WATER DESALINATION BY REVERSE OSMOSIS

Module 5.1.0 - AGENDA

- Water Quality
- Osmosis & Reverse Osmosis
- Pretreatment
- R.O. Membranes
- Operation and Plant Control
- Troubleshooting
- Cleaning
- Cost Comparisons
- Process Flow Diagram

Salt Content

- Low Salinity Water (TDS < 500 mg/l)
  - Rivers
  - Springs
  - Deep Wells
- Brackish Water (TDS 500 - 16,000 mg/l)
- Heavy Brackish (TDS 16,000 - 30,000 mg/l)
- Sea Water (TDS > 30,000 mg/l)

Brackish Water Ionic Composition

(Please refer to page 4 of your notes)

- Greece Well
- Yuma Arizona Well
- Virgin Island Well
- Riyadh Well
- Dhahran Well

Sea Water Ionic Composition

(Please refer to page 5 of your notes)

- Normal Sea Water
- Eastern Mediterranean
- Arabian Gulf
- Red Sea
- Atlantic Ocean

W.H.O. Drinking Water Standards 1988

(Please refer to page 6 of your notes)

pH	6.0 - 9.6	(7.5 - 8.5 desirable
TDS	1000 mg/l max.	(500 max. desirable)
Sodium	200 mg/l max.	(20 mg/l desirable)
Hardness	500 mg/l max.	(100 mg/l desirable)
Iron	0.3 mg/l max.	(None desirable)
Chloride	600 mg/l max.	(25 mg/l desirable)

1. Osmosis

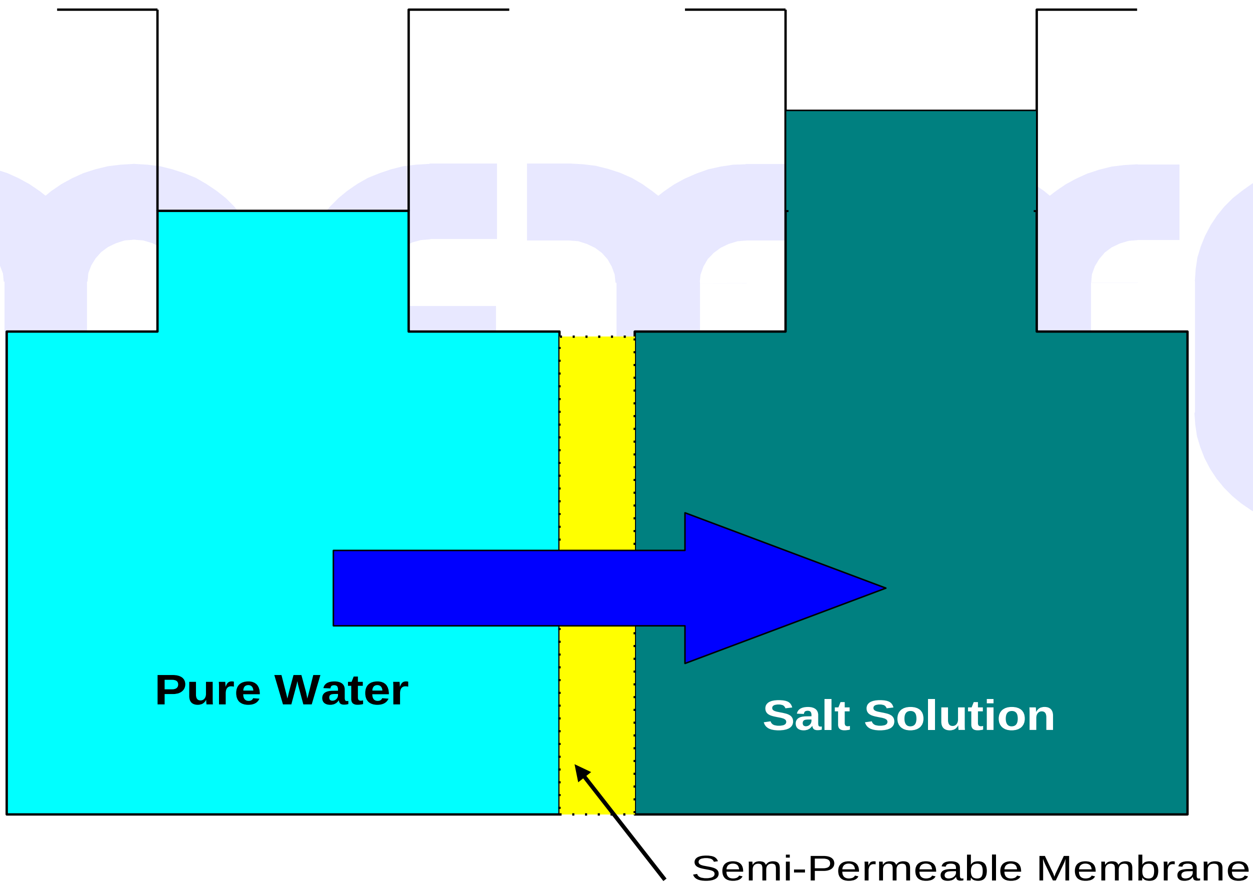
Osmosis is a natural occurring process used by many plant & animal tissues to transport liquids across cell walls.

2. Semi Permeable Membrane

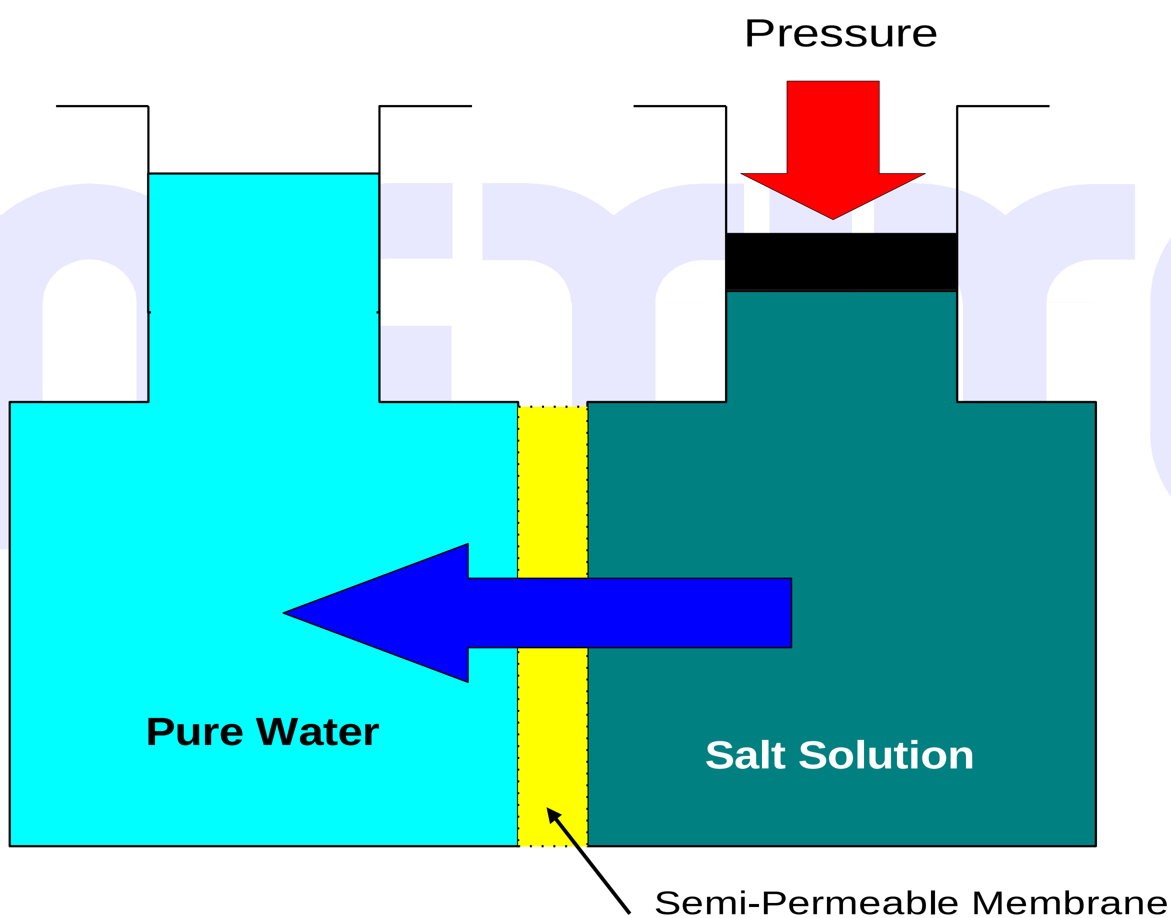
Cell walls are examples of Semi-Permeable membranes which allow water to pass through, while not allowing salts to pass.

3. Semi Permeable Membrane

4. Osmosis



5. Reverse Osmosis



Overview

- Major fouling impurities
- Scaling
- Suspended solids & Colloidal matter
- Biological Matter
- Metal Oxides
- Silica

1. Major Fouling Components

- Sparingly soluble (scale-forming) salts
  - Calcium Carbonate
  - Calcium Sulphate
  - Barium Sulphate
  - Strontium Sulphate
  - Calcium Fluoride
- Suspended solids & colloidal matter
- Micro-organisms (bacteria & protozoa)
- Metal oxides (e.g. Iron & Aluminium)
- Silica

Module 5.1.3 - Pretreatment

2. Scale Control

- Caused by precipitation of sparingly soluble salts :
  - Calcium Carbonate $CaCO_3$
  - Calcium Sulphate $CaSO_4$
  - Barium Sulphate $BaSO_4$
  - Strontium Sulphate $SrSO_4$
  - Calcium Fluoride CaF_2
- Scaling Potential Determined by :
  - Chemical Analysis of Feed Water
  - R.O. system recovery
  - Solubility limits of salts

3.1 Calcium Carbonate $CaCO_3$

- Exists in most waters (as soluble Calcium Bicarbonate, $Ca(HCO_3)_2$)
- For Brackish Waters, scaling potential calculated by Langlier Saturation Index (LSI)
- For Sea Water/Brine water the scaling potential is calculated by SDSI

3.2 Calculating Scale Potential of $CaCO_3$

$$LSI = pH_b - pH_s$$

Where

LSI	=	Langlier Saturation Index
pHb	=	pH of brine water
pHs	=	pH of saturation (i.e. where $CaCO_3$ will neither deposit nor dissolve)

- Negative LSI $CaCO_3$ tends to dissolve
- Positive LSI $CaCO_3$ tends to precipitate

3.3 Pretreatments against $CaCO_3$ scaling

- Addition of Acid to lower LSI
- Addition of antiscalant to reduce scaling tendency when LSI > 0
- Softening of feed using Ion Exchange

3.4 Calcium Carbonate Scale

$$HCO_3^- \Leftrightarrow H^+ + CO_3^{2-}$$

$$K_2 = \frac{[CO_3^{2-}][H^+]}{HCO_3}$$

$$Ca^{++} + CO_3^{2-} \Leftrightarrow CaCO_3 \Downarrow$$

$$K_{sp} = Log\,\frac{K_{sp}}{K_2} - Log\,[Ca^{2+}] - Log\,[HCO_3^-]$$

$$= pCa + pHCO_3 + C$$

$$LSI = pH_b - pH_s$$

4.1 Sulphate Salts

- If $CaSO_4$, $BaSO_4$ or $SrSO_4$ are present in feed water, solubility limits must be calculated
- To avoid precipitation IP_b must be less than K_{sp}

Where

IP_b = the Ion product of the brine water

K_{sp} = the solubility product

4.2 Calcium Sulphate

✍ $IP_b = (mCa^{2+})_b(mSO_4^{2-})_b$

$IP_b > K_{sp}$ - Precipitation occurs

$IP_b < K_{sp}$ - Solution is unsaturated

$IP_b = K_{sp}$ - Solution saturated (equilibrium)

Guideline IPb $\leq$ 0.8 K_{sp}

4.3 Controlling Sulphate Scaling

- Reduce Recovery
- Use Antiscalant

5.1 Suspended Solids & Colloids

- Suspended Solids - removable settling
- Colloids - not removable by settling
  - Negative charges on surface - stable in water
  - In R.O. process colloids concentrate at surface or membrane with salts
  - Leads to colloid destabilization
  - Colloids coagulate & foul membrane

5.2 Measuring Colloid Fouling Potential

- Use Silt Density (SDI)
- SDI = $$\frac{\left[100\left(1-\left(\frac{t_i}{t_f}\right)\right)\right]}{t_t}$$

Where

t_t = Total test time in minutes (usually 15)

t_i = Initial test time in sec. To fill 500 mg sample

t_f = Time in second to fill 500 ml sample after 15 min.

5.3 Controlling Colloids Problems

- Media Filtration
- Coagulation / Flocculation
  - (On-line or off-line)

6.1 Biological Fouling

- Most water sources contain micro-organisms
- Form slime layer on membrane surface
- Leads to rapid pressure drop increase across cartridge filter preceding H.P. Pump
- Samples from feed & brine must regularly be tested for Total Bacterial Count (TBC)

6.2 Controlling Biological Fouling

- Chlorination prior to filtration stage
- Water ***MUST*** be de-chlorinated prior to reaching membranes

7.1 Metal Oxides

- Most common is iron
- Frequently encountered in water in Ferrous (Fe^{2+}) form
- In presence of Oxygen, Fe^{2+} (soluble) oxidized to Fe^{3+} (insoluble)
- Aluminum can precipitate as Aluminum Hydroxide

7.2 Controlling Metal Oxide Fouling

- Oxidation
- Chemical Precipitation

8.1 Silica (SiO_2)

- When super-saturated, soluble silica forms colloidal silica or silica gel on membranes
- Control by
  - Reducing recovery
  - Lime softening
  - pH Control
  - Temperature control

Module 5.1.4.0 - Membrane Types

Overview

- Material
- Designs

Module 5.1.4.0 - Membrane Types

1. Materials

- Cellulose Acetate (Brackish Water)
- Cellulose Tri-Acetate (Brackish & Sea Water)
- Polyamide (Brackish & Sea Water)
- Composite Polyamide TFCL (Brackish & Sea Water)

Module 5.1.4 - Membrane Types

2. Membrane Designs

- Plate & Frame
- Tubular
- Spiral Wound
- Hollow Fibre

Overview

- Basic Equations
- Water Quality
- Recovery
- Chemical Addition

2. Membrane Designs

- Plate & Frame
- Tubular
- Spiral Wound
- Hollow Fibre

1.1 Basic Equations

- $Q_w = K_w\,(A/t)(\Delta P - \Delta\Pi)\ TM$

Where

Q_w	=	flow rate through membrane
K_w	=	permeability coefficient
A	=	membrane surface area
t	=	membrane thickness
ΔP	=	differential pressure across membrane
$\Delta\Pi$	=	osmotic pressure differential
T	=	temperature effect
M	=	membrane flux decline effect

1.2 Basic Equations

- $Q_f = Q_p + Q_b$

Where

Q_f = feed flow rate

Q_p = permeate flow rate

Q_b = brine flow rate (reject)

1.3 Basic Equations

- $Y = Q_p / Q_f$

Where

Y = recovery (conversions)

Q_p = permeate flow rate

Q_b = feed flow rate

1.4 Basic Equations

- $CF = Q_f / Q_b$

Where

CF = concentration factor

Q_b = brine flow rate (reject)

Q_f = feed flow rate

1.5 Basic Equations

- $CF = 1/(1-Y)$

  Where

  - CF = concentration factor
  - Y = recovery (conversions)

- Brine chemical composition can be estimated using this equation

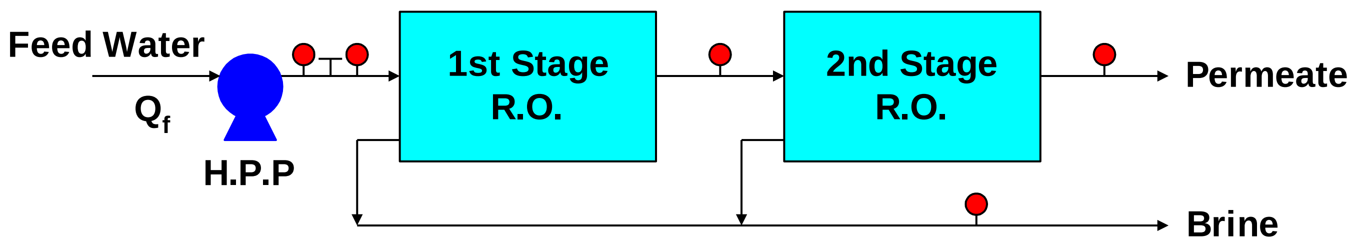
2.1 Water Quality

- Check that .....
  - Chlorine in feed is zero
  - Iron in feed is less than 0.05 mg/l
  - SDI of feed water is less than 3
  - TDS of feed water is within R.O. design criteria

3.1 Pressures

Check …..

- Pump discharge pressure
- System pressure (1st stage)
- Intermediate pressure
- Reject (Brine) pressure
- Permeate pressure



3.2 Why pressure is important

- ✍ Assure plant is running according to design pressure
- ✍ Allows normalization of plant operation to evaluate performance
- ✍ Indicates fouling when pressure changes significantly under steady operating

4.1 Recovery

- Ratio of permeate flow to total feed flow

- $$Y = \frac{Q_p}{Q_f}$$

4.2 Important to operate at Design Recovery in order to

- Prevent over-saturation of sparingly soluble salts
- Not exceed hydraulic guidelines of membranes, e.g. min. & max. brine rates, flux etc.
- Produce required permeate quality

5. Chemical Addition

Dosing sets include:

- Coagulant to reduce colloidal fouling
- Acid dosing for pH adjustment to reduce scaling potential
- Chlorine dosing to control microbiological growth
- De-chlorinating agent to remove free chlorine prior to membrane
- Antiscalant dosing
- Alkali dosing to adjust permeate water pH to required level

1. Troubleshooting Techniques

- Most problems related to fouling
- Indicators
  - Permeate Quality
  - Permeate Quantity
  - Salt Rejection
  - Pressure Differential
- Accurate operation log is critical for successful troubleshooting

2. On-line Investigations

- Performed while system in operation
- Measure the following:
  - Salt rejection
  - Product flow
  - Pressures
- Every permeator has to be checked

3. On-line Investigations

- Permeators removed from service
- Individual elements identified

1. Why Clean?

Frequent cleaning is not required for properly designed and operated R.O. Systems

2. When to Clean?

- Productivity reduced by 10 - 20%
- Salt passage increased by 1.5x
- Bundle pressure drop $\Delta P > 60$ psi

Module 5.1.7 - Cleaning

3. How to Clean?

- Cleaning should be performed after R.O. data has bee normalized
- Changes observed not due to changes in operating conditions
- If bacteriological tests show bacteria in permeate then biocide cleaning is required

4. Different Cleaning Chemicals

- Detergent to remove colloidal foulants
- Citric acid to remove iron oxide
- Formaldehyde for biological control

5. Cleaning Equipment

Importance of Flushing

- Corrosion rates of stainless steel elements in stagnant water are very high
- Antiscalant, if used, produces a metastable state with respect to precipitation of sparingly soluble salts
- Upon shutdown, precipitation can occur within four hours if the permeators are not flushed

Importance of Flushing

- Upon shutdown, reverse osmosis process will cease and natural osmosis will occur
- Water flows from the fiber bore to the fiber feed-brine side
- If an adequate volume of permeate water at positive pressure (draw-back tank) is not supplied, fiber dehydration will occur

Reverse Osmosis

FLUSHING WATER REQUIREMENTS

HOLLOW FINE FIBER MEMBRANES

Membrane Type	Membrane Size	Water Quantity Per Membrane
B_9 & B_{10} Twin	8 inch	80 Gallons
B_9 & B_{10} Single	8 inch	40 Gallons
Single	4 inch	12.5 Gallons

FLUSHING WATER REQUIREMENTS

SPIRAL (5 MINUTES)

Membrane Type	Membrane Size	Water Quantity Per Membrane
Vessel with 6 Membranes	8 inch	30 - 40 GPM
Vessel with 6 Membranes	4 inch	8 - 10 GPM

DRAWBACK REQUIREMENTS

Membrane Type	Size	Water Requirement
Twin	8 inch	24 Gallons
Single	8 inch	12 Gallons
Single	4 inch	4 Gallons

MAXIMUM CLEANING FLOWS

Membrane Type & Size	Flow
B_9, and B_{10} Twin	21 GPM
B_9, and B_{10} Single	12 GPM
Single	4 GPM

Module 5.1.8 - Cost Comparisons

1. Permeator Replacement Rates

Plant	Capacity m^3/day	Startup Date	Average % Replacement Rate/year
KSA - Jeddah	2,270	1983	7
Malta - Marsa	5,680	1983	7
Bahrain - Ras Abu Jarur	45,420	1984	7

2. Cost Comparison R.O. vs. Distillation

Capital and Total Water Cost

Location	Middle East			U.S.A.		
Type	R.O.	MSF	MED	R.O.	MSF	MED
Capital Cost US$/$m^3$/day	1,673	2,637	2,760	1,005	2,719	2,479
Total Water Cost US$/$m^3$	1.18	1.58	1.45	1.02	1.87	1.47

3.1 Reasons for R.O. Economic Advantages

- ✍ R.O. requires ¼ - ½ energy required by thermal process

3.2. Reasons for R.O. Economic Advantages

- Major Technological Improvement in R.O. has taken place in recent years
  - B-10 twin allows higher pressure (upto 1,200 psi) at higher recoveries (50 - 60%)
  - Dual Bundle design results in lower capital costs and higher plant availability

Module 5.1.8 - Cost Comparisons

3.3 Reasons for R.O. Economic Advantages

- Prices of non-ferrous metals in thermal processes have increased 50 - 100% in the last 10 years
- Membrane prices, however, have remained fairly constant

3.4 Reasons for R.O. Economic Advantages

- **Materials of construction** used throughout thermal plants are more costly than in R.O. plants, because of the higher operating temperatures

3.5 Reasons for R.O. Economic Advantages

- ✍ Extensive operator training required for thermal processes, but not for R.O. plant

3.6 Reasons for R.O. Economic Advantages

✍ Modular approach of modern R.O. plant eliminates the need to shut down the entire plant for scheduled or emergency maintenance

3.7 Reasons for R.O. Economic Advantages

- R.O. plants require only **half the space** need for thermal desalting systems

3.8 Reasons for R.O. Economic Advantages

- R.O. plants require around **1/3 of the sea water feed** necessary for MSF and MED systems
- Intake and pre-treatments systems are smaller
- Environmental impact more acceptable

Module 5.1.9 - Process Flow Diagram

Sea Water R.O. Plant