Application Of Membrane Separation Technology to Mining Processes

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Presentation Outline

- Introduction
- Brief overview of membrane processes
- CANMET research
- Case Studies
- Conclusions and recommendations

- The 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.

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.

Introduction

- Greater focus on water recycling and minimization of water use
- Market niche for membranes
- Although an established technology in water treatment, membrane separation is an emerging technology in the mining industry

Membranes: What are they?

- Membranes are thin ***semipermeable*** barriers or ***permselective*** 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 Separation

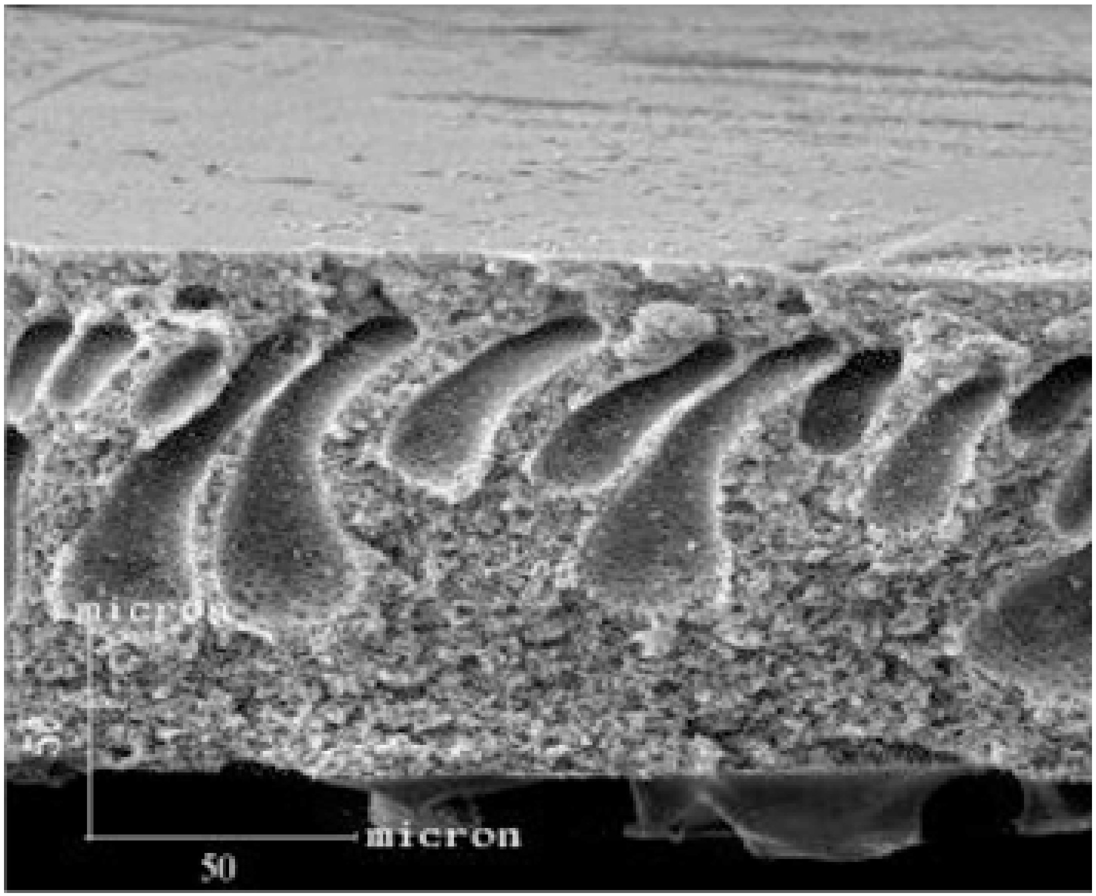
Pressure driven membrane separation process types:

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

Other:

- Electrodialysis

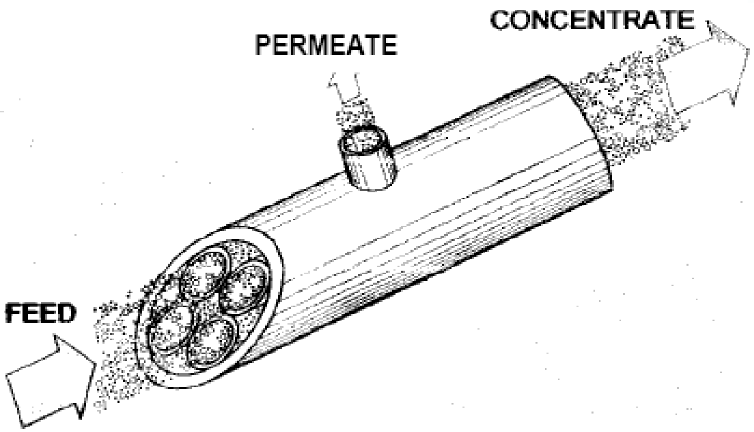
X-Section of RO Asymmetric Membrane

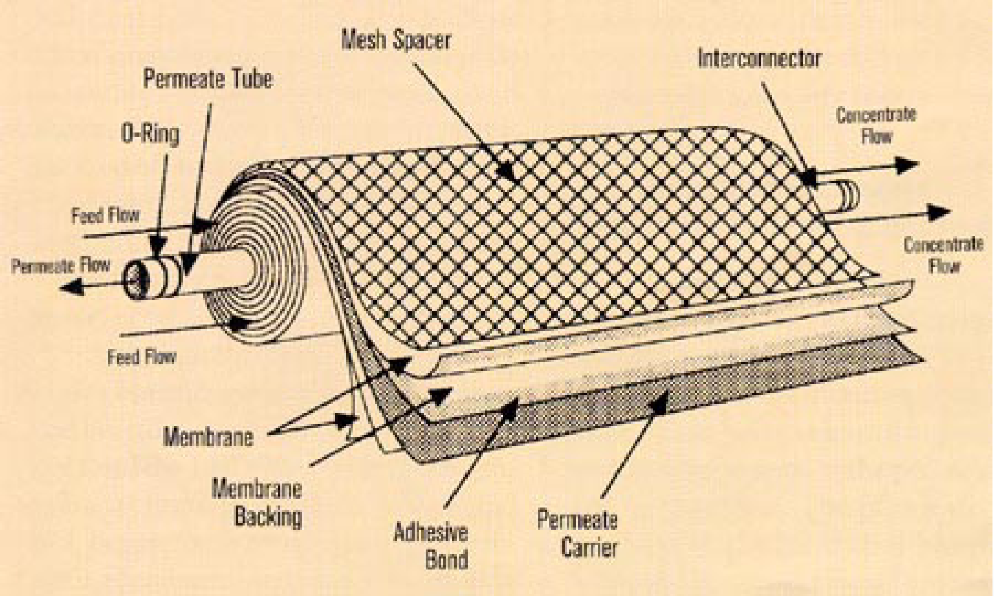


Membrane Configuration

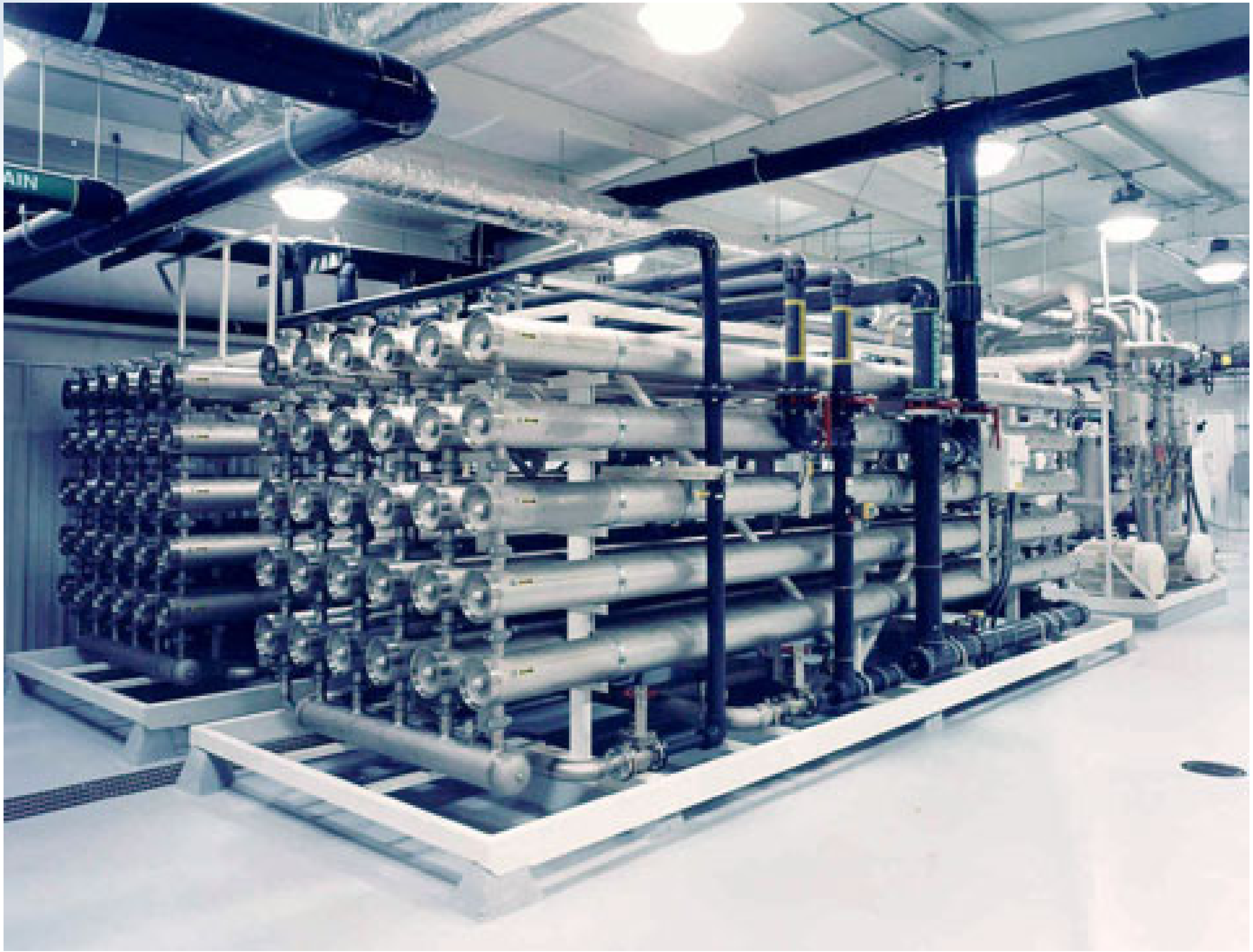
www.mediaandprocess.com/

Tubular
Membrane
Module





Spiral-Wound Module

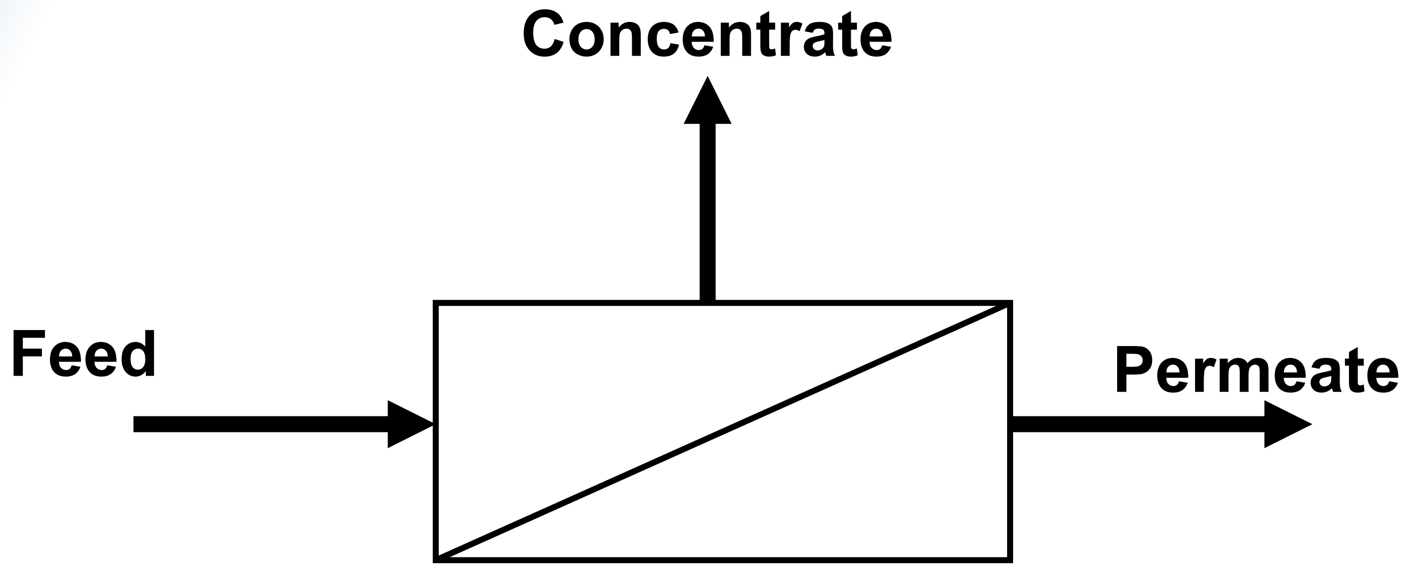


Membrane Separation

Membrane Process Stages

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

Membrane Separation



Membrane – System Design

Important considerations for the process:

- Feed water characterization,
- Pre-treatment requirements,
- Membrane selection,
- Array design, flowrates, recovery, permeate flux,
- Antiscalant selection and dosage,
- Membrane cleaning (chemicals, T, pH, cleaning duration and frequency), and
- Post-treatment requirements.

Membrane Fouling

Membrane Fouling

Five principal fouling mechanisms have been identified:

(i) Concentration polarization,

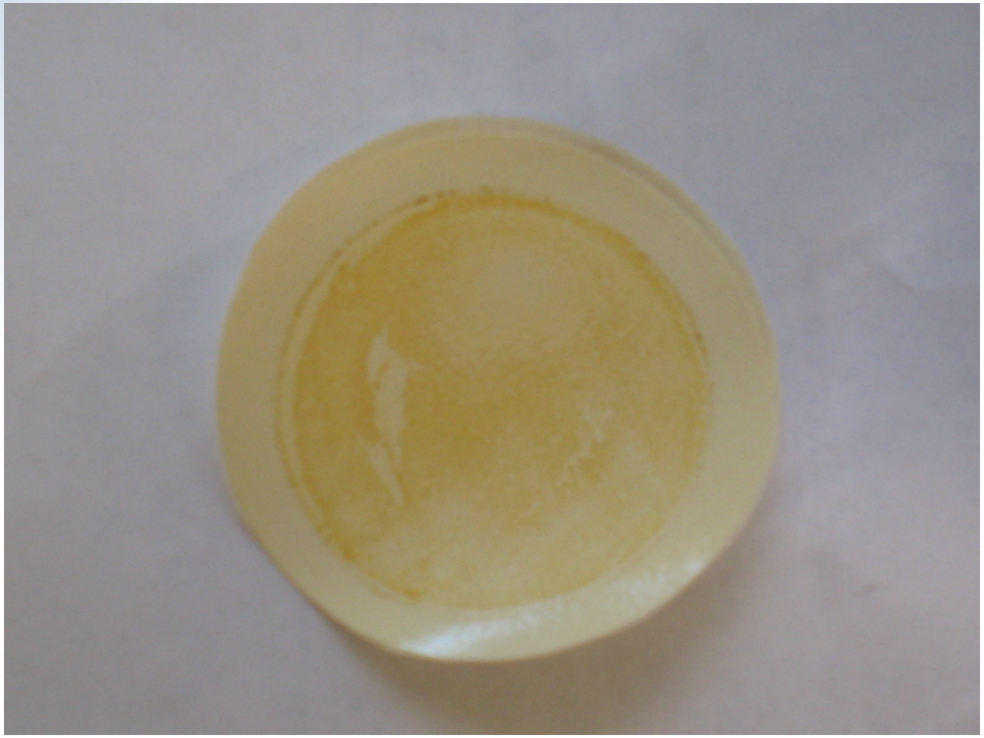
(ii) Cake formation,

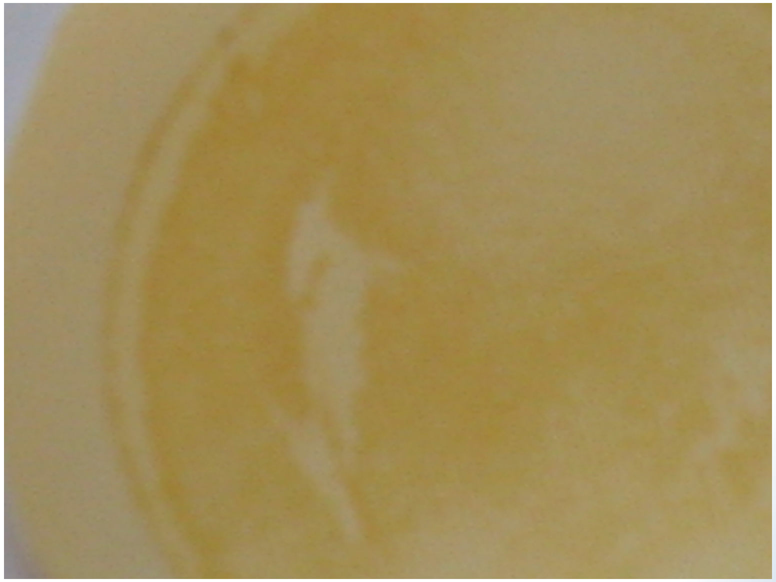
(iii) Inorganic precipitation,

(iv) Organic adsorption, and

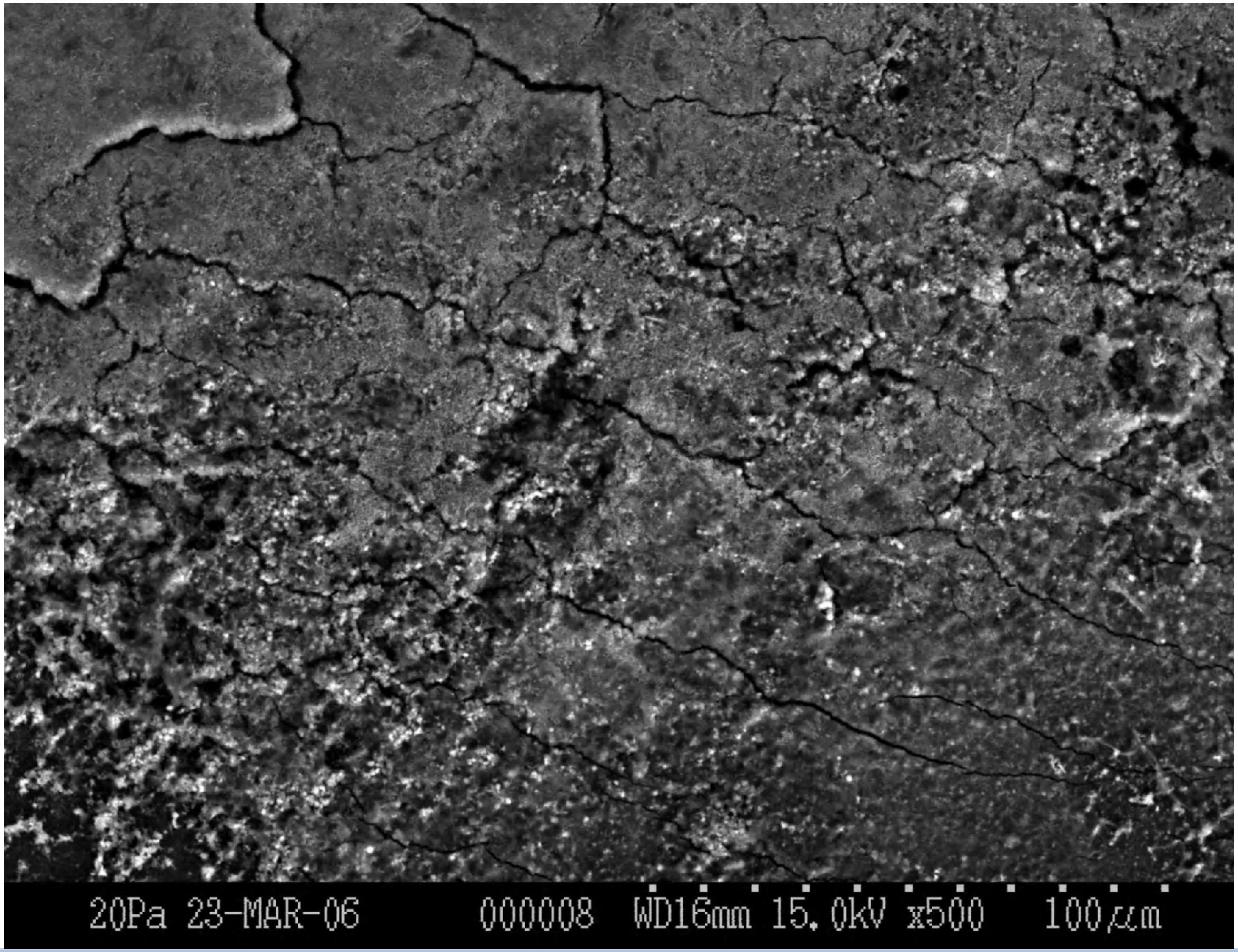
(v) Biological fouling.

Membrane Coupon After Test with Raw AMD

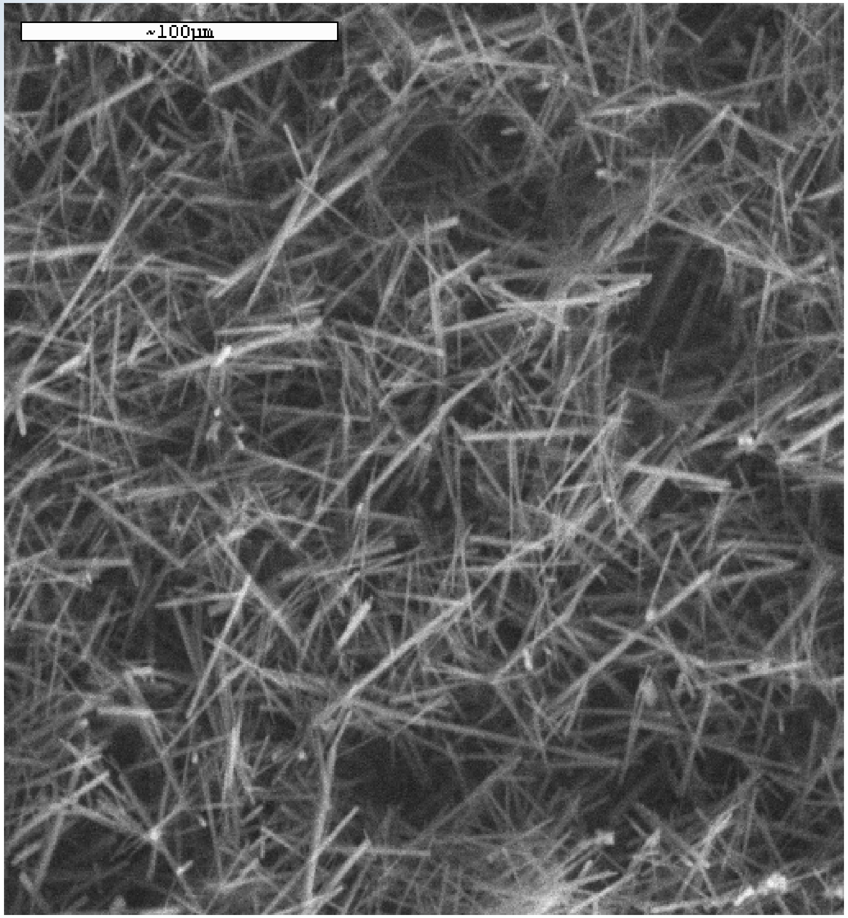


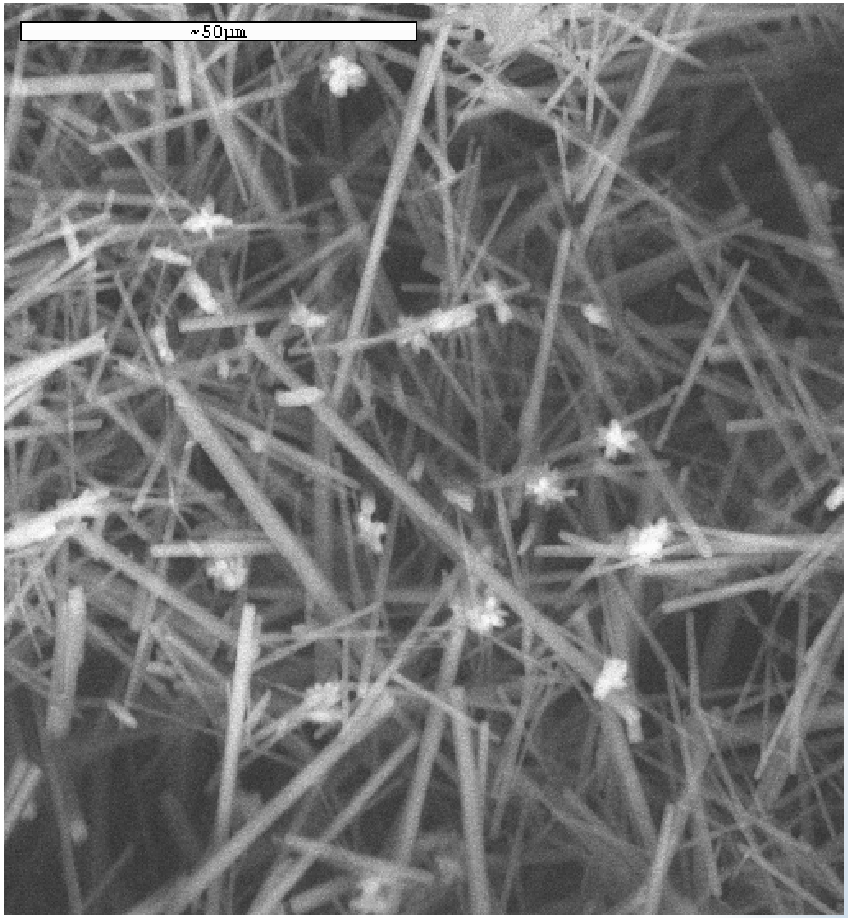


SEM of a Membrane Coupon After Raw AMD Test



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





Concentrate Treatment

Concentrate Treatment Options

- Treatment options: thermal and non-thermal
- liming
- Brine concentrator
- Crystallizer
- Evaporator
- Metal recovery
- Precipitation/coagulation-sedimentation/ filtration

Membrane Separation – Concentrate treatment

- Possibility of no wastewater discharge, only solid salt crystals and clean water.
- A crystallizer, combined with other technologies such as a brine concentrator, evaporator, or in some cases reverse osmosis (RO), preconcentrates the wastewater
- In the vapor compression crystallizer , the brine concentrator uses 25 to 37 BTU per pound of waste feed which is 60 to 90 kWh per 1,000 gallons of feed, 30 times more efficient than conventional single effect steam-driven evaporators.
- Capacity: treatment of up to 1000 gal/min

Reference: GE-Ionics

Reference: GE-Ionics

MMSL Membrane Laboratory Facilities

Membrane Research - MMSL

- New Program at MMSL
- We have laboratory and pilot scale capacity

Objectives:

- Development of membrane based processes for ARD and mine effluent treatment and Effluent polishing
- Incorporation of membranes in processing circuits; Zero discharge processes

Membrane Research - MMSL

Collaborations

Process Development

- Collaboration with membrane system manufacturing company – Seprotech Systems Inc.
- NRCC, EC and SAIC Canada

Materials and Membrane Development

- Microdyn-Nadir – US Branch

Academia

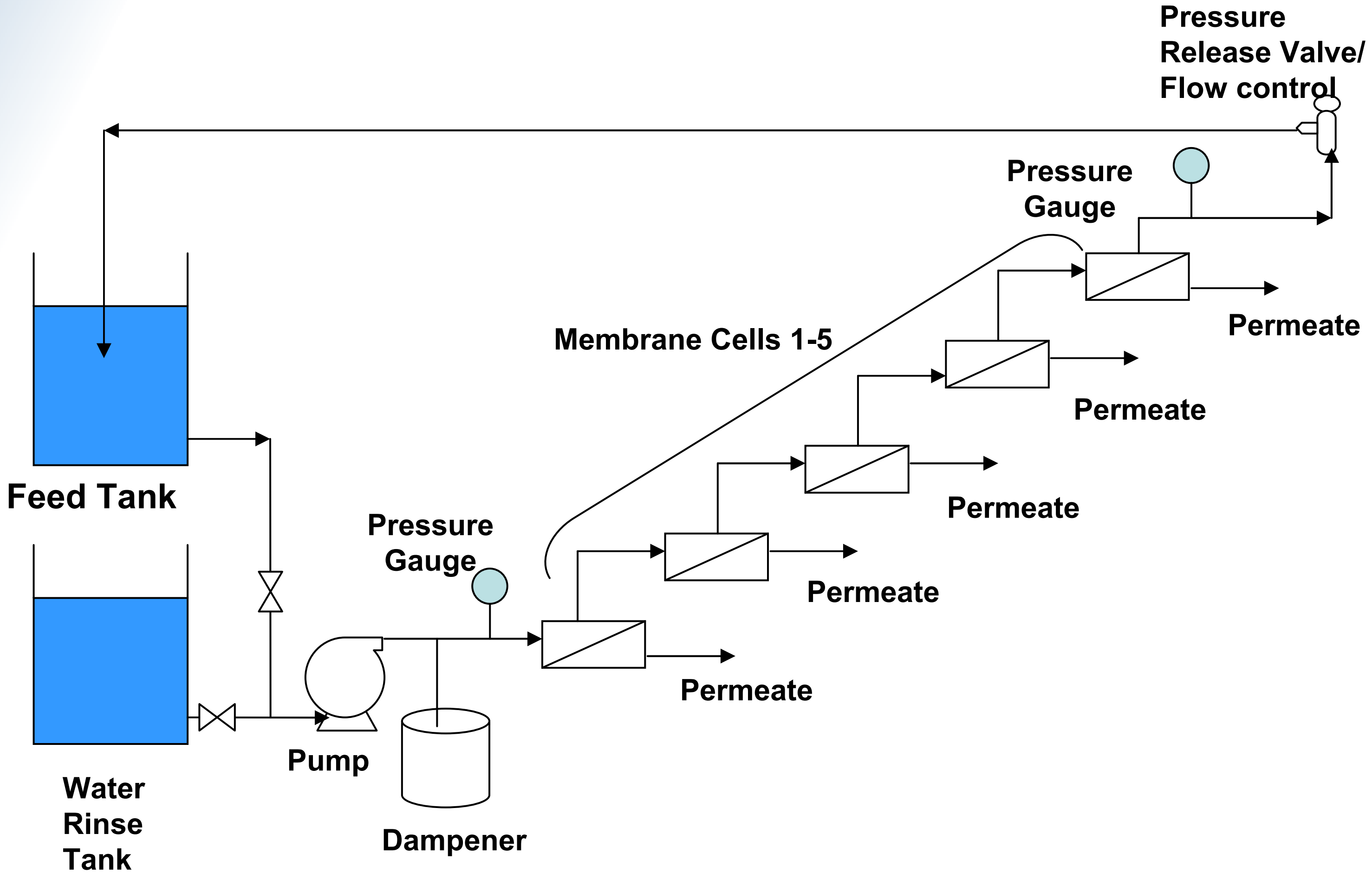
- University of Ottawa – Industrial Membrane Research Institute

Seek new research partners

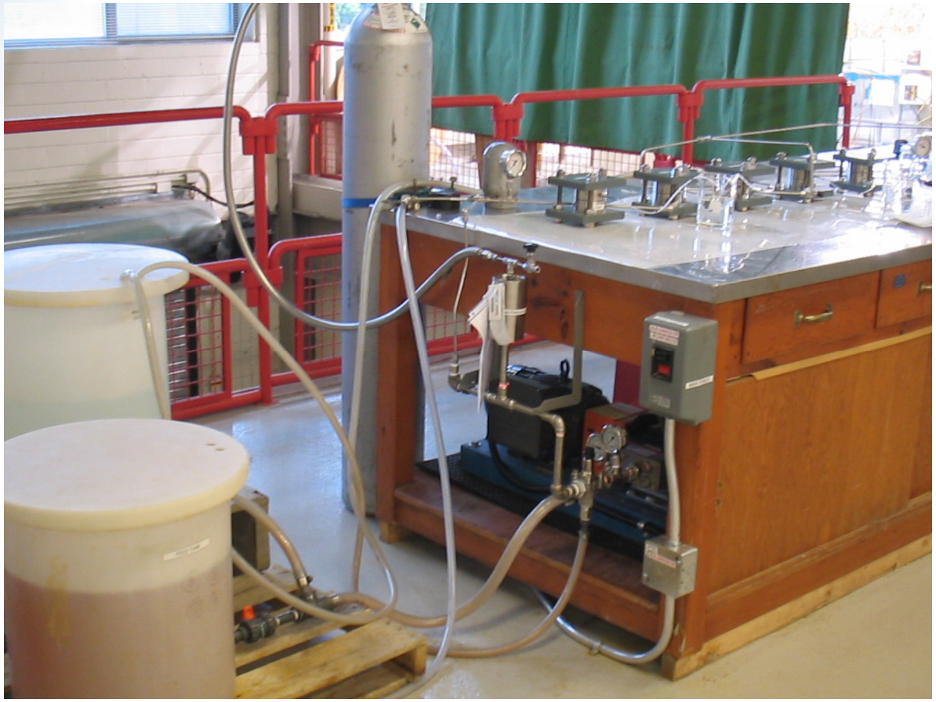
Some Clients

Vale Inco, Cameco Corporation,

5 Cell Membrane Test System



Bench-scale membrane test system



CANMET Mining and Mineral Sciences Laboratories

MMSL Results AD/Ammonia/TDS

Experimental Conditions – Membrane Tests

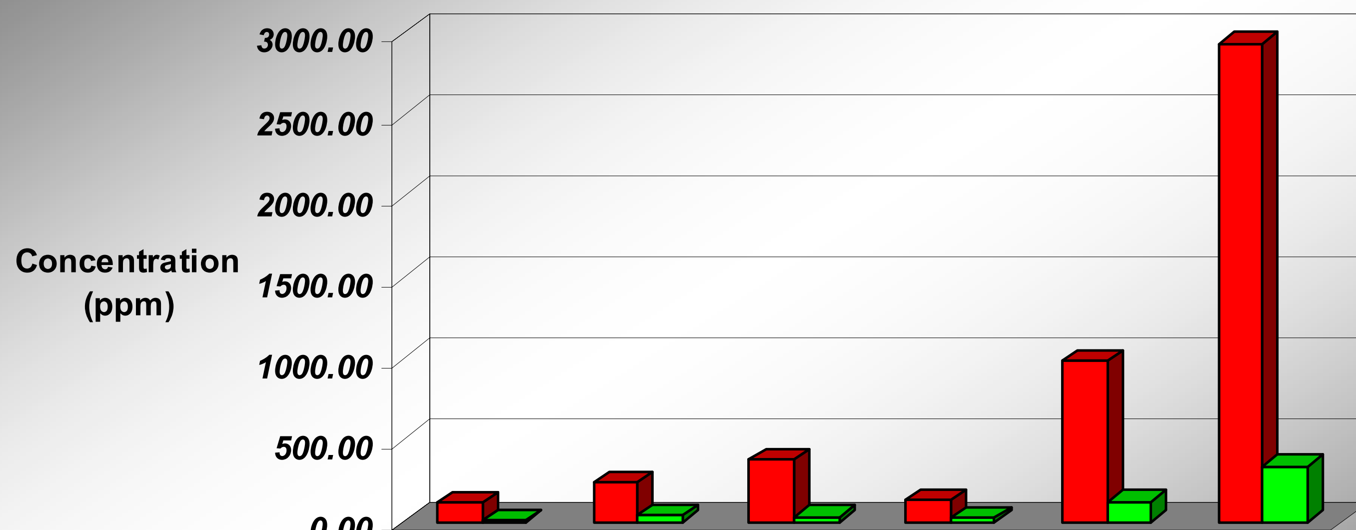
Feed Chemical Composition:

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**

Selected Membranes

Membrane Code	Type	Material/ Membrane Type	MWC	Operating Pressure range	pH Range	Temperature Range (ºC)	Manufacturer
HL2521T	NF	TFC	NA	450	3-9	50	DESAL
AG2521T	RO	TFC	NA	450	4-11	50	DESAL
YM-DL-SP3001*	NF	TFC	0	NA	2-11	NA	GE Osmonics
YM-HL-SP3001*	NF	TFC	0	NA	3-9	NA	GE Osmonics
CE2026TF	RO	CA/TFC	NA	140-400	5-6	30	DESAL
YM-DK-SP3001*	NF	TFC	0	NA	2-11	NA	GE Osmonics
CG2540 FF	RO	TFC	NA	450	3-8	30	DESAL
NP010	NF	PES Asymmetric	700	600	1-14	50	Microdyn-Nadir
NP030	NF	PES Asymmetric	500	600	1-14	50	Microdyn-Nadir
UH005 UF	UF	PES/TFC	5000	NA	1-14	NA	Microdyn-Nadir

Permeate Metal Concentrations
Membrane NP030 NF-PES @ 400 psig



	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

Metal

Membrane Separation Tests

Raw AD solution feed and permeate sulphate concentrations obtained from a DESAL and GE Sepa™ RO and NF membranes tested at 100 to 500 psig.

Pressure (psig)	100		200		300		400		500	
	Feed	permeate	Feed	permeate	Feed	permeate	Feed	permeate	Feed	permeate
Membrane	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
HL2521T	3526	396	3581	355	3614	330	3739	318	3840	548
AG2521T	3526	81	3581	47	3614	32	3739	22	3840	54
YM-DL-SP3001	3526	364	3581	190	3614	166	3739	5	3840	427
YM-HL-SP3001	3526	426	3581	378	3614	352	3739	332	3840	631
CE2026TF	3526	144	3581	74	3614	53	3739	36	3840	97
YMDK SP3001	3359	333	2944	313	2910	461	2895	246	-	-
CG2540 FF	3359	3.40	2944	131	2910	89	2895	29	-	-

Results

High rejection RO membranes at 25<u>+</u> 2 °C, feed 1 at pH 4 and operating pressure of 600 psig with no added antiscalant.

Compound	Feed (ppm)	%R SW30-2540	Permeate (ppm) SW30-2540	%R Koch2540-SW	Permeate (ppm) Koch2540-SW
NH_4^+	3450	99.54	21.00	99.59	18.50
SO_4^{2-}	18143	99.82	33.00	99.73	49.50
Na	3170	99.72	8.78	99.00	31.73
Mg	730	99.88	0.86	99.08	6.75
Fe	5.55	99.73	0.02	99.45	0.03
Co	5.12	98.74	0.06	98.86	0.06
Ca	11.31	95.23	0.54	95.23	0.54
Zn	7.18	89.14	0.78	96.61	0.24
Ni	5.05	98.04	0.10	98.20	0.09
Cu	5.2	99.76	0.01	98.82	0.06
PWP (gfd)		61.94		37.51	
Permeate Flux (gfd)		23.34		17.50	

Case Histories

Case History

- Major acid drainage pit – 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 Utah 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

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 was a feasibility study conducted at Asarco's Globe Plant to improve their wastewater treatment process by reducing the operating costs, sludge volume and improving discharge water quality.
- A number of process configurations were examined including a membrane separation polishing system

ASARCO

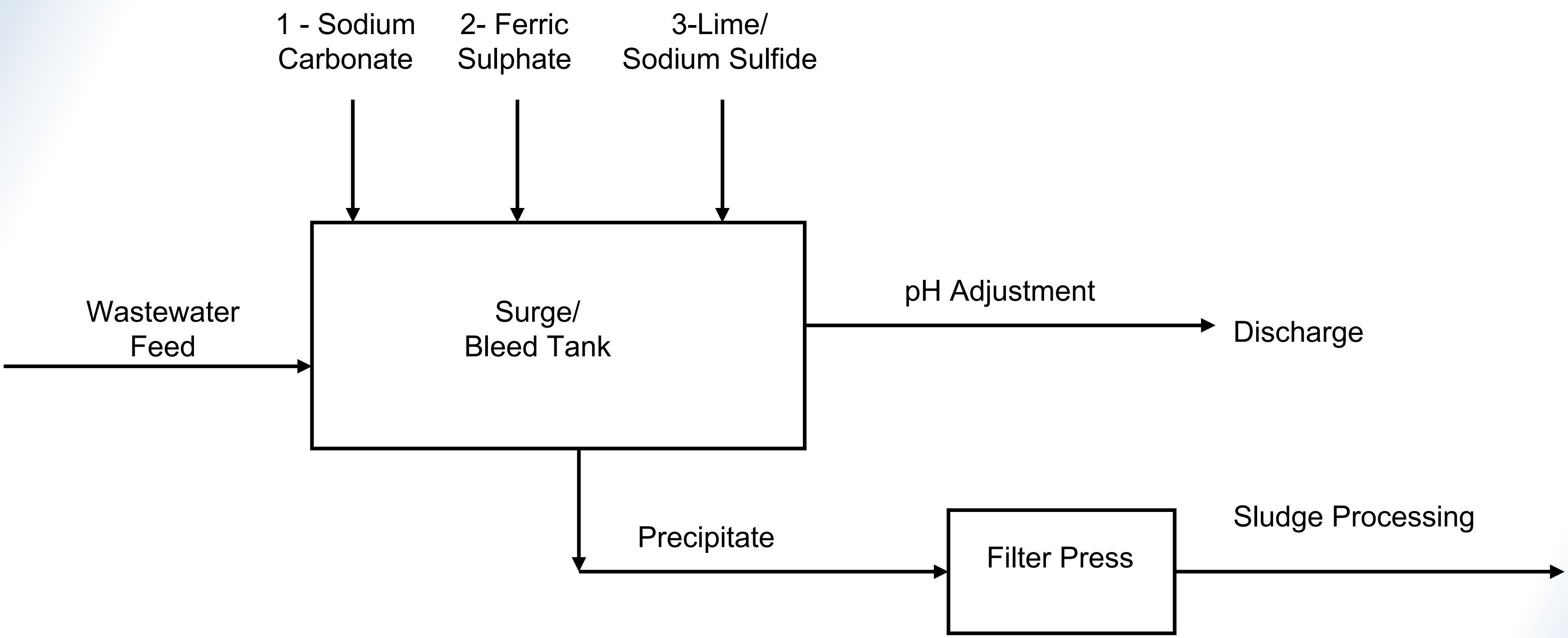
- Asarco Inc. is a large producer of non-ferrous metals such as copper, zinc, lead, silver and gold.
- The Asarco Globe plant has been a metal refining facility since 1886, producing a wide range of non-ferrous metals.
- In 1986, the company installed and operated a chemical precipitation system to treat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

ASARCO

- 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

Block diagram of Asarco's precipitation process

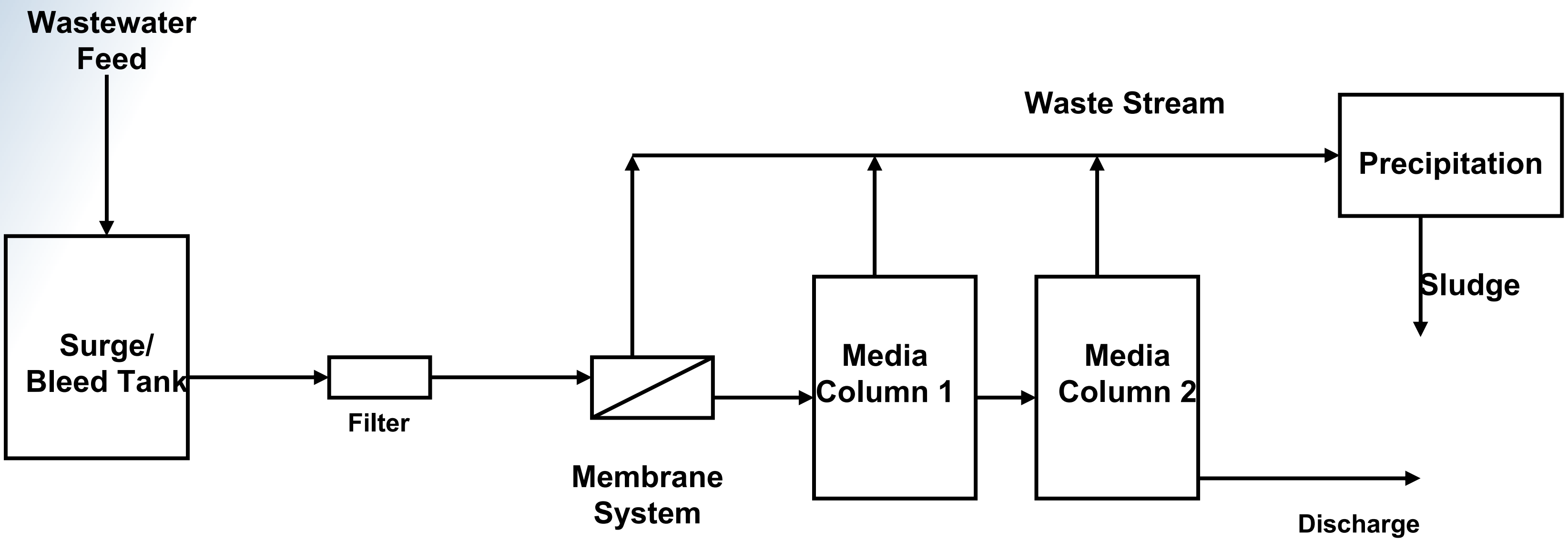


ASARCO

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	0.02
Se (mg/L)	0.056	<0.01
Cd (mg/L)	14.5	0.10
Zn (mg/L)	35.5	0.35
Pb (mg/L)	3.07	<0.05
Ni (mg/L)	0.06	0.025
Fe (mg/L)	0.99	0.10
Mn (mg/L)	3.33	0.12
Cu (mg/L)	0.07	0.02

ASARCO



Block diagram of Asarco's membrane separation process

ASARCO

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

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.

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.
- The examples show that the application of membrane separation technology in water management in mining and metal processing operations provides good opportunities for high water recovery and volume reduction.

In Closing

- There is opportunity for improving process economics and performance, as well as exceeding environmental water discharge criteria and cost effectively produce discharge streams of significantly higher quality .
- With the goal of better discharge water quality with minimal or no impact on the environment more complex and multi component hybrid processes could be needed which may include chemical and/or physical methods in combination with a membrane separation step.

In Closing

For mining streams and effluents, two most important issues for membrane separation are membrane fouling and brine disposal. As a result, 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

Thank You!

Case History

V-SEP

- New Logic Research Inc. has developed a Vibratory Shear Enhanced Processing System (V-SEP). 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.
- The shear created by the lateral movement of the membrane surface keeps the colloidal particles in suspension. The result is improved relative throughput per area of membrane.

Case History

V-SEP

- The vibrational shear combined with the laminar flow of the feed solution across the membrane surface allows for a very high recovery.
- 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 -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