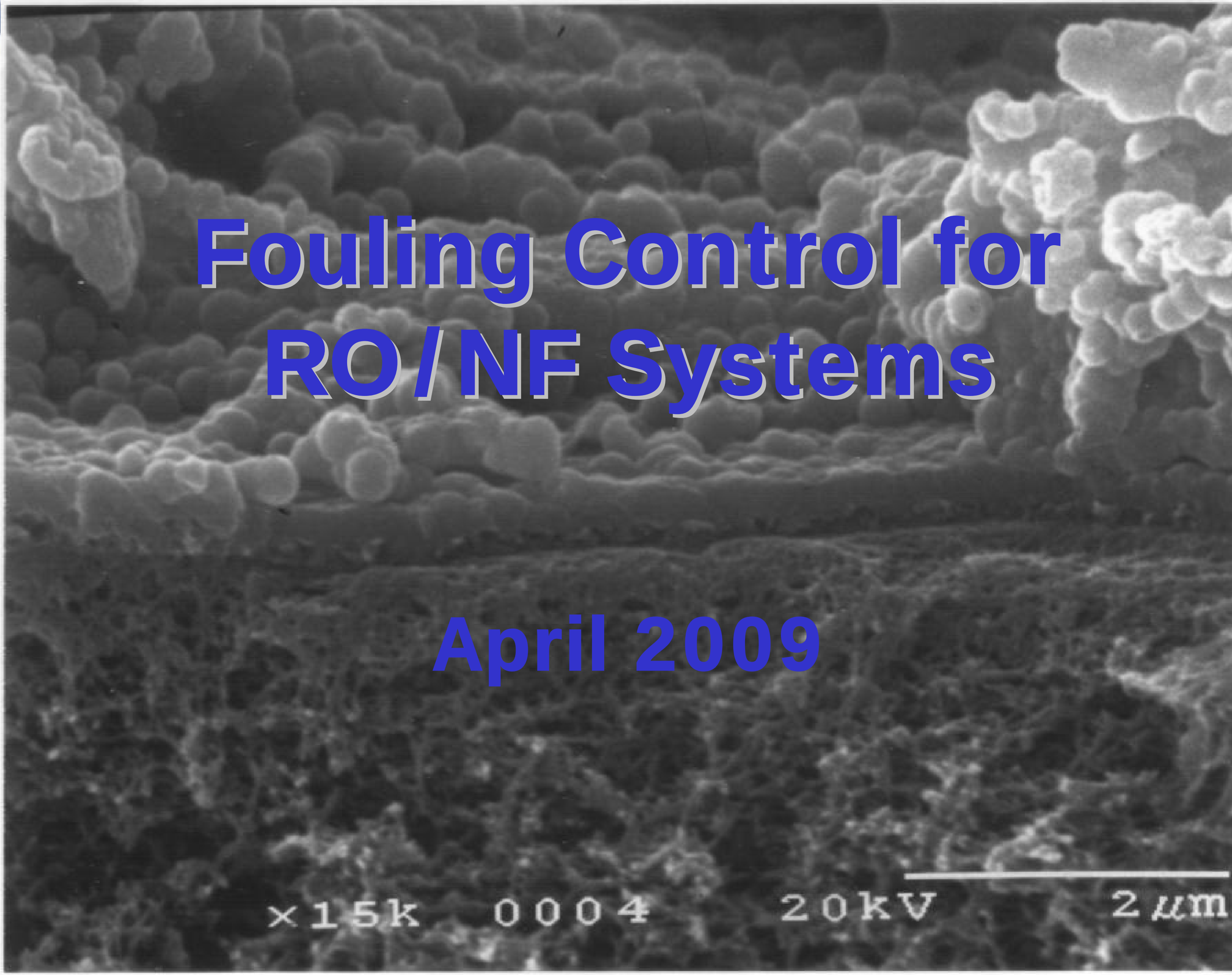
Fouling Control for RO/NF Systems

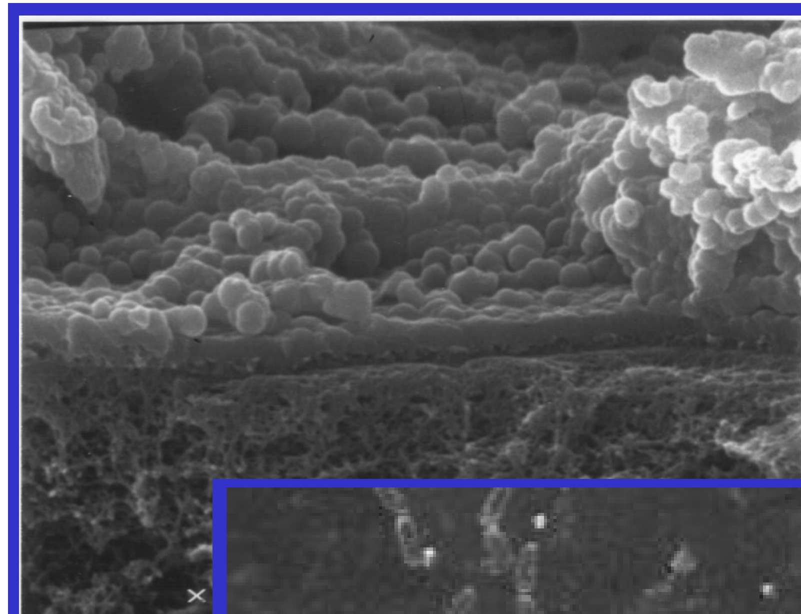
April 2009

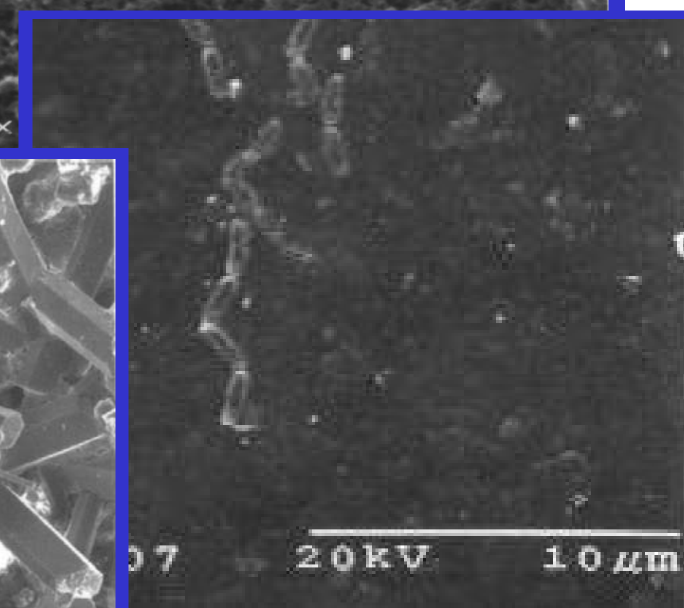


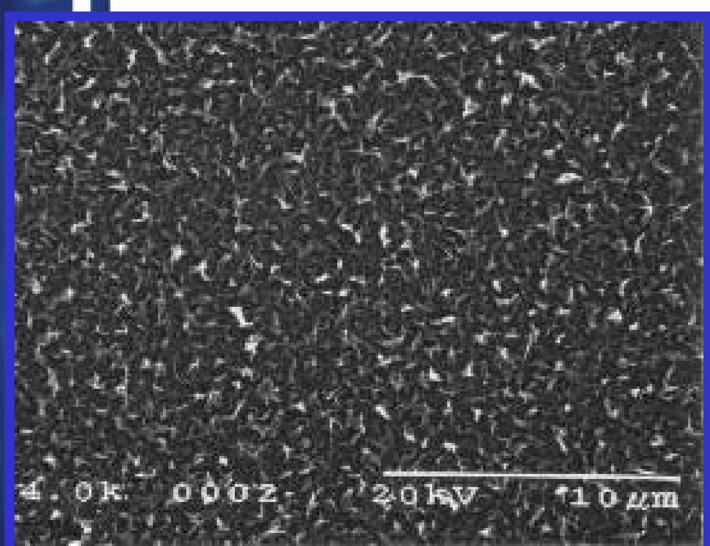
Keys to Treatment with Membrane Technology

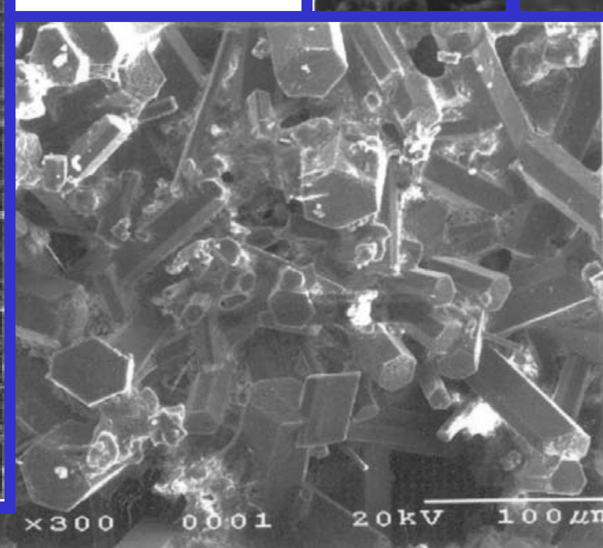
Fouling Control

- Colloidal Material
- Biogrowth
- Scaling
- Organic Adsorption
- Coagulant post-precipitation









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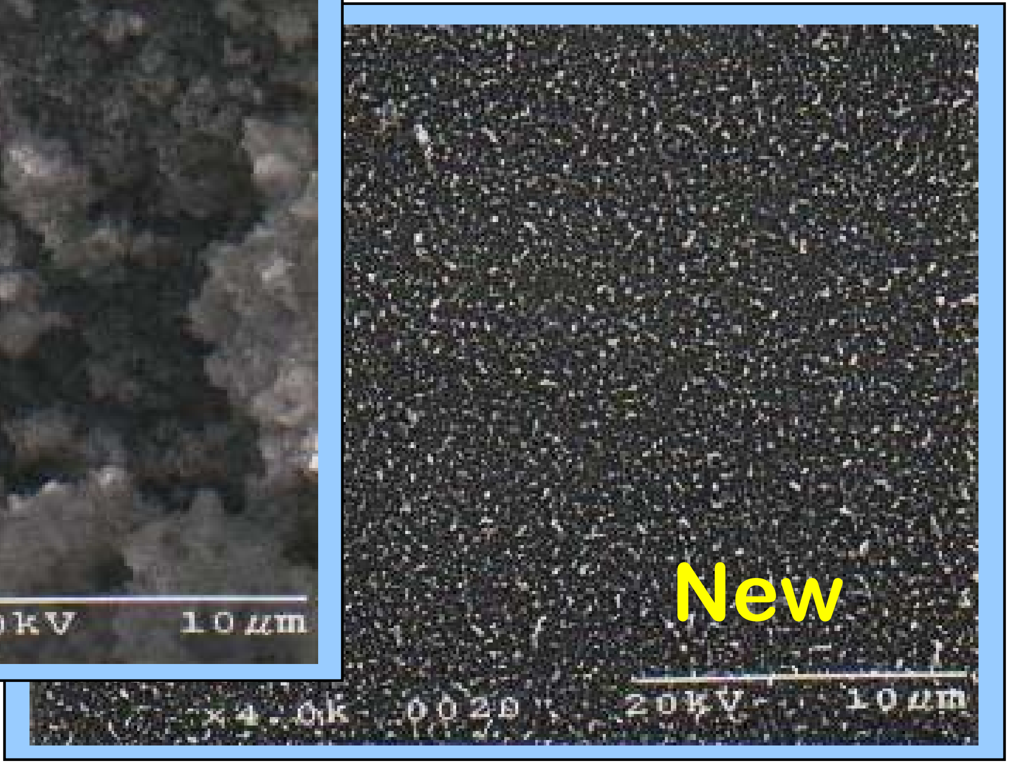
Membrane Fouling



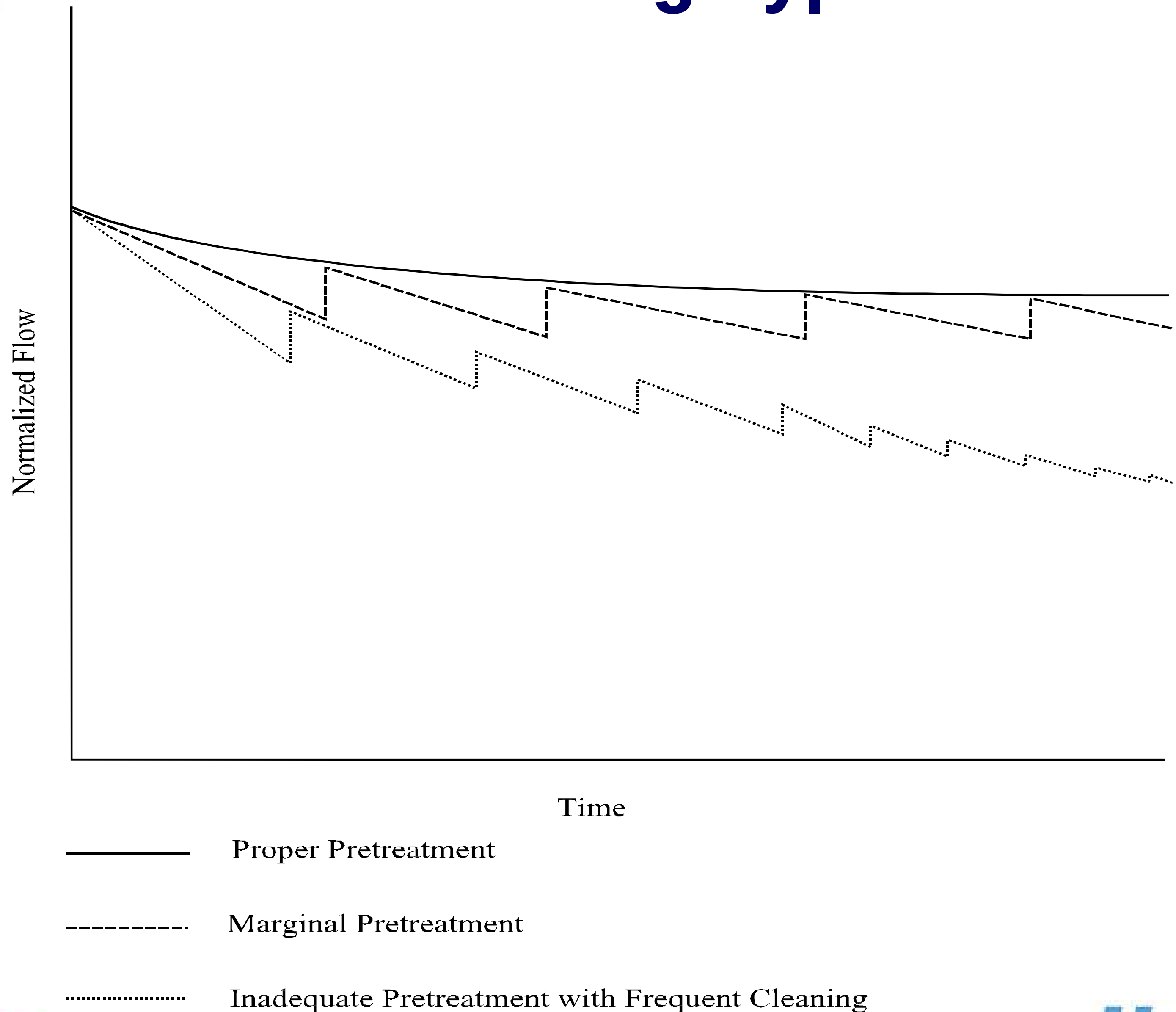
Coating of Membrane Surface

Flux Reduction / High Operating Press

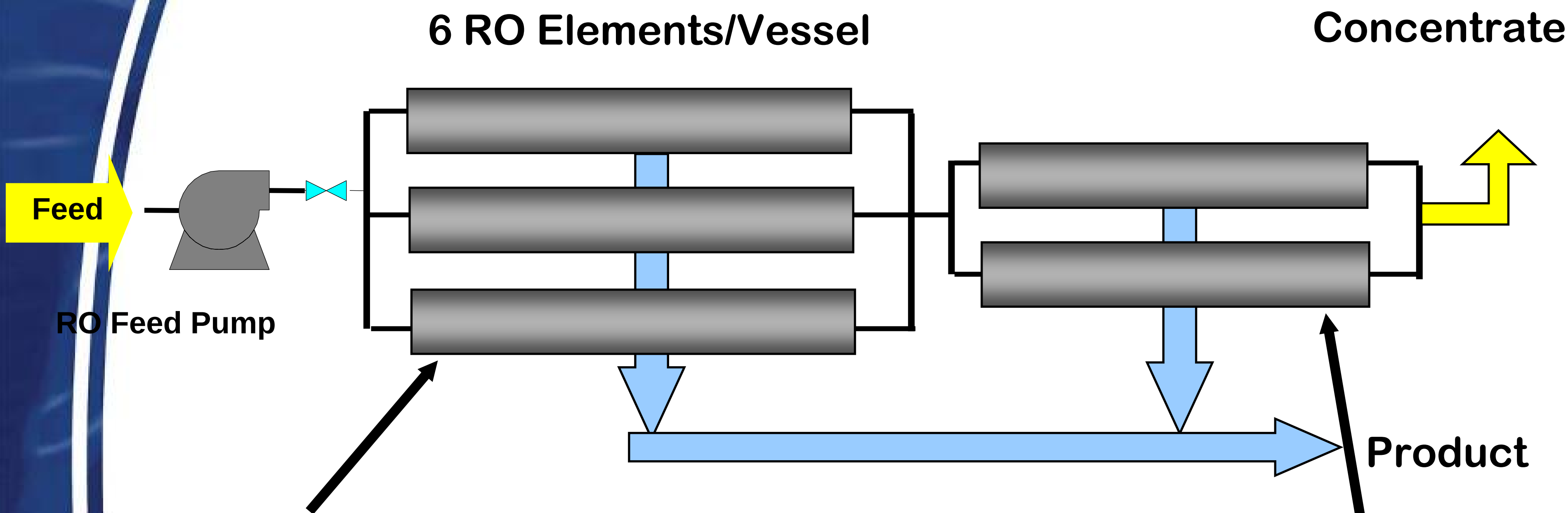
Frequent Chemical Cleaning

Shorter Membrane Life

Fouling Types



Types of Fouling



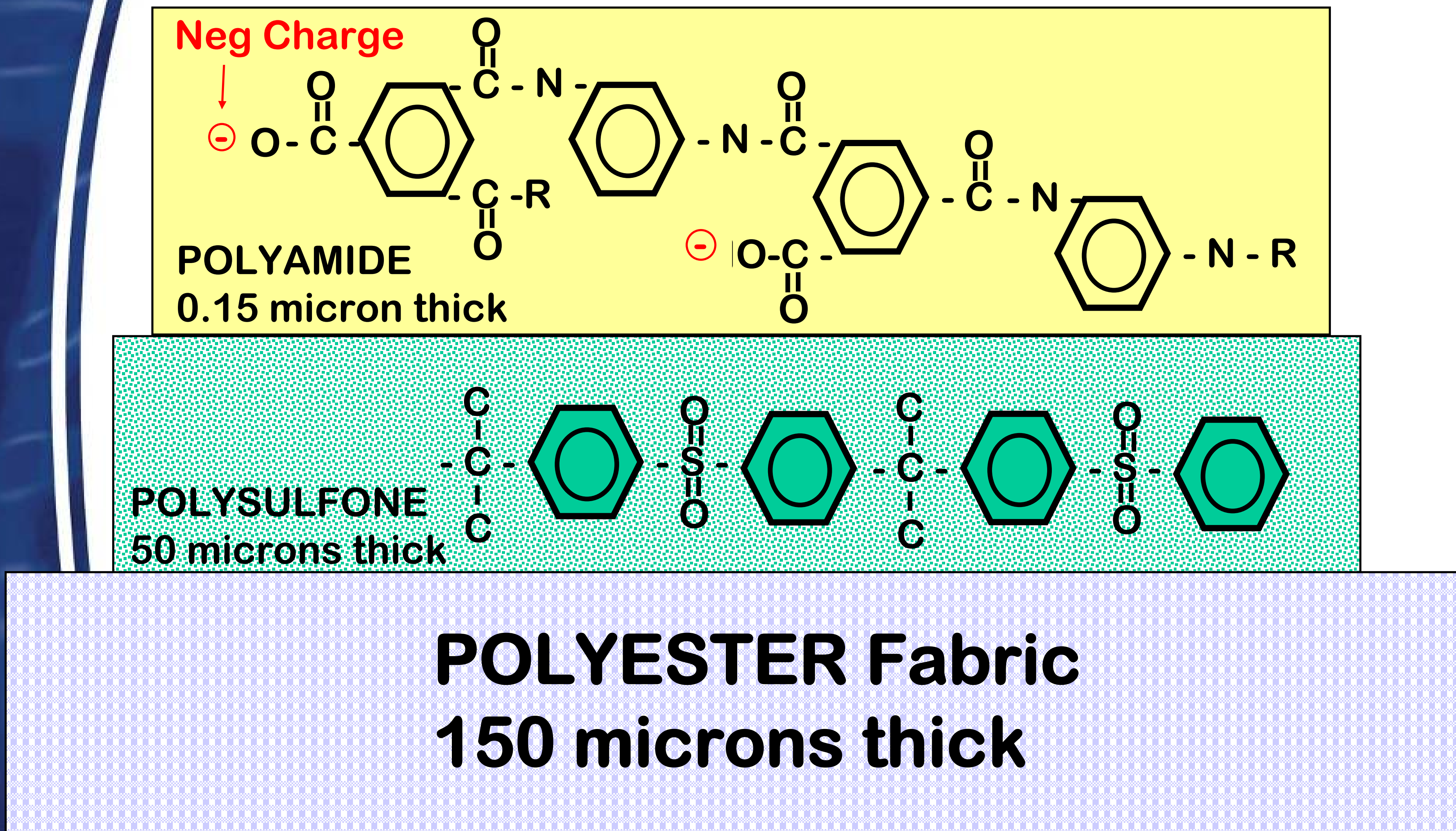
Lead Element Fouling

- Colloidal
- Biological
- Dissolved Organics

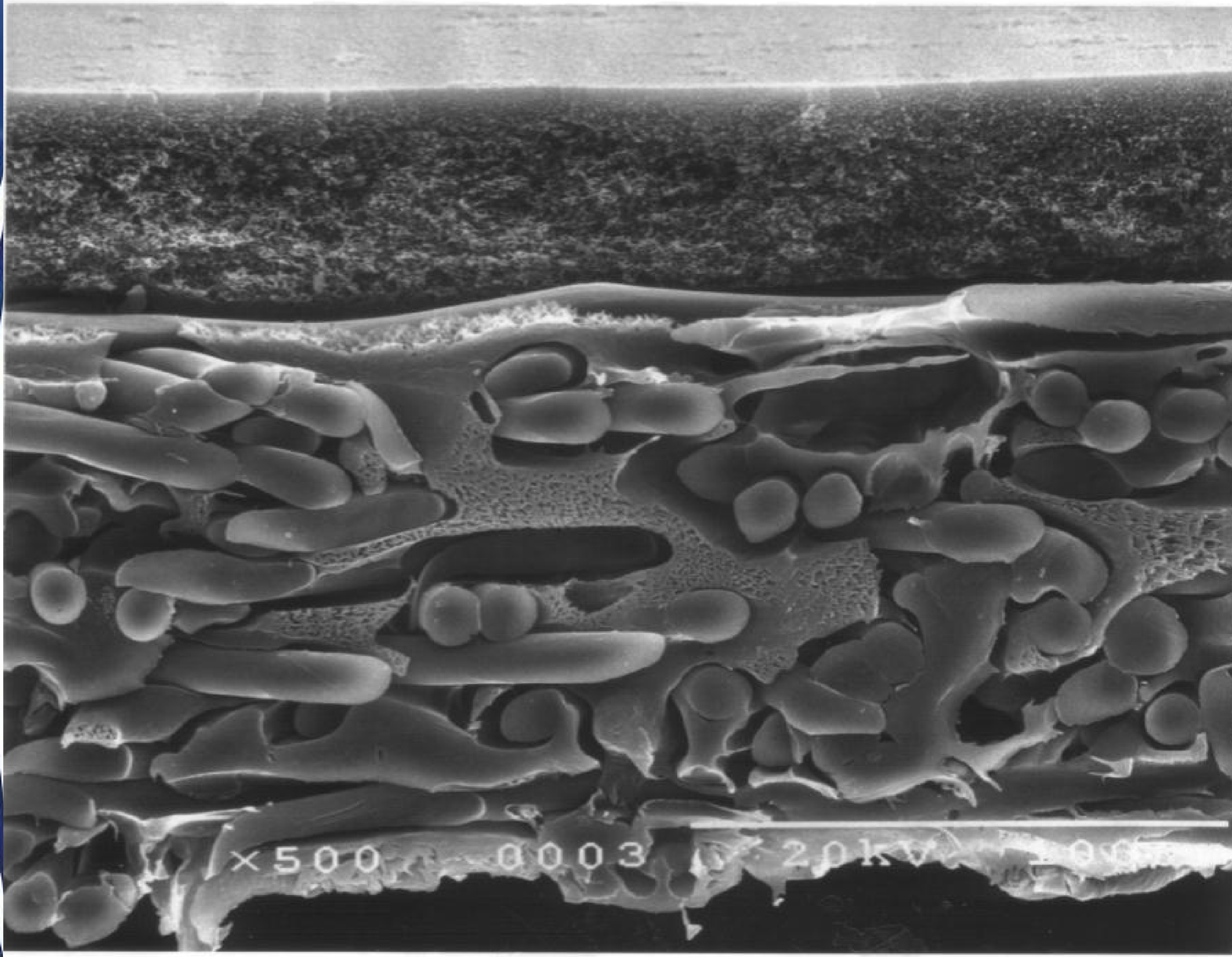
Tail Element Fouling

- Scaling by Silica, Sulfates, and Carbonates
- Dissolved Organics

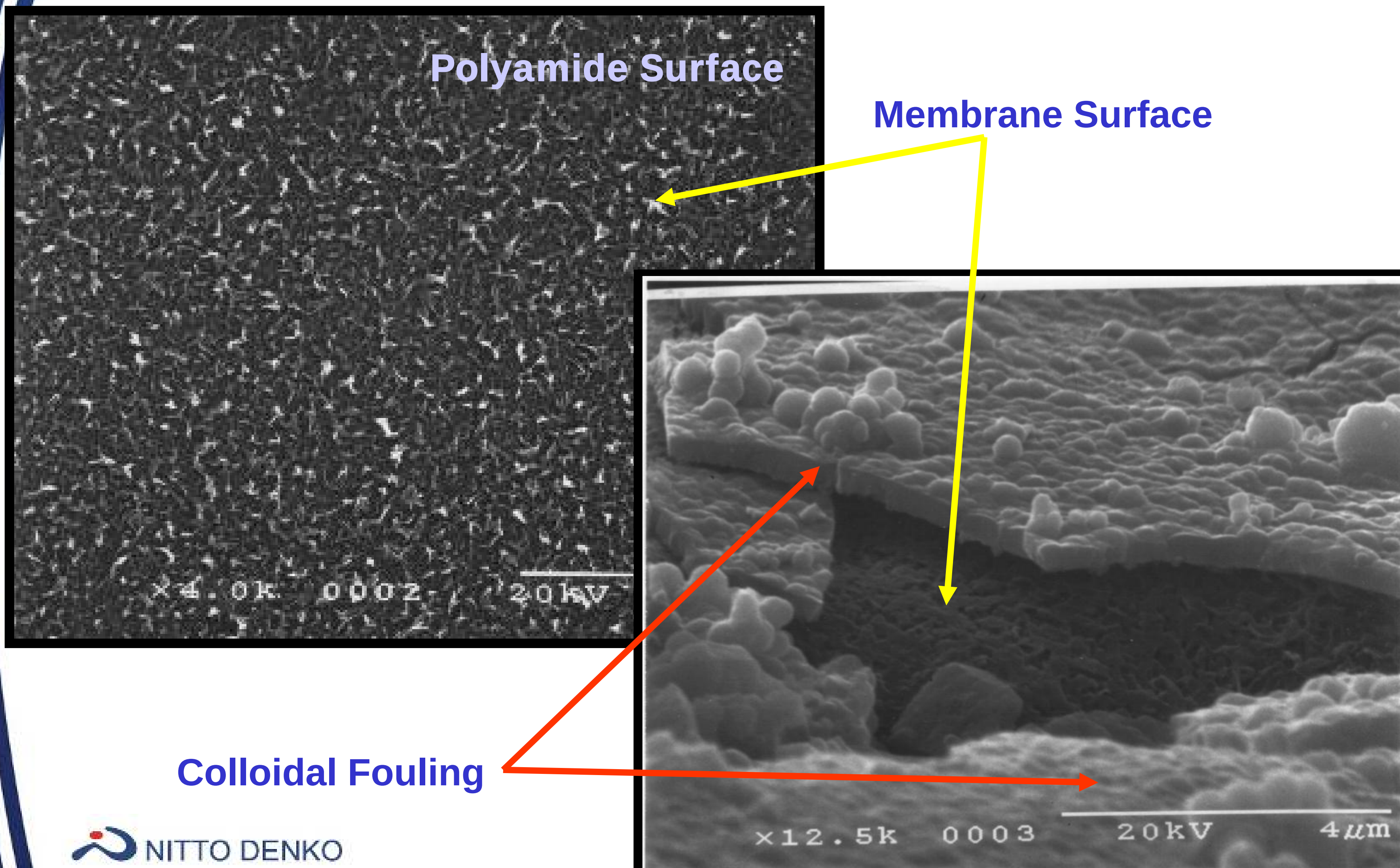
Chemical Composition of Typical RO Membrane



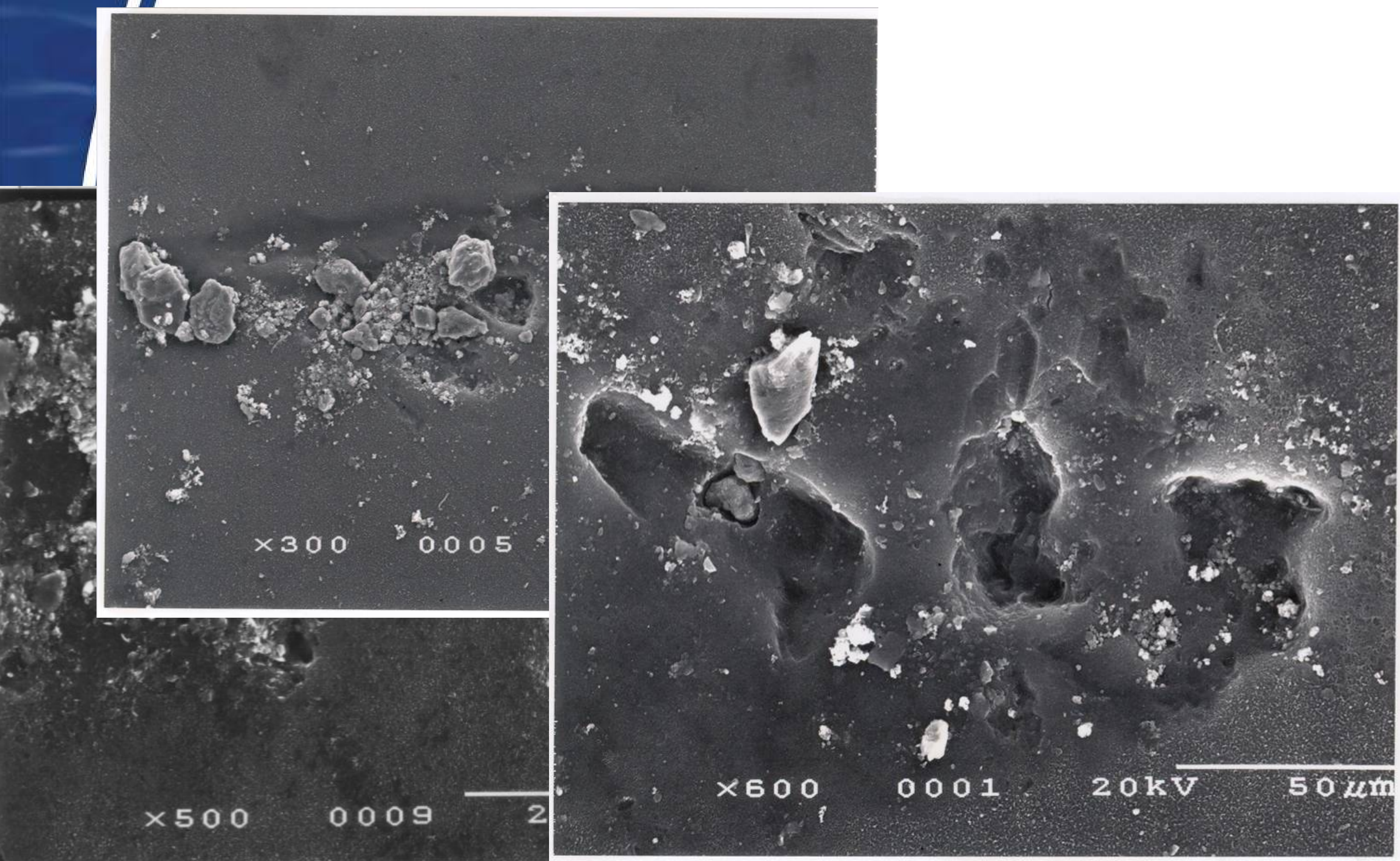
Composite PA Membrane Cross-Section



Keeping RO Membranes Clean

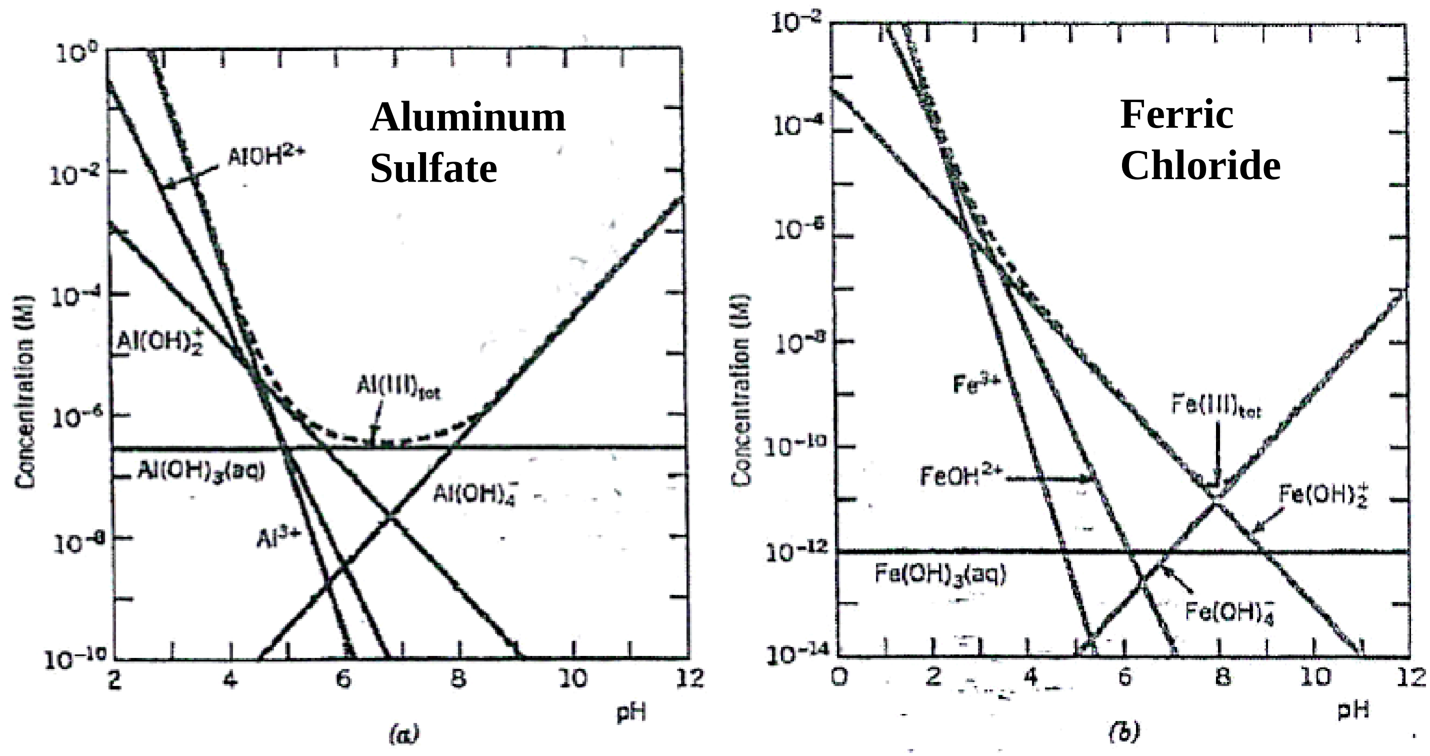


Surface Damage Caused by Particulate Matter on RO Surface



Coagulant Formation of Colloidal Foulant

C.J. Gabelich et al. / Desalination 150 (2002) 15–30



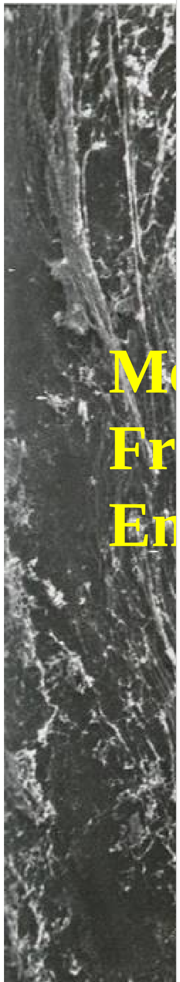
Solubility of amorphous (a) $Al(OH)_3$ and (b) $Fe(OH)_3$. Polynuclear complexes not included [25].

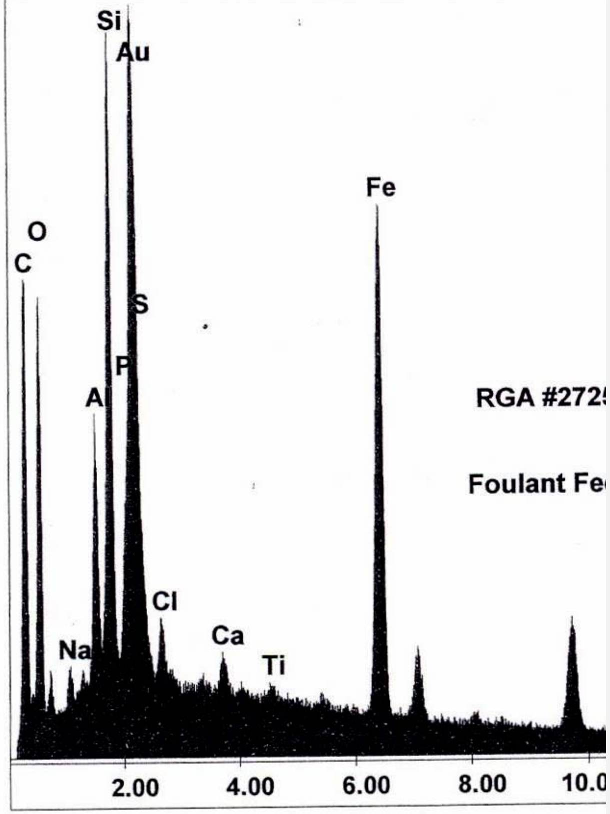
$$Al_2(SO_4)_3 \cdot 14\,H_2O + 3\,Ca(HCO_3)_2 \Rightarrow 2\,Al(OH)_3\downarrow + 3\,CaSO_4 + 6\,CO_2 + 14\,H_2O$$

$$2\,FeCl_3 + 3\,Ca(HCO_3)_2 \Rightarrow 2\,Fe(OH)_3\downarrow + 3\,CaCl_2 + 6\,CO_2$$

At pH 8.0, the solubility of iron is about 1 ug/l as $Fe(OH)_2^+$ and is much lower than for aluminum, which is 0.5 mg/l as $Al(OH)_4$

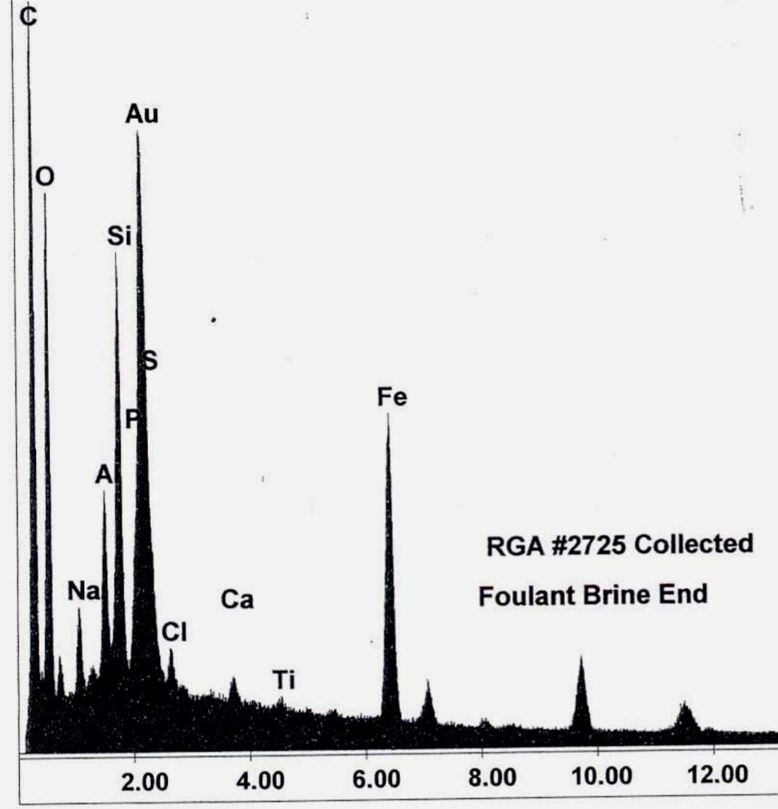
M
Fr
En





EDAX ZAF Quantification (Standardless)
Element Normalized

Element	Wt %	At %	K-Ratio	
C K	24.48	49.29	0.0467	1.10
O K	17.64	26.66	0.0357	1.08
NaK	0.82	0.86	0.0021	1.01
AlK	3.05	2.73	0.0149	1.01
SiK	6.87	5.92	0.0418	1.03
P K	1.86	1.45	0.0120	1.01
AuM	24.33	2.99	0.1958	0.74
S K	2.03	1.53	0.0111	1.04
ClK	1.03	0.70	0.0064	0.99
CaK	0.63	0.38	0.0050	1.01
TiK	0.32	0.16	0.0027	0.92
FeK	16.94	7.33	0.1538	0.93
Total	100.00	100.00		



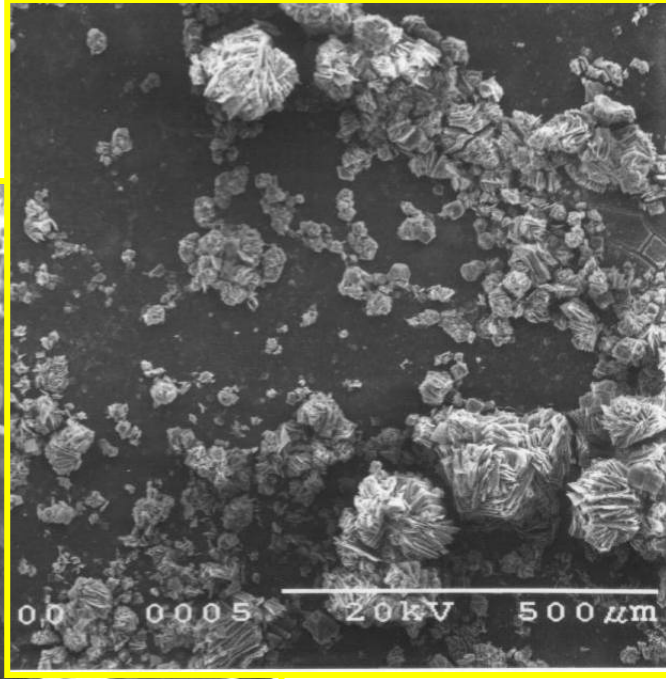
EDAX ZAF Quantification (Standardless)
Element Normalized

Element	Wt %	At %	K-Ratio	Z	A
C K	33.22	55.73	0.0746	1.0776	0.2085
O K	23.24	29.27	0.0456	1.0594	0.1851
NaK	1.71	1.50	0.0048	0.9912	0.2803
AlK	2.22	1.66	0.0114	0.9860	0.5220
SiK	4.54	3.26	0.0291	1.0146	0.6298
P K	1.36	0.89	0.0094	0.9851	0.6953
AuM	19.98	2.04	0.1695	0.7199	1.1777
S K	1.92	1.21	0.0114	1.0112	0.5874
ClK	0.57	0.33	0.0038	0.9653	0.6788
CaK	0.39	0.20	0.0032	0.9892	0.8286
TiK	0.23	0.10	0.0019	0.9039	0.9068
FeK	10.60	3.82	0.0948	0.9042	0.9792
Total	100.00	100.00			

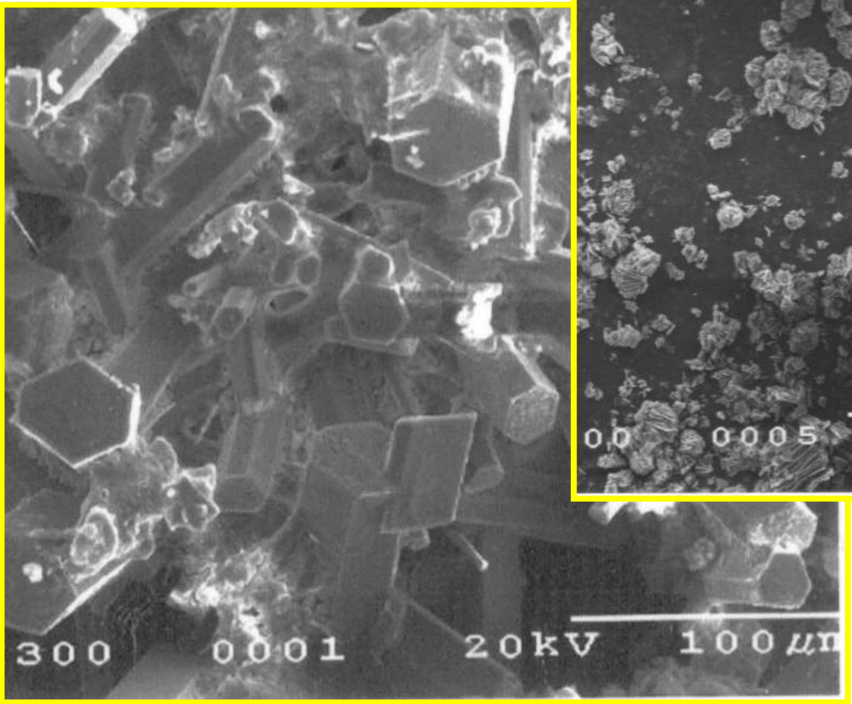
Particulate on Spiral Wound Element

Scaling – Precipitation of Sparingly Soluble Salts

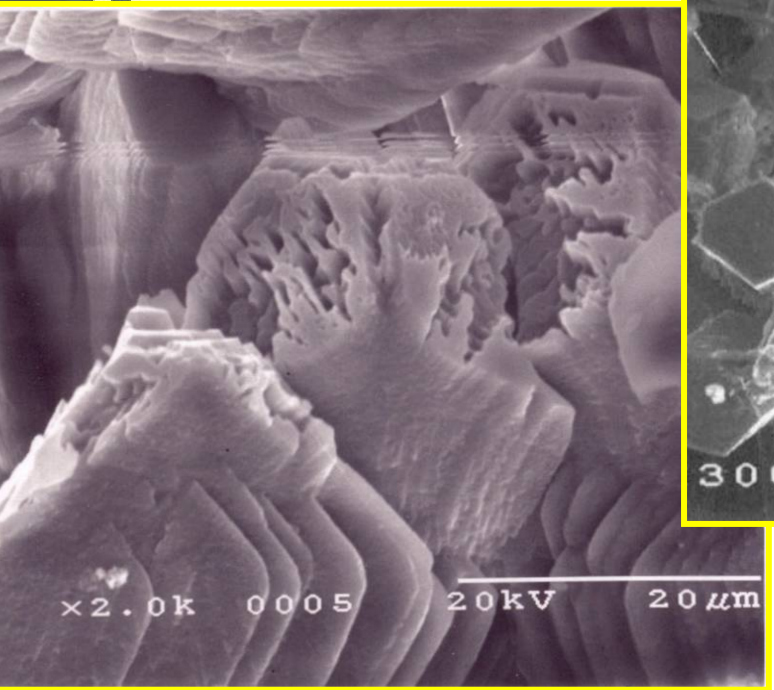
Calcium Phosphate



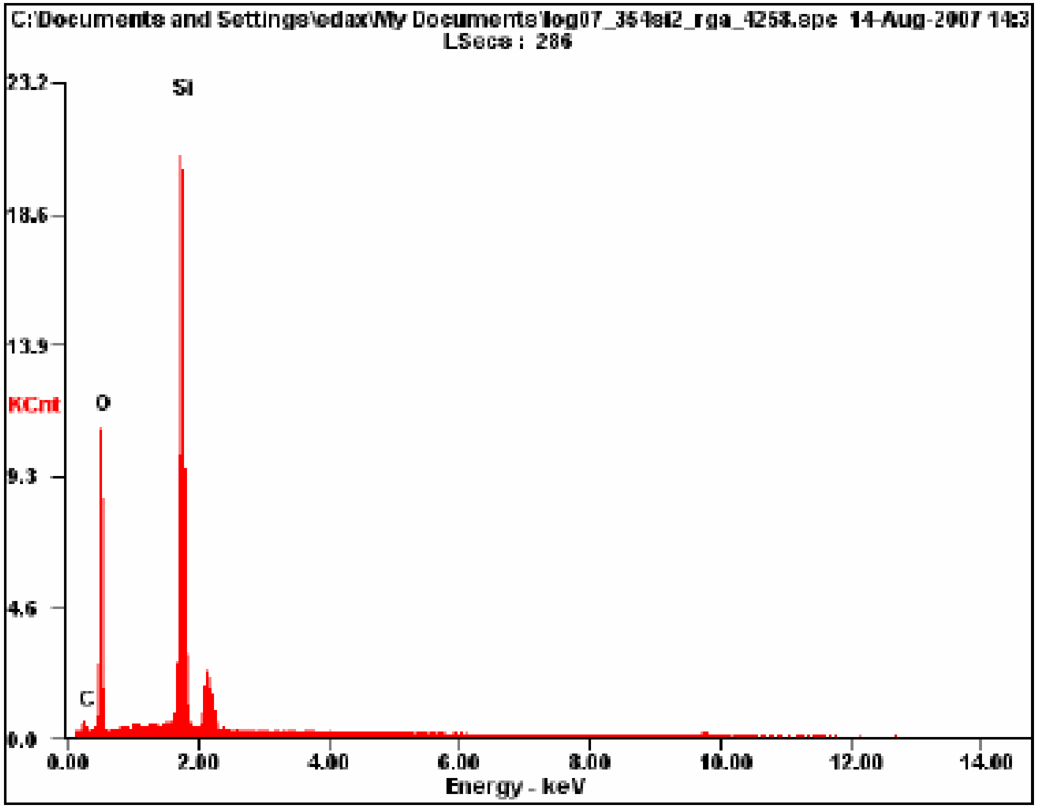
Calcium Sulfate



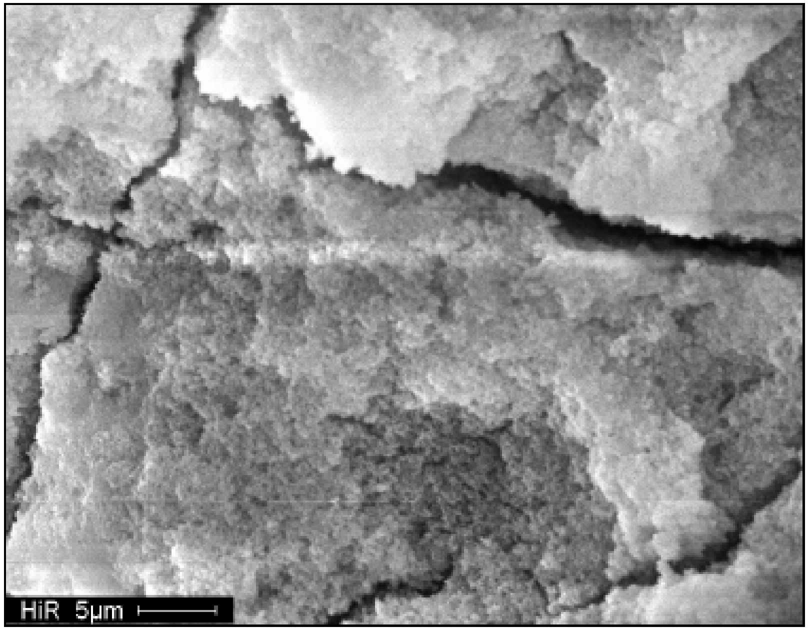
Calcium Carbonate



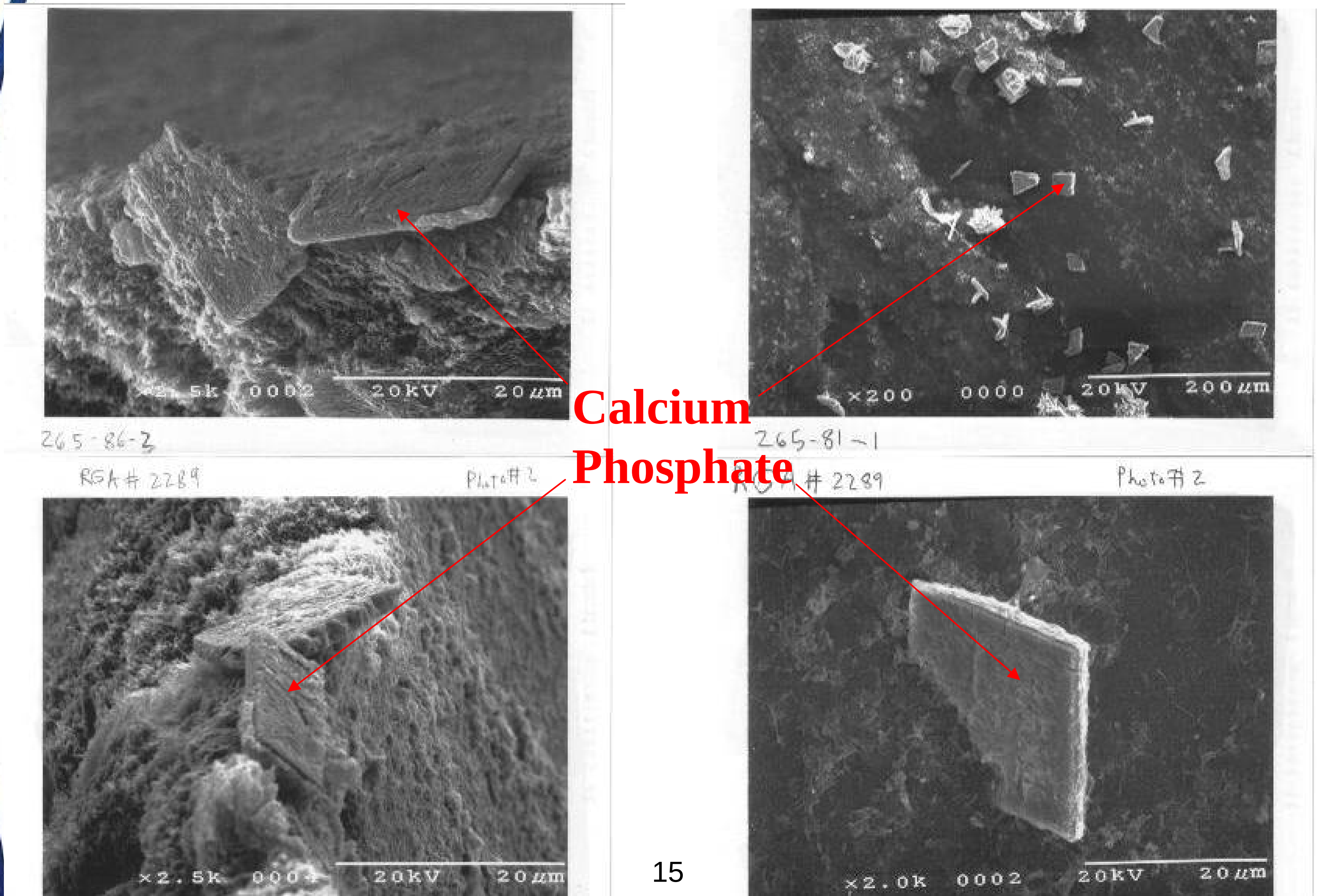
Silica Scale



Element	*Wt%*	*At%*
CK	10.22	16.23
OK	44.49	53.02
SiK	45.29	30.75
Matrix	Correction	ZAF



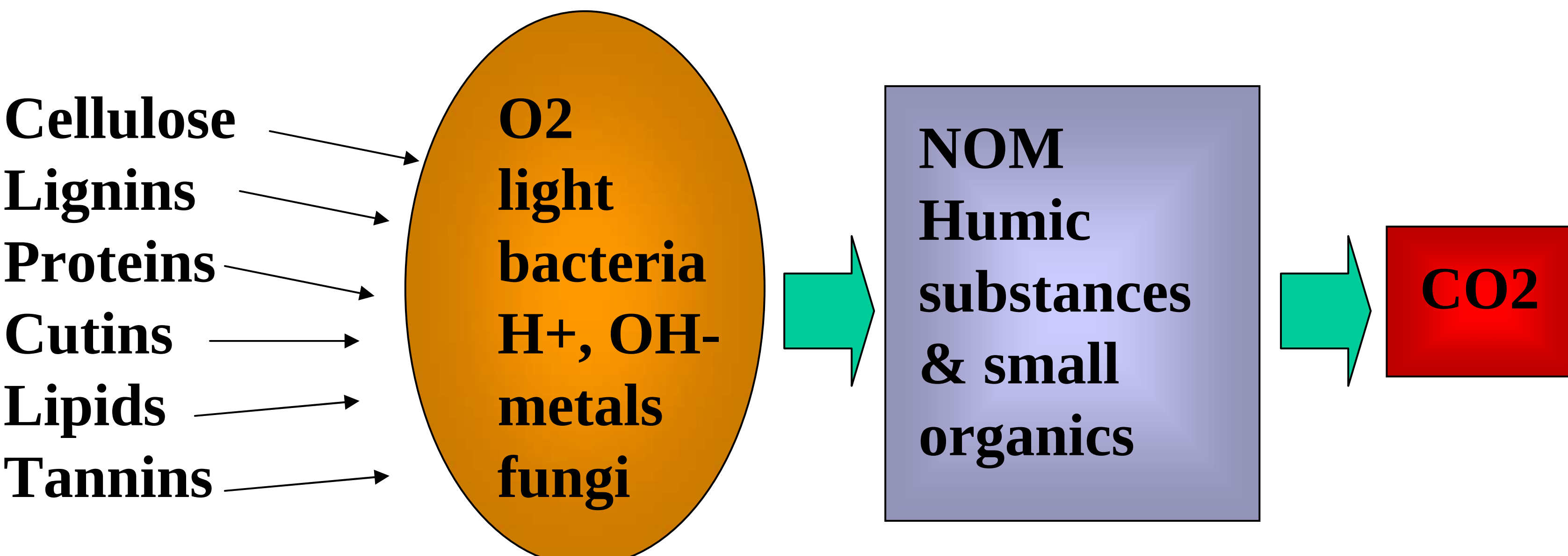
Damage of Membrane Surface by Calcium Phosphate Scale



Complex Organics: Naturally Occurring Matter (NOM)

Plant and animal decay products

- **Terrestrial- woody and herbaceous plants**
- **Aquatic- algae and macrophytes**



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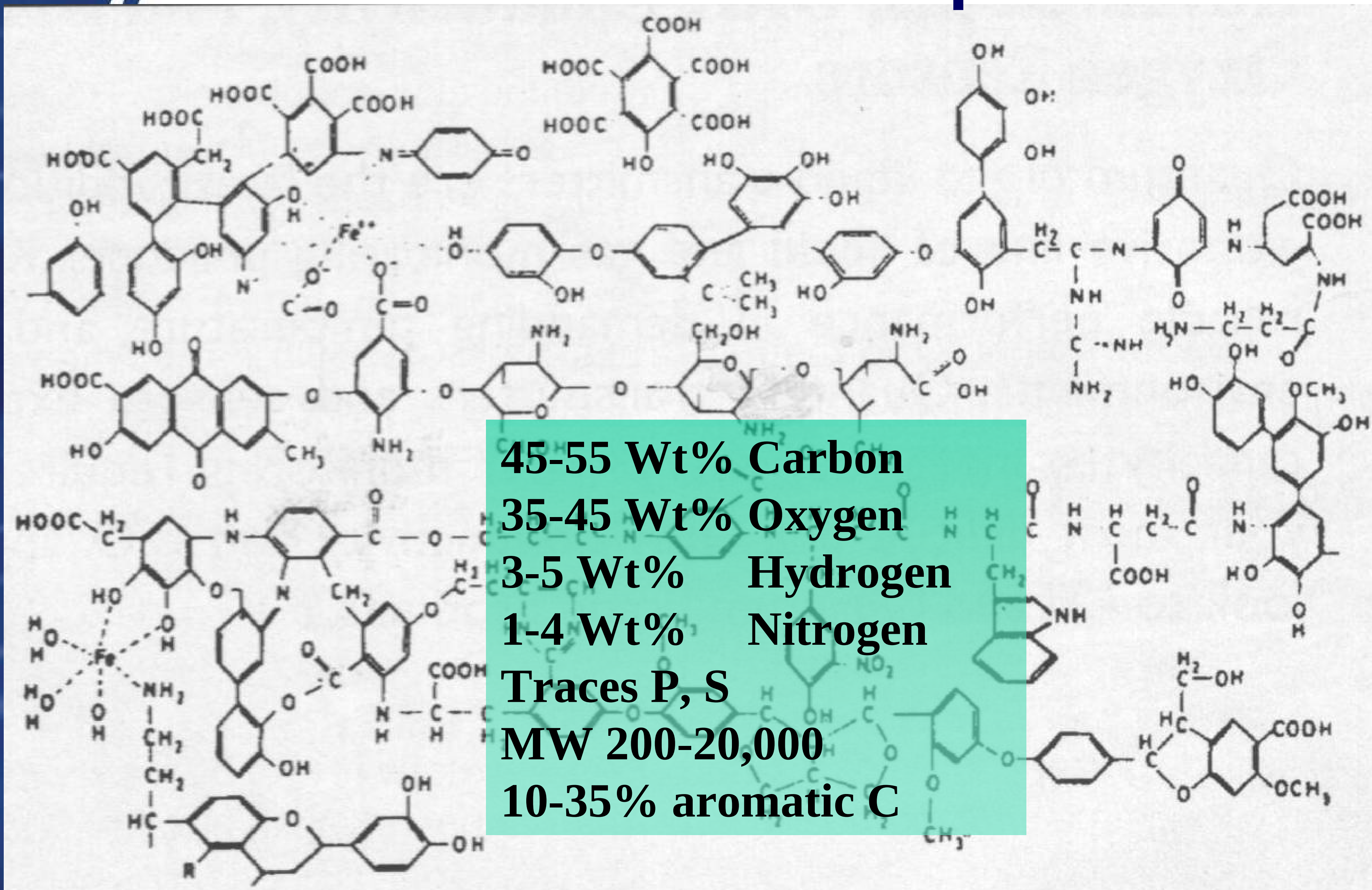
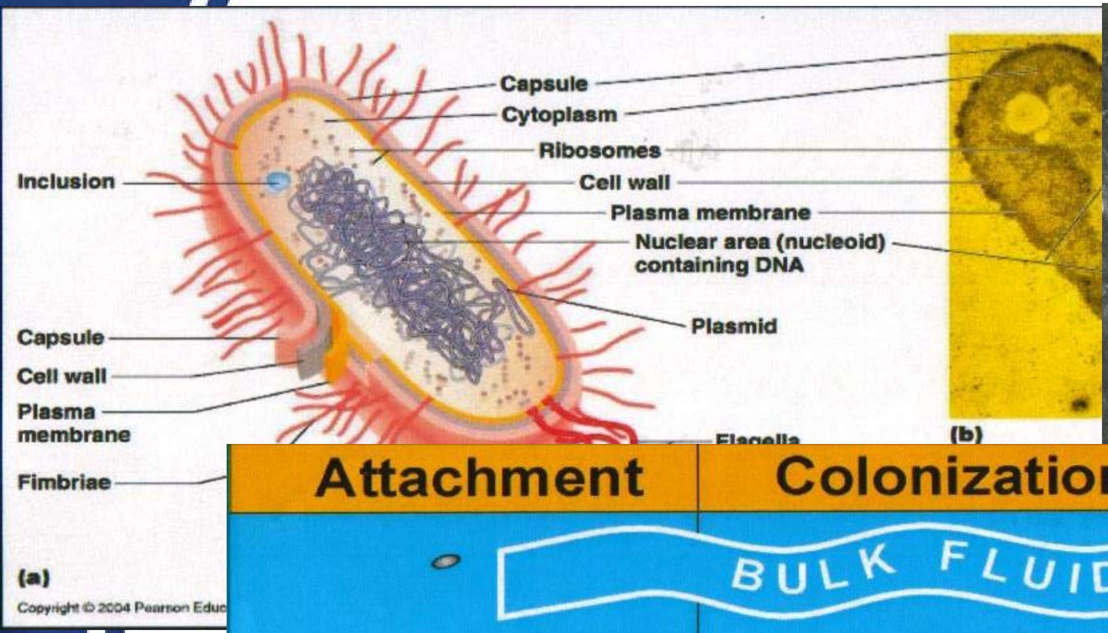
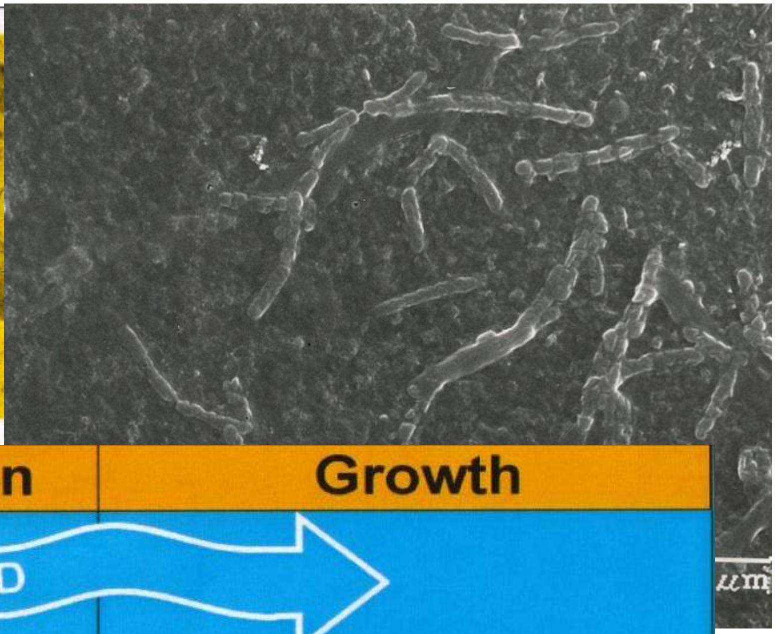
Naturally Occurring Matter(NOM): Structure and Composition

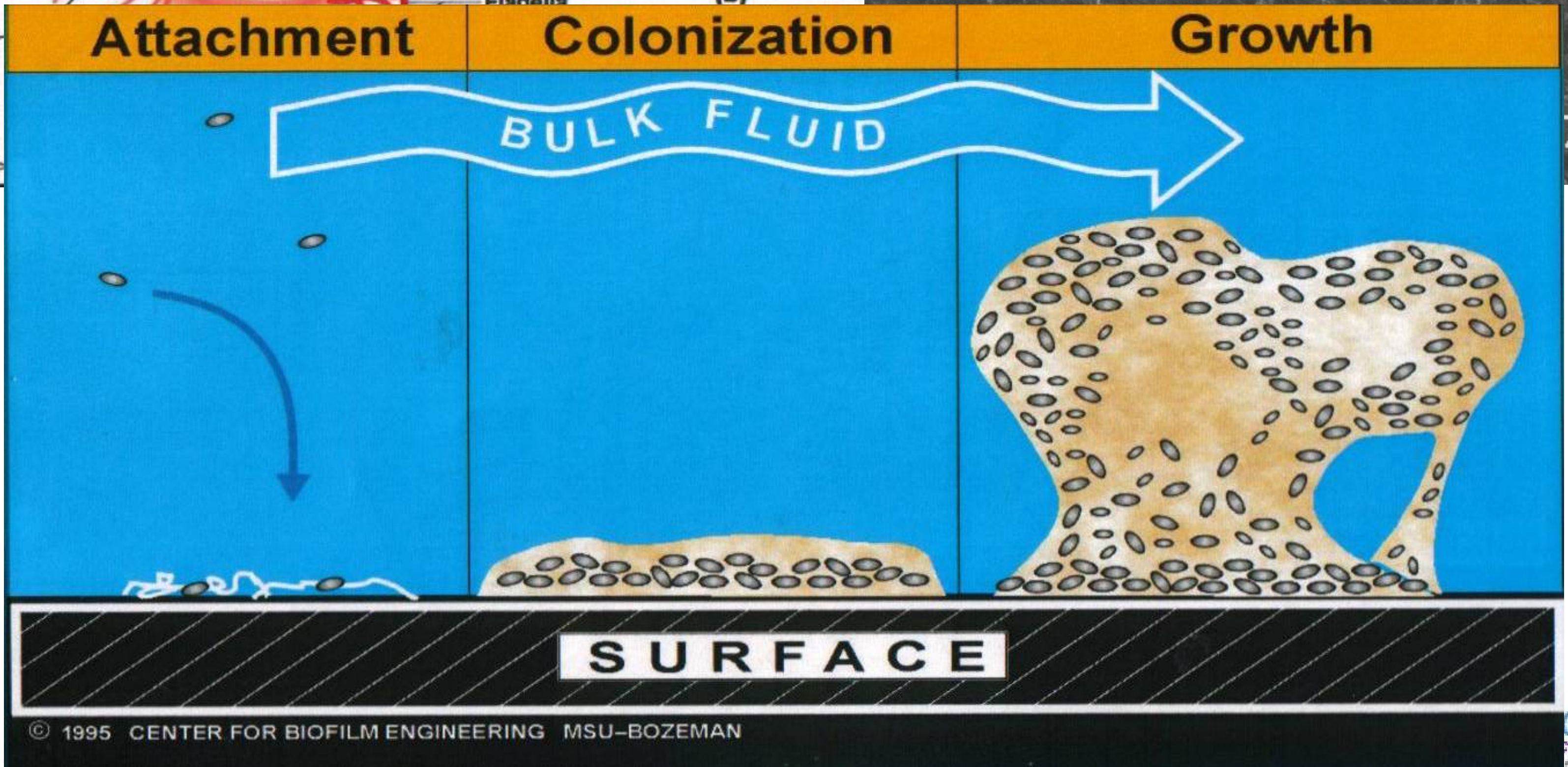


45-55 Wt% Carbon
35-45 Wt% Oxygen
3-5 Wt% Hydrogen
1-4 Wt% Nitrogen
Traces P, S
MW 200-20,000
10-35% aromatic C

Biofouling


Capsule
Cytoplasm
Ribosomes
Inclusion
Cell wall
Plasma membrane
Nuclear area (nucleoid) containing DNA
Plasmid
Capsule
Cell wall
Plasma membrane
Fimbriae
(a)
(b)




Attachment
Colonization
Growth
BULK FLUID
SURFACE
© 1995 CENTER FOR BIOFILM ENGINEERING MSU–BOZEMAN

Biofouled Membrane

Foulant Distribution in SWRO Pressure Vessel

Position	Ex-fact Rej, %	Ex-fact GPD	Retest Rej, %	Retest GPD	Retest DP, psi
1 (lead)	99.79	5354	99.78	5227	9.5
2	99.70	5126	99.84	5519	5.0
3	99.74	5729	99.81	6013	4.5
4	99.78	5775	99.81	6074	4.0
5	99.80	5427	99.88	5459	3.8
6	99.74	5511	99.83	6171	3.5
7	99.80	6127	99.84	6097	3.0
8 (tail)	99.80	6127	99.85	6074	3.2


RGA 2725
A653657

Prevention of Fouling

How Can I Prevent Scale Formation in My RO/NF System?

- Calcium Carbonate
  - Lower pH, lower recovery, change AS, soften water
- Calcium Sulfate
  - Lower recovery, Optimize Antiscalant, soften water
- Barium Sulfate
  - Lower Recovery, change AS, soften water
- Calcium Phosphate
  - Lower pH, change AS, lower recovery
- Silica
  - Increase pH, optimize AS, lower recovery

Recovery Limitations: Scaling

Hydranautics (warnings in program)

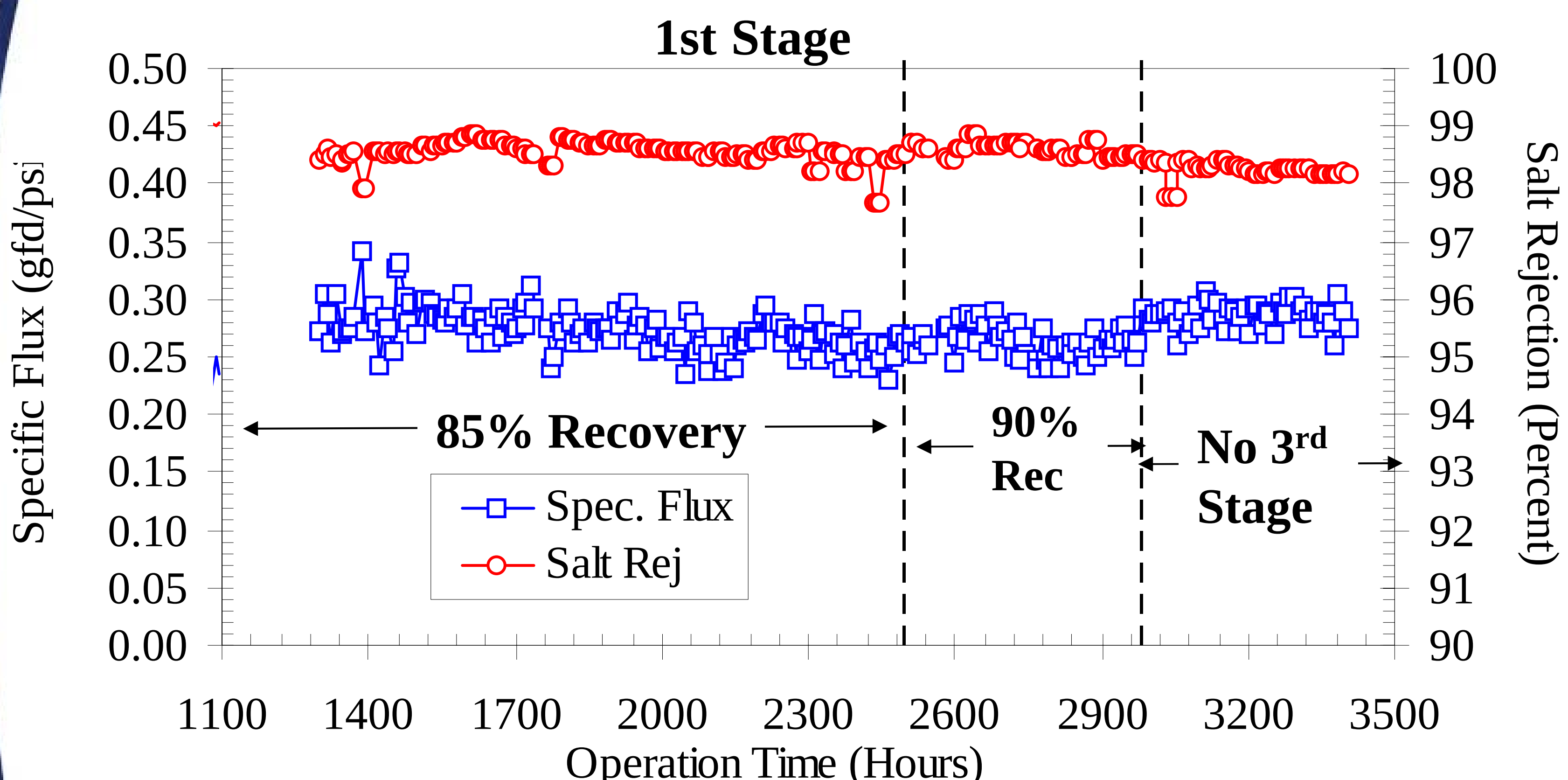
Saturation Limits:

CaSo4 230 %
SrSO4 800 %
BaSO4 6000 %
SiO2 100 %
LSI <1.8 (Brackish Feed w. Scale Inhibitor)

Proprietary Chemicals (software provided by vendors)

	Product A	Product B
$CaSO_4$	350%	250%
Sr_2SO_4	3500%	3000%
Ba_2SO_4	10500%	6500%
SiO_2		240 mg/L
$CaCO_3$	L.S.I. 3.0	L.S.I. 2.5
CaF_2	1300000%	10000%

Example of Normalized Data Showing Scale Formation



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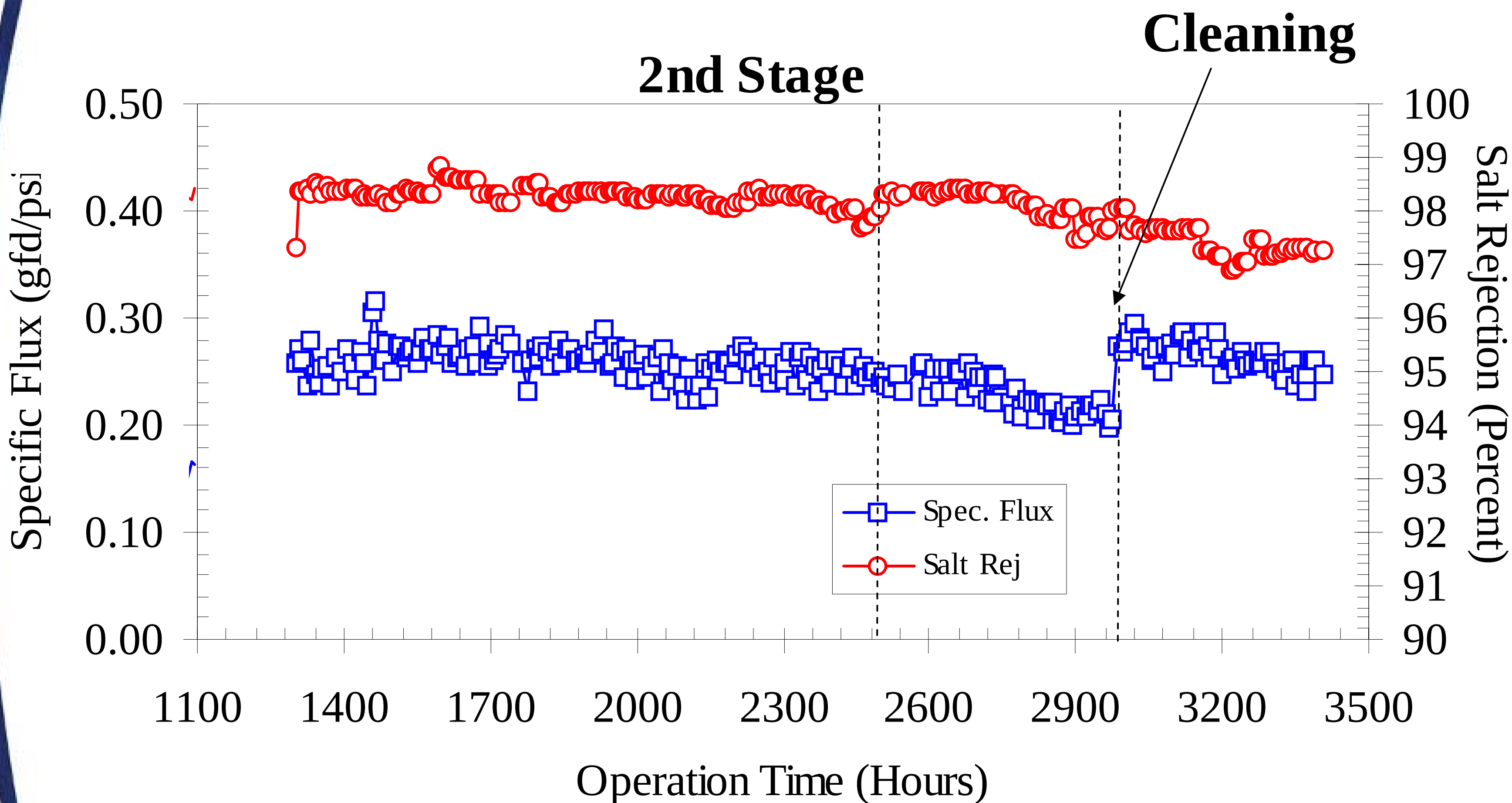
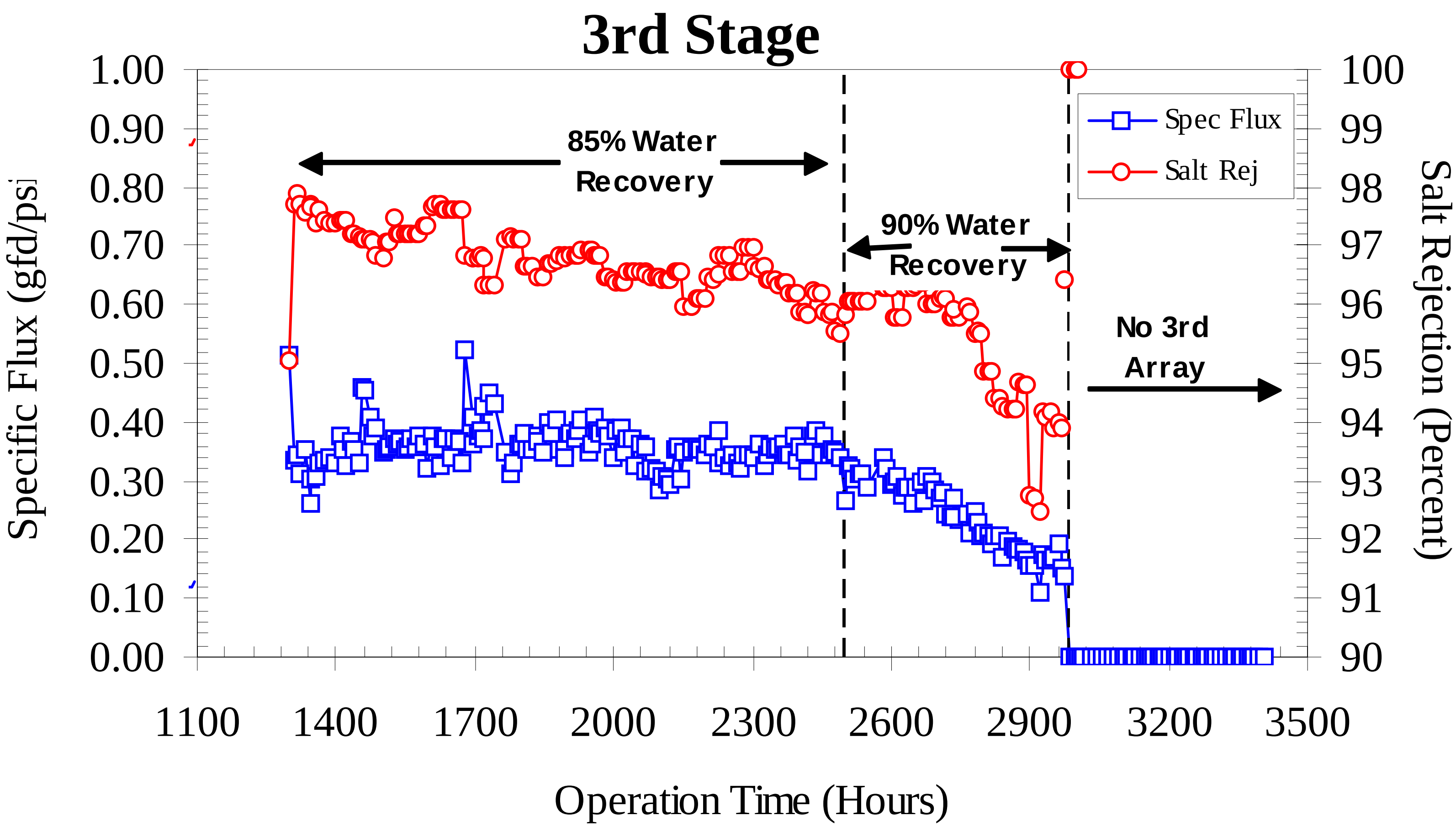
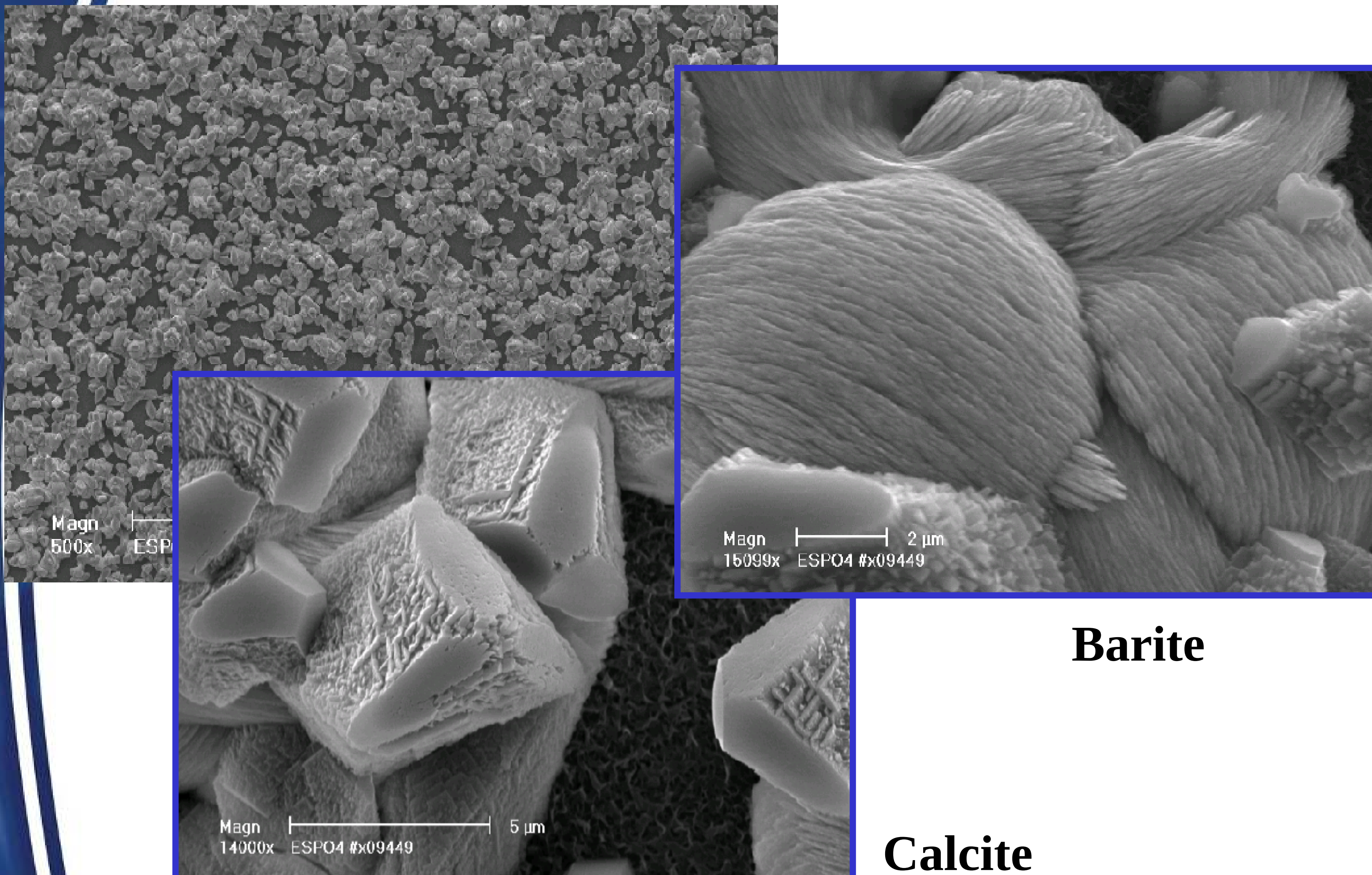
Example of Normalized Data Showing Scale Formation



Example of Normalized Data Showing Scale Formation



Third Stage Element Showing Scale Formation



Barite

Calcite

How Can I Reduce Colloidal Fouling in My RO/NF System?

- Measurement
  - SDI (< 3 preferred)
  - Turbidity (< 0.1 preferred)
  - Particle Counts (<100 of 2 µm particles/ml)
- Optimize Your Media Filtration
  - Media Selection
  - Coagulant Optimization
  - Proper Filtration Velocities

SDI - Silt Density Index

- Test is used to indicate the quantity of particulate matter in water
- SDI is used to determinate effectiveness of pretreatment
- SDI has been empirically correlated with the fouling tendency of membranes
- SDI will vary with filter paper manufacturer
- SDI may vary with water temperature

SDI formula

$$SDI_T = (1 - T_0/T_T)/T * 100$$

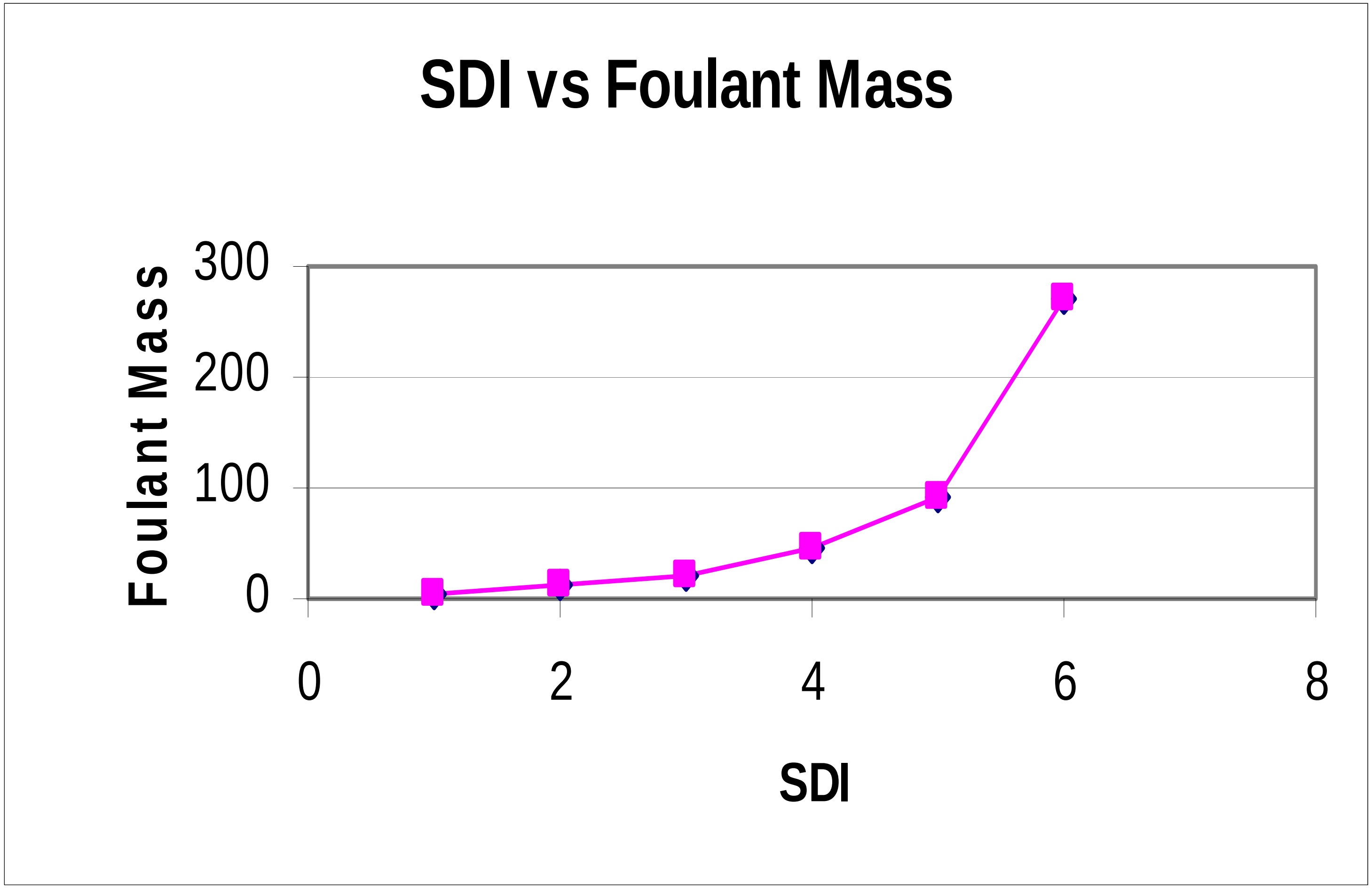
T = Total elapsed flow time (usually 15 min.)

T_0= Initial time required to collect 500 ml of sample

T_T= Time required to collect 500 ml of sample after test time T (usually 15 min.)

Test should be done at 207 kPa ± 7 kPa

How Can I Reduce Colloidal Fouling in My RO/NF System?



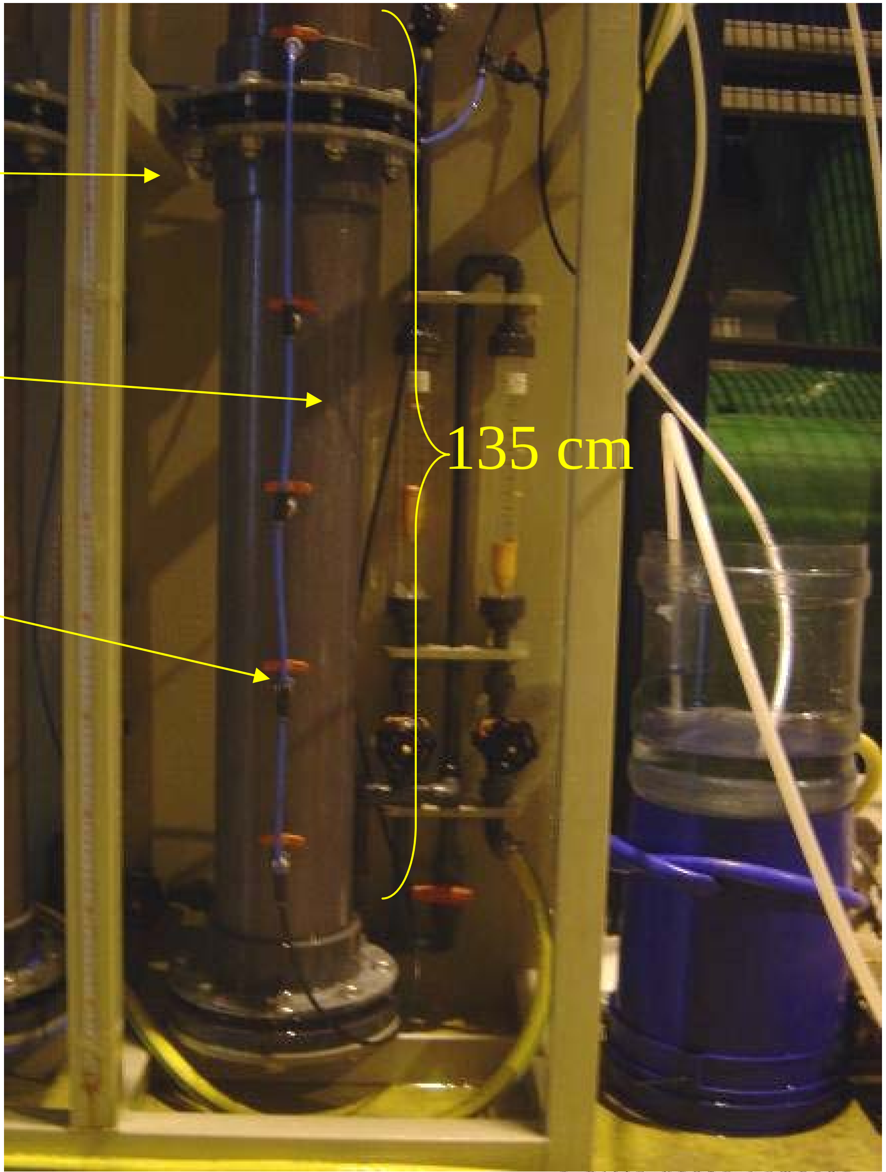
“Silt Density Indices (SDI), percent plugging factor (%PF); their relation to actual foulant deposition”, Seymour S.Kremen, Matt Tanner, Desalination 119 (1998) 259-262

Optimized Media Filtration for Improving Colloidal Foulant Removal

150 mm Tube

Media Layer

Pressure Taps



Pilot Trials at the Plant

Example SWRO Pilot Plant Trials in Mediterranean Region

3 x 150mm columns @ 11 m/hr filtration velocity

- Col #1: New Media, same coagulant as plant
- Col #2: Existing Media, new coagulant
- Col #3: New Media, new coagulant

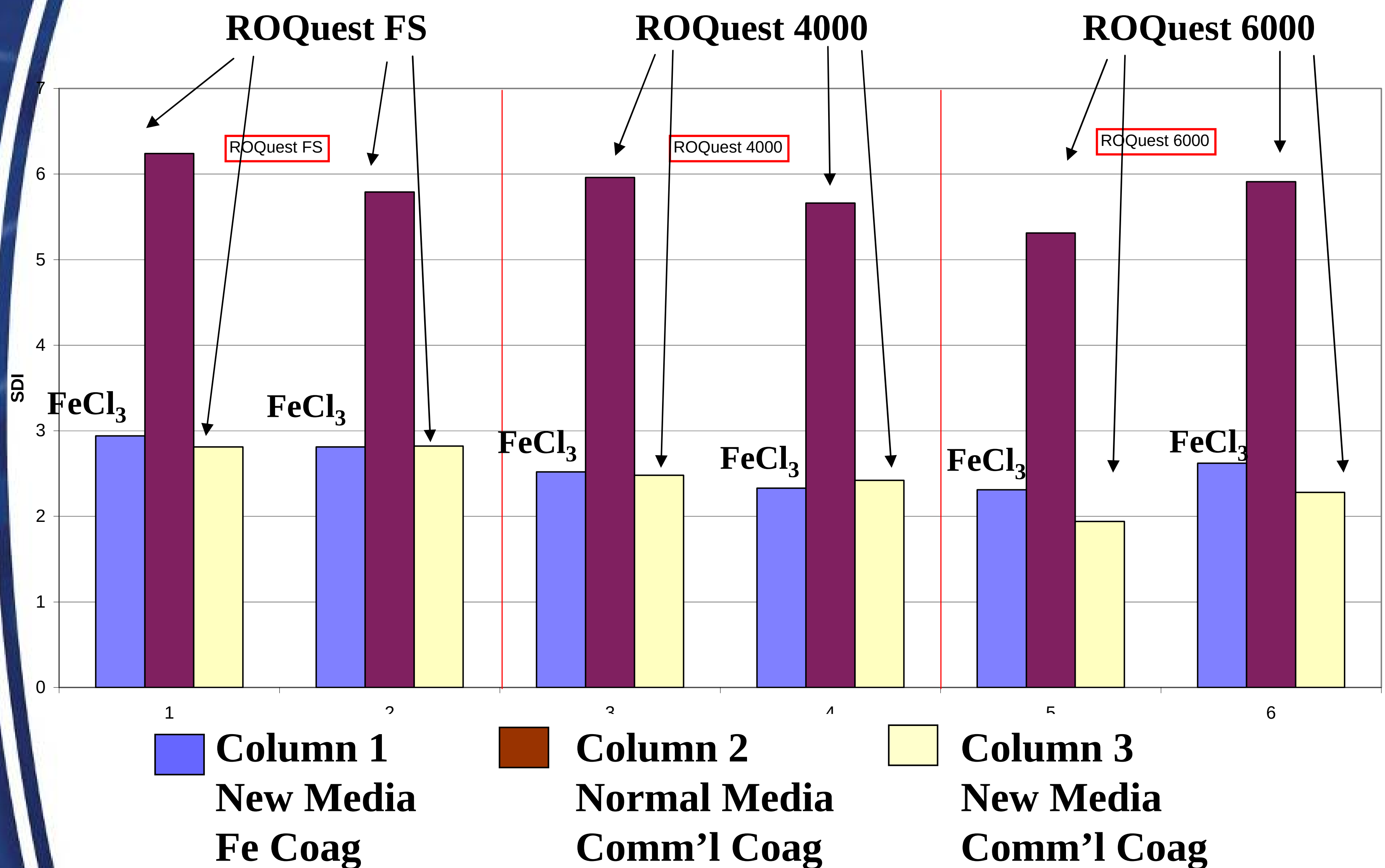
Media

- Existing Media: 300 mm depth of 2.1 mm grain sand + 1000 mm depth of 0.94 mm grain sand
- New Media: 500 mm depth 0.4-0.8mm fine sand + 700 mm porous volcanic pumice

Coagulant

- Existing Coagulant: Ferric Chloride
- New Coagulant: Avista ROQuest Commercial Coagulant/Flocculant (FS, 4000, 6000)

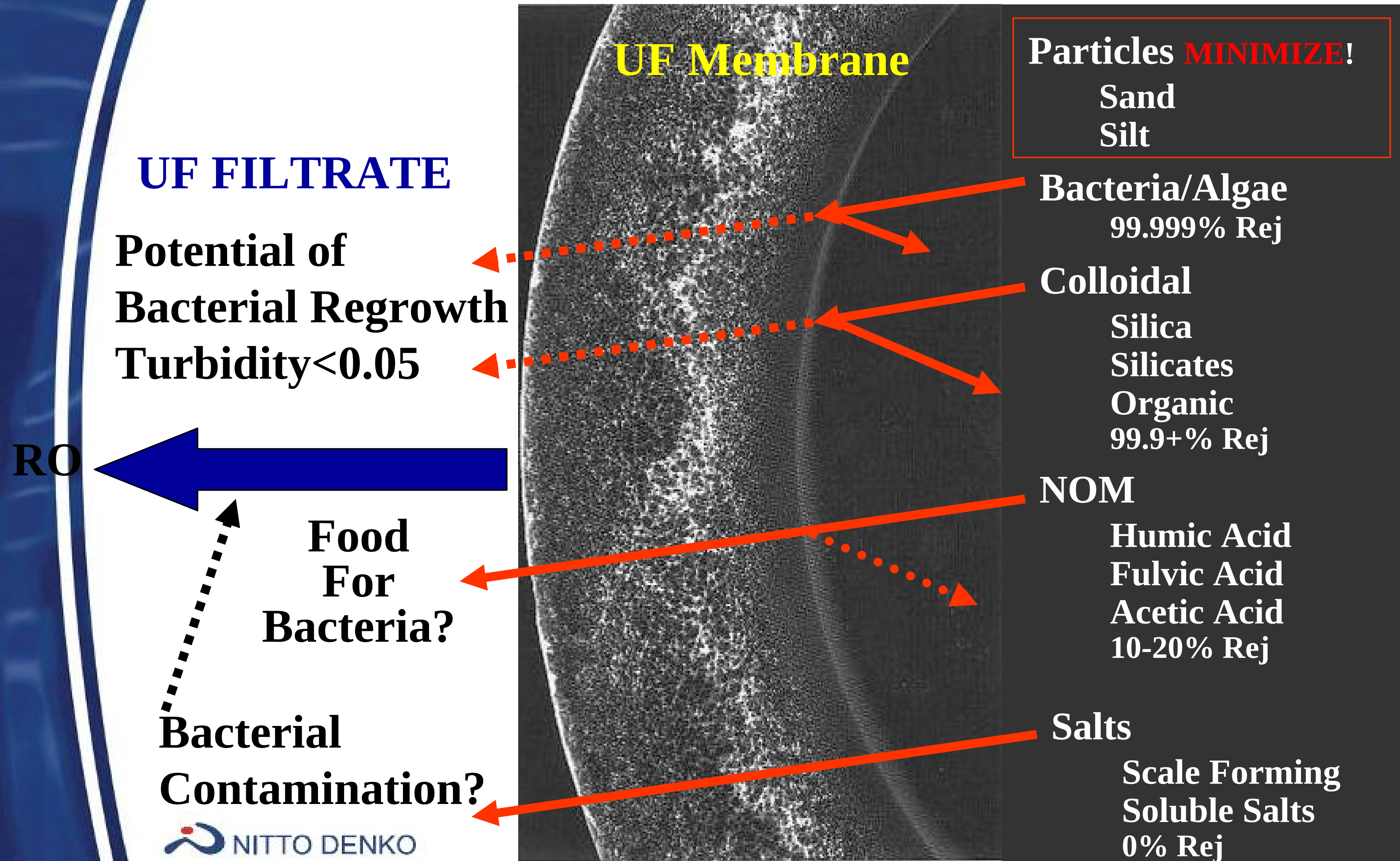
Filtration Test : SDI Comparison of Various Coagulants/Flocculants



How Can I Reduce Colloidal Fouling in My RO/NF System?

- Measurement
  - SDI (< 3 preferred)
  - Turbidity (< 0.1 preferred)
  - Particle Counts (<100 of 2 µm particles/ml)
- Optimize Your Media Filtration
  - Media Selection
  - Coagulant Optimization
  - Proper Filtration Velocities
- Membrane Pretreatment
  - MF is generally 0.2 micron
  - UF is generally 0.02 micron

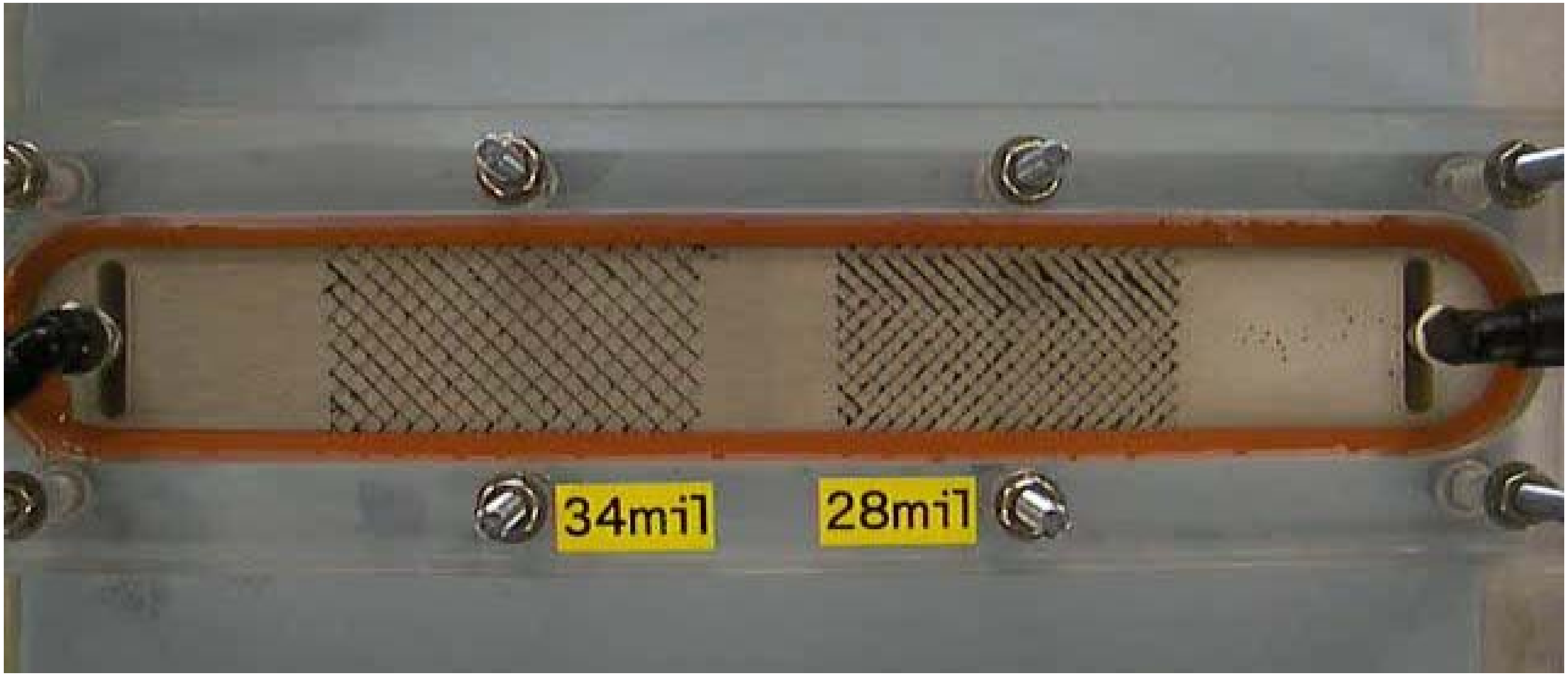
Role of UF Pretreatment: Example
Hydracap Capillary UF Membrane



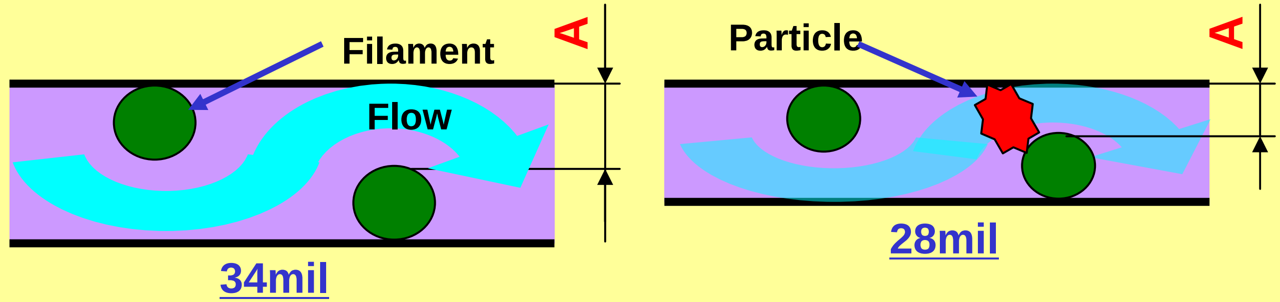
How Can I Reduce Colloidal and Particulate Fouling in My RO/NF System?

- Measurement
  - SDI (< 3 preferred)
  - Turbidity (< 0.1 preferred)
  - Particle Counts (<100 of 2 µm particles/ml)
- Optimize Your Media Filtration
  - Media Selection
  - Coagulant Optimization
  - Filtration Velocities
- Membrane Pretreatment
  - MF is generally 0.2 micron
  - UF is generally 0.02 micron
  - Maintain Fiber Integrity
- **Feed/Brine Spacer in the Element**
  - **Increased thickness minimizes dP Increase**

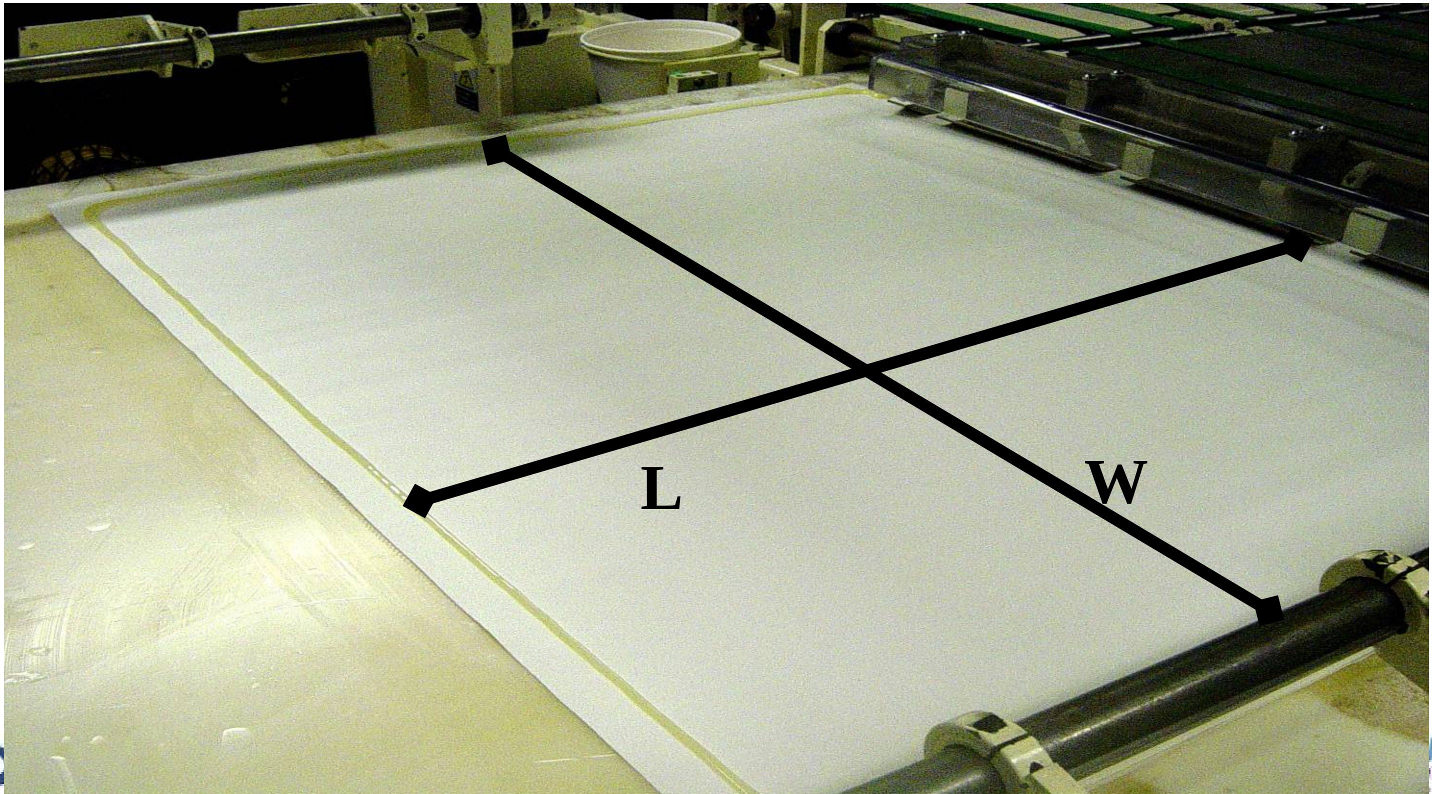
Effect of Feed/Brine Spacer Thinkness on Fouling Rates:



Automated Glue Line Control Allows Thicker Spacers without Membrane Area Loss



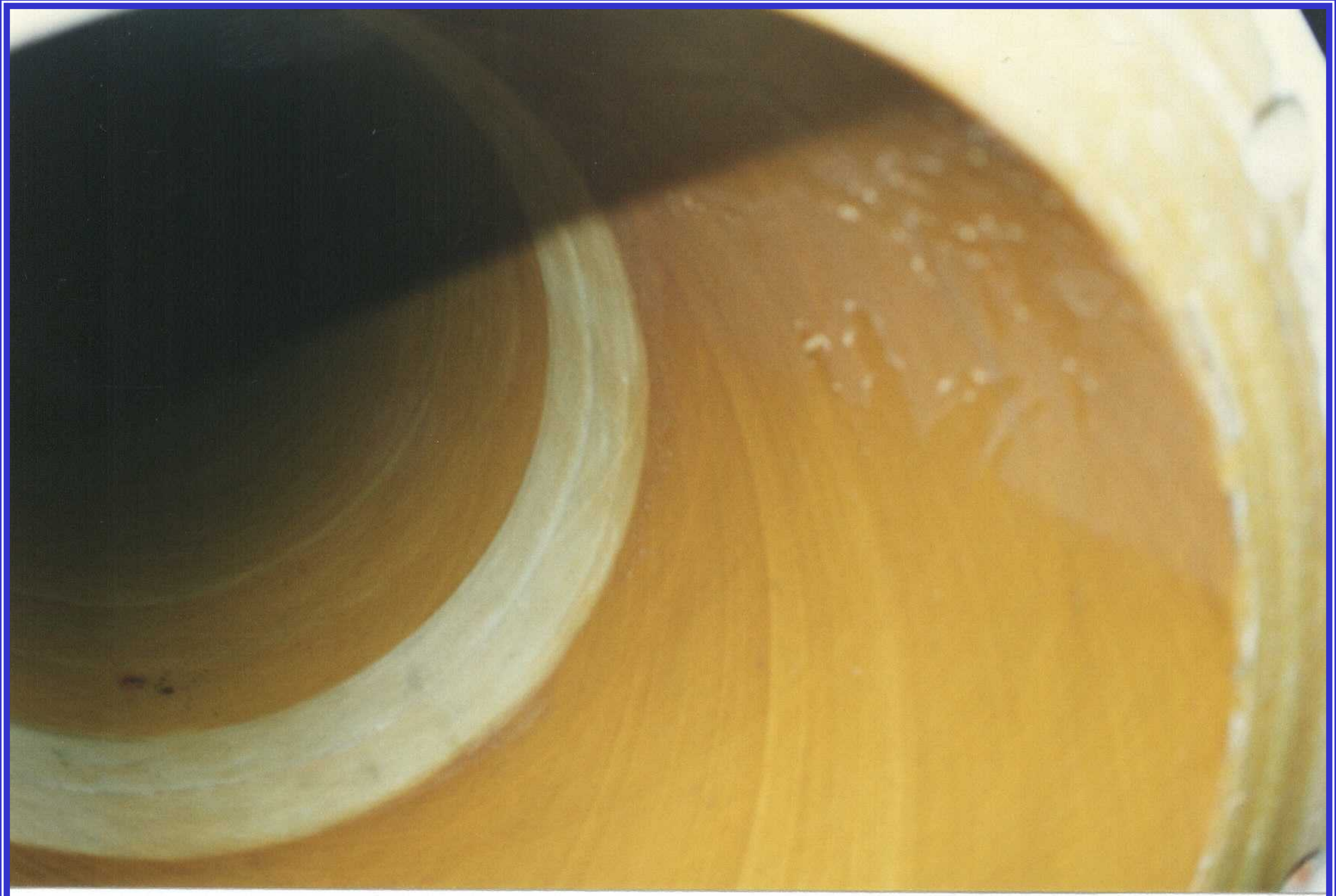
Clearance A of 34mil is 20% wider than 28mil's



How Can I Reduce Biofouling in My RO/NF System?

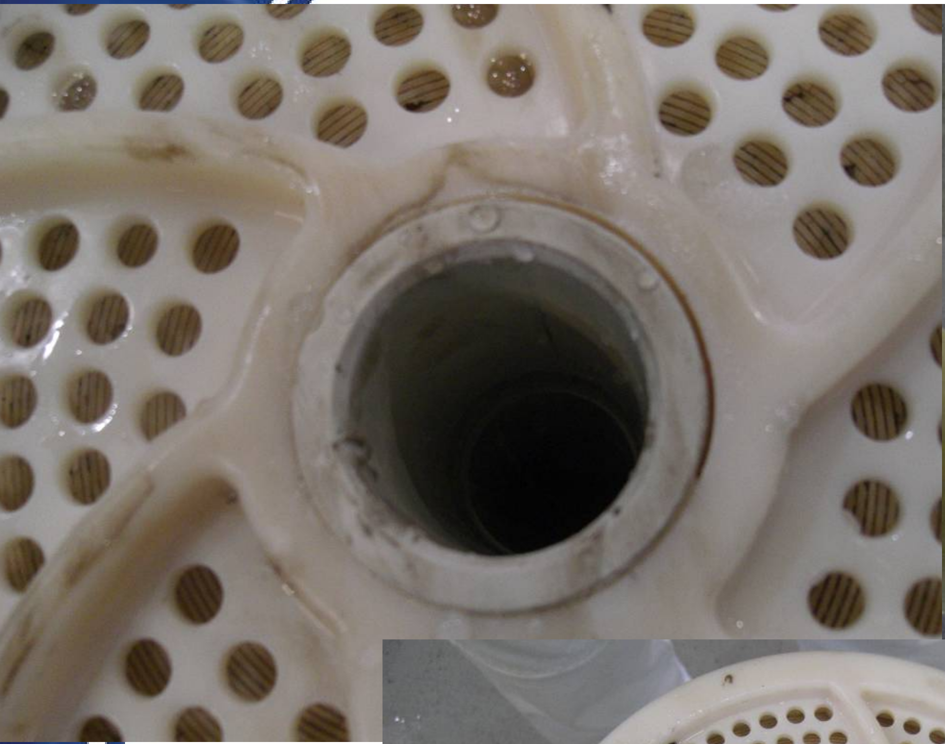
- Measurement
  - Bacteria Counts
  - Slime Formation
  - Weigh Elements
- Prevent Formation of Assimible Organic Carbon (AOC)
  - Avoid Continuous Chlorination/Dechlorination
  - Use Shock Dosing as Needed
  - Disinfect Lines
  - UV Prior to High Pressure pump
- Chemical Prevention of Biofouling
  - DBNPA Non Oxidizing chemical
  - Isothiazolin
  - Chloramines (with caution)

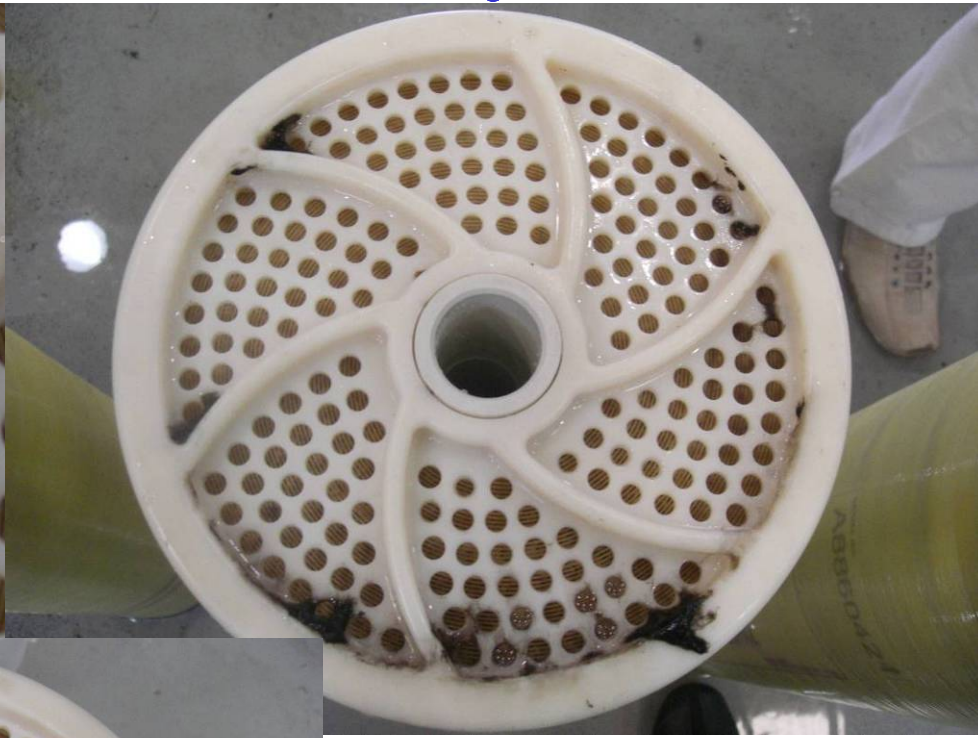
Heavy Biofouling



Biofouling - pipework cleaning

BWRO Train A Performance - Biofouling



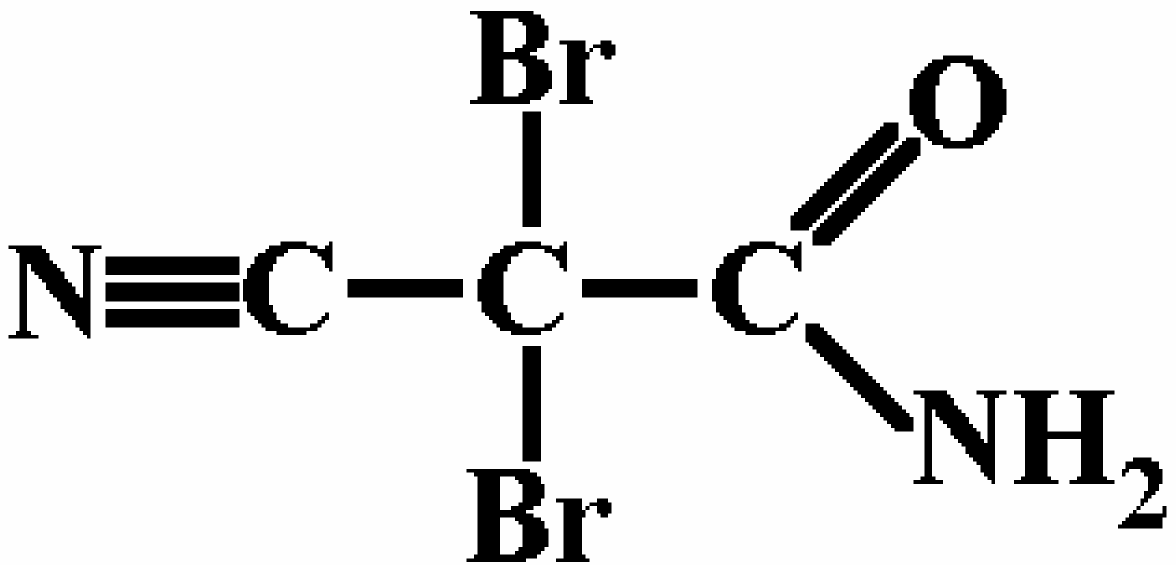


DBNPA Non Oxidizing Biostatic Agent

- Slug dosing, 10 – 100 ppm of active ingredient for 30 minutes to 3 hours every 5 days
- During slug dosing, the permeate should be dumped if it is for a potable water system.
- For continuous dosing, between 0.5 to 1 ppm of active ingredient is recommended.
- Although DBNPA is non-oxidizing, it will give an ORP reading of about 400 mv when in the range of 0.5 – 3 ppm (for comparison, 1 ppm chlorine typically gives an ORP reading of about 700 mv).
- For CIP use, 100-200 ppm of active ingredient for 1 hour would be recommended and keep pH neutral

DBNPA

2,2-dibromo-3-nitrilopropionamide



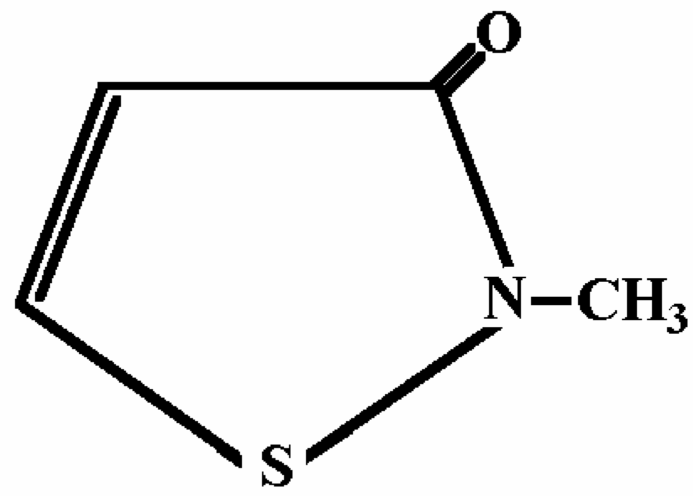
MW = 242

Formula: $C_3H_2Br_2N_2O$

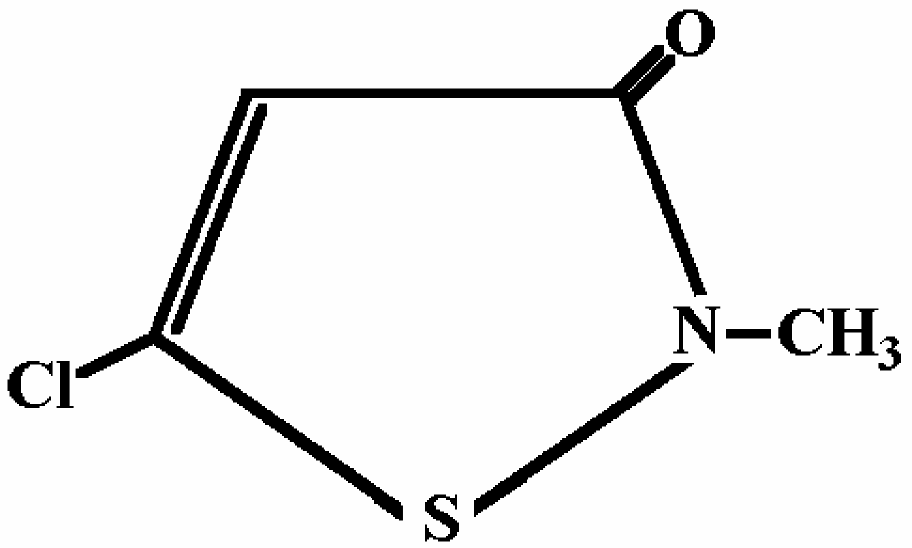
Isothiazolin

- **4 Hours of Contact time (or more)**
- **Broad Spectrum Biostatic Agent**
- **Target: Aerobic and Anaerobic Bacteria, Fungi, and Algae**
- **pH Range: 6 – 9**
- **Known under trade name - Kathon**

Isothiazolin

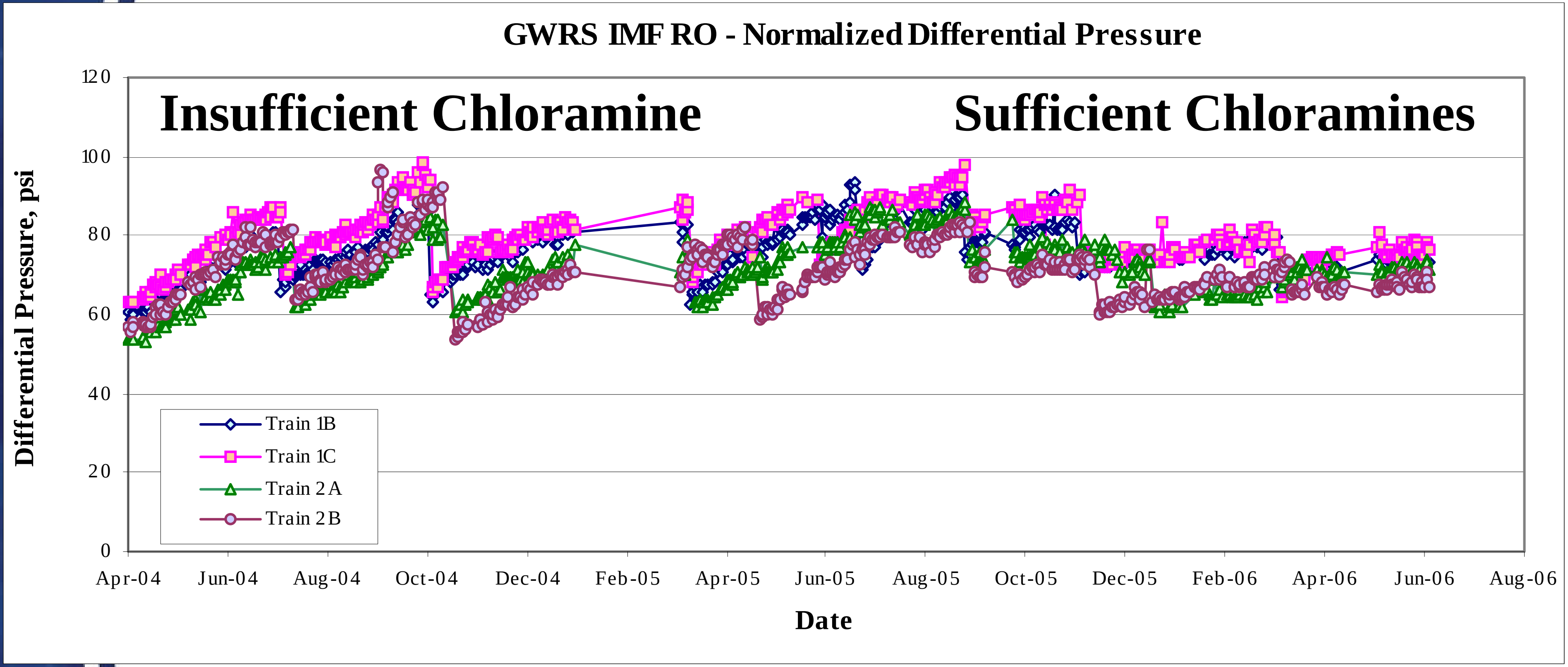


2-methyl-4-isothiazolin-3-one

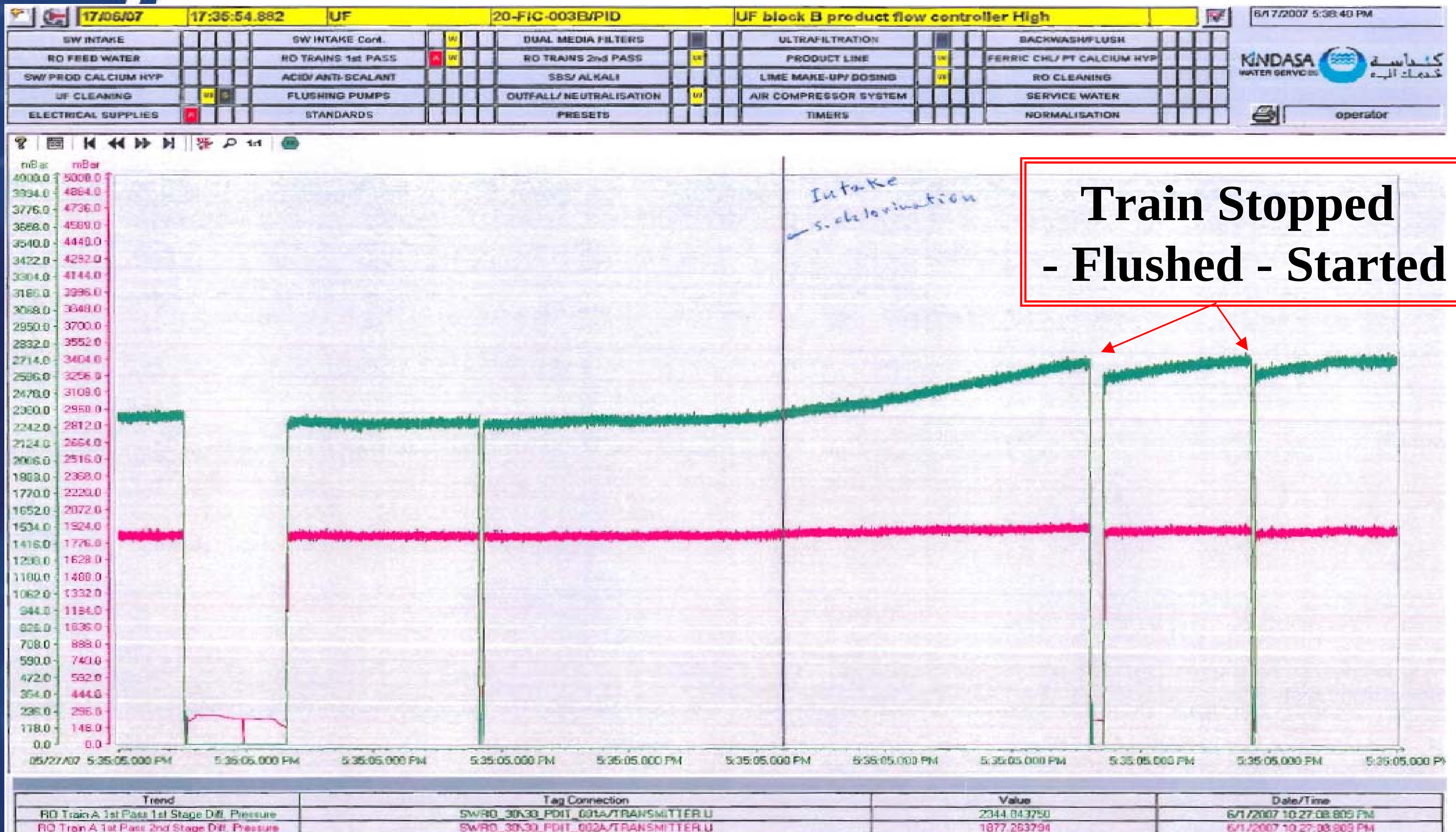


5-chloro-2-methyl-4-isothiazolin-3-one

Chloramine Use in Wastewater



Permeate Flushings



NITTO DENKO

HYDRANAUTICS
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Trouble-Shooting Guidelines

Possible Cause	Possible Location	Pressure Drop	Feed Pressure	Salt Passage
Metal Oxide Fouling (e.g. Fe,Mn,Cu,Ni,Zn)	1st stage lead elements	Rapid increase	Rapid increase	Rapid increase
Colloidal Fouling (organic and/or inorganic complexes)	1st stage lead elements	Gradual increase	Gradual increase	Slight increase
Mineral Scaling (e.g. Ca, Mg, Ba, Sr)	Last stage tail elements	Moderate Increase	Slight increase	Marked increase
Polymerized Silica	Last stage tail elements	Normal to increased	Increased	Normal to increased
Biological Fouling	Any stage, usually lead elements	Marked increase	Marked increase	Normal to increased
Organic Fouling (dissolved NOM)	All stages	Gradual increase	Increased	Decreased
Antiscalant Fouling	2nd stage most severe	Normal to increased	Increased	Normal to increased

Strategy to Minimize Membrane Fouling

Colloidal Fouling
• Effective Fine Filtration (UF, MF preferred)
•Optimize Coagulation of colloidal particles
•Eliminate Filter Bypass

Biofouling
•No Continuous Chlorination
•Minimize Excess SBS Over-dosing
•Sanitize System as Needed
•Remove Bio-food source with effective coagulation/filtration
•Eliminate GAC filters

Scaling
•Prevent oxidation of Fe^{2+}
•Exceeding saturation rarely an issue with 1st pass SWRO
•Calculate correctly saturation in BWRO
•Use proper AS

Organic Adsorption
•Minimize the destabilization of the organics in the water
• Intake protected from free oil, free oil monitors

Cleaning Procedures

System

Planned Regime

Cleaning Sequences

Cleaning Procedure

Manual procedure with necessary interlocks

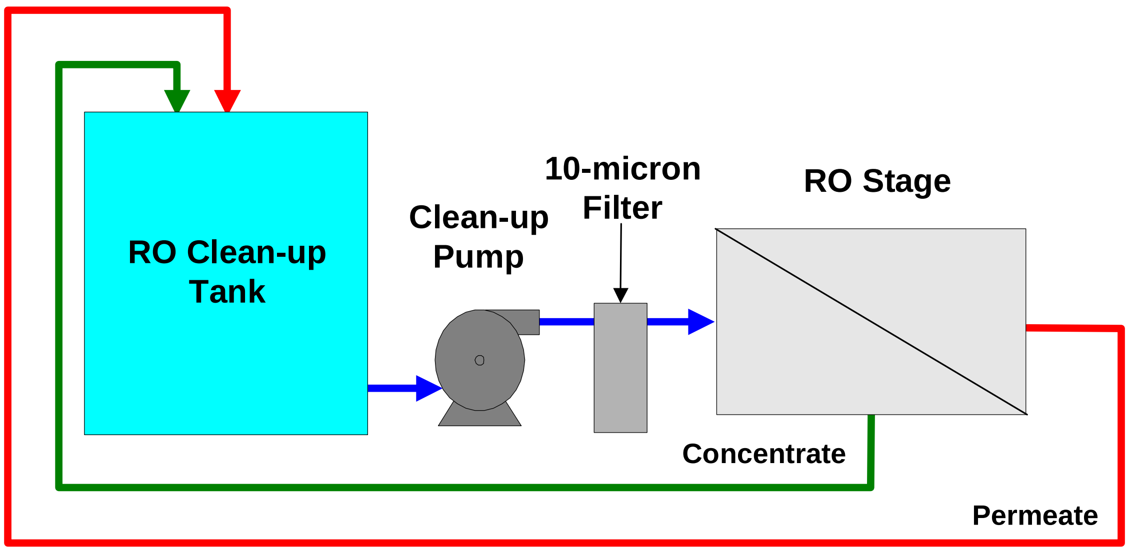
System consists of:

- cleaning tank
  - Sizing for retention time ~ 4 minutes
  - Take in consideration losses in the system
  - Eliminate foaming
  - Eliminate suckback
- cleaning pump – size with flow 10 – 12 $m^3/h/PV$
- cleaning heater – important to keep T as high as possible close to 40ºC
- Cleaning once every 6 months

Cleaning regime depends on the type of fouling

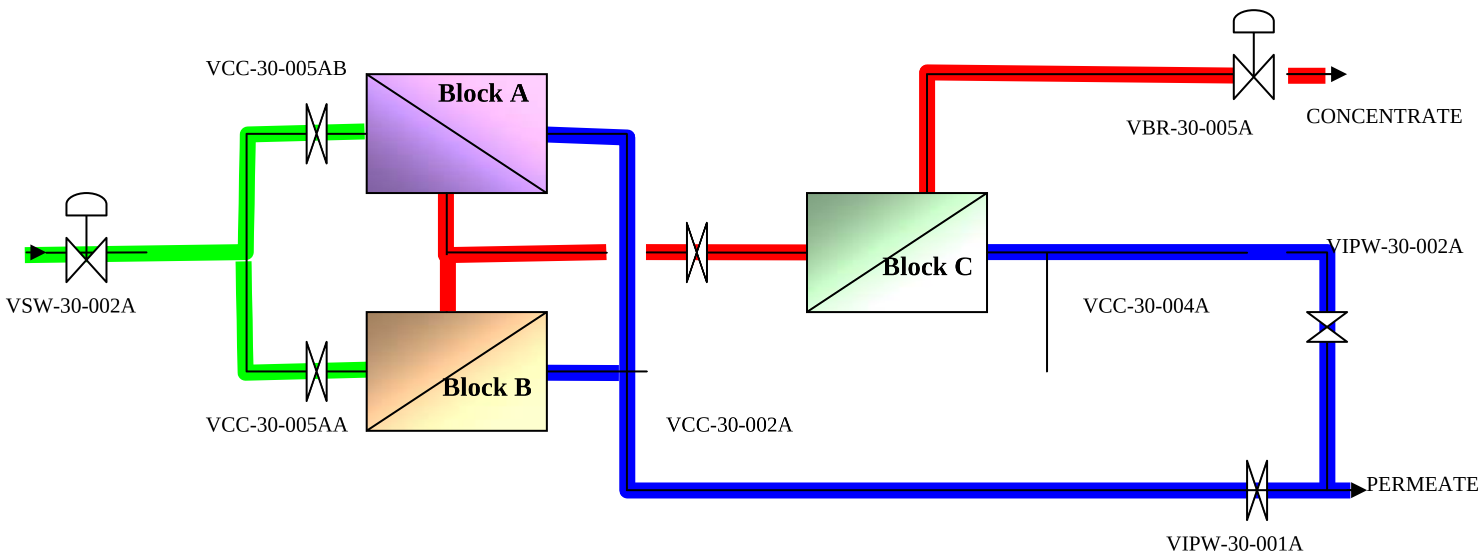
Cleaning Process

RO Cleanup Skid



Cleaning Solution Volume Requirement per RO Element (these volumes do not include volumes required for piping, filters, etc) (these volumes do not include initial 20% of volume dumped to drain)				
Element Size	**Normal Fouling** (Gallons)	**Heavy Fouling** (Gallons)	**Normal Fouling** (Liters)	**Heavy Fouling** (Liters)
4 x 40 inches	2.5	5	9.5	19
6 x 40 inches	5	10	19	38
8 x 40 inches	9	18	34	68
8.5 x 40 inches	10	20	38	76

Simplified Flow diagram



Cleaning System

Cleaning Process

Alkaline or acidic cleaning

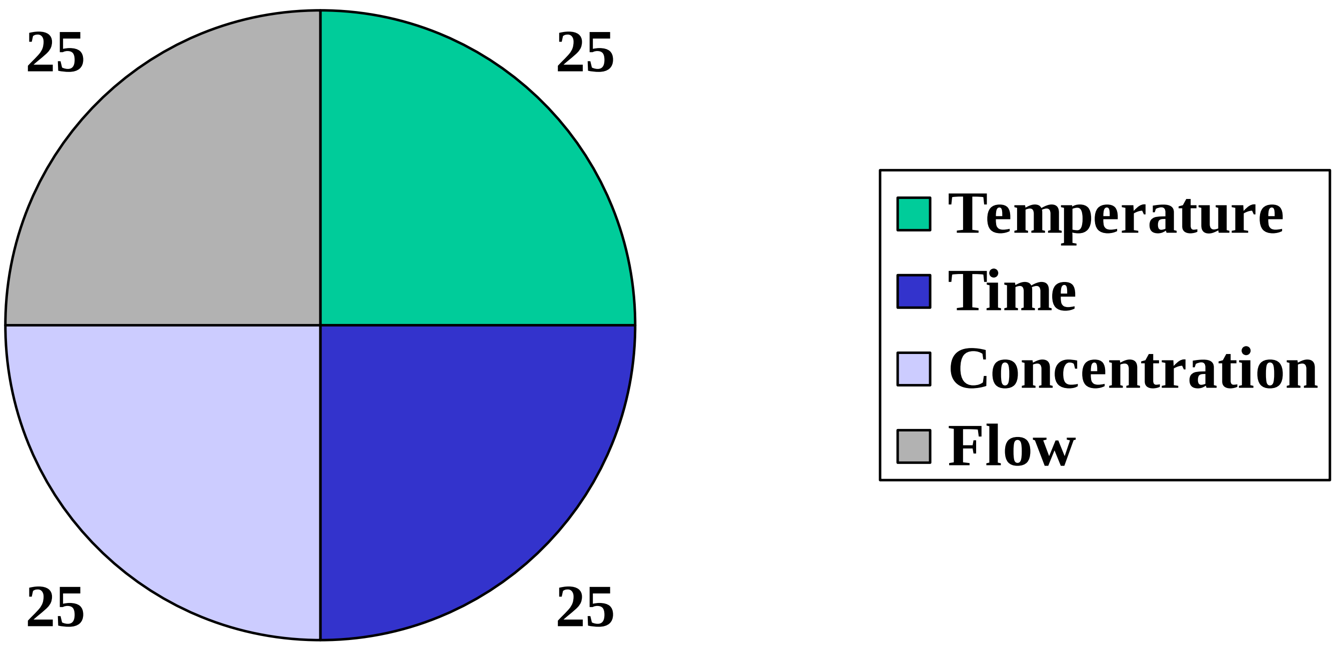
Steps:

- Seawater flush
- Freshwater flush
- Chemical makeup
- Fluid Displacement
- Low flow / high flow recirculation
- Soak
- Drain

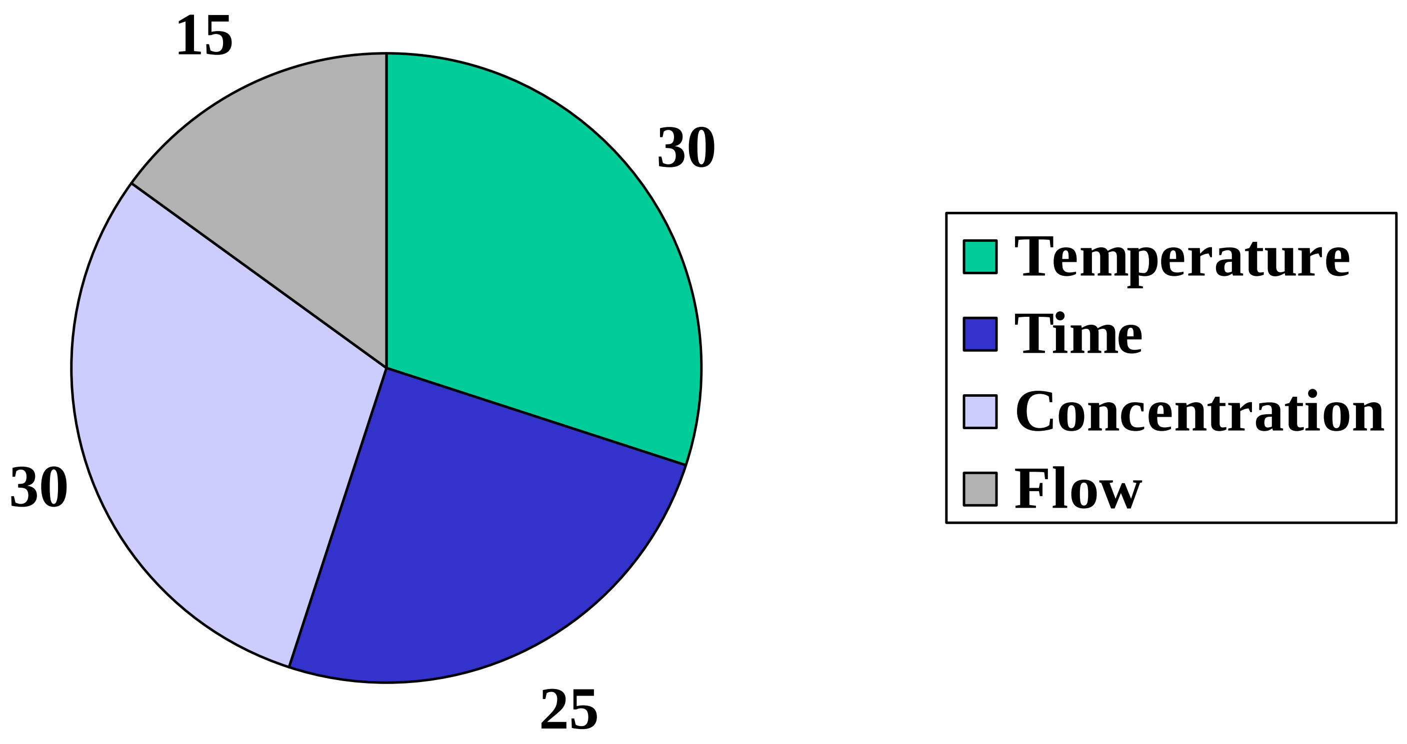
Cleaning Process - Important Points

- Compatibility of cleaning chemicals with membranes
- Correct cleaning temperature - 35º - 45ºC
- Correct cleaning flows
- Do not exceed differential pressure
- Soak and recirculate – 30 minutes : 30 minutes
- No water hammer or surges must occur!

Cleaning Procedure - Influencing Factors



Cleaning Procedure - Influencing Factors



Cleaning Solutions – Generic Chemicals

Cleaning Solution	Bulk Ingredients	Quantity	Target pH Adjustment	Target Temp.
1	**Citric acid** (as 100% powder)	17.0 pounds (7.7 kg)	Adjust to pH 4.0 with ammonium hydroxide.	104 F (40 C)
2	**STPP** (sodium tripolyphosphate) (as 100% powder) **Na-EDTA** (Versene 220 or equal) (as 100% powder)	17.0 pounds (7.7 kg) 7.0 pounds (3.18 kg)	Adjust to pH 10.0 with sulfuric or hydrochloric acid.	104 F (40 C)
3	**STPP** (sodium tripolyphosphate) (as 100% powder) **Na-DDBS** Na-dodecylbenzene sulfonate	17 pounds (7.7 kg) 2.13 pounds (0.97 kg)	Adjust down to pH 10.0 with sulfuric or hydrochloric acid.	104 F (40 C)

Cleaning Process Conditions

Hydranautics pH and Temperature Limits for Cleaning (See Table 3 for target pH and temperatures)			
Membrane	**45 C (113 F)**	**35 C (95 F)**	**30 C (86 F)**
CPA	2-10	2-12	2-12
ESPA	2-10	2-12	2-12
LFC	2-10	2-12	2-12
SWC	2-10	2-11	2-12
ESNA	3-10	2-12	2-12

Cleaning and Flushing Flow Rates per RO Pressure Tube (Pressures are not to exceed 60 psi (4 bar) at inlet to tubes.)		
Element Diameter	**GPM**	**LPM**
4-inches	6 to 10	23 to 38
6-inches	12 to 20	46 to 76
8-inches	24 to 40	91 to 151
8.5-inches	27 to 45	102 to 170

Conclusions

- Normalize Data at least daily
- Analyze your performance indicators to narrow down the type of fouling
- Remove elements from the system to analyze the membrane for exact foulant
- Follow membrane supplier and chemical supplier guidelines to prevent or alleviate fouling
- Clean membranes when normalized permeate flow drops 10-15% or if normalized pressure drop increases by 15-20% or normalized SP increases 10 – 15%

Preservation

- **Preservation should be done if membrane part is stopped for longer than a week**
- **Typical preservation solution**
  - **1% SBS**
  - **Proprietary chemicals**
- **Winter preservation solution**
  - **1% SBS + 20% glycerine**
- **pH of solution must not drop bellow 3**
- **In case of short time preservation**
  - **~1,000 mg/l of SBS is sufficient for 1.5 – 2 months**
  - **You must regularly analyze residual SBS – it must not drop bellow 500 mg/l**

THANK YOU