Treatment of Acidic Drainage Streams Using Membrane Separation

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Abstract

In an in-house study at CANMET-Mining and Mineral Sciences, the application of two pressure-driven membrane separation processes, nanofiltration (NF) and reverse osmosis (RO), were assessed for treating raw acidic drainage and the effluent from a high density lime neutralization process. A number of membranes from different membrane manufacturers were evaluated for their performance in treating these effluent streams under different operating conditions.

The high flux RO membranes showed the best performance, achieving rejections up to 99.9% for both sulphate and metals species present in the raw and treated AD samples tested under operating pressures in the range of 100-500 psig. NF experiments showed both sulphate and metal removals as high as 99%.

Background and Literature Review

The objective of this study work was to assess and evaluate the application and performance of reverse osmosis (RO) and nanofiltration (NF) for treating a typical acidic drainage (AD) stream, as an alternative or a supplementary treatment to the conventional chemical and high density sludge (HDS) processes. A number of membranes suitable for the application were obtained from different membrane manufacturers. Their performance was assessed based on water flux, rejections of target contaminants and permeate quality. It should be noted that the performance data of the membranes are subject to the test conditions of this specific study, and the properties and composition of the AD sample tested.

In North America, there are currently no set discharge limits for sulphate levels in mining discharge streams. However, regulatory agencies in Canada and the United States are becoming concerned about the elevated sulphate and total dissolved solids (TDS) in the effluents due to the resulting increases in the salinity levels in the receiving bodies of water (Lorax 2003). The mitigation of sulphate levels in the discharge streams will likely become a necessary added step in AD treatment processes and membrane separation is probably one of few potential technologies that could help fill this gap.

Feasibility of the application of different membrane separation processes for the treatment of mine effluents and process streams has been demonstrated in the literature (Awadalla and Kumar 1994, Awadalla and Hazlett 1992). Different studies have shown successful application of RO, NF and ultrafiltration (UF) membranes for the treatment of AD and other streams for the removal of contaminant such as sulphate, metals, nitrate and ammonia (Awadalla and Kumar 1994; Awadalla and Hazlett 1992, Mortazavi 2008).

A number of studies have demonstrated the effectiveness of membrane separation processes for mine water and effluent treatment; however, there are even more applications possible for the mining sector which could be coupled with treating AD (Bertrand *et al.* 1997, Butler and MacCormick 1996, Stewart *et al.* 1997, Awadalla and Kumar 1994, Solomon *et al.* 1989, Bostjancic and Ludlum 1996, Sikora and Szyndler 2004, Tiepel and Shorr 1985, Miller 2005, Green *et al.* 1993, Harrison Western 1997, Nieuwenhuis *et al.* 2000, van der Graaf *et al.* 1999 and O'Neail *et al.* 1981).

The feasibility of the application of RO and NF, and even UF, for the removal of hardness, nitrate, ammonia, heavy metals and oxyanions has been demonstrated in the published literature. United States Environmental Protectio Agency (USEPA) considers RO as a best available technology to meet

anticipated regulations for small surface-water plants without existing facilities and groundwater treatment plants (Rautenbach and Voβenkaul 2001, Rautenbach and Groschl 1990, Waypa *et al.* 1997).

Treatment of Acidic Drainage

Various studies have shown successful application of RO and NF membranes for the treatment of AD. The literature invariably shows high rejections of metals associated with membrane applications; however, high recovery operations could be limited by calcium sulphate and/or iron fouling related problems. Membrane research examining the treatment of industrial effluents shows progressive improvements with the development of better membranes. Some of these advancements include: high flux RO and NF membranes; new membrane materials, both polymeric and inorganic; and better fouling control and prevention strategies (Bhattacharyya *et al.* 1979, 1982, Awadalla and Hazlett 1992, Sastri 1978, 1979, Sastri and Ashbrook 1976, Valenzuela *et al.* 2005, Nieuwenhuis *et al.* 2000, Lorax 2003).

An example of the application of membranes is the joint Anglo Coal and Ingwe Collieries reclamation project in the municipality of Emalahleni in Mpumalanga, South Africa for the treatment of 20 ML/day mine water and AD (Holtzhausen 2006). AD collected from three mine sites was first pipelined to two storage facilities where it was neutralized by lime addition to remove iron, aluminum and magnesium. After the clarification, the water was treated with UF and RO membranes. The membrane separation step was repeated three times to maximize water recovery and minimize concentrate brine volume. The process was expected to produce 100 m^3/day of brine and 100 tonnes/day of gypsiferous waste. The brine was then directed to evaporation ponds for final disposal.

The RO treatment of AD has a potential to generate large volumes of concentrate that would need disposal, or further treatment and subsequent disposal. This concentrate stream could be further processed to recover the metals, which would generate revenue to offset the costs of the treatment operation (Reidinger and Schultz 1996, Wilmoth 1973, Hill *et al.* 1971, Awadalla and Kumar, 1994).

Reverse osmosis or NF can be utilized, as a final polishing step, after lime treatment and neutralization as suggested by Awadalla and Hazlett (1992). A combination of ion exchange and RO can also be utilized for the treatment of AD, or any other water with extreme pH values and high metal content. This combination of processes could overcome the limitations arising from the high concentrations of calcium sulphate and/or iron, which could create serious fouling problems (Hill *et al.* 1970, Blackshaw *et al.* 1974, 1976).

Nanofiltration and RO were used successfully at the Kennecott Utah Copper's Bingham Canyon Mine to treat AD and contaminated groundwater. This mine has been in operation for over 100 years, with more than 70 years of active leaching (20,000 – 70,000 gpm). This activity has created a large groundwater contamination problem, including 62 million m^3 of acidic water with a pH < 4.0 and 247 million m^3 of sulphate water with sulphate levels of 1.5 to 9.2 g/L.

The water at the site contained high levels of Al, Ca, Cu, Fe, Mg, Mn, Zn, SO_4, TDS and pH's of ~2.9 to 3.4. The highest levels of contaminants reported were; 92,000 ppm TDS, 73,800 ppm sulphate, 9,900 ppm Mg, 5,960 ppm Al. The rest of the contaminants were in the range of 150-500 ppm (Baker 2004).

An extensive account of the literature on the application membrane separation is presented by Mortazavi (2008).

Experimental

Membranes

A number of high flux RO and NF membranes, supplied by different membrane manufacturers were selected for the AD treatment tests. Table 1 provides a list of the membranes used in this study.

Table 1. List of the membranes assessed and their operating conditions.

Membrane Code	Type	Material/ Membrane Type	MWC	Operating Pressure range	pH Range	Temperature Range (°C)	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

TFC – thin film composite, CA-cellulose acetate, PES-polyethersulphone

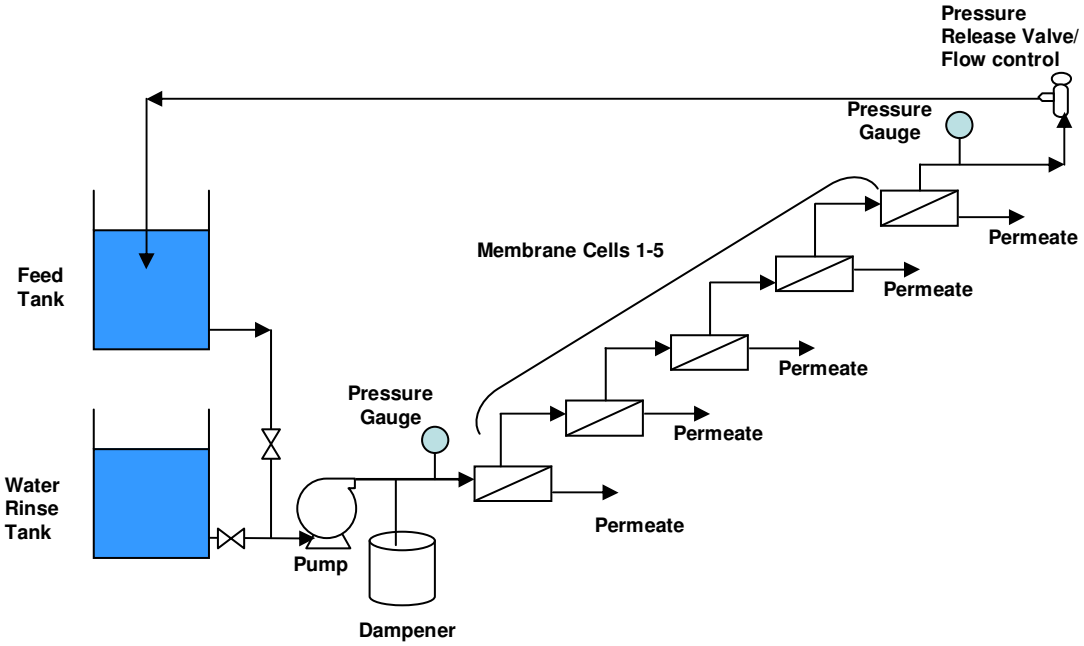

Figure 1. General schematic diagram of the bench-scale membrane test system.

Bench-scale Membrane Testing System

The test system used in this study consisted of a feed tank, rinse tank, a chiller for temperature control, a positive displacement pump and five stainless steel (SS) membrane test cells. Figure 1 shows a schematic

diagram of the constant pressure test system. The feed is pumped through the feed side of the five membrane cells, which are connected to each other in series. A pressure regulator, located at the pump outlet, is equipped with pressure release and flow bypass valves, which are used to adjust the pump outlet pressure. The system is equipped with a flow dampener installed after the pump outlet. An adjustable pressure release valve, installed after the last membrane cell, is used to adjust the pressure across the membrane cells as well as to control the flowrate of the feed to and across the membrane surface. The permeate is collected from each cell and the feed is returned to the feed tank. A cooling system is used in the feed tank to maintain the temperature of the feed.

Feed Solutions

A raw AD sample was collected from a mine site in north-western Quebec. The raw AD sample was processed through a HDS pilot process to produce the effluent. Table 2 presents the typical compositions of the raw AD and HDS-treated samples.

Table 2. Compositions of raw and treated AD feed samples.

Parameter	Raw AD (ppm)	HDS-Treated Effluent (ppm)
pH	2.4	6.0-9.2
Conductivity	5.5	4.8
Alkalinity	-	22.0
Al	109	3.4
Ca	289.9	1038
Cu	2.8	<0.03
Fe	377.5	0.423
Mg	117.2	71.3
Mn	11.5	0.2
Ni	0.4	<0.1
S_{total}	1006	991.1
Zn	1.2	<0.1
SO_4	3526	2219

Membrane Test Procedure

The flat sheet membranes were cut into circular coupons of effective permeation surface areas of 11.64 cm^2. The coupons were loaded into the membrane cells facing the feed side of the cell. Membranes were tested under operating pressures of 100-500 psig, depending on the membrane's specified maximum operating pressure, and operating temperatures of 25 ±2°C. Deionised water was then circulated in the system and the membranes were conditioned for 40-60 minutes. The pure water permeation rate (PWP) was measured before and after the test. Prior to collection of permeate samples the membranes were conditioned with the feed solution for 40-60 minutes.

At least two permeate samples were collected during the course of one test. After the samples were collected, the conductivity and pH of the permeate samples were measured and the permeate flux was calculated. The surfaces of the membranes were visually examined and further analyzed using scanning electron microscopy and energy dispersive x-ray spectroscopy (SEM-EDX). These results are not presented in this paper.

Analytical Methods

Samples of the feed and permeate were analyzed at the Analytical Services Group at CANMET-MMSL, an ISO 9002 certified laboratory. The analyses for sulphate and chloride were conducted with HPLC, and the metals analyses were performed by ICP-MS and ICP-AES scan.

Results and Discussions

The results presented in the tables in this section are the average results from duplicate tests unless specified otherwise.

Nanofiltration Experiments

Two NF membranes, NP010 and NP030 (supplied by Microdyne-Nadir) were tested. The two membranes were polyethersulfone (PES) thin film composite. NP030 is a tighter membrane than NP010 with a Molecular Weight Cut-off (MWC) of 500 daltons. Tables 3 and 4 present the results of the NF experiments at different feed pressures and show that the NP030 performed better than NP010 in terms of percent rejection (%R) and the residual TDS concentrations in the permeate stream. NP010, with a larger MWC than NP030, showed much higher permeate flux at each feed pressure tested. Sulphate concentrations as low as 384 (for NP030) corresponding to a percent rejection of 88%. Rejection values in the range of 82% to 99% were achieved for the different metals present in the solution. The tables also show that the permeate quality deteriorated at 500 psig pressure for both membranes; however, this change in permeate quality was more pronounced for the NP010. Due to the higher flux of NP010, which would correspond to higher water recoveries, in the absence of an antiscalant, the metals in the solution would reach their solubility limits and precipitate on the surface of the membrane. This effect, with the same degree of severity, would be observed at higher pressures for NP030. Additionally, the effect of concentration polarization and increased local osmotic pressure at the membrane-feed interface would further result in the deterioration in the permeate quality at higher pressures and flux.

Table 3. NF membrane sulphate and metal rejection data from raw AD solution.

Membrane	**NP010 NF-PES (%R)**			**NP030 NF-PES (%R)**		
	% Rejection			**% Rejection**		
Pressure (psig)	**200**	**400**	**500**	**200**	**400**	**500**
Al	80.2	92.8	85.8	85.2	94.0	91.4
Ca	66.2	79.8	72.5	75.3	85.6	84.3
Cu	64.4	76.9	71.2	73.0	83.4	82.8
Ni	96.5	99.9	76.3	93.4	99.9	99.9
Fe	75.1	88.9	83.8	81.5	91.8	89.8
Mg	64.9	80.5	72.1	74.3	85.5	82.6
Mn	64.8	79.1	71.1	74.3	84.8	82.2
S_{total}	70.5	83.5	78.6	78.5	88.1	87.0
Zn	64.7	78.8	71.5	64.5	83.2	82.3
SO_4	**70.8**	**83.4**	**79.1**	**78.6**	**88.4**	**87.1**

Table 4. Raw AD solution feed and permeate compositions obtained from a NF membrane test at 200 to 500 psig.

Membrane	**NP010 NF-PES**					
Pressure (psig)	**200**		**400**		**500**	
	Feed	**Permeate**	**Feed**	**Permeate**	**Feed**	**Permeate**
pH	2.3	2.6	2.4	2.7	2.1	2.3
Conductivity (mS/cm)	4.1	2.0	4.1	1.6	4.1	1.7
Al (ppm)	114	22.7	113.7	8.2	111.6	15.9
Ca (ppm)	242.7	82.1	240.7	48.7	239.2	65.7
Cu (ppm)	3.9	1.4	4.22	1.0	4.7	1.4
Ni (ppm)	3.9	0.14	0.37	ND	0.5	0.12
Fe (ppm)	384.8	95.8	381.8	42.3	384.5	62.5
Mg (ppm)	127.8	44.9	126.8	24.7	126.7	35.3
Mn (ppm)	11.9	4.19	11.8	2.5	12.1	3.5
S_{total} (ppm)	992.	292.7	989.0	162.9	991.7	212.8
Zn (ppm)	2.6	0.9	3.03	0.6	3.5	1.0
SO_4 (ppm)	2950	862	2937	489	2982	623
Permeate Flux ($L/m^2.h$)		66.4		94.2		113.7
Membrane	**NP030 NF-PES**					
Pressure (psig)	**200**		**400**		**500**	
	Feed	**Permeate**	**Feed**	**Permeate**	**Feed**	**Permeate**
pH	2.3	2.6	2.4	2.8	2.1	2.5
Conductivity (mS/cm)	4.1	1.7	4.1	1.2	4.1	1.3
Al (ppm)	114.2	16.9	113.7	6.9	111.6	9.6
Ca (ppm)	242.7	59.9	240.7	34.7	239.2	37.7
Cu (ppm)	3.9	1.1	4.2	0.7	4.7	0.8
Ni (ppm)	3.9	0.3	0.4	ND	0.5	ND
Fe (ppm)	384.8	71.3	381.8	31.5	384.5	39.2
Mg (ppm)	127.8	32.8	126.8	18.4	126.7	22.0
Mn (ppm)	11.9	3.1	11.8	1.8	12.1	2.2
S_{total} (ppm)	992.7	213.6	989.0	117.3	991.7	130.1
Zn (pm)	2.6	0.9	3.0	0.5	3.5	0.6
SO_4 (ppm)	2950	630	2937	340	2982	384
Permeate Flux ($L/m^2.h$)		14.9		24.6		25.1

Using the NP010 and NP030, a series of tests were conducted with the effluent from an HDS process treating the raw AD. Tables 5 and 6 show the results of the tests. Similar results to those of the tests presented in Tables 3 and 4 were observed. NP030 showed better %R for sulphate (88.5%) compared to the NP010 (76.39%). The deterioration of the permeate quality was not seen at 500 psig pressure indicating the possibility of achieving a higher water recovery with treated AD sample.

Table 5. NF membrane sulphate and metal rejection data from lime treated AD solution.

Membrane	NP010 NF-PES			NP030 NF-PES		
	% Rejection			% Rejection		
Feed Pressure (psig)	**200**	**400**	**500**	**200**	**400**	**500**
Al	78.2	81.0	99.9	76.7	99.9	99.9
Ca	59.7	62.0	74.6	75.3	81.2	86.8
Fe	54.7	99.9	99.9	3.7	84.4	99.9
Mg	53.5	55.6	69.6	70.1	76.4	83.2
Mn	50.8	56.0	70.6	50.7	72.2	82.8
S_{total}	59.3	63.1	76.0	75.3	82.5	88.0
Zn	23.9	44.40	-	91.5	-	-
SO_4	**59.9**	**62.4**	**76.4**	**76.0**	**82.6**	**88.5**

Table 6. Lime treated AD solution feed and permeate compositions obtained from a NF membrane test at 200 to 500 psig.

PM NP010 NF-PES						
Pressure (psig)	**200**		**400**		**500**	
	Feed	Permeate	Feed	Permeate	Feed	Permeate
pH	6.4	6.4	6.5	6.9	6.4	6.5
Conductivity (mS/cm)	2.6	1.3	2.7	1.3	2.7	0.9
Alkalinity	12	11	12	-	11	9
Al (ppm)	0.4	0.08	0.30	0.06	0.28	ND
Ca (ppm)	617.8	249.0	584.70	222.2	569.2	144.5
Fe (ppm)	0.14	0.06	0.08	ND	0.06	ND
Mg (ppm)	71.3	33.1	70.47	31.26	69.8	21.3
Mn (ppm)	0.1	0.03	0.06	0.03	0.06	0.02
S_{total} (ppm)	589.9	240.1	582.2	214.9	576.8	138.6
Zn (ppm)	0.03	0.02	0.05	0.03	0.03	0.03
SO_4 (ppm)	1750	702	1716	646	1709	404
Permeate Flux ($L/m^2.h$)		48.05		65.70		84.44
NP030 NF-PES						
Pressure (psig)	**200**		**400**		**500**	
	Feed	Permeate	Feed	Permeate	Feed	Permeate
pH	6.4	6.6	6.5	7.0	6.4	6.6
Conductivity (mS/cm)	2.6	1.0	2.7	0.7	2.7	0.6
Alkalinity	12	-	11.5	8.7	10.50	8.40
Al (ppm)	0.4	0.1	0.3	ND	0.3	ND
Ca (ppm)	617.8	152.55	584.70	109.78	569.20	75.3
Fe (ppm)	0.14	0.15	0.08	0.01	0.06	ND
Mg (ppm)	71.3	21.3	70.5	16.6	69.8	11.8
Mn (ppm)	0.06	0.03	0.06	0.02	0.06	0.01
S_{total} (ppm)	589.9	145.6	582.2	102.2	576.8	69.1
Zn (ppm)	0.03	0.09	0.05	0.05	0.03	0.04
SO_4 (ppm)	1750	421	1716	298	1709	196
Permeate Flux$L/m^2.h$)		11.5		21.3		26.2

Reverse Osmosis and Nanofiltration Experiments – DESAL and GE Sepa™ Membranes

Four NF membranes and three high flux RO DESAL and GE Sepa™ membranes were tested. Tables 7 and 8 show the permeate flux of the membranes in tests with raw and lime treated AD, respectively, at feed pressures of 100-500 psig. An increase of flux with pressure was observed up to 400 psig and a drop was observed at 500 psig. After each test the inspection of the surface of the membranes coupons showed the presence of a residue on the surface. The data indicated that the precipitated residue on the surface of the membrane did not become a barrier to mass transfer until the feed pressure exceeded 400 psig. The drop in permeate flux at higher pressures, which is more significant for the membranes with larger pore size, is due to a number of possible factors such as compaction of the surface residue, pore plugging, and concentration polarization.

Table 7. Permeate flux at feed pressures of 100-500 psig for DESAL and GE Sepa™ RO and NF membranes – Raw AD.

Membrane	HL2521T	AG2521T	YM-DL-SP3001	YM-HL-SP3001	CE2026TF	YM-DK-SP3001	CG2540 FF
Pressure (psig)	**Permeate Flux (L/m^2.hr)**						
100	52	27	32	49	9	12	10
200	130	67	73	114	20	22	19
300	158	58	106	154	31	34	29
400	226	97	121	179	42	47	40
500	86	64	110	150	43	63	63

Permeate flux raw AD mean of duplicate runs

Table 8. Permeate flux at feed pressures of 100-500 psig for DESAL and GE Sepa™ RO and NF membranes – Lime treated AD.

Membrane	HL2521T	AG2521T	YM-DL-SP3001	YM-HL-SP3001	CE2026TF	YM-DK-SP3001	CG2540 FF
Pressure (psig)	**Permeate Flux (L/m^2.hr)**						
100	53	76	104	100	13	12	13
200	45	27	74	199	21	22	24
300	26	52	104	148	48	37	38
400	49	95	135	158	64	49	58
500	29	57	67	37	-	63	70

All data are mean of duplicate runs except for CE2026TF, YM-DK-SP3001 and CG2540 FF

Tables 9 to 12 present the separation data for the sulphate for the DESAL and GE Sepa™ membranes. The data for metals removal are not presented. With the drop in flux, an increase in the concentration of salts and sulphate in the permeate stream is expected as seen in rejection and concentration data in Table 10. The magnitude of the increase in the TDS of the permeate from each membrane is greater for the membranes with higher flux and larger pore size, which is expected. This decrease in permeate quality was not observed in the tests with the lime treated AD feed as seen in Tables 11 and 12. This was due to the lower initial total TDS content of the treated AD feed.

Table 9. Sulphate rejections obtained from DESAL and GE Sepa™ RO and NF membranes – Raw AD solution.

Pressure (psig)	100	200	300	400	500
Membrane	**Sulphate Rejection (%)**				
HL2521T	88.8	90.1	90.9	91.5	85.7
AG2521T	97.7	98.7	99.1	99.4	98.6
YM-DL-SP3001	89.7	94.7	95.4	99.9	88.9
YM-HL-SP3001	87.9	89.4	90.3	91.1	83.6
CE2026TF	95.9	97.9	98.5	99.0	97.5
YMDK SP3001	90.1	89.4	84.2	91.5	-
CG2540 FF	99.9	95.6	96.9	99.0	-

Table 10. Raw AD solution feed and permeate sulphate concentrations obtained from 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	-	-

Table 11. Sulphate rejections obtained from DESAL and GE Sepa™ RO and NF membranes – Lime treated AD solution.

Pressure (psig)	100	200	300	400	500
Membrane	**% Rejection**				
HL2521T	96.2	93.3	91.6	92.2	94.3
AG2521T	96.9	98.8	99.1	98.9	99.5
YM-DL-SP3001	99.1	99.0	98.5	96.2	97.7
YM-HL-SP3001	97.4	94.1	90.1	91.5	94.3
CE2026TF	81.5	91.2	94.4	96.1	97.4
YMDK SP3001	99.7	99.4	99.5	99.4	99.6
CG2540 FF	99.9	99.9	99.9	99.9	99.9

Table 12. Lime treated 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	2219	84	2219	148	2140	180	2016	158	1880	107
AG2521T	2219	70	2219	27	2140	20	2016	22	1880	10
YM-DL-SP3001	2219	21	2219	22	2140	32	2016	76	1880	44
YM-HL-SP3001	2219	58	2219	131	2140	213	2016	172	1880	107
CE2026TF	2219	410	2219	195	2140	120	2016	79	1880	49
YMDK SP3001	1868	6	1808	11	1824	9	1801	10	1848	7
CG2540 FF	1868	ND	1808	ND	1824	ND	1801	ND	1848	ND

ND: Not Detected

Conclusions

Based on the data and observations in this work the following conclusions can be noted:

- Membrane separation is a viable option for the removal metals and sulphate from AD streams that can achieve rejections of as high 99.99% of sulphate.
- Based on the results, a membrane step can be effective in the treatment of the raw AD stream prior to a lime treatment step or as a polishing step treating the discharge effluent from the lime treatment process.
- The two membrane processes, NF and RO showed significant levels of TDS removal from the two AD streams tested with the order of performance of NF<RO.

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