Attachment 1

Calculations

Foth & Van Dyke

Client	Kennecott Minerals Company	Scope ID	04W018
Project	Eagle Project		
Prepared by	JJF1	Date	04/01/06
Checked by	HJA	Date	04/12/06

Wastewater Treatment Plant Water Quality Estimates

	04EA-054A[1] (µg/L)	04EA-054B[1] (µg/L)	04EA-054D[1] (µg/L)	04EA-054E[1] (µg/L)	18-34 m 05EA-107[2] (µg/L)	97-114 m 05EA-107[2] (µg/L)	Upper Bedrock Leakage Composite[3] (µg/L)	86 purges 249 - 302 m 04EA-084[2] (µg/L)	Lower Bedrock Leakage[4] (µg/L)	Total Leakage Composite[5] (µg/L)	Incremental Change[6] (µg/L)	Composite Mine Drainage[7] (µg/L)	TDRSA Contact Runoff[8] (µg/L)	WWTP Influent Wastewater[9] (µg/L)	Lime Clarifier Effluent[10] (µg/L)		1st Stage Recovery (%)	1st Stage RO Feed Log Mean Concentration (µg/L)	1st Stage RO Rejection Rate (%)	Reference (GE - Osmonics) Published Rejection Rate (%)
Aluminum	100	100	100	100	50	50	**83**	50	**50**	**68**	88	156	1.0	140	140		75%	258	97.3%	99+%
Antimony	5	5	5	5	5	5	**5.0**	5	**5**	**5.0**	16	21	0.4	19	19		75%	35	97.3%	
Arsenic	2	2	2	2	2	2	**2.0**	19	**19**	**10**	17.0	27	83	33	33		75%	60	97.3%	
Barium	27	60	20	20	20	20	**28**	20	**20**	**24**	4.0	28	30	28	28		75%	53	97.3%	
Beryllium	1.0	1.0	1.0	1.0	1.0	1.0	**1.0**	1.0	**1.0**	**1.0**		1.0		1.0	1		75%	1.85	97.3%	
Boron	1,340	1,370	2,720	3,910	940	4,100	**2,397**	5,900	**5,900**	**3,973**	70	4,043	580	3,671	3,671		75%	6785	57.0%	35-70%
Cadmium	0.5	0.5	0.5	0.5	0.5	0.5	**0.5**	5.0	**5.0**	**2.5**	10.0	13	0.2	11	11		75%	21	97.3%	96-98%
Calcium	8,900	34,000	25,000	19,000	5,900.0	3,100.0	**15,983**	76,000	**76,000**	**42,991**	4,000	46,991	199,000	63,345	14,000	Note 13	75%	25877	97.3%	96-98%
Chloride	18,000	26,000	64,000	42,000	1,200	97,000	**41,367**	2,000,000.0	**2,000,000**	**922,752**	1,580	924,332	10,000	825,963	825,963		75%	1526703	98.4%	95-97%
Chromium	5	5	5	5	5	5	**5.0**	5	**5.0**	**5.0**	4.5	10	0.45	8.5	9		75%	16	97.1%	
Cobalt	10	10	10	10	10	10	**10.0**	10	**10.0**	**10**	720	730	0.80	652	500	Note 14	75%	924	97.3%	
Copper	5	5	5	5	5	5	**5.0**	5	**5.0**	**5.0**	150	155	60	145	145		75%	268	97.3%	98-99%
Fluoride	170	190	140	120	530	850	**333**	1,000	**1,000**	**633**	98	731	500	706	706		75%	1306	97.7%	94-96%
Iron	22	20	130	61	88	79	**67**	1,800	**1,800**	**847**	6,400	7,247	2.0	6,467	1,000	Note 15	75%	1848	97.3%	98-99%
Lead	1.0	1.0	1.0	1.0	1.0	1.0	**1.0**	1.0	**1.0**	**1.0**	9.0	10	0.40	9.0	9		75%	17	97.3%	
Lithium	10	14	23	14	13	16	**15**	130	**130**	**67**	26	93	19	85	85		75%	157	97.3%	
Magnesium	3,600	2,500	4,100	3,800	2,400	980	**2,897**	61,000	**61,000**	**29,043**	5,000	34,043	18,000	32,317	8,000	Note 16	75%	14787	97.3%	96-98%
Manganese	20	20	20	20	22	20	**20**	68	**68**	**42**	950	992		992	500	Note 17	75%	924	97.3%	98-99%
Mercury	0.000653	0.000428	0.000651	0.00495	0.00081	0.00351	**0.00183**	0.00021	**0.00021**	**0.00110**	0.04000	0.04110	0.04000	0.0410	0.0410		75%	0.076	97.3%	96-98%
Molybdenum	10	10	11	10	10	10	**10**	10	**10**	**10**	13	23	1.5	21	21		75%	38	97.3%	
Nickel	25	29	25	25	25	25	**26**	25	**25**	**25**	36,400	36,425	8,330	33,403	2,000	Note 18	75%	3697	97.3%	98-99%
Nitrogen, Ammonia					76	93	**85**	260	**260**	**163**	10,000	10,163		10,163	10,163		75%	18786	99.9%	
Nitrogen, Nitrate					50	50	**50**	50	**50**	**50**		50		50	50		75%	92	78.4%	93-96%
Phosphorus, total					10	33	**22**	15	**15**	**18**		18		18.5	18		75%	34	97.7%	99+%
Potassium	2,000	8,100	7,100	4,300	2,900	1,700	**4,350**	9,200	**9,200**	**6,533**	1,000	7,533	29,000	9,842	9,842		75%	18192	98.2%	95-97%
Selenium	1.0	1.0	1.1	1.0	1.0	1.0	**1.0**	17.0	**17**	**8.2**	20.0	28	4.0	26	26		75%	47	97.3%	
Silver	0.2	0.2	0.2	0.2	0.2	0.2	**0.2**	0.5	**0.5**	**0.3**	4.5	4.8	0.05	4.3	4.3		75%	8.0	97.5%	94-96%
Sodium	24,000	27,000	41,000	40,000	21,000	80,000	**38,833**	970,000	**970,000**	**457,858**	1,000	458,858	19,000	411,536	411,536		75%	760680	98.0%	95-97%
Strontium					170	91	**131**	4,800	**4,800**	**2,232**	20	2,252	200	2,031	2,031		75%	3754	99.2%	96-99%
Sulfate	5,600	6,300	28,000	12,000	5,000	5,000	**10,317**	5,000	**5,000**	**7,924**	110,000	117,924	575,000	167,099	167,099		75%	308864	99.4%	99+%
Thallium							~		~	-	8.0	8.0	0.05	7.1	7		75%	13	97.3%	
Vanadium							~		~	-	7.0	7.0	0.75	6.3	6		75%	12	97.4%	
Zinc	10	10	11	12	10	12	**11**	19	**19**	**15**	150	165	1,900	351	351		75%	649	97.3%	98-99%
Totals																				

Wastewater Treatm	Reference (Filmtec) Published Rejection Rate (%)	1st Stage RO Permeate (µg/L)	2nd Stage Recovery (%)	2nd Stage RO Feed Log Mean Concentration (µg/L)	2nd Stage RO Rejection Rate (%)	2nd Stage RO Permeate (µg/L)	CRP Recovery (%)	CRP after Micro-filtration (µg/L)	CRP after Metals IX (µg/L)	CRP RO Feed Log Mean Concentration (µg/L)	CRP RO Rejection Rate (%)	CRP Permeate (µg/L)	Combined CRP and 2nd Stage RO Permeate [11] (µg/L)	Evaporator Feed ug/L	Evaporator Distillate [12] ug/L	Effluent ug/L	Effluent % of Part 22 (%)
Aluminum	86-89%	7	85%	16	97.8%	0.35	84%	100	100	218	97.7%	5.00	2	1,420	0.23	1.85	1%
Antimony		0.95	85%	2.12	97.8%	0.0475	84%	54	54	119	97.7%	2.76	1.00	773	0.13	0.98	33%
Arsenic		1.65	85%	3.68	97.8%	0.0825	84%	95	95	206	97.7%	4.73	1.70	1,343	0.22	1.66	7%
Barium		1.4	85%	3.12	97.8%	0.07	84%	80	80	175	97.7%	4.01	1.40	400	0.07	1.36	0%
Beryllium		0.05	85%	0.11	97.8%	0.0025	84%	2.87	3	6	97.7%	0.14	0.05	41	0.01	0.05	2%
Boron		2920	85%	6517	97.9%	140	84%	10011	10011	21840	97.7%	250 note 19	178	128,230	20.98	173.51	69%
Cadmium	97%	0.55	85%	1.23	97.8%	0.0275	84%	32	32	69	97.7%	1.58	0.60	448	0.07	0.58	23%
Calcium	99%	700	85%	1562	97.8%	35	84%	14000	200	436	97.7%	10	26	710	0.12	25.26	
Chloride	99%	24000	85%	53566	99.5%	250	84%	2280269	2280269	4974737	97.4%	131100	45,239	30,914,000	5,057.15	44,090.95	18%
Chromium		0.45	85%	1.00	97.8%	0.0225	84%	26	26	56	97.7%	1.29	0.50	366	0.06	0.49	1%
Cobalt		25	85%	56	97.8%	1.25	84%	500	500	1091	97.7%	25	9	7,100	1.16	9.16	46%
Copper	99%	7.25	85%	16	97.8%	0.3625	84%	416	416	907	97.7%	21	7.40	5,901	0.97	7.22	1%
Fluoride	98%	30	85%	67	97.8%	1.5	84%	1961	1961	4279	97.2%	120	42	26,350	4.31	40.92	4%
Iron		50	85%	112	97.8%	2.5	84%	100	100	218	97.7%	5.00	3	400	0.07	3.21	1%
Lead		0.45	85%	1.00	97.8%	0.0225	84%	26	26	56	97.7%	1.29	0.50	366	0.06	0.49	24%
Lithium		4.25	85%	9	97.9%	0.2	84%	244	244	531	97.7%	12	4.30	3,492	0.57	4.19	5%
Magnesium	98-99%	400	85%	893	97.8%	20	84%	8000	200	436	97.7%	10	17	710	0.12	16.52	0%
Manganese		25	85%	56	97.8%	1.25	84%	100	100	218	97.7%	5.00	2.50	1,420	0.23	2.44	5%
Mercury		0.00205	85%	0.0046	97.8%	0.0001025	84%	0.12	0.12	0.26	97.7%	0.006	0.00210	2	0.00027	0.00205	0%
Molybdenum		1.05	85%	2.34	97.8%	0.0525	84%	60	60	131	97.7%	3.01	1.10	855	0.14	1.07	6%
Nickel	96-99%	100	85%	223	97.8%	5	84%	100	100	218	97.7%	5.00	5.00	1,420	0.23	4.86	10%
Nitrogen, Ammonia		10	85%	22	55.2%	10	84%	398	398	869	90.8%	80	2,367	4,560	1,000.00	2,327.94	47%
Nitrogen, Nitrate	93-98%	20	85%	45	77.6%	10	84%	114	114	249	71.8%	70	31	700	0.11	30.12	1%
Phosphorus, total		0.8	85%	1.79	97.8%	0.04	84%	46	46	100	97.7%	2.29	0.80	651	0.11	0.78	0%
Potassium		320	85%	714	97.8%	16	84%	343260	343260	748871	99.5%	3580	1,241	155,820	25.49	1,206.27	
Selenium		1.3	85%	2.90	97.8%	0.065	84%	75	75	163	97.7%	3.73	1.30	1,058	0.17	1.27	5%
Silver		0.2	85%	0.45	97.8%	0.01	84%	11	11	25	97.7%	0.57	0.20	163	0.03	0.20	1%
Sodium	99%	15400	85%	34371	99.1%	310	84%	1427831	1427831	3115021	97.1%	89000	30,804	23,253,000	3,803.91	30,032.57	25%
Strontium	96%	30	85%	67	97.8%	1.5	84%	5615	5615	12249	97.7%	281	97	79,728	13.04	94.60	4%
Sulfate	98-99%	1700	85%	3794	99.7%	10	84%	461449	461449	1006718	99.5%	4800	1,700	6,523,000	1,067.08	1,681.92	1%
Thallium		0.35	85%	0.78	97.8%	0.0175	84%	20	20	44	97.7%	1.00	0.40	285	0.05	0.39	39%
Vanadium		0.3	85%	0.67	97.8%	0.015	84%	17	17	38	97.7%	0.86	0.30	244	0.04	0.29	13%
Zinc	93-98%	17.55	85%	39	97.8%	0.8775	84%	1006	1006	2195	97.7%	50	18.00	14,285	2.34	17.55	1%
Totals:														61,129,240	10,999		

Notes:

[1] Data from holes 04EA-054A, -054B, -054D, and -054E from Appendix B .

[2] Data from holes 05EA-107 and 04EA-084 from Appendix B.

[3] The upper bedrock leakage composite is the average of holes 04EA-054A, 04EA-054B, 04EA-054D, 04EA-054E, 05EA-107 (60 ft - 115 ft) and 05EA-107 (320 ft - 375 ft).

[4] The lower bedrock leakage is from hole 04EA-084, 817-991 ft.

[5] The total leakage composite is estimated as 55% from the upper bedrock leakage and 45% from the lower bedrock leakage.

[6] The incremental change is the incremental water quality for underground mine during operations due to rock wall leachings. Data from Table 2, Geochimica Technical Memorandum titled Water Quality in Underground Mine During Operational Conditions. , November 7, 2005. (Appendix B) The incremental change for nitrogen (ammonia) is the estimated increase in ammonia due to blasting residuals.

[7] The composite mine drainage is the sum of the total leakage composite and the incremental change.

[8] The TDRSA contact runoff is the water quality for the development Rock stockpile with limestone addition. Data from Table 3, Geochimica Technical Memorandum titled Water Quality from the Development Rock Storage Pad During Operations, November 7, 2005. (Appendix B)

[9] The WWTP influent wastewater is the water quality of the of the combined 180 gpm mine drainage water and the 21.7 gpm TDRSA runoff water.

[10] Estimated concentration following metals precipitation process. Treatment reductions are estimated for calcium, cobalt, iron, nickel, magnesium and manganese. Other metals will be treated by co-precipitation in the solids contact clarifier. The lime treatment reduction for these other metals were conservatively not estimated.

[11] Estimated concentration of the combined second stage RO permeate and the concentrate reduction process RO permeate.

[12] Estimated concentration in the evaporator distillate based on 10 ppm estimated total dissolved solids carryover in the evaporator. The 10 ppm is proportioned using the mass flow for each parameter feeding the evaporator.

[13] Calcium concentration in the filtered effluent of metals precipitation process is estimated as 14 mg/L based on engineering judgment and vendor recommendation. This value may vary with incoming wastewater alkalinity and other operational considerations. (Lime softening treatment can produce calcium concentrations down to 8 to12 mg/L or 20 to 30 mg/L as calcium carbonate, Reference Sanks, Water Treatment Plant Design.)

[14] Cobalt concentration in the filtered effluent of metals precipitation process is estimated as 0.5 mg/L based on engineering judgment and vendor recommendation. .The solubility of cobalt is less than 0.1 mg/L at pH 10. The estimated treatment value of 0.5 mg/l considers additional factors such as solids carryover. (Solubility data from Benjamin, M.M. (2002), Water Chemistry, McGraw-Hill, pp. 398.)

[15] Iron concentration in the filtered effluent of metals precipitation process is estimated as 1.0 mg/L based on engineering judgment and vendor recommendation. Ferric iron has a solubility of less than 0.1 mg/L at a pH of 10. The estimated treatment value of 1.0 mg/l considers additional factors such as solids carryover. (Solubility data from American Waterworks Association, Water Quality and Treatment, Industrial Water Pollution Control, 4th Edition.)

[16] Magnesium concentration in the filtered effluent of metals precipitation process is estimated as 8 mg/L based on engineering judgment and vendor recommendation. (Lime softening treatment can produce magnesium concentrations down to 2.4 mg/L or 10 mg/L magnesium as calcium carbonate, Reference Sanks, Water Treatment Plant Design.)

[17] Manganese concentration in the filtered effluent of metals precipitation process is estimated as 0.5 mg/L based on engineering judgment and vendor recommendation. (Lime softening plants are used to treat in potable water applications to meet the potable water standard of 0.5 mg/L.)

[18] Nickel concentration in the filtered effluent of metals precipitation process is estimated as 2.0 mg/L based on engineering judgment and vendor recommendation. The solubility of nickel ranges from 0.4 mg/L at pH 10 to less than 0.1 mg/L at pH 11. The estimated value of 2.0 mg/l considers additional factors such as solids carryover and allows flexibility to optimize pH for overall treatment plant performance. (Solubility data from Eckenfelder, Industrial Water Pollution Control, 2nd Edition.)

[19] The concentrate reduction process permeate will flow to an ion exchange unit for boron treatment. The ion exchange resin will be regenerated prior to reaching 0.25 mg/L of boron in the ion exchange effluent. Ion exchange resins, such Amberlite IRA743 manufactured by Rohm and Hass, can treat to boron concentrations of less than 0.02 mg/L.

Client:	Kennecott Minerals Company	Scope ID.:	04W018
Project:	Eagle Project		
Prepared by:	JJF1	Date:	04/01/06
Checked by:	HJA	Date:	04/12/06

Wastewater Treatment Plant Treatment Calculation for Nickel

Estimate upper bedrock leakage composite concentration for nickel:

Data from holes 04EA-054A, -054B, -054D, and -054E from from Appendix B.:

04A-054A: 25 ug/L
04A-054B: 29 ug/L
04A-054D: 25 ug/L
04A-054E: 25 ug/L

Data from holes 04EA-107, -084 from Appendix B:
04EA-107, 18-34 ft.: 25 ug/L
05EA-107, 97-114 ft.: 25 ug/L

Average upper bedrock leakage composite concentration = (25+29+25+25+25+25)/6 = 25.7 ug/L

Estimate lower bedrock leakage composite concentration for nickel:

The lower bedrock leakage is from hole 04EA-084, 817-991 ft. from Appendix B:
04EA-084, 817-991 ft: 25 ug/L

Estimate total leakage composite:

The total leakage composite is estimated as 55% from the upper bedrock leakage and 45% from the lower bedrock leakage.

Total leakage composite = 0.55 x 25.7 + 0.45 x 25 = 25.4 ug/L

Estimate rock wall leaching incremental change:

The incremental change is the incremental water quality for underground mine during operations due to rock wall leachings. Data from Table 2, Geochimica Technical Memorandum titled Water Quality in Underground Mine During Operational Conditions. , November 7, 2005. (Appendix B)

Nickel incremental change: 36,400 ug/L

Estimate composite mine drainage:

The composite mine drainage is the sum of the total leakage composite and the incremental change.

Nickel composite mine drainage: 25.4 ug/L + 36,400 ug/L = 36,425 ug/L.

Estimate TDRSA contact runoff concentration:

The TDRSA contact runoff is the water quality for the development rock stockpile with limestone addition. Data from Table 3, Geochimica Technical Memorandum titled Water Quality from the Development Rock Storage Pad During Operations, November 7, 2005. (Appendix B)

Nickel TDRSA runoff = 8,330 ug/L

Estimate wastewater treatment plant influent concentration:

The WWTP influent wastewater is the water quality of the of the combined 180 gpm mine drainage water and the 21.7 gpm TDRSA runoff water.

Nickel WWTP influent concentration = 180/(180+21.7) x 36,425 ug/L + 21.7/(180+21.7) x 8,330 ug/L = 33,403 ug/L

Estimate lime clarifier filtered effluent concentration:

Nickel concentration in the filtered effluent of metals precipitation process is estimated as 2.0 mg/L based on engineering judgment and vendor recommendation. The solubility of nickel ranges from 0.4 mg/L at pH 10 to less than 0.1 mg/L at pH 10.5. The estimated value of 2.0 mg/l considers additional factors such as solids carryover and allows flexibility to optimize pH for overall treatment plant performance. (Solubility data from Eckenfelder, Industrial Water Pollution Control, 2nd Edition.)

Nickel lime clarifier filtered effluent concentration: 2,000 ug/L

Estimate first pass RO permeate concentration:

Basis:

Recovery: 75% (Equipment manufacturers recommendation)
Rejection rate: 97.3% (Equipment manufactures recommendation for KEMC project, typical nickel rejection rates published by GE Osmonics are 98 to 99%, typical nickel rejection rates published by Dow - Filmtec are 96 to 99%)

$\text{Rejection \%} = [\text{Conc}_{\text{(log mean feed)}} - \text{Conc}_{\text{(permeate)}}] / \text{Conc}_{\text{(log mean feed)}} \times 100$

$\text{Conc}_{\text{(permeate)}} = \text{Conc}_{\text{(log mean feed)}} - (\text{Rejection \%} \times \text{Conc}_{\text{(log mean feed)}}) / 100$

Estimate nickel log mean concentration of first pass feed:

$\text{Conc}_{\text{(log mean feed)}} = \text{Feed Concentration} \times \ln[1 / (1-\text{Recovery})] / \text{Recovery}$

$\text{Conc}_{\text{(log mean feed)}} = 2000\ \text{ug/L} \times \ln[1 / (1-0.75)] / 0.75 = 3{,}697\ \text{ug/L}$

$\text{Nickel 1st pass permeate} = \text{Conc}_{\text{(log mean feed)}} - (\text{Rejection \%} \times \text{Conc}_{\text{(log mean feed)}}) / 100$

$\text{Nickel 1st pass permeate} = 3{,}697\ \text{ug/L} - (97.3 \times 3{,}697) / 100 = 100\ \text{ug/L}$

Estimate second pass RO permeate concentration:

Basis:

Recovery: 85% (Equipment manufacturers recommendation for second pass)
Rejection rate: 97.8% (Equipment manufactures recommendation for second pass, typical nickel rejection rates published by GE Osmonics are 98 to 99%, typical nickel rejection rates published by Dow - Filmtec are 96 to 99%)

$\text{Rejection \%} = [\text{Conc}_{\text{(log mean feed)}} - \text{Conc}_{\text{(permeate)}}] / \text{Conc}_{\text{(log mean feed)}} \times 100$

$\text{Conc}_{\text{(permeate)}} = \text{Conc}_{\text{(log mean feed)}} - (\text{Rejection \%} \times \text{Conc}_{\text{(log mean feed)}}) / 100$

Estimate nickel log mean concentration of second pass feed:

$\text{Conc}_{\text{(log mean feed)}} = \text{Feed Concentration} \times \ln[1 / (1-\text{Recovery})] / \text{Recovery}$

$\text{Conc}_{\text{(log mean feed)}} = 100\ \text{ug/L} \times \ln[1 / (1-0.85)] / 0.85 = 223\ \text{ug/L}$

$\text{Nickel 2nd pass permeate} = \text{Conc}_{\text{(log mean feed)}} - (\text{Rejection \%} \times \text{Conc}_{\text{(log mean feed)}}) / 100$

$\text{Nickel 2nd pass permeate} = 223\ \text{ug/L} - (97.8 \times 223) / 100 = 4.9\ \text{ug/L}$

Estimate concentrate reduction process (CRP) RO permeate concentration:

Basis:

Recovery: 84% (Equipment manufacturers recommendation for CRP)
Rejection rate: 97.7% (Equipment manufactures recommendation for second pass, typical nickel rejection rates published by GE Osmonics are 98 to 99%, typical nickel rejection rates published by Dow - Filmtec are 96 to 99%)

Rejection % = [Conc $_{\text{(log mean feed)}}$ - Conc $_{\text{(permeate)}}$] / Conc $_{\text{(log mean feed)}}$ x 100

Conc $_{\text{(permeate)}}$ = Conc $_{\text{(log mean feed)}}$ - (Rejection % x Conc $_{\text{(log mean feed)}}$) / 100

Estimate nickel log mean concentration of CRP feed:

CRP feed concentration is after microfiltration and the metals polishing ion exchange processes. The estimated nickel concentration following the microfiltration and metals polishing ion exchange unit is 100 ug/L based on engineering judgment and vendor recommendation. As reference, the solubility of nickel is less than 0.1 mg/L at pH 10.5. (Solubility data from Eckenfelder, Industrial Water Pollution Control, 2nd Edition.)

Conc $_{\text{(log mean feed)}}$ = Feed Concentration x ln[1 / (1-Recovery)] / Recovery

Conc $_{\text{(log mean feed)}}$ = 100 ug/L x ln[1 / (1-0.84)] / 0.84 = 218 ug/L

Nickel CRP permeate = Conc $_{\text{(log mean feed)}}$ - (Rejection % x Conc $_{\text{(log mean feed)}}$) / 100

Nickel CRP permeate = 218 ug/L - (97.7 x 218) / 100 = 5.0 ug/L

Estimate combined 2nd stage RO permeate and CRP RO permeate:

2nd pass RO permeate flow: 350 gpm (design influent flow) x 0.75 (recovery 1st pass) x 0.85 (recovery second pass) = 223 gpm

Flow to CRP process: 350 gpm (design flow) - 223 gpm (2nd pass permeate flow) - 10 gpm (flow to evaporator) = 117 gpm

Nickel in combined permeate streams: +223/(223+117) x 4.9 ug/L + 117 / (223+117) x 5 ug/L = 5 ug/L

Estimate evaporator distillate concentration:

Estimated concentration in the evaporator distillate based on 10 ppm estimated total dissolved solids carryover in the evaporator. The 10 ppm is proportioned using the mass flow for each parameter feeding the evaporator. 10 ppm estimate based on evaporator manufacturer's estimated range of 2 to 10 ppm.

Estimate concentration of nickel in evaporator feed water:

The source of the evaporator feed water is the CRP RO concentrate. The CRP RO unit has an estimated overall recovery of 84 % with an overall rejection rate of 97.7%. The estimated concentration in the CRP concentrate is 1420 ug/L based on an overall concentration factor of 14.2. This overall concentration factor considers the portion of the concentrate which is recycled back to the CRP microfiltration process for further metals removal. The total estimated concentration of all parameters in the CRP concentrated is 61,100,000 ug/L. (See attached spreadsheet.)

Estimate fraction of nickel in evaporator feed water:

Nickel fraction = 1420 ug/L / 61,100,000 ug/L or 0.000023 parts Ni/ parts total solids

Estimate concentration of nickel in evaporator distillate:

Estimate that the nickel fraction in distillate is similar to the nickel fraction in the feed water and base total TDS in distillate of 10 mg/L.

Nickel concentration = 10 mg/L x 1420 ug/L / 61,129,240 ug/L = 0.00023 mg/L = 0.23 ug/L

Estimate WWTP effluent concentration:

Effluent concentration is based on combining evaporator distillate and RO permeate streams:

Nickel in combined permeate streams: = 5 ug/L
Nickel in evaporator distillate = 0.23 ug/L

Based on design flow of 350 gpm:

2nd pass RO permeate flow: = 223 gpm

Flow to CRP process: = 117 gpm

Combined permeate flow = 223 +117 = 340 gpm

Flow of evaporator distillate stream = 10 gpm

Nickel in effluent = 340/350 x 5.0 ug/L + 10/350 x 0.23 ug/L = 4.9 ug/L

Osmonic Engineering Memo No. 13

OSMONICS®

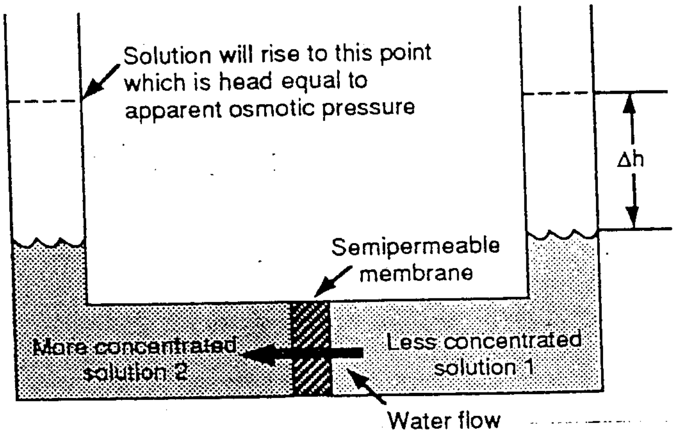
Engineering Memo #13

Re: **Fundamentals of OSMO® Systems**

From: **The Osmonics Engineering Department**

OSMO systems are designed to produce purified water by a process called reverse osmosis.. An understanding of this process can best be gained by a review of the process of osmosis. A simple osmosis system is shown in Figure 1 below:

Figure 1 - Osmosis



Normal osmosis takes place when water passes from a less concentrated solution to a more concentrated solution through a semipermeable membrane. A semipermeable membrane will pass water molecules but will not pass a great percentage of the solute (i.e., dissolved material) – <u>most</u> of this material is rejected. The word <u>most</u> is emphasized because in practice there is no such thing as a perfect membrane.

A certain amount of potential energy exists between the two solutions on each side of the semipermeable membrane, with the more dilute solution exhibiting the higher potential energy level. Water, like everything else in nature, will flow from the solution with the higher potential energy level (dilute solution) to the solution with the lower potential energy level (more concentrated solution). The highest energy level for water is pure water; as solutes (i.e., impurities) are added, the water becomes less pure and the energy level of the water is reduced.

Due to this energy difference, water will flow from the less concentrated solution to the more concentrated solution until the system is in equilibrium. Equilibrium will be reached when the differential head, Δh is equivalent to the apparent, or differential, osmotic pressure. This state of equilibrium can be expressed as follows:

$$\Delta h = (\pi_2 - \pi_1) = (\Delta\pi) \qquad \text{(Eq. - 1)}$$

π_1 = Absolute osmotic pressure of less concentrated (higher energy) solution.

π_2 = Absolute osmotic pressure of more concentrated (lower energy) solution.

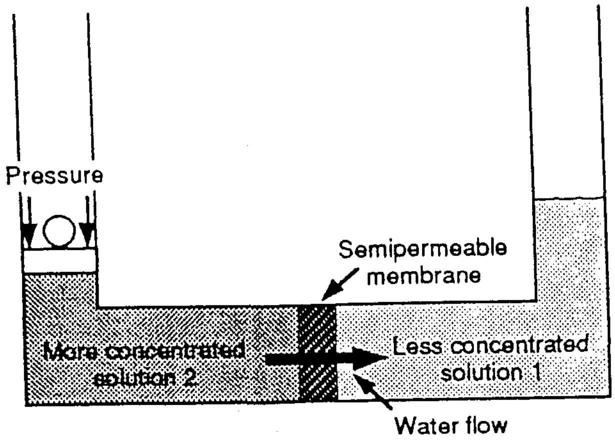
The absolute osmotic pressures, π_1 and π_2 of the solutions shown in Figures 1 and 2 are defined as the potential energy difference between any solution and pure water. Keep in mind the higher the purity, the higher the potential energy. Remember that extremely pure water has a very high potential energy level and is a very aggressive material.

Reverse osmosis can be defined as the separation of one component of a solution from another component by means of pressures exerted on a semipermeable membrane. Usually, RO is used for the separation of dissolved solids (solute) from water (solvent). Referring to Figure 2, the addition of pressure energy to the more concentrated solution will accomplish the same thing as the differential head, and it will stop the transport of water through the membrane when the head pressure equals the $\Delta\pi$ head. As more pressure is applied, the water will flow from the concentrated solution to the dilute solution, in effect, reversing normal osmotic flow. The addition of pressure has increased the energy level of the more concentrated solution above the energy level of the less concentrated solution. Water always flows from higher energy to lower energy. In this case, the flow will be from the more concentrated to the less concentrated. The rate of water transport is a function of:

1. The pressure applied.
2. The apparent, or differential, osmotic pressure between the solutions. (Differential osmotic pressure is the difference between the absolute osmotic pressures of the two solutions.)
3. Area and characteristics of the membrane.

4. The solution temperature.

Figure 2 - Reverse Osmosis

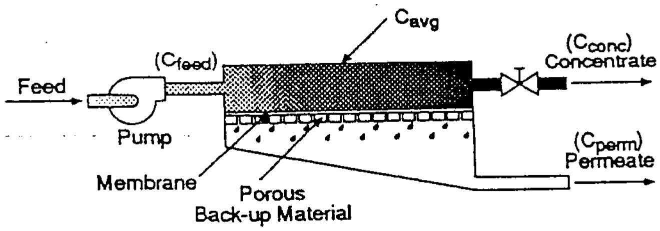


A reverse osmosis machine, regardless of size of complexity, can be conceptualized as the simple "black box" shown in Figure 3.

C_{feed} = Concentration of Feed
C_{perm} = Concentration of Permeate

C_{conc} = Concentration of Concentrate
C_{avg} = Average Concentration Over the Membrane

Figure 3



DEFINITION OF TERMINOLOGY

1. Total Dissolved Solids (TDS) The total organic and inorganic material dissolved in the water expressed as a concentration C (e.g. mg/L, ppm).

2. Feed. The solution which enters the system under pressure with solute concentration = C_{feed}. Example: C_{feed} = 150 mgL TDS

3. Permeate. The solution (usually purified water) which passes through the membrane and is collected for use. The solute concentration = C_{perm}.

4. Concentrate (brine, retentate). The solution which exits from the system which has not passed through the membrane. It is enriched in a particular rejected material. The solute concentration = C_{conc}.

5. Rejection. The percentage of dissolved material which does not pass through the membrane.

6. Passage. The percentage of dissolved material which does pass through the membrane.

7. Recovery. The ratio of permeate rate to feed rate:

$$\text{Recovery} = \frac{\text{Permeate Rate}}{\text{Feed Rate}} = \frac{(Q_{perm})}{(Q_{feed})} \qquad \text{(Eq. - 2)}$$

8. Concentrate Concentration. The concentration of the concentrate stream, or blow-by, as it exits the machine. It is related to feed concentration and recovery as follows:

$$C_{conc} = \frac{C_{feed}}{(1 - \text{Recovery})} \qquad \text{(Eq. - 3)}$$

(See Recovery example later in text.)

NOTE: This formula is based on the mass balance $(Q_{feed})\,C_{feed} = (Q_{conc})C_{conc} + (Q_{perm})C_{perm}$ and assumes that $C_{perm} = 0$. This is an over-simplification which assumes a "perfect" membrane. It works satisfactorily when the solute rejection is 95% or greater, but severely distorts the true system when solute rejections are less than 85%.

9. Average Concentration. The average concentration which the membrane is exposed to in the machine. It is calculated by averaging the C_{feed} and C_{conc}.

$$C_{avg} = \frac{C_{feed} + C_{conc}}{2} \qquad \text{(Eq. - 4)}$$

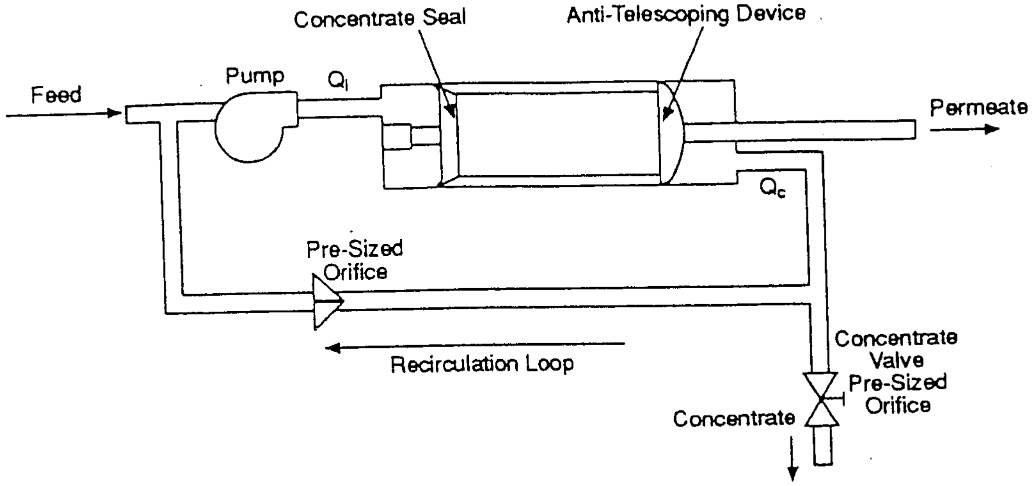
NOTE: Again, this is an over-simplification and has the same restrictions as the above equation. It tends to give a higher C_{avg} than what will actually occur and is therefore a conservative estimate.

Small OSMO systems operate at relatively low recovery, typically less than 50%. The cost of higher recoveries on small systems is not justifiable, especially when the permeate quality is considered. We design the systems to operate on a flow rate, Q_p, through the sepralator (membrane element), of about 5 gpm (19 Lpm) in order to create turbulent flow. The basic, once-through, recovery of a typical sepralator that produces 10 gph (39 Lph) of permeate flow is only:

$$\frac{10 \text{ gph}}{300 \text{ gph}} = 3\%$$

This low recovery is increased by recirculating a percentage of the concentrate Q_c, that has passed

Figure 4



over the sepralator (not through the membrane but over it) through an orifice restriction back to the pump, where it is mixed with the incoming feed solution. The amount that is recirculated is a function of the restriction in the orifice and the concentrate valve, which is an orifice-type valve that allows a predetermined amount of concentrate to flow at all times. (This is covered under Osmonics U.S. Patent #3,716,141. This apparatus is also patented in a number of foreign countries, notably Germany, Switzerland, Canada and Japan.)

We can also increase recovery by adding sepralators to the system, as we do in the larger units. Recovery is increased since each sepralator removes more permeate, adding to the total permeate rate without a corresponding increase in feed rate. In actual practice, both recirculation and the addition of sepralators is used to increase recovery. On some bigger systems, very little recirculation is necessary to achieve the recovery desired, and if recycle is not used, the quality of the permeate will be higher. All OSMO machines are manufactured so that Q_i can be increased if necessary to avoid fouling the sepralators.

For a given input feed rate, Q_{feed}, the permeate rate, Q_{perm}, obtained from a machine is a function of a number of interrelated factors. Among these are:

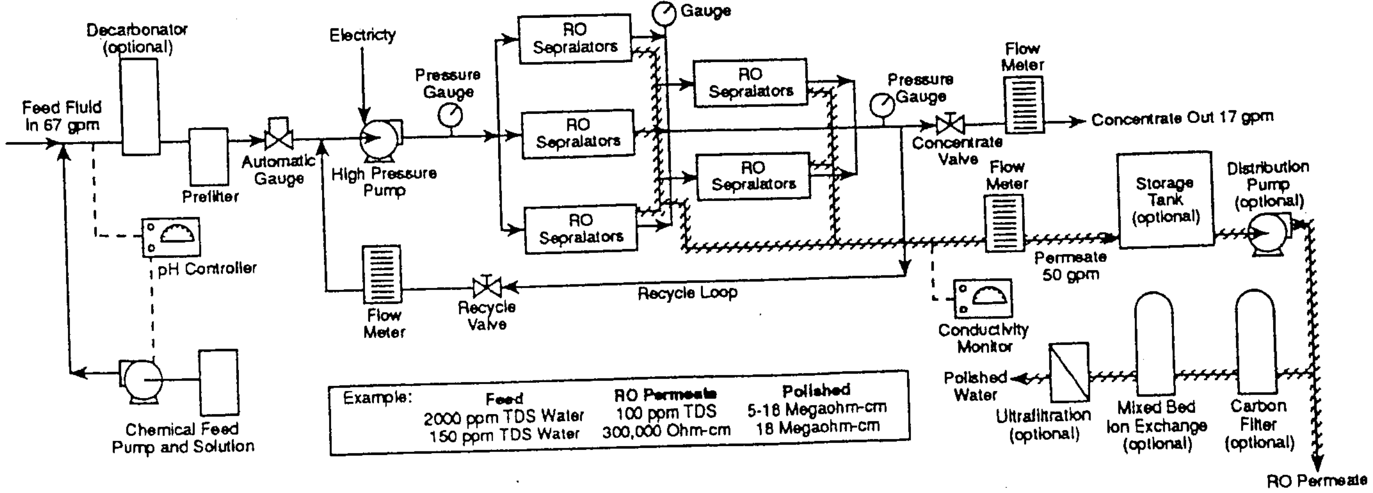
1. The number of sepralators used in the machine.
2. The type of membrane used.
3. The operating pressure.
4. The apparent osmotic pressure, Δπ, of the solution in the machine, which is a function of average concentration and solute type.
5. The temperature of the solution.
6. The condition of the membrane.

To estimate the concentrate concentration (blow-by) in terms of feed concentration at any given recovery, use the following method:

$$\text{(A)} \quad C_{conc} = \frac{C_{feed}}{1 - \text{Recovery}} \qquad \text{(Eq. - 3)}$$

TYPICAL 50 GAL/MIN (189 Lpm)
OSMO REVERSE OSMOSIS SYSTEM
FOR WATER TREATMENT

Figure 5



Example:	Feed	RO Permeate	Polished
	2000 ppm TDS Water	100 ppm TDS	5-18 Megaohm-cm
	150 ppm TDS Water	300,000 Ohm-cm	18 Megaohm-cm

EXAMPLE 1

Recovery = 80% = 0.80 using Eq. 4 we have:

$$C_{feed} = 500 \text{ ppm}$$

$$C_{conc} = \frac{500}{1-0.80} = \frac{500}{0.20} = 5(500) = 2500 \text{ ppm}$$

To estimate the average concentration with a given feed concentration and concentrate concentration, use the following method:

$$\text{(B)} \qquad C_{avg} = \frac{C_{feed} + C_{conc}}{2}$$

$$C_{feed} = 500 \text{ ppm}$$

$$C_{conc} = 2500 \text{ ppm}$$

$$C_{avg} = \frac{500 + 2500}{2} = \frac{3000}{2} = 1500 \text{ ppm}$$

As mentioned previously, the process of reverse osmosis and the rejection of dissolved materials takes place under pressure, with the solution passing across the membrane, and only a percentage of the solvent passing through the membrane. This is not mechanical filtration such as you find in a cartridge filter where all of the solution passes through the filter media and some of the suspended material in the solution is caught by direct interception or inertial impaction on the filter media. Rather, the feed solution passes over the membrane, and pressure forces a percentage of the solvent (usually water) through the membrane, while some of the initial solution, enriched in solutes, remains to be carried away.

For most pure water applications where the input feed concentration is low (less than 1000 ppm) and we operate the machines at relatively low recoveries (typically 33% to 75%), the C_{avg} that we experience in the machine is low, resulting in an osmotic pressure that is a low percentage of the operating pressure.

- THE OSMOTIC PRESSURE FOR AN NaCl SOLUTION IS ABOUT 1 PSIG (0.069 BAR) PER 100 PPM TDS.
- THE OSMOTIC PRESSURE FOR AN Na_2SO_4 SOLUTION IS ABOUT 0.5 PSIG (0.034 BAR) PER 100 PPM TDS.
- IT IS BEST TO ASSUME THAT ALL YOUR TDS IS NaCl WHEN MAKING ESTIMATES IN ORDER TO BE SURE YOU HAVE NOT UNDERESTIMATED.

In the previous example, the 1500 ppm average concentration would represent about 15 psig (1.0 bar). This is a very low percentage of the typical 430 psig (29.6 bar) operating pressure for 43 Series machines, so it can be essentially neglected in our calculations. (See Page 2, #7.)

However, in a typical plating (metal reclamation) application, we do have higher concentrations in the feed, and we operate at relatively high recoveries. Therefore, we must take the resulting osmotic pressure into account because it becomes a large percentage of the operating pressure. Thus, it has a considerable effect on permeate rate for a given set of conditions.

EXAMPLE 2

Let us calculate the same parameters for a typical plating application:

$$\text{(A)} \; C_{conc} = \frac{C_{feed}}{1 - \text{Recovery}} \quad \text{where: Recovery} = 95\% = 0.95$$

$$C_{feed} = 2500 \text{ ppm}$$

$$C_{conc} = \frac{2500}{1-0.95} = \frac{2500}{0.05} = 20\,(2500) = 50{,}000 \text{ ppm}$$

$$\text{(B)} \; C_{avg} = \frac{C_{feed} + C_{conc}}{2} \quad \text{where: } C_{feed} = 2500 \text{ ppm}$$

$$C_{conc} = 50{,}000 \text{ ppm}$$

$$C_{avg} = \frac{2500 + 50{,}000}{2} = \frac{52{,}500}{2} = 26{,}250 \text{ ppm}$$

This average concentration will result in an osmotic pressure of approximately 260 psig (17.9 bar), assuming NaCl, and is a large percentage of the operating pressure, P_{op}. This must be taken into account when sizing machines.

TABLE 1

SOME SAMPLE OSMOTIC PRESSURES

NOTE:
1. Percent concentration times 10,000 is equivalent to ppm or mg/L.
2. One oz/gal is equivalent to 7500 mg/L.
3. Linear interpolation can be used to estimate intermediate concentrations.

SALTS:	Concentration	Osmotic Pressure	
Sodium Chloride (NaCl)	0.5%	55 psi	3.8 bar
	1.0%	125 psi	8.6 bar
	3.5%	410 psi	28.2 bar
Sodium Sulfate (Na_2SO_4)	2.0%	110 psi	7.6 bar
	5.0%	304 psi	20.9 bar
	10.0%	568 psi	39.1 bar

Calcium Chloride ($CaCl_2$)	1.0%	90 psi	6.2 bar
	3.5%	308 psi	21.2 bar
Copper Sulfate ($CuSO_4$)	2.0%	57 psi	3.9 bar
	5.0%	115 psi	7.9 bar
	10.0%	231 psi	15.9 bar

	Concentration	Osmotic Pressure	
ORGANICS:			
Sucrose MW 342	3.3%	36 psi	2.5 bar
	6.4%	73 psi	5.0 bar
	9.3%	110 psi	7.6 bar
	24.0%	350 psi	24.1 bar
	30.0%	500 psi	34.5 bar
	35.0%	645 psi	44.4 bar
Dextrose (glucose) MW 198	3.3%	62 psi	4.3 bar
	9.3%	190 psi	13.1 bar
	24.0%	605 psi	41.7 bar
	30.0%	863 psi	59.5 bar

For other organics, use the following ratio:

$$\frac{\text{MW of Sucrose}}{\text{MW of Organic}} \times \pi \text{ sucrose} = \pi \text{ organics}$$

USING OSMOTIC PRESSURE

When dealing with a solution which has a high osmotic pressure, the effect of $\Delta\pi$ becomes significant and the basic equation of reverse osmosis also becomes important. This equation is:

$$P_{eff} = P_{op} - \Delta\pi \qquad \text{(Eq. -5)}$$

where:

P_{op} = The operating pressure applied against the membrane

$\Delta\pi$ = The apparent osmotic pressure as discussed earlier

P_{eff} = The effective pressure available to force permeate through the membrane

When considering an application, the P_{eff} must be found in order to estimate the Q_{perm} that can be expected from a sepralator. The $Q_{perm,\,act}$ is the actual permeate rate for a particular system. Q_{perm} is the specified permeate rate when the effect of $\Delta\pi$ is negligible. To estimate:

$$Q_{perm,\,act} = \frac{P_{eff}}{P_{spec}} Q_{perm,\,spec} \qquad \text{(Eq. -6)}$$

where the P_{spec} is the pressure at which Q_{perm} is given. For PR and HR membranes, the $Q_{perm,\,spec}$ is given at P_{spec} = 400 psig (27.6 bar).

The next two examples will help to clarify the effect of $\Delta\pi$ and the method of calculating the expected permeate rate for a given sepralator.

EXAMPLE 3

Using Example 2, we found:

$\Delta\pi$ = 260 psi (17.9 bar)

If we are operating at an average pressure of 400 psig (27.6 bar) we have:

$$P_{eff} = P_{op} - \Delta\pi$$

$$P_{eff} = 400 \text{ psi } (27.6 \text{ bar}) - 260 \text{ psi } (17.9 \text{ bar})$$

$$P_{eff} = 140 \text{ psi } (9.6 \text{ bar})$$

To estimate the permeate rate for an OSMO-411T-ST10 sepralator we will use:

$$Q_{perm,\,act} = \frac{P_{eff}}{P_{spec}} Q_{perm,\,spec}$$

where:

$Q_{perm,\,spec}$ = 50 gph (189 Lph)

P_{spec} = 400 psig (27.6 bar)

P_{eff} = 140 psig (9.6 bar)

and therefore:

$$Q_{perm,\,act} = \frac{140 \text{ psig}}{400 \text{ psig}} (50 \text{ gph}) = 17.5 \text{ gph } (66 \text{ Lph})$$ per OSMO-411T-ST10 sepralator

In other words, we will get about 1/3 of the normal Q_{perm} from the sepralator due to the osmotic pressure effect. This OSMO machine will require three times the number of sepralators needed to produce the same amount of water as a water purification unit operating at lower recoveries.

EXAMPLE 4

Let us now look at a sugar application where both dextrose and sucrose are being concentrated. We will assume that the dextrose makes up 20% of the dissolved solids, DS, and sucrose makes up the remainder. Since over 99.9% of both dextrose and sucrose are rejected by the SEPA®ST10 membrane, our equations will be quite accurate.

Assume we start with a 2% sugar solution and want to remove 90% of the water. We have a required recovery of 90%. Using Equation 3 we have:

$$C_{conc} = \frac{2\%}{0.1} = 20\%$$

d Equation 4 gives:

$$C_{avg} = \frac{2\% + 20\%}{2} = 11\%\ DS$$

We know that 20% of the DS is dextrose and 80% is sucrose so we have:

Sucrose = 0.80 x 11% = 8.8% DS

Dextrose = 0.20 x 11% = 2.2% DS

With Table 1 we can estimate the osmotic pressure for the individual sugars. We have:

For Sucrose: 6.4% = 73 psi (5.0 bar)
8.8% = $\Delta\pi_{suc}$ psi
9.3% = 110 psi (7.6 bar)

and using proportions:

$$\frac{\Delta\pi_{suc} - 73}{110 - 73} = \frac{8.8 - 6.4}{9.3 - 6.4}$$

$$\Delta\pi_{suc} - 73 = \frac{2.4}{2.9}(37)$$

$$\Delta\pi = 30.6 + 73 = 103.6 \text{ psi } (7.1 \text{ bar})$$

For Dextrose: 0% = 0 psi (0 bar)
2.2% = $\Delta\pi_{dex}$
3.3% = 62 psi (4.3 bar)

and

$$\frac{\Delta\pi_{dex} - 0}{62 - 0} = \frac{2.2 - 0}{3.3 - 0}$$

$$\Delta\pi_{dex} = 41.3 \text{ psi } (2.9 \text{ bar})$$

The osmotic pressure of different components of a solution are additive so the total osmotic pressure, $\Delta\pi_{tot}$, will be the sum of the $\Delta\pi_{suc}$ and the $\Delta\pi_{dex}$ which is 145 psi (10.0 bar). We should first consider that the concentrate will be 20% DS and we will have a $\Delta\pi_C$ of about 268 psi (18.5 bar). It will probably be best to operate at 500 psig (35.5 bar) in order to get more Q_{perm} per sepralator and yet keep membrane compaction as low as possible. Using P_{op} = 500 psig (34.5 bar), the average effective pressure is:

$$P_{eff} = 500 - 145 = 355 \text{ psi } (24.5 \text{ bar})$$

and the average Q_{perm} per sepralator for OSMO-411T-ST10 sepralators using Eq. 6 is:

$$PR_{act} = \frac{355}{400}(50) = 44 \text{ gph } (167 \text{ Lph}) \text{ per sepralator.}$$

Remember that this is an estimated Q_{perm} and that factors such as recycle rate, recovery, and tendency to foul can have strong effects on the actual operation, Q_{perm}. As a general rule, the P_{op} should be at least 100 psig (6.9 bar) greater than the $\Delta\pi$ of the concentrate. It is best to try to keep P_{op} at least 200 psig (13.8 bar) over the $\Delta\pi$ of the concentrate; however, compaction effects must be carefully weighed when P_{op} exceeds 500 psig (35.5 bar).

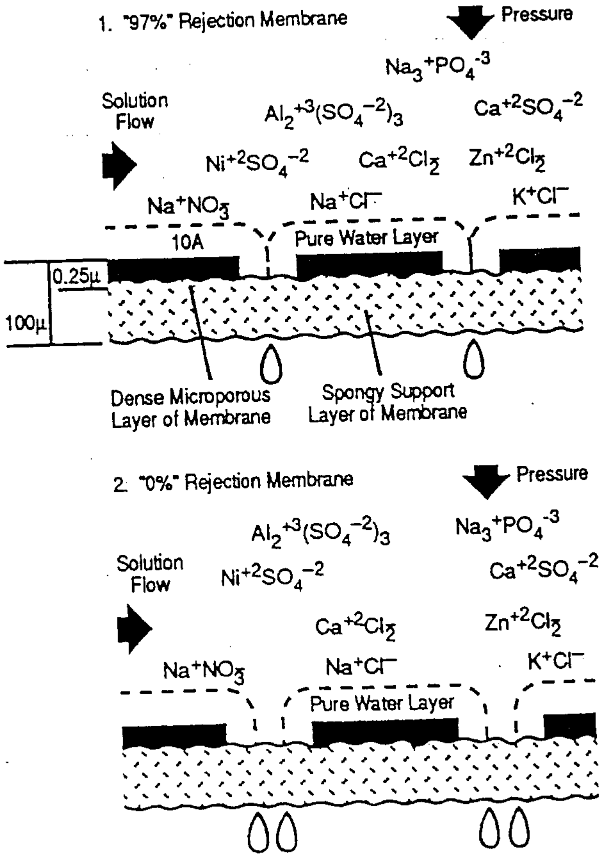
Another "rule of thumb" is that elements which have similar general properties will tend to have similar osmotic pressures for their salts. For example, nickel cadmium and copper are similar elements, are in close proximity in the periodic table, and the sulfate salts they form have nearly identical osmotic pressure concentration data.

To obtain $\Delta\pi$ for unknown solutions use a PES/OSMO unit as outlined in the "PES – Questions and Answers" Engineering Memo.

THERE ARE TWO FUNDAMENTAL MECHANISMS OF REJECTION AT WORK IN THE REVERSE OSMOSIS PROCESS.

1. Mechanism of Salt Rejection. Refer to Figure 6. The dissolved, ionized salts each carry an electrical charge the magnitude of which is a function of the valence and the "activity" of the ion. The ion is, in general, repelled away from the surface of the membrane to a degree proportional to its valence.

Figure 6



Higher valence ions are repelled farther than lower valence ions. The rejection of each ion by a membrane is a result of its valence. (Refer to Table 2.)

The repulsion of ions away from the membrane (dielectric effect) causes a very thin layer of pure water to form on the surface of the membrane, aided by the preferential sorption of pure water to the membrane surface, and the pressure on the solution forces some of the pure water molecules through the pores.

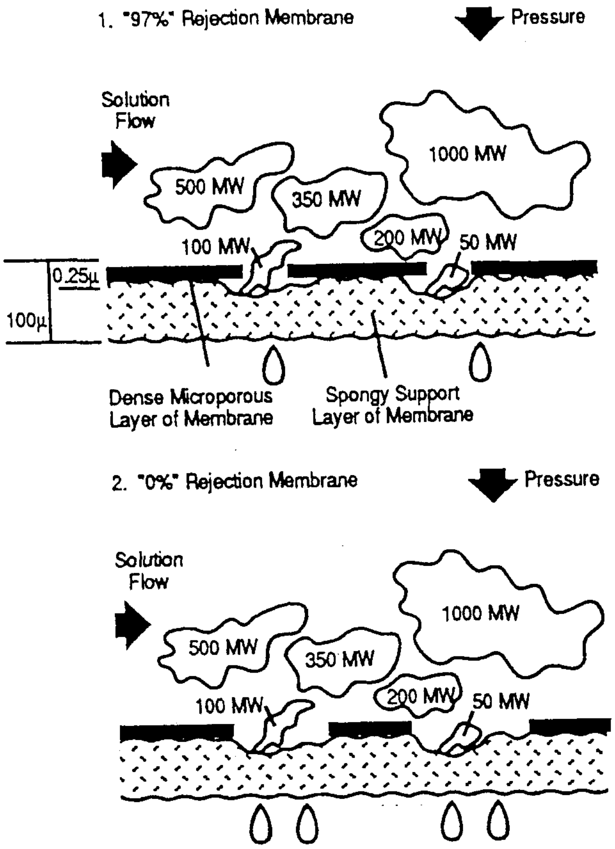
The ions are generally considered to be repulsed away from the surface of the membrane because of an electrostatic "di-pole" effect, similar to like poles of a pair of magnets, that is set up between the charged ion and the surface of the membrane by virtue of a "mirror" effect. In other words, the charge on the ion sets up or induces an equal and like charge on the membrane surface which, in turn, causes a force or repulsion to exist between the membrane and the charged ion. Due to this effect, the rejection of dissolved ionized salts by reverse osmosis can be considered as a physico-chemical or an electro-chemical interaction between the membrane and those constituents in the solution, and hence it can be considered to be chemically filtered.

2. <u>Mechanism of Organic Rejection</u>. Refer to Figure 7. Dissolved organics are rejected primarily by a screening or "sieving" mechanism (as are emulsed or suspended solids). The rejection of any given organic molecule is a function of membrane pore size, molecule size and the geometry of the molecule, (i.e., length to diameter ratio, etc). The size of an organic molecule is, in general, directly related to its molecular weight. There are exceptions; for example, a slightly ionized organic molecule will have a larger "apparent" size.

   Referring to Table 2, we notice that some small organics may be enriched in the permeate due to preferential passage through the membrane. These molecules are actually adsorbed toward the membrane and because of their small size readily pass through the membrane faster than water.

   It is sometimes desirable and necessary to be able to predict the quality of the permeate water one can expect, given a specific input feed analysis and recovery rate. (Permeate quality is, of course, a function of input feed concentration, average concentration in the machine and concentrate concentration).

Figure 7



In order to determine what concentration one can expect in the permeate of any given constituent in the feed, follow these steps:

1. At any stipulated recovery, calculate what the average concentration of a given constituent will be in the machine using Equation 3 and 4.
2. Refer to Table 2 for percent passage. For example, the passage of the cation sodium is given as 4%.
3. Take the average concentration figure from (1), multiply it by the passage figure from (2), and the result is the concentration of that constituent which will appear in the permeate.

<u>EXAMPLE 5</u>

a. Recovery = 80%

b. Na^+ = 100 ppm in feed

c. SEPA-HR

Using Eq. 3

1. $C_{conc} = \frac{C_{feed}}{(1 - \text{Recovery})} = \frac{100}{1 - 0.8} = \frac{100}{0.2}$

   $= 5(100) = 500$ ppm

Using Eq. 4

2. $C_{avg} = \frac{C_{feed} + C_{conc}}{2} = \frac{100 + 500}{2}$

   $= \frac{600}{2} = 300$ ppm

3. $C_{perm} = C_{avg} \times \text{passage}^{*}$

   $C_{perm} = 300 \times 0.04 = 12$ ppm

   *From the Table for SEPA-HR membrane (Na has 96% rejection or 4% passage).

NOW:

4. For SEPA-SR membrane, the permeate concentration is:

   $C_{perm} = 300 \times 0.08 = 24$ ppm or double the permeate concentration with the SEPA-HR sepralator.

As you can see from the examples, passage is a more appropriate term than rejection. Passage is more useful in defining permeate quality. Keep in mind that the passages in Table 2 are given for the SEPA-HR membrane, and the SEPA-SR membrane passes about twice as much salt as the SEPA-HR does. Hence, the passage of the sulfate ion on the SEPA-HR membrane would be 0.01(1%) and the passage of the sulfate ion by the SEPA-SR membrane would be 0.02 (2%).

Another reason to think in terms of passage is that, while it appears to be a very small change from 99% rejection to 98% rejection, it is more accurate to describe the change as 1% passage to 2% passage, which is a 100% difference. This is a dramatic change which will cause the conductivity of the water to double.

MEMBRANE REJECTIONS:

Organics are rejected mainly on a size basis, with a cut-off between 100 and 200 molecular weight for the SEPA-HR or HR(PA) membranes. Compounds which react in water similarly to salts (i.e., they are partially ionized) but are organic in nature will still be rejected to some extent when the molecular weight is less than 100.

The SEPA-SR and PR membranes cut off around 250 and 300 MW respectively. The SR passes approximately twice as much salt and the PR about three times as much salt as the SEPA-HR membrane does.

Note: The following rejections are based on the average concentration for a membrane. If a system has 50% recovery, part of the membrane sees the feed concentration and part of the membrane sees a concentration that is double the feed concentration. Likewise, at 75% recovery the final concentration increases to 4 times the feed. For estimating purposes, take an average of the feed and the concentrate and use the average to figure the expected purity of the permeate.

TABLE 2

TYPICAL MEMBRANE REJECTIONS

SALTS

CATIONS

Name	Symbol	Percent Rejection	Percent Passage (Average)	Maximum Concentration Percent
Sodium	Na^{+}	95-97	4	3-4
Calcium	CA^{+2}	96-98	3	*
Magnesium	Mg^{+2}	96-98	3	*
Potassium	K^{+1}	95-97	4	3-4
Iron	Fe^{+2}	98-99	2	*
Manganese	Mn^{+2}	98-99	2	*
Aluminum	Al^{+3}	99+	1	5-10
Ammonium	NH_4^{+1}	88-95	8	3-4
Copper	Cu^{+2}	98-99	1	8-10
Nickel	Ni^{+2}	98-99	1	10-12
Zinc	Zn^{+2}	98-99	1	10-12
Strontium	Sr^{+2}	96-99	3	-
Hardness	Ca and Mg	96-98	3	*
Cadmium	Cd^{+2}	96-98	3	8-10
Silver	Ag^{+1}	94-96	5	*
Mercury	Hg^{+2}	96-98	3	-
ANIONS				
Chloride	Cl^{-1}	95-97	4	3-4
Bicarbonate	HCO_3^{-1}	95-96	4	5-8
Sulfate	SO_4^{-2}	99+	1	8-12
Nitrate	NO_3^{-1}	93-96	6	3-4
Fluoride	F^{-1}	94-96	5	3-4
Silicate	SiO_2^{-2}	95-97	4	-
Phosphate	PO_4^{-3}	99+	1	10-14
Bromide	Br^{1}	94-96	5	3-4
Borate	$B_4O_7^{-2}$	35-70**	-	-
Chromate	CrO_4^{-2}	90-98	6	8-12
Cyanide	CN^{-1}	90-95**	-	4-12
Sulfite	SO_3^{-2}	98-99	1	8-12
Thiosulfate	$S_2O_3^{-2}$	99+	1	10-14
Ferrocyanide	$Fe(CN)_6^{-3}$	99+	1	8-14

*Must watch for precipitation, other ion controls maximum concentration.

**Extremely dependent on pH; tends to be an exception to the rule.

The following are typical rejections of salts and organics using the OSMO-411-HR sepralator. As can be seen divalent ions tend to reject better than monovalent ions. If monovalent ions are combined with divalent ions, the rejection will be controlled by the divalent ion.

For estimating purposes, take an average of the feed and the concentrate and use this average concentration to figure the expected purity of the permeate.

Salts complexed with organics of large molecular weights will tend to act like the organics they are complexed with.

ORGANICS

	Molecular Weight	Percent Rejection	Maximum Concentration Percent
Sucrose sugar	342	100	25
Lactose sugar	360	100	25
Protein	10,000 Up	100	10-20
Glucose	198	99.9	25
Phenol	94	***	—
Acetic acid	60	***	—
Formaldehyde	30	***	—
Dyes	400 to 900	100	—
Biochemical Oxygen Demand	(BOD)	90-99	—
Chemical Oxygen Demand	(COD)	80-95	—
Urea	60	40-60	Reacts similar to a salt
Bacteria & virus	50,000-500,000	100	—
Pyrogen	1000-5000	100	-

***Permeate is enriched in material due to preferential passage through the membrane.

GASES, DISSOLVED

Carbon dioxide	CO_2	30-50%
Oxygen	O_2	Enriched in permeate
Chlorine	Cl_2	30-70%

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Dow Filmtec Membranes - Estimated Percent Rejection of Various Solutes

FILMTEC Membranes

Estimated Percent Rejection of Various Solutes by FILMTEC Membranes

In order to assist customers in estimating the rejection of FILMTEC™ FT30 membranes, tests have been performed with a variety of solute compounds. The results of these tests are indicated as a % rejection for each compound listed in the tables below.

Actual system performance may vary from the listed data, particularly with changes in feed water concentration, pH and temperature. For this reason, these tables should be used as a quick screen. Pilot trials should be performed to determine actual rejection in a specific application.

Solute	MW	Rejection, %
1, 1, 1-Trichloroethane	133	98
1, 2-Dibromoethane	173	15
1, 2-Dichloroethane	99	37
1, 2, 3-Trichlorobenzene	181	>57
1, 2, 4-Trichlorobenzene	181	96
1, 2, 4-Trimethylbenzene	120	57
1, 2-Dichlorobenzene	147	70-92
1, 3-Dichlorobenzene	147	66-69
1, 4-Dichlorobenzene	147	61
1-Chlorododecane	204	87
1-Methylnaphthalene	142	67
2, 2', 5, 5'-Tetrachlorobiphenyl	290	46
2, 4, 6-Trichlorophenol	197	100
2, 4-Dichlorophenol	163	93
2, 6-Dimethylphenol	122	92
2, 6-Di-Tert-Butyl-4-Methylphenol	220	96
3, 8-Dimethylphenol	122	92
3-Hydroxy-Capric Acid	188	>98
3-Pentanone	86	74
4-Ethylphenol	122	84
4-Isopropylphenol	136	84
5-Chlorouracil	146	88
Acetic Acid	60	45
Acetone	58	70
Aluminum Nitrate	213	86
Aluminum Sulfate	342	89
Aniline	93	64-75
Anthraquinone	208	93
Benzene	78	19
Benzoic Acid	122	92
Benzothiazole	133	79
Biphenyl	154	91
Bis (2-Ethylhexyl) Phthalate	390	94
Boric Acid	230	
Bromodichloromethane	163	79
Bromoform	94	>67
Cadmium Sulfate	208	97
Caffeine	174	99
Calcium Chloride	111	99
Calcium Nitrate	164	95
Carbon Tetrachloride	153	98
Cesium Chloride	168	97
Chlorobenzene	112	0-50
Chloroform	119	71-90
cis-1, 2-Dichloroethylene	97	20
Clofibric Acid	214	>99
Copper Sulfate	160	99
Cyclohexanone	98	95
Dibromochloromethane	208	79
e-Caprolactum	113	85
Ethanol	46	38-70
Ethyl Benzene	106	71
Formaldehyde	30	35
Furfural	96	35
Glucose	180	98-99
Glycine	188	78
Heptaldehyde	114	100
Humic Acid		98
Hydrochloric Acid	36	28
Isophorone	138	96
Isopropanol	60	90
Lactic Acid (pH 2)	90	94
Lactic Acid (pH 5)	42	99
Magnesium Chloride	120	98
Magnesium Sulfate	120	99
Manganese (II) Sulfate	151	97
Methanol	32	25
Methyl Ethyl Ketone	72	73
Methyl Isobutyl Ketone	100	98
Naphthalene	128	80
Nickel Chloride	130	96-99
Nickel Sulfate	155	97-99
o-Cresol	108	84
o-Xylene	106	67
p & m Xylene	106	38
Pentachlorophenol	266	>86

Solute	MW	Rejection, %
Phenol-80%	94	65
Phosphoric Acid	96	94
Quinoline	129	97
Silica	60	98
Sodium Acetate (1%)	82	88
Sodium Bicarbonate	84	98
Sodium Bromide	103	96
Sodium Chloride	58	99
Sodium Cyanide	49	95
Sodium Di-H Phosphate	120	98
Sodium Fluoride	42	98
Sodium Hydrogen Sulfate	120	76
Sodium Iodide	150	97
Sodium Mono-H Phosphate	142	98
Sodium Nitrate	85	93-98

Solute	MW	Rejection, %
Sodium Orthophosphate	164	99
Stearic Acid	204	71
Strontium Chloride	158	96
Succinic Acid	118	35
Sucrobe	342	99
Sulfuric Acid	98	84
Tetrachloroethylene	165	68-80
Tin (II) Sulfate	215	85
Tributyl Phosphate	266	49
Trichloroethylene	131	30-43
Trimesic Acid	210	96
Urea	60	70
Zinc Chloride	136	93
Zinc Sulfate	161	98

FILMTEC Membranes

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