ASSOCIATION OF WATER TECHNOLOGIES

Training Seminars

Membrane Training 2024 - Section 3
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Aquassuance

1

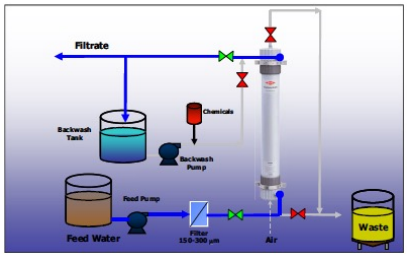
SECTION 3: MEMBRANE ELEMENTS, PHYSICS, UNIT COMPONENTS, AND AN OUTLINE OF SYSTEM CONFIGURATIONS:

2023 Technical Training Seminars:

- Polymeric membrane materials – and hydrophobicity
- Types, structures, and formats of membranes – ceramic, flat sheet, spiral wound, hollow tube
- A to Z of membrane terminology:
  - Membrane Rejection/Water flux and salt passage
  - Recovery rate/Concentration factor
  - Normalized Permeate Flow/Normalized Salt Passage
  - Mass balance/Ion rejections
- Membrane element standard sizes and capacities –
  - focus on MF/UF and NF/RO. Also, EDI
- MT system basic configurations: Arrays/ Stages/T rains
  - Subsystems and components: PV's, pumps, 5µ filters,
  - valves, startup/end flush, ER systems, piping and
  - Instrumentation, shims, separators, etc.
- Overview of MT units + pre/post-treatment, to provide integrated process WT equipment systems
- Unit Operation - what happens from first inch to the last inch in an RO system!

2

REMINDER: FILTRATION USING A MF/UF MODULE



3

EXAMPLE OF UF STANDARD PLANT:

Standard Features
Hollow-Fiber or Ceramic UF Membranes
Many MWCO and Micron Ratings Available
Stainless Steel Pumps, Valves, Pressure Gauges
Corrosion-Resistant Piping
60Hz/230V-460V, 3-phase TEFC motor
Automatic Backwash System (Hollow-Fiber only)
Filtrate and Concentrate Flowmeters
Total Automatic Operation with PLC Control
Self-backwashing Sediment Strainer
Turbidity Meter

Optional Features
Chemical Dosing System
Clean-In-Place System
TDS, pH, Temperature Instruments
Special Color or Private Label
50Hz Motor
Crating

We need chem dose, CIP, and instruments to stay out of trouble!

System Specifications

MODEL	PRODUCTION GPD	PRODUCTION m3/D	RECOVERY (%)	SYSTEM CONFIGURATION: NUMBER AND SIZE ELEMENTS	SYSTEM CONFIGURATION: MOTOR 60Hz (HP)	SYSTEM CONFIGURATION: MOTOR 50Hz (KW)	APPROXIMATE SHIPPING DIMENSIONS (LxWxH) (inches)	APPROXIMATE SHIPPING DIMENSIONS (LxWxH) (cm)	APPROXIMATE SHIPPING DIMENSIONS WEIGHT (lbs/Kg)	APPROXIMATE SKID DIMENSIONS (LxWxH) (inches)	APPROXIMATE SKID DIMENSIONS (LxWxH) (cm)	APPROXIMATE SKID DIMENSIONS WEIGHT (lbs/Kg)
HERC-UF-5-HF	7,200	27	95	4 (4" x 40")	6	4.4	124 x 40 x 72	315 x 102 x 183	1175/534	168 x 32 x 90	274 x 81 x 152	875/398
HERC-UF-10-HF	14,400	55	95	7 (4" x 40")	6	4.4	120 x 50 x 72	315 x 127 x 183	1366/591	168 x 42 x 90	274 x 96 x 152	1060/455
HERC-UF-15-HF	21,600	82	95	2 (8" x 40")	6	4.4	168 x 50 x 72	427 x 127 x 183	1470/670	156 x 42 x 90	396 x 96 x 152	1155/523
HERC-UF-20-HF	28,800	109	95	2 (8" x 60")	10	6	168 x 60 x 72	427 x 152 x 183	1766/773	156 x 52 x 90	396 x 132 x 152	1368/614
HERC-UF-30-HF	43,200	164	95	3 (8" x 40)	10	6	168 x 60 x 72	427 x 152 x 183	1900/864	156 x 52 x 90	396 x 132 x 152	1550/705
HERC-UF-45-HF	64,800	245	95	4 (8" x 60")	10	8	168 x 60 x 72	427 x 152 x 183	2100/955	156 x 52 x 90	396 x 132 x 152	1756/796
HERC-UF-60-HF	86,400	327	95	6 (8" x 60")	10	8	226 x 60 x 84	579 x 152 x 213	2900/1316	216 x 48 x 72	549 x 122 x 183	2500/1134

4

LOOK FIRST AT SELECTING MF/UF MEMBRANES

- For MF/UF membranes, PES has a better wetting ability than PVDF, and also better strength.
- However, PES has less flexibility than PVDF. Also, PVDF is better during backwashing, and accepts air scouring during industrial applications –so tends to be costly than PES or PS.
- Hydrophilic… Cellulose acetate(CA).
  Polyacrylonitrile (PAN)
  Polether sulfone (PES)
  Polysulfone (PS or PSF)
  Polyvinylidiene fluoride (PVDF
  Poluethylene (PE)
  Polypropylene (PP) … Hydrophobic

5

MF/UF MEMBRANE CAPILLARY MODULES

Company	MF/UF	Element Description	Brand	Module
Memtec *Sintered substrate*	MF	10x 1" tubes	SS	6" x 72"
	MF	4x 1" tubes	S1	4" x 72"
Koch *200 ppm Cl2*	MF	19x ½" tubes	Super Cor XLMKF	6" x 139"
	UF	37x ½ " tubes	HFM 513	6" x 139"
Duraflow	MF	13 x 1" tubes	DF 413	6" x 72"
	MF	10 x 1" tubes	DF 415L	6" x 72"
Hydra Nautics	UF	1.2 mm ID Cap	Hydracap 40LD	10" x 48"
	UF	0.8 mm ID Cap	Hydracap 40	10" x 48"
QUA	UF	1.2 mm HF	QSEP3412	9" x 72"
	UF	0.8 mm HF	QSEP 4508	9" x 72"
BASF Inge	UF	1.5 mm HF	Dizzer XL25	10" x 47"
	UF	0.9 mm HF	Dizzer XL 38	10" x 47"
Toray	UF	HF (Industrial)	HFU 1020N	8.5" x 44"
	UF	HF(Drinking)	HFS 1020N	8.5" x 44"
DOW	UF	HF SFD = drinking	SFP 2660	6" x 60"
	UF	HF SFD = drinking	SFP 2860	8" x 60"

6

UF MEMBRANE MODULE SPECS.

Table 2: Module Specifications

Module Properties	SFX-2660		SFX-2860		SFX-2880	
	SI	US	SI	US	SI	US
Length - L	1860 mm	73.2"	1860 mm	73.2"	2360 mm	92.9"
Length - L1	1500 mm	59.1"	1500 mm	59.1"	2000 mm	78.7"
Length - L2	1610 mm	63.4"	1630 mm	64.2"	2130 mm	83.9"
Length - L3	1710 mm	67.3"	1820 mm	71.7"	2320 mm	91.3"
Diameter - D	165 mm	6.5"	225 mm	8.9"	225 mm	8.9"
Width – W1	125 mm	4.9"	180 mm	7.1"	180 mm	7.1"
Width – W2	250 mm	9.8"	342 mm	13.5"	342 mm	13.5"
Surface Area	33 m2	355 ft²	51 m2	549 ft²	77 m2	829 ft²
Volume per Module	16 L	4.2 gal	35 L	9.3 gal	39 L	10.3 gal
Weight (water filled)	41 kg	90 lbs	83 kg	183 lbs	100 kg	220 lbs
Shipping Weight (w/o packaging)	25 kg	55 lbs	48 kg	106 lbs	61 kg	135 lbs
Fibers/ Module	5,760		9,000		10,000	
Housing	UPVC		UPVC		UPVC	

7

EXAMPLE OF TECHNICAL DATE SHEET:
DOW UF MODULE SFP 2860 + SFD 2860

Model	Type	Part #	Membrane area m²	Membrane area ft²	Module volume Liters	Module volume Gallons	Weight (empty/ water filled) Kg	Weight (empty/ water filled) lbs
SFP-2860	Pretreatment	280933	51	549	35	9.3	48/83	106/183
SFD-2860	NSF/ANSI 61 Drinking water	324168	51	549	35	9.3	48/83	106/183

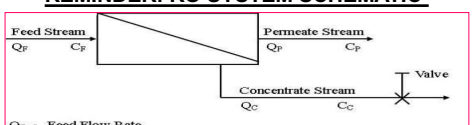
	SI units	US units
Filtrate Flux @ 25°C	40-120 l/m²/ hr	24-70 gfd
Flow range	2.0 – 6.1 m³/hr	9.2 – 26.7 gpm
Temperature	1-40°C	34-104°F
Max. inlet module pressure (@ 20°C)	6.25 bar	93.75 psi
Max. operating TMP	2.1 bar	30 psi
Max operating air scour flow	12 nm³/hr	7.1 scfm
Max backwash pressure	2.5 bar	36 psi
Operating pH	2- 11	
NaOCl (max.)	2,000 mg/L	
TSS (max.)	100 mg/L	
Turbidity (max.)	300 ntu	
Particle size (max.)	300 µ	
Flow configuration	Outside in, dead end flow	
Expected filtrate turbidity	≤0.1 NTU	
Expected filtrate SDI	≤2.5	

- **PVDF polymeric hollow fibers for high strength and chem resistance. 8"OD x 60"L.**
- **0.03 µm nominal pore diameter, for removal of bacteria/ viruses/ particulates inc. colloids to protect downstream processes, e.g. RO.**

Note: 26.7 gpm x 60 x 24 = 38,448 gpd. Divide this by 70 gfd = 549 sq ft membrane surface

8

REMINDER: RO SYSTEM SCHEMATIC



Q_F - Feed Flow Rate
C_F - Solute Concentration in Feed
Q_P - Permeate Flow Rate
C_P - Solute Concentration in Permeate
Q_C - Concentrate Flow Rate
C_C - Solute Concentration in Concentrate

$$\text{Recovery} = \frac{Q_P}{Q_F}$$

(Expressed as Percent)

TDS = Total Dissolved Solids: Usually considered the total of the ionic contaminants (salts) in solution.

mg/L (milligrams per liter) is the same as ppm (parts per million)

9

EXAMPLE OF STANDARD INDUSTRIAL RO UNIT

SYSTEM CONFIGURATION

MODEL	PRODUCTION GPD	PRODUCTION m3/D	RECOVERY (%)	NUMBER AND SIZE ELEMENTS	MOTOR 60Hz (HP)	MOTOR 50Hz (KW)	APPROXIMATE SHIPPING (L x W x H) (inches)	APPROXIMATE SHIPPING (L x W x H) (cm)
HERC-RO-5	5,200	20	65	6 (4")	3	4	124 x 40 x 72	315 x 102 x 183
HERC-RO-10	10,400	50	65	12 (4")	5	4	120 x 50 x 72	315 x 127 x 183
HERC-RO-15	21,000	80	65	18 (4")	5	4	168 x 60 x 72	427 x 127 x 183
HERC-RO-20	28,800	110	70	24 (4")	10	5	168 x 60 x 72	427 x 152 x 183
HERC-RO-25	35,000	130	75	30 (4")	10	7.5	168 x 60 x 72	427 x 152 x 183
HERC-RO-30	42,200	170	75	36 (4")	15	11	168 x 60 x 72	427 x 152 x 183
HERC-RO-45	64,800	250	63	12 (8")	15	11	228 x 60 x 64	579 x 152 x 213
HERC-RO-60	86,400	330	75	16 (8")	20	15	228 x 60 x 64	579 x 152 x 213
HERC-RO-75	108,000	415	75	20 (8")	25	15	228 x 74 x 64	579 x 188 x 213
HERC-RO-90	129,600	490	75	24 (8")	20	15	228 x 74 x 64	579 x 188 x 213
HERC-RO-110	158,400	600	75	30 (8")	25	15	306 x 74 x 64	777 x 188 x 213

Standard Features

Fiberglass-Wrapped TFC Membranes
Stainless Steel Pump, Valves, Pressure Gauges Corrosion-Resistant Piping
60Hz/230V-460V, 3-phase TEFC motor
Automatic High and Low Feed Pressure Shut-off Permeate and Concentrate Flowmeters
Automatic Feed Water Shut-off Valve
Stainless Steel 5-micron Sediment Prefilter
Fiberglass Pressure Vessels

Optional Features

Prefilter Pressure Gauges
Chemical Dosing System
Clean-in-Place System
TDS, pH, Temperature, Turbidity Instruments
PLC Control
Special Color or Private Label
50Hz Motor
Concentrate Recycling
Automatic Feed Water or Permeate Flush
Crating

We need all the mech. engineered extras, if you want to stay out of trouble

Design Assumptions

- Feed water of 500 mg/L TDS at 25 C, SDI < 3, Turbidity < 1
- Negligible permeate backpressure
- 3rd year of operation allowing for Flux Decline and Salt Passage Increase
- Flux, Minumum Brine Flow, and Recovery in accordance with membrane manufacturers recommendations

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10

NEXT, LOOK AT NF/RO MEMBRANE SELECTION

Its important to ask do we need Hydrophobic or Hydrophilic membranes?

- **Hydrophilic means "water loving." Hydrophilic membranes attract water, and push away other molecules in order to allow water access to the membrane. This keeps contaminants away from the membrane allowing it stay clean and functioning for a longer period of time.**
- **Hydrophobic means "afraid of water." These membranes will block the passage of water and are commonly used for applications involving separation of water from other materials.**
- **RO membranes are usually based on a thin film composite (TFC) comprising a *polyamide* coating on a hydrophobic substrate (to reduce fouling risks and increase permeation rates), such as polysulfone (PS). The PS itself may be bonded with a PEG gel, or substituted with, say, (very strongly hydrophobic) polyvinylidene fluoride (PVDF).**
- **Some manufacturers claim to be able to produce very hydrophilic polyamide coatings, as a market differentiator.**

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11

NANOFILTRATION MEMBRANE ELEMENTS

FILMTEC™ Membranes
Nanofiltration Elements Available for Pilot Testing

DOW

For pilot testing, the following nanofiltration elements are available.

Product	Application
NF200	Medium to high salt passage, medium calcium passage (50-65%), high chlorine rejection (99%) and high TOC rejection
NF270	High salt passage, medium calcium passage (40-60%) and high TOC removal
NF90	High salt removal (90%), high rich removal, particular, herbicide removal and TOC removal

Product Specifications

Product	Nominal Active Surface Area m² (ft²)	GMD	Product Water (gpd)	Flow Rate (LMH)	Solute Passage (%)	Atrazine Passage (%)
NF200-2540	28 (2.6)	89092				
CaCl2			550	66.7	50-65	<7
MgSO4			660	72.5	<3	
NF200-4040	82 (7.6)	89196				
NaCl			1,600	252.3	50-65	<7
MgSO4			1,950	213.8	<3	
NF270-2540	28 (2.6)	149996				
CaCl2			1,000	187.7	40-60	
MgSO4			850	134	<3	
NF270-4040	82 (7.6)	149982				
CaCl2			2,925	461.3	40-60	
MgSO4			2,500	394.3	<3	
NF90-2540	28 (2.6)	149982				
NaCl			525	82.8	5-15	
MgSO4			625	64.8	<3	
NF90-4040	82 (7.6)	149983				
NaCl			1,400	220.8	5-15	
MgSO4			1,850	291.7	<3	

1. Permeate flow and salt rejection based on the following test conditions:
   2,000 ppm NaCl, 15 psi (1.0 MPa), 77°F (25°C), and recovery as indicated below
   2,000 ppm MgSO4, 70 psi (0.5 MPa), 77°F (25°C), and recovery as indicated below
2. Flow rates for individual elements may vary +/- 20%.

Note the variable flow rate, depending on what is are primary contaminants to be removed!

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12

DOW FILMTEC CITY/SURFACE WATER RO MEMBRANES

FILMTEC™ Membranes

2. Tapwater Elements

- **FILMTEC Home Drinking Water Elements**
- **FILMTEC High Flow 100 Gallons Per Day Drinking Water Element**
- **FILMTEC Small Commercial Elements**
- **FILMTEC Tape-Wrapped 2540 Elements for Commercial Applications**
- **FILMTEC Tape-Wrapped 4040 Elements for Commercial Applications**
- **FILMTEC Extra Low Energy (XLE) Elements for Commercial Systems**



13

Product Information

DOW FILMTEC™ Membranes

RO Elements for commercial systems: XLE = extra low energy,
LP = low pressure, TW = tap water

Product Specifications

Product	Part number	Active Area ft² (m²)	Feed Spacer Thickness (mil)	Permeate Flow Rate gpd (m³/d)	Stabilized Salt Rejection (%)
XLE-4040	154546	87 (8.1)	28	2,600 (9.8)	99.0
LP-4040	212819	78 (7.2)	34	2,900 (11.0)	99.2
TW30-4040	80610	78 (7.2)	34	2,400 (9.1)	99.5

1. Permeate flow and salt rejection based on the following test conditions: 77°F (25°C), 15% recovery and applied pressure: 100 psig (6.9 bar) for XLE-4040, 145 psig (10 bar) for LP-4040 and 225 psig (15.5 bar) for TW30-4040. FILMTEC TW30-4040 specifications are based on a 2,000 ppm NaCl feed stream. FILMTEC LP-4040 and FILMTEC XLE-4040 specifications are based on a 500 ppm NaCl feed stream.
2. Permeate flows for individual elements may vary +/-20%.
3. For the purpose of improvement, specifications may be updated periodically.

Membrane Type	Polyamide Thin-Film Composite
Maximum Operating Temperature	113°F (45°C)
Maximum Operating Pressure	600 psig (41 bar)
Maximum Feed Flow Rate	14 gpm (3.2 m³/hr)
Maximum Pressure Drop	13 psig (0.9 bar)
pH Range, Continuous Operation*	2 - 11
pH Range, Short-Term Cleaning (30 min.)*	1 - 13
Maximum Feed Silt Density Index (SDI)	SDI 5
Free Chlorine Tolerance*	<0.1 ppm

* Maximum temperature for continuous operation above pH 10 is 95°F (35°C).
Refer to Cleaning Guidelines in specification sheet 609-23010.
Under certain conditions, the presence of free chlorine and other oxidizing agents will cause premature membrane failure. Since oxidation damage is not covered under warranty, FilmTec recommends removing residual free chlorine by pretreatment prior to membrane exposure. Please refer to technical bulletin 609-22010 for more information.

4"x 40" RO

14

NITTO DENKO HYDRANAUTICS
A Nitto Denko Company

4"x 40" RO

	Membrane Element	CPA2-4040
Performance:	Permeate Flow:	2,250 gpd (8.5 m³/d)
	Salt Rejection :	99.5 % (99.2% minimum)
Type	Configuration:	Spiral Wound
	Membrane Polymer:	Composite Polyamide
	Membrane Active Area:	85 ft² (7.9 m²)
Application Data*	Maximum Applied Pressure:	600 psig (4.16 MPa)
	Maximum Chlorine Concentration:	< 0.1 PPM
	Maximum Operating Temperature:	113 °F (45 °C)
	pH Range, Continuous (Cleaning):	2-10 (1-12)*
	Maximum Feedwater Turbidity:	1.0 NTU
	Maximum Feedwater SDI (15 mins):	5.0
	Maximum Feed Flow:	16 GPM (3.6 m³/h)
	Minimum Ratio of Concentrate to Permeate Flow for any Element:	5:1
	Maximum Pressure Drop for Each Element:	10 psi

* The limitations shown here are for general use. For specific projects, operating at more conservative values may ensure the best performance and longest life of the membrane. See Hydranautics Technical Bulletins for more detail on operation limits, cleaning pH, and cleaning temperatures.

15

NITTO DENKO HYDRANAUTICS
A Nitto Denko Company

8"x 40" RO

	Membrane Element	CPA2
Performance:	Permeate Flow: Salt Rejection:	10,000 gpd (37.9 m^3/d) 99.7 % (99.5 % minimum)
Type	Configuration: Membrane Polymer: Membrane Active Area:	Spiral Wound Composite Polyamide 365 ft^2 (36.9m^2)
Application Data*	Maximum Applied Pressure: Maximum Chlorine Concentration: Maximum Operating Temperature: pH Range, Continuous (Cleaning): Maximum Feedwater Turbidity: Maximum Feedwater SDI (15 mins): Maximum Feed Flow: Minimum Ratio of Concentrate to Permeate Flow for any Element: Maximum Pressure Drop for Each Element:	600 psig (4.16 MPa) < 0.1 PPM 113 °F (45 °C) 2-10 (1-12)* 1.0 NTU 5.0 75 GPM (17.0 m^3/h) 5:1 10 psi

* The limitations shown here are for general use. For specific projects, operating at more conservative values may ensure the best performance and longest life of the membrane. See Hydranautics Technical Bulletins for more detail on operation limits, cleaning pH, and cleaning temperatures.

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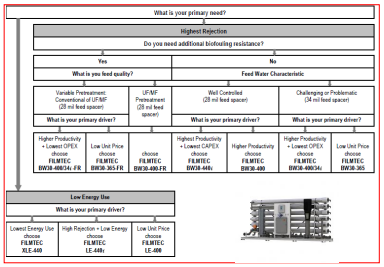
16

DOW FILMTEC BRACKISH WATER MEMBRANE ELEMENT GUIDE: *what do we need?*



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17

DOW FILMTEC SEAWATER MEMBRANE ELEMENT GUIDE: *what do we need?*

	Performance Attributes						Construction Features				Reliability Features				
	Feed Pressure (psi)	Flow Rate (gpd)	Stabilized Salt Rejection (%)	Stabilized Boron Rejection (%)	Minimum Pressure (psi)	Highest Capability	35°C Standard Feed Spacer	24 mil Feed Spacer	28 mil Feed Spacer	Active Area (ft²)	1200 psi Feed Pressure	Resistant TOC Fouling	pH 11.5 Cleaning Range	Aggressive Cleanability	Demonstrated Active Area
SW30XLE-400i NEW	800	9,000	99.70	88	1,200		■		■	400	■	■	■	■	■
SW30HR LE-400i NEW	800	7,500	99.75	91	1,200		■		■	400	■	■	■	■	■
SW30HR LE-400	800	7,500	99.75	91	1,200				■	400	■	■	■	■	■
SW30HR-380	800	6,000	99.70	90	1,000				■	380		■	■	■	■
SW30HR-320	800	6,000	99.75	91	1,200	■		■		320	■	■	■	■	■

The above values are normalized to the following conditions: 32,000 ppm NaCl, 5 ppm boron, 800 psi (5.5 MPa), 77°F (25°C), pH 8 and 8% recovery.

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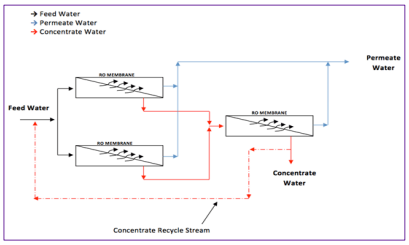
18

KEY REVERSE OSMOSIS COMPONENTS

- A frame, piping, valves, and pre-filters (*to remove SS that foul membranes and protect the HP pump*) 25 % of cost!
- High pressure pump 25 % of cost!
- RO Membrane elements and pressure vessels 25% of cost !
- CIP tank, permeate storage tank ,and control panel 25% of cost!

19

REVIEW OF SOME BASICS OF RO SYSTEM DESIGN



20

1. CONSIDER THIN FILM COMPOSITE MEMBRANES

1) Less expensive than cellulose acetate membranes (which tend to have good tolerance to oxidizers, but limited pH range and lower pressure ratings)
2) Typical salt rejection for TFC is 97 to 98%
3) Typical TFC operating pressures are 200 - 300 PSI, but up to 600 psi
4) Wide pH operating range of 2 – 11
5) Very Low Chlorine Tolerance
6) Less susceptible to compaction
7) TFC have three modes of rejection: ionic charge, MW, and physical size

21

2. IMPORTANT EQUATIONS

- TDS = TOTAL DISSOLVED SOLIDS
- AVE TDS = $\frac{\text{FEED TDS + CONC TDS}}{2}$
- % SALT PASSAGE = $\frac{\text{PERM TDS}}{\text{AVG TDS}}$
- % SALT REJECTION = 100 – SALT PASSAGE
- TDS MEASURED IN MICROSIEMENS
- RULE OF THUMB: 10 PPM = 20 µS

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22

3. THERE IS AN EFFECT ON CONCENTRATION AND FOULING RISKS WITH HIGH RECOVERY RATES

$$C_C = \frac{C_F}{1 - \text{Recovery}} = XC_F$$

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

Percent Recovery	Concentration Factor
33%	1.5
50%	2
67%	3
75%	4
80%	5
90%	10
95%	20
97.5%	40
98%	50
99%	100

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23

4. MORE DESIGN CONSIDERATIONS

- Consider: Flux Rate, Cross Flow Rate?
- Consider: Pressure Differential across unit?

Pressure Drop Examples

- 60 gpm-12 psi
- 50 gpm – 8.3 psi
- 40 gpm – 5.8 psi

For 8" diameter & 40" long membranes

Design Flux Rates

- Typical 14-17 gallons/sq ft/day
- 12-14 gallons/SqFt/day is a conservative design rate

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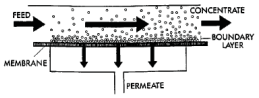
24

5. MORE TO CONSIDER WHEN DESIGNING AN RO/ NF MEMBRANE SYSTEM

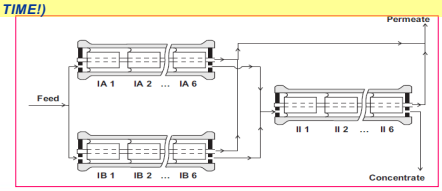


- RO / NF system performance is typically characterized by two parameters: permeate flow and salt rejection.
- These should always be referenced to a given feed water analysis, feed pressure, temp, and recovery rate.
- The goal of the designer of an RO / NF system for a certain required permeate flow is to minimize feed pressure and membrane costs while optimizing permeate quality and recovery.

25

6. REMEMBER: PERMEATE FLOW RATES AND FLUX RATES DECREASE THRU A PV

As feedwater flows through each PV there is a decrease in feed pressure to each element, plus a decrease in each element's permeate flow and flux rate (AND OVER TIME!)



26

7: CONSIDER FOULING FACTORS, FLUX, AND SDI

- The factor having the greatest influence on design is the fouling tendency of the feed water as measured by SDI and lab. analysis.
- Membrane fouling is primarily caused by particles and colloidal material present in the feed water and concentrated at the membrane surface. The conc. of the fouling materials at the membrane surface increases with increasing permeate flux (i.e. permeate flow rate per unit membrane area)
- The concentration of fouling materials at the membrane surface also increases with increasing RO element recovery (i.e. the ratio of permeate flow rate to feed flow rate for a single element).
- A system with high permeate flux rates is, therefore, likely to experience higher fouling rates and more frequent chemical cleaning.
- A membrane system should be designed such that each element of the system operates within a frame of recommended operating conditions, to minimize the fouling rate and to exclude mechanical damage.

27

8. RO STAGES (BANKS) – DESIGN RULES OF THUMB

- Recovery (Permeate) rates help dictate design.
- Recovery (Permeate) rates above 65%, usually a 3 stage RO would be recommended.
- Below 65% a two stage is recommended as it will give better pressure drops and meet minimum flows.
- Single Pass is a 50% Permeate and 50% Reject
- Dual Pass where second pass treats the reject is a 75% flow unit.
- Dual Pass where second pass treats the permeate is a 25% flow unit.

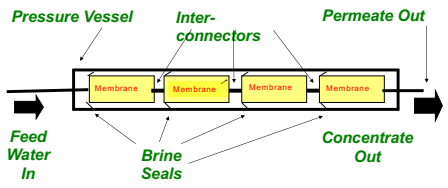
28

9. STEPS TO DESIGNING AN RO/ NF MEMBRANE SYSTEM

1. Consider Feed Source, Feed Concentration, Feed / Product Flow, SDI, and desired Product Quality
2. Select the desirable Flux rate and Flow rate
3. Configuration and Number of Passes
4. Select Membrane and Element Type
5. Select Average Membrane Flux (Design Flux)
6. Calculate the Number of Elements Needed
7. Calculate the Number of Pressure Vessels Needed
8. Select the Number of Stages
9. Balance the Permeate Flow Rate

29

AWT TRAINING Seminars PUTTING RO ELEMENTS INTO A PV



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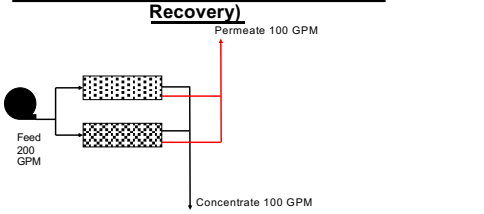
Single Stage RO Unit: Designed for 50% Recovery)



31

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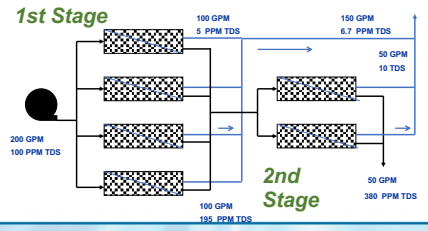
TWO STAGE RO UNIT (75% RECOVERY) (DESIGN FOR HIGH VOLUME/QUANTITY)

1. 75% Two Stage RO's are common in process.
2. Used to improve the recovery rates and reduce the amount of water wasted in a process.
3. In this setup, the concentrate (Reject) from the first stage is feed to the second stage.
4. 50% recovery from each stage yields 75% permeate and 25% reject with 4 cycles of solids concentration.
5. There is a decrease in the permeate quality.

32

Two-Stage RO Unit: Designed for 75% Recovery with an 4 -2 Array, for Higher Volume



33

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TWO PASS RO UNIT (25% RECOVERY) (DESIGN FOR HIGH QUALITY PERMEATE)

1. 25% Two pass RO's are used for high quality water.
2. Quality of permeate is improved, but reject quantity is increased
3. In this setup, the permeate from the first pass is feed to the second pass.
4. 50% recovery from each pass yields 50% of the make up in the first pass and then 50% of the first pass permeate in the second pass
5. 2% salts in first stage permeate the 2% of that in the second stage permeate.
6. Use reject water to backwash pretreatment filters.

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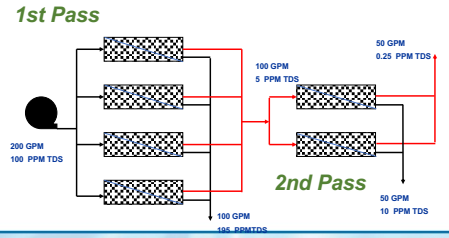
34

Two-Pass RO Unit Designed for a 25% Recovery of Very High Quality Permeate



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35

TWO STAGE RO UNIT (75% RECOVERY ON A 24 - 12 ARRAY)

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36

EXAMPLE OF 8" X 40' RO ELEMENT

For years, the DOW™ FILMTEC™ BW30-365 has been the element of choice for system designers, OEMs, and system operators requiring consistently high performance and maximum element life when treating difficult feed waters.

This element offers proven performance, high rejection, and exceptional robustness and durability across a wide range of feed conditions where unit price is a key driver.

Nominal Active Surface Area ft² (m²)	Permeate Flow Rate gpd (m³/d)	Stabilized Salt Rejection (%)	Minimum Salt Rejection (%)
365 (34)	9,500 (36)	99.5	99.0

37

DESIGN GUIDELINES FOR 8" FILMTEC ELEMENTS

Feed source		RO Permeate	Well Water	Surface Supply		Wastewater (Filtered Municipal Effluent)	
						MF[1]	Conventional
Feed silt density index		SDI < 1	SDI < 3	SDI < 3	SDI < 5	SDI < 3	SDI < 5
Average system flux	gfd	21-25	16-20	13-17	12-16	10-14	8-12
	l/m²h	36-43	27-34	22-29	20-27	17-24	14-20
Maximum element recovery %		30	19	17	15	14	12

Active Membrane Area	Maximum permeate flow rate, gpd (m³/d)					
320 ft² elements	9,000 (34)	7,500 (28)	6,500 (25)	5,900 (22)	5,300 (20)	4,700 (18)
365 ft² elements	10,000 (38)	8,300 (31)	7,200 (27)	6,500 (25)	5,900 (22)	5,200 (20)
380 ft² elements	10,600 (40)	8,600 (33)	7,500 (28)	6,800 (26)	5,900 (22)	5,200 (20)
390 ft² elements	10,600 (40)	8,900 (34)	7,700 (29)	7,000 (26)	6,300 (24)	5,500 (21)
400 ft² elements	11,000 (42)	9,100 (34)	7,900 (30)	7,200 (27)	6,400 (24)	5,700 (22)

38

HYDRANAUTICS
High Performance Membrane Products
A Nitto Denko Corporation

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Hydranautics Design Limits

The Following System Design Limits should be observed when designing a Reverse Osmosis system.

Average flux rates and expected % decrease in flux per year:

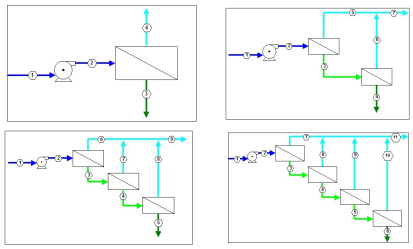
Water Type	SDI	Flux	% Flux Decline/year
Surface water	(SDI 2 - 4)	8 - 14 GFD	7.3 - 9.9
Well water	(SDI < 2)	14 - 18 GFD	4.4 - 7.3
RO Permeate	(SDI < 1)	20 - 30 GFD	2.3 - 4.4

Expected % Salt Passage Increase per year:

MembraneType	Abbreviation	% SP Increase/year
Cellulosic membrane	CAB1, CAB2, CAB3	17 - 33
Composite Membrane Brackish, Low Pressure	ESPA1, ESPA2, ESPA3	3 -- 17

39

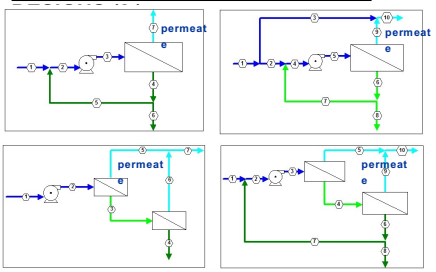
REMINDER OF RO STAGED ARRAY DESIGNS (1.)



1- ,2- ,3- and 4-pass designs

40

REMINDER OF RO STAGED ARRAY



RO software provide Recycled Reject and Permeate configurations

41

WHAT IS FORWARD OSMOSIS?
– IT'S THE SAME AS NATURAL OSMOSIS!

- FO and RO differ in that RO requires a pump and energy consumption to produce separations, or in the case of water; purification.
- FO uses natural energy of osmotic gradients to drive exchange process.
- FO has a disadvantage in water purification of a much lower flow rate than RO.
- FO is also not effective at producing ultra pure water, but is more applicable in purifying brines and non-water solutions.
- RO works on a principle of literally forcing water through the membrane and leaving the contaminants, in total, behind.
- FO works on a principle of a net exchange of ions back and forth across the membrane, but it needs a DRAW solution to work.

FO developers include Modern Water, Oasys, HTI, Trevi, Desalgae

42

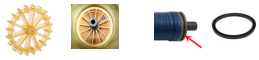
WHAT IS FORWARD OSMOSIS?
– *IT'S THE SAME AS NATURAL OSMOSIS!*

- Maintenance on large RO pumps is a big problem.
- Water pre-treatment critical for RO systems to avoid membrane fouling.
- Energy consumption in SWRO is a big cost. *ENERGY RECOVERY SYSTEMS!*

The driving force for FO separation is an osmotic pressure gradient. A concentrated "draw" solution (relative to feed soln. induces a net flow of FW through the membrane into the draw solution, thus effectively separating the feed water from its solutes. (RO s uses hydraulic pressure as the driving force for separation, by counteracting the osmotic pressure gradient that would otherwise favor water flux from the permeate to the feed.)
Typically, waste heat is used to remove the "pure" diluent water from the draw solution. Draw Soln. then reused. Big problem is finding the optimum draw solution! The future of FO probably lies with the dewatering of very high salinity brines and various niche applications.

43

MEMBRANE TERMS A-Z: *Do we need a test? 1*



Anti-Telescoping Device (ATD):
- A plastic device located on the ends of a RO element, and helps to provide structural support to the RO membrane envelopes preventing unraveling and extension.

Array :
- Describes the physical arrangement of the pressure vessel (PV), e.g., 4:3:1 - 3 stages with 8 total vessels; stage 1 has 4 PVs, stage 2 has 3 PVs and stage 3 has 1 PV. The reject of each stage is the feed stream for the next successive stage.

Asymmetric:
- A membrane constructed of the same material (CA or polyamide) having an increase in porosity from surface to base. The surface has a dense thin barrier skin and a thick porous support layer.

Brine Seal:
- Brine seals are plastic/rubber devices that seal the outside of one end of a RO membrane element against the wall of the component housing. Brine seals are designed to prevent by-passing of feed water around the element.

44

MEMBRANE TERMS A-Z: *Do we need a test? 2*

Cellulose Acetate Membranes:
- Originally made of cellulose diacetate, cellulose triacetate or blend.
- CA membranes need a residual of chlorine to protect them from biological attack.
- Tight pH operating requirements.
- Uncharged/non-polar functional groups (polyamide/polysulfone are), so do not attract foulants to the surfaces easily.

Concentration Factor:
- The degree that RO feed water TDS are concentrated in the brine. CF = 1/(1-Y) where Y = % recovery expressed as a decimal.

Concentration Polarization:
- Refers to the concentration gradient of salts on the high pressure side of the RO membrane surface created by the less than immediate re-dilution of salts left behind as water permeates through the membrane itself.
- The high salt concentration in this boundary layer impacts the RO performance by increasing the osmotic pressure at the membrane's surface leading to reduced flux, increased salt leakage, and increased probability of

45

MEMBRANE TERMS A-Z: *Do we need a test? 3*

Vexar

Conversion or Recovery:
- Conversion/recovery refers to the % of RO feed which is converted into permeate

Cross Flow Separation:
- Refers to a filtration process with the feed stream running parallel to the filter media and a concentrate stream continuously removing contaminants from the surface media (and a permeate stream = total of 3 streams.)

Elements/modules:
- Physical devices housing RO membrane. Spiral wound NF/RO systems can have up to 6-7 elements per PV. MF/UF Hollow fiber systems have only one element per PV.

Feed Channel Spacer:
- Found in spiral wound elements. A plastic netting material placed between the flat sheets of a RO membrane to promote turbulence in the feed /concentrate stream. This material is referred to as "Vexar."

46

MEMBRANE TERMS A-Z: *Do we need a test? 4*

Flux:
- Expressed as volume per area, per unit of time. Expresses rate at which water permeates RO membrane. (gall/ft²/day (GFD) or liters/m²/hour (l/m²/hr).
- We may design a system based on a flux rate of 12-15gfd with clean water
- The flux of a RO membrane is directly proportional to temperature and pressure. **As a rule of thumb, flux decreases by about 1.5% per 1°F drop. Cold winters?**

Salt flux:
- Amount of TDS that has passed through a given area of membrane/unit of time
- Remember, Salt flux is a function of concentration gradient, not driving pressure. So, with increasing driving pressure, the conc. of salts in permeate decreases due to constant salt leakage (e.g., milligrams) and increases flux (e.g. liters).
- Net effect of increased drive pressure is to dilute a constant amount of salt with more pure water.

***Note**: 1 GFD = 1.66 l/m2/hr*

47

MEMBRANE TERMS A-Z: *Do we need a test? 5*

Hydrolysis:
- Refers to the chemical breakdown of a RO membrane from exposure to low or high pH, bio-activity and temperature. Normally associated with CA membranes where the acetyl groups are replaced by hydroxyl groups.
- Hydrolysis increases with increased salt leakage (i.e. greater conductivity of permeate) and a lower feed pressure requirement. Oxidants and temperature can also cause hydrolysis in (TFC).

Membrane Compaction:
- Refers to the physical compression of the RO membrane itself, which results in a decrease in flux. Compaction rate is directly proportional to an increase in temp. and pressure.
- Compaction occurs naturally over time, requiring a greater feed pressure.
- Feed pumps are sized to the pressure requirements of the third year.
- Compaction is permanent and can occur quickly in CA membranes if operated at high pressures for any extended period of time.
- Polyamide membranes have greater structural strength and can be operated at higher than normal pressures with little concern to compaction.
- Change as a result of compaction is expected for Cellulose Acetate (CA) and TFC membranes during the first 200 hours of operation.

48

MEMBRANE TERMS A-Z: *Do we need a test? 6*

Nanofiltration:
- Similar to RO but less effective at removing TDS. NF are membrane softeners (Ca, Mg) but cannot reject the single-positive charged soft ions (e.g. Na, K.)

Net Driving Pressure (NDP):
- Refers to the difference between the feed pressure and the osmotic pressure. The net driving pressure is the measure of the actual driving pressure available to force the water through the membrane.
- As net driving pressure increases, the flux increases proportionally (given all other factors are held constant).

Normalized Permeate Flow:
- Refers comparison of a measured permeate flow rate to a standard (or start up) condition. Permeate flow is a function of the NDP, temp. and membrane condition.
- A decrease in the NPF of 10-15% indicates RO membrane cleaning is required.

O-Rings:
- Used to seal RO permeate water tube inter-connectors of adjacent elements to prevent intrusion of (poor quality) high pressure feed into the low pressure (good quality) permeate water. A damaged O-Ring will result in higher salt concentration of the permeate in that section of the system.

49

MEMBRANE TERMS A-Z: *Do we need a test? 7*

Osmotic Pressure:
- Pressure required to prevent the flow of water across a semi-permeable membrane separating two solutions having different ionic strengths. For RO, it is the osmotic pressure that has to be overcome in order to produce permeate.
- A useful "rule of thumb" is for every 100 mg/L of TDS difference between feed and permeate, 1 psi of osmotic pressure exists.

Permeate/product:
- The portion of the reverse osmosis feed water stream water which passes thru the RO membrane

Pressure vessel:
- Housing for membrane elements or modules. Available in SS, HDPE, or GRP.

Polyamide Membranes:
- From early 1970's. Asymmetric polymer is used TFC spiral wound membranes.
- used because lower pressure needed & more flexible operating conditions.
- Intolerant of oxidizers and anionic surface charge increases fouling risk.

50

MEMBRANE TERMS A-Z: *Do we need a test? 8*

Product Channel Spacer:
- Made from Tricot knit fabric, and is placed between two layers of the flat sheet membrane and used to prevent RO membrane from closing-off on itself under the high pressure of operation. Permeate water flow in a spiral path across the product channel spacer into the product collection tube.

Silt Density Index:
- SDI test used to characterize fouling potential of a RO feedwater. (see elsewhere).

Salt Passage:
- Describes the % quantity of salt which passes through the RO membrane into to the permeate stream. a function of temp, velocity and concentration gradient.
- Salt passage = (TDS-product)/(TDS-Feed) x 100 Salt Passage = (1 - Salt Rejection)

51

MEMBRANE TERMS A-Z: *Do we need a test? 9*

Spiral Wound Element:
A membrane configuration comprised of "*flat sheet membrane - permeate channel spacer - flat sheet membrane - feed channel spacer*" combinations, rolled up around a product collection tube.

Staging (Reject or Product staging):
- The reject from one group of RO PVs becomes the feed stream of a second group of RO PVs. Used to increase recovery of water. 1xstage typically recovers 50 - 60% of the feed. 2x stage, say 75 - 80%. 3x stage is >85%.
- Product Staging/"multiple pass". the product from first group of RO PV becomes the feed water stream for a second stage, and increases the quality of the permeate.

Telescoping:
•Longitudinal unraveling of spiral wound elements. Caused by hydraulic surges or temp. extremes, so anti-telescoping devices (ATD's) used on elements.

Thin Film Composite (TFC):
- RO membrane manufactured as three layers bonded together. The two base layers provide strength/support. The asymmetric design have a thin skin (3rd) layer of either polyamide or charged polysulfone deposited/coated/cast on the surface.

52

SO WHAT WATER DO YOU NEED TO TREAT? *CONTAMINANTS? PROBLEMS? QUALITY NEEDED?*

Can you get away with simple filtration, a water softener, or use RO, EDI, or an IX demineralizer, as a pure water source, to blend with clean water? It starts with trusted water analyses and other reliable data!



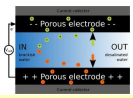

For example, in Texas, brackish groundwater is primarily treated with RO, as it is easy to deliver water below, say, 500 ppm TDS, by blending with low TDS permeate, but what is the energy cost? Could we use NF, as it has a lower salt rejection and higher water permeability? We might need 10-12% more membranes to deliver an equivalent final blended water quality, but can save, perhaps, 40% energy. The starting point is to determine the sodium content of the raw water, so back to needing a decent analysis!

53

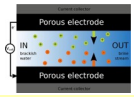
ITS NOT JUST RO! BEFORE MEMBRANES THERE WAS CAPACITIVE DEIONIZATION

Capacitive deionization (CDI) is an efficient *adsorption/ desorption, batch cycle* technology because it removes salts from water – not water from salt! It deionizes water (mainly brackish) by applying an electrical potential difference over two porous carbon aerogel electrodes.

Anions, ions (negative charge), are removed and stored in the Anode (positively polarized) electrode. Likewise, cations (positive charge) are stored in the cathode (negatively polarized electrode).



Adsorption of ions from the brackish water to desalinate it

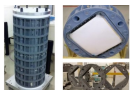


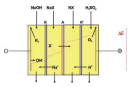
Desorption of ions from the brackish water to regenerate the electrodes

Evapco CapDI

54

REMEMBER ELECTRODIALYSIS (ED)& ELECTRODEIONIZATION (EDI)!






ELECTRO DIALYSIS (ED): A process where ions are transported/removed through semi permeable cation/anion selective membranes, under influence of an electric potential.

- Cation membranes are polyelectrolytes (sulphonated polystyrene), which rejects neg. charged ions and allows positively charged ions to flow through. *Also EDR &EDI!*
- Anion-selective membranes consist of polystyrene with quaternary ammonia.

multiple membranes are arranged in rows, which alternately allow positively or negatively charged ions to flow through, the ions can be removed from wastewater.

EDI: Is a well established process for producing DI water. It uses ion exchange resins plus IX membranes, and an applied electric current, but without chemicals for regeneration. EDI can be used after NF or RO. It can replace MB DI, or used before MB to produce ultra high purity water. At the very least, EDI has to have a soft water feed!

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55

CAPACITIVE DEIONIZATION HASN'T GONE AWAY. NOW *MEMBRANE* CAPTIVE DEIONIZATION (CapDI)

CapDI is a development of CDI to include ion selective membrane separation of ions. (e.g. Voltea). i.e. Electro-desalination/sorption using a temporary ion-storage, double-layer super-capacitor, for collection/discharge.

PROCESS: water flows between electrodes, separated from the water by membranes that allow positive/negative ions to pass (but not water moles.) FW passes between oppositely charged electrodes, which electrostatically removes dissolved ions, leaving pure water flowing out of the cell.

FW flushes the cell at a lower flow rate, while electrode polarity is reversed.

- CDI is batch process: electricity + adsorption on electrodes
- CapDI is batch process: electricity + water passing thru a cat/anion membrane
- ED is electrodialysis + membranes
- EDR is ED + periodic electrode reversal to maintain quality
- EDI/CEDI is electricity + membrane + IX resin – high purity!

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56

ELECTROPHORESIS – WITHOUT/WITH MEMBRANES, WITHOUT/WITH IX RESINS

Electrophoresis is an *electro-kinetic* process which separates charged particles in a fluid using an electrical charge. In practical physics and chemistry, **electrophoresis** refers to the separation of ***charged*** particles carried through or across a span of gel, under the influence of an electric field.

Various types of electro-chemical (EC) separation equipment are available in the global WT market; some types have their origins dating back to before the advent of electric lighting, and were commercialized more than 60-70 years ago. Example is:

- ***Electro-desalting (EDS),*** using DC voltage *(but no membranes)* for desalting crude oil.
- ***Chloralkali process*** is similar, but incorporates a membrane.

Other types of non-membrane/non-IX, include:

- ***electro-disinfection*** **(EDF),**
- ***capacitive deionization*** **(CDI),**
- ***electro-hydrodynamics*** **(EHD),**
- ***electro-coagulation*** **(EC),**
- ***electro-particle precipitation*** **(EPP),**
- ***electro-filtration*** **(EF),**
- **electro-flotation (EFL),**
- ***magnetic ferric filtration.***

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57

ELECTROPHORESIS – WITHOUT/WITH MEMBRANES, WITHOUT/WITH IX RESINS

Collectively, **membrane-based electro-chemical technologies** are classed as **electro-membrane processes (EM**).

Some specific EM design types include the following:

- ***electro-dialysis*** **(ED),**
- ***electro-dialysis reversal*** **(EDR),**
- ***electro-deionization,*** **or *continuous electro-deionization*** **(EDI or CEDI). Uses continuously regenerating Cation & Anion IX resins**
- ***fractional electro-deionization*** **(FEDI). Applies different currents for both weak/strongly ionized impurities.**
- ***ED with bipolar membranes*** **(EDBM)**
- **Membrane Capacitative Deionization (MCDI) – aka *Capacitive Membrane Deionization* (CapDI).**
- **EM technologies also include *gas separation membranes*.**

58