METITO

Commitment to a Cleaner Environment

Module 5.1

WATER DESALINATION

BY REVERSE OSMOSIS

Module 5.1 - AGENDA

- Water Quality
- Osmosis & Reverse Osmosis
- Pretreatment
- R.O. Membranes
- Process Flow Diagram

Module 5.1 Water Quality

OVERVIEW

Salt Content of different water sources :

- **Brackish Water**
- **Sea Water**
- **Drinking Water Standards**

Module 5.1.1- Water Quality

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)

Module 5.1.2 - Osmosis & Reverse Osmosis

1. Osmosis

Osmosis is a natural phenomenon by which water flows across a semi-permeable membrane.

Module 5.1.2.1 - Osmosis & Reverse Osmosis

2. Semi-permeable membrane

Semi-permeable membrane is selective:

It allows water to pass through, while does not allow salts.

Module 5.1.2.2 - Osmosis & Reverse Osmosis

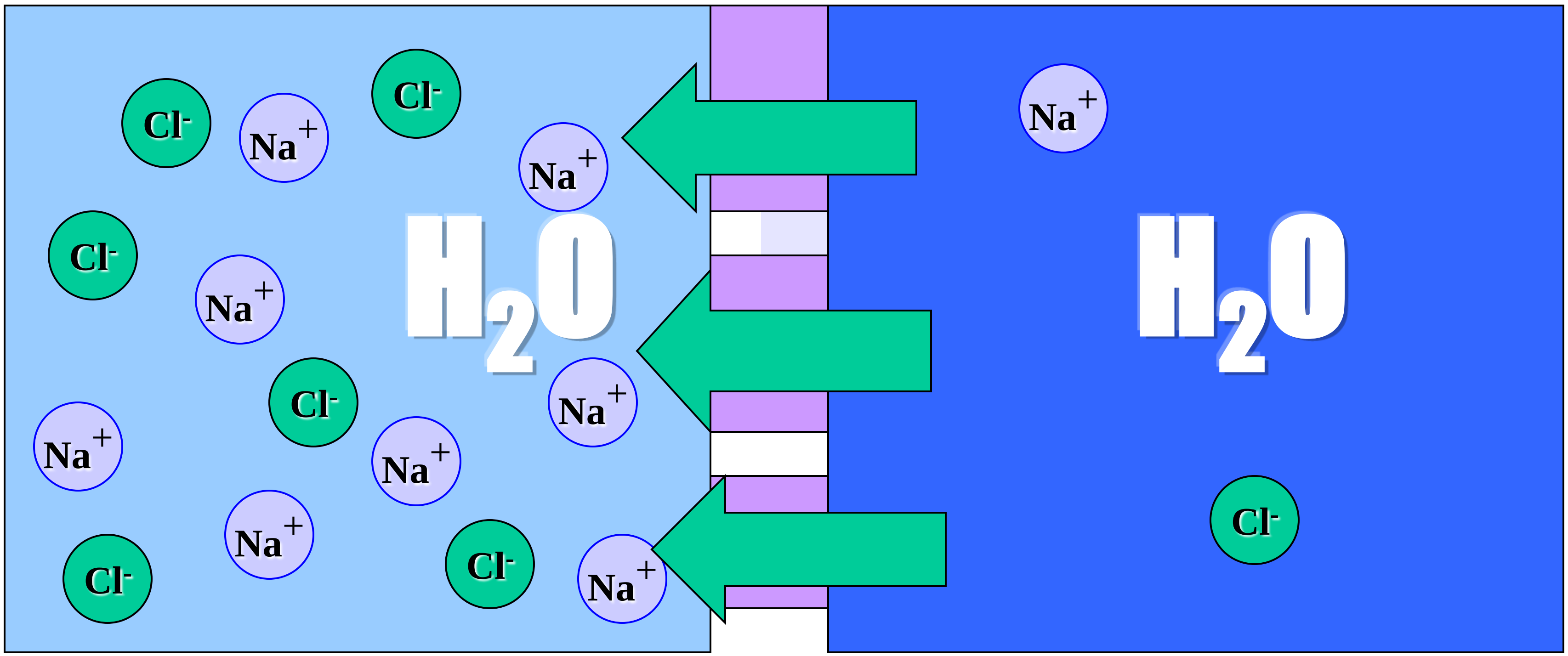
- When a membrane separates two water solutions with different salt concentrations, water will flow from the side with the low salt concentration to the side with the high salt concentration

Module 5.1.2.3 - Osmosis & Reverse Osmosis

- This water movement through the membrane occurs as a result of a chemical potential which is, mainly, a function of dissolved solids under constant temperature and pressure. This **phenomenon is called osmosis.**

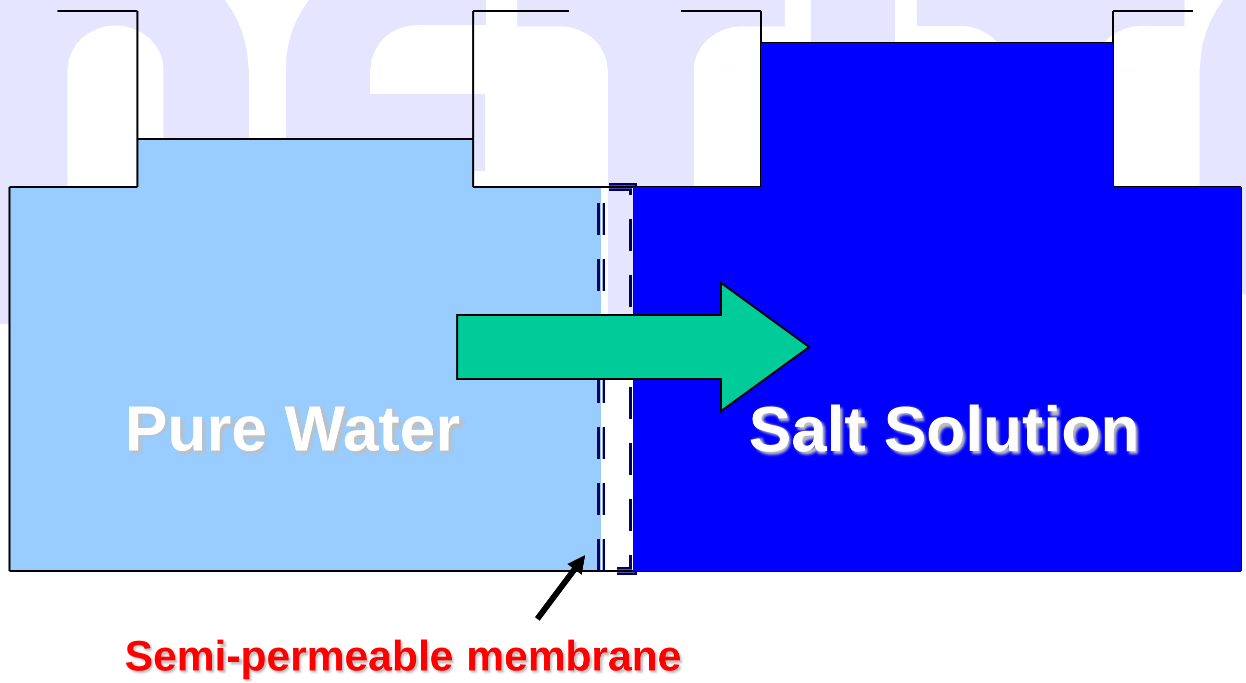
Module 5.1.2.4 - Osmosis & Reverse Osmosis

3. Semi Permeable Membrane



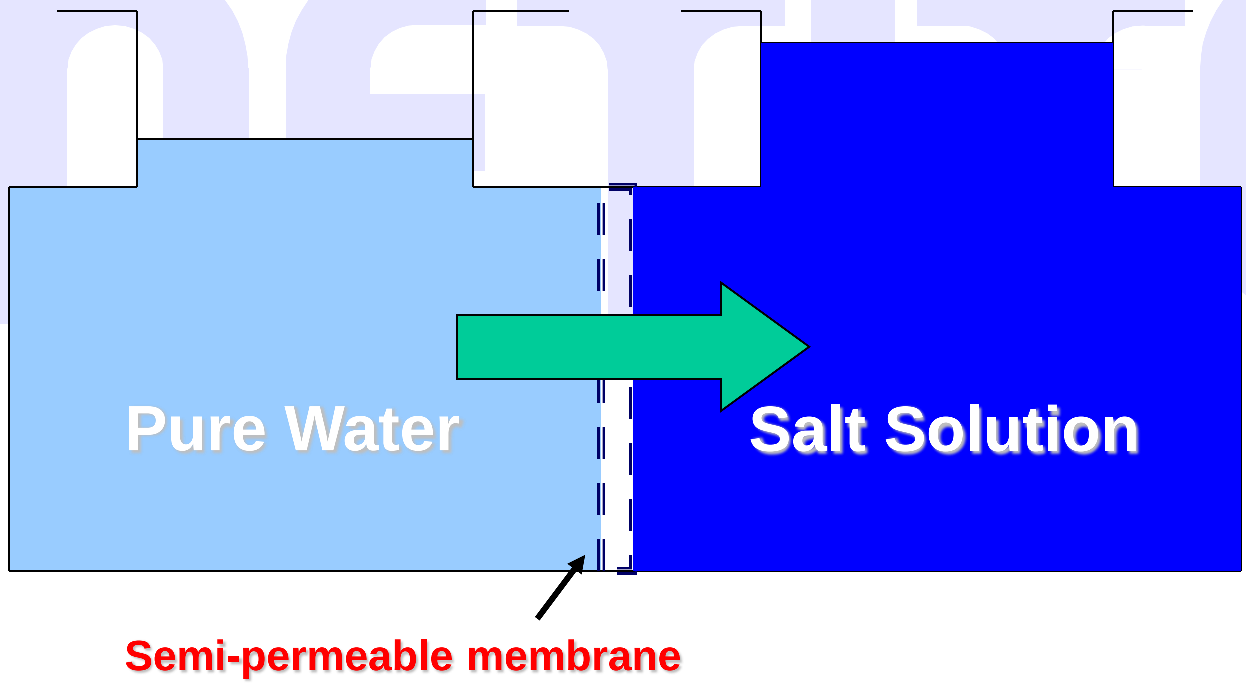
Module 5.1.2.5 - Osmosis & Reverse Osmosis

4. Osmosis



Module 5.1.2.6 - Osmosis & Reverse Osmosis

- **5. Osmosis Equilibrium**

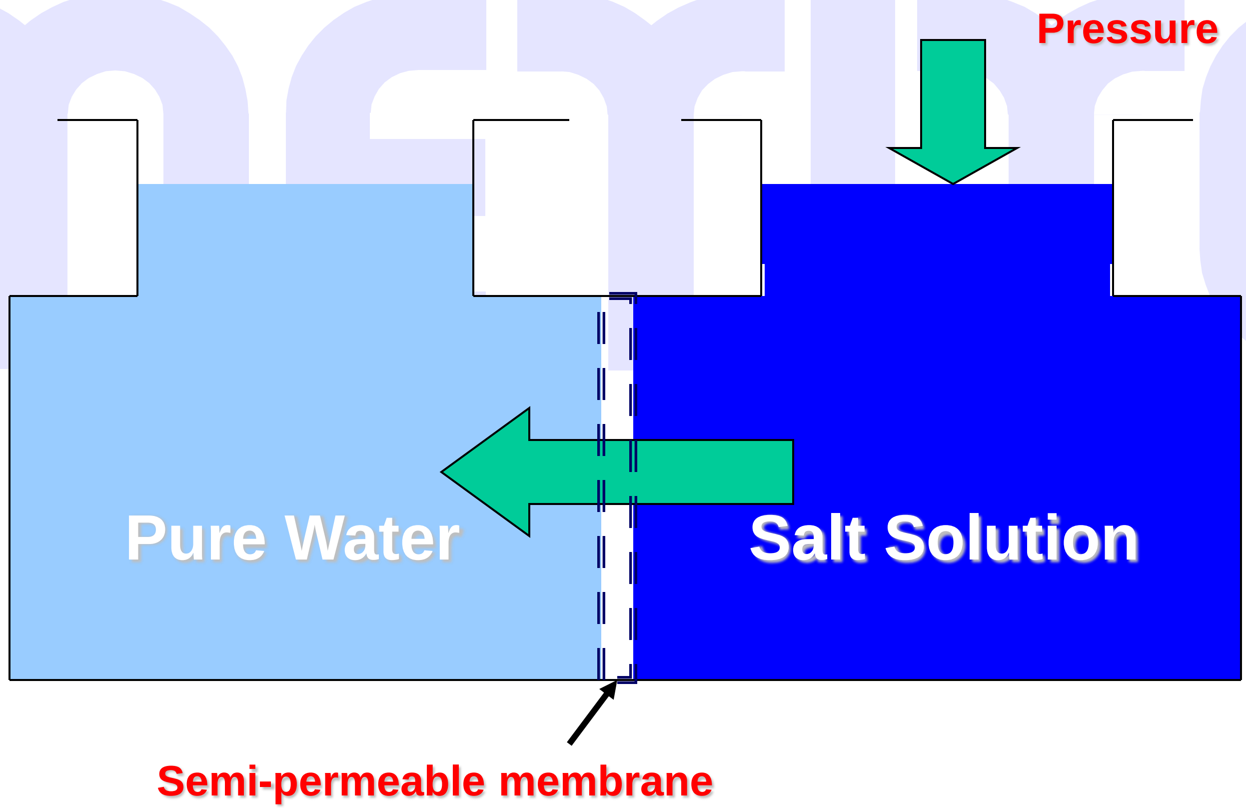


Module 5.1.2.7 - Osmosis & Reverse Osmosis

- **6. Reverse Osmosis**
- **Additional pressure applied will cause water to flow in a reverse direction from the high salt side to the low salt side. This is known as Reverse Osmosis**

Module 5.1.2.8 - Osmosis & Reverse Osmosis

6. 1 Reverse Osmosis



Module 5.1.3 - Pretreatment

OVERVIEW

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

Module 5.1.3 - Pretreatment

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 Flouride CaF_4

Scaling Potential Determined by :

- Chemical Analysis of Feed Water
- R.O. System Recovery
- Solubility Limits of Salts

Module 5.1.3 - Pretreatment

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 Langelier Saturation Index (LSI)
- For Sea Water / Brine Water the scaling potential is calculated by SDSI

Module 5.1.3 - Pretreatment

3.2 Calculating Scale Potential of $CaCO_3$

$$LSI = pH_b - pH_s$$

Where

- *LSI = Langelier Saturation Index*
- *pH_b = pH of brine water*
- *pH_s = 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

Module 5.1.3 - Pretreatment

3.3 Pre-treatments against $CaCO_3$ Scaling

- Addition of Acid to lower LSI
- Addition of Anti-scalant to reduce scaling tendency when LSI > 0
- Softening of Feed using Ion Exchange

Module 5.1.3 - Pretreatment

4.1 - Sulphate Salts

- If $CaSO_4$, Ba SO_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

Ipb = the Ion Product of the Brine Water

Ksp = the solubility product

Module 5.1.3 - Pretreatment

4.2 - Sulphate Salts

$$Ip_b = (mCa^{2+})_b(mSO_4^{2-})_b$$

$IP_b > Ksp$ - Precipitation Occurs

$IP_b < Ksp$ - Solution is unsaturated

$IP_b = Ksp$ - Solution saturated (equilibrium)

Guideline $IP_b \leq 0.8$ Ksp

Module 5.1.3 - Pretreatment

4.3 - Controlling Sulphate Scaling

- Reduce Recovery
- Use Anti-scalants

Module 5.1.3 - Pretreatment

5.1 - Suspended Solids & Colloids

- Suspended Solids - Removable by Settling
- Colloids - not removable by settling

  - Negative charges on surface - stable in water
  - In R.O. process colloids concentrate at surface of membrane with salts
  - Leads to colloid de-stabilisation
  - Colloids coagulate & foul membrane

Module 5.1.3 - Pretreatment

5.2 - Measuring Colloid Fouling Potential

Use Silt Density Index (SDI)

$$SDI = \frac{[100(1-(t_i/t_f))]}{t_t}$$

Where

t_t = total test time in minutes (usually 15)

ti = initial test time in sec. To fill 500 ml sample

t_f = time in sec. to fill 500 ml sample after 15 min.

Module 5.1.3 - Pretreatment

5.3 - Measuring Colloid Fouling Potential

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

Module 5.1.3 - Pretreatment

6.1 - Biological Fouling

- Most water sources contain microorganisms
- Form Slime Layer on Membrane Surface
- Leads to rapid pressure drop increase across cartridge filter preceding H.P. Pump
- Samples from feed & brine must be regularly tested for Total Bacterial Count (TBC).

Module 5.1.3 - Pretreatment

6.2 - Controlling Biological Fouling

- Chlorination prior to filtration stage
- Water must be de-chlorinated prior to reaching membranes.

Module 5.1.3 - Pretreatment

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).
- Aluminium can precipitate as Aluminium Hydroxide.

Module 5.1.3 - Pretreatment

7.2 Controlling Metal Oxide Fouling

- Oxidation
- Chemical Precipitation

Module 5.1.3 - Pretreatment

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 5.1.3 - Pretreatment

- **9.1 Chemical Addition**
- The RO system comprises several chemical dosing sets to achieve a suitable feed water quality.

Module 5.1.3 - Pretreatment

- **9.2 Chemical Addition**
- This is performed to comply with the membrane guidelines.
- The most important chemical dosing sets are :

Module 5.1.3 - Pretreatment

- Coagulant/Coagulant aid to reduce colloidal fouling
- Acid dosing for pH adjustment to reduce scale potential
- Cl_2 dosing to prevent any biological growth.

Module 5.1.3 - Pretreatment

- Reducing agent dosing to remove Cl2 from water entering the membranes.
- Antiscalant dosing.
- Addition of alkaline to adjust permeate water pH to the required level.

Module 5.1.4 - Membrane Types

OVERVIEW

- Material
- Designs

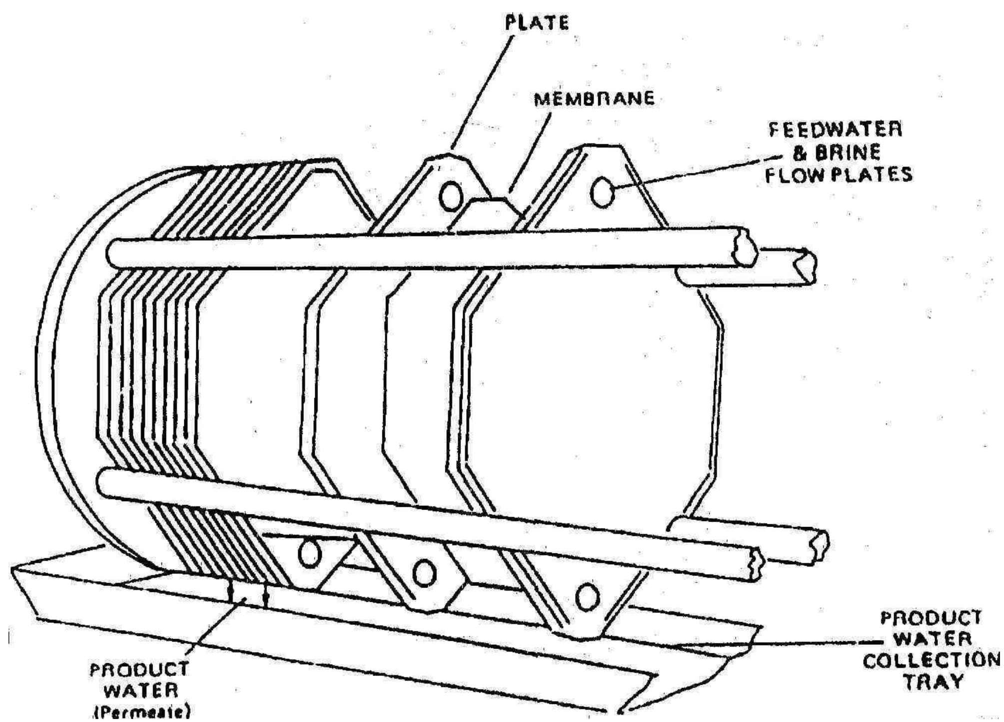
Module 5.1.4 - Membranes Types

1. Materials

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

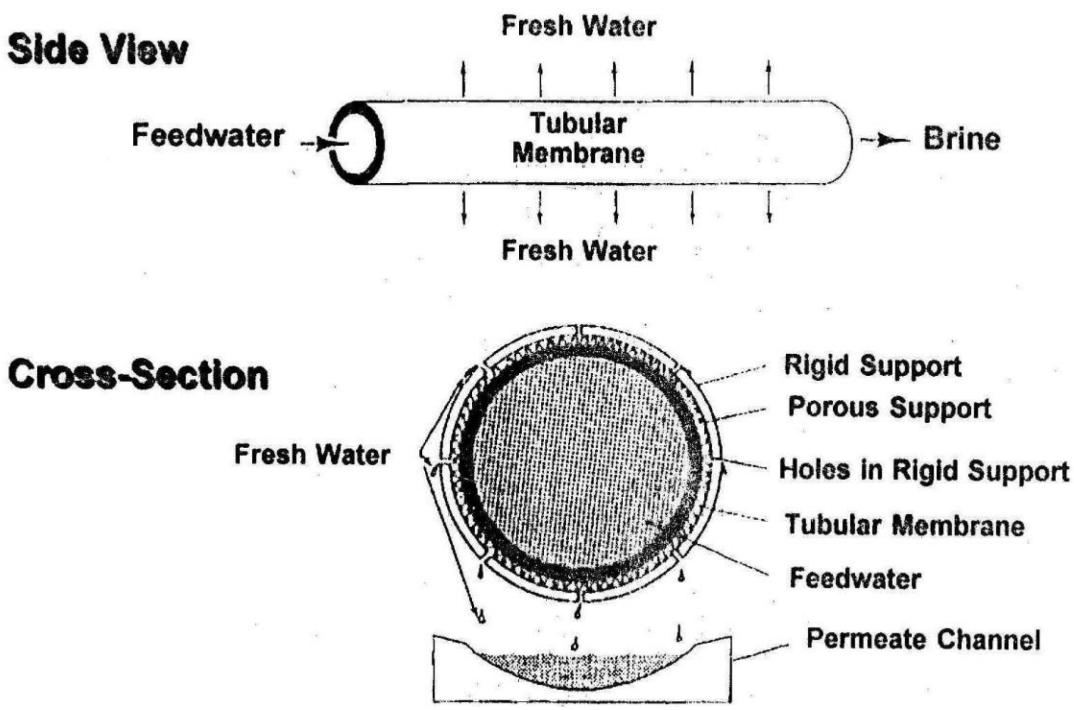
Module 5.1.4 - Membranes Types

2.1 Plate & Frame Design



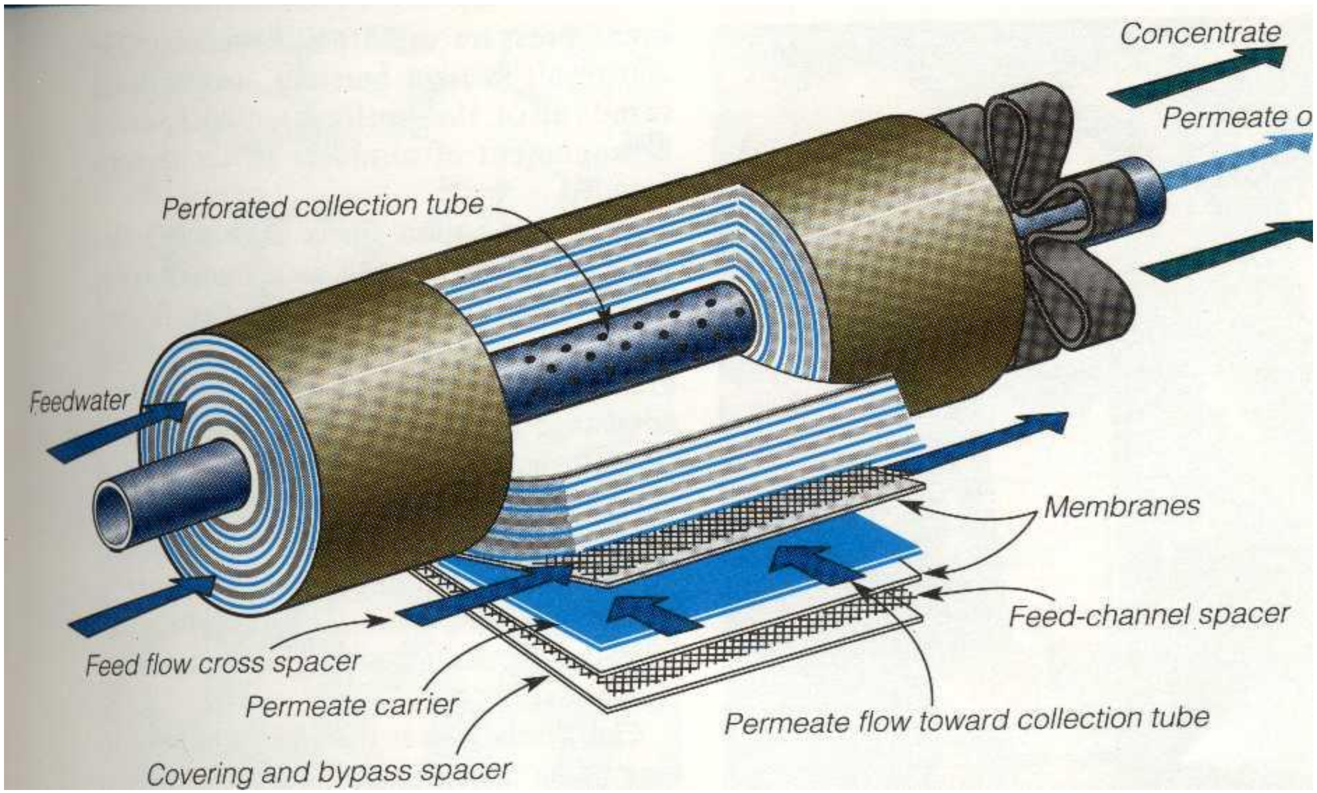
Module 5.1.4 - Membranes Types

2.2 Tubular Design



Module 5.1.4 - Membranes Types

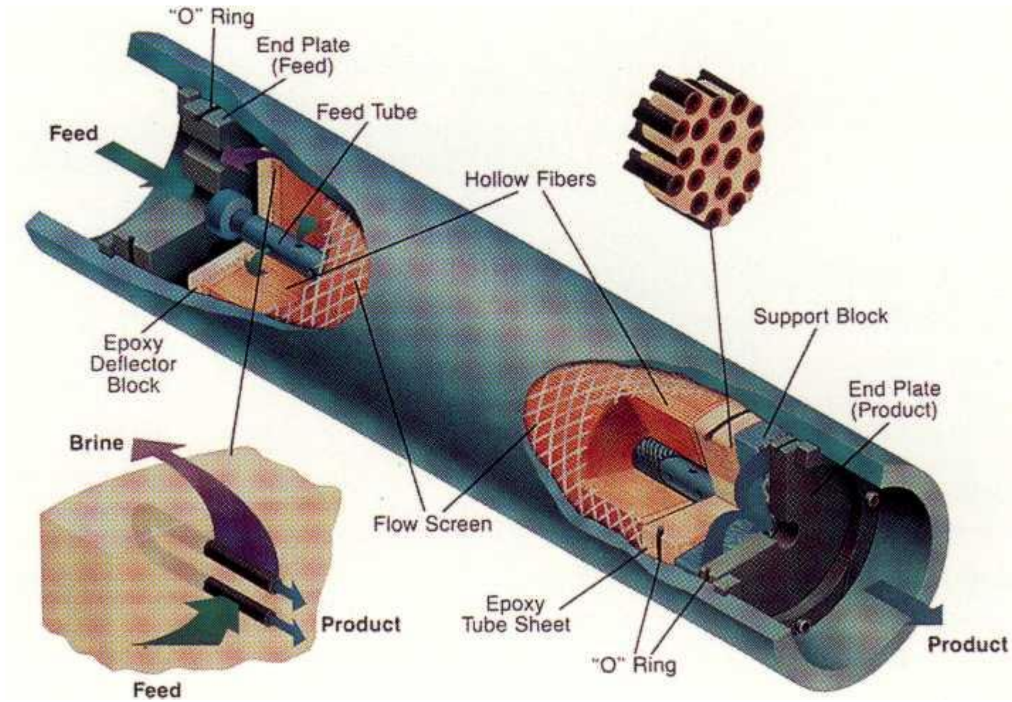
2.3 Spiral Wound Design



Module 5.1.4 - Membrane Types

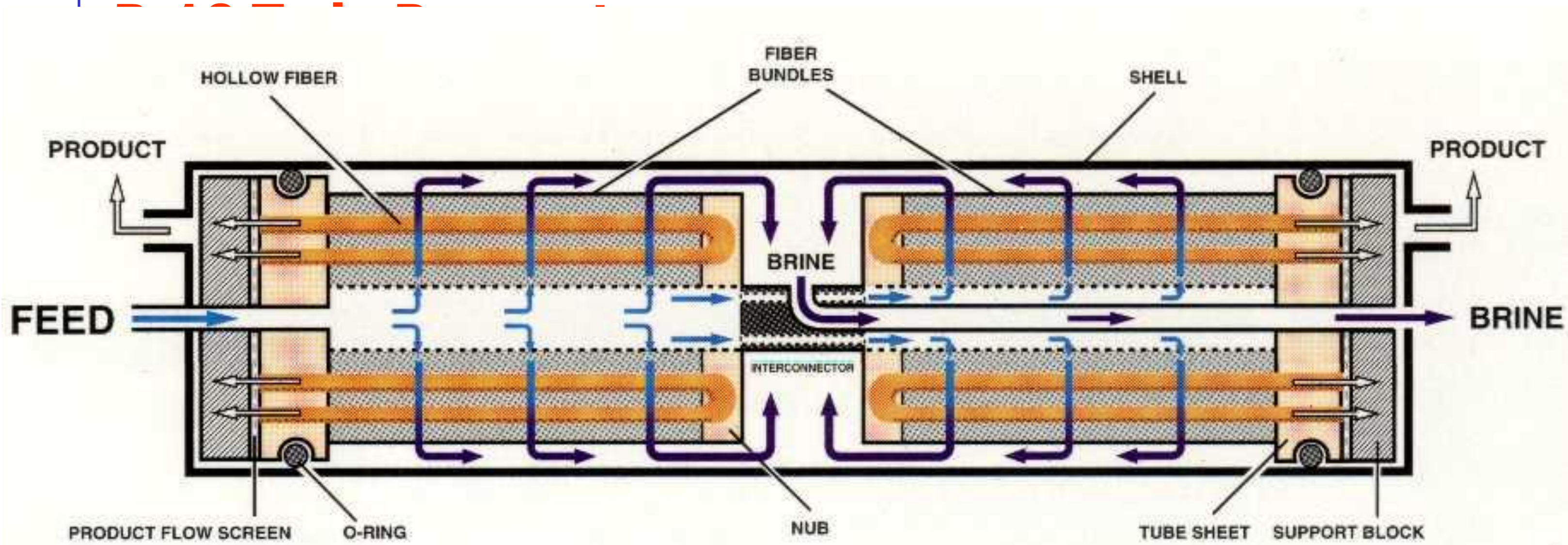
2.4 Hollow Fibre Design

[B-10 Single Bundle Permeator]



Module 5.1.4 - Membrane Types

2.5 Hollow Fibre Design



Module 5.1.5 - Design

OVERVIEW

- Basic Equations
- Water Quality
- Pressures
- Recovery
- Chemical Addition

Module - Design

1.1 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)

Module 5.1.5 - Design

1.2 Basic Equations

$$Y = Q_p / Q_f$$

Where

Y	=	recovery (conversions)
Q_p	=	permeate flow rate
Q_f	=	feed flow rate.

Module 5.1.5 - Design

1.3 Basic Equations

$$CF = Q_f / Q_b$$

Where

CF	=	concentration factor
Q_b	=	brine flow rate (reject)
Q_f	=	feed flow rate

Module 5.1.5 – Design

1.4 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

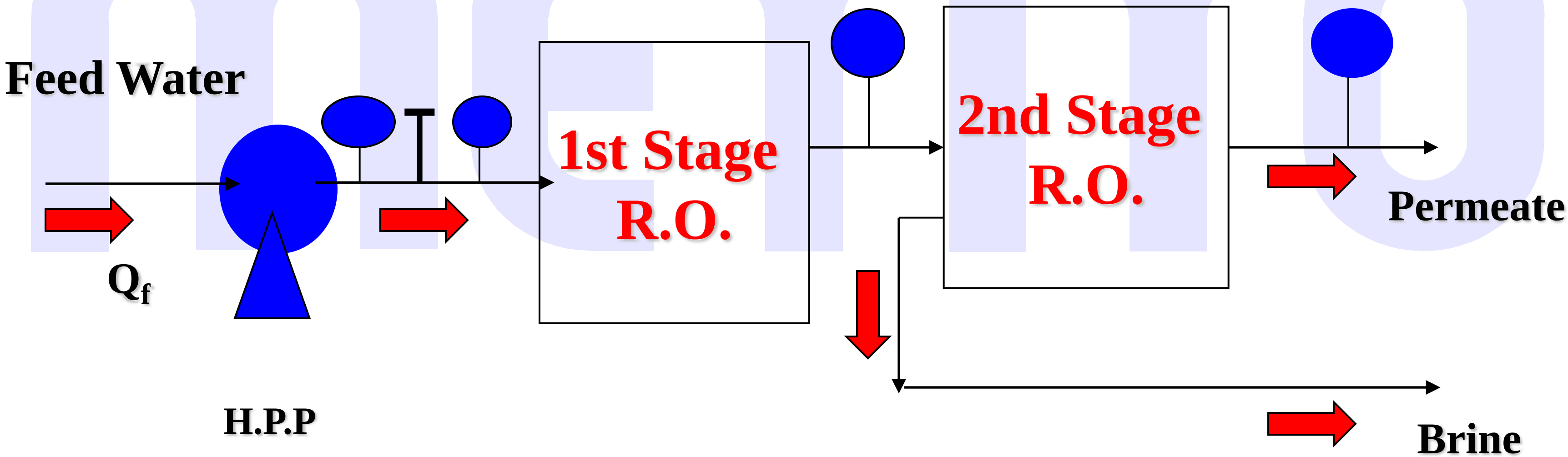
Module 5.1.5- Design

1.5 Pressures

Check……

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

Module 5.1.5- Design



Module 5.1.5 - Design

Brine Staged Systems

- Brine staging involves feeding the brine from a first set of membranes into a second set for additional desalting.
- The product from both sets is then blended together.

Module 5.1.5 - Design

Advantages of Brine staging

- Overall salt rejection
- Maximize the amount of product
- Achieve the brine flow rate

Module 5.1.5 - Design

Product Staged Systems

- Product water from the first RO system becomes the feed water for the second system
- Each stage is a separate RO plant requiring its own feed systems

Module 5.1.5 - Design

Advantages of Product staging

- Better Product Quality
- High recovery from second pass
- Maximum system recovery – Brine from the second pass has a lower TDS than the raw feed to the first unit, it can be recycled / added to the feed water of the first system

Module 5.1.5 – Design

Recovery

- Ratio of permeate flow to total feed flow

$$Y = Q_p/Q_f$$

Module 5.1.5 – Design

- **Design Guidelines**

Parameters	Dimensions	RO Permeate	Brackish Well
Feed SDI	%/min	1	3
Average system flux	l/m2/h	35-39	25-32
Max. lead element flux	l/m2/h	48	43
Max. Feed Flow	m3/hr	17	16
Min. Brine Flow	m3/hr	2.4	3
Max. DP / Vessel	bar	3	3
Max. DP / Element	bar	1	1

Module 5.1.5 – Design

. Design Guidelines

Parameters	Dimensions	Brackish Surface	Sea Well
Feed SDI	%/min	3	3
Average system flux	l/m2/h	18-23	15-19
Max. lead element flux	l/m2/h	31	35
Max. Feed Flow	m3/hr	13	15
Min. Brine Flow	m3/hr	3.6	3.6
Max. DP / Vessel	bar	2	3
Max. DP / Element	bar	1	1

Module 5.1.5 – Design

– Design Guidelines

Parameters	Dimensions	Sea Open	Tertiary Waste
Feed SDI	%/min	3	3
Average system flux	l/m2/h	12-16	9-13
Max. lead element flux	l/m2/h	28	19
Max. Feed Flow	m3/hr	13	12
Min. Brine Flow	m3/hr	3.6	3.6
Max. DP / Vessel	bar	2	2
Max. DP / Element	bar	1	1

Module 5.1.5 - Design

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.

Module 5.1.5 - Design

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-chlorination agent to remove free chlorine prior to membranes.
- Antiscalant dosing.
- Alkali dosing to adjust permeate water pH to required level.

Module 5.1.5 - Design

Flushing & Cleaning

Module 5.1.5 - Design

1. Why Clean ?

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

Module 5.1.5 - Design

2. When to clean

- Productivity reduced by 10 - 20%
- Salt passage increased by 1.5X
- Vessel pressure drop ΔP 1.5X

Module 5.1.5 - Design

3. How to Clean

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

Module 5.1.5 - Design

4. Different Cleaning Chemicals

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

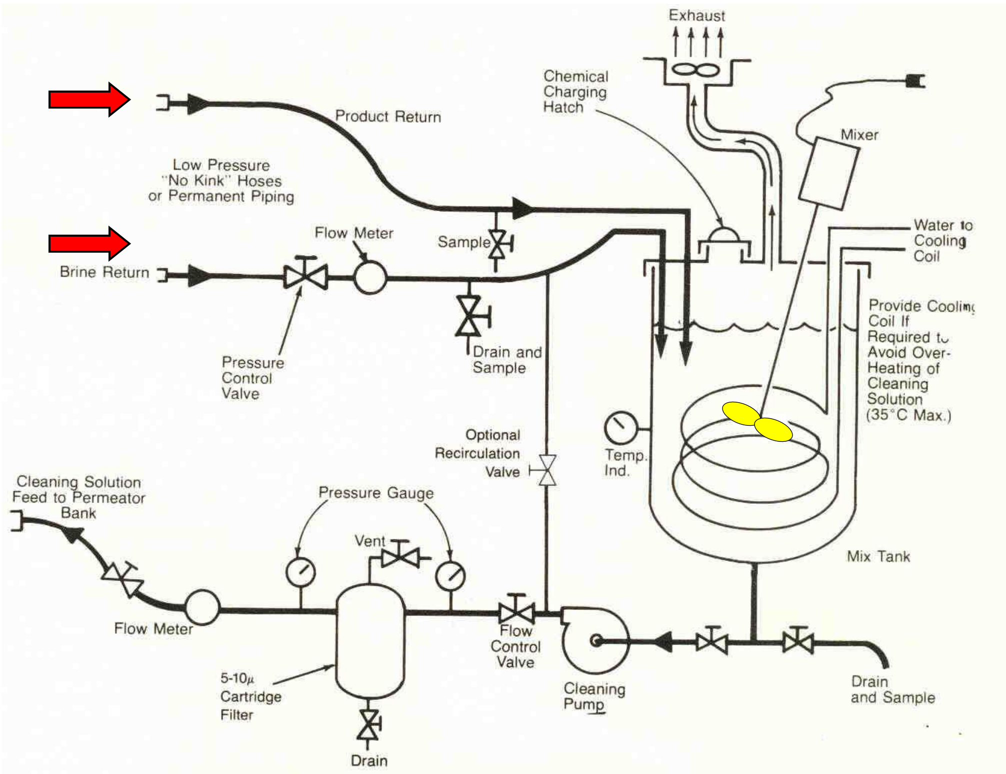
Module 5.1.5 - Design

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.

Module 5.1.5 - Design

5. Cleaning Equipment



Module 5.1.5 - Design

Flushing Flow rates

- Vessel with 6 Membranes 8“ 30-40 GPM
- Vessel with 6 Membranes 4“ 8 - 10 GPM

Module 5.1.8 - Cost Comparisons

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

Module 5.1.8 - Cost Comparisons

3.3 Reasons for R.O. Economic Advantages

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

Module 5.1.8 - Cost Comparison

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.

Module 5.1.8 - Cost Comparisons

3.5 Reasons for R.O. Economic Advantages

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

Module 5.1.8 - Cost Comparisons

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.

Module - Cost Comparisons

3.7 Reasons for R.O. Economic Advantages

R.O. Plants require only half the space needed to the thermal desalting systems.

Module - Cost Comparisons

3.8 Reasons for R.O. Economic Advantages

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

END OF PRESENTATION