4th November, 2008

RO Training Materials

for

Shuaibah III Expansion RO Project

Toray Industries, Inc.
RO Membrane Products Dept.

'TORAY'

Contents

Toray RO membrane

Training Module # 1

Basic Terminology

November, 2008

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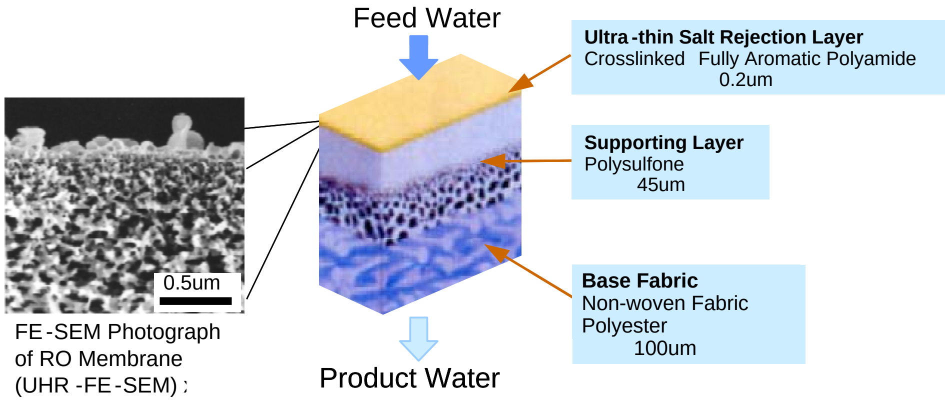
Reverse Osmosis Element

- A reverse osmosis element can take several forms
  - Flat sheet, in a plate and frame device
  - Tubular
  - Spiral wound
  - Hollow Fine Fiber

  - Our discussion is limited to the Spiral Wound configuration. This is the most commonly used configuration for large scale water and waste water reclamation purposes

Reverse Osmosis Membrane

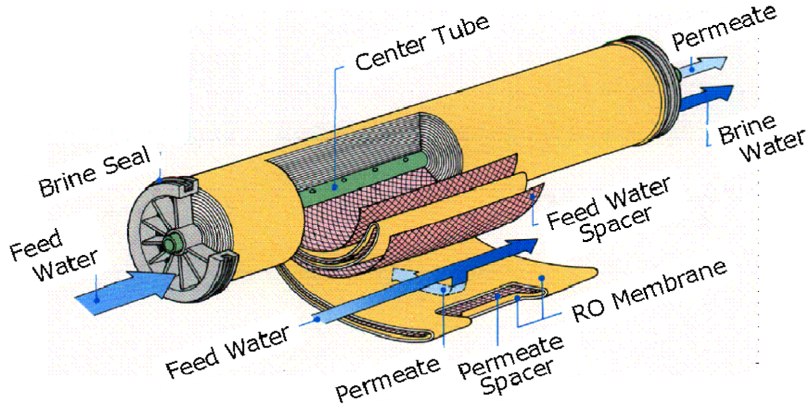


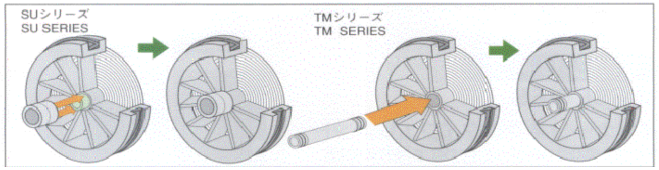
FE-SEM Photograph of RO Membrane (UHR-FE-SEM) :

The RO Membrane

- The membrane layer which makes the separation is extremely thin (approximately 200 nanometer)
- It is supported on a porous polysulphone backing layer which gives the membrane layer some strength (approximately 45 micron thick)
- The polysulphone is itself supported on a non-woven polyester backing fabric (approximately 100 micron thick)

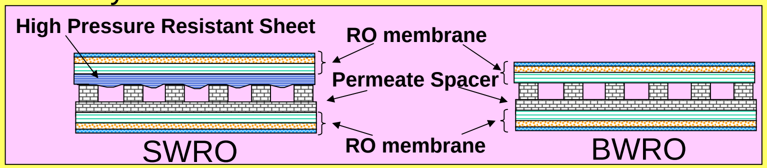
Schematic Figure of The Spiral Wound Element





Anatomy of a Spiral wound Element (1)

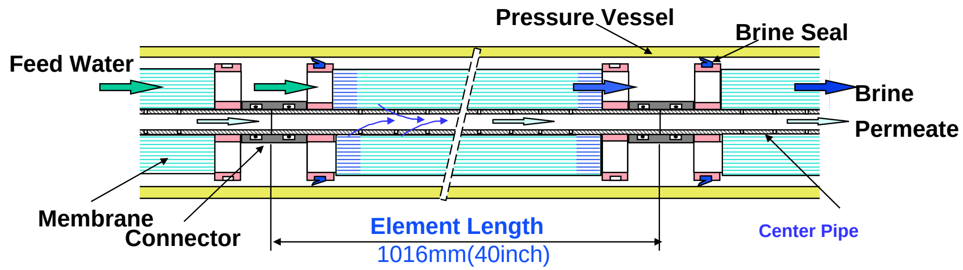
- The pressurized feed water flows in an axial direction through the feed/brine spacer mesh (commonly referred to as "Vexar")
- The pressure forces some of the feed water through the membrane layer, leaving the majority of the dissolved salts on the feed side of the membrane. The water crossing the membrane is called permeate
- The permeate is collected in the permeate spacer material
- The permeate spacer material is located between 2 sheets of membrane. The 2 sheets of membrane plus the permeate spacer is collectively called a leaf



Anatomy of a spiral wound element (2)

- The permeate carrier material is sealed to the 2 layers of membrane on 3 sides (both ends, plus the outer edge). The inner edge of the permeate carrier material is adjacent to the central product tube (permeate center pipe)
- Permeate entering the product carrier material travels down the leaf to the central product tube.
- An 8" diameter element will have multiple leaves, each terminating at the central product tube. Shorter leaves are preferable to improve the efficiency of operation of the element

Systems of Elements

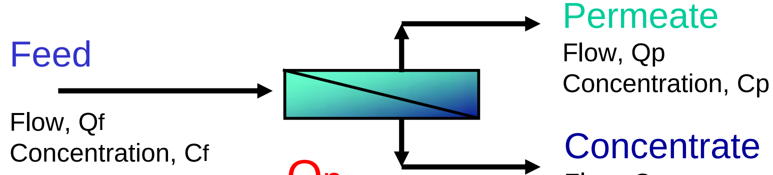


- Elements can be coupled together in series, typically up to 7 x 40" long elements.
- The elements are located inside a pressure vessel.
- The pressure vessel has offset feed and brine ports, and central ports at each end for removing the permeate

Technical Words for RO systems

- Recovery Rate & Concentration Factor
- Array
- Interbank Booster Pumps
- Permeate Back Pressure
- Flux
- Salt Rejection & Salt Passage
- Scaling
- Fouling
- Differential Pressure

Recovery Rate & Concentration Factor



- Recovery = $\frac{Qp}{Qf}$

- Concentration Factor = $\frac{Qf}{Qc} = \frac{1}{1\text{-Recovery}}$

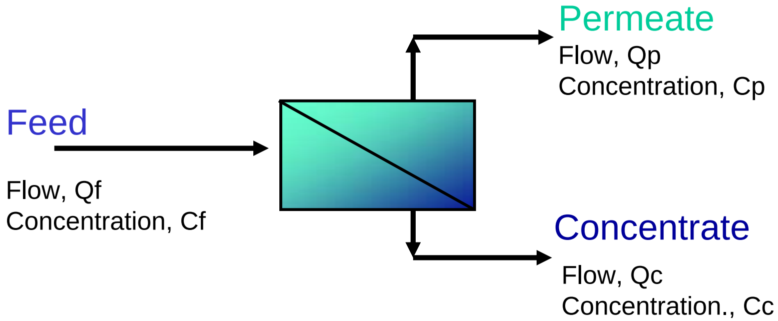
Relationship between Recovery and Concentration Factor

Recovery	Concentration Factor
50%	2
75%	4
87.5%	8
90%	10

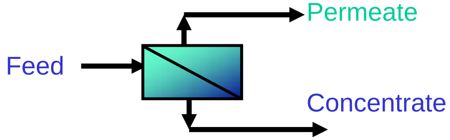
With high rejection membrane, concentration factor gives us a good feel for how highly salts will be concentrated in the Brine stream

Array

An array is a set of RO elements consisting of banks of vessels connected in parallel. If there is more than one bank, the banks are concentrate staged

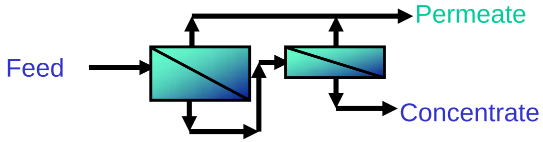


Multiple Bank Design



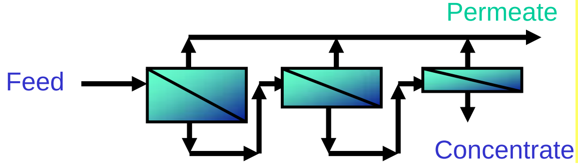
1 bank system

- Low recovery SWRO (< 45%)



2 bank system

- BWRO system (< 80%)
- High Recovery SWRO (<60%)
- High Recovery 2nd Pass (<90%)



3 bank system

- High Recovery BWRO system (< 90%)
- High Recovery 2nd Pass (<95%)

Interbank Booster Pumps

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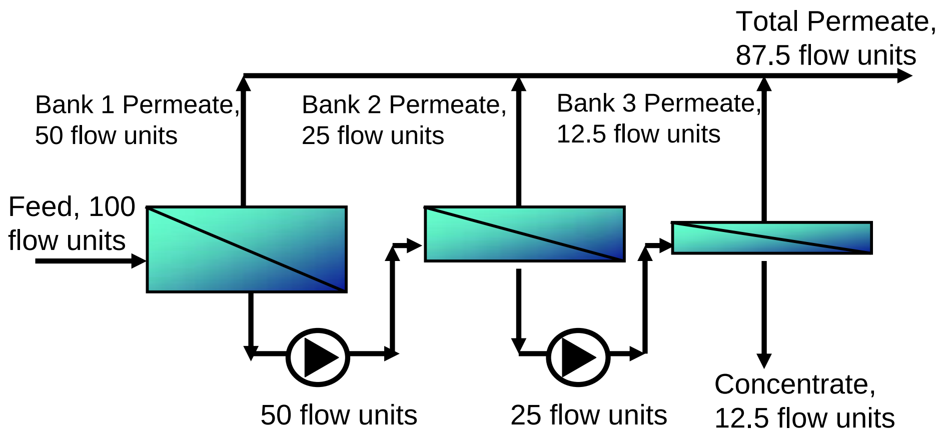

Interbank Booster pumps are used to equalize flow/ flux between banks

Permeate Back Pressure

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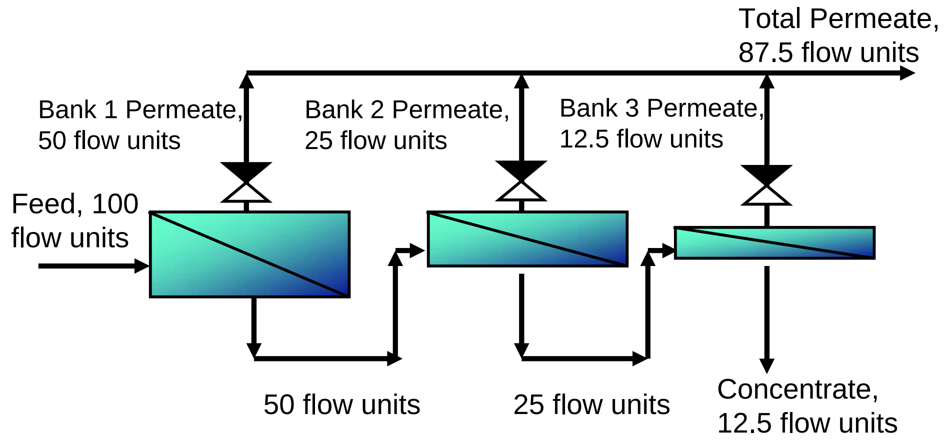

Permeate Back Pressure can be caused by discharging permeate to elevated storage tanks/ degasser towers, in which case it applied equally on all banks

Permeate Back pressure can also be applied to selected banks (usually bank 1) with a throttling valve to restrict the flow from that bank to equalize fluxes

Flux

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$$\text{- Ave. System Flux} = \frac{Qpt}{St}$$

Where:
Qpt : Total permeate flow rate
St : Total active membrane surface

$$\text{- Element Flux} = \frac{Qpi}{Si}$$

Where:
Qpi : Single element permeate flow rate
Si : Single element membrane surface

Average system flux and highest single element flux are one of the most important factor for good RO system operation.

Different average system fluxs are recommended for each raw water source and pretreatment system.

Salt Rejection & Salt Passage

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$$\text{- Salt Rejection} = 1 - \frac{Cp}{Cfb}$$

Where:
Cp : Permeate concentration of a salt
Cfb : Feed - Brine Ave. concentration of a salt

$$\text{- Salt Passage} = 1 - \text{Rej.} = \frac{Cp}{Cfb}$$

- Rejection is the measure of how well a particular dissolved ion or compound is retained on the feed side of the membrane.
- Salt passage is defined as the ratio of concentration in the permeate of a particular dissolve ion or compound to salt concentration in the Feed stream of the same ion or compound
- Typical Salt rejection calculations are made for:
  1. Conductivity (a measure of all dissolved ions)
  2. Chloride ion
  3. Hardness
  4. Sulphate
  5. TOC
  6. Silica

Where:
Cp : Permeate concentration of a salt
Cfb : Feed – Brine Ave. concentration of a salt

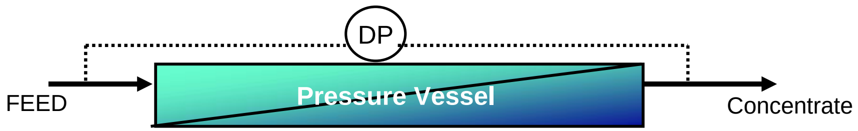
Scaling

- The deposition of sparingly soluble salts onto the membrane surface and/or the feed channel material.
  - Scaling occurs primarily in the downstream elements because of the higher concentrations existing in this portion of the RO system.
  - Common scalants include
    - calcium sulfate,
    - calcium carbonate.
    - Silica
  - Less common Scalants include
    - Calcium Phosphate
    - Calcium Fluoride
    - Barium sulfate

Fouling

- The deposition of suspended particles on the membrane surface.
  - Foulant on the membrane surface increases the resistance to the flow of water through the membrane.
  - Fouling causes lower productivity at constant net pressure or higher net pressure at constant productivity.
  - Sometimes higher salt passage will be caused by fouling.

Differential Pressure



- Increase of normalized *Differential Pressure* indicates fouling of feed / brine channel.
- Typical causes of DP increase.
  - Upstream :

    - Suspended solids, colloid, bacteria, silt, clay, iron corrosion and pretreatment coagulant in the feedwater
  - Downstream : scaling
  - Any stage mainly lead position : Biological fouling

Toray RO membrane

Training Module # 2

Factor affecting RO performance

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MF/UF & RO : What is the difference ? (1)

MATERIALS OF CONSTRUCTION

MF / UF

- One asymmetric material layer – polysulphone, polyacrylonitrile, PVDF
- Homogeneity allows backwash to be made frequently

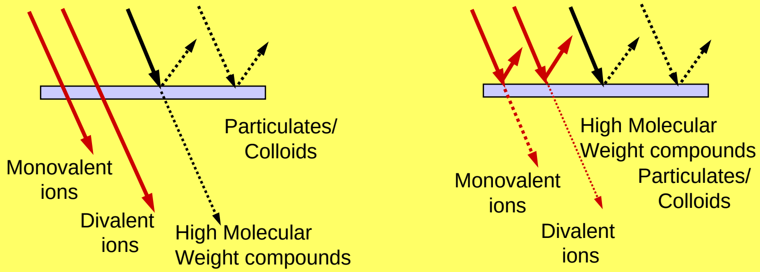
RO

- 2 stage process:
  - Polysulphone cast onto backing fabric
  - membrane layer (200 - 300 nm) coated onto polysulphone
- Risk of de-lamination if backwashed - surface clean only

MF/UF & RO : What is the difference ? (2)

SEPARATIONS - WHAT IS THE DIFFERENCE?

MF / UF | RO



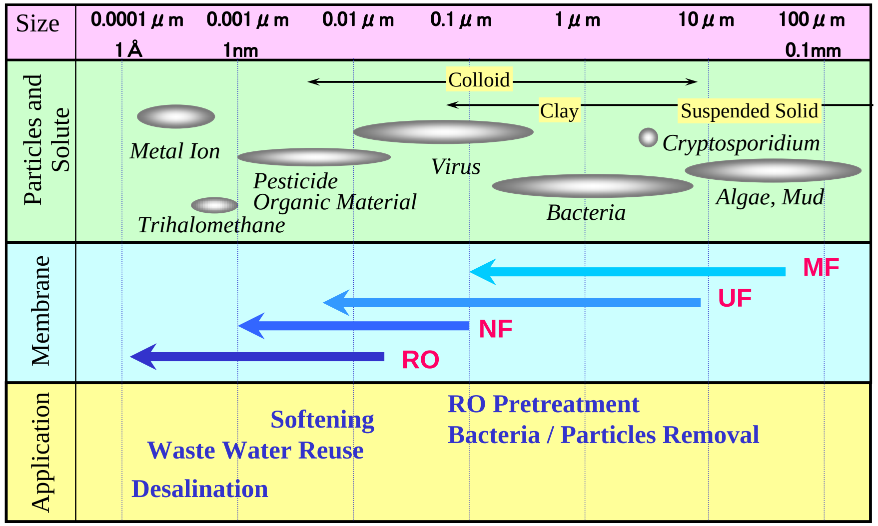
MF / UF Membrane Reject
-Particulates / colloids

MF / UF membrane does not reject dissolved ions.

RO Membrane Reject
- Monovalent ions well : > 99%
- Divalent ions extremely well : > 99.8%
- Extremely High Rejection for
  – high molecular weight molecules
  – particulates/colloids etc

MF/UF & RO : What is the difference ? (3)

Particle size and Separation Process



Osmotic Pressure

Van't Voff Equation

$$\pi = \frac{nRT}{V}$$

WHERE:

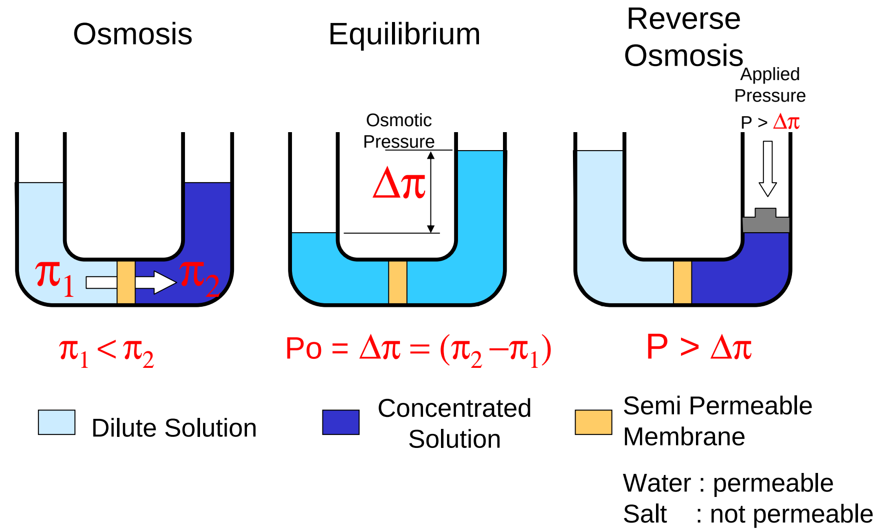
n	=	Moles
R	=	Gas constant
T	=	Temperature
V	=	Volume

Typical Osmotic Pressure

All of dissolved solute causes osmotic pressure.

	Concentration (mg/L)	Osmotic Pressure (π) (bar)
NaCl	2,000	1.6
NaHCO3	2,000	1.2
MgSO4	2,000	0.7
Glucose	10,000	1.3
Seawater	35,000	26.2

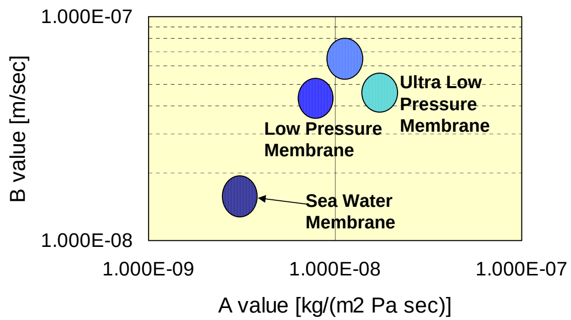
Principle of Reverse Osmosis



" A value " & " B value "

Performance of RO membrane is characterized by "A value" and "B value"

- "A" value: water mass transport coefficient
- "Bi" value: salt mass transport coefficient (for ion species "i")



Suitable membrane selection is very important for your RO system design.

Key Concept : " A value "

Water Permeability : $Jv = A \times Pnet$

Permeate Flow Rate : $Qp = Jv \times S$

Net Driving Pressure : $Pnet = (P_f - \Delta\pi - \Delta P/2 - P_p)$

WHERE:

Jv	=	Water Permeability (=Flux)
A	=	Water Mass Transport Coefficient
Qp	=	Permeate Flow Rate
S	=	Membrane Area
Pnet	=	Net Driving Pressure
P_f	=	Feed Applied Pressure
$\Delta\pi$	=	Differential Osmotic Pressure
ΔP	=	Hydraulic Pressure Losses
P_p	=	Permeate Pressure

Key Concept : " B value "

Salt Permeability : Jsi = Bi x (Cmi – Cpi)

Salt Flow Rate : Qsi = Jsi x S

WHERE:

Jsi	=	Salt Permeability(species " i ")
Bi	=	Salt Mass Transport Coefficient (species " i ")
Cmi	=	Concentration at Membrane Surface(species " i ")
Cpi	=	Concentration at Permeate(species " i ")
Qsi	=	Salt Flow Rate (species " i ")
S	=	Membrane Area

Key Concept : "Permeate Concentration"

Permeate Concentration : Cpi = Jsi / Jv

= (Cmi x Bi) / (Bi + Jv)

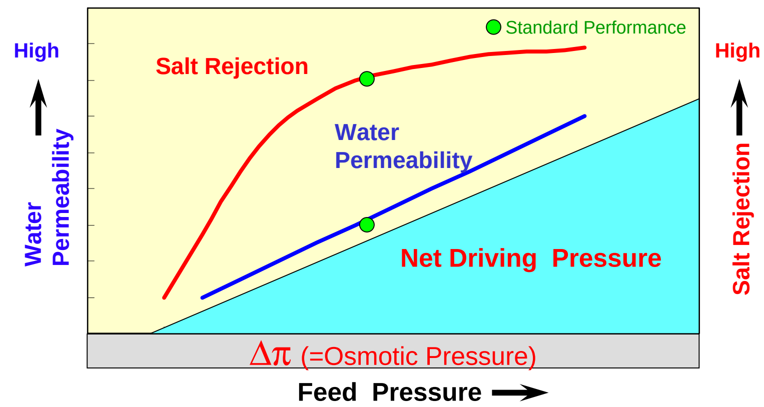
WHERE:

Cpi	=	Concentration at Permeate(species " i ")
Jsi	=	Salt Permeability(species " i ")
Jv	=	Water Permeability (=Flux)
Bi	=	Salt Mass Transport Coefficient (species " i ")
Cmi	=	Concentration at Membrane Surface(species " i ")

Factors Affecting RO Performance

- Net driving pressure effects
- Temperature effects
- Salinity effects
- pH effects
- Brine flow rate(=Recovery) effects
- Molecular effects on "B" value

Net Driving Pressure Effect (1)



Assuming Temperature, Brine Flow Rate, Feed pH and Feed Concentration are constant.

Increasing Net Driving Pressure	Water Permeability ⇧	Salt Rejection ⇧

Net Driving Pressure Effect in pressure vessel

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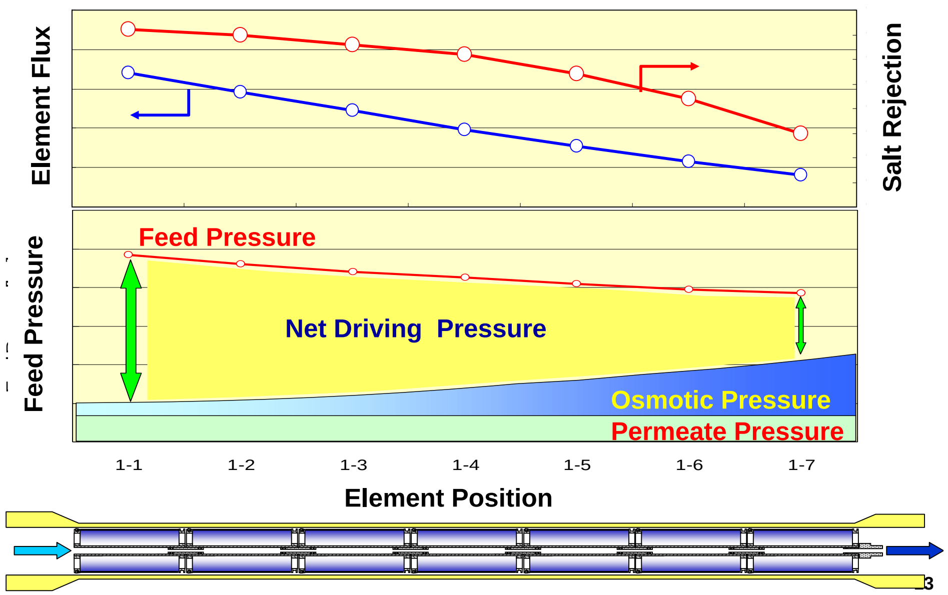

Temperature Effect

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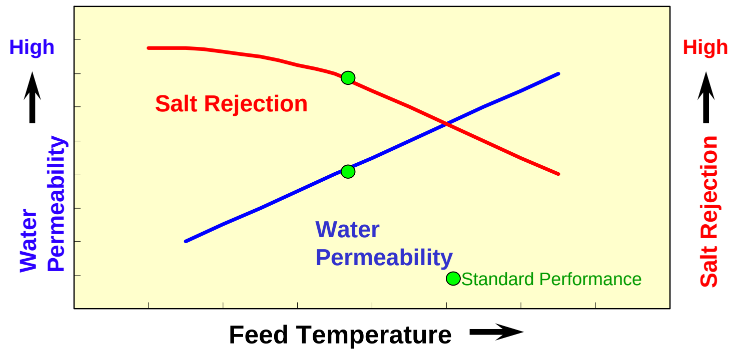

Assuming Feed Pressure, Feed pH, Feed Concentration and Brine Flow Rate are constant.

Increasing	Water Permeability	Salt Rejection
Feed Temperature	↑	↓

Water permeability will increase about 3% per 1degC

- Highest water temperature must be considered for warranty exposure
- Highest operating pressure should be checked at lowest operating temperature.

Salinity Effect

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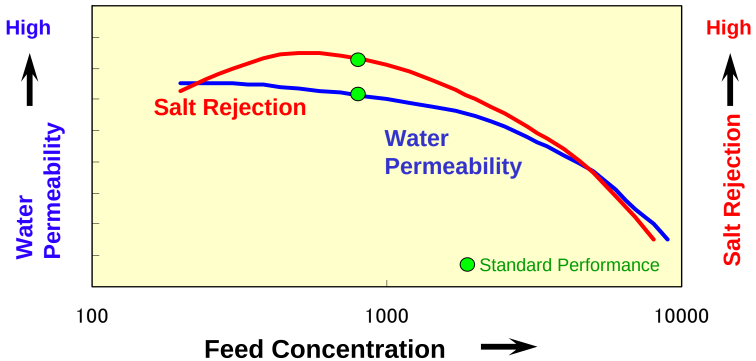

Assuming Feed Pressure, Feed Temperature Feed pH and Brine Flow Rate are constant.

Increasing	Water Permeability	Salt Rejection
Feed Salinity	↓	↓

- Salt rejection decreases at lower feed salinity (<400mg/l as NaCl) due to RO membrane negative charge effect.

pH Effect (1)

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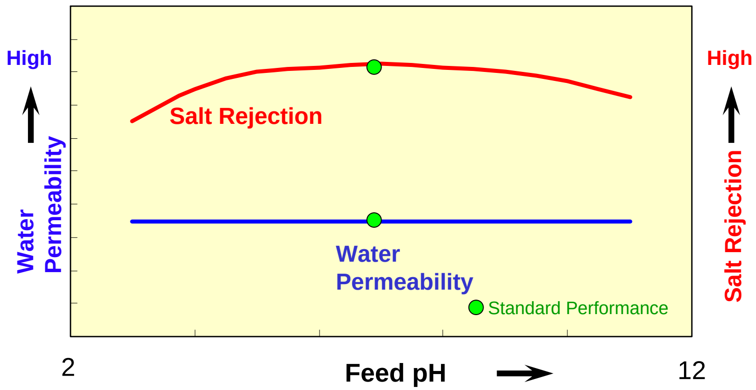

Assuming Feed Pressure, Feed Temperature Feed Concentration and Brine Flow Rate are constant.

Increasing	Water Permeability	Salt Rejection
Feed pH	→ Almost Stable	↗ ↘

- Salt rejection is rather constant over a broad pH range.
- Salt rejection will decrease at extremely high and low feed pH

pH Effect (2) Example of dissociation and its effect

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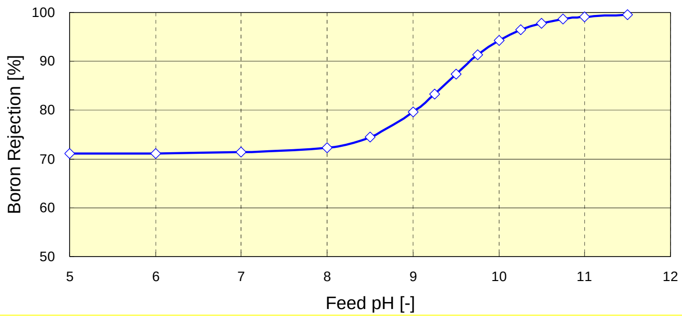
Example of dissociation and its effect on rejection – Boron -



- Several ions change its ionized or non-ionized condition by pH.
  Hydrofluoric Acid, Acetic Acid, Boric Acid, Ammonia etc.
- Rejection at non-Ionized condition is not higher than at ionized condition
  Boron (by TM700) : Borate $B(OH)_3$: 70-75%
  Boric $B(OH)_4$ - : 99.5%

Brine Flow Rate (=Recovery) Effect

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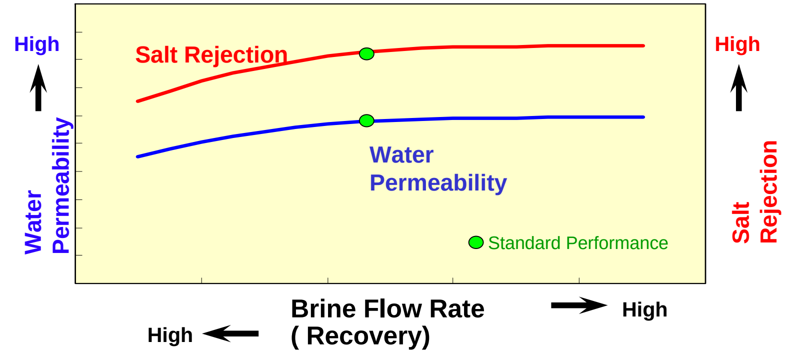

Assuming Feed Pressure, Feed Temperature Feed Concentration and Feed pH are constant.

Increasing	Water Permeability	Salt Rejection
Brine Flow Rate	⇧	⇧
Recovery	⇩	⇩

- Low Brine flow rate (= high recovery) causes higher membrane surface salinity.

Molecular Effects

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Factors influencing permeation rates of dissolved materials:

1. Greatest Influence: Electrical Charge Density
   Typical RO performance

	Monovalent Ions	> 99 %
	Divalent Ions	> 99.7%
	Trivalent Ions	> 99.9%

2. Moderate Influence: Molecular Weight
   - This is a secondary effect, after charge density
   - The larger the molecular weight, the lower the "B" value.

     Methanol (MW= 32) : 15 %
     Ethanol (MW= 46) : 55 %
     Isopropanol (MW= 60) : >90 %

3. Slight Influence: Molecular Structure
   - Molecules with side branch structures tend to have higher salt rejection than more linear molecules

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Toray RO membrane
Training Module # 3
Boron Removal

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What is Boron ? (1)

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Predominant reason for limiting Boron in Water

1. For Human
   - Reproductive danger (represent)
   - Teratogenic properties (suspected)
     WHO preliminary limit < 0.5 mg/l
     EU guideline < 1.0 mg/l
2. Damage to Plant and Crops
   - Leaf damage (citrus tree is very sensitive)
   - Reduce fruit yield
   - Induce premature ripening

- Boron concentration in sea water : 4.5 – 5.5 mg/l
- Sea water desalinated water by RO membrane does not meet requested Boron revel.

→ Special Application is required to remove Boron

What is Boron ? (2)

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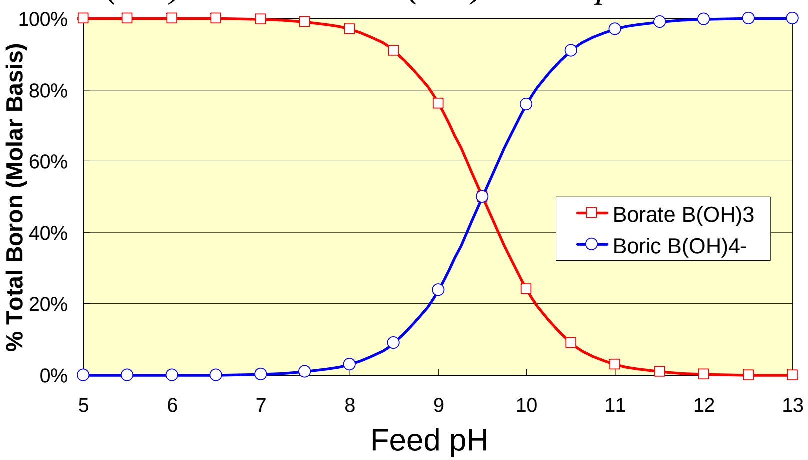
$$H_3BO_3 + H_2O \rightarrow H_4BO_4^- + H^+ \quad pKa = 9.2$$

$$B(OH)_3 + OH^- \rightarrow B(OH)_4^- \quad pKb = 4.8$$



Boron Removing Process (1)

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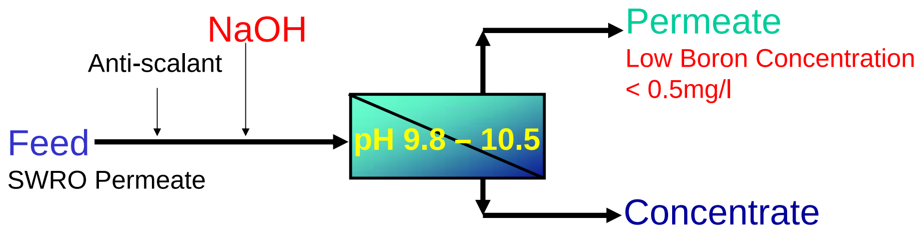
High pH RO Operation - SWRO permeate is treated again with high pH



Borate will be changed to ionized Boric

$$H_3BO_3 + H_2O \rightarrow H_4BO_4^- + H^+ \quad pKa = 9.2$$

Borate (H_3BO_3), Boric ($H_4BO_4^-$)

Boron Removing Process (2)

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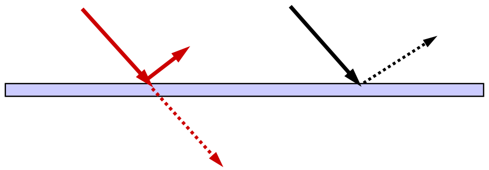
Borate will be changed to ionized Boric

$$H_3BO_3 + H_2O \rightarrow H_4BO_4^- + H^+ \quad pKa = 9.2$$

Borate (H_3BO_3), Boric ($H_4BO_4^-$)

Difference of removal performance (TM720)

H_3BO_3 : 70% $H_4BO_4^-$: 99.5%



Boron Removing Process (3)

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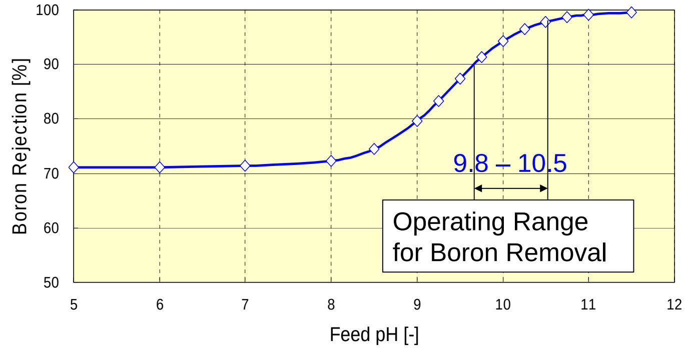

Boron rejection will be improved to more than 90% by high pH operation.

Required permeate Boron concentration is achieved !!

Suspected Problem during High pH operation

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Scaling problem is caused by excessive high pH operation , too low anti-scalant dosing or too high recovery operation.

Scaling substance : $CaCO_3$, $Mg(OH)_2$

pH control, anti-scalant dosing and correct recovery operation are very important.

- Correct pH measurement,
- Good and enough pH meter calibration
- Correct anti-scalant dosing
- Check anti-scalant dosing rate and consumption very frequently.
- 2nd pass brine pH & conductivity checking

Toray RO membrane

Training Module # 4

RO element installation

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Before decide to install RO element

Check following items before decide to install RO element (refer handling manuals for more detail information)

- System Preparation
- Pressure Vessel Preparation
- Feed Water Analysis

Before decide to install RO element (1)

***System Preparation** (it is strongly recommended especially for new plant)*

1. Piping flush out
   - All piping from pretreatment to RO flush to remove all harmful materials.
   - Flushing time approx. 30minutes.
2. Pretreatment stabilization
   - Confirm pretreatment stabilization (all process must be known to be working stably and within specification.
3. Instrument Calibration
   - Instrument calibration (all flow, pressure and quality measurement equipment must be checked and calibrated)
4. Hydraulic Testing
   - All necessary hydraulic testing of pipeworks must be completed.
5. High pressure inspection
   - Check the high pressure inspection – pressurized RO system including vessels with actual operating pressure must leak free.
6. **Control system completion** - RO process control and data logging

Before decide to install RO element (2)

Pressure Vessel Preparation

Consult documentation from vessel manufacturer for specific information for the vessel as installed on the system. The following information is generic in nature.

•Clean the inside

- Clean the inside of the vessels before RO element loading. Remove any dust and debris that could collect on the membrane surface or scratch the surface of the vessel.
- Clean the inside wall with rubbing clean cloth or sponge. If feed / brine port is locating on horizontal position of pressure vessel, this cleaning is important to remove upper position.

Note : Be sure to avoid scraping the pipe along the vessel's inner surface. Score marks on the bore of the vessel may result in flow bypass round the elements, or leaking endcaps.

Before decide to install RO element (3)

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Water Analysis

Feed water quality must be checked before RO installation by reliable method and party. All analysis results must be satisfied warranty conditions.

Correct water sampling, water preparation and procedure is very much important for proper water analysis. ➡ please refer training material

Check important preparation items in pre-start-up check sheet. Some of items are very difficult to improve after RO element installation.

RO elements installation (1)

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For successful RO elements installation

-RO elements installation must be done after all necessary preparations are checked and satisfied the condition.

- Prepare clean space to put necessary parts (interconnector, endplate, etc.)
- Use safe protection items (safety gloves, safety glasses, safety shoes)
- Check and prepare necessary parts before RO installation. (lubricate O-ring, count the interconnector, endplate, etc.)
- RO elements installation works should be done systematically, and its procedures are well known by all workers. (refer the schematic sample procedure of RO installation in next page)
- Each installation worker should know his responsible work before starting.
- Keep clean around the RO train during installation.

Refer handling manuals and training module for more detail information

RO elements installation (2)

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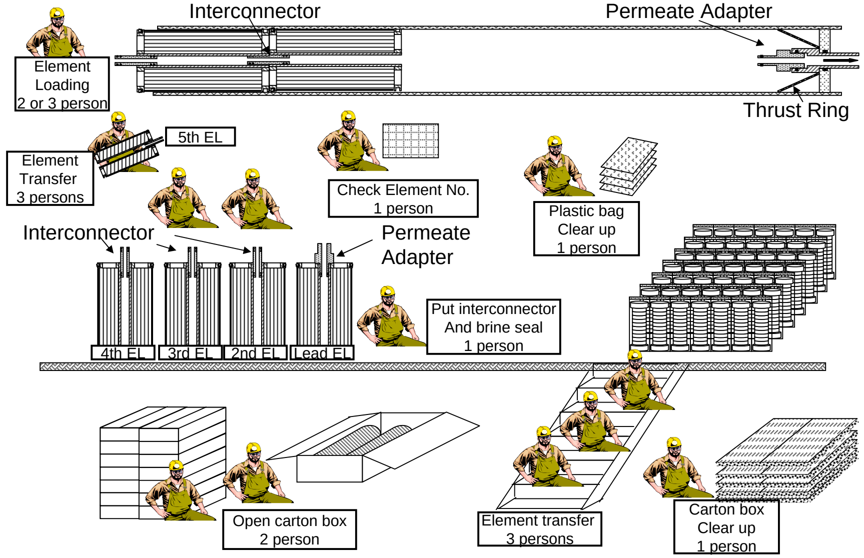
Schematic sample procedure of RO elements installation



RO elements Loading Check List

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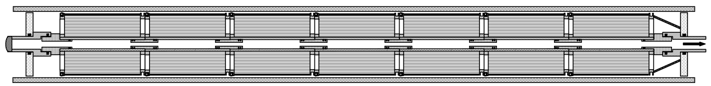
RO Membrane Loading Logging List " Train " Date : ____________

Feed Side ⟶ Brine Side

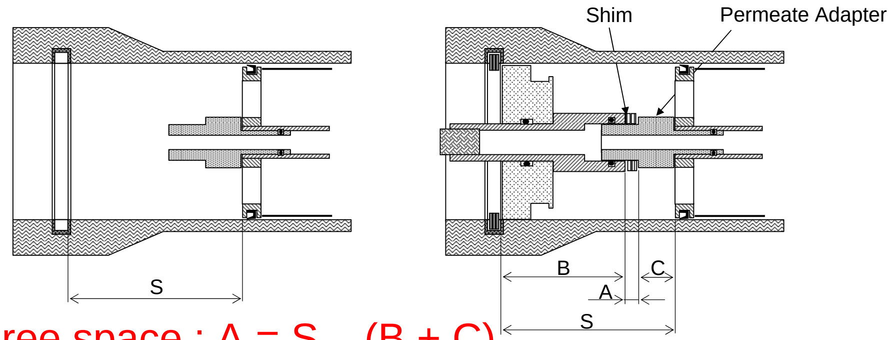
Vessel No.	1	2	3	4	5	6	7	Number of Shims

Feed Side 1 2 3 4 5 6 7 Brine



Shimming (1)

The shimming process :
- Helps to minimize element movement inside the vessel when the system is shut down and re-started.
- Helps to minimize O-ring movement against the sealing surfaces, so reducing wear and possibility of “rolling” O-rings. This reduces leakage.



Free space : A = S – (B + C)

Refer handling manuals and training module for more detail information

Shimming (2)

Shimming Procedure

1) Ensure that all elements are installed into pressure vessel correctly.
2) Push elements firmly into the pressure vessel so they are completely located into the down stream end plate.
3) Measure the distance S : Feed side edge of lead element to retaining ring groove inside edge.
4) Free space A is calculated by following.

   Free space : D = A – (B + C)

5) Decide the number of shims for this pressure vessel

   - Number of shims = (A – 1mm) / thickness of shim(truncate the decimal place)

Refer handling manuals and training module for more detail information

Toray RO membrane
Training Module # 5
RO System start - up

November, 2008

Toray Industries, Inc.,

Before RO system start-up

For RO system start-up, following items must be checked and verified. All items must satisfy its requirement.
(refer to handling manuals for more detail information)

- Pre-start-up checklist
- Equipment requirement for start-up
- Feed water qualities

Never fail to check all necessary items.

It is strongly requested to keep warranty conditions just after pre-treated water feed into RO elements to keep RO membrane performance.

Pre – start – up checklist

After installing RO elements, check all items in pre-start-up checklist.

Pre-start-up checklist include important items and it is offered as a guideline.

RO start-up should not be initiated, if any item could not satisfy the condition.

Refer handling manuals and training module for more detail information.

Complete and accurate records are required in case of a system performance warranty claim.

Equipment Requirements for Start-up

The initial system start up should be performed immediately after element loading.

The following equipment is recommended to be available.

- Safety glasses (for use with any chemicals)
- Thermometer
- pH meter
- Conductivity meter (handy type)
- Clean plastic bottles with caps for samples
- Analysis equipment :
  Total Hardness, Calcium, Alkalinity, Chloride, Sulphate, Iron, Boron, Free and Total chlorine, Redox potential

Refer handling manuals and training module for more detail information

Feed Water Qualities for Start-up

'TORAY'

Before starting the reverse osmosis unit, ensure the entire pretreatment has been commissioned and working in accordance with the specifications. It is strongly recommended that a full analysis of the feed water to be supplied to the RO should be made.

Other tests required:
- Absence of oxidants (ex. Chlorine)
- Turbidity + SDI
- SBS concentration measurement in pretreated water (if chlorine is used for pretreatment)

The raw water must be stable with respect to :
Flow rate, SDI, Turbidity, Temperature, pH, Conductivity, Bacteria count(plate count)

Refer handling manuals and training module for more detail information

Start-up Sequence - Air venting (1) -

'TORAY'

Proper air venting is essential to prepare the membranes for service. It is extremely important that all air is purged from the feed / brine side of the system to prevent hydraulic shock.

Air remaining in the elements and/or in the pressure vessels might be led to excessive forces on the element in flow direction or in radial direction and causing fiberglass shell cracking, if the feed pressure is ramped up too quickly at high pressure operation start-up.

Refer handling manuals and training module for more detail information

Start-up Sequence - Air venting (2) -

'TORAY'

Air Venting Procedure (1)

1. Prior to initial start up, all pre-check must be completed.
2. Check all valves to ensure correct position. The feed pressure control valve, concentrate control valve and permeate drain valve should be fully open.
3. All permeate and concentrate should be directed to drain.
4. 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.
5. Use low pressure water at a low flow rate to flush air out of the pressure vessels and elements. Flush at 1 – 2 bar pressure.
6. Keep the low flow rate until flushing water coming from brine side. Recommended flow rate is 2.5m3/hr for each vessel.

Start-up Sequence - Air venting (3) -

'TORAY'

Air Venting Procedure (2)

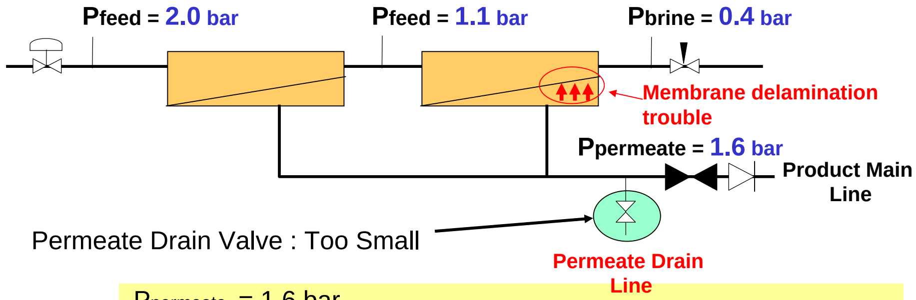
7. After water coming from brine side, increase brine flow rate up to normal operation value.
8. During flushing operation, check carefully for any leaks, and tighten connections where necessary.
9. Check the water condition from air vent line in brine side. Continue flushing until air is not contained in the water. Flushing time should be more than one hour with pre-treated water.
10. Stop flushing and repeat again from step 5 to 8. This repeating flushing is very effective to purge air in dead space.
11. Repeat step 9 until air venting is completed.

Refer handling manuals and training module for more detail information

Start-up Sequence - Air venting (4) -

Permeate Back Pressure Trouble at Flushing

If permeate drain valve is not opened or too small, permeate side pressure would be increased almost close to feed inlet pressure.



$P_{permeate}$ = 1.6 bar

Maximum back Pressure at 2nd bank end position = 1.2 bar

➔ Exceeding back pressure limit (=0.7 kg/cm2)

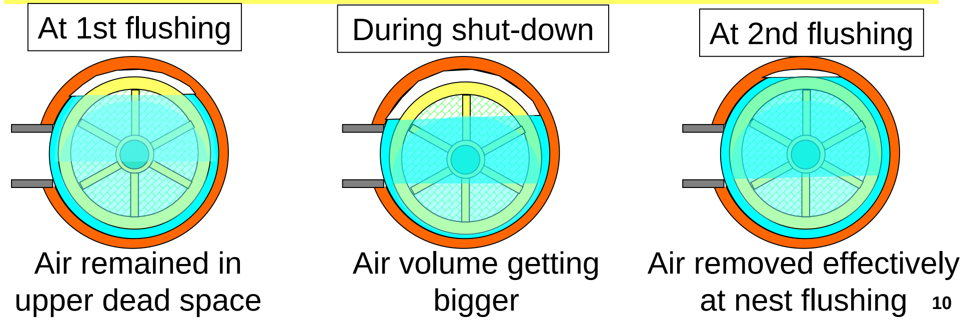
➔ Membrane delamination trouble may occur.

Refer handling manuals and training module for more detail information

Start-up Sequence - Air venting (5) -

Advantage of repeated Air Venting

1. During air-venting, air will be compressed and remained in the dead space of upper place in pressure vessel and elements. The long time flushing will reduce small amount of this air.
2. During the shut-down after 1st flushing, remaining air volume will be getting bigger by reducing pressure.
3. At the next flushing air could be removed more effectively.



Start-up Sequence – proper start-up (1) -

Important points for proper start-up (1)

Proper start-up is essential to prepare the membranes for service, and to prevent damage through allowing too high feed / brine flow (causing excessive pressure drop), hydraulic shock or too quick ramp up of pressure increasing.

It is strongly recommended to minimize the start-up frequency.

1. Ensure all relative valves are positioned correctly. Permeate and brine dump line must be opened to drain, if these lines closed, pipes might burst by excess high pressure.
2. Slow and Steady pressurizing (<0.5bar increase per second). Crack open the feed control valve. After high pressure pump start, slowly open the feed control valve and slowly close the brine control valve. If pressure increasing speed is too quick, review feed valve open speed and brine valve close speed.

Refer handling manuals for more detail information

Start-up Sequence – proper start-up (2) -

Important points for proper start-up (2)

3. RO feed water must be stable within required quality. (After additional RO train operation, pretreatment flow rate will increase, and it might cause the change of RO feed water quality. Consult your pretreatment supplier how to keep pretreated water quality during additional RO train operation.)
4. Check additions of chemicals after additional RO train operation. (pretreatment coagulant, acid, NaOCl, SBS, etc.)
5. In case of SBS(NaHSO3) dosing for chlorine removal, min. 0.5mg/l HSO3- must be detectable in brine at any time.
6. Prior to final evaluation of trial run, operate for minimum two hours at design operating conditions.
7. Adjust RO operating parameters to targeted permeate and brine flow rate. Do not exceed design recovery ratio during any stage of operation.
8. Proper on-line data logging. (Proper on-line data logging is very important to check start-up sequence and RO membrane performance by normalization)

Start-up Sequence – proper start-up (3) -

TORAY

Important points for proper start-up (3)

6. Necessary data taking after initial start-up of new RO elements. (Initial data would be used for checking RO elements performance and used as a standard performance for normalization.)

   - Permeate conductivity for each vessel

   - The data of 1, 24, 48 hour after start-up should be checked carefully.

   Feed : Feed pressure, Temperature, Conductivity, TDS, SDI, pH, Turbidity(NTU), ORP, Free and Total chlorine (not detectable)

   Brine : Brine flow, Conductivity, TDS, pH

   Permeate : Permeate flow of each bank and total system, Conductivity from each bank, total system and each vessel

7. Dump permeate until required water quality is obtained.

Refer handling manuals for more detail information.
In the case of special RO system, please consult Toray Membrane

Start-up from emergency shut-down

TORAY

In the case of start-up from emergency shut-down, the start-up sequence which previously described must be done.

Toray RO membrane

Training Module # 6

RO System shut - down

November, 2008

Toray Industries, Inc.,

Note : Refer handling manuals for more detail information

RO Shut – Down Procedure (1)

Shut – Down Sequence (1)

Proper shut-down is another essential matter to keep good membranes performance for service. It is important to prevent damage through allowing too high feed / brine flow (causing excessive pressure drop), hydraulic shock or too quick ramp down of pressure decreasing.

It is strongly recommended to minimize the shut-down frequency.

Refer handling manuals for more detail information

RO Shut - Down Procedure (2)

Shut - Down Sequence (2)

Typical shut - down sequence for a RO system using a feed and concentration control valve.

1. Slowly start to close feed inlet control valve.
2. Slowly start to open concentrate control valve to maintain concentration flow at design value.
   (reverse sequence of start-up is suitable for shut-down. Do not exceed differential pressure limit (=2bar).
3. When high pressure pump discharge flow rate decrease to its minimum flow rate, switch off high pressure pump.

Refer handling manuals for more detail information

RO Shut – Down Procedure (3)

Shut – Down Sequence (3)

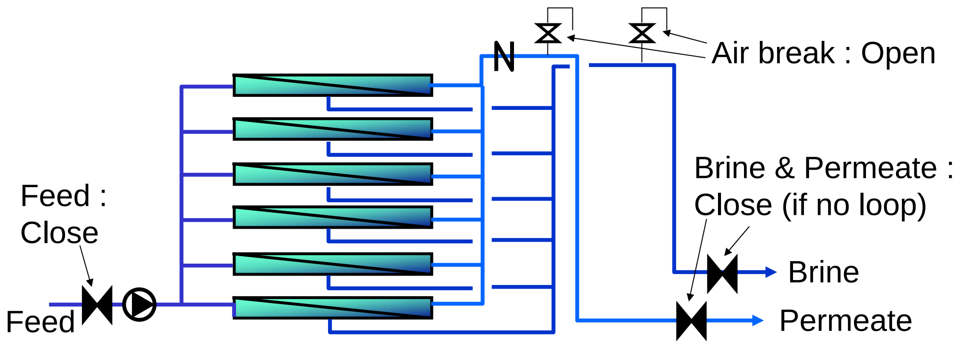
4. RO system should be flushed with pre-treated feed water at low pressure.
5. In case of special RO system such as high pH Boron removal, it is necessary to exchange from special feed water to neutral pH condition. Apply SWRO permeate without containing any chemical for flushing.
6. Continue flush until concentrate conductivity approaches feed conductivity. The objective of the flush is to remove high concentration water from the system. Note that higher flow rate is OK, provided pressure vessel differential pressure does not exceed the limit (=2 bar).
7. After flush, close feed inlet valve completely.
8. Close concentrate and permeate valves, if air break loop is not installed.
9. Take care that permeate back pressure never exceed 0.7bar at flushing and after shutdowns.
10. Adjust chemical dosing for proper pretreatment conditions.

Refer handling manuals for more detail information

RO Shut – Down Procedure (4)

Shut – Down Sequence (4)

System should be left completely filled with water. It is recommended to install a loop and automatic air break valve on the brine and permeate line to prevent water drain during shut-down by siphon effects.



RO Shut – Down Procedure – Short term shut down -

Short – Term Shut Down

Short-term shut-down is for periods where an RO train (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 flushing water, while simultaneously venting any gas from the system.
  - Flushing water Temperature : 5 – 35degC
    pH Range : 3 – 7
  - Sea water RO system : pretreated feed water (no chlorine)
  - 2nd pass RO system : 1st pass permeate (without any chemicals)
- When the pressure vessels are filled, close the valves.
- Repeat flushing at every 12 hours.
- Do not exceed permeate back pressure limit at flushing (=0.7 kg/cm2)

Open permeate side valve to prevent excess permeate back pressure

RO Shut – Down Procedure – Long term shut down -

Long – Term Shut Down (1)

Long-term shut-down is for periods where an RO train (plant) must remain out of operation for more than four days with the RO elements in place. Prepare each RO train as follows:

For long-term shut-down, there are two conditions.

Case 1 : Pre-treated feed water flushing
Case 2 : Preserved in SBS solution (if Case 1 is not available)

Case 1 : Pre-treated feed water flushing
- Flushing water Temperature : 5 – 35degC
  pH Range : 3 – 7
- Sea water RO system : pretreated feed water (no chlorine)
- 2nd pass RO system : 1st pass permeate (without any chemicals)
- Repeat flushing at every 12 hours.

Open permeate side valve to prevent excess permeate back pressure

RO Shut – Down Procedure – Long term shut down -

Long – Term Shut Down (2)

Case 2 : Preserved in SBS solution

a) Flush the RO section with RO permeate.
b) Flush with 500 – 1000 mg/l SBS solution (by circulation)
c) When the RO section is filled with this solution (make sure that it is completely filled), close all necessary valves to remain the solution in the RO section.
d) Repeat Steps a) and b) with fresh solution.
   - Every thirty (30) days, if the temperature is below 27deg.C
   - Every fifteen (15) days, if the temperature is above 27deg.C
e) The pH of preservation solution should be kept above pH 3 at any time.

Open permeate side valve to prevent excess permeate back pressure

Toray RO membrane

Training Module # 7

Storage / Preservation

November, 2008

Toray Industries, Inc.,

Note : Refer to handling manuals for more detail information

Storage / Preservation Procedure (1)

General

Note :

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

Element preservation is needed for long term storage of new and used elements and long term RO system shut-down.

Safety :

When using biocide solutions as membrane preservatives, follow accepted safety procedures. Always wear eye protection. Consult the relevant Material Safety Data Sheets (MSDS) as supplied by the manufacturer of the chemicals prior to use.

Storage / Preservation Procedure (2)

Storage / Handling of New Elements (1)

Preferably, elements should be stored of 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 conditions:

1. Store elements in cool, dark and dry place inside closed building. Keep away from direct sunlight.
2. An ambient air temperature range of 5degC to 35degC. Avoid freezing.
3. New elements are vacant-sealed in a bag made from oxygen impermeable special plastic and packed in a carton boxes. The carton boxes should be opened directly before installation.

Storage / Preservation Procedure (3)

Storage / Handling of New Elements (2)

4. Don't stack more than 7 layers of carton boxes. Make sure boxes are kept dry.
5. When open plastic bags, open it at one end and do not tear open, for possible re-use.
6. When open the carton boxes, keep parts of the packaging materials for the event that elements must be removed and stored.

Storage / Preservation Procedure (4)

TORAY

Storage / preservation of used elements

1) If RO elements were removed from pressure vessel for storage or shipping, they need to be preserved in a 500 – 1,000mg/l SBS solution.
   Note : In the case of used RO elements performance investigation by Toray or another party, please consult the preservation solution before preserve RO element in the solution.
2) To make up the preservation solution, use food grade SBS.
3) 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.
4) After the elements are preserved and repacked, recommended storage conditions are the same as for new RO elements.

Storage / Preservation Procedure (5)

TORAY

Storage Solution pH

SBS solution as it degrades may produce sulfuric acid, which will lower the pH of the solution in the storage bag. The pH mush not go below 3.0. All repackaged elements should be randomly checked for pH during the 3 monthly inspection. If pH is below 3, SBS solution must be refreshed newly.

Shipping

When RO elements have to be shipped, RO elements must be preserved with a SBS preservation solution. Ensure following items.

- The plastic bag does not leak.
- The elements is properly identified.
- The preservation solution is correctly labeled.

In the case of used RO elements performance investigation by Toray or another party, please consult the preservation solution before preserve RO element in the solution.Toray recommends to use original plastic bag and polystyrene cap for packing.

Toray RO membrane

Training Module # 8

RO System Normalization

November, 2008

Toray Industries, Inc.,

What is normalization ?

RO feed water condition change (Temperature, TDS, pH)

RO operating condition change (Flow rate, Recovery)

↓

Required pressure and/or permeate quality change
(at fixed permeate flow operation)
(feed pressure, permeate TDS)

↓

These changes make difficult to know the real RO membranes performance

↓

Normalization is necessary to know real RO membranes performance at specific operating conditions(=reference data)

Advantage of RO system normalization

Normalization & Monitoring

Very useful information to know actual RO membrane performance, and it helps to know the possible reasons at troubleshooting.

Normalized Data

Account for following data :
Feed water pressure, Temperature, Concentration, pH and Recovery

Good accuracy is highly required for data monitoring. If data has big difference from real value or fluctuation, it would show wrong normalized performance.

If any change is observed in normalized data

Change of normalized data is the sign of performance change or trouble.

- Check all event at plant operation
- Check all measuring instruments (pressure, flow, conductivity, Temp, pH etc)
- Check feed water condition and operating conditions
- Check product conductivity of each vessel and specify the trouble point

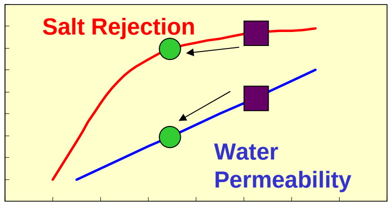
How to normalize RO performance ?

Calculate RO performance correction factors from each operating conditions to normalization standard condition
(typically, the first day operating conditions are used for REFERENCE data)

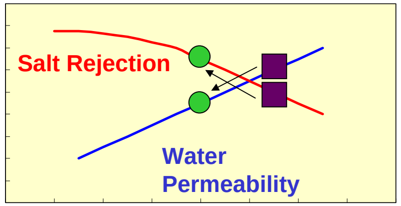
➔ Normalized Permeate Flow, Normalized Salt Passage, Normalized Delta-P)

● Reference condition ■ Operating condition

Feed pressure correction



Feed Temperature correction



Correcting conditions : Pressure, Temperature, Salinity, Flow Rate, Recovery

Toray's RO Normalization program " TorayTrak "

1. TorayTrak is available for

(1) Data Collection

- Important items of RO operation, including feed water information
- Easy transfer of project data to files using export-import tools

(2) RO data normalization

- Normalized performance : permeate flow, salt passage, Delta-P
- Calculation Method : ASTM Standard D-4516

(3) Graph Making

- It is helpful to check the suspected reason of performance trouble from the comparison check between RO feed water information and normalized performance.

Note :
Refer to TorayTrak manuals for more detail information

Toray RO membrane

Training Module # 9

RO System Maintenance

November, 2008

Toray Industries, Inc.,

Note : Refer to handling manuals for more detail information

RO system maintenance procedure (1)

In order to be able to track the performance of a RO system, regular and systematic records must be kept.

Apart from tracking performance, the log sheets are valuable tools for troubleshooting, and are required in the case of warranty evaluation.

Potential problems in an RO system can be recognized early by monitoring the changes of permeate flow rate, 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.

Successful RO System operation could be achieved by good maintenance.

RO system maintenance procedure (2)

Schematic flow for troubleshooting

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

↓

Troubleshoot : Corrective measures, performed in time

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

RO system maintenance procedure (3)

RO System Start-up Report

1. Provide a complete description of the RO system, using existing flow diagrams and process and instrumentation diagrams, to show water source, pretreatment details, RO configuration and post treatment details.
2. Include a copy of completed pre-start-up checklist.
3. Provide copies of calibration charts / curves for all major meters and gauges used in the RO system.
4. Record initial performance at 1hour, 24hours and 48hours of operation of RO system and pretreatment system.

Note : Refer handling manuals for more detail information

RO system maintenance procedure (4)

TORAY

RO Operating Data (1)

The following data must be logged and recorded into an appropriate log sheet at least once per shift for each operational train.

1. Date, time, hours of operation
2. Pressure drop across pretreatment cartridges and each bank (if installed)
3. Feed, concentrate and permeate pressure for RO array (note if back pressure is applied to any stage / bank, permeate pressure must be recorded separately for each bank)
4. Interbank pressures (may be measured as a pressure between each stage / bank, or using a differential pressure gauge across each bank)
5. Permeate and concentrate flow for each RO array (if flow from each RO stage / bank is measured, each individual flow should be recorded)

Refer to handling manuals for more detail information

RO system maintenance procedure (5)

TORAY

RO Operating Data (2)

6. Conductivity of feed permeate and concentrate streams for each array. (if permeate flows are measured separately for each bank, permeate conductivities should also be measured for each bank)
7. Permeate conductivity of each pressure vessel for every 2weeks.
8. pH of feed, permeate concentrate streams
9. SDI measurement (before and after cartridge filters of feed stream)
10. Turbidity measurement (feed stream) if can be measured
11. Water temperature of feed stream

Refer to handling manuals for more detail information

RO system maintenance procedure (6)

TORAY

RO Operating Data (3)

12. Detail of any instrument recalibration work (all meters + gauges should be checked for calibration according to the manufacturers instructions every 3 months (or more frequently if recommended by manufacturer)
13. Any unusual incidents or events (e.g. pretreatment upsets / loss of dosing etc.)
14. Complete feed water analysis of the feed, permeate and concentrate stream at start-up and the period based on warranty condition. A feed analysis should be made if there is a significant change in the feed conductivity (unrelated to temperature).

Refer to handling manuals for more detail information

RO system maintenance procedure (7)

TORAY

Water Analysis Details

Feed Water Analysis should include the following ions :
Red color : Mandatory items of Shuaibah III warranty condition

- Temperature	- pH	- Calcium	- Magnesium
- Sodium	- Potassium	- Barium	- Strontium
- Chloride	- Sulphate	- Nitrate	- Fluoride
- Bicarbonate	- Silica	- Boron	- Iron (once a week)
- TDS (by 180degC) (once a week)	- SDI (every shift only)		
- Conductivity	- Sodium Bisulphite (feed and brine) (every shift only)		
- Chlorine (after SBS dosing)			
- ORP (Redox)	- Turbidity (NTU)		

RO system maintenance procedure (8)

Pretreatment Operating Data (1)

The proper operation of the RO unit will in large part depend on the successful operation of the pretreatment system.

Specific record keeping requirements should be provided by the manufacturer's of the pretreatment unit operations. Those requirements should be strictly adhered to, as problems on the pretreatment will often point to the answer for problems being seen on the RO (fouling / salt passage increase)

Refer to handling manuals for more detail information

RO system maintenance procedure (9)

Pretreatment Operating Data (2)

Typically the following parameters will be recorded.

1. Total chlorine concentration in the RO feed (unless known to be totally absent)
2. Discharge pressure of any well / booster pumps
3. Pressure drop across any filters (at least once per shift)
4. Consumption of all chemicals used (daily)
5. Instrument calibration operations
6. Any unusual incidents which occur (upsets / shutdowns / chemical dosing problems ets.)

Refer to handling manuals for more detail information

RO system maintenance procedure (10)

Maintenance Log (1)

In addition to the process logs referred to above, a maintenance log must be kept :

1.Record all routine maintenance activities carried out

2.Record any mechanical equipment failures and date of return to service

3.Record any changes made to membrane element locations, with element serial numbers

4.Record any additions of element and/or vessels to arrays

5.Record all calibration activities on gauges and meters

Refer to handling manuals for more detail information

RO system maintenance procedure (11)

Maintenance Log (2)

6. Record routine replacement of filters / cartridge filters / pH sensors
7. Record all cleaning / flushing activities carried out on the RO, including :
   - Date carried out
   - Elements being cleaned
   - Solution details
   - Solution pH (before / after cleaning)
   - Solution temperature
   - Flow Rate
   - Detailed description of cleaning sequence (shut down / flush period / recirculation period / soak period)

Refer to handling manuals for more detail information

'TORAY'

Toray RO membrane

Training Module # 10

RO System Troubleshooting

November, 2008

Toray Industries, Inc.,

Troubleshooting with Normalized Performances

'TORAY'

- A table showing following normalized RO system performances give a great deal of insight into what may be causing the problem
  - Normalized Product Flow Rate
  - Normalized Salt Rejection
  - Normalized Differential Pressure Increasing Ratio
- See the following slides for different scenarios.

Typical signs of RO system trouble (1)

'TORAY'

Behavior of operation control items and countermeasure

Cause		Phenomena: Product flow rate	Phenomena: Rejection	Phenomena: Differential pressure	Checking items	Measures
Element	Degradation of membrane	↗	**↘**	↘	Use time, feed liquid temperature, water quality	Cleaning, replacement
Element	Leak in element	↗	**↘**	↘	Vibration, back pressure or shock	Ditto
Element	Leak from O-ring	↗	**↘**	↘	Vibration, shock, degra-dation of material quality	Replacement of O-ring
Element	Brine seal failure	↘	**↘**	↘	Degradation of material quality, adhesion of vessel	Replacement of seal Normal fitting
Element	Center pipe damage	↗	**↘**	↘	Excessive differential pressure, high water temperature	Replacement of element
Element	Element deformation	↘	↘	**↗**	Ditto	Ditto
Element	Contanination of membrane surface (suspended solid)	↘	↘	**↗**	Pretreatment conditions, quality of raw water	Chemical cleaning
Element	Ditto (scaling)	↘	↘	↗	Ditto	Chemical cleaning
Element	Ditto (organic, oil)	**↘**	↘	↗	Ditto	Ditto

Typical signs of RO system trouble (2)

'TORAY'

Raw water and pretreatment	Temeperature change	High	**↗**	↘	↘	Seasonal fluctuation, pump efficiency	Pressure adjustment, cooling
Raw water and pretreatment	Temeperature change	Low	**↘**	→	↗	Seasonal fluctuation, heater	Pressure adjustment, heater
Raw water and pretreatment	Pressure change	High	**↗**	↗	↘	Pump, valve	Pressure adjustment
Raw water and pretreatment	Pressure change	Low	**↘**	↘	↗	Pump, valve, filter	Ditto
Raw water and pretreatment	Chang of quantity of brine	Too much	→	→	**↗**	Feed flow rate, valve	Flow rate adjustment
Raw water and pretreatment	Chang of quantity of brine	Too little	↘	↘	**↘**	Feed flow rate, valve differenetial pressure	Ditto
Raw water and pretreatment	pH too high or too low (degradation of membrane)		↗	↘	↘	pH control	pH adjustment
Raw water and pretreatment	Concentration	High	**↘**	↘	↘	Water quality check	Pressure adjustment
Raw water and pretreatment	Concentration	Low	**↗**	↗	↗	Ditto	Ditto
Raw water and pretreatment	Excessive amount of difficultly soluble substance(Precipitation)		↘	↘	↗	Quality of raw water, recovery ratio, pH	Pressure adjustment recovery ratio adjustment, pretreatment before adjustment
Raw water and pretreatment	Existence of chlorine, hydrogen peroxide		**↗**	**↘**	↘	Quality of raw water, chemical injection pump	Chemical injection condition

Note:
The small upward arrow mark indicates the increasing trend whereas the downward arrow indicates the reducing trend.
The extent varies depending on state.
The large arrows indicate mainly occurring phenomenon.

Troubleshooting - High Permeate TDS -

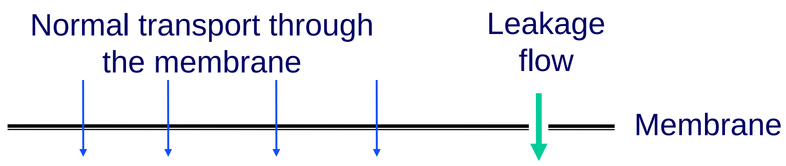
High Permeate TDS

Poor permeate quality can be caused by the following:

- Changes in operating conditions
- Damage to membrane (oxidants, hydrolysis, etc..)
- Fouling
- Mechanical Leakage

Troubleshooting - Mechanical Leakage (1) -

Mechanical leakage is the direct passage of feed water (or concentrate) to the permeate, bypassing the membrane.



Troubleshooting - Mechanical Leakage (2) -

Causes of Mechanical Leakage

- O-ring leak
- Interconnector or Permeate Tube crack
- Glue Line failure
- Membrane delamination
- Membrane fracture
- Membrane mechanical abrasion
- Membrane degradation through chemical exposure

Troubleshooting - Mechanical Leakage (3) -

Techniques to confirm Mechanical Leakage

- Perform Profile
    - Compare to baseline startup data
    - Probe suspect vessels

- Review rejection of Sulfate ion

Troubleshooting - Pressure Vessel Profile (1) -

'TORAY'

The *"Pressure Vessel Profile"* is a measurement of the permeate concentration from each individual vessel.

- Identifies which vessels in an array have high salt passage.
- A *Pressure vessel profile* should be taken at startup, as a baseline record.
- Record complete system data whenever a *Pressure Vessel Profile* is performed.

Troubleshooting - Pressure Vessel Profile (2) -

'TORAY'

Best recorded by preparing a series of circles arranged similar to the vessel rack assembly and writing each vessel's reading in its respective circle.

Example: 24:12 array at 75% recovery

First Bank						Second Bank		
49	51	53	47	52	48	93	98	89
55	54	51	82	49	52	91	97	101
53	95	55	53	93	50	93	295	95
54	48	52	54	49	51	94	98	92

Troubleshooting - Pressure Vessel Probing (1) -

'TORAY'

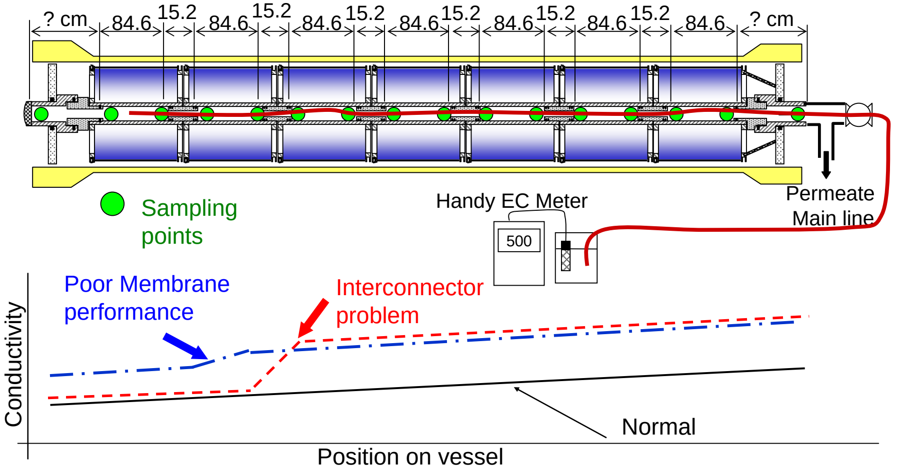
A flexible tube is inserted through the permeate port of a vessel to measure the permeate concentration at known intervals through the vessel.

- Performed on vessels identified by the *Pressure Vessel Profile*.
- Locates the elements or o-rings which are the source of high salt passage.

Refer to Training Material for more detail information

Troubleshooting - Pressure Vessel Probing (2) -

'TORAY'



Sampling tube apparatus

Supple thin wall gum rubber (5cm) Cut open the edge of the tube (3cm)

Troubleshooting - Membrane Delamination (1) -

'TORAY'

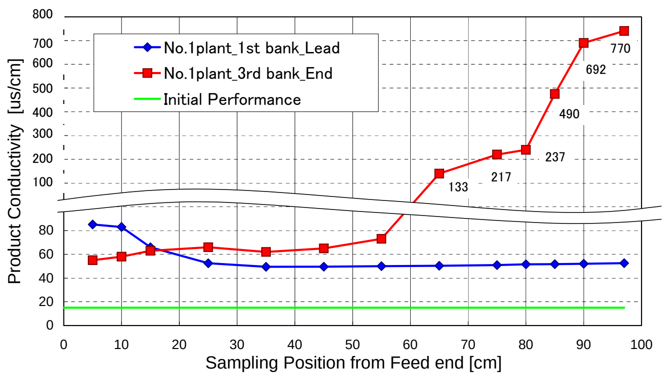


Fig. Result of permeate conductivity measurement by center pipe probing

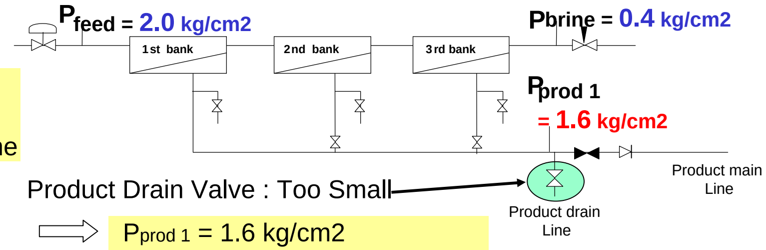
Troubleshooting - Membrane Delamination (2) -

'TORAY'

Caused by - Excess Permeate Back Pressure
- Mechanical failure in system
- Design problem
- Operation error

Countermeasures - Correct excessive back pressure
(< 0.7 kg/cm^2, preferably < 0.4 kg/cm^2)

Example)
High back-P by
too small drain line



⇨ $P_{prod\ 1}$ = 1.6 kg/cm2
Back Pressure = 1.2 kg/cm2

Troubleshooting - Membrane Oxidation (1) -

'TORAY'

- If composite polyamide RO membrane elements are exposed to the oxidizing chemicals such as free chlorine, chloramine, bromine, ozone, or other oxidizing chemicals, irreparable damage is happened to the membrane, normally, evidenced by decrease of salt rejection.
- Lead end elements are typically more affected than the others in case of oxidizing chemical presents in RO feed water.
- If several specific conditions are assembled, chlorine generating problem might be occurred.
  - Dissolved Oxygen,
  - NaHSO3(SBS),
  - Heavy Metal Ion
    (Cu, Co, Mn, etc. Low concentration, ppb order, is enough)
  - High Salinity Chloride Ion

Troubleshooting - Membrane Oxidation (2) -

'TORAY'

Chlorine Generation Mechanism under existing of Heavy Metal

Even if RO feed water does not contain Chlorine, Chlorine will be generated.

- Following substances are required to generate chlorine.
  1. Dissolved Oxygen, 2. NaHSO3 (SBS)
  3. Chloride Ion 4. Heavy Metal Ion(Cu, Co, Mn. etc.)
- Following chemical reactions in the process of generating chlorine (e.x. with Copper).

$SO_3^{2-} + Cu^{2+} \rightarrow SO_3^- + Cu^+$ *1

$SO_3^- + O_2 \rightarrow SO_5^-$ *1

$SO_5^- + SO_3^{2-} \rightarrow SO_5^{2-} + SO_3^-$ *1

$SO_5^{2-} + Cl^- \rightarrow ClO^- + SO_4^{2-}$ *1

$(ClO^-: \text{Chlorine}, Cl_2)$

Reference

*1 : C. H. Barron and H. A. O'Hern, Chemical Eng. Sci. 21(1966) 397-404

Troubleshooting - High Operating Pressure -

TORAY

High Operating Pressure (Low Permeate Flow)

High operating pressure(= low permeate flow) can be caused by the following:

- Membrane fouling
- Differential pressure increase (Plugging of the feed channel)
- Scaling

Troubleshooting - Membrane Fouling (1) -

TORAY

Membrane Fouling

- The deposition of suspended particles on the membrane surface.
  - Foulant on the membrane surface increases the resistance to the flow of water through the membrane.
  - Fouling causes lower productivity at constant net pressure or higher net pressure at constant productivity.
  - Sometimes higher salt passage will be caused by membrane fouling.

Refer to Handling Manuals for more detail information

Troubleshooting - Membrane Fouling (2) -

TORAY

Membrane fouling is caused by

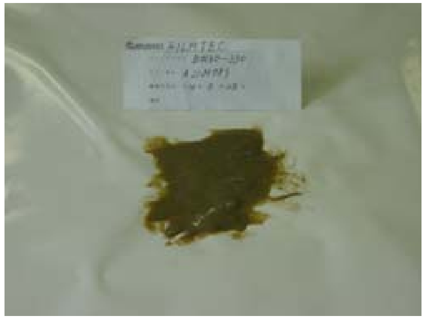
- Improper pretreatment system
- pretreatment condition upset
- Chemical dosing system upset
- Improper material selection (piping, valve, pump, etc.)
- Improper flushing after shutdown
- Scaling by excess recovery ratio
- Biological contamination in feed water
- Feed water chemistry change

Refer to Handling Manuals for more detail information

Troubleshooting - Membrane Fouling (4) -

TORAY

Cause of Trouble : Fouling (Suspended Solid, Coagulant)
(SS leakage from pretreatment)



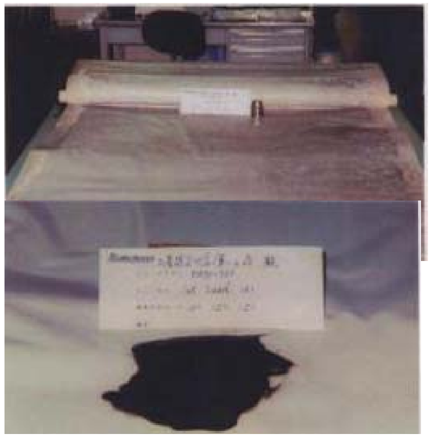
Fouling Amount : 62.4g
(Dry weight)

Ash Ratio : 75.9%
(SiO_2:32%, Al:9.7%, Fe:4.8%)

Troubleshooting - Membrane Fouling (5) -

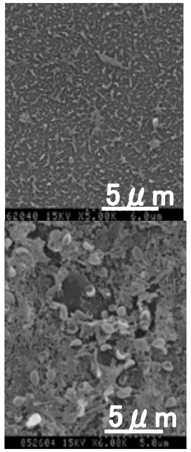
TORAY

Cause of Trouble : Fouling (Biological Fouling)



New Membrane

After Fouling (Bacteria and Fe)



Fouling Amount : 130g
(Dry weight)

Ash Ratio : 32.2%
(SiO2:11%, Al:5.1%, Na:2.1%)

Troubleshooting - Differential Pressure Increase (1) -

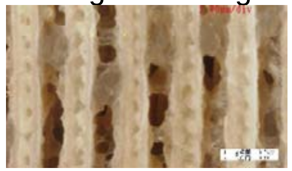
TORAY

Differential Pressure Increase = Plugging of the Feed Channel

- Increase of normalized *Differential Pressure* indicates fouling of feed / brine channel.
- Typical causes of DP increase.
  - Upstream :
    - Suspended solids, colloid, bacteria, silt, clay, iron corrosion and pretreatment coagulant in the feedwater
  - Downstream : scaling
  - Any stage mainly lead position : Biological fouling

Clean condition

Biological fouling

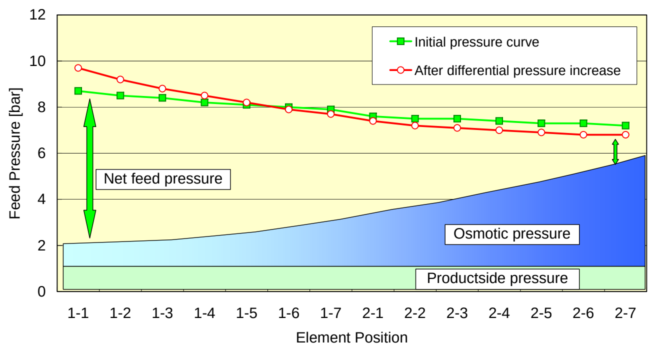


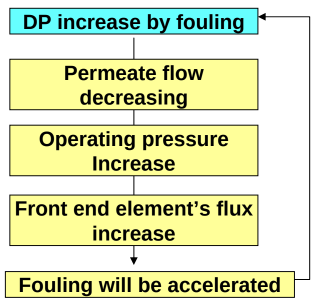
Troubleshooting - Differential Pressure Increase (2) -

TORAY

Problem of High Differential Pressure (1)

- Fouling will be accelerated
- RO element mechanical trouble by thrust force
- Getting difficult to remove by cleaning



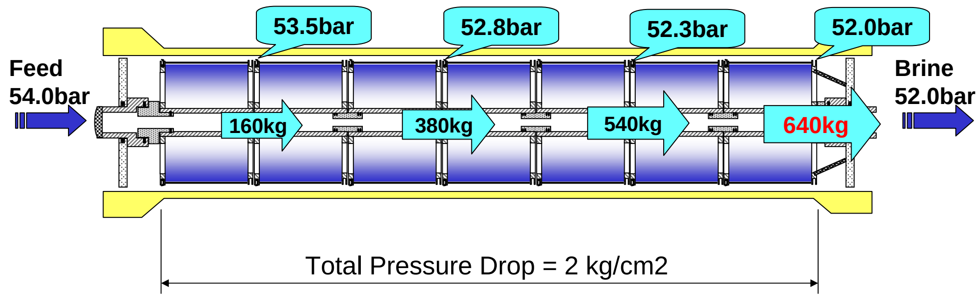


Troubleshooting - Differential Pressure Increase (3) -

TORAY

Problem of High Differential Pressure (2)

- Fouling will be accelerated
- RO elements mechanical trouble by thrust force
- Getting difficult to remove by cleaning



Final Element Axial Load = 2kg/cm2 x 320cm2 = 640 kg

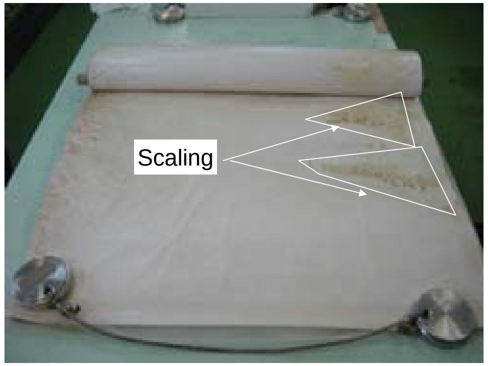
Troubleshooting - Scaling (1) -

- The deposition of sparingly soluble salts onto the membrane surface and/or the feed channel material.
  - Scaling occurs primarily in the downstream elements because of the higher concentrations existing in this portion of the RO system.
  - Common scalants include calcium sulfate, silica and calcium carbonate.
  - Normalized Product Flow Rate will be decreased.
  - Normalized Salt rejection might be decreased by membrane mechanical ablations caused by scaling.
  - Differential pressure will be increased.

Troubleshooting - Scaling (2) -

Cause of Trouble : Scaling

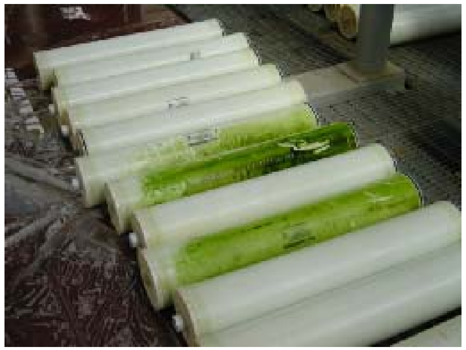
Scaling caused by : - Too much high recovery
- Higher pH operation
- Lower antiscalant dosing
- Water chemistry change



Troubleshooting - Single Element Test on site (1) -

Single Element Performance Test on site (1)

- RO element outside visual checking
- Single element weight checking
- Single element performance checking



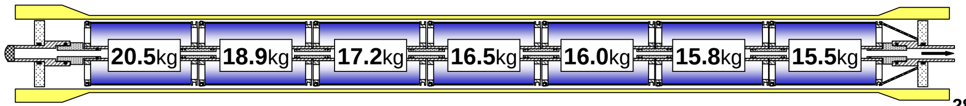
Troubleshooting - Single Element Test on site (2) -

Single Element Performance Test on site (2)

- RO element outside visual checking
- Single element weight checking
- Single element performance checking

Measuring RO element weight after 30 min vertical standing water drain.

- New element weight : around 15 -16kg
  (depend on water drain condition)
- Weight checking will help to know fouling tendency in the pressure vessel.



Single Element Performance Test on site (3)

- RO element outside visual checking
- Single element weight checking
- Single element performance checking

Single RO element performance measuring equipment on site is very helpful :

- To check RO membrane performance more reliably.
- To check RO membrane performance before / after cleaning.
- To carry out pre-cleaning test (if single element cleaning test is available)

Toray RO membrane

Training Module # 11

RO System Cleaning

November, 2008

Toray Industries, Inc.,

Refer to Handling Manual for more detail information

RO System Cleaning

RO system cleaning should be done, if RO membrane surface and/or feed channel were subjected to fouling by foreign materials.

Fouling is caused by

- Improper pretreatment system
- pretreatment condition upset
- Chemical dosing system upset
- Improper material selection (piping, valve, pump, etc.)
- Improper flushing after shutdown
- Scaling by excess recovery ratio
- Biological contamination in feed water
- Feed water chemistry change

RO System Cleaning – Typical Fouling Materials -

Typical fouling materials

- Suspended Solid, Colloid, silt, clay
- Hydrates of metal oxides (Iron, manganese, copper, aluminum, etc.)
- Pretreatment coagulant
- Scale (Silica, calcium carbonate, calcium sulfate, etc.)
- Organic chemicals (antiscalant, cationic polymer, nonionic polymer, etc.)
- Biological contamination and its growth

RO System Cleaning – Schedule a cleaning when -

- Normalized Product Flow Rate decreases by 10% or
- Normalized Differential Pressure increases by 20% or
- Normalized Permeate Quality decreases by 20%

If fouling tendency is observed, initiate to carry out followings :

- Check plant condition by follow the “Troubleshooting”
- Analyze feed water. Check the potential of fouling and scaling.
- Check the foulant on cartridge filters.
- Check the foulant on inside surface of RO feed piping.
- Check SDI and Bacteria count on several suspected positions to cause fouling from pretreatment discharge to RO inlet.
- Check RO elements outside conditions.
- Investigate RO element performance, foulant and suitable cleaning method.

More worse situation might be cause by a wrong choice of cleaning chemicals or conditions.

RO System Cleaning – When to Clean -

TORAY

When to clean

- Normalized Product Flow Rate decreases by 10% or
- Normalized Differential Pressure increases by 50% or (preferably 30%)
- Normalized Salt Rejection decreases by 20%

If the time of cleaning is delayed too long, it will be difficult to remove the foulants completely from the membrane surface and the feed channel.

RO System Cleaning – Danger When Cleaning -

TORAY

- Cleaning solutions represent harsh environments for the membrane. Clean only when necessary.
- pH extremes can damage the membrane. Always measure the pH prior to exposing the membrane.

pH range and Temperature guideline for cleaning

Membrane	45 deg.C	35 deg.C	30 deg.C
TM820	3 - 10	2 - 11	2 – 12
TM720	3 - 10	2 - 11	1 – 12

Stronger cleaning conditions may result more effective cleaning, however, can shorten the useful membrane life.

To optimize the useful membrane life, apply mildest cleaning conditions, including pH, temperature and contact time.

RO System Cleaning – How to Clean -

TORAY

How to clean

- Always clean vessels in parallel, never in series. Clean each bank separately, if multi-bank RO is cleaned.
- If possible, try to dissolve the foulant or scale.
- Loosen by soaking then breakup and disperse with shear force and flush out of the system. Higher flow rate is preferable in case of sticky undissolve foulant, like biological fouling.

RO System Cleaning – What to Clean With -

TORAY

What to Clean With

- Low pH cleaners are designed to dissolve heavy metal hydrates and calcium carbonate scale.
- High pH cleaners are designed to loose and swell the foulant, then disperse and suspend with the aid of shear force allowing removal from the system.
- Typically, low pH cleaning followed by high pH cleaning is more effective.
- If brand name cleaning chemicals are used for cleaning, check the compatibility with the membrane in advance.

RO System Cleaning – Some TIPS on Cleaning (1) -

TORAY

1. Cleaning Line Checking

Check and flush cleaning line, including cartridge filter before initiate cleaning. Cleaning line may contain rotten water or heavy bacteria growth after last cleaning. RO membrane might be fouled by this dirty solution.

2. Cleaning and Flushing Flow Rate

8inch element : 80 to 150 litter/min per RO pressure Vessel
Higher flow rate is preferable to remove sticky foulant, however, never exceed the differential pressure limit (= 2.0kg/cm2)

3. RO Cleaning Tank

- 100% drainage
- Return line located near the bottom to minimize foam formation when using a surfactant.

RO System Cleaning – Some TIPS on Cleaning (2) -

TORAY

4. Instrumentation and monitoring

Temperature, pH, flow rate and pressure should be measured and monitored correctly.

5. Sampling points

Sampling valves should be located to allow pH and TDS measurements and cleaning solution sampling.

6. Permeate Return Line

Separate permeate return line to cleaning tank is required.During cleaning and flushing, a small amount of permeate will be produced. The permeate return line and valves must be opened to atmospheric pressure during the cleaning and flushing. If permeate line pressure exceed brine pressure, membrane delamination would be caused along with glue lines.

RO System Cleaning – Some TIPS on Cleaning (3) -

TORAY

7. RO system cleaning and Flushing procedure (1)

- Clean a lowest pressure as possible (1 - 2bar)
- RO permeate water or De-ionized water should be used for all cleaning and flushing process. It should not contain chlorine, hardness and transition metals.
- Drain initial 20% of returned cleaning solution, if possible. This solution highly contain the foulant.
- Start circulation with slow flow increase. For the first 5 minutes, slowly throttle the flow rate to 1/3 of the target flow rate. For the second 5 minutes, increase the flow rate to 2/3 of the target flow rate, and then increase the flow rate to the target flow rate.
- Readjust the pH back to the target, if it changed more than 0.5 pH unit.

RO System Cleaning – Some TIPS on Cleaning (4) -

TORAY

7. RO system cleaning and Flushing procedure (2)

- Drain and flush the cleaning tank.
- After completion of the chemical cleaning procedure, a low pressure cleaning rinse is required for RO system and cleaning system with clean water.
- A second cleaning can be initiate after rinsing of RO system with clean water.
- After final chemical cleaning and clean water rinsing, pretreated feed water flushing will be carried out. The permeate line should remain open to drain at this time.
- After restart-up the RO system, RO permeate should be dumped until it meets the quality requirements of the process (conductivity, pH, etc.).
- It is not unusual to take a period from a few hours to a few days for the RO permeate quality to fully stabilize.

7. RO system cleaning and Flushing procedure (3)

- Record all cleaning / flushing activities carried out on the RO, including :
  - Date carried out
  - Elements being cleaned
  - Solution details
  - Solution pH (before / after cleaning)
  - Solution temperature
  - Flow Rate
  - Detailed description of cleaning sequence

    (shut down / flush period / recirculation period / soak period)

Toray RO membrane

Training Module # 12

RO Elements Replacement

November, 2008

Toray Industries, Inc.,

RO Elements Replacement

- RO elements replacement will be carried out, if RO membrane performance is deteriorated.

- Normally, periodical partial RO elements replacement is applied to keep guaranteed permeate water requirement and to minimize the RO elements amounts for replacement (= maximize the RO elements life)

- Only the worse performance RO elements should be replaced and disposed to keep permeate requirement.

Why Partial Replacement is applied ?

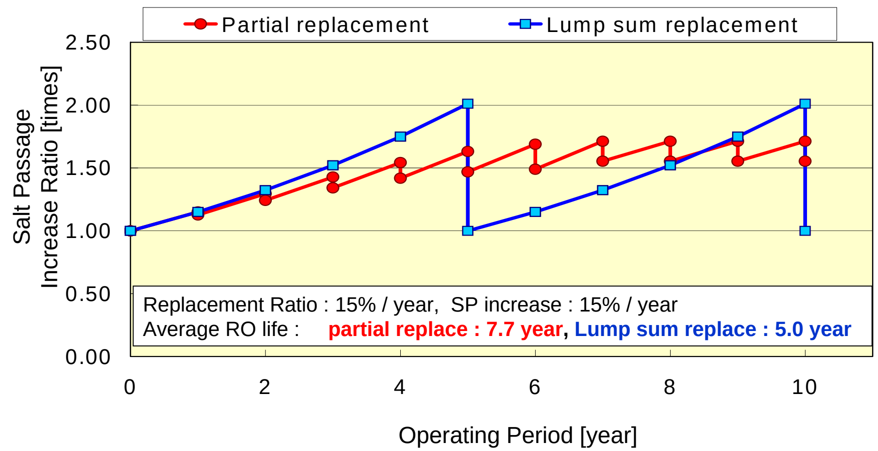
- Normally, lead side elements are forced under heavy duty conditions. Therefore, lead side elements performance are poorer and highly fouled rather than down stream RO elements.
- In this case, RO system performance will be improved very much with lead side RO elements partial replacement.

After 3years used SWRO elements performance in middle east

Position	Test Time	Weight	Product Flow Rate	Salt Rejection	Differential Pressure
Lead (1st)	**Production**	18.0 kg	23.3 m^3/d	99.73 %	10 kPa
	Returned	20.5 kg	16.1 m^3/d	99.67 %	25 kPa
End (6th)	**Production**	18.0 kg	21.6 m^3/d	99.79 %	10 kPa
	Returned	18.5 kg	20.4 m^3/d	99.78 %	10 kPa

"Partial Replacement" vs. "All Train Replacement"

Partial Replacement can expand RO elements life with keeping required permeate quality



How to decide the replace RO elements

TORAY

- To minimize the amount of RO elements replacement, check following items prior to decide the RO elements replacement.
  - Pressure Vessel Profile
  - Pressure Vessel Probing
  - Single RO elements performance
- Single RO elements performance of several loading positions and several pressure vessels should be checked prior to decide the number of replace RO elements.
- Minimum amount of the worst performance RO elements should be replaced to keep permeate requirement.

How to decide the replace RO elements (2)

TORAY

- Lowest product flow rate
  - Normally, fouling tendency of one RO train is similar in all pressure vessels.
  - Check relation between the RO elements product flow rate tendency and loading position in the pressure vessel.
- Highest differential pressure
  - Check relation between the RO elements differential pressure tendency and loading position in the pressure vessel.
  - If only lead side RO element has higher differential pressure even though this RO element has good performance for both product flow rate and salt rejection, it might be possible to use this element again in brine side position.

How to decide the replace RO elements (3)

TORAY

- Lowest salt rejection
  - After the RO system operation, salt rejection performance of each element might have a variation depending on the production performance.
  - Check the worse salt rejection RO elements by pressure vessel profiling and probing. These worse quality membranes should be changed with high priority.
  - If more large number of RO elements have to be replaced to keep required quality addition to above worse RO elements, check the result of single RO elements performance test. Then replace from worse position in worse quality pressure vessels.

Training Material for Shuaibah III Project : SDI measurement

1 SDI Measurement

Colloidal fouling of RO elements is one of the serious problem for RO plant operation. The source of silt or colloids in RO feed water often includes clay, colloidal silica, iron corrosion products and bacteria. Pretreatment coagulant can also cause fouling if it is not removed in pretreatment correctly.

Silt Density Index (SDI) measurement is good technology to check the colloidal fouling potential of RO feed water. Periodical SDI measurement is also effective to check the reason of RO performance problem at the trouble shooting.

2 Procedure of SDI measurement

1) Preparation the equipment
- Handy SDI meter
- 47mm diameter membrane filter support
- 47mm diameter Millipore membrane filter (0.45micron-m, Type - HA)
- Pressurized RO feed water (>2.5bar)
- Pressure Regulator (if handy SDI meter is out of service)
- 5 bar (70psi) pressure gauge (if handy SDI meter is out of service)
- 500ml sample cylinder (if handy SDI meter is out of service)

2) Procedure (if use handy SDI meter, follow its instruction)

a) Flushing the sampling line carefully (more than 10 min is recommended)

b) Place the membrane filter on its support.

c) Open isolate valve and adjust feed pressure to 2.1 bar(=30psi). At the same time, start to measure initial time, T0, necessary to filter 500ml of sample water. Feed pressure to be kept constant by continuous adjustment.

Note : T0 measurement is very much important, therefore, if long times passed until pressure adjustment, measure T0 again with another new filter.

d) After 5, 10 and 15 min, measure again the time necessary to filter 500ml.

SDI 5 = (1 – T0 / T5) x 100 / 5

SDI 10 = (1 – T0 / T10) x 100 / 10

SDI 15 = (1 – T0 / T15) x 100 / 15

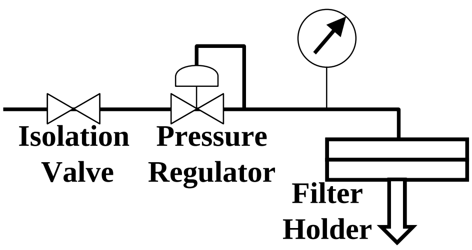
Note : Relation of T0 and T15 for SDI result

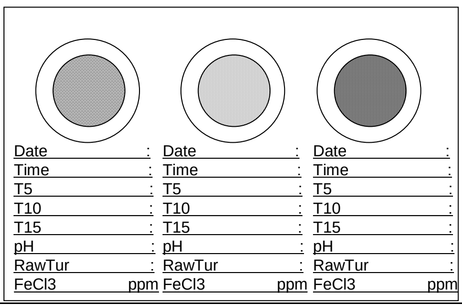
T15 is 1.43 times as long as T0 : SDI = 2.0

T15 is 1.82 times as long as T0 : SDI = 3.0

T15 is 2.50 times as long as T0 : SDI = 4.0

e) Keep the filter sample in SDI log book with SDI5, SDI10 and SDI15 value. Sampling water pH, raw water Turbidity and Ferric chloride dosing (ppm) are recommended to keep record together. Photo album is recommend for keeping sample.





RO feed SDI measurement Log Sheet

$SDI = (1-T0 / T15) / 15 \times 100$

Date : Time : T_0 : sec T_15 : sec SDI_15 : pH : Turbidity : NTU FeCl3 dosing : ppm	Date : Time : T_0 : sec T_15 : sec SDI_15 : pH : Turbidity : NTU FeCl3 dosing : ppm	Date : Time : T_0 : sec T_15 : sec SDI_15 : pH : Turbidity : NTU FeCl3 dosing : ppm	Date : Time : T_0 : sec T_15 : sec SDI_15 : pH : Turbidity : NTU FeCl3 dosing : ppm
Date : Time : T_0 : sec T_15 : sec SDI_15 : pH : Turbidity : NTU FeCl3 dosing : ppm	Date : Time : T_0 : sec T_15 : sec SDI_15 : pH : Turbidity : NTU FeCl3 dosing : ppm	Date : Time : T_0 : sec T_15 : sec SDI_15 : pH : Turbidity : NTU FeCl3 dosing : ppm	Date : Time : T_0 : sec T_15 : sec SDI_15 : pH : Turbidity : NTU FeCl3 dosing : ppm

Training Material for Shuaibah III project : Water Sampling & preparation for Analysis

1 Water Sampling

Correct water sampling is very important to check the RO performance and successful RO plant operation.

Water sampling for ion analysis is not so difficult. But for bacteria count, please strictly follow the recommendation from specialist of your bacteria analysis method.

1) Preparation the equipment
   - Clean sampling bottle with cap (please follow the size by analysis persons request)
   - Clean plastic hose with union (Ex. 10mm, 1m)
   - Low TDS water for rinsing (Ex. RO permeate, distilled water)

2) Procedure
   a) Prepare tag paper for each sampling bottle and put it on the sampling bottle. It is recommended to prepare all sampling bottle in laboratory or clean place.
   b) Put plastic hose to sampling point. This is to prevent corrosion by sea water spattering.
   c) Flushing the sampling line at least 2 min. If the sampling line is so long from main line, please wait more long time.
   d) <u>Rinse the sampling bottle 2 times by sampling water.</u>
   e) Fill the sampling water <u>until the all of air go out</u>.
   f) Put the cap to the sampling bottle.
   g) After taking sample, wash out the sea water by low TDS water.

2 Water preparation for Analysis

Correct water preparation for water analysis is very much important to check the RO performance and successful RO plant operation.

1) Preparation
   - Enough amount of sampling water for sensor rinsing
   - Analysis instrument, which is calibrated correctly by periodical calibration.

2) Procedure
   a) Rinse the sensor and sample bottle for analysis by distilled water.
   b) <u>Rinse the sensor and sample bottle for analysis 2 times by water sample.</u>
   (If water sample is taken just after distilled water rinse, this value might be lower than reality by dilution)
   c) Read the analysis result

No.	TM – Shuaibah III– 0003

Training Material for Shuaibah III project : Preparation for RO Element Loading

1	Preparation for RO elements loading Before starting RO elements loading, please confirm following items. (please refer the detail to handling manual) 1) System Preparation a) All control systems and data logging systems for pretreatment and RO are working correctly. b) All piping for RO, including RO flushing line, RO cleaning line and RO feed water line, flush to remove any debris, oil, metal residues, solvents, or oxidants to prevent contact with the RO membranes. c) Pretreatment stabilization – all upstream processes must be known to be working stably and within specification. d) Instrument calibration – all flow, pressure and quality measurement equipment must be checked and calibrated. e) All necessary hydraulic testing of pipework must be completed. f) Check the high pressure inspection – Pressurized RO system 2) Vessel Preparation Clean the inside of the vessels before RO elements loading. Simply hosing down the inside of the vessel usually will not be sufficient to clean the vessel. Consult your vessel supplier about the procedure to clean vessel inside wall. 3) O-ring preparation - 4 pcs of O-rings for 1 interconnector - 6 pcs or interconnectors for 1 pressure vessel (incase of 7m pressure vessel) - Glycerin for lubricants It is strongly recommended that new o-rings for all components (interconnectors and end cap adaptor parts) are used. a) Lubricate O-rings by glycerin before put O-ring to interconnectors of adaptors. It is recommended to mix the O-rings and lubricants in plastic bag, if a lot of amount of O-rings are used. b) It is recommended that O-rings are expanded slightly to position them over the groove for installation – O-ring is adequately expanded to avoid twisting when it is put on interconnector. 4) Brine seal preparation - 1 piece of brine seal for each RO element a) Lubricate brine seal by glycerin before put brine seal to RO element. It is recommended to mix the brine seal and glycerin in plastic bag, if a lot of amount of brine seals are used. 5) End plate preparation a) Remove end plates from both end of pressure vessel after complete flushing. Check the inside of pressure vessel again and if necessary clean mechanically. b) Install permeate adaptor with O-ring into the permeate port of brine side end plate. Lubricate both parts using glycerin. c) Install brine side end plate with thrust ring into the brine side of pressure vessel. Install retaining ring set according to the instruction manual of pressure vessel supplier.

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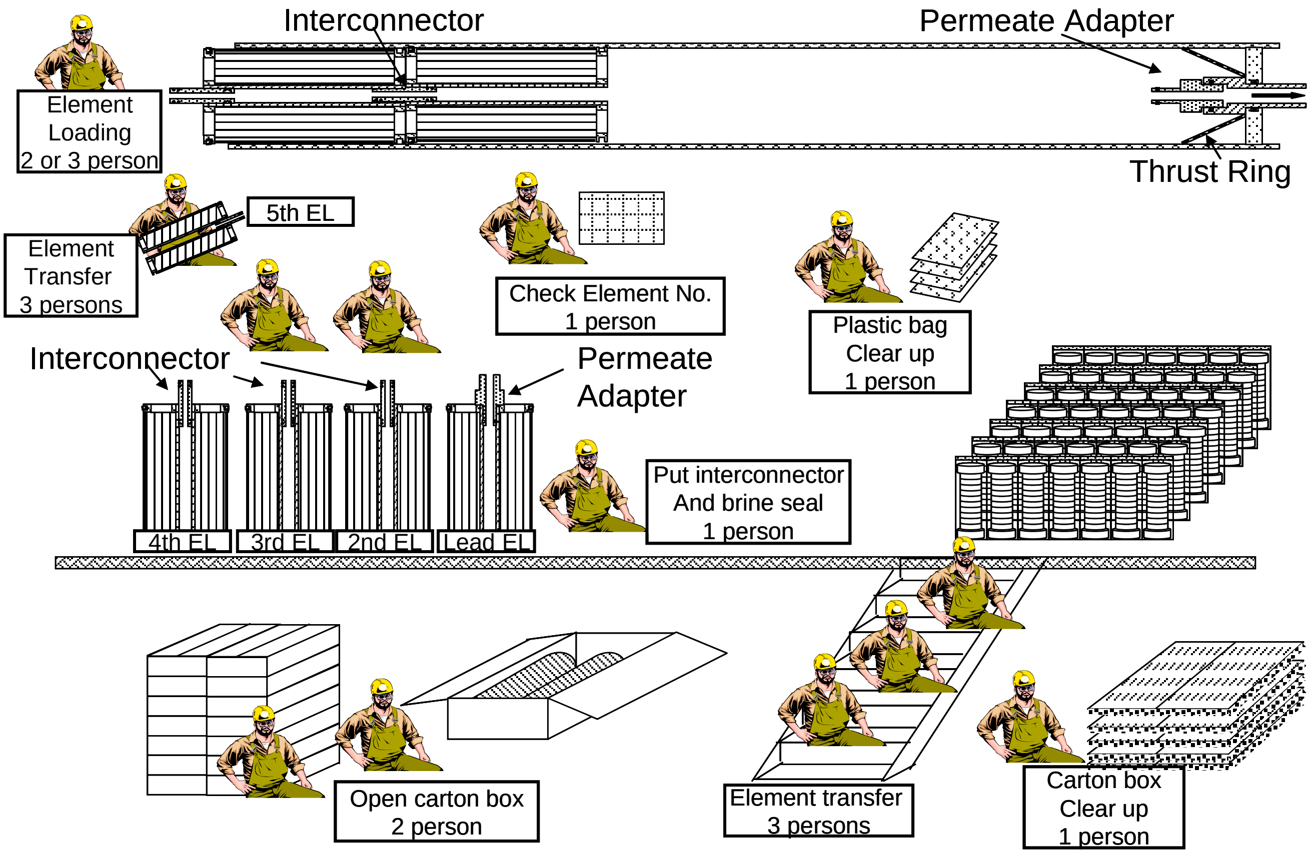
Training Material for Shuaibah III Project : RO Element Loading

1 RO elements loading

1) Preparation
- Number of RO element : M pcs
- Number of Pressure Vessel : N pcs
- Interconnectior : M – N pcs
- O-ring for interconnector : 4 x M pcs
- Brine seal : M pcs
- Permeate adopter (feed side) : N pcs
- Loading position logging note.
- Clean white cotton grove

Note : O-rings and brine seals should be lubricated before this procedure and groove them properly.
It is strongly recommended to ware long sleeve working shirt during RO installation to prevent skin problem by GRP element outside.

2) Procedure for RO element loading (refer the schematic drawing in page 2/2)
It is recommended to carry out this procedure by at least 4 persons.
a) Ensure that all preparation for RO element loading (TM-Shuaibah III-0003) was finished correctly.
b) Open the carton box and take RO elements out.
c) Stand RO elements for 1 pressure vessel in one line (7pcs for 7m vessel) with feed side up.
d) Cut open the plastic bag of top end straight.Some of these bags should be kept and re-used in case any RO elements must be conserved or shipped.
e) Put brine seal into the groove at feed side end of the element, with the U-cup facing the direction of flow.
f) Install interconnector (with O-ring) into the feed side of RO element permeate center pipe. For the lead element of vessel, install permeate adopter into permeate center pipe.
g) Check the number of RO element in loading check sheet.
h) Insert RO element from the feed side end into the pressure vessel about 2/3, after lubricating brine seals and vessel's inner surface with glycerin.
i) Connect the two elements at the interconnector, keeping them in line not to load the weight of the element to the interconnector and/or product tube and to avoid damages to interconnector, product tube or brine seal. 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 not to load the weight of the element to the interconnector and/or product tube and to avoid damages to interconnector, product tube or brine seal.
j) Repeate procedures described in step h) to i). Insert elements one by one into the pressure vessel.
k) Push the last element home until the first (downstream) element's permeate tube is firmly connected.



Interconnector
Permeate Adapter
Element Loading 2 or 3 person
Thrust Ring
5th EL
Element Transfer 3 persons
Check Element No. 1 person
Plastic bag Clear up 1 person
Interconnector
Permeate Adapter
Put interconnector And brine seal 1 person
4th EL
3rd EL
2nd EL
Lead EL
Open carton box 2 person
Element transfer 3 persons
Carton box Clear up 1 person

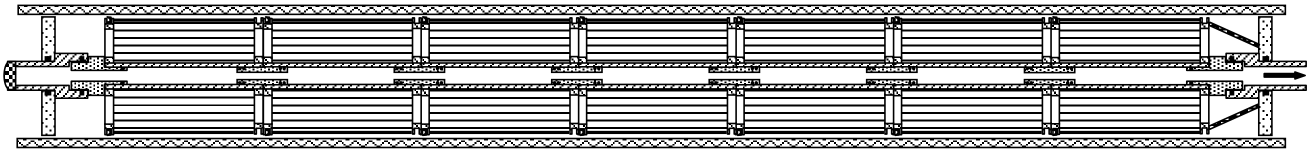
RO Membrane Loading Check Sheet " Train " Date : ____________

Feed Side → Brine Side

Vessel No.	1	2	3	4	5	6	7	Number of Shims

Feed Side Brine

1 2 3 4 5 6 7



Training Material for Shuaibah III Project : Procedure for Shimming

1 Shimming

After installing all RO elements, use shim rings provided by pressure vessel supplier to reduce the free space in the vessel. (Please refer the detail in handling manual)

Advantage of Shimming

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

1) Preparation
- Shim rings : plastic ring material, PVC etc. 5 mm thickness
- Measuring scale

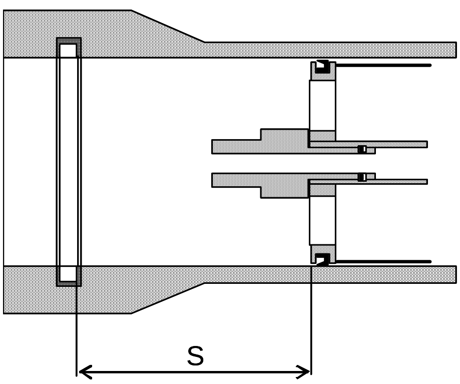
2) Procedure
a) Ensure that all elements are installed into pressure vessel correctly. Push elements firmly into the pressure vessel so they are completely located into the down stream end plate.
b) Measure the distance S : Feed side edge of lead element to retaining ring groove inside edge
c) Free space D is calculated by following.

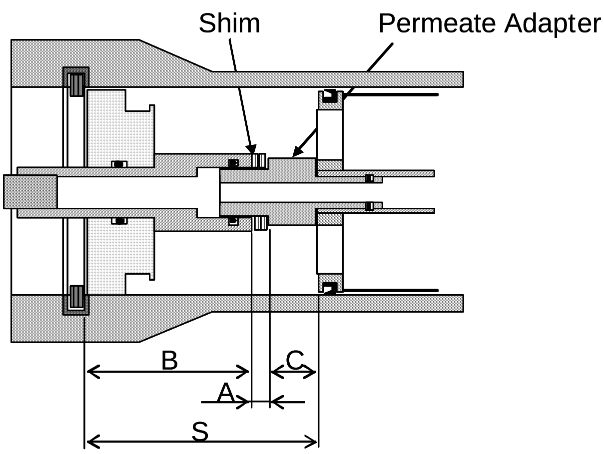
S = A – (B + C)

A : Free space
S : Distance between element edge to retaining ring groove inside edge
B : Distance of end plate + permeate port
C : Distance of permeate adapter

d) Decide the number of shims for this pressure vessel

Number of shims = (A – 1mm) / thickness of shim(truncate the decimal place)
Distance





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No.	TM – Shuaibah III – 0006

Training Material for Shuaibah III Project : Pre-Start-up check list

No.	Check	Checking Items
1		Corrosion resistant materials used throughout pretreatment / RO, including chemical dosing equipment, piping, pump wetted parts
2		All piping and equipment are compatible with the pH range expected (normal operation and cleaning operations)
3		All pretreatment filters backwashed / rinsed and in clean condition
4		New / clean cartridge filters installed correctly in the housings
5		Filter cartridges must be free of surfactants, lubricants, and textile aides.
6		Feed line flushed / purged (usually done before high pressure pump + RO connected)
7		Chemical addition points correctly installed, and chemical addition equipment operational (including spares)
8		Check valves correctly installed on chemical lines
9		Adequate mixing for pretreatment chemicals with the feed water before entering RO
10		Provision made to prevent RO operation if dosing pumps are shut down / chemical flow stops
11		Provision made to prevent chemical addition / dosing pumps operating if the RO is shut down
12		If chlorine is used anywhere on the pretreatment, ensure chlorine is completely removed before contact with RO membrane
13		Planned instrumentation is adequate to allow plant monitoring / data normalization
14		Planned instrumentation is installed / operational / calibrated
15		Pressure relief protection is installed and correctly set
16		Provision exists for the prevention of product pressure from exceeding feed / concentrate pressure by more than 0.7 kg/cm2 at any time
17		All interlocks, time delay relays and alarms are correctly set and tested
18		Provision exists for permeate sampling on all RO vessels
19		Provision exists for sampling of feed, concentrate and permeate streams
20		Provision exists, and pipework is correctly installed for normal operation and cleaning mode
21		Pressure vessels are securely attached to the frame
22		All pressure vessels have been loaded with membrane elements, and end caps are installed with retaining assemblies correctly installed
23		All vessel connections are correctly made, and secure
24		Permeate header is open, with no closed valves
25		Permeate flow is directed to drain
26		Reject control valve is in the open position
27		Feed flow valve is throttled / bypass line is partly open to limit feed flow to < 50% of operating feed flow

Date : ______________________ Date : ______________________

Checked by ______________________ Confirmed by ______________________

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Training Material for Shuaibah III Project : Pressure Vessel Probing

1 Center Pipe Probing

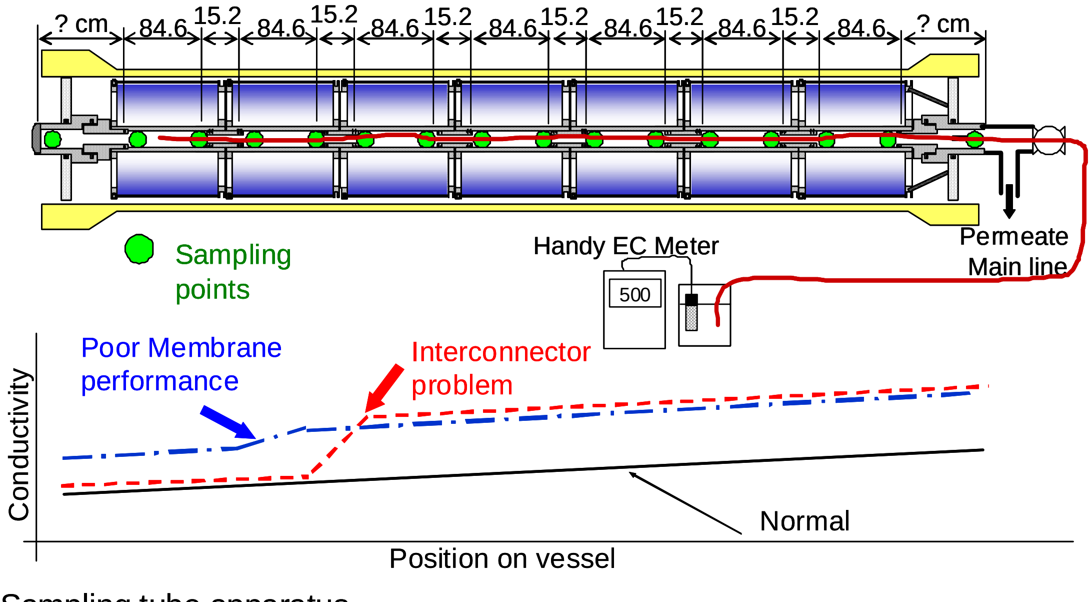
Center pipe probing is very much important to investigate salt rejection problem at site. It is possible to know the suspected reason of deterioration such as O-ring trouble, permeate adopter trouble, etc.

If one or some of pressure vessels show significantly higher permeate conductivity, these pressure vessels should be probed by this method.

1) Preparation
   - 6mm plastic flexible tube (12m, sampling point should be marked before installation)
   - 1/2 inch Ball valve (inner ball should be bigger than 10mm diameter)
   - Water sampling cup (300ml)
   - Handy type conductivity meter
   - Measuring scale

2) Procedure for center pipe probing
   a) Connect 1/2 inch Ball valves to individual pressure vessel permeate manifolds, where are plugged at normal operation.
   b) Start RO system and wait several hours to stabilize the system performance.
   c) Connect the probing tube to one of the valve and install 6mm plastic flexible tube to the end of pressure vessel (check the installed distance by maker)
   d) A few minutes should be waited to rinse out the tube, then, measure conductivity of sample.
   e) Pull the tube to next position. Sample should be taken at least before and after interconnector. After pulling the tube, wait few minutes again to rinse out the tube.
   f) Repeat step e) to the end of pressure vessel.
   g)

A normal profile result shows a steady increase of permeate conductivity from the feed side to brine side. If an usual large deviation is observed in the result, this profile locates the source of the high salt passage problem.



Sampling tube apparatus

Supple thin wall gum rubber (5cm)   Cut open the edge of the tube (3cm)

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PRODUCT WATER QUALITY CHECK SHEET "Train ____"

DATE : ____________________ TIME : ______________________ Measured by : ______________________

Temperature : ____________ Conductivity Feed Permeate Feed Permeate

Initial ________ ________ us/cm Final ________ ________ us/cm

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	
12																	12
11																	11
10																	10
9																	9
8																	8
7																	7
6																	6
5																	5
4																	4
3																	3
2																	2
1																	1
	A	**B**	C	D	E	F	G	H	I	J	K	L	M	N	O	P	