,000
5. Feed water pH		6.5	6.5
6. Feed water (SDI_{15})		3	2.5
7. Feed water temperature	℃	20	25
8. Feed water pressure	MPa	1.44	1.23
9. Feed water chlorine concentration	ppm	0	0
10. Feed water individual ion conc.	ppm	–	–
11. Brine conductivity	µS/cm	–	7,300
12. Brine pH		7.0	6.9
13. Differential pressure for each bank	MPa	1.0/1.0	1.0/1.0
14. Brine flow rate	m^3/d	325	325
15. Total permeate conductivity	µS/cm	125	89
16. Permeate conductivity for each vessel		–	–
17. Permeate pressure	MPa	0.03	0.03
18. Total permeate flow rate	m^3/d	975	975
19. Permeate flow rate for each bank	m^3/d	705/270	–
20. Permeate individual ion concentration	ppm	–	–
21. Total recovery ratio	%	75	75
22. Recovery ratio for each bank	%	54/46	–
23. Normalized salt rejection (or salt passage)		*)	*)
24. Normalized permeate flow rate		*)	*)

*) Values are obtained by following calculation procedures

Normalized Salt Passage

		Design Value	Daily operation data
Recovery ratio	%	75	75
Feed concentration (from fig.430.1 & 430.1.1)	ppm TDS	1,500	1,000
Average feed water Concentration (from eqn. (3))	ppm TDS	2,773	1,848
Permeate concentration (from fig. 430.1 and 430.1.1)	ppm TDS	59	43
Salt passage (from eqn. (1))	%	2.1	2.3
CC_H (from fig.430.2)		1	0.98
CC_T (from fig.430.3)		1.17	1
CC_P (from fig.430.4 & 430.4.1)		0.95	0.89
CC_C (from fig.430.5, -5.1 & -5.2)		0.77	0.90
Normalized salt passage From eqn. (6)	%	1.80	1.81

Normalized salt passage of daily operation data matches design value. Membrane element performance is stable with respect to salt rejection.

Normalized permeate flow rate

		Design Value	Daily operation data
Feed pressure	MPa	1.44	1.23
Pressure drop (total)	MPa	0.2	0.2
Permeate pressure	MPa	0.03	0.03
Average osmotic pressure (from fig. 430.6)	MPa	0.23	0.15
NDP (from eqn.(9))	MPa	1.09	0.95
Permeate flow rate	m^3/d	975	975
Temperature	℃	20	25
TCF (from fig. 430.7)		1.14	1
NPFR (from eqn.(7))	m^3/d	1,112	1,108

Normalized permeate flow rate of design value and daily operation data are different by – 0.4%. This permeate flow performance is regarded as stable.

7. Variations of operation data from nominal value

As a guideline, the following tolerance is applicable for deviations:

Items	Accepted deviation *)	
	(A)	(B)
Normalized salt passage	±20%	±5%
Normalized permeate flow rate	±5%	±2%

*) These values are the percentages of variation of determined value from the mean value by

(A) = data read by varying persons

(B) = single operator precision

8. Precautions and useful information for monitoring operating data

Daily monitoring of operating parameters provides a solid basis for evaluation of RO system performance.

Recognize deviant performance trends for salt passage, permeate flow rate or pressure drop. This enables timely selection of appropriate countermeasures, avoiding irreversible damage to membrane elements or other system components.

1) Guidelines for maintenance (considerations for cleaning) are described in RSU-530
1) Troubleshooting guides are described in RSU-710 section.
2) Typical signs of system performance change are shown in section RSU-720
3) In order to evaluate actual system status and to detect trends early, a systematic-graphical-monitoring chart (example see Fig.430.8) of normalized performance data is recommended.

For large projects and special applications, quality of plant monitoring can be a criterion for a system warranties which have to be agreed upon.

9. RO system operation parameters and check points

Table A1: Softened drinking or well water, SDI < 2 average, peak 3

Parameters	Online Monitoring (Continuously)	Daily (data sheet)	Period-ically (1)	Alarm & safety system
1. Date and time of data logging		X		
2. Total operating hours		X		
3. Number of vessels in operation			X	
4. Feed water conductivity	X (2)	X		
5. Total hardness		X		X
6. Feed water pH	X	X	X	
7. Feed water FI (SDI_{15})		X		
8. Feed water temperature	X (3)	X		X (3)
9. Feed water pressure	X	X		X
10. Feed water chlorine concentration	X (4)	X (4)		X (4)
11. Feed water ORP	X	X		
12. Brine surplus of HSO_3 (> 0.5 mg/l) *)		X		X
13. Feed water individual ion concentration			X (6)	
14. Brine conductivity		X		
15. Brine pH	X		X	
16. Pressure drop of each bank	X	X		X
17. Brine flow rate	X	X		X
18. Total permeate conductivity	X	X		X
19. Permeate conductivity of each vessel			X	
20. Permeate pressure	X (5)	X		X (5)
21. Total permeate flow rate	X	X		X
22. Permeate flow rate for each bank		X		
23. Permeate individual ion concentration			X (6)	
24. Total recovery ratio		X		
25. Recovery ratio for each bank			X	
26. Normalized salt passage			X	
27 Normalized permeate flow rate			X	

*) HSO_3^- surplus in brine >= 0.5 mg/l if raw water is chlorinated

Notes:

(1) Log these parameters monthly from initial start-up operation. In case of trouble shooting or fluctuating operating conditions, the operating party is requested to check these parameters more frequently, depending on particular situation.

(2) In case of significant fluctuations

(3) In case of high fluctuations or heat exchanger systems

(4) If chlorine is detected in feed water, plant must be stopped immediately and flushed with chlorine-free water.

(5) In case of fluctuating pressure > 0.5 MPa, closed permeate loop or (automatic) valve → risk of water hammer.

(6) Recommended procedure is water analysis of individual ions, comparing results with projected data. Required typical ions are listed in Table B.

Table A2: Drinking or well water, SDI < 3 average, peak 4, NTU < 0.5

Parameters	Online Monitoring (Continuously)	Daily (data sheet)	Period-ically (1)	Alarm & safety system
1. Date and time of data logging		X		
2. Total operating hours		X		
3. Number of vessels in operation		X	X	
4. Feed water conductivity	X (2)	X		
5. Feed water pH	X (3)	X		X (3)
6. Feed water FI (SDI_{15})		X		
7. Feed water turbidity (NTU)	X		X	
8. Feed water temperature	X (4)	X		X (4)
9. Feed water pressure	X	X		X
10. Feed water chlorine concentration	X (5)	X (5)		X (5)
11. Feed water ORP	X	X		
12. Brine surplus of HSO_3 (> 0.5 mg/l) *)		X (8)		X
13. Antiscalant concentration in feed water		X		X (5)
14. Feed water individual ion concentration			X (6)	
15. Brine conductivity		X		
16. Brine pH	X (3)	X		
17. Pressure drop of each bank	X	X		X
18. Brine flow rate	X	X		X
19. Total permeate conductivity	X	X		X
20. Permeate conductivity of each vessel			X	
21. Permeate pressure	X (7)	X		X (7)
22. Total permeate flow rate	X	X		X
23. Permeate flow rate for each bank		X		
24. Permeate individual ion concentration			X (6)	
25. Total recovery ratio		X		X
26. Recovery ratio for each bank			X	
27. Normalized salt passage			X	
28. Normalized permeate flow rate			X	

*) HSO_3^- surplus in brine >= 0.5 mg/l if raw water is chlorinated

Notes:

(1) Log these parameters monthly from initial start-up operation. In case of trouble shooting or fluctuating operating conditions, the operating party is requested to check these parameters more frequently, depending on particular situation.

(2) In case of significant fluctuations

(3) In case of high fluctuations or acid dosing

(4) In case of high fluctuations or heat exchange system

(5) If there is any possibility of chlorine content in feed water

(6) Recommended procedure is water analysis of individual ions, comparing results with projected data. Required typical ions are listed in Table B.

(7) In case of fluctuating pressure > 0.5 MPa, closed permeate loop or (automatic) valve → risk of water hammer.

(8) Volumetric recording of daily consumption, divided by total daily feed flow.

Table A3: Surface water/tertiary effluent, SDI < 4, max 5, NTU < 0.5 average, peak 1.0

Parameters	Online Monitoring (Continuously)	Daily (data sheet)	Periodically (1)	Alarm & safety system
1. Date and time of data logging		X		
2. Total operating hours		X		
3. Number of vessels in operation		X		
4. Feed water conductivity	X	X		
5. Feed water pH	X	X		X
6. Feed water FI (SDI_{15})		X		X
7. Feed water turbidity (NTU)	X	X		X
8. Feed water temperature	X	X		X
9. Feed water pressure	X	X		X
10. Feed water chlorine concentration	X	X		X
11. Feed water ORP	X	X		
12. Brine surplus of HSO_3 (> 0.5 mg/l) *)		X		X
13. Antiscalant concentration in feed water		X		X
14. Feed water individual ion concentration			X (2)	
15. Brine conductivity		X		
16. Brine pH	X	X		
17. Pressure drop of each bank	X	X		X
18. Brine flow rate	X	X		X
19. Total permeate conductivity	X	X		X
20. Permeate conductivity of each vessel			X	
21. Permeate pressure		X		X
22. Total permeate flow rate	X	X		X
23. Permeate flow rate for each bank		X		
24. Permeate individual ion concentration			X (2)	
25. Total recovery ratio		X		X
26. Recovery ratio for each bank			X	
27. Normalized salt passage			X	
28. Normalized permeate flow rate			X	

*) HSO_3^- surplus in brine >= 0.5 mg/l if raw water is chlorinated

Notes:

(1) Log these parameters monthly from initial start-up operation. For trouble shooting or fluctuating operating conditions, additional check-ups are required, depending on particular situation.

(2) Recommended procedure is water analysis of individual ions, comparing results with projected data. Required typical ions are listed in Table B.

Table B: Typical Water Analysis Items

Items		**Feed Water**	**Permeate**
1. Conductivity(℃)	(µS/cm)	X (1)	X
2. Total dissolved solids	(TDS)	X	X
3. pH	(−)	X	X
4. Chloride	(Cl^-)	X (1)	X
5. Nitrate	(NO_3^-)	X	X
6. Bicarbonate	(HCO_3^-)	X (1)	X
7. Sulfate	(SO_4^{2-})	X	X
8. Phosphate	(PO_4^{3-})	X	
9. Fluoride	(F^-)	X	
10. Sodium	(Na^+)	X	X
11. Potassium	(K^+)	X	X
12. Ammonium	(NH_4^+)	X	
13. Calcium	(Ca^{2+})	X (1)	X
14. Magnesium	(Mg^{2+})	X (1)	X
15. Strontium	(Sr^{2+})	X	
16. Barium	(Ba^{2+})	X	
17. Iron as ion	(Fe^{3+})	X	
18. Manganese	(Mn^{2+})	X	
19. Silicate	(SiO_2)	X	X
20. Silicic acid	(SiO_3^-)	X	X
21. Boron	(B)	X	X
22. Chemical oxygen demand	COD	X	
23. Biological oxygen demand	BOD	X	
24. Total organic carbon	TOC	X	X
25. Carbon Dioxide	(CO_2)	X	
26. Microorganism	(unit/cc)	X	
27. Hydrogen Sulfide	(H_2S)	X	
28. Temperature	(℃)	X	

Note:

Above table is for reference only. Selection of required ions for analysis will also depend on feed water quality and required permeate quality.

(1) These values constitute the minimum information required for a qualified RO lay-out. Ions not analyzed will not be available for calculation of scaling potentials.

Table C: RO System Maintenance Items Record

Items	Frequency & Procedure
1. Instruments (1) pressure sensors & indicators (2) system control devices	Regular calibration and maintenance should be performed according to the maintenance manual supplied by engineering of system manufacturer.
2. Cartridge Filter Change Use only pre-washed filter cartridges free of surfactants and textile aides.	Record date changed, differential pressure of old and new (clean) cartridges, and pore size, material and working of filter cartridges used.
3. RO System Cleaning As a minimum, record the following: 1) Type of cleaning solution and its concentraton 2) Conditions during cleaning (pressure, temperature, flows, pH, conductivity, time)	Perform according to maintenance manual supplied by system manufacturer. Guidelines and instructions are given in RSU-530.
4. Membrane Treatment upon Shutdown Record preservation method, concentration of conservation solutions, operating conditions before shutdown and duration of conservation.	Perform according to system manufacture's operating manual. Guidelines & introductions are given in RSU-510.
5. Pretreatment Operating Data RO system performance depends largely on proper operation of the pretreatment system.	Residual chlorine conc., Discharge press. of booster pump, consumption of all chemicals, calibration of gauges and meters.
6. Maintenance Log	Record routine maintenance, mechanical failures and replacements, and any change of element locations etc.

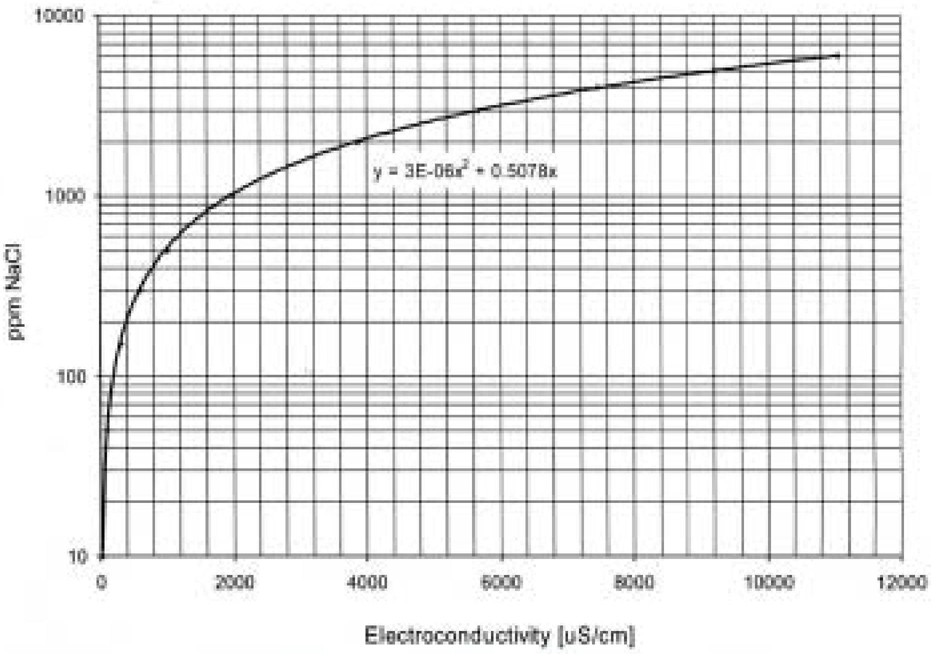


Fig. 430.1: Conductivity / NaCl concentration conversion factors at 25 °C

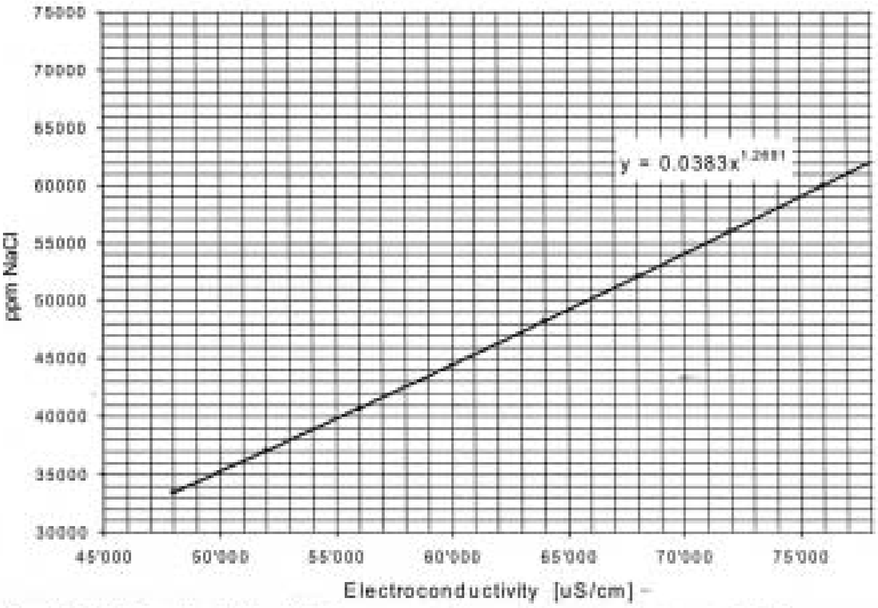


Fig. 430.1.1: Conductivity / NaCl concentration conversion factors at 25 °C

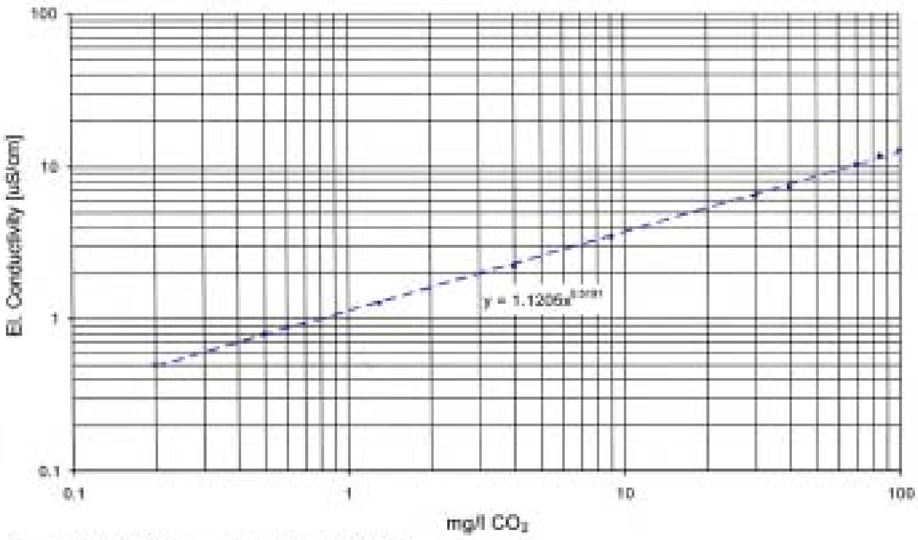


Fig. 430.1.2: CO_2-conductivity at 25 °C

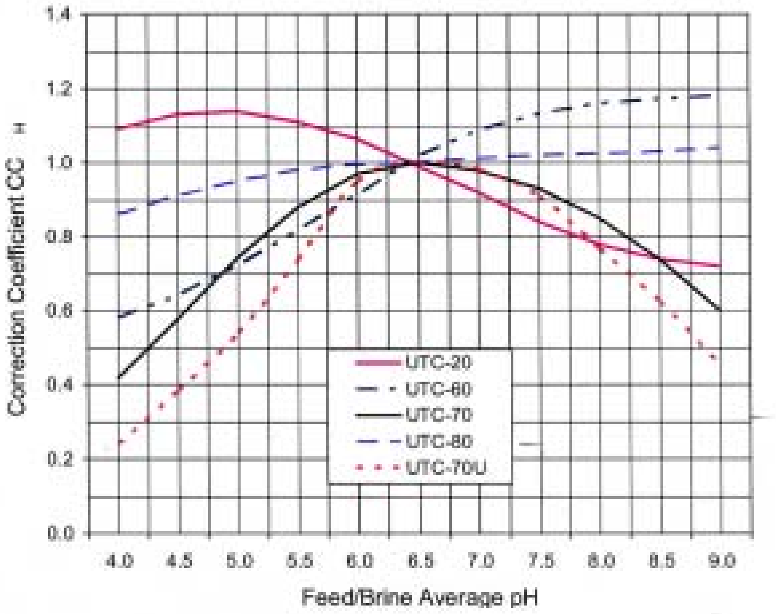


Fig. 430.2: pH-correction Coefficient CC_H

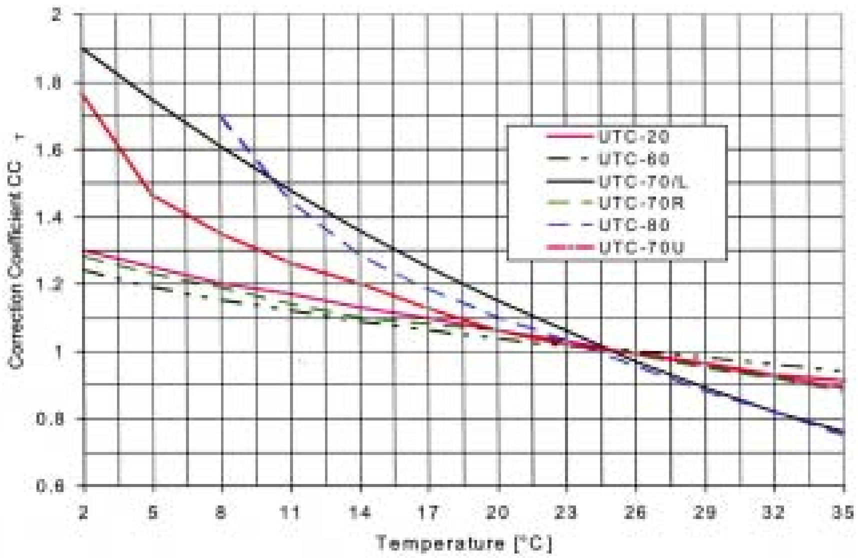


Fig. 430.3: Temperature correction coefficient CC_T

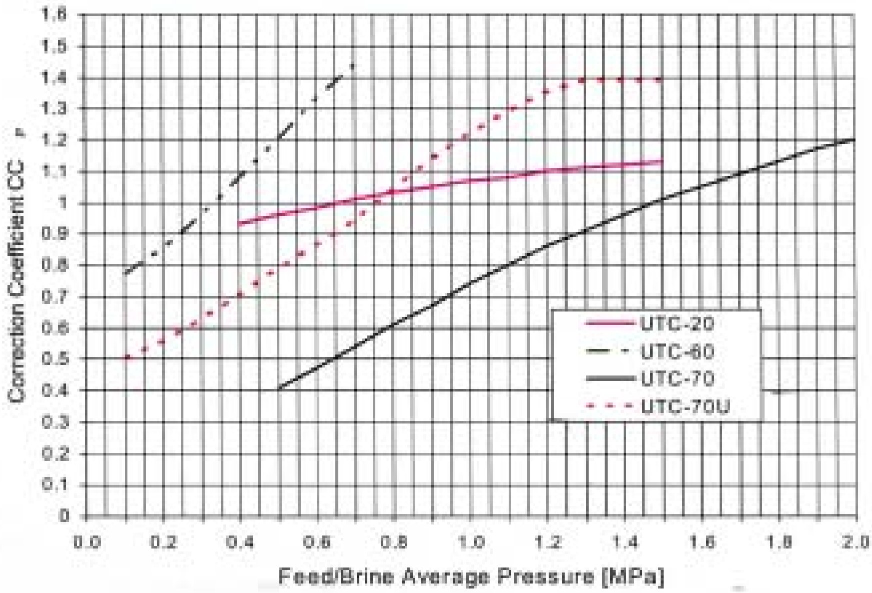


Fig. 430.4: Pressure Correction Coefficient CC_P

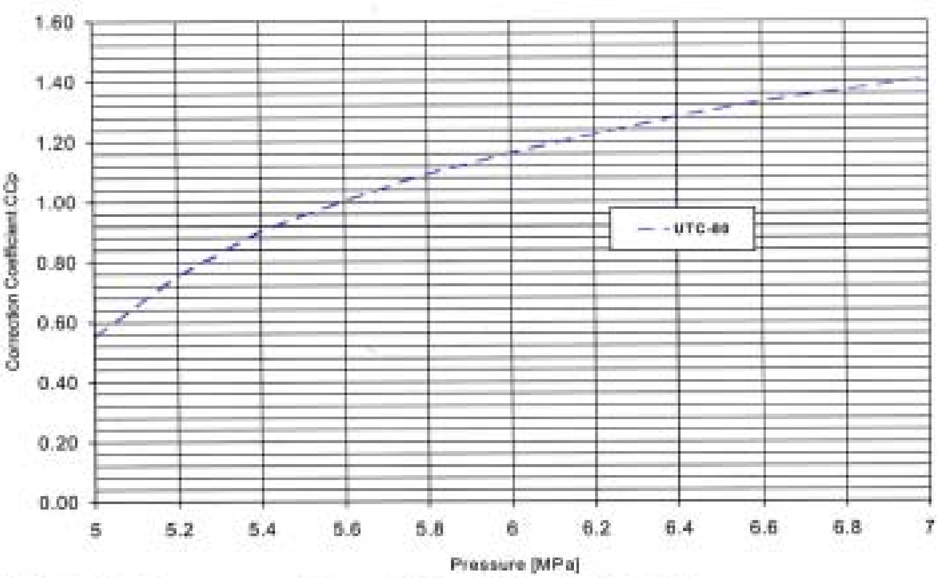


Fig. 430.4.1: Pressure correction coefficient CC_P (UTC-80 series)

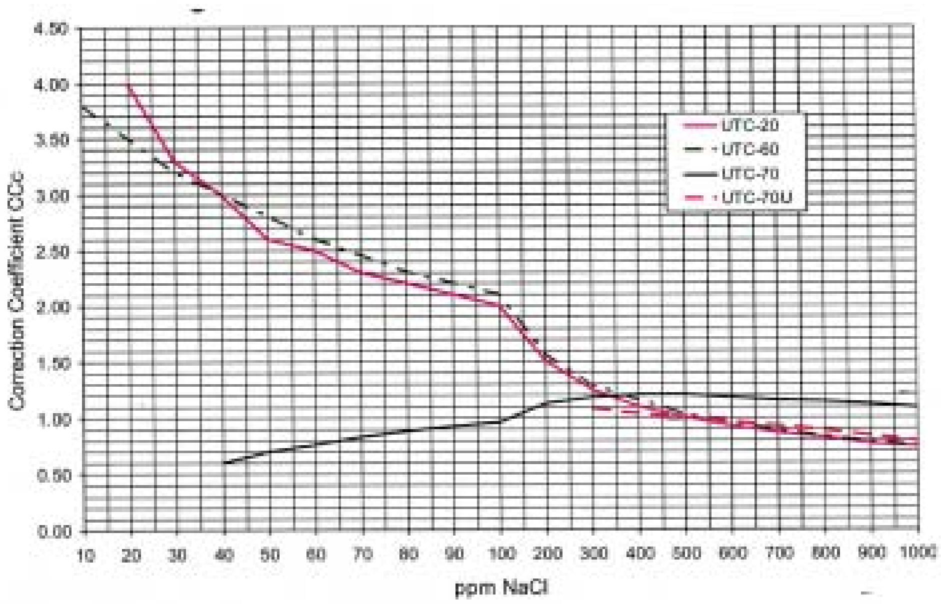


Fig. 430.5: Concentration correction coefficient CC_C

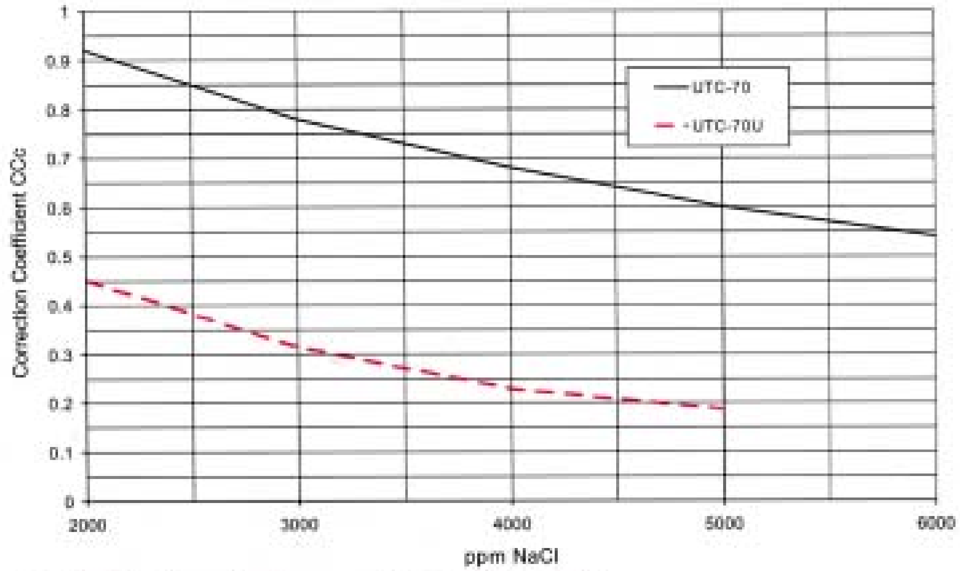


Fig. 430.5.1: Concentration correction coefficient CC_c

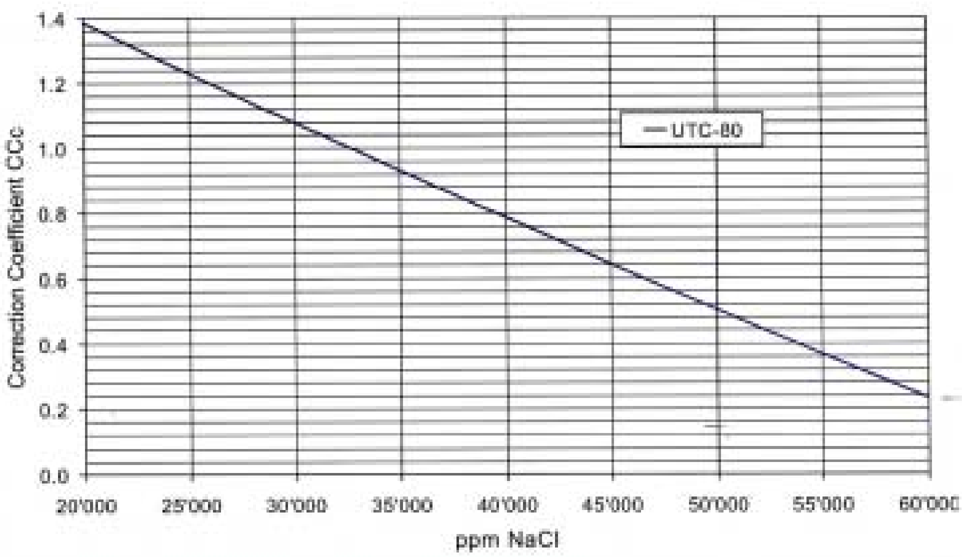


Fig. 430.5.2: Concentration correction coefficient CC_c

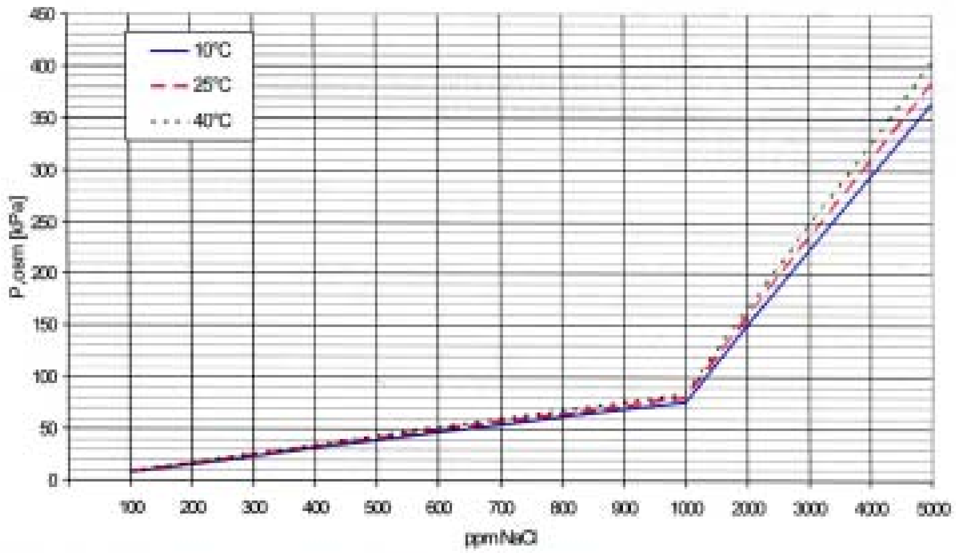


Fig. 430.6.1: Osmotic pressure of NaCl (brackish water)

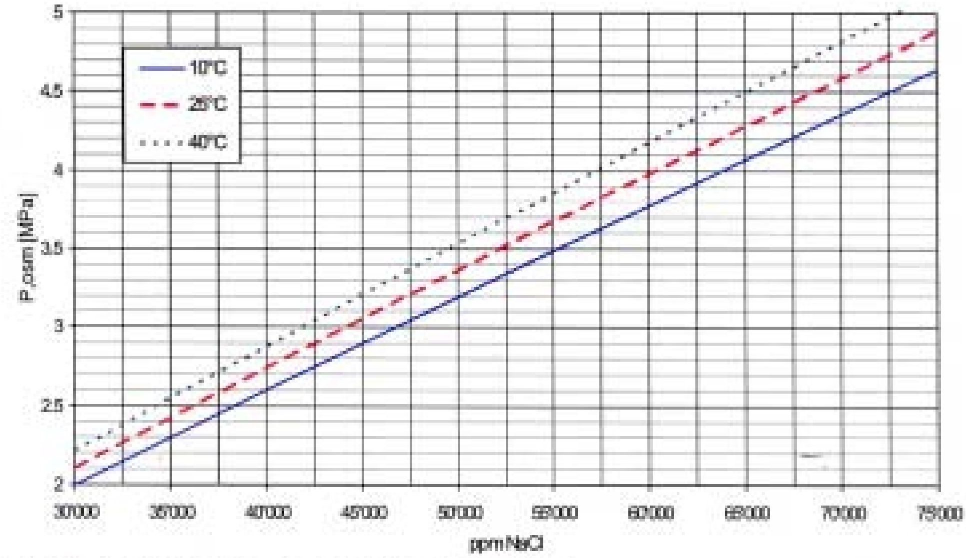


Fig. 430.6.2: Osmotic pressure of NaCl (see water)

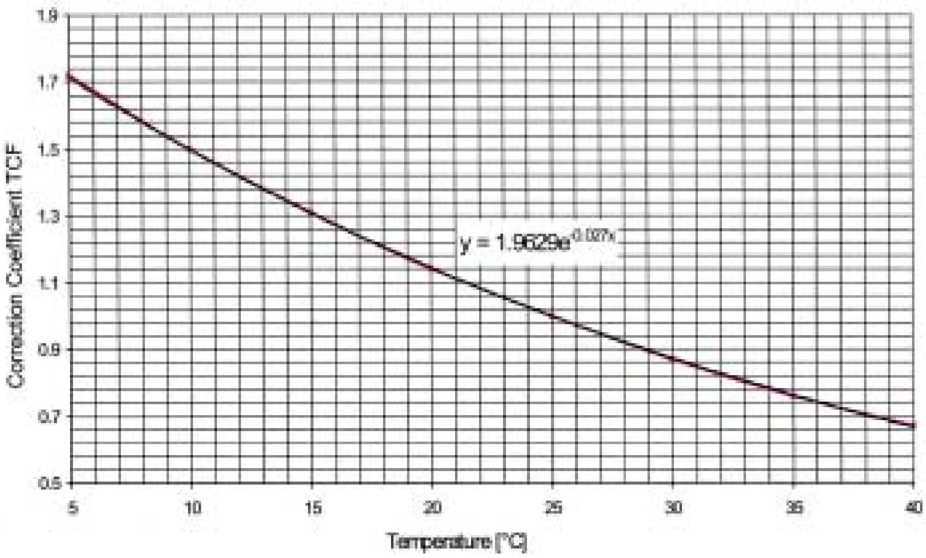


Fig. 430.7: Temperature correction factor TC_F

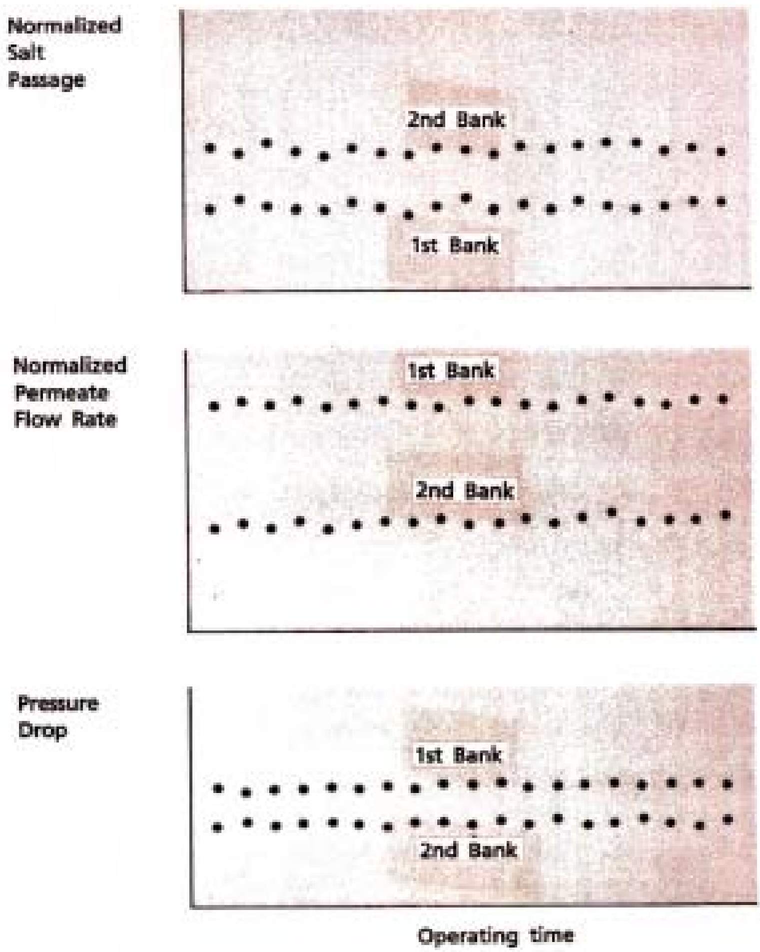


Fig. 430.8: Typical monitoring chart for RO system

Note:

Daily monitoring is recommended. Watch out for performance change trends.

In this example, no performance change is observed.

Shutdown considerations for RO systems

1) Flush brine at RO system shutdown with product water or feed water of sufficient quality at low pressure to completely displace brine from pressure vessels.
2) Ensure membrane elements are kept wet and properly sterilized and/or frost protected at all times during shut-downs.
3) Ensure guidelines for temperature and pH of the preservation water are observed during shut-downs.
4) Take care of that product back pressure never exceeds 0.07 MPa after shut-downs. Product backpressure is defined as product pressure minus feed resp. brine pressure. If RO trains are running in parallel connection to a common permeate header, and with time-shifted running patterns, special attention must be paid. Suitable design elements, such as e.g. check-and relief valves must be installed in permeate lines of individual trains.
5) Composite polyamide RO membrane elements have limited tolerance to chlorine exposure. They should not be exposed to chlorinated water under any circumstances. Any such exposure may result in irreparable damage to the membrane, normally evidenced by increase salt passage.
6) So absolute care must be taken to avoid chlorine exposure following:
   - Disinfection of piping or pretreatment equipment upstream of the membrane
   - Preparation of cleaning or storage solutions
   - Care must be taken to ensure that no trace of chlorine is present in the feedwater to the RO membrane elements.
   - If residual chlorine is present in the RO feed, it must be removed with sodium bisulfite (SBS) solution, with allowance for adequate contact time to accomplish complete dechlorination.

1. Short-Term Shut-down

Definition:

Short-term shut-down is for periods where an RO plant must remain out of operation for more than one day, but fewer than four days, with the RO elements in place.

Prepare each RO train as follows:

Flush the RO section with feed water, while simultaneously venting any gas from the system.

1) When the pressure tubes are filled, close the valves.
2) Repeat 1) and 2) above at every 12 hours.

2. Long-Term Shut-down

Definition:

Long-term shut-down is for periods where an RO plant must remain out of operation for more than four days with the RO elements in place.

Prepare each RO train as follows:

1) The system is cleaned to remove contamination and fouling deposits on the membrane.
2) Flush the RO section by circulation of the 500 – 1000 mg/l SBS solution as preservation solution (approx 1 hour).
3) When the RO section is filled with this solution (make sure that it is completely filled), close all necessary valves to retain the solution in the RO section.
4) Repeat Steps 2) and 3) with fresh solution.
   - Every thirty (30) days if the temperature is below 80°F (27°C)
   - Every fifteen (15) days if the temperature is above 80°F (27°C)
5) pH in the preserved RO system needs to be controlled periodically to be sure that it does not drop below pH 3.
6) During shut-down period, maximum temperature should not exceed 40°C and minimum temperature should be more than 0°C.

Notes: Any contact of the SBS solution with outside air (oxygen) will oxidize SBS to sulfate and pH will drop continuously. After all SBS is consumed, remaining oxygen is not reacted and biological status becomes unstable.

Preservation and cleaning

Proper preservation and cleaning of Reverse Osmosis (RO) membrane element are key factors in keeping high characteristics of the membrane element.

Selection RSU-500 (this section) presents proper preservation procedures during system shut-down and guidelines for RO membrane element cleaning.

Preservation procedures for RO elements during system shut-down periods

Store elements under clean conditions to maintain performance of and to prevent bacterial growth. Consideration for preservation:

1) After shut-down, displace brine with treated RO feed water, softened water or permeate. If potential for scaling and fouling necessitates, membranes must be flushed according to RSU-540 with treated RO feed water, softened water or permeate.
2) To maintain performance, elements must be wet at all times.
3) To prevent propagation of bacteria in the pressure vessel, sterilization in accordance with TORAY recommendations, see RSU-560, is recommended.
4) If elements are contaminated and extended shut-down is scheduled, perform chemical cleaning prior to conservation. This removes foulant from membranes and minimizes bacterial growth, see RSU-520, RSU-530, RSU-550.
5) Allowable temperature and pH range of preservation water in the pressure vessel will be:
   Temperature Range: 5 – 35 ℃
   pH Range :3 – 7
6) Make-up water for preservation solution must be free from residual chlorine or other oxidizing agents. For preservation, use sodium bisulfite solution, see RSU-560.

General instructions and conditions for RO cleaning

The surface of an RO membrane is subject to fouling by suspended solids, colloids and precipitation. Pre-treatment of feed water prior to the RO process is designated to avoid contamination of membrane surface as much as possible. Best operating conditions (permeate flow rate, pressure, recovery and pH-value), will contribute considerably to less fouling of membranes. In case of high SDI value of pre-treatment feed water (even in allowable range), membrane fouling can cause performance decline in long-term operation. It can also be a consequence of large variations in raw water quality, or of errors in RO operation mode. According to typical tendency of trouble (fouling, scaling, membrane damage, etc.), see RSU-720.

Fouling of the membrane surface will result in a performance decline, i.e. lower permeate flow rate and/or higher solute passage and/or increased pressure drop between feed and brine.

Fig.520.1 illustrates the flux decrease against expected performance. Since the membrane will usually remain intact, repeated (periodical) flushing or cleaning can largely restore performance. In most cases, foulant removal will bring temporary relief, as illustrated by the “saw tooth” pattern in Fig.520.1.

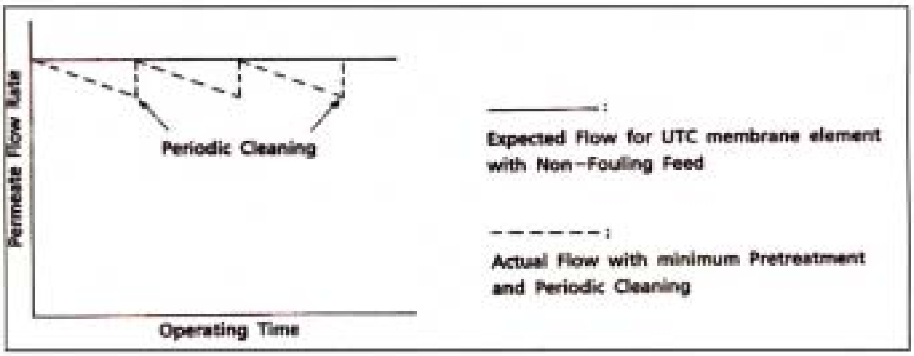


Fig. 520.1: Effect of fouling on permeate flow rate

Guidelines for RO cleaning

1. When to clean:

For best efficiency of cleaning procedure, elements must be cleaned before fouling has fully developed. If cleaning is postponed for too long, it will be difficult or impossible to completely remove foulants from membrane surfaces and to re-establish full performance.

Commence cleaning when feed-brine differential pressure of any bank reaches 150% of initial value, or normalized permeate flow rate decreases by more than 10%, or normalized permeate quality decreases by more than 20%.

Easy checking whether fouling occurs or not is a measuring of the weight of membrane element. If the weight becomes much higher than that of new element, fouling is occurred. The rough weight of the new element is 4 kg at 4-inch, 17 kg at 8-inch.

2. Determination of foulants

It is important to determine the type of foulants on the membrane surface before cleaning. The best approach for this is a chemical analysis of residues collected with a membrane filter for SDI value determination.

In situations where chemical analysis is not available, it is often possible to classify foulants by color and consistency of residue on the membrane filter. A brownish color will direct investigation to consider iron fouling. White or beige indicates silica, loam, calcium scale, or biological fouling. Crystalline constitution is a feature of calcium scale or inorganic colloids. Bio-fouling or organic material will – besides the smell – often show slimy/sticky consistency.

3. Selection of cleaning procedure

Once contamination of the membrane surface has been identified, the correct cleaning procedure must be selected. If foulants are believed to be metal hydroxides, such as ferric hydroxide, or calcium scale, citric acid cleaning etc. procedure is recommended, (see RSU-550 and RSU-555). In case the primary problem is believed to be organic or biological fouling, a cleaning procedure with detergents is recommended, but excess biofouling may result less effect (see

RSU-550 and RSU-557).

4. Evaluation of the effectiveness of cleaning

Descriptions of various cleaning procedures are given in RSU-550. Observing recommended cleaning procedures will usually yield good results. Pressure drop across the modules should be reduced to initial value while permeate flow rate and solute rejection will be restored. If performance is not sufficiently improved after cleaning, a different recommended cleaning procedure may be lead to a better results. Foulants will frequently adhere to membrane surface or remain in spacer material. Final removal takes several successive cleaning procedures in many cases. Alternating chemical cleanings with citric acid (alkaline-acid) are frequently more effective than either alone. Detergent together with alkaline cleaning will be occasionally effective.

Flushing procedures without chemicals

The plainest dirt removal procedure is flushing. Flushing cleans the membrane surface by high flow velocity using a large quantity of feed water at low pressure. It is effective for cleaning of light organic fouling, provided it is applied before significant performance decline has been observed. Best, perform flushing several hours after shut-down of the RO system, in order to utilize the soaking effect for separation of foulant layers from the membrane 's surface.

General operating conditions for flushing are as follows:

Flushing water: Pre-treated feed water
Pressure: Low pressure (0.1 – 0.2 MPa)
Water flow rate: High flow rate is preferable.
Limit pressure drop is up to max 0.2 MPa per vessel
Maximum feed flow rate per vessel is as follows:
8.0 inch element: 200 l/min
4.0 inch element: 50 l/min
Temperature: < 45℃
Period: 0.5 – 1.0 hour
Flush each bank separately. Do not re-circulate flushing water.

Instructions for chemical cleaning

1. General guidelines

Chemical cleaning is used to remove contaminations from membrane surfaces by dissolving and/or separating through physical and chemical interaction with cleaning chemicals.

It is usually applied after flushing. It is good practice to perform chemical cleaning as periodical and preventive maintenance or before extended shut-down of the system.

After chemical cleaning, use pre-treated raw water or permeate to completely flush resulting dissolved or suspended solids out of the RO system.

Chemical cleaning agents:	As listed in Table 1
Make-up water:	Softened water or permeate, free of heavy metals, residual chlorine or other oxidizing agents.
Required quantity of cleaning solution:	40 – 80 liters per 8-inch element 10 – 20 liters per 4-inch element
Cleaning operation pressure:	Low pressure (0.1 – 0.2 MPa)
Min. feed flow rate:	40 l/min for each 8-inch vessel 10 l/min for each 4-inch vessel
Temperature:	as high as possible; however max. 45℃. In case temperature of cleaning solution exceeds 45℃ due to heat build-up (liquid friction) from circulating pump, consider installation of a cooling facility. And it is better to make temperature limit by pH value.
Type of cleaning:	Alternation of circulation and soaking, each bank separately
Circulation period:	0.5 – 1.0 hour (repeat 2 – 3 times) is recommended
Soaking period:	2 – 24 hours incl. circulation time (depends on type of fouling)
Method of cleaning:	Circulating and soaking in each bank
Final flushing period:	Min. 1 – 2 hours, depending upon application

Contamination	Chemical Reagent	Cleaning Conditions	Ref.
Calcium scale Metal hydroxides Inorganic colloids	Citric acid 1 – 2 %	pH value: 2 – 4 adjust with ammonia (NH_3)	RSU-555
Organic matter Bacterial matter	Alkaline solution[1)] or Dodecyl Sodium Sulfate (DSS, Sodium Lauryl Sulfate) 0.1 – 0.5% with alkaline solution or Polyoxyethylene Sodium Lauryl Sulfate(PSLS), 0.1 – 0.5% with alkaline solution	pH value: 9 – 11 adjust with sodium hydroxide, or sodium tripolyphosphate or trisodium phosphate	RSU-557

1) Alkaline solution with EDTA is more effective in some cases.

2. Dimensioning a cleaning system

For a typical flow diagram of a cleaning system, see Fig.532.1.
Required useful flow volume of the cleaning tank can be calculated as following:

- Consider system volume (pipework, pressure vessel etc.) for preparation of cleaning solution
- Useful volume Vn = A – B – C where

A = Quantity of cleaning solution per element, times number of elements.
40 – 60 l for each 8-inch element, 10 – 15 l for each 4-inch element, according to degree of fouling:
1 = slightly fouled 40/10 l, 2 = medium fouled 50/12 l, 3 = heavily fouled 60/15 l.

B = System volume (cleaning system piping, volume of pressure vessels and pipe Headers

C = Volume of water in elements subject to simultaneous cleaning. (10 l for 8-inch, 2.5 l for 4-inch)

Flow for cleaning (= discharge of pump) is for example approx. 6 m^3/h/8-inch vessel and 1.5 m^3/h/4-inch vessel.
Pump head is calculated from:

- max. differential pressure across RO elements (= approx. 0.2 MPa)
- pressure loss of piping system and pressure vessel connections
- max. differential pressure across cleaning cartridge filter (approx. 0.2 MPa)

Examples:

Item	Unit	Case a)	Case b)	Case c)	Case d)
Element size	Inch	8	8	8	4
Cleaning bank	pc.vessels	30	10	6	3
Cleaning flow	m^3/h	180	60	36	4.5
Elements in each vessel	pcs.	6	6	4	3
Total elements	pcs.	180	60	24	9
Degree of contamination	°	1	2	3	3
Solution per element	liter	40	50	60	15
Cleaning volume A	liter	7,200	3,000	1,440	135
ND of cleaning pipe	mm	150	100	65	25
Length of cleaning pipe	m	13	100	60	20
ND of header	mm	200	200	100	20
Length of header	m	10	0	4	3
Volume of pipeworks B	liter	2,611	785	231	11
Water volume each element	liter	10	10	10	2.5
Total water volume elements C	liter	1,800	600	240	22.5
Useful volume of cleaning tank required: V_n	liter	2,789	1,615	969	102

Table 2: Dimensioning a cleaning system

Important notes

- Provide a separate return line for permeate. During the entire cleaning period, permeate must be returned to cleaning tank without back pressure.
- Design of cleaning tank must allow for complete draining.
- End pieces of clean-and permeate return lines should be submerged in cleaning solution inside the cleaning tank to avoid foam formation.
- Spent cleaning solutions must be neutralized before discharge. Consider local regulation for chemicals discharge.

When working with chemicals, follow safety regulations.
Wear eye protection, suitable gloves and rubber apron!

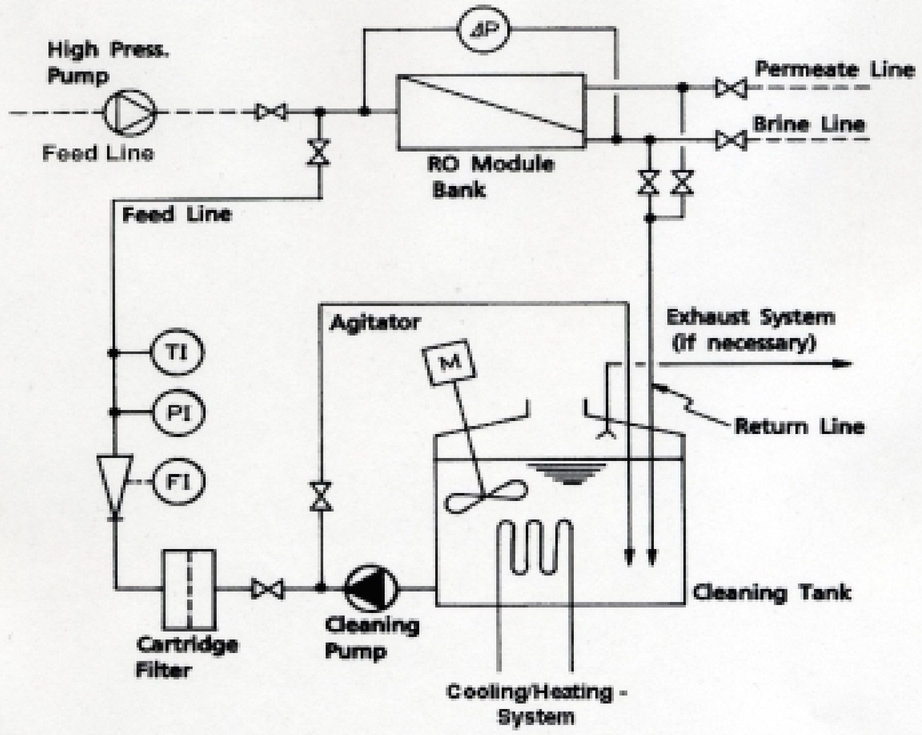


Fig. 550.1 : **Typical flow diagram of a cleaning system**

——————— Cleaning line

- - - - - - Offline during cleaning

(FI) Feed flow rate indicator

(PI) Pressure indicator

(TI) Temperature indicator

(ΔP) Differential pressure indicator for each bank

Note:

Clean each bank separately.

Citric acid cleaning procedure

1. Pre-flushing of elements

Prior to cleaning with citric acid solution, it is advisable (although not conditional) to flush elements with softened water permeate (see RSU-540).

2. Preparation of solution

1) Fill cleaning tank with water

   Cleaning tank is filled with permeate or tap water, free of oxidizing agents. The amount of cleaning water is determined by size of RO system and degree of fouling, (see RSU-550).

2) Dissolved citric acid

   Add citric acid (white powder), by and by, to the cleaning water to obtain a 2 % (by weight) – solution. Continuous agitation of the solution will be needed to dissolve citric acid quickly and completely. Break any large chunks prior to filling in, to avoid damage of agitator or pump.

   For example: To prepare 1,000 l of solution 20 kg of citric acid are used.

3) pH adjustment with ammonia (NH_3) or sodium hydroxide (NaOH) to specified value, if necessary. (see RSU-550)

   pH of the solution should be adjusted with ammonium hydroxide during agitation. Use exhaust system if necessary to draw off released ammonia gas. Use of a barrel pump or manual chemical pump helps to minimize release of ammonia gas.

   The amount of ammonium hydroxide (NH_4OH), required to adjust the pH to 3.5 can be calculated approximately in proportion to the amount of citric acid by following formula

   Amount of NH_4OH (100%) = 0.1 $\times$ Amount of citric acid (100%) in kg

   For example, if the calculated amount of citric acid is 20.4 kg, the required amount of ammonium hydroxide (30% by weight) is 6.8 kg = (0.1 $\times$ 20.4) / 0.3.

3. Circulation of cleaning solution

Circulate cleaning solution at low pressure; approx. 0.1 MPa. Higher temperature is favorable in order to obtain better results.

Note: 35℃ may not be exceeded. A longer period of circulation is preferable for cleaning, but may be limited by increasing temperature, (see RSU-550).

Soaking of elements in the cleaning solution is effective to dissolve the foulants. Repeated alternating and soaking and re-circulation of cleaning solution is recommended.

4. Flushing of elements

Discard all spent cleaning solution. The cleaning tank is completely emptied. Flush out and completely displace any residual cleaning solution from elements, pressure vessels and pipe lines with feed water or permeate. This is easiest done by filling cleaning tank with water and directing the return line to drain, directly before tank, (see RSU-540).

Flush each bank separately. Do not re-circulate flushing water.

5. General description of citric acid

Appearance: white crystalline powder, without chunks

pH: ~ 1.7 (100 g/l water, 20℃)

Density: 1.665 g/cm^3 (18℃)

CAS Number: 77 – 92 – 9

Main component: $(HOOCCH_2)_2C(OH)COOH$

Safety precautions: low hazard potential, irritant

Alkaline solution and Dodecyl Sodium Sulfate (DSS) with alkaline and DSS cleaning procedure

1. Pre-flushing of elements

Prior to cleaning with DSS solution, it is advisable (although not conditioned) to flush elements with softened water or permeate (see RSU-540).

2. Preparation of solution

1) Fill cleaning tank with water

Cleaning tank is filled with permeate or tap water, free of oxidizing agents. The amount of cleaning water is determined by size of RO system and degree of fouling (see RSU-550).

2) Dissolve detergent (DSS or PSLS if necessary)

Add DSS to cleaning water to obtain a 0.2% (by weight) for example – solution. Attention – this chemical creates lots and lots of foam! Pre-dissolution in a small vessel is needed prior to belonging into the cleaning liquid. Continuous, slow agitation of the solution will be needed to evenly dissolve DSS. To minimize foam formation, use low rpm stirrer.

For example: To prepare 1,000 l of the solution 2 kg of DSS are used.

3) Monitor pH value

The pH of the detergent solution should be in the range of 9 – 11. If pH is outside this range, adjustment is required.

3. Circulation cleaning solution

Circulate cleaning solution at low pressure; approx. 0.1 MPa. Higher temperature is favorable in order to obtain better results.

Note: 35℃ may not be exceeded. A longer period of circulation is preferable for cleaning, but may be limited by increasing temperature, (refer to RSU-532).

To minimize foam formation, design return line and permeate return line such that end pieces is below surface of cleaning solution inside tank.

Soaking of the elements in cleaning solution is effective to dissolve foulants.

Repeated and alternating soaking and recirculation of cleaning solution is recommended.

4. Flushing of elements

Discard all spent cleaning solution. The cleaning tank is completely emptied. Flush out and completely displace any residual cleaning solution from elements, pressure vessels and pipe lines with feed water or permeate. This is easiest done by filling cleaning tank with water and directing the return line to drain, directly before tank, (see RSU-540).

Flush each bank separately. Do not re-circulate flushing water.

5. General description of DSS

Appearance: Powder or aqueous solution
pH: 7 – 8 as 1% solution (based on powder)
Charge in solution: Anionic
Solubility in water: 10 g/100 ml
Main component: $CH_3(CH_2)_{11}SO_3Na$ Dodecyl Sodium Sulfate (Sodium Lauryl Sulfate)
CAS no.: 151 – 21 – 3

6. General description of TSP (Trisodium phosphate)

Appearance: White crystalline powder, without chunks
pH: strong alkalinity in solution
Density: 1.630 g/cm^3 (18℃)
Solubility in water: 28.3 g/100 ml
Main component: Na_3PO_4
CAS no.: 7601 – 54 – 9

7. General description of NaOH (Sodium hydroxide)

Appearance: White crystalline powder or granular or chunks
pH: strong alkalinity in solution
Density: 2.130 g/cm^3 (18℃)
Solubility in water: soluble in random ratio
Main component: NaOH
CAS no.: 1310 – 73 – 2

Safety precautions:

- Inhalation: Causes irritation to the respiratory tract. Symptoms may include coughing, shortness of breath. May cause allergic reaction in sensitive individuals. Remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.
- Ingestion: Large doses may cause gastrointestinal distress, nausea and diarrhea. Remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention. If conscious, induce vomiting.
- Skin Contact: Mildly irritating to skin, causes dryness and a rash on continued exposure. May cause allergic skin reactions. Immediately flush skin with plenty of soap and water. Remove contaminated clothing and shoes. Get medical attention. Wash clothing before reuse.
- Eye Contact: Causes irritation, redness, and pain. Immediately flush eyes with plenty of water for at least 15 minutes, lifting lower and upper eyelids occasionally. Get medical attention immediately.
- Consult MSDS of supplier of detergent before use.

Sterilization methods for RO/NF – elements

To prevent propagation of bacteria, it is recommended to immerse elements in sterilizing solution of 0.2 – 0.3 weight-% formaldehyde (HCHO) at pH 6 – 8, adjusted by sodium bicarbonate ($NaHCO_3$).
Above method is most effective as sterilization and it is applicable during any period of shut-down.

Note: This method is not applicable for new elements. Elements must be in use at least 24 hours operation before formaldehyde sterilization.

If formaldehyde sterilization cannot be applied to the system, following alternative solutions can be applied to each model membranes based elements:

Membrane Model:	**Sterilization solutions:**
Other than 800 series	Solution A or B
800 series	Solution B

Alternative sterilizing solutions and their applications are listed following. The elements can be immersed (not in operation) in these solutions for sterilization at system shut-down.

Sterilizing Solution	**Concentration [ppm]**	**Duration of Treatment [hr]*1**
A: Hydrogen Peroxide (H_2O_2) *3	2,000 – 10,000	1*2
B: Sodium bisulfite	5,000 – 10,000	no limit*2

Notes:

*1 Contact time with sterilizing solution must not exceed this duration to avoid performance decline.

*2 After completion of sterilization with the solution, flush system and fill up with clean water meeting specifications for resuming normal operation or entering prolonged shut-down periods.

*3 Hydrogen peroxide for this application must be prepared with de-ionized feed water with less than 0.2 ppb ion. Inadequate application of this solution may result in solute rejection decline. Use of hydrogen peroxide in presence of heavy metal residues will lead to fast and irreversible damage of composite membranes as well.

Notes:

1) The water used to prepare sterilizing solution must be free of residual chlorine or other equivalent oxidizing agents. (*)
2) All chemicals selected for application with membrane elements must match requirements for the respective membrane product.

(*) Dosing free chlorine or chloramines is an applicable sterilization procedure for special cases; however Toray consultation will be required for planning and advice regarding execution. Element performance may be influenced by chlorine. In any case, acidic cleaning is required prior to application of chlorine; target is complete removal of any heavy metal residues. Chlorination in presence of heavy metal residues will lead to fast and irreversible damage of composite membranes as well.

Sanitizing of RO-Elements (TS-types)

Occasional or periodic hot water sanitization (pasteurization) is a preventive measure to reduce bacteria and, fungus growth. The following recommendations are applicable for Toray hot water resistant elements (TS-types):

- Temperature slope during heating and cool down period max. 2.0℃ / minute
- Preferably use permeable, or at least softened water.
- For effective pasteurization water temperature must be 65℃ up to 80℃. Below this range, effect is weak. Above this temperature, modules can be irreversibly damaged.
- Feed-pressure during hot water treatment must be always < 0.15 MPa
- Differential pressure max. 0.1 MPa / element
- Frequency of hot water treatment depends on feed water quality and use of product water. Average frequency of treatment should, however, not exceed 1 treatment / week.
- Determine necessity and effectiveness of treatment by microbiological investigations

It is important to open permeate side valve and to keep no permeate side back pressure condition during high temperature treatment. Feed and/or brine pressure should be higher than permeate side pressure to avoid permeate back pressure problem.

Membrane treatment with Toray MT – 701 resp. MT – 801 procedure

Note: This procedure should be applied after consulting Toray and in coordination with them. Evaluation and determination whether this procedure can be used, should be left exclusively to Toray.

In most cases, flux is recovered largely by a careful chemical cleaning prior to membrane treatment. In cases where restoration of salt rejection is fouled insufficient, membrane treatment (MT) procedure as described below is recommended.

1) Prior to carrying out MT, perform cleaning of elements to remove any contamination and/or scaling. This is necessary for the MT to be successful. A clean membrane surface is a preferable.
2) The MT is performed with the RO system running in regular operation.

- Adjust pH of feed water during dosage to a range of 7.0 – 7.5.
- Permeate must be discarded during treatment
- Record operating data before starting addition of MT chemical.
- Add MT to feed water for approx. 30 minutes. The concentration of MT in feed water should be approx. 1,000 ppm.
- Total MT required is calculated as follow:
  MT (kg) = (Feed flow (m^3/ h))×(0.5)×(1,000)×10^{-3}
- Viscosity of concentrated MT (as shipped) is high. Pre-dilution to a concentration of 5% or less is necessary before adding to the feed water with a suitable chemical metering pump.

3) After pH of feed water reaches indicated range, start dosing MT to reach a concentration of approx. 1,000 ppm MT in feed stream. For thorough mixing, dosing point of MT liquid is best situated after cartridge filters and before high pressure pump.
4) Operating conditions during MT dosing should be maintained as follows:

Pressure:	100 – 120% of regular operating pressure, never less.
Permeate flow rate:	100 – 120% of the standard flow
Feed water:	Regular quality (except pH)
Feed water pH:	7.0 – 7.5
Temperature:	Regular
Recovery ratio:	Regular

Time of treatment: 10 – 30 minutes. The duration of MT treatment should be determined by checking effect (recovered salt rejection, increasing feed pressure and decreasing permeate flow).

Note: MT may not be effective in some cases such as mechanical damage, or where salt rejection has determined too much.

5) Recommended criteria for concluding MT are:
- Salt passage does not improve further/clearly.
- Permeate flow rate decreases approx. 10% from MT start value at constant operating pressure.
- Net pressure to produce the same volume of permeate increases 10% from MT start value at constant permeate flow.

6) Immediately after MT, adjust pH of feed water to 3～4, and maintain for 30～60 minutes with all other operation parameters as regular.
During MT and low pH operation, permeate should be drained.

7) Continue operation after pH phase at regular conditions for at least 5 hours. Shut-down shortly after MT may result in permeate flow decline.

Storage and preservation

1. General

To prevent biological growth on membrane surfaces during storage and performance loss in subsequent operation, TORAY RO elements must be preserved in a solution.

Element preservation is needed for:

- Long term storage of new and used elements
- RO system shut-down > 24 hours

In case RO elements are in system, see RSU-440 (Shutdown considerations for RO system).

2. Storage of new elements

Preferably, elements should be stored or shipped as packed by TORAY, outside of pressure vessels, and loaded into pressure vessels directly before start-up. Adequate storage conditions will help to minimize bio growth during storage.

Toray specifies the following optimal storage condition:

1) Store elements in cool, dark and dry place inside closed building. Keep away from direct sunlight.
2) Avoid freezing and temperature above 35℃.
3) New elements are stored as shipped in preservation solution of 0.5 – 1% solution bisulfite solution ($NaHSO_3$).
4) New elements are vacant-sealed in a bag made from oxygen impermeable special plastic and packed in carton boxes. The carton boxes should be opened directly before installation.

3. Storage/preservation of used elements

1) If Toray elements were removed from pressure vessel for storage or shipping, they need to be pressured in a 500 – 1,000 ppm sodium bisulfite solution. To make up the preservation solution, use food grade sodium bisulfite and good

water. Usually, sodium disulfite $Na_2S_2O_5$ is used, which reacts with water forming bisulfite:

$Na_2S_2O_5 + H_2O$ ------- $2NaHSO_3$

2) Use softened, chlorine-free water; preferably RO or NF permeate. After soaking elements for about 1 hour in the preservation solution, take them out of this solution and package them in an oxygen barrier bag. Seal and label the bag, indicating packaging date. Recommended oxygen barrier bags are sold by Toray or their representatives.

3) Instead of solution bisulfite, formaldehyde can be used as preservation solution at 0.2 to 0.3% (by weight) concentration*). Formaldehyde is a more effective biocide than sodium bisulfite and is hardly oxydized.

   Observe applicable safety regulations when working with formaldehyde.

   *) Elements must be in operation for at least 72 hours under regular conditions before they can be preserved with formaldehyde, otherwise loss of flux can occur.

   Note: Formaldehyde is harmful and, hence, forbidden for many food-related applications. Responsibility in any case rests with user.

4) After the elements are preserved and repacked, recommended storage conditions are the same as for new RO elements.

Handling of new element

In order to maintain good element performance, observe the following:

1. Precautions which should be taken during storage

1) The elements are shipped from TORAY sealed in oxygen impermeable plastic bags and packaged in carton boxes. Open carton boxes directly before installation.
2) Elements can be stored within a temperature range of 5℃ to 35℃. Avoid storage in direct sunlight. If outside temperature may drop to 0℃ or lower, cover cartons with insulting material and/or heat storage room. Do not allow elements to freeze.
3) Do not stack more than 5 layers carton boxes. Make sure boxes are kept dry.

2. General notes for installation into pressure vessels

1) Carefully open plastic bags at one end is recommended for possible re-use.
2) Keep part of the packing material for the event when elements are removed and stored.
3) Enumerate pressure vessels and record installation location of each membrane element with exact sequence of elements inside each pressure vessel. The recorded information must be updated upon installation of new elements or change of element positions.
4) To avoid damage of elements, handle with care and do not drop. Touch elements with clean hands or gloves only and avoid contamination where possible.
5) Take care to keep the exterior of element clean.
6) See detailed procedures in RSU-410.

Troubleshooting

1. Preface and references to troubleshooting

Potential problems in an RO system can be recognized early by monitoring the changes of permeate flow rate(*), salt passage(*) (salt rejection) and pressure drop of the RO membrane modules.
It is, therefore, recommended for the system operator to record and review daily operation data and to take prompt and appropriate countermeasures or to correct any concerns or problems to prevent future complications.
Normalization of the value marked with* is required in order to properly understand the operation data. Procedures for normalization are described in the O&M section of this manual operation monitoring methods of RO system.
Typical performance changes and their countermeasures are shown in the following chapter.
The steps of troubleshooting are briefly summarized below:

Check:	Calibration of Instruments

↓ Meters (Pressure, Temperature, Conductivity, pH, Flow rate) etc.

Review:	Record of daily operation data, normalization plant history and plant specification

↓

Investigate:	Reason of performance change and possible causes

↓ Refer to RSU-720

Troubleshoot:	Corrective measures, performed in time

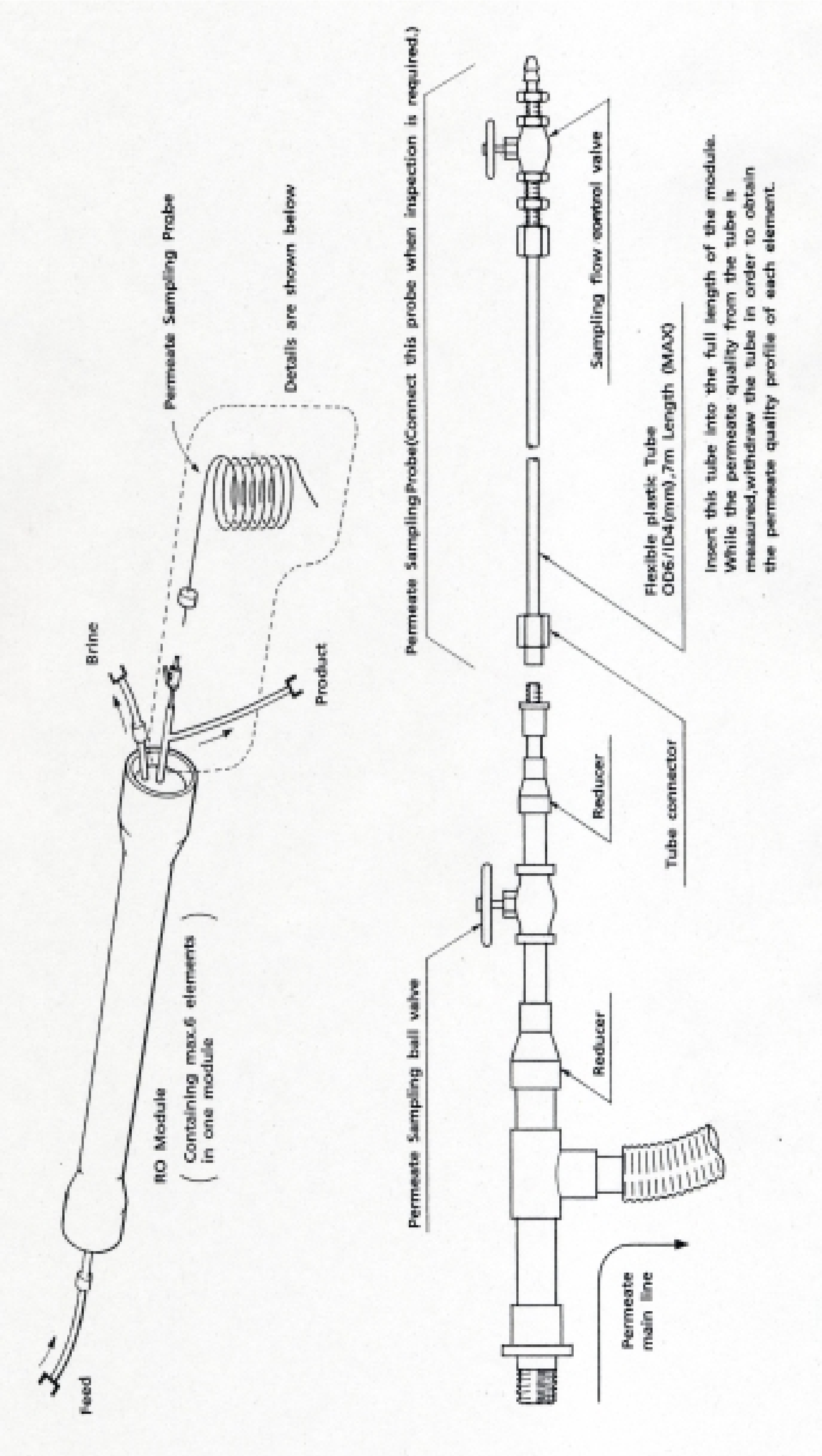
Chemical cleaning, Sterilization,
Replacement of necessary parts,
Change of operating conditions, etc.

2. Center pipe probing method

When the salt passage is increased (electro conductivity increase) and you would like to confirm the water quality deterioration position in the pressure vessel, center pipe probing method can be used. Regarding the apparatus, refer to Fig.710.1.

You can measure the water quality (electro conductivity) at different position in the pressure vessel by sampling the water at different position using center pipe probing.

Fig. 710.1 **Recommended Piping Arrangement and Permeate Sampling Probe for Each Element in One Module**



Typical performance changes and countermeasures

The following points are conditional for determination of performance of changes.
It is assumed that the following requirements have been complied with:

1. Regular calibration of measuring instruments and maintenance of plant components.
2. Logging and evaluation of operating data, monitoring of system operation.

This section is about problems and countermeasures regarding salt passage and permeate flow rate. The role of feed water conditions such as pressure, temperature, concentration, pH and recovery ratio in the system performance is discussed in RSU-430.

The following abbreviations are used in this section:

NPFR = Normalized permeate flow rate
NSP = Normalized salt passage
DP = Differential pressure

Case A: Normalized permeate flow rate (NPFR) decline – first bank

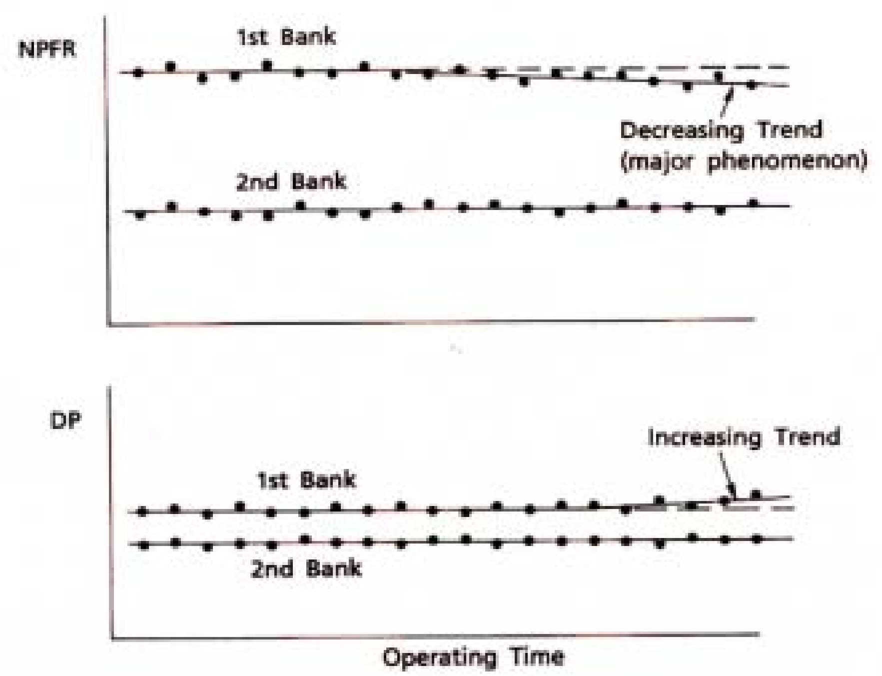


Figure 720.1: NPFR and DP in first concentrate stage

Potential Causes	Countermeasures
1) Change in feed water quality	Check operating parameter (recovery, flux,..) Optimize pretreatment, check cartridge filters (both installation and replacement status)
2) Fouling by metal hydroxides, inorganic colloids, organic or bacterial matter or particles	Analysis of foulant followed by appropriate chemical cleaning and/or sterilization (see RSU-530, RSU-560) Optimize pretreatment, check cartridge filters

Case B: Normalized permeate flow rate (NPFR) decline – last bank

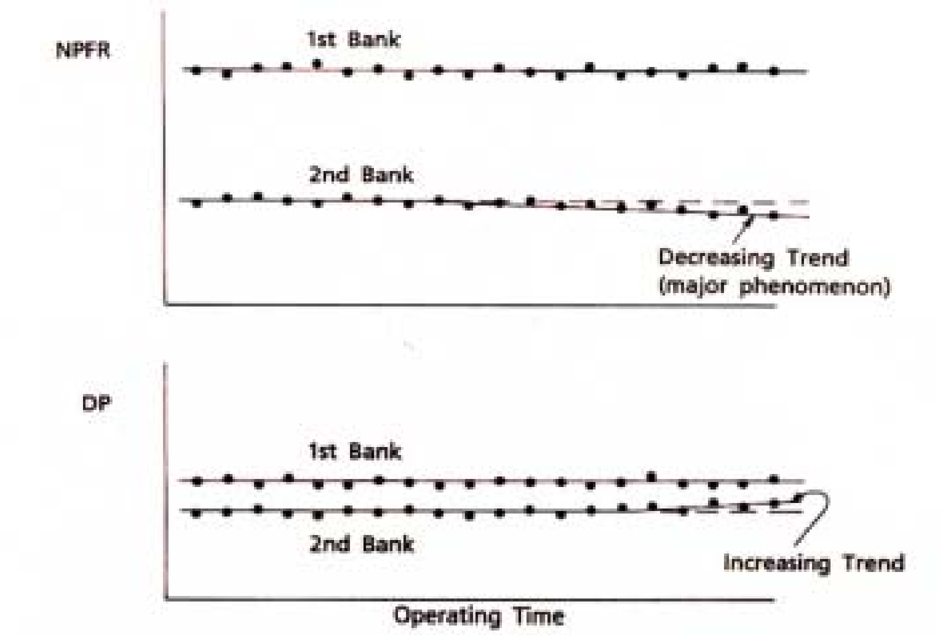


Figure 720.2: NPFR and DP in last concentrate stage

Potential Causes	Countermeasures
1) Change in feed water quality	Check operating parameter (recovery, flux,) Optimize pretreatment, esp. regarding scale inhibition
2) Fouling by metal hydroxides, inorganic colloids, organic or bacterial matter scaling	Check & optimize pretreatment, Analysis of foulant Chemical cleaning and/or sterilization (see RSU-530, RSU-560) Analysis of precipitate, followed by chemical cleaning

Case C: Normalized salt passage (NSP) increase – almost all vessels

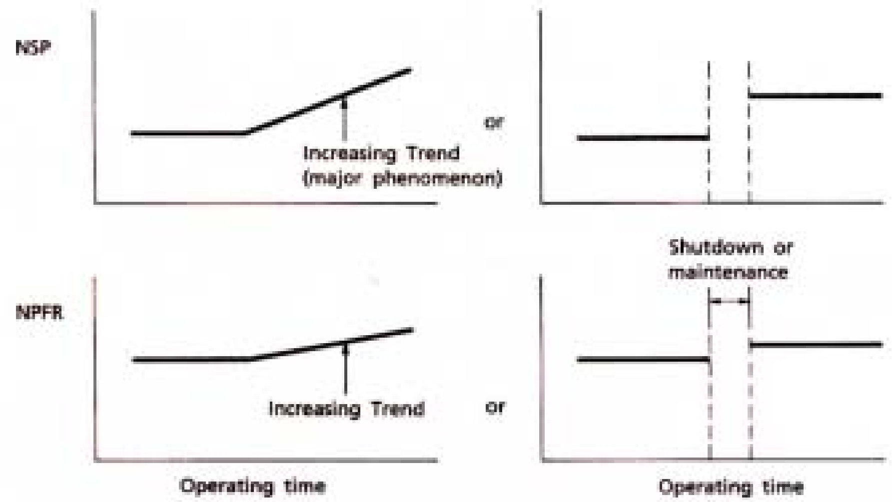


Figure 720.3: Normalized Salt Passage (NSP) increase – all banks

Potential Causes	Countermeasures
1) Membrane affected by exposure oxidants, use of non-guideline chemicals, operation outside recommended parameter range	Check, modify and/or optimize chemicals applied to the system Check and adjust operating conditions according to recommendations of manufacturer
2) Mechanical damage due to precipitation of sparingly soluble salts	Check pH adjustment and/or dosing rate of scale inhibitor Adjust recovery according to limits given by water chemistry
3) Mechanical damage due to particles in feed water	Optimize pretreatment, check cartridge filters.

Case D: Normalized permeate flow rate (NPFR) decline – all banks simultaneously

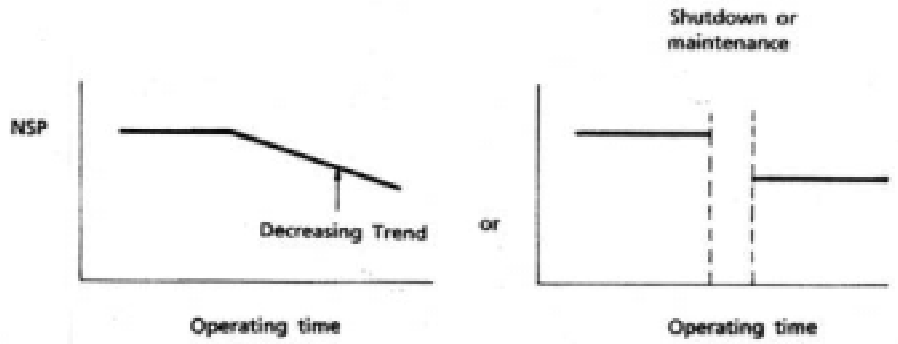


Figure 720.4: Normalized Permeate Flow Rate (NPFR) – all banks

Potential Causes	Countermeasures
1) Membrane affected by exposure to undesirable chemicals, use of non-guideline chemicals, operation outside recommended parameter range	Check, modify and/or optimize chemicals applied in system and maintenance

Case E: Differential pressure (DP) increase

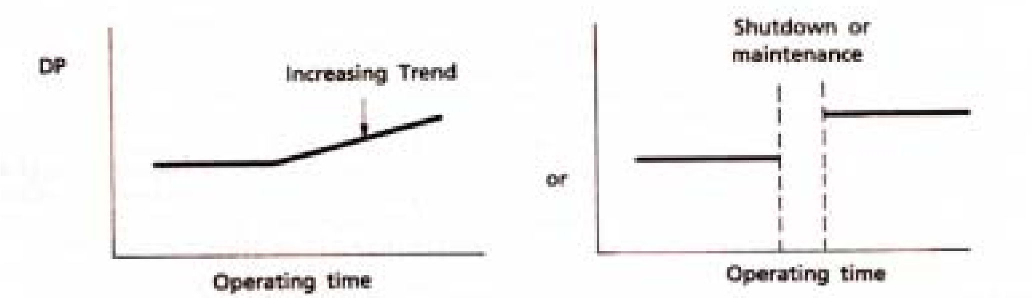


Figure 720.5: Differential Pressure (DP) increase

Potential Causes	Countermeasures
1) Fouling or scaling	Refer to Case A and B
2) Excessive feed flow	Check and adjust operating conditions according to recommendations of manufacturer

Case F: Normalized salt passage (NSP) increase – partial vessel

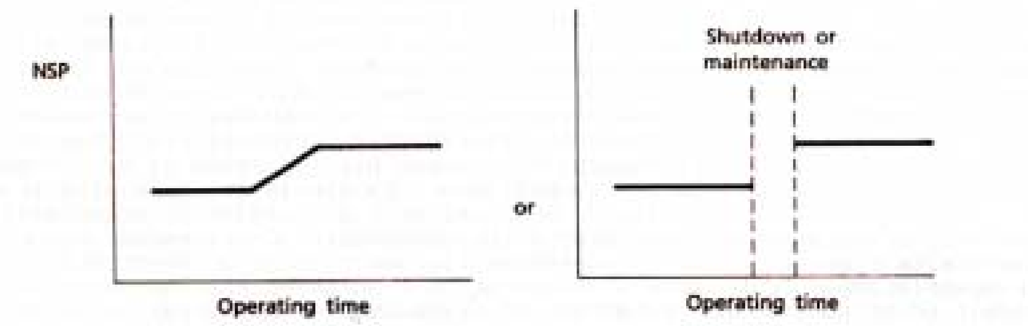


Figure 720.6: Normalized Salt Passage (NSP) increase

Potential Causes	Countermeasures
1) Mechanical leakage due to - O-ring seal damage - Excessive feed flow - Excessive pressure drop - Excessive back pressure	Detect location of leakage in a particular vessel by permeate sampling probe. Make sure that back pressure (permeate minus feed or brine pressure) is less than 0.07 MPa at any time. Check and adjust operating conditions according to recommendations of manufacturer, in particular for recovery and concentrate flow. Make sure that these values are not exceeded under start-up and shut-down conditions.