ASSOCIATION OF WATER TECHNOLOGIES

Training Seminars

Membrane Training 2024 – Section 1
Colin Frayne
Aquassuance

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SECTION 1: POLYMERIC MEMBRANE SEPARATION TECHNOLOGIES

2023: SECTION 1A: INTRODUCTION

THIS IS A ONE-DAY COURSE;

- IN 4 X 2 HR SESSIONS
- PROVIDING A BROAD (AND MOSTLY PRACTICAL)DISCUSSION OF A WIDE SPECTRUM OF POLYMERIC MEMBRANE TECHNOLOGIES–WITH AFOCUS ON COMMERCIAL/INDUSTRIAL RO.S

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SOME TRADITIONAL SEPARATION TECHNOLOGIES

- **A wide variety of separation technologies are employed in the art and science of water treatment. Traditional technologies employ various types of mass transfer kinetics to separate substances, typically in a water, or oil/water phase, including: mesh screens, gravity sand filters, carbon, multi-media pressure filters, pre-coats & hydrocyclones.**
- **Also, precipitation, distillation, evaporation, magnetism, gas stripping, sedimentation, coagulation, flocculation, clarification, ion-exchange, and centrifugation, API/Lamella, DAF/IAF, MEV,MSF, molecular sieves.**




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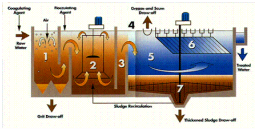
SOME MORE TRADITIONAL SEPARATION TECHNOLOGIES

- Other non-membrane separation technologies include: chemical demuslifiers, xanthanate frothers, lime/lime-soda softeners, coalescers, walnut shell filters, brine concentrators, falling film evaporators, sedimentation tanks, API'S Lamella's, thickeners, RBC, SBR &ICBR.
- Also, Veolia 3FM flexible fiber filters, Guerney variable pore microfilters (VPMF), Suez "Densadeg" and Veolia "Actiflo" high rate clarifiers/ thickeners + micro-sand ballast. Ovivo Carrousel AS systems.



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YET MORE TRADITIONAL SEPARATION TECHNOLOGIES

- Other non-membrane separation technologies include: Electrocoagulation e.g. Green Machine, DW Powell, Elgressy, and capacitive deionization (CDI) – adsorption/desorption via nanoporous carbon aerogel electrodes

EVAPCO CDI unit

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INTRO. TO MEMBRANE SEPARATION TECHNOLOGIES

- Osmotic or pumped pressure-driven membrane technologies:
- MF, UF, NF, and Hyperfiltration (Reverse Osmosis/RO)
- Forward Osmosis/FO (+ critical draw solutions)
- *(All using cellulose acetate, TFC, PVDF, PES, etc, in hollow fiber, spiral-wound, plate & frame sheet format. Also, ceramic body units.)*
- Membrane Bioreactors (MBR) – internal or external UF membranes
- Electro-deionization: ED, EDI, EDR, Continuous electro-deionization (CEDI) – e.g. Evoqua/Ionpure. Also, capacitive membrane deionization (CAPDI) – e.g. Voltea
- Gas separation – Liquicel membrane contactors (using macroprous hollow fiber membranes)
- Electro-filtration – combo of membrane filtration & electrophoresis

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INTRO. TO MEMBRANE SEPARATION TECHNOLOGIES

- Separation effectiveness of substances depends, in part, on size and mass of molecules, particles, minerals, or biologics involved.
- Traditional (*or macro*) technologies typically involve substances larger than a colloid, (i.e. *a dispersed-phase of particles or emulsions within a continuous phase, of approx. 1μm to 1nm*.)
- Modern polymeric membrane (*or micro*) technologies have been developed only over the last 40 years or so, and are associated with the separation of molecules or particles smaller than a colloid – although there is no universally agreed cut-off point.



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INTRO. TO MEMBRANE SEPARATION TECHNOLOGIES

- REVERSE OSMOSIS (RO) and other types of modern membrane technologies (MF/UF/NF, etc.) are filtration methods that can remove silt, large molecules, ions, and other contaminants, by applying pressure to the solution (feed) on one side of a selective membrane.
- The result is that the solute (concentrate) is retained on the pressurized side of the membrane and the "pure" water solvent (permeate) passes to the other side of the membrane.
- To be "selective," the membrane should not allow silt, large molecules or ions, etc. through the pores (holes), but, based on the membrane type (e.g. cut-off points), may permit smaller soluble components to pass freely with the "pure" water.

New separation technology

Old technology

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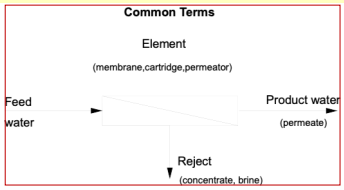
INTRO. TO MEMBRANE SEPARATION TECHNOLOGIES

WE PLACE RO MEMBRANE ELEMENTS INTO PV's WITHIN AN ASSEMBLED RO SYSTEM

THERE ARE SOME COMMON TERMS USED IN THE INDUSTRY



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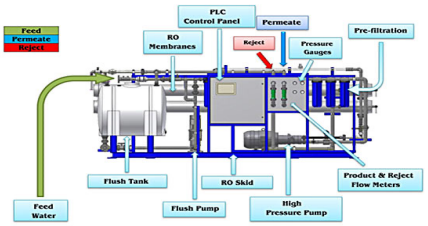
COMPONENTS OF A TYPICAL REVERSE OSMOSIS PLANT



- *MEMBRANES ARE PUT INTO PRESSURE VESSELS AND CONSTRUCTED IN STAGES*
- *SEVERAL STAGES ARE FREQUENTLY USED TO GET DESIRED RECOVERY RATES UP.*

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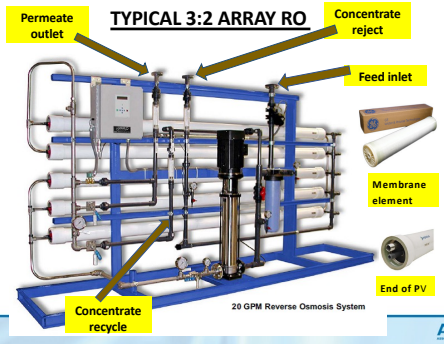
TYPICAL 3:2 ARRAY RO



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INTRODUCTION: MEMBRANE SEPARATION TECHNOLOGIES

- Membrane technologies are typically based on a process known as "crossflow" or "tangential flow" filtration, which allows for continuous processing of liquid streams. (although dead-end filtration processes are also employed in, say, UF/MF).
- In the crossflow process, the bulk solution flows over and parallel to the membrane surface and, because the system is pressurized, "pure" water is forced through the membrane - called "permeate".
- The turbulent flow of the bulk solution over the surface helps to minimize the accumulation of particulate matter.

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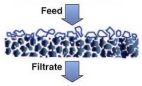
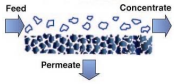
INTRODUCTION: MEMBRANE SEPARATION TECHNOLOGIES

FLOW PATTERNS FOR MACRO FILTRATION & NF/RO

Conventional Filtration



Crossflow Filtration



- Most Conventional (macro /particle) filtration flows by pressure or gravity down through the media, but some systems (e.g. some cartridge filters) can flow upwards.
- All NF/RO membrane technology systems use cross flow filtration. The fluid feed stream runs tangential to the membrane, establishing a pressure differential across the membrane causing some of the particles to pass through the membrane. Remaining particles continue to flow across the membrane, "cleaning it".

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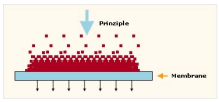
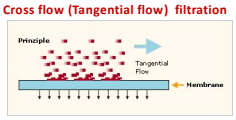
INTRODUCTION: MEMBRANE SEPARATION TECHNOLOGIES

FLOW PATTERNS FOR MF/UF

Dead-end filtration



Cross flow (Tangential flow) filtration



- Manufacturers of MF/UF membrane modules choose either Dead-End or Cross Flow.
- With Dead-End filtration ,all the fluid passes through the membrane and all particles larger than the pore sizes of the membrane are stopped at its surface. Trapped particles can start to build up a "filter cake" on the membrane surface, which reduces filtration efficiency until the filter cake is washed away in a back flushing/rinse cycle. But Dead-End an be used to recover expensive/difficult metals (*Ag, Au, Pt, Cr, Ni, Cd*)
- In contrast to the Dead-End filtration technique, the use of a Cross Flow (Tangential Flow) will prevent thicker particles from building up a "filter cake".

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INTRODUCTION: MEMBRANE SEPARATION TECHNOLOGIES

MEMBRANE PORE SIZES

- Expressed as *nominal molar mass* (Mol. Wt.)
- And/or *nominal pore size* or *Mol. Wt. cut off* (MWCO)
- Removes >90% of material of that size.
- Pore size variability: Different manufacturers use own system (*shoe sizes?*)
- Various types of membrane materials used – different hydrophobicities.
- Various manufacturing processes for tubes, flat sheets, ceramics, etc., such as: air casting, immersion casting, and melt casting.
- MF & UF typically used for separation of suspended solids
- UF is needed for macro-molecules & viruses
- NF provides for multivalent cation removal (e.g. softening)
- RO is needed for "pure" water. Its an alternative to distillation, evaporation, or demineralization by ion-exchange.

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INTRODUCTION: MEMBRANE SEPARATION TECHNOLOGIES

MEMBRANE RECOVERY RATES

The advantages of RO systems designed for high recovery rates are the volume of concentrate is small, the feed pump is smaller, less membranes reqd. (e.g. RO 440 sq ft.) and lower CAPEX cost. BUT, potential disadvantages are significant:

- Higher concentration of contaminants can result in precipitation and greater propensity for fouling.
- In nanofiltration and reverse osmosis applications, the concentrated salts will result in higher osmotic pressure, requiring a higher pressure pump, and a more pressure-resistant system build.
- Also, with RO/NF, as recovery rates are increased, the ionic purity of the permeate decreases.
- As higher recoveries reduce the quantity of concentrate to be discharged, the higher TDS of this concentrate stream can itself present discharge problems.

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INTRODUCTION: MEMBRANE SEPARATION TECHNOLOGIES

- 1. Microfiltration (MF) – food/beverage for clarification, concentration, recovery & sterilization. Also pharma/biotech use. pore sizes = 0.1-10 µ
- 2. Ultrafiltration (UF) – separation/concentration of macro-molecules & colloids. Pore sizes 1 to 100 nm. Applications include electro-paints, gray water, emulsions, oily wastes, milk, cheese/protein processing. Also, a pretreatment "roughing" filter for ion-exchange and EDR (*more on ED processes later*), for producing boiler MU water
- 3. Nanofiltration (NF) - softening, removal of color/dyestuffs/ THMs, and treating contaminated ground water. Pore size approx 1 nm. NF rejects Ca/Mg, but not so good with Na/K. Also, drinking water industry
- 4. Hyperfiltration (Reverse Osmosis) - is membrane distillation/ desal/ desalting. Pore sizes 1 to 10 Angstrom units. ALL RO plants susceptible to fouling, so adequate pretreatment and operation is essential
- Note: Different membrane manufacturers produce loose/tight pore size variations with different MW cut-off points (indicators of pore size).

Membranes are now cheap and can be cost effective in many applications – its often simple stuff!

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INTRODUCTION: MEMBRANE SEPARATION TECHNOLOGIES

MEMBRANE TECHNOLOGIES: A QUICK COMPARISON

- Macro filtration (such as sand/anthracite) is often used for solids/liquid separation in cooling towers, for filtering well water , or as a pre-treat to, say, 2 bed demineralizers + MB demin, for ultrapure water production. Typically, we will not filter better than 10 µ particle size.
- Combined conventional technologies might get us to 1 µ (500K MW cutoff)
- Using MF as an alternative – we instantly get to, say, 0.1 µ (100K MW cutoff)
- With UF we can filter/separate down to, say, 0.01 µ (20K MW cutoff)
- Nano filtration (NF) will take out Ca/Mg/Fe/Al/Zn salts and get us down to, say, 0.001 µ (200 MW cutoff)
- RO separates down to the ionic level, say, 0.0001 µ (100 MW cutoff)
- Note that we can use RO for, say, HP boiler feedwater and, starting with city water, we only need a pressure of 200 psi, and can easily get down to 1-10 µS/cm conductivity, with perhaps 70-80% permeate recovery.
- However, if we use seawater RO (SWRO) for production of, say, drinking water, then we need >1000 psi and can only get to a purity of 500-800 µS/cm, and with only 30-35% recovery. *Why?* Its down to net driving pressures, membrane types, fouling risks, pretreatment, etc. - as discussed later!

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INTRODUCTION: MEMBRANE SEPARATION TECHNOLOGIES

RO systems around the world come in different shapes, sizes, and qualities




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INTRODUCTION: MEMBRANE SEPARATION TECHNOLOGIES

Sometimes working conditions are poor and equipment quality is worse!






Central American sugar mill: Trinidad factory. Well water storage (95 ppm silica). Simple sand filter pretreat. ITT/WET MS 60K RO unit (60,000 gpd) @70% recovery. Demin & Permeate tank.

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INTRODUCTION: MEMBRANE SEPARATION TECHNOLOGIES

RO units are usually shipped as fully assembled/skid mounted, standard units, based on a build drawings and a specific bill of quantities for any particular model.




Larger RO systems are designed and engineered, using 3D software. Final assembly of RO trains forms part of site construction.

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Engineered Systems use standard components and are assembled on the shop floor.

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SECTION 1B: OVERVIEW OF SEMI-PERMEABLE MEMBRANE TECHNOLOGY AND MEMBRANE TECHNOLOGY SYSTEMS:

- Review of relative molecular and particle sizes.
- Review of areas of application
- What do MT systems look like?
- Theory of osmosis and pressure driven osmosis.
- Osmotic /Applied pressure/Net Driving Pressure
- Overview of which industries where MT is used
- New MT applications, Forward RO & developments
- Benefits of MT
- Limitations of membranes
- Overview of potential problems
- Pretreatment/post treatment schemes
- Overview of need to control incoming water contaminants
- SDI test and membrane inflow quality requirements
- Control of scaling
- Control of fouling, corrosion, and bio control
- Need for CIP
- Need for membrane storage protection
- Shutdown/startup flush outs, idle mode protection

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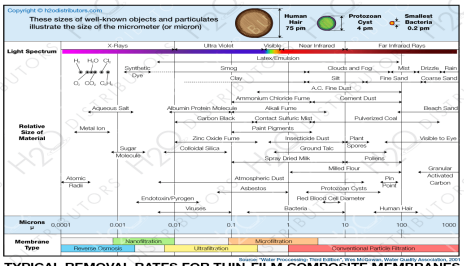
NEW WORLD OF WATER TREATMENT



TYPICAL REMOVAL RATES FOR THIN-FILM COMPOSITE MEMBRANES

At 65 PSI Feed Pressure and 77° Temperature

Arsenic	94%	Barium	99%	Flouride	93%	Nitrates	87%	Nitrites	87%
Asbestos	99%	Cadmium	98%	Lead	99%	Radium	80%	Hexavalent Chromium	86%
Cyanide	86%	Copper	99%	Mercury	91%	Selenium	96%	Trivalent Chromium	88%

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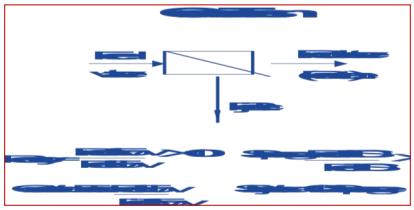
THE NUMBER AND TYPES OF MEMBRANE ELEMENTS IN A SYSTEM IS BASED ON OUTPUT VOL/QUALITY NEEDS

SO THERE ARE SOME COMMON EQUATIONS USED TO CALCULATE PERMEATE RECOVERY RATES, SALT PASSAGE, CONC. FACTOR, ETC.



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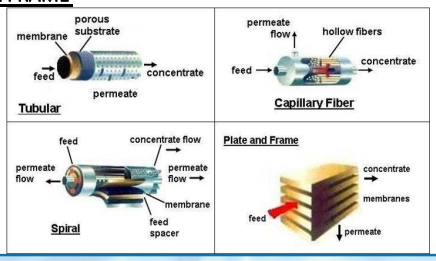
MEMBRANES CAN BE CA PLASTIC, POLYMER, OR CERAMIC. + TUBULAR, CAPILLARY FIBER, SPIRAL WOUND , OR SHEET TYPE IN PLATE & FRAME



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MEMBRANES CAN BE CA PLASTIC, POLYMER, OR CERAMIC. + TUBULAR, CAPILLARY FIBER, SPIRAL WOUND , OR SHEET TYPE (IN PLATE & FRAME)

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MEMBRANES FOR MF/UF

Most usually in hollow fiber polymer format (PES or PVDF), but also sheet, or ceramic format, (e.g. for juice/beer clarification)

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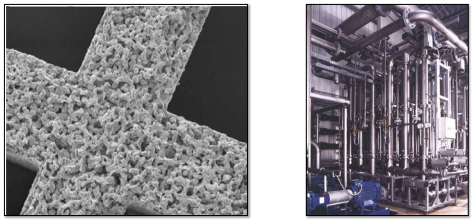
CERAMIC MEMBRANES

Ceramic membranes: - often used for microfiltration in F&B industries. They offer durability, longevity, & handle high temps. and strong cleaners.



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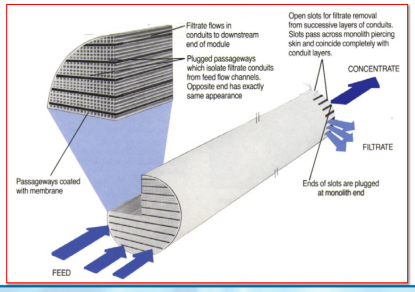
MORE ON CERAMIC MEMBRANES



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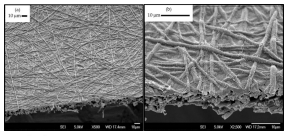
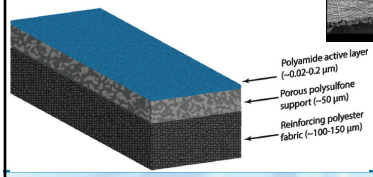
THIN FILM COMPOSITE MEMBRANES

TFC polyamide membranes consist of a porous support layer(s) and a dense thin film layer – usually in a spiral wound format.





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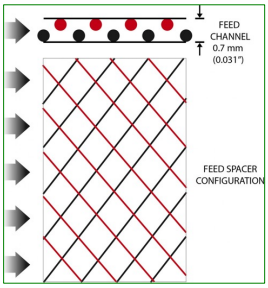
FEED & PERMEATE COLLECTION SPACER DIAGRAM

Side view

Looking down on the spacer sheet (plan view)



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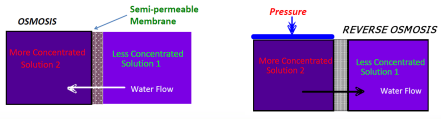
OSMOSIS THEORY & PRESSURE DRIVEN OSMOSIS

- If Reverse Osmosis is the opposite of Osmosis, what is Osmosis? It's a natural process in which a dilute stream flows through a semi-permeable membrane into a more concentrated solution on the other side, thus, diluting the conc. solution (e.g. when transferring nutrients thru a plant's root system and into the plant.)
- Reverse Osmosis is when the flow is reversed by applying external pressure on the side of the more highly concentrated stream. i.e. a water source under pressure flows through a semi-permeable membrane, leaving much of its dissolved salts and ions behind, creating a dilute permeate and a very concentrated reject water.



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OSMOTIC PRESSURE ACROSS A MEMBRANE

- The transfer rate across a membrane, of a high TDS water source (e.g. seawater), will be slower than the transfer of a low TDS water. The more concentrated the feed, the slower the transfer rate across the membrane.
- Every 1000 ppm TDS creates 10 psi of pressure differential, as lower concentrated water will tend to migrate back through the membrane (by osmosis) to the more concentrated feed water. Thus, the osmotic pressure has to be overcome in order to produce high quality permeate in an RO.
- The initial TDS concentration of the feed water solution crossing the RO membrane dictates the required Applied Pressure, Permeate Quality and Membrane Selection (to reduce pressure or minimize fouling, or improve compatibility).

ppm TDS in feed water	Natural Osmotic Pressure psi	Natural Osmotic Pressure Bar
100 ppm	1 psi	0.069 Bar
1,000 ppm	10 psi	0.69 Bar
5,000 ppm	50 psi	3.45 Bar
10,000 ppm	100 psi	6.9 Bar
15,000 ppm	150 psi	10.35 Bar

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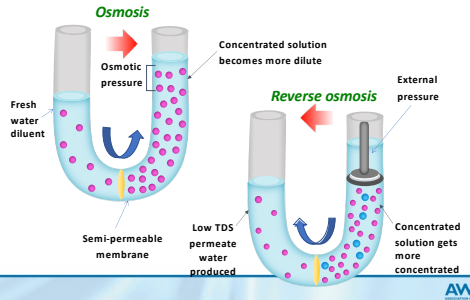
OSMOTIC DIFFUSION – REVERSE OSMOSIS



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RO PERFORMANCE: NET DRIVING PRESSURE &TEMP

- Performance of the RO membrane element is affected by two key factors; temperature of the feed water and the net driving pressure across the element.
- Higher temperatures improve permeate flow rates.
- Fouling rate or higher osmotic pressure decreases permeate flow rates

Net Driving Pressure (NDF) = difference between applied (pump) feed pressure minus sum of all back pressures (i.e. osmotic pressure, pipe pressure losses, head losses, etc.)

Feed Water Temperature °C	°F	Correction Factor	Feed Water Temperature °C	°F	Correction Factor
5	41.0	2.58	18	64.4	1.29
6	42.8	2.38	19	66.2	1.24
7	44.6	2.22	20	68.0	1.19
8	46.4	2.11	21	69.8	1.15
9	48.2	2.00	22	71.6	1.11
10	50.0	1.89	23	73.4	1.09
11	51.8	1.78	24	75.2	1.04
12	53.6	1.68	25	77.0	1.00
13	55.4	1.61	26	78.8	0.97
14	57.2	1.54	27	80.6	0.94
15	59.0	1.47	28	82.4	0.91
16	60.8	1.39	29	84.2	0.88
17	62.6	1.34	30	86.0	0.85

EXAMPLE

Question
For a TFC membrane, permeate rate at 77 °F= 1800 gpd. What is the permeate rate at 59 °F?
Answer
Temp. correction factor (from table) = 1.47
Permeate flow at 59 °F =
1800 ÷ 1.47 = 1224 gpd

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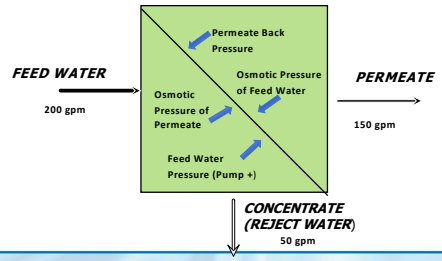
NET DRIVING PRESSURE



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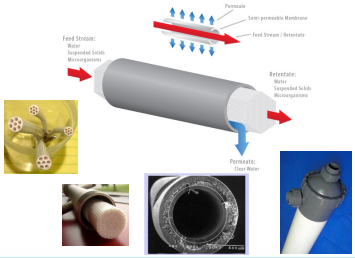
MICRO/ULTRA FILTRATION:

MODEL CONFIGURATION - Hollow Fiber Membrane



MEMBRANES:

- Polyacrylonitrile (PAN) – UF Only
- Polyvinylidene fluoride (PVDF).
- Polyethylene (PE) & propylene (PP) – MF Only.
- Polytetrafluoroethylene (PTFE) – MF Only.
- Ceramics *-for high resistance, but needs high flux rate to compete with polymers, so must have low NTU feedwater*

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MICRO/ULTRA FILTRATION: APPLICATIONS

UF MODULES

Examples of MF applications:
- Cold sterilization of beverages /pharma
- Clarification of fruit juice, wines and beer
- Separation of bacteria from water (biological wastewater & effluent treatment
- Plating shop metals separation (Cr, Cd, Ni, Zn)
- Pre-treatment for Nano Filtration or RO
- Solid-liquid separation for pharma or food ind.

Examples of UF applications:
- Dairy industry (milk, cheese)
- Food industry (proteins)
- Metals – flotation/separation
- Precious metals recovery
- Oil/ water emulsions separation
- Paint/Textiles Industries
- Drinking water

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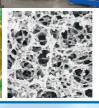
NANO & HYPER-FILTRATION (RO):





MEMBRANES:

- Polyamide (PA)
- Polycarbonate (PC)
- Polyethylene-terephthalate (PET)
- Polysulfone (PS)
- Polyether-sulfone (PES)
- Cellulose di-acetate/nitrate (CA/CN)

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NANO & HYPER-FILTRATION (RO): APPLICATIONS

NANOFILTRATION (NF) APPLICATIONS:

- Used most often with low TDS water, e.g. surface water/fresh groundwater, for softening ,removal of disinfection by-product precursors, and microbiological organism removal.
- Also NF is becoming more widely used in food processing (such as dairy) for simultaneous concentration and partial (monovalent ion) demineralisation.

RO APPLICATIONS:

- Food/Beverage Production.
- Boiler/Steam/Power pre-treat.
- Pretreatment for high-purity water.
- Bio-pharma/Computer chip fab plants
- Water Jet Cutting.
- Humidification.
- SWRO for drinking water
- Blending/reuse for Cooling makeup



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FORWARD RO, AND OTHER NEW DEVELOPMENTS IN MEMBRANE TECHNOLOGY APPLICATIONS

1. 16" membrane elements now being used in very large SWRO plant worldwide, with reduced pressure designs and enhanced energy recovery using ER turbochargers.
2. New build SWRO now exceed 50 -100 MGD output
3. Truck mounted, robust ceramic UF for Africa. Output is 200 m3/day supplies 5,000 people. Cost $300K
4. Development of novel, low fouling/low energy FO systems (*Osmosis!*) by using NH_3/CO_2 as high osmotic pressure additive in draw solution to induce pure water to diffuse from feed water back across the membrane. Heating to 105 °F recovers NH_3/CO_2 for reuse. Uses: Emergency drinks, produced water treat.




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BENEFITS & LIMITATIONS OF MEMBRANES

For years, coagulation/flocculation, along with settling, media filtration, and precoat filters have been the "standard" for removing contaminants from water sources. Since early 1990's MF has gained momentum and is now considered mainstream technology for this purpose. Advances in material science/membrane technology have driven this trend.

BENEFITS:

- Improved removal of contaminants at absolute pore sizes at higher efficiency
- Automated procedures, easy to operate
- Smaller footprint. Cost keeps reducing
- No phase change required, as distillation
- Simple flowsheet. Almost no moving parts
- Very little chemistries used

LIMITATIONS:

- Operate either on/off. No flow variability
- Tend not to operate much above room temp.
- Fouling can be a big problem
- Seldom provide two pure product streams.
- Each stream is contaminated by the other.
- Tend to be designed for specific parameters, such as throughput, water contaminant level, and not capable of modification or staging for changes in water quality.
- Membranes can be subject to chemical incompatibilities.

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AN OVERVIEW OF POTENTIAL PROBLEMS: FOULANTS & CONTAMINANTS FROM FEED WATER:

WE CAN SELECTIVELY REMOVE THESE CONTAMINANTS BY CORRECT SELECTION OF MEMBRANE TYPES, BUT:

Class	Examples
Suspended solids	Dirt, clay, colloidal materials, silt, dust, insoluble metal oxides and hydroxides
Dissolved organics	Trihalomethanes, synthetic organic chemicals, humic acids, fulvic acids
Dissolved ionics (salts)	Heavy metals, silica, arsenic, nitrate, chlorides, carbonates
Microorganisms	Bacteria, viruses, protozoan cysts, fungi, algae, molds, yeast cells
Gases	Hydrogen sulfide, methane, radon, carbon dioxide

All types of membrane technologies are at risk of fouling! Optimizing pre-treatment minimizes the need and frequency for CIP and other forms of cleaning.

We have excellent antiscalent chemistries, so the primary risks today are generally due to colloidal clays, silt, and bio-foulants.

High transmembrane pressure, & flux rates are fouling indicators

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NF/RO MEMBRANE FOULING: SILT, SCALES, DEPOSITS, BIOLOGICS, ETC.

- All membranes lose performance with time. A major cause for loss of performance is due to fouling of membrane surfaces.
- Essentially an RO plant is in either an ON or OFF mode, so important variables that control membrane fouling must be considered at the design stage - especially pre-treatment.
- For any given design, membrane fouling and scaling can be reduced by running only under optimum operating conditions.

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MORE NF/RO MEMBRANE FOULING:

- Membrane recovery is defined as *the ratio of permeate flow to feed flow* for that membrane. Recovery rates can be reduced by increasing feed flow or decreasing operating pressure. Lower operating pressure produces less permeate flow. If feed flow can be maintained at pre-membrane-aging design value , then a lower recovery is obtained.
- The effect of lower recovery is to reduce overall concentrations of all substances in the RO system. More favorable boundary layer conditions are also achieved by reducing the system recovery rates.
- The concentration of all materials in the feed water is highest near the membrane surface. As permeate is removed through the membrane, all impurities are left behind near the membrane surface.
- The layer of water next to the membrane surface (boundary layer) gets more and more concentrated in substances. Concentrations reach a certain steady level depending on feed velocity, element recovery and membrane permeate flux rate (gall/ft^2/day of permeate).

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SUMMARY: FOULING FACTORS, FLUX, AND SDI

- The conc. of the fouling materials at the membrane surface increases with increasing RO element recovery (FLUX, i.e. *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 need 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.
- The silt density index (SDI) is a measure of the fouling capacity of water in NF/RO systems. The test measures the rate at which a 0.45 µ filter is plugged when subjected to a constant pressure of 206.8 kPa (30 psi).
- An increase in feed water SDI is often a sign of pre-treat problems!
- An early sign of colloidal fouling is often an increased pressure differential across the system during operation. Membrane cleaning?

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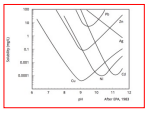
THE NEED FOR PRE-TREATMENT

Softening, Filtration?



Heavy metal removal by precipitation?

- Pretreatment is important when working with RO and NF membranes due to the nature of their spiral wound design. The material is engineered in such a fashion as to allow only one-way flow through the system.
- As such, the spiral wound design does not allow for back-pulsing with water or air-agitation to scour its surface and remove solids.
- Since accumulated material cannot be easily removed from the membrane surface in NF/RO systems during operation, they are highly susceptible to fouling (i.e. loss of production capacity).

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PRETREATMENT BASICS FOR A NF/RO MEMBRANE SYSTEM

- We need feed pretreatment for RO/NF, such as media filtration for removal of suspended solids and iron, plus carbon filters for removal of organics and chlorine (or use bisulfite)
- We need hardness control agents, such as a softener or acid, and antiscalent chemicals
- We may need pH adjustment , both pre- and post- RO
- We may need intermediate pre-and post- RO storage tanks with repressurization pumps (and anti-contamination devices)
- We will need some form of membrane cleaning system (CIP). Also, membrane sterilization/ & long-term storage chemistries
- We may need incoming feed water temperature control or stabilization in winter months (keep the temp. over 70°F)
- We may also need MF or UF as a pretreatment with recovered water, and perhaps a MB polisher or EDI as a post treatment

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PRETREATMENT EXAMPLE: MANGANESE GREENSAND WITH AIR SCOUR/ $KMnO_4$ + CARBON FILTERS

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PRETREAT EQUIPMENT DESIGN NOTES

- MM pressure filtration is standard for RO pre-treatment , and designed to reduce the max. feed-water turbidity below 1 NTU and SDI below 5. Some designers push the RO feed water flow rate to 15 gall/sq. ft./min. This is generally too high! A better max. is 9-10 gall/sq. ft./min, with 5-6 gall./sq. ft/min being preferred. For continuous operation, dual or triple MM filters will be required.
- Carbon filters. To remove organics and/or chlorine. Design for 4-6 gall./sq. ft/min, to ensure adequate contact time
- Cartridge filtration: It is standard practice to incorporate a 5µ cartridge filter unit in the RO feed-water supply line, immediately before the RO high pressure pump, as a final preventative measure
- Microfiltration membranes. Used as an RO pretreat for treated wastewater. Typically 0.5 micron filtration. Will provide SDI <3

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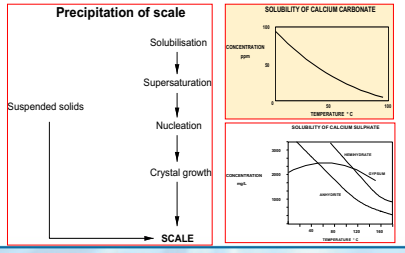
WE NEED ANTISCALENT – ACID OR SOFTENER? USUALLY A POLYMER AND/OR PHOSPHONATE



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LATER WE WILL LEARN ABOUT FOULING RISKS, SUSCEPTIBILITIES OF MEMBRANE TYPES, USE OF CIP SYSTEMS, ETC.

OTHER TYPES OF SCALES

Calcium phosphate	- Solubility decreases as pH increases - Deposits usually amorphous but transform to hydroxyapatite.
Silicate	- Calcium or Magnesium silicates form under alkaline conditions. - Solubility of alkaline silicates decreases as pH increases.
Iron oxide	- Ferrous ions converts to ferric ions

- Control of fouling, corrosion, and bio control
- Need for CIP
- Need for membrane storage protection
- Need to understand shutdown/startup flush outs, and idle mode protection system

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