Solutions for reducing extremely hardness in treated water †

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Supplementary Materials

Table S1. Purolite C100E characteristics

Typical physical and chemical characteristics	
Polymer Structure	Gel polystyrene crosslinked with divinylbenzene
Appearance	Spherical Beads
Functional Group	Sulfonic Acid
Ionic Form	Na^+ form
Total Capacity (min.)	1.9 eq/L (41.5 Kgr/ft^3) (Na^+ form)
Moisture Retention	46–50 % (Na^+ form)
Particle Size Range	300–1200 μm
< 300 μm (max.)	1 %
Uniformity Coefficient (max.)	1.7
Reversible Swelling, $Na^+ \rightarrow H^+$ (max.)	10 %
Reversible Swelling, $Ca^{2+} \rightarrow Na^+$ (max.)	8 %
Specific Gravity	1.27
Shipping Weight (approx.)	800–840 g/L (50.0–52.5 lb/ft^3)
Temperature Limit	120 °C

Table S2. Membrane characteristics and operating parameters

Membrane	**RO 1812-ACM2-31**	**NF 1812-TS40-31*)**
Solute Rejection	99.5 % NaCl	99.0 % $MgSO_4$
Membrane Type	Thin-Film Composite (TFC), polyamide	Thin-Film Composite (TFC), polypiperazine
Configuration	Spiral Wound Sanitary Element	
Feed Spacer Thickness	31 mil**)	
Active Membrane Area	0.23 m^2	
Max. Applied Pressure	55 bar	
Max. Operating Temperature	50 °C	
Cleaning pH Range	1.0–12.0	
Chlorine Tolerance	< 0.1 ppm	
Max. Pressure Drop	1.4 bar per element; 6 bar per housing	

Notes: *) pore size 200–300 Da; **) 1 mil = 25.4 μm

Table S3. Water quality of groundwater treated by the existing treatment process (without softening)

Year	Sample no.	Sampling date	El. conductivity mS/m	pH -	Fe mg/L	Mn mg/L	SO_4^{2-} mg/L	ΣCa+Mg mmol/L	Ca mg/L	Mg mg/L	$CaCO_3$ mg/L
2023	31019	05.09.	100.0	7.91	<0.02	<0.05					
	30768	05.09.	98.6	7.88	<0.02	<0.05	183.4	4.34	131.34	27.70	442.02
	19629	06.06.	100.3	7.97	<0.02	<0.05					
	15091	02.05.	100.3	7.87	<0.02	<0.05					
	11302	03.04.	100.6	7.55	0.03	0.13					
	7916	07.03.	101.3	7.81	<0.02	<0.05					
	4315	07.02.	101.3	7.98	<0.02	<0.05					
	4522	07.02.	102.2	7.97	<0.02	<0.05	193.9	4.41	132.65	27.70	445.30
2022	30453	06.09.	92.3	7.98	<0.02	<0.05					
	30623	06.09.	88.5	8.03	<0.02	<0.05	144.5	4.10	115.90	30.60	415.41
	19229	07.06.	104.3	7.77	<0.04	<0.05					
	14683	03.05.	102.2	7.88	<0.04	0.17					
	11109	05.04.	88.2	7.8	<0.04	<0.05					
	6909	01.03.	87.2	7.94	<0.04	0.06					
	6183	22.02.	97.2	7.87	<0.04	<0.05					
	5985	22.02.	99.7	7.87	<0.04	0.09	190.4	4.40	135.37	26.50	447.15
2021	30010	07.09.	91.4	7.95	<0.04	<0.05	168.8	4.09	119.05	28.90	416.28
	17807	01.06.	90.5	8.01	<0.04	<0.05					
	17012	25.05.	90.1	8.04	<0.04	<0.05					
	10294	06.04.	90.1	7.98	<0.04	0.06					
	8993	23.03.	90.5	7.93	<0.04	<0,05					
	5632	23.02.	106.5	7.85	<0.04	0.2	228.7	4.52	136.57	28.70	459.20
	257	05.01.	89.8	8.08	<0.04	0.09					
2020	27888	01.09.	103.9	7.86	<0.04	<0.05	241.5	4.54	138.72	28.70	464.57
	16448	02.06.	106.9	8.19	0.05	<0.05		4.55	130.16	32.80	460.08
	12976	05.05.	90.8	7.97	<0.04	<0.05					
	10729	14.04.	93.6	8.02	<0.04	<0.05		4.20	130.53	23.80	423.94
	6731	03.03.	90.2	7.93	<0.04	<0.05		4.12	121.36	27.00	414.22
	5723	25.02.	89.3	7.93	<0.04	<0.05	156.3	3.99	121.18	24.10	401.83
2019	31623	01.10.	87.7	8.02	<0.04	<0.05					
	27924	03.09.	90.9	8.06	<0.04	<0.05	132.2	3.50	92.32	26.30	338.83
	27754	03.09.	86.8	7.86	<0.04	0.15	153.0	3.90	109.1	27.70	386.49
	17276	04.06.	91.7	8.10	<0.04	<0.05					
	13788	06.05.	85.3	7.96	<0.04	0.06					
	10062	02.04.	93.7	8.03	<0.04	0.11					
	6492	05.03.	96.2	8.15	<0.04	<0.05					
	5497	26.02.	98.9	8.06	<0.04	<0.05	193.0	4.30	125.88	29.10	434.16
2018	34220	06.11.	96.0	8.20	<0.04	0.06					
	26420	04.09.	94.9	8.09	<0.04	<0.05	197.5	4.27	129.44	25.20	426.99
	24021	14.08.	94.8	8.13	<0.04	0.08					
	12031	24.04.	97.5	7.93	<0.04	0.13					
	6434	06.03.	93.3	6.91	<0.04	<0.05					
	3369	06.02.	92.7	7.24	<0.04	0.05	163.4	4.24	130.81	24.10	425.88

Table S4. Summary of NF and RO tests

Operating pressure		Treated solution	Flux L/(m²h)			Feed volume	Permeate volume	Retentate volume	Test duration
bar			min	max	average	L	L	L	s
NF	4	0.5% $MgSO_4$	13.58	15.03	15.41	5.00	2.55	2.45	2,910
		groundwater	20.51	22.79	21.74	5.00	2.55	2.45	1,720
		0.5% $MgSO_4$	13.60	15.00	15.50	5.00	2.55	2.45	2,910
	6	0.5% $MgSO_4$	19.70	26.40	25.51	5.00	2.55	2.45	1,560
		groundwater	30.22	33.90	32.42	5.00	2.55	2.45	1,200
		0.5% $MgSO_4$	19.64	26.50	25.48	5.00	2.55	2.45	1,560
	8	0.5% $MgSO_4$	33.75	35.64	34.75	5.00	2.55	2.45	1,120
		groundwater	31.80	44.55	42.16	5.00	2.55	2.45	880
		0.5% $MgSO_4$	33.88	35.57	34.68	5.00	2.55	2.45	1,120
	10	0.5% $MgSO_4$	42.87	44.91	44.29	5.00	2.55	2.45	820
		groundwater	42.49	55.13	52.32	5.00	2.55	2.45	730
		0.5% $MgSO_4$	42.84	44.89	44.30	5.00	2.55	2.45	820
RO	10	0.5% NaCl	9.13	15.86	14.81	5.00	2.55	2.45	2,880
		groundwater	24.84	26.61	25.97	5.00	2.55	2.45	1,500
		0.5% NaCl	9.08	15.88	14.80	5.00	2.55	2.45	1,500
	15	0.5% NaCl	25.59	28.79	26.94	5.00	2.55	2.45	1,560
		groundwater	33.91	44.72	39.12	5.00	2.55	2.45	1,000
		0.5% NaCl	25.60	28.80	26.96	5.00	2.55	2.45	1,560
	20	0.5% NaCl	29.75	34.53	33.02	5.00	2.55	2.45	1,260
		groundwater	32.65	48.09	44.99	5.00	2.55	2.45	900
		0.5% NaCl	29.73	34.59	33.00	5.00	2.55	2.45	1,260

Table S5. Monitored parameters in the feed and effluent streams during NF of 0.5% $MgSO_4$ saline solution

Sample	Pressure bar	pH -	EC µS/cm	Mg mg/L	SO_4^{2-} mg/L	TDS mg/L
feed		7.58	3,440	720	2,160	4.72
permeate	4	8.01	44	16	7	0.03
retentate		8.21	5,720	1,312	4,200	8.62
feed		7.58	3,440	720	2,160	4.72
permeate	6	8.01	33	10	6	0.05
retentate		7.66	5,800	1,337	4,400	8.85
feed		7.58	3,440	720	2,160	4.72
permeate	8	7.31	30	6	4	0.01
retentate		7.29	6,000	1,404	4,300	9.14
feed		7.58	3,440	720	2,160	4.72
permeate	10	8.11	40	7	3	0.02
retentate		7.48	6,100	1,411	4,300	9.16

Table S6. Monitored parameters in the feed and effluent streams during RO of 0.5% NaCl saline solution

Sample	Pressure bar	pH -	EC µS/cm	Cl^- mg/L	TDS mg/L
feed		6.54	9,010	3,408	5.08
permeate	10	5.93	362	1,024	0.18
retentate		6.02	15,820	52,440	9.34
feed		6.54	9,010	3,408	5.08
permeate	15	6.65	244	517	0.09
retentate		6.57	15,590	52,053	9.24
feed		6.54	9,010	3,408	5.08
permeate	20	6.41	107	32	0.15
retentate		6.71	17,850	6,744	10.12

Table S7. Rejection factor of selected parameters in NF and RO

Treated solution	Membrane process/pressure	Rejection factor			Treated solution	Membrane process/pressure	Rejection factor		
		Ca	Mg	SO_4^{2-}			Mg	SO_4^{2-}	Cl^-
groundwater	NF 4 bar	0.775	0.744	1.000	0.5% $MgSO_4$	NF 4 bar	0.988	0.998	-
	NF 6 bar	0.792	0.813	1.000		NF 6 bar	0.993	0.999	-
	NF 8 bar	0.854	0.709	0.992		NF 8 bar	0.995	0.999	-
	NF 10 bar	0.863	0.721	0.996		NF 10 bar	0.995	0.999	-
	RO 10 bar	1.000	0.970	0.990	0.5% NaCl	RO 10 bar	-	-	0.980
	RO 15 bar	1.000	0.926	0.990		RO 15 bar	-	-	0.990
	RO 20 bar	0.979	0.709	0.992		RO 20 bar	-	-	0.995