

Supplementary Material

Clinical Autopsy of a Reverse Osmosis Membrane Module

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1 Supplementary Figures and Tables

1.1 Supplementary Figures

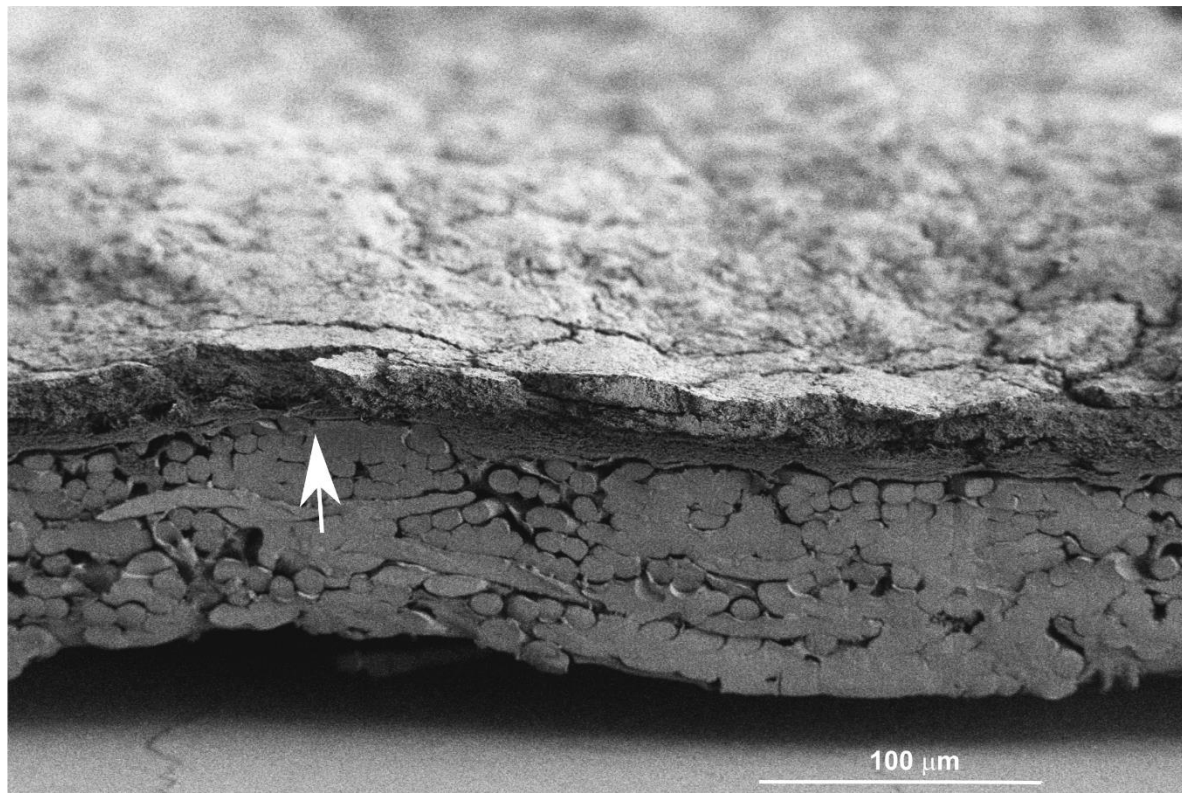


Figure S1. The arrow shows a zone of the fouled membrane where the polysulfone material is compressed and hardly visible.

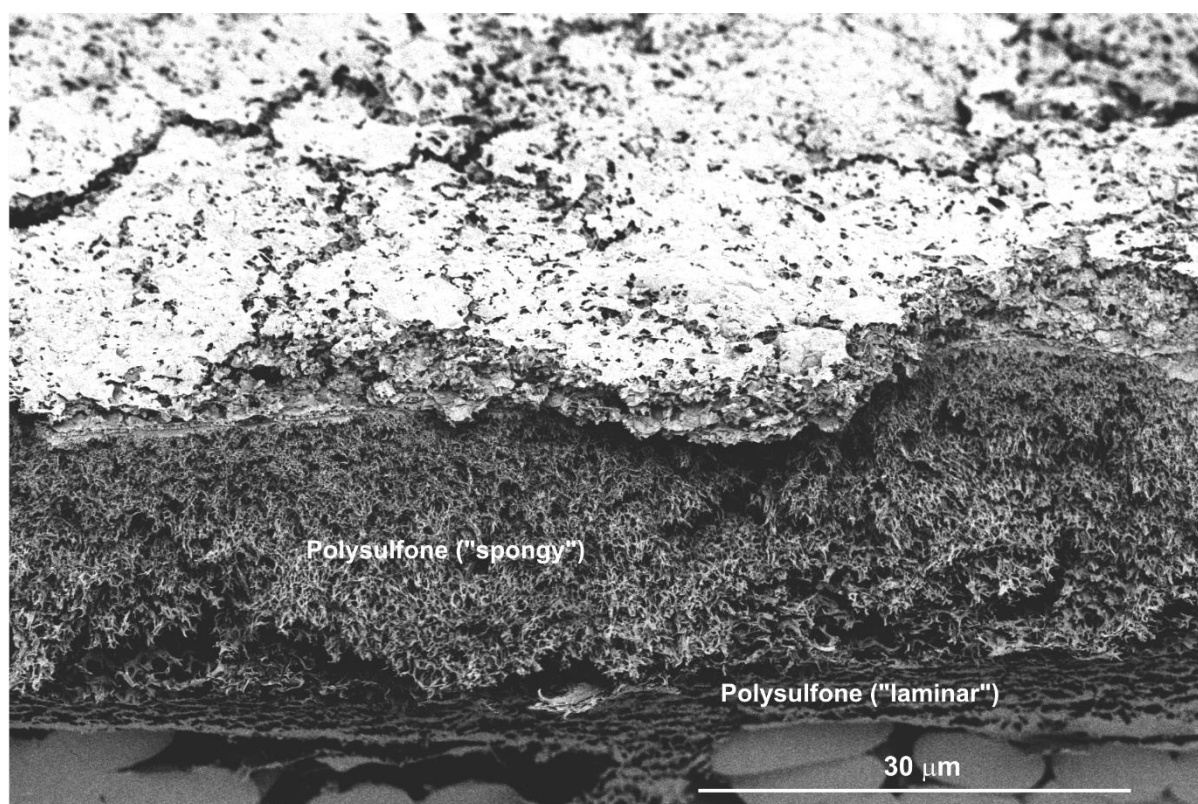


Figure S2. Two structures (i.e., morphologies) of polysulfone on the fouled membrane.

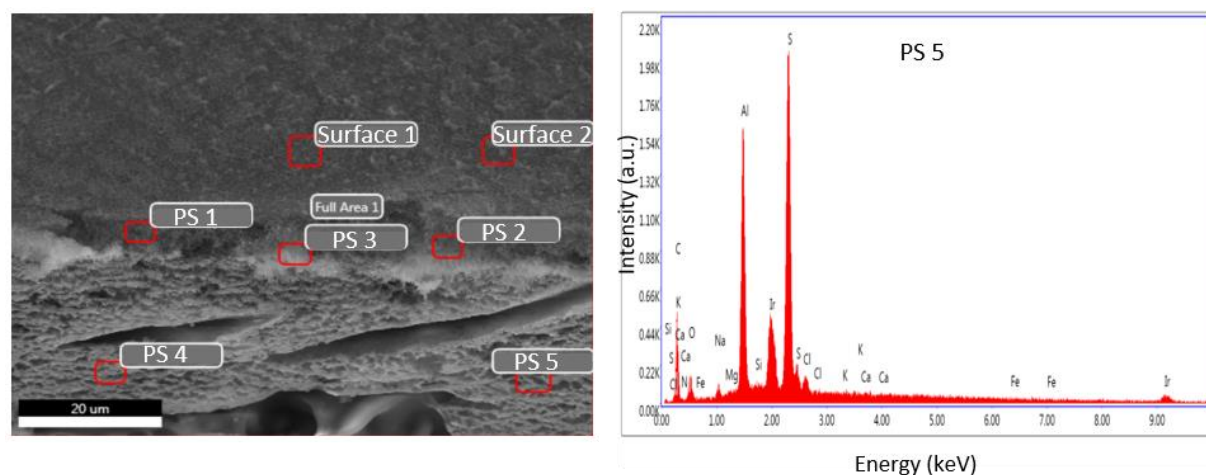
1.2 Supplementary Tables

Table S1. Feed seawater parameters.

Parameter	Unit	Range	Values for design	Max. value
pH	at 25°C	8.0 ~ 8.8	8.3	8.3
Temperature	°C	18 – 35°C	18 – 35°C	35°C
Total dissolved solids (TDS)	mg/l	40.81 ~ 40.89	42000	50000
Total suspended solids (TSS)	mg/l	10	20	20
Turbidity	NTU	0.2 ~ 4.4	10	10
NH ₄ ⁺	mg/l	≤ 1.2	1.2	1.2
K	mg/l	484 ~ 600	484	484
Na	mg/l	12200 ~ 13534	13000	15966
Ca	mg/l	480 ~ 702	520	520
Mg	mg/l	1488 ~ 1698	1539	1539
HCO ₃ ⁻	mg/l	170	170	170
Cl ⁻	mg/l	22000 ~ 24461	23346	27913
SO ₄ ²⁻	mg/l	360 ~ 3726	3205	3205
Dissolved silica as SiO ₂	mg/l	0.4	0.4	0.4
Fe	mg/l	0.01 ~ 0.8	0.2	0.2
Cu	mg/l	0.04 ~ 0.6	0.05	0.05
Mn	mg/l	2.0	2.0	2.0
Al	mg/l	1.0	1.0	1.0
Zn	mg/l	2.0	2.0	2.0
PO ₄ ³⁻	mg/l	0.2	0.2	0.2
Br	mg/l	79	79	79
Ba	mg/l	0.157	0.157	0.157
B	mg/l	5.4	5.4	5.4
Sr	mg/l	2 ~ 10	10	10
CO ₃ ²⁻	mg/l	100	100	100
NO ₃ ⁻	mg/l	2.0	2.0	2.0
Residual chlorine as Cl ₂	mg/l	0.5 ~ 1.0	0.5 ~ 1.0	0.5 ~ 1.0

Table S2. Elemental composition of a virgin membrane. Data corresponds to various locations of the scanning electron image. Surface 1 and Surface 2 correspond to the polyamide membrane surface. Based on the sulfur content, and on the physical appearance, two distinct polysulfone structures or layers are distinguished. Polysulfone layer having a low sulfur content (PS 1, PS 2, and PS 3), and polysulfone layer having a high sulfur content (PS 4 and PS 5).

Virgin membrane

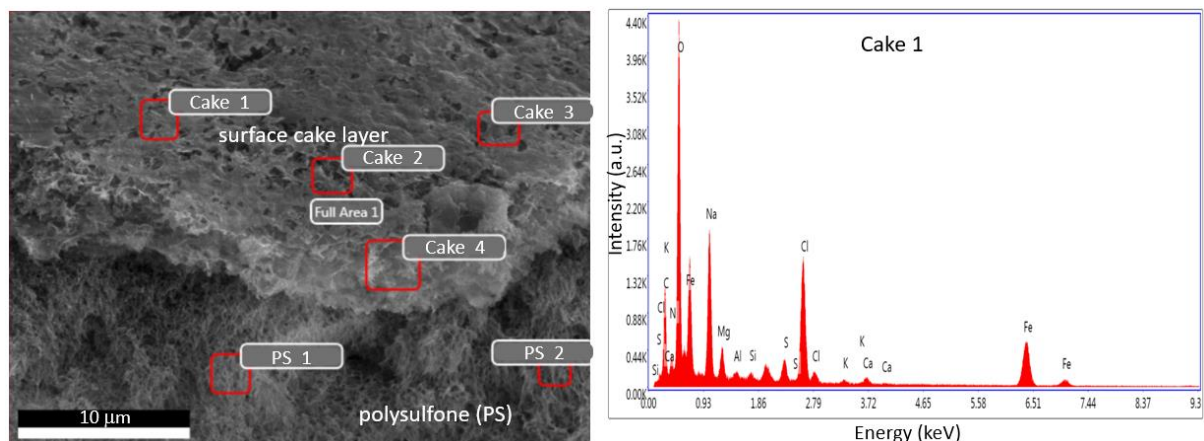


Atomic [%]

Element	Surface 1	Surface 2	PS 1	PS 2	PS 3	PS 4	PS 5
C	64.60	76.32	84.69	85.83	86.29	76.83	69.84
N	3.06	4.10	0.01	0.00	0.00	0.02	0.21
O	18.30	13.57	10.66	9.35	9.13	5.56	4.45
Na	6.11	2.89	1.17	0.38	0.32	0.08	0.00
Mg	0.20	0.11	0.05	0.12	0.08	0.00	0.00
Al	0.30	0.19	0.20	1.89	1.95	6.25	8.76
Si	0.15	0.07	0.07	0.03	0.02	0.02	0.01
S	6.61	2.47	3.05	2.32	2.13	10.69	15.68
Cl	0.40	0.20	0.03	0.01	0.00	0.17	0.61
K	0.05	0.02	0.02	0.03	0.01	0.04	0.13
Ca	0.03	0.01	0.01	0.01	0.02	0.06	0.03
Fe	0.17	0.04	0.04	0.03	0.04	0.27	0.28

Table S3. Elemental composition of the fouling cake layer at the membrane inlet. Data corresponds to various locations of the cake layer as specified in the scanning electron image. Two locations of the polysulfone (PS1 and PS2) layer were also analyzed for comparison. The intensity vs energy plot for location cake 1 is shown as example of the results output.

Sample membrane Inlet zone

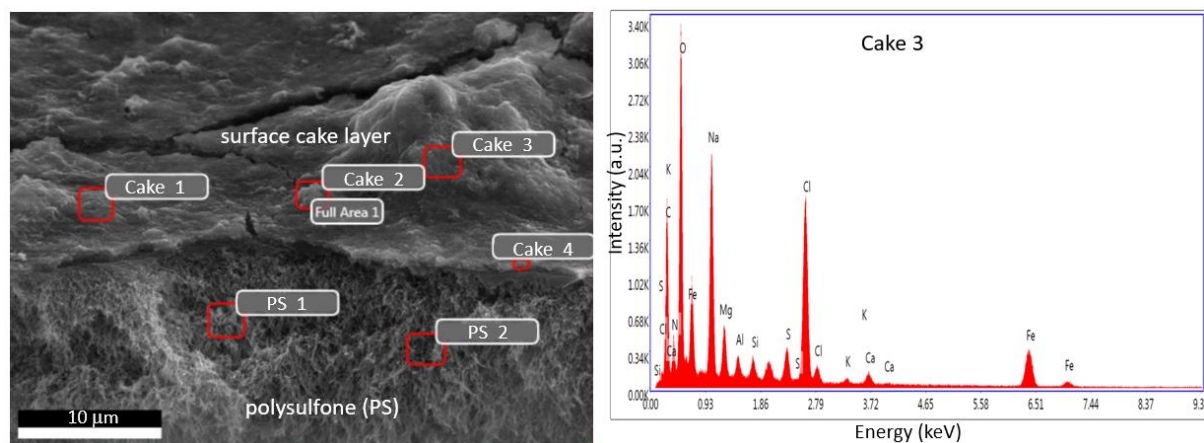


Atomic [%]

Element	Cake 1	Cake 2	Cake 3	Cake 4	PS 1	PS 2
C	26.93	31.03	28.90	47.59	83.33	86.28
N	11.37	11.18	11.52	8.47	0.01	0.01
O	36.76	33.02	34.94	26.48	10.90	8.48
Na	9.57	9.02	9.55	5.44	1.57	1.50
Mg	1.47	1.38	1.35	0.76	0.11	0.09
Al	0.36	0.72	0.29	2.40	0.30	0.23
Si	0.35	0.72	0.34	0.45	0.09	0.07
S	0.80	0.82	0.70	1.01	2.59	2.44
Cl	4.65	5.06	5.07	3.19	0.87	0.74
K	0.17	0.17	0.11	0.09	0.04	0.03
Ca	0.36	0.36	0.31	0.19	0.05	0.04
Fe	7.21	6.53	6.91	3.93	0.13	0.08

Table S4. Elemental composition of the fouling cake layer at the membrane outlet. Data corresponds to various locations of the cake layer as specified in the scanning electron image. Two locations of the polysulfone (PS1 and PS2) layer were also analyzed for comparison. The intensity vs energy plot for location cake 3 is shown as example of the results output.

Sample membrane Outlet zone



Atomic [%]

Element	Cake 1	Cake 2	Cake 3	Cake 4	PS 1	PS 2
C	41.31	39.74	35.32	57.14	83.80	84.94
N	15.54	13.89	13.24	15.56	0.01	0.01
O	29.65	30.38	29.73	18.15	7.42	9.55
Na	5.67	5.95	8.90	4.09	1.51	1.57
Mg	0.72	0.82	1.38	0.42	0.21	0.14
Al	0.20	0.32	0.48	0.32	0.92	0.22
Si	0.14	0.23	0.50	0.12	0.12	0.07
S	0.93	1.29	0.79	1.59	4.39	2.44
Cl	2.86	3.28	4.93	2.09	1.31	0.89
K	0.11	0.13	0.14	0.07	0.09	0.04
Ca	0.20	0.27	0.38	0.12	0.06	0.03
Fe	2.67	3.71	4.22	0.33	0.16	0.09

Table S5. Main cations in the fouling material of the membrane and spacer.

Cation	$\mu\text{g}/\text{cm}^2$
Na	185
Mg	28
Al	2
K	9
Ca	4
Fe	150
Zn	2