Application Of Membrane Separation Technology to Mining Processes

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Presentation Outline

- Introduction
- Overview of membrane processes
- Case Studies
- Conclusions and recommendations

This work was co-funded by CANMET-MMSL and the MEND Program

- Objective of the work was to provide a review of the literature on the applications of membrane separation technology in mitigation of AD and mine effluents.

Membrane Separation

Introduction

- Water Quality and management is a growing concern for different industrial sectors including oil and gas and Mining
- Conventional treatment methods are being challenged to meet lower residual concentrations of metals and other contaminants in the discharge stream.
- Economics and costs of the treatment option is an important factor in technology selection and often dominate the selection of treatment options, unless other factors such as regulatory requirements are the driver

Introduction

- Greater focus on water recycling and minimization of water use
- In the past decade, membrane separation processes have attracted significant attention and have found their place in different sectors of the industry especially in water and wastewater treatment

Membrane Separation

- Membrane separation is an effective method for treatment of AMD and mining effluents
- Although an established technology in water treatment, membrane separation is an emerging technology in the mining industry
- With proper design, membrane Separation could potentially become a primary technology for water management in mining operations

Membranes: What are they?

- Membranes are thin ***semipermeable*** barriers or films of materials that allow certain substances to pass;
- Synthetic membranes are usually 100-500 microns thick;
- Membranes are made from polymers, ceramics and metals;
- Majority of the commercially available membranes are polymeric membranes.

Membrane – Material

The polymers typically used for the active layer in commercially available include:

- Cellulose acetate,
- Polyethersulfone,
- Polyetheramides,
- Polyamides,
- Polypropylene,
- PVDF and
- Polysulfones.
- Ceramics

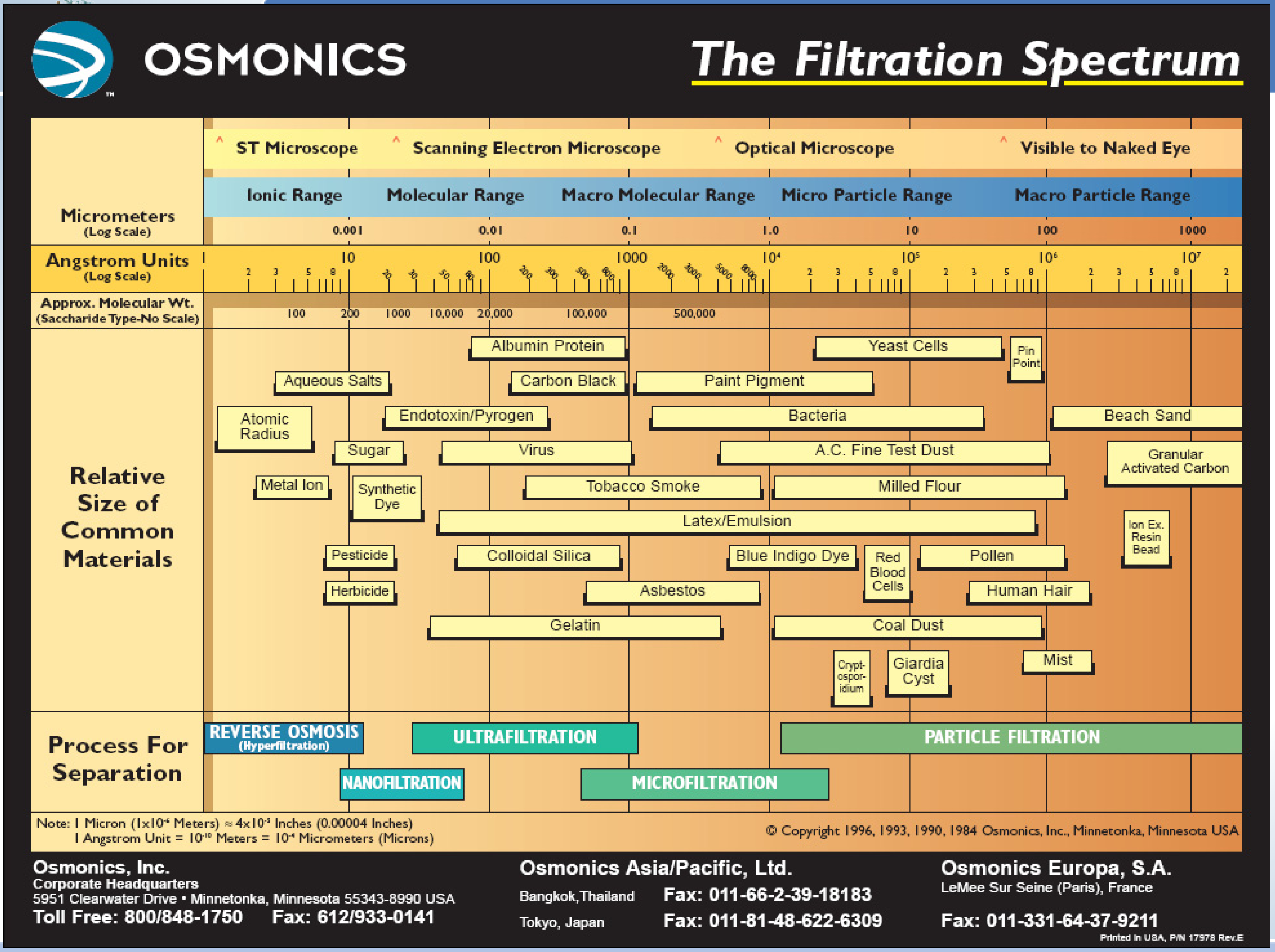
Membrane Separation

Pressure driven membrane separation process types:

- Reverse Osmosis (RO)
- Nanofiltration (NF)
- Ultrafiltration (UF)
- Microfiltration (MF)

Other:

- Electrodialysis


OSMONICS
The Filtration Spectrum
ST Microscope
Scanning Electron Microscope
Optical Microscope
Visible to Naked Eye
Ionic Range
Molecular Range
Macro Molecular Range
Micro Particle Range
Macro Particle Range
Micrometers (Log Scale)
0.001
0.01
0.1
1.0
10
100
1000
Angstrom Units (Log Scale)
10
100
1000
10⁴
10⁵
10⁶
10⁷
Approx. Molecular Wt. (Saccharide Type-No Scale)
100
200
1000
10,000
20,000
100,000
500,000
Relative Size of Common Materials
Albumin Protein
Yeast Cells
Pin Point
Aqueous Salts
Carbon Black
Paint Pigment
Atomic Radius
Endotoxin/Pyrogen
Bacteria
Beach Sand
Sugar
Virus
A.C. Fine Test Dust
Granular Activated Carbon
Metal Ion
Synthetic Dye
Tobacco Smoke
Milled Flour
Latex/Emulsion
Ion Ex. Resin Bead
Pesticide
Colloidal Silica
Blue Indigo Dye
Red Blood Cells
Pollen
Herbicide
Asbestos
Human Hair
Gelatin
Coal Dust
Crypt-ospor-idium
Giardia Cyst
Mist
Process For Separation
REVERSE OSMOSIS (Hyperfiltration)
ULTRAFILTRATION
PARTICLE FILTRATION
NANOFILTRATION
MICROFILTRATION
Note: 1 Micron (1x10⁻⁶ Meters) ≈ 4x10⁻⁵ Inches (0.00004 Inches)
1 Angstrom Unit = 10⁻¹⁰ Meters = 10⁻⁴ Micrometers (Microns)
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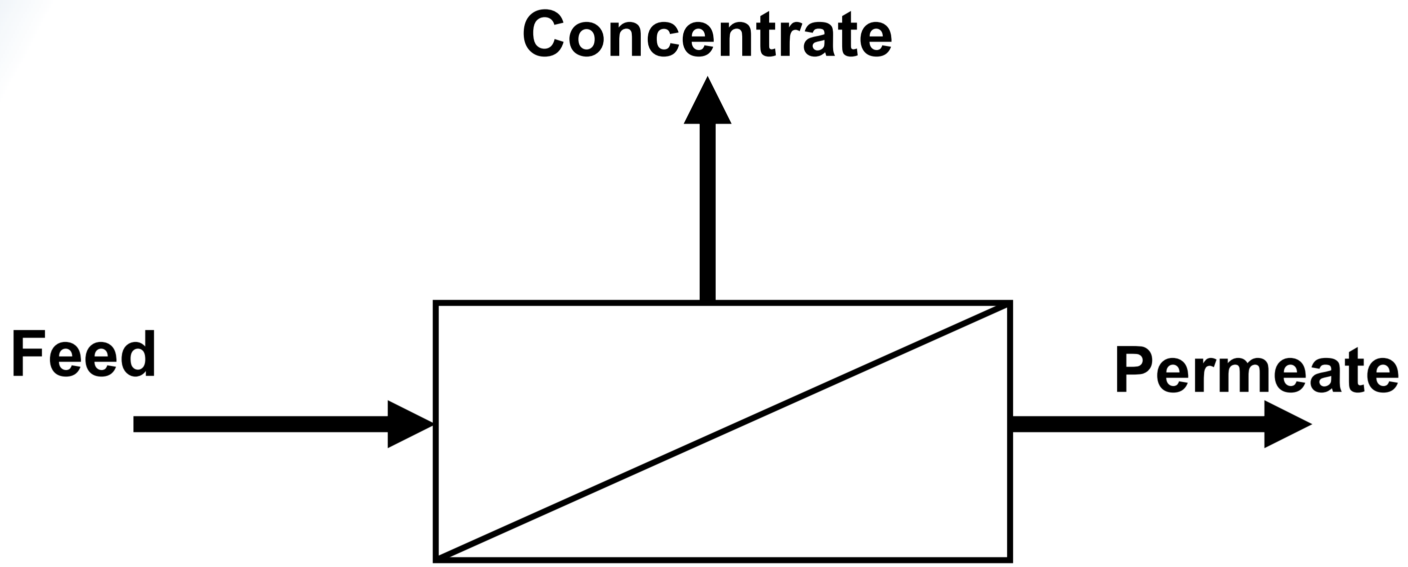
Membrane Separation



Membrane Applications

- Since commercial membranes are available over a wide range of pore sizes, membrane filtration technologies can effectively remove various contaminants.
- From a contaminant-based perspective, membrane separation applications can be grouped into three main areas: solid–liquid separation, organic removal, and inorganic removal.
- USEPA considers RO as a best available technology to meet anticipated regulations for small surface-water plants without existing facilities and groundwater treatment plants.

Membrane Separation

Reverse Osmosis

- **Pretreatment**
  Ultrafiltration, multimedia filter, activated carbon filter and deionization filter (softener), pH adjustment
- **Post Treatment**
  Polishing ion exchange, polishing ultraviolet disinfection, cartridge filtration, evaporators, brine concentration, crystallization

Membrane Fouling

Membrane – Fouling Control

Five principal fouling mechanisms have been identified:

(i) Concentration polarization,

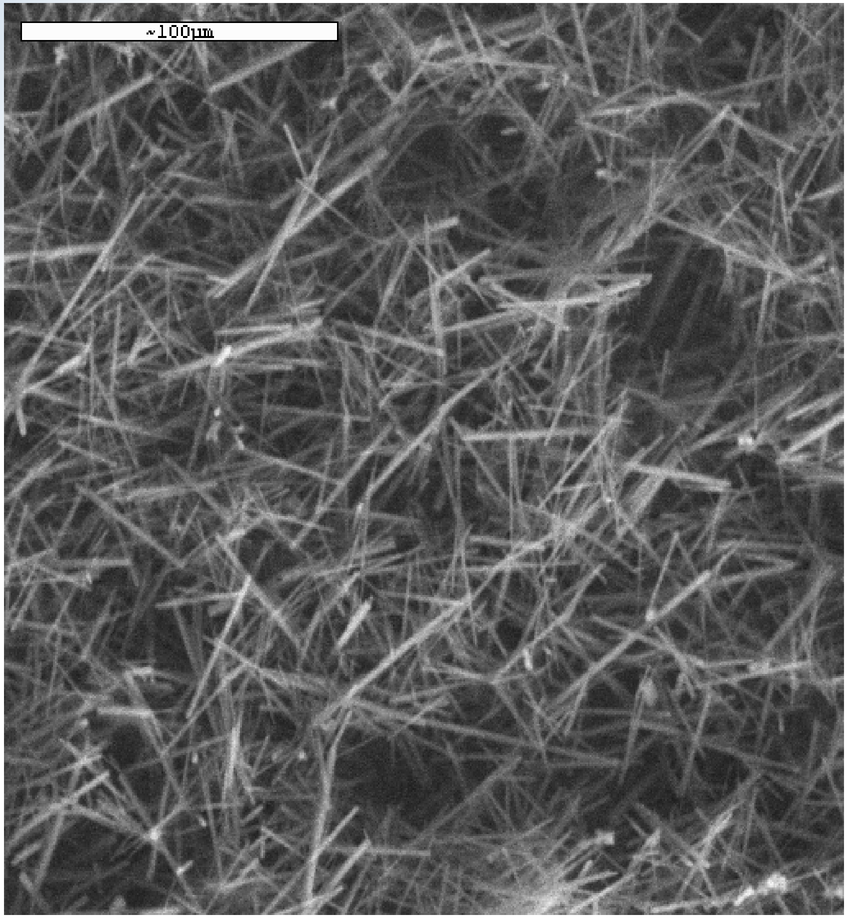
(ii) Cake formation,

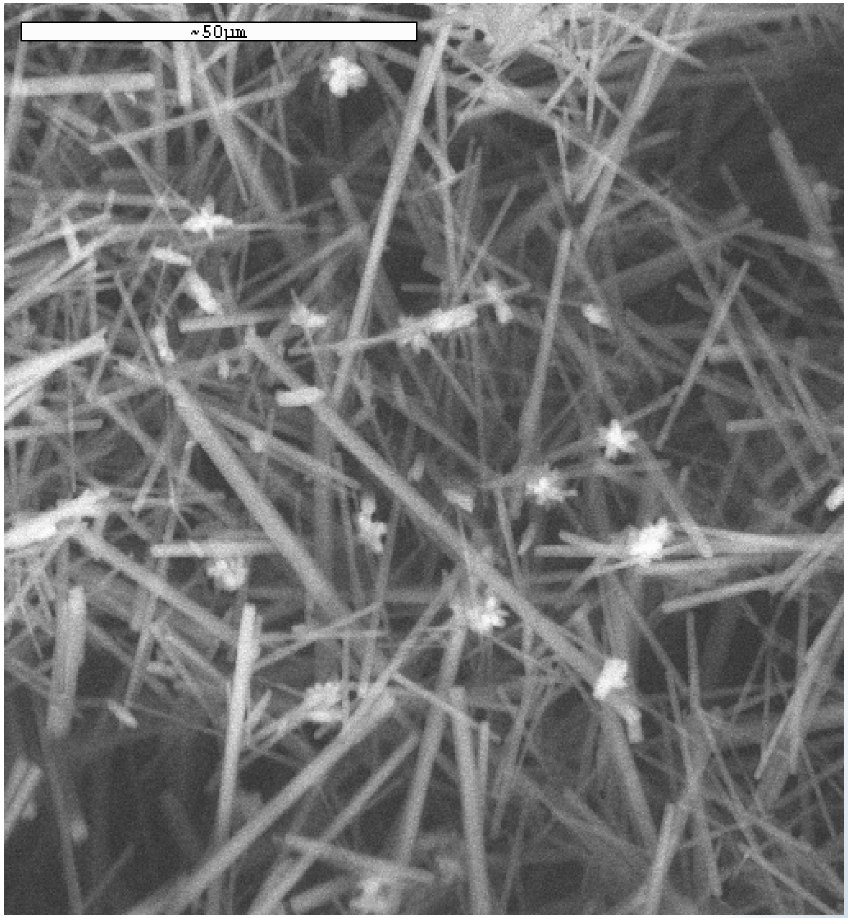
(iii) Inorganic precipitation,

(iv) Organic adsorption, and

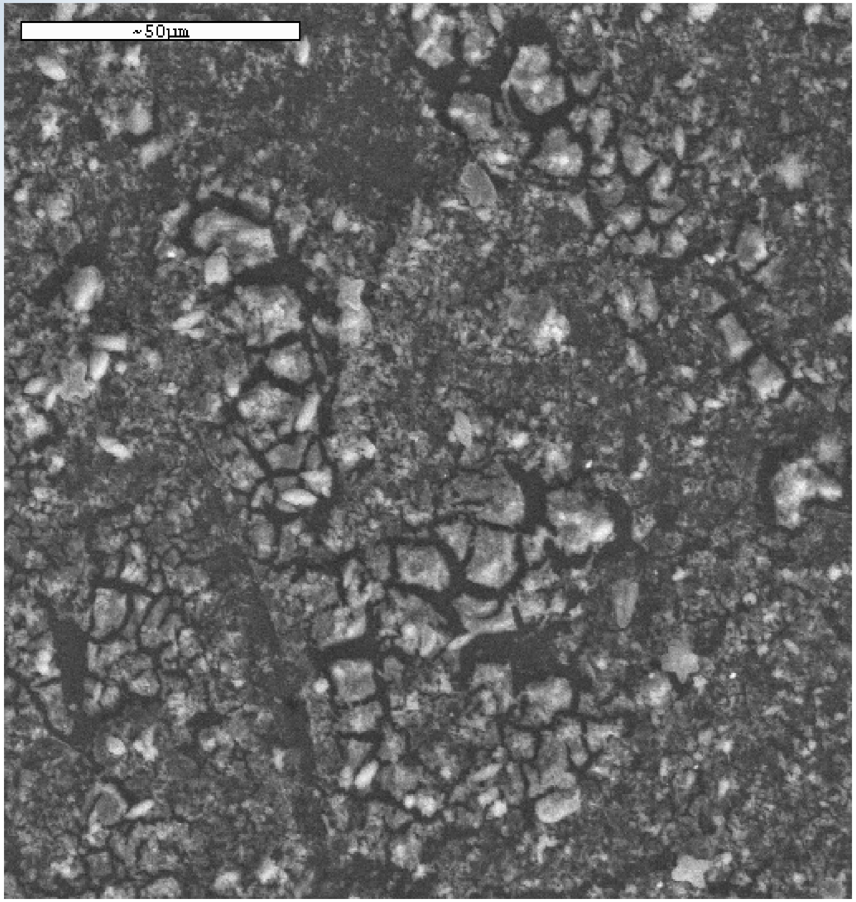
(v) Biological fouling.

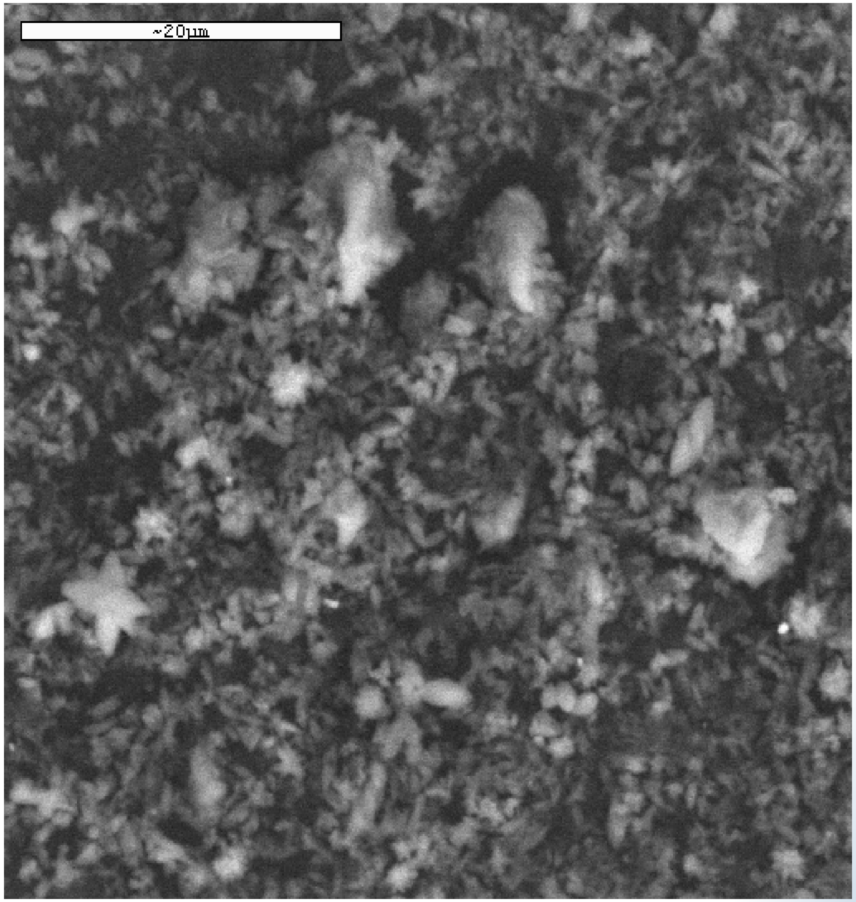
- **Feed at pH 9.66 showed high degree of fouling (HL2521TF)**
- **450 psig and 25 ^{o}C – $MgCO_3.2H_2O$**



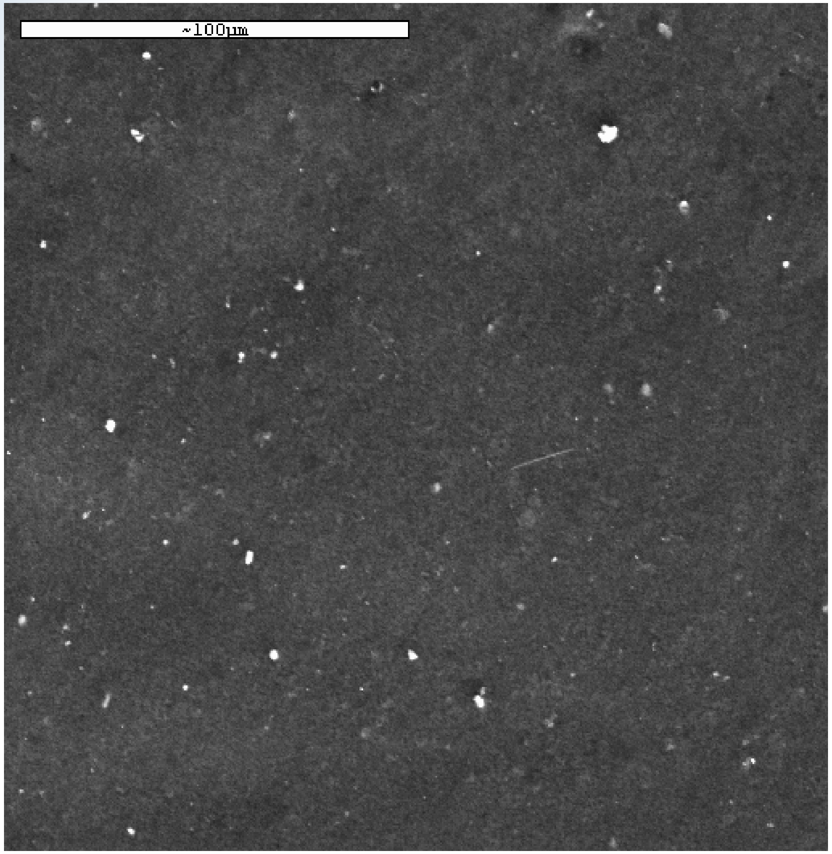


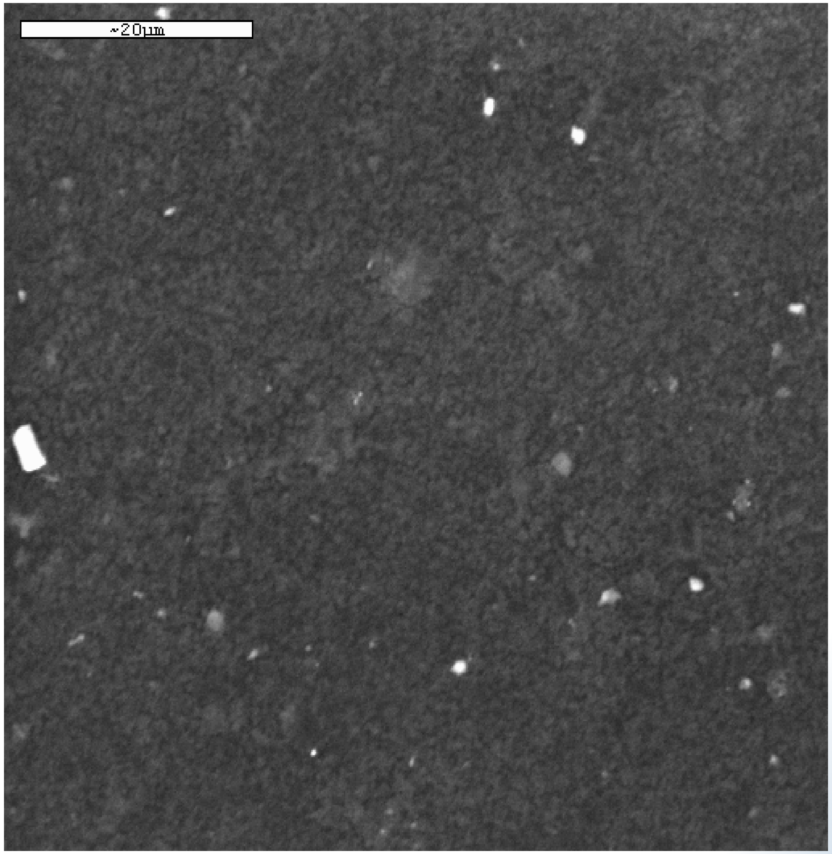
- **Feed at pH 9.66 showed high degree of fouling (HL2521TF)**
- **SHMP was used 450 psig and 25 ^oC**



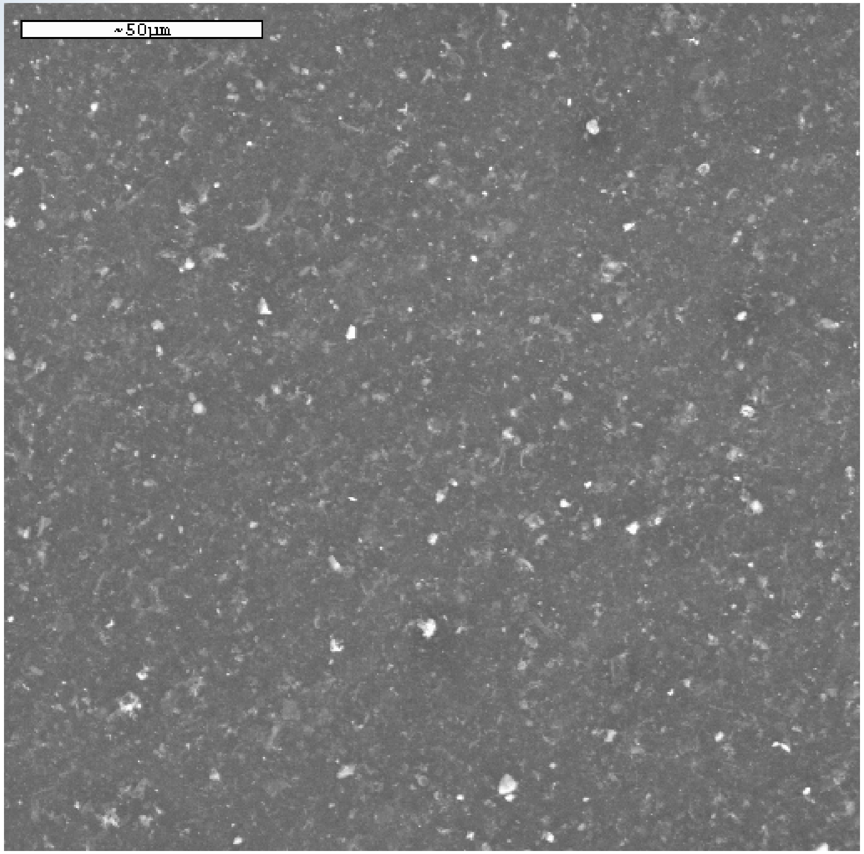


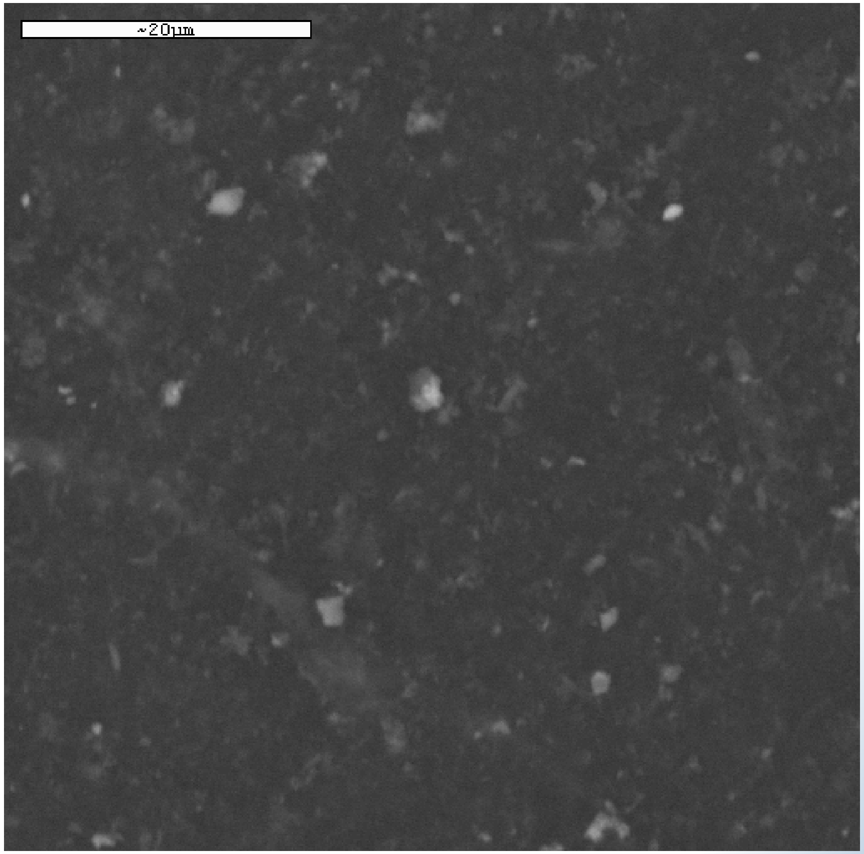
SEM of the solids deposited on the surface of Filmtec SW30-2540 RO membrane after testing with a feed at pH 4 in the absence of antiscalants.





SEM of the solids deposited on the surface of Filmtec SW30-2540 RO membrane after testing with a feed at pH 7 in the absence of antiscalants.





Membrane – Fouling Control

Method	Reference
Direct Methods	
Periodic hydraulic or chemical cleaning	Porter, 1990
Impulse feed	Boonthanon *et al.*, 1991
Turbulence promoter	Shen and Probstein, 1979
Dean Vortex	Mallubuhotal and Belfort, 1997
Rotating-vibrating membrane	Reed *et al.*, 1997, Silva *et al.*, 2000
Outside aeration	Silva *et al.*, 2000
Inside gas sparging	Cabassud *et al.*, 1997
Indirect Methods	
Pretreatment by coagulation-filtration	Chellam *et al.*, 1997
Pretreatment by air floatation	Braghetta *et al.*, 1997a,b
Membrane surface modification	Weisner and Chellam, 1999
Selecting optimum operating conditions	Belfort et al., 1994
Changing operation modes	Cote et al., 1998

Concentrate Treatment Options

- The concentrate stream can potentially be a brine stream.
- Given the flowrates encountered in mining applications, even at high water recoveries the concentrate stream can generate large volumes of brine that require management.

Concentrate Treatment Options

- Membrane separation is concentrating process and the higher the water recovery, the higher the strength of the concentrate stream which could be a concentrated brine stream.

Treatment options: thermal and non-thermal

- liming
- Brine concentrator
- Crystallizer
- Evaporator
- Metal recovery
- Precipitation/coagulation-sedimentation/ filtration

Concentrate Treatment Options

- In a study of technologies for the treatment of underground mine water discharged by Grootvlei Proprietary Mines in South Africa, RO was one of the technologies assessed (Schoeman and Steyn, 2001).
- The TDS in the feed, 2000-4500 mg/L, was reduced to potable water standards at 85% water recovery.
- The flowrate of the brine stream for an 80 ML/d plant at 85% recovery was estimated to be 12 ML/d.
- The brine disposal option was the use of evaporation ponds, and forced evaporation.
- The estimated capital costs for a brine flow rate of 12 ML/d was $14.7M US dollars for unlined evaporation ponds (based on $1222/1000L of brine), $57.1M for lined evaporation ponds, $18M (based on $1222/1000L of brine) and $75.3M for ocean disposal.

MMSL Results
AD/Ammonia/TDS

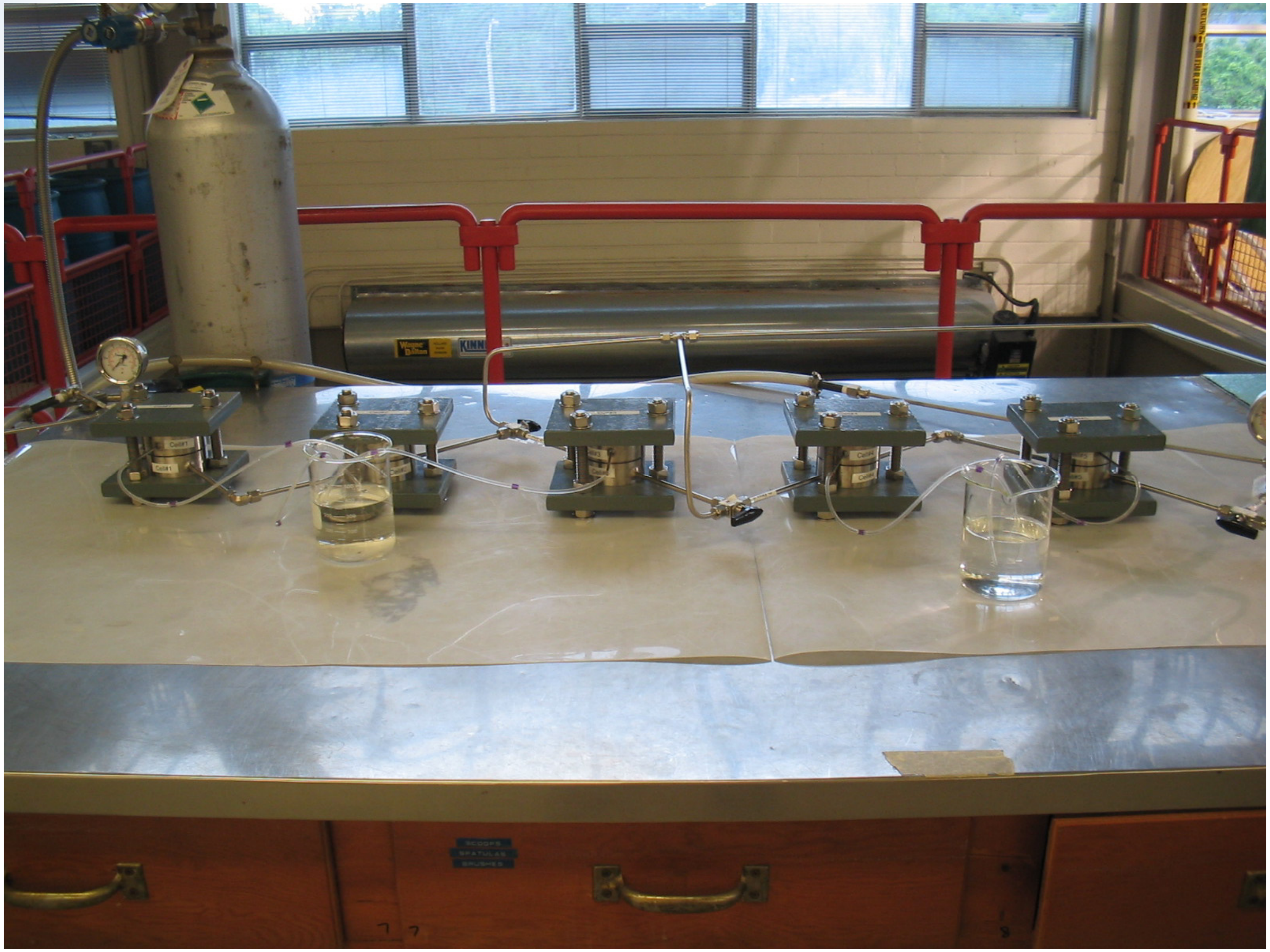
Selected Membranes

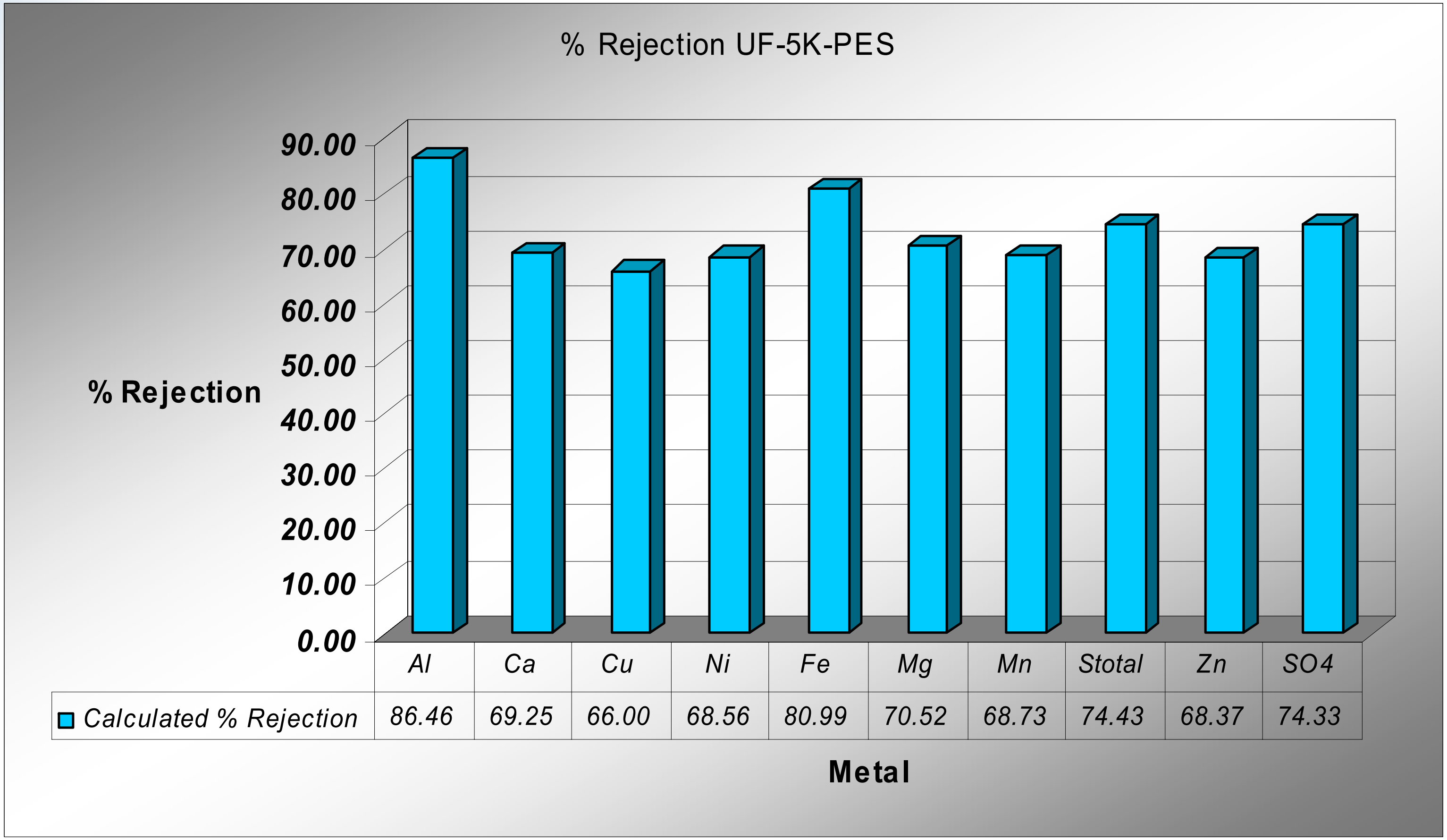
Membrane	Type	Material/ Configuration	Manufacturer/ supplier	Max. P (psig)	Max. T (°C)	pH range
YMDKSP3001	NF	TFC	GE Osmonics		N/A	N/A
CG2540	RO	TFC	DESAL	450	30	3-8
AG2521	RO	TFC	DESAL	450	50	4-11
HL2521	NF	TFC	DESAL	450	50	3-9
CE2026	RO	TFC	DESAL	140-400	30	5-6
SW30-2540	RO-HR	TFC	Filmtec	800	45	2-11
2540-SW	RO-HR	TFC	Koch	800	45	2-11

Experimental Conditions – Membrane Tests

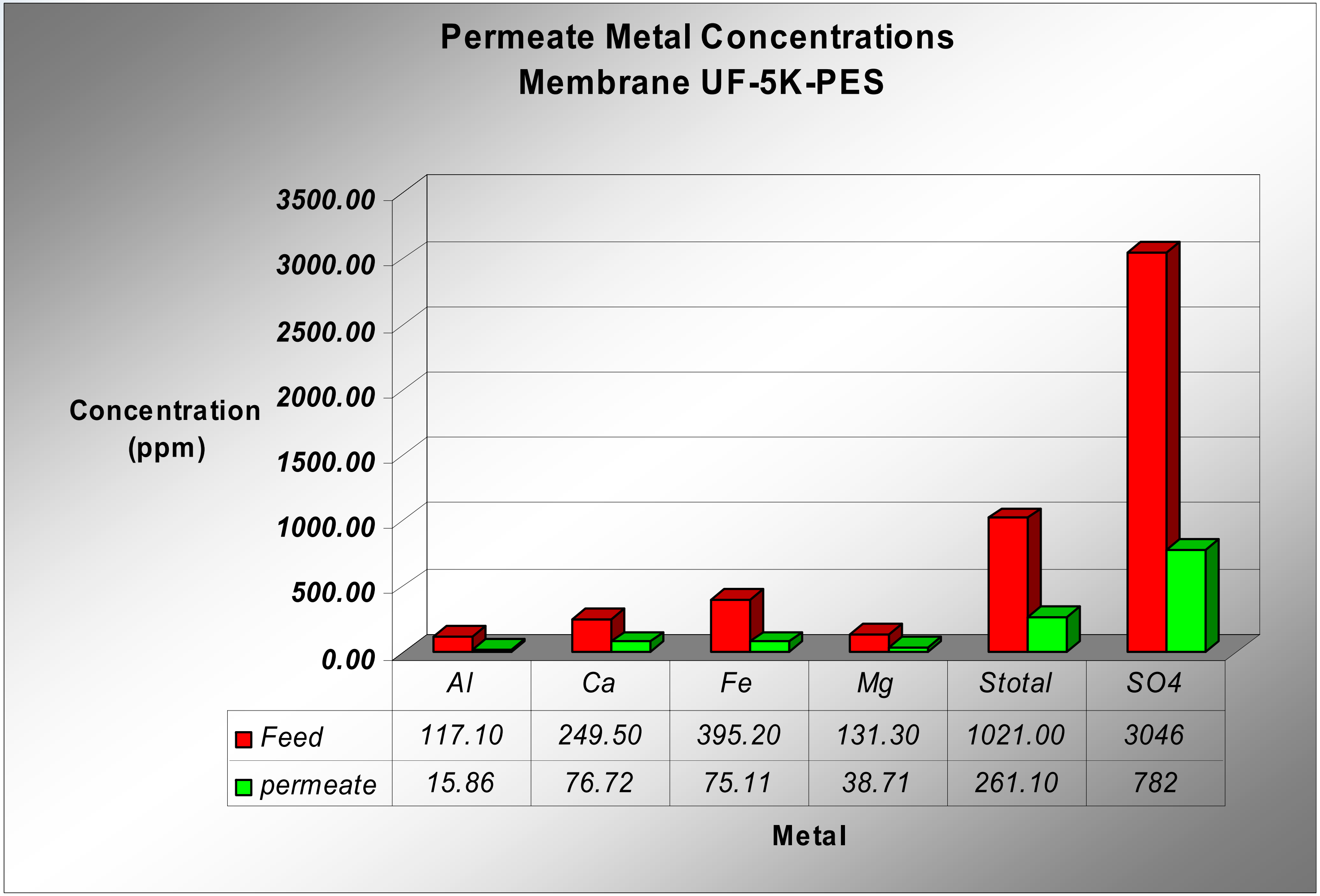
Feed Chemical Composition:

Parameter	Raw AMD (ppm)	Treated AMD (ppm)
pH	2.42	9.19
Conductivity	5.47	4.81
Alkalinity	-	22.0
Al	109	3.39
Ca	289.9	1038
Cu	2.8	<0.032
Fe	377.5	0.423
Mg	117.2	71.3
Mn	11.46	0.211
Ni	0.387	<0.12
S_{total}	**1006**	**991.1**
Zn	1.22	<0.1
SO_4	**3526**	**2219**

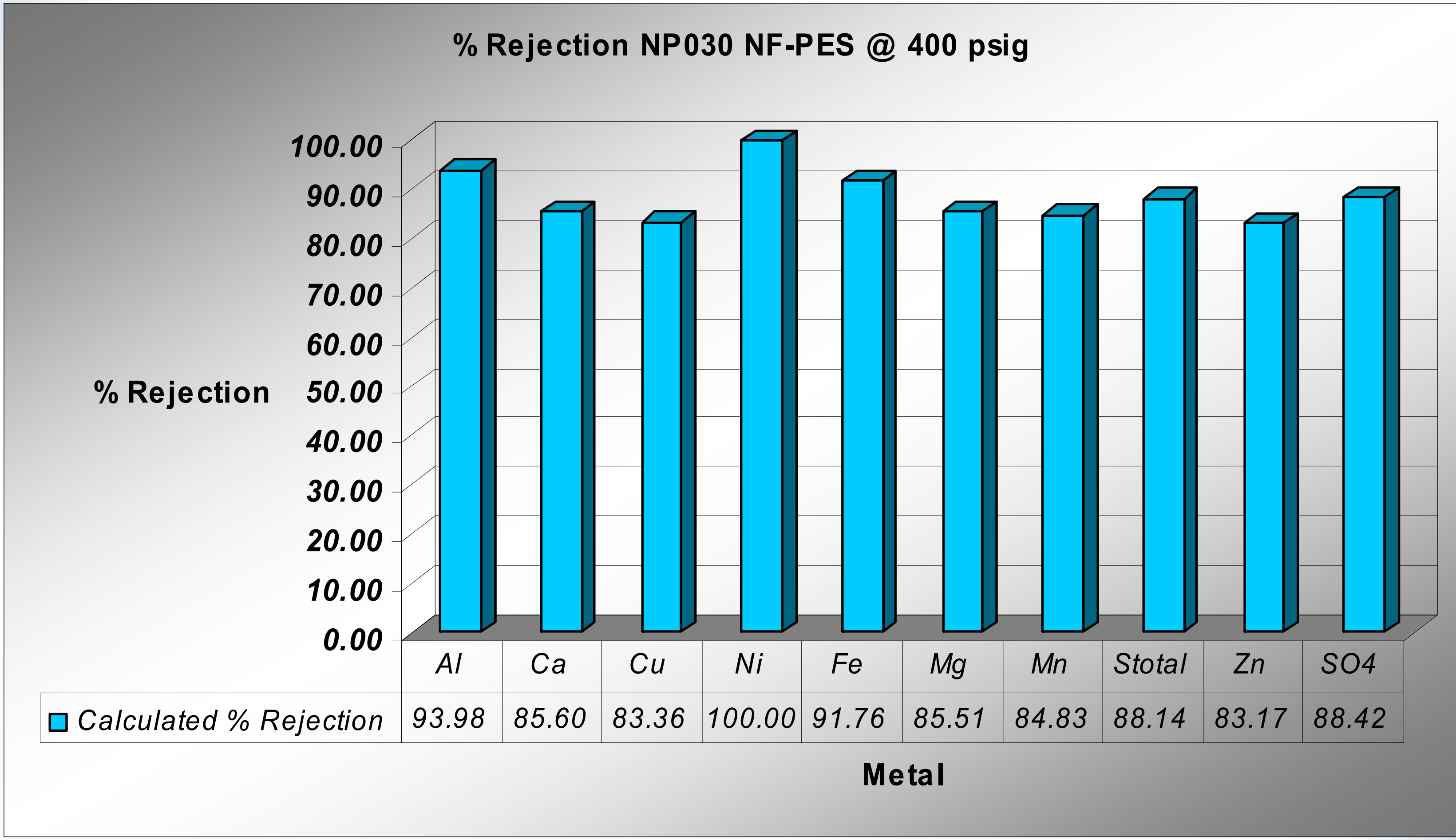


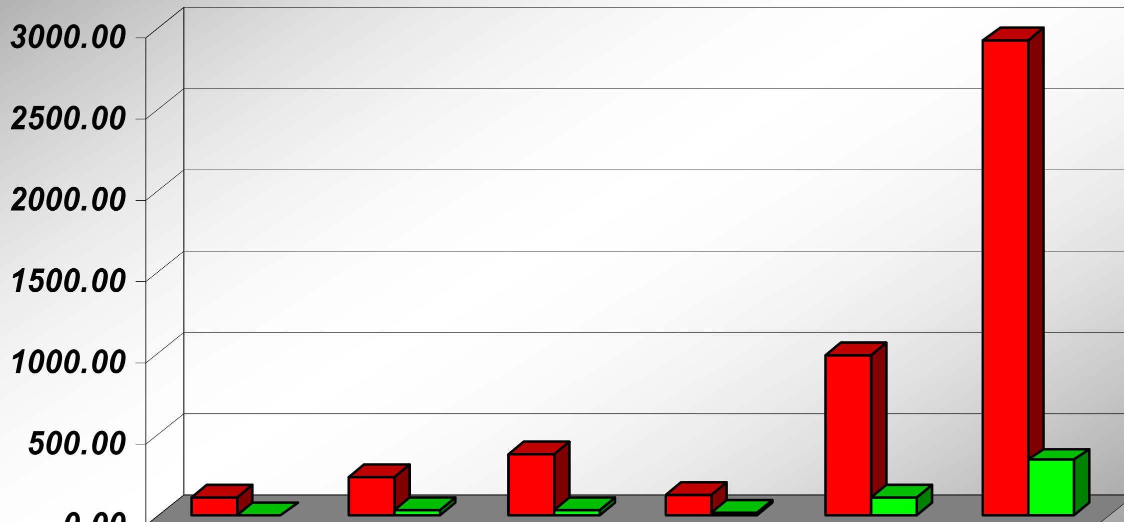


	Al	Ca	Cu	Ni	Fe	Mg	Mn	Stotal	Zn	SO4
Calculated % Rejection	86.46	69.25	66.00	68.56	80.99	70.52	68.73	74.43	68.37	74.33



	Al	Ca	Fe	Mg	Stotal	SO4
Feed	117.10	249.50	395.20	131.30	1021.00	3046
permeate	15.86	76.72	75.11	38.71	261.10	782


% Rejection NP030 NF-PES @ 400 psig
% Rejection
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Al
Ca
Cu
Ni
Fe
Mg
Mn
Stotal
Zn
SO4
Calculated % Rejection
93.98
85.60
83.36
100.00
91.76
85.51
84.83
88.14
83.17
88.42
Metal



	Al	Ca	Fe	Mg	Stotal	SO4
Feed	113.70	240.70	381.80	126.80	989.00	2937
permeate	6.85	34.67	31.47	18.37	117.25	340

Membrane Separation Tests

% Rejection obtained with different membranes for Sulphate – RAW AMD

Pressure (psig)	*100*	*200*	*300*	*400*	*500*
Membrane	**% Rejection**				
HL2521T	**88.77**	**90.09**	**90.87**	**91.50**	**85.73**
AG2521T	**97.70**	**98.69**	**99.11**	**99.41**	**98.59**
YM-DL-SP3001	**89.68**	**94.69**	**95.41**	**99.89**	**88.88**
YM-HL-SP3001	**87.92**	**89.44**	**90.26**	**91.12**	**83.57**
CE2026TF	**95.92**	**97.93**	**98.53**	**99.04**	**97.47**
CG2540 FF	**99.99**	**99.99**	**99.99**	**99.99**	**99.99**

Case Histories

Case History

- Major acid pit drainage – Cananea, Mexico (1996)
  - 250 Lps (~4000 gpm)
- Newmont Mining Corporation – Yanacocha, Peru
  - 1500 gpm built in 2004
  - Additional capacity of 6000 gpm added
- Encana Oil and Gas (USA) Inc. Colorodo Western Slope
  - 15000 barrels/day high TDS coalbed methane water to surface discharge water standards

Case History

Kennecott Utha Copper's Bingham Canyon Mine to treat acidic drainage and contaminated groundwater

- The site has been in operation for over 100 years and more than 70 years of active leaching
- Extensive groundwater contamination - 62 million m^3 of acidic water with a pH of <4.0 and 247 million m^3 of sulphate water with sulphate levels greater 1500 ppm
- Application of RO and NF achieved rejections of 97 – 99.8% rejection of sulphate and metals – treating in excess of 20,000 GPD
- Scaling was a problem – successfully resolved by the addition of antiscalant

Case History

Utilization of Ceramic Membrane for Acid Mine Drainage Treatment

- The area around the towns of Black Hawk and Central City, Colorado
- Contamination due to discharge of high concentrations of heavy metals from the waste rock and mine tailings into surface water streams from over 800 abandoned mines and tunnels in the area
- The goal of the study was to identify an efficient and cost-effective treatment system for the removal of heavy metals without the expense of a clarifier system
- Foot-print constraints
- A comparison between a conventional clarifier, a ceramic membrane system and a polymeric membrane system was made

Case History

- The costs data from the study were normalized to a 250 gpm sized system for the purpose of the comparison
- Use of membrane system resulted in 30% reduction in chemicals, 75% reduction in labour
- Metals removal of over 99%

Case History

First system

- general clarifier consisting of:
  - pH adjustment
  - flocculation zone in a rectangular clarifier,
  - sedimentation in a rectangular clarifier.
  - Resulted in approximately 70-80% removal of heavy metals
  - required a large land area in order to accommodate the required retention times required for coagulation/flocculation and sedimentation.

Case History

Second system

- a polymeric membrane system (MF/UF?) with a footprint of only 10% of that for the conventional system
- system showed significantly better performance; over 90% metals removal
- After three months of operation the polymeric membranes became brittle and failed.
- The system throughput was 10 gpm and the trans-membrane pressure was 35-40 psig.
- No information was provided on the system maintenance.
- pH adjustments were made prior to the membrane skids, and
- the concentrate stream was neutralized and the sludge was pressed and landfilled.

Case History

Third system

- a ceramic tight MF membrane system developed by BASX systems with a pore size of 0.2 µm.
- The system was more robust than the polymeric system and yielded heavy metals removal of over 99% in most cases
- the operating costs were reduced by 30%.
- The system throughput was 10 gpm and the trans-membrane pressure was 35-40 psig.

Case History

Process	Metal	Removal Efficiency (%)
Clarifier	Cadmium	0-85
	Chromium	> 99
	Lead	90-95
	Manganese	0-3
	Zinc	0-90
Polymeric Membrane system	Cadmium	85-95
	Chromium	>99
	Lead	>99
	Manganese	50-80
	Zinc	85-95
Ceramic Membrane System	Cadmium	90-99
	Chromium	>99
	Lead	>99
	Manganese	70-90
	Zinc	90-95

Case History

Capital Costs ($USD)			
Cost Item	Ceramic Membrane System	Polymeric Membrane System	Conventional Treatment (coagulation/flocculation/ sedimentation) System
Estimated capital costs for a 250 gpm treatment plant	1,900,000	1,800,000	4,200,000

Case History

Annual Operating Costs (USD)			
Cost Item	Ceramic Membrane System	Polymeric Membrane System	Conventional Treatment (coagulation/flocculation/ sedimentation) System
General building and equipment maintenance	20,000	20,000	100,000
Treatment chemicals	60,000	78,000	255,000
Sludge disposal	20,000	20,000	25,000
Operator labor	30,000	90,000	120,000
Monitoring costs	18,000	18,000	18,000
Power costs for pumping	80,000	80,000	0.0
Membrane replacement cost	0.0	100,000	0.0
Contingency (15%)	34,200	60,900	77,700
Total costs	262,200	466,900	569,800
Present value annual costs (1997) for 10 year life of the plant	1,611,105	2,868,898	3,660,319

Case History

A Comparison of Conventional Precipitation and Membrane Treatment of Wastewater at ASARCO Globe Plant in Denver Colorodo

This case study presents a summary of a feasibility study conducted at Asarco's Globe Plant to improve their wastewater treatment process by reducing the operating costs, sludge volume and discharge water quality.

ASARCO Case Study

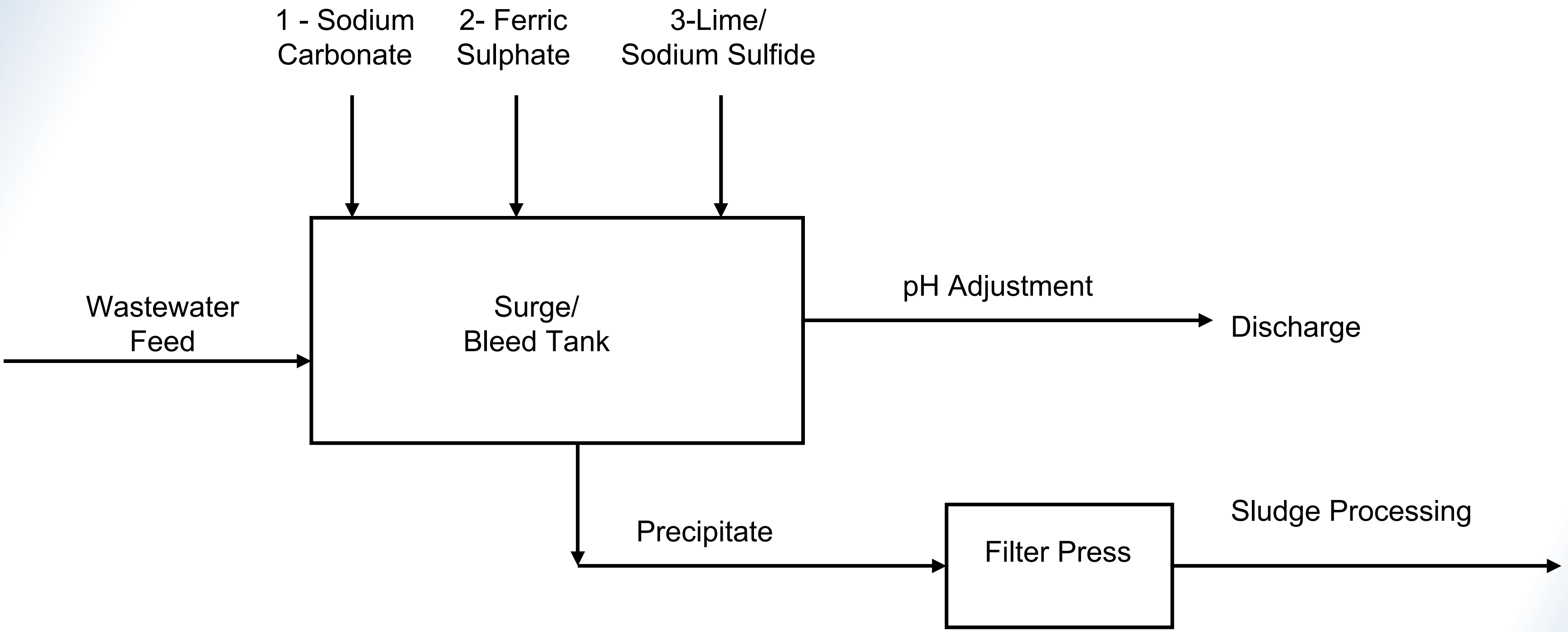
- Asarco Inc. is a large producer of non-ferrous metals such as copper, zinc, lead, silver and gold.
- The Asarco Globe plant has been a metal refining facility since 1886, producing a wide range of non-ferrous metals.
- In 1986, the company installed and operated a chemical precipitation system to treat wastewaters containing arsenic, selenium, lead, zinc, cadmium, nickel, iron, manganese, copper, chromium and silver.

ASARCO Case Study

- Asarco Inc
- Lime and sodium sulphide at pH 9.8 are added, followed by filtration and sludge dewatering. The final effluent water pH is adjusted to pH 7.5 before final discharge. The total operating cost of the wastewater treatment, including the depreciated initial capital cost was $58.34 (in 1993) per 1000 gal of treated wastewater.

ASARCO Case Study

Block diagram of Asarco's precipitation process

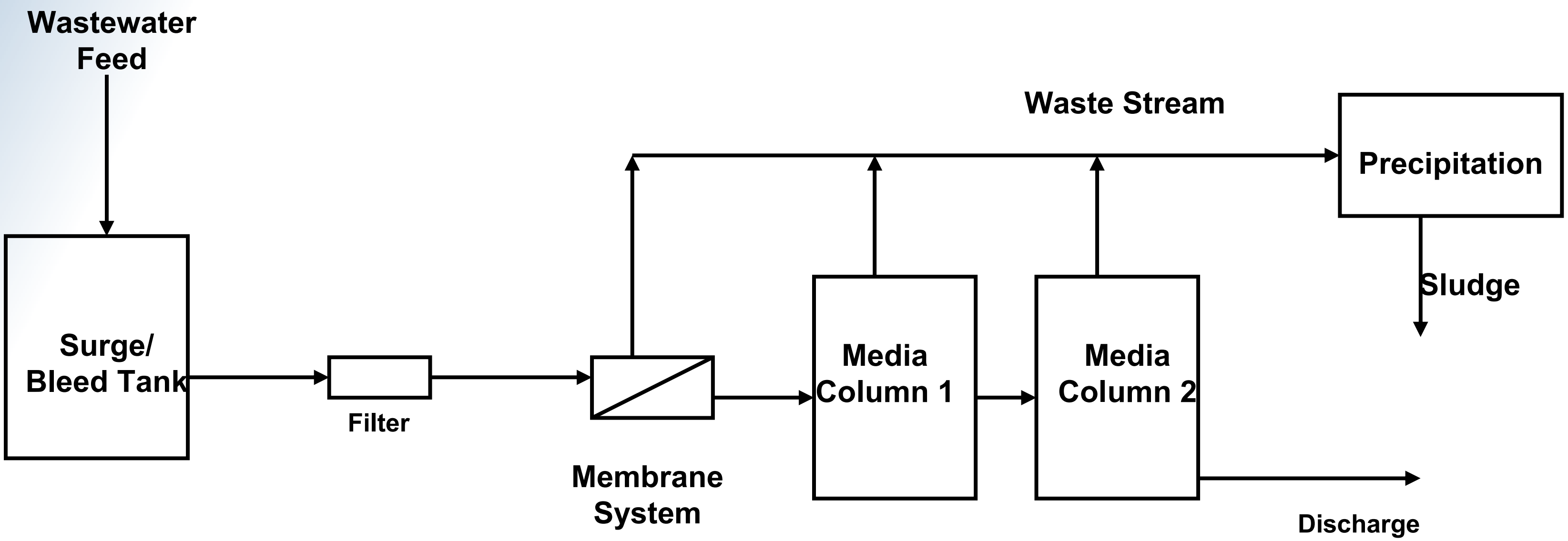


ASARCO Case Study

Asarco's Globe Plant precipitation system performance.

Component	Wastewater Feed (mg/L)	Treated Water (mg/L)
pH	4.0	~7
TDS	3000-10000	<3000
As (mg/L)	10.1	0.024
Se (mg/L)	0.056	<0.010
Cd (mg/L)	14.5	0.10
Zn (mg/L)	35.5	0.35
Pb (mg/L)	3.07	<0.050
Ni (mg/L)	0.060	0.025
Fe (mg/L)	0.986	0.100
Mn (mg/L)	3.33	0.120
Cu (mg/L)	0.07	0.020

ASARCO Case Study



Block diagram of Asarco's membrane separation process

ASARCO Case Study

Asarco's Globe Plant membrane separation system performance.

Component	Wastewater Feed (mg/L)	Treated Water (mg/L)
pH	4.0	~7
TDS	3000-10000	<1000
As (mg/L)	10.1	0.006
Se (mg/L)	0.056	<0.010
Cd (mg/L)	14.5	0.02
Zn (mg/L)	35.5	0.010
Pb (mg/L)	3.07	0.050
Ni (mg/L)	0.060	0.050
Fe (mg/L)	0.986	0.10
Mn (mg/L)	3.33	0.050
Cu (mg/L)	0.07	0.012

ASARCO Case Study

Costs Items	Precipitation System	Membrane Separation System
Water Quality	Meets Discharge Criteria	Meets and Exceeds Discharge Criteria
Capital Cost	$1,000,000 (1986)	$300,000 (1993)
Reagent Cost (per 1000 gal)	$9.88	$0.93
Direct Operating Cost (per 1000 gal)	$10	$3.33
Sludge weight (per 1000 gal)	160 lbs	24 lbs
Total Treatment Cost (per 1000 gal)	$58.34	$15.67

As the above table shows, compared to the precipitation system, the membrane system reduced the amount of the generated sludge by 85% and reduced the operating cost by 73% while producing better discharge water quality.

Case History

Vibratory Shear Enhanced Processing System (V-SEP)

- Developed by New Logic International Inc.
- Used at high TDS concentrations and in the presence of sulphates and carbonates.
- V-SEP technology utilizes vibrational oscillation of the membrane surface with respect to the liquid phase which prevents the build up of suspended solids or precipitated colloidal particles on the membrane surface.

Case History

Vibratory Shear Enhanced Processing System (V-SEP)

- The vibrational shear plus laminar cross-flow of the feed allows for very high recoveries.
- Water recoveries of up to 97% have been achieved with the treatment of AD in a single V-SEP pass (Miller, 2005).
- A single V-SEP unit has a throughput capacity of 5 to 200 US gallons per minute with a footprint of 20 square feet and a power consumption of 15 hp.

Case History

Vibratory Shear Enhanced Processing System (V-SEP)

- The life expectancy of a V-SEP module is 2 years.
- The throughput of a V-SEP unit at 20 gfd is reported as 10,500,000 gal/year with an annual power cost of $7,180 US, and system maintenance and cleaning costs of $8,640 US (Miller, 2005).

Case History -VSEP

polyamide RO membrane with a nominal salt rejection of 99% and a maximum pressure and temperature of 600 psig and 60 °C.

Component	Feed (mg/L)	Lime Precipitation (mg/L)	V-SEP Permeate (mg/L)
TDS	10,000	3,000	240
pH	2.7	8.5	8.5
Ca	490	600	36
Mg	420	350	18
Na	70	70	6
Fe	1,100	0.1	<0.1
Mn	182	3.6	<0.1
Cu	186	<0.1	<0.1
Zn	550	<0.1	<0.1
SO_4	8,000	2,000	100

Case History – AD & Ash Water

Desalination and reuse of AD and Ash Water

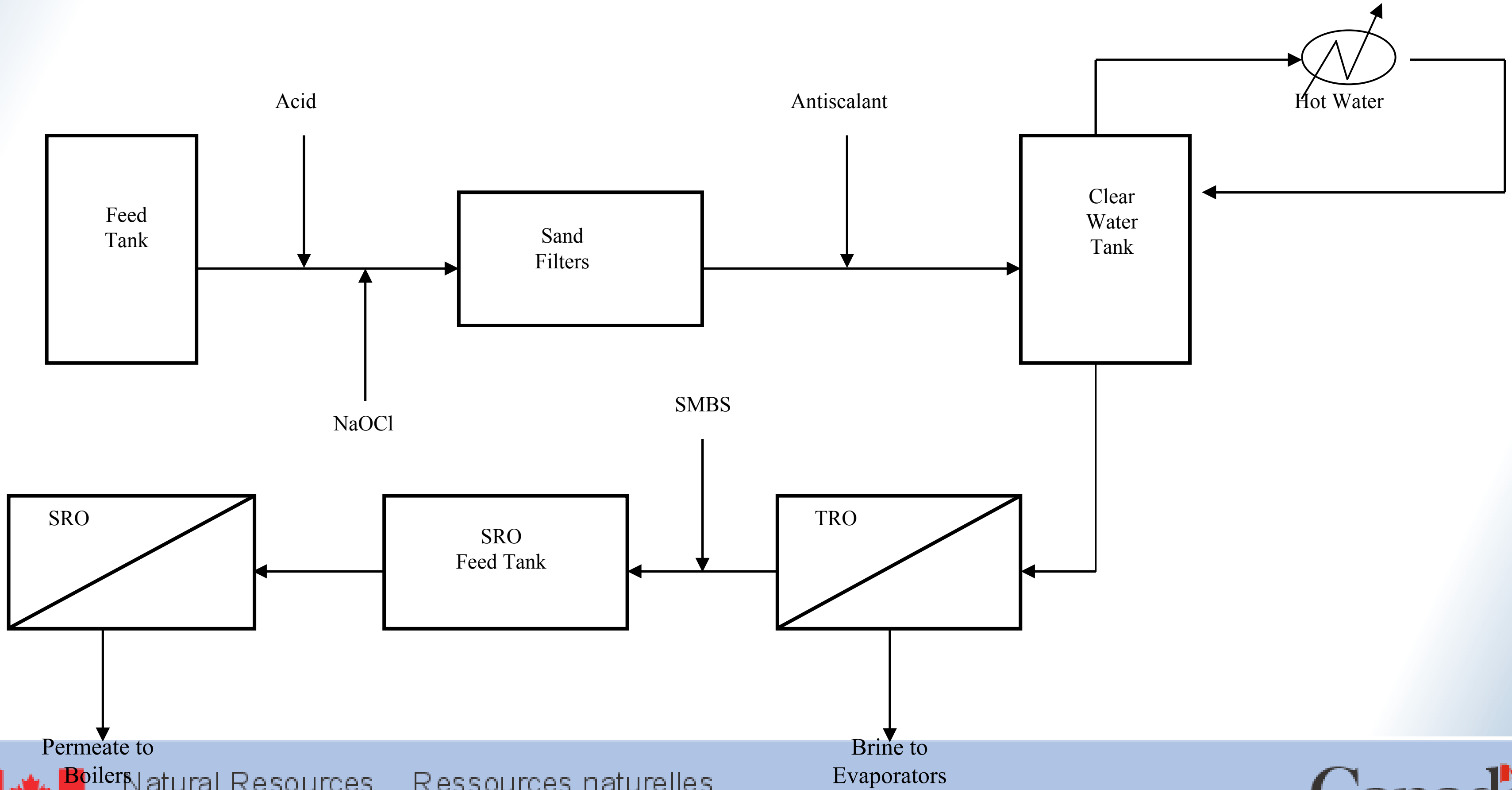
- This case study reviews the membrane plant put in place at the Sasol Technology Limited operation in Secunda, Republic of South Africa.
- At this plant, RO and EDR was used to treat AD and ash water and then convert them to boiled feed water (Nieuwenhuis *et al.*, 2000).
- Sasol Technology Ltd. was able to design and operate a successful membrane operation and reduce water intake.

Case History – AD & Ash Water

- The processes installed were a tubular RO (TRO) followed by a second RO with spiral wound modules (SRO) for the recovery and treatment of ash water.
- For the treatment of AD, a combination of EDR and SRO was used to successfully convert AD to boiler feed water.
- The operating costs of the two processes were similar and was R3.50/m3 of the final boiler feed water.

TRO-SRO system Design

The TRO system's standard flux was 524 ± 65.5 L/m2.day with average salt rejection of 94.5%.



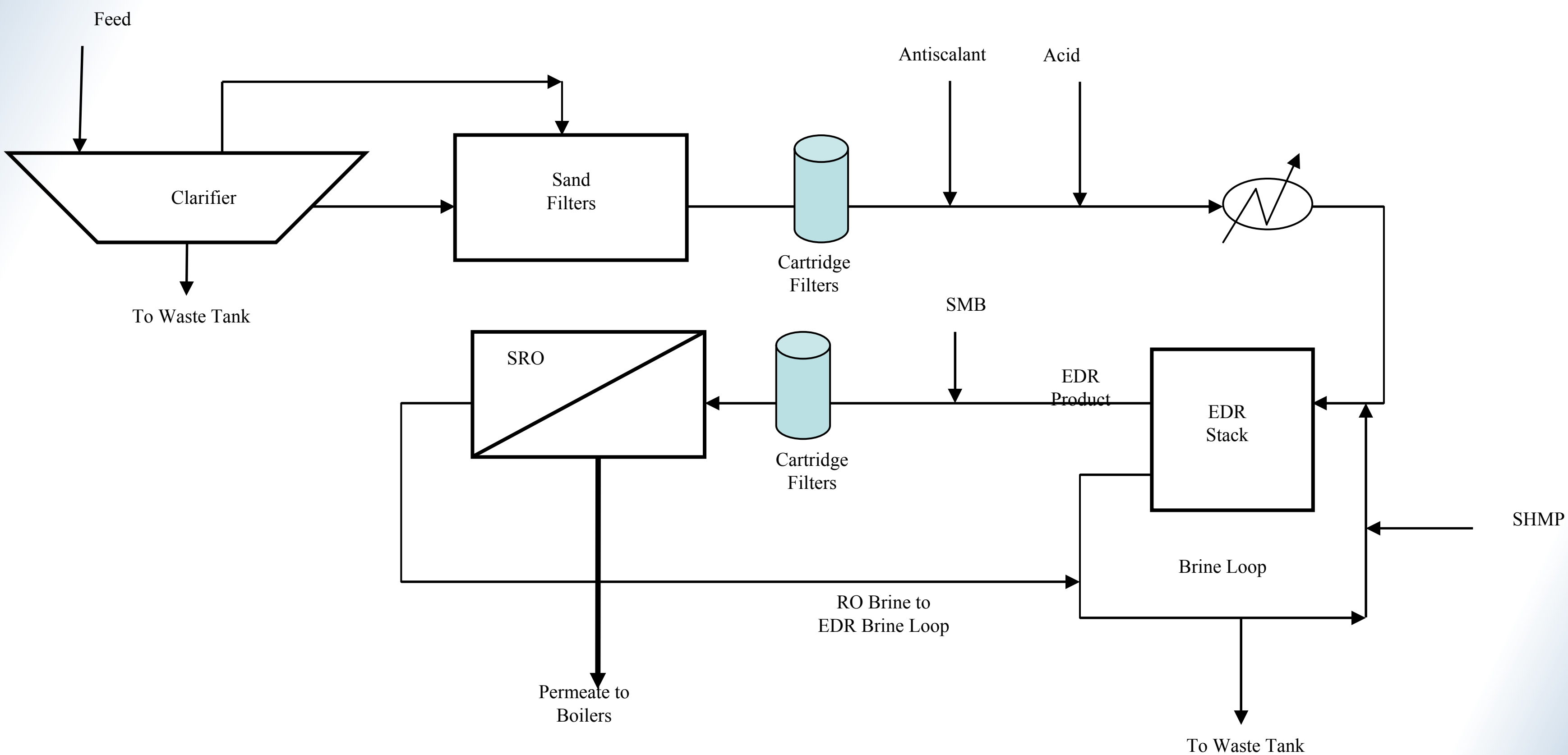
TRO feed and permeate compositions

Component	Feed Concentration (mg/L)	Permeate Concentration (mg/L)
TDS	3998 ± 786	**96 ± 38**
Ca	422 ± 94	**4.6 ± 3.2**
Ba	0.2 ± 0.09	**>0.2**
Na	917 ± 79	**48 ± 7**
Cl	828 ± 238	**44 ± 4**
SO_4^{2-}	3254 ± 842	**7.5 ± 5.1**
F	18 ± 4.9	**2 ± 0.3**
TOC	52 ± 14	**<10**

SRO feed and permeate compositions

Component	Target	Average
Water Recovery (%)	90	**88 ± 8.8**
Conductivity (µS/cm)	<30	**26 ± 6.1**
CIP/Train/month	1	**2.4**
Flux (L/m^2.h)	25	**23.5 ± 1.7**
Feed Pressure (kPa)	1350	**1390 ± 159**

EDR-SRO system Design



Performance data for the EDR stacks

Component	Feed Concentration (mg/L)	EDR Permeate Concentration (mg/L)
TDS	3998 ± 786	**1435 ± 438**
Ca	422 ± 94	**36 ± 15**
Na	917 ± 79	**358 ± 151**
Cl	828 ± 238	**121 ± 42**
SO_4^{2-}	3254 ± 842	**701 ± 487**
TOC	2.12 ± 1.1	**1.98 ± 0.4**

Performance data for the SRO units of the EDR plant

Component	Target	Average
Water Recovery (%)	85	**79 ± 1.6**
Conductivity (µS/cm)	80	**33 ± 9**
CIP/Train/month	1	**2.5**
Flux ($L/m^2.h$)	25	**20.1 ± 3.2**
Feed Pressure (kPa)	1350	**1350**

The overall EDR plant water recovery was 76%.
The SRO concentrate was recycled to the EDR stacks as brine makeup.

In Closing

- The case studies presented cover different membrane applications in different scenarios and provide comparative examples of membrane and conventional wastewater and effluent treatment technologies.
- All the examples show that the application of membrane separation technology in water management of mining and metal processing operations provides good opportunities for water recovery. As well,
- There is the strong possibility of improving process economics and performance over conventional methods, and exceeding environmental water discharge criteria.

In Closing

For mining applications the main technology development drivers are:

- Membrane fouling – lowering membrane replacement costs, maximizing recoveries
- Pretreatment as a means of fouling control
- Maximizing water recoveries
- Brine disposal and the minimization of its associated costs

In Closing

Any research roadmap for membrane applications in mining should address:

- Development of a fundamental understanding of factors that affect the long-term performance of membrane separation and the limiting steps:
  - understanding of fouling mechanisms, and the related membrane surface properties that reduce fouling and scaling.
- Development of adequate pretreatment processes that are economically non-prohibitive. Such considerations would take into account particulate matter and dirt loading (TSS), organic and biological matter and their potential for downstream fouling,

In Closing

Any research roadmap for membrane applications in mining should address:

- Development of high flux low fouling membranes and membrane materials. These would include:
  - membrane material development to improve existing polymeric materials;
  - the development of new polymers that would have suitable chemical, physical and mechanical surface properties; and
  - module and system design.
- Strategies to deal with membrane process concentrates, which could include extraction of valuable chemicals and metals of value and water recovery.

Thank You!

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