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Ceramic Membranes with In Situ Doped Iron Oxide Nanoparticles for Enhancement of

Antifouling Characteristics and Organic Removal

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SUPPORTING INFORMATION

SI – 1: NP identification and membrane characterization

To gain an insight into the reactions taking place during the modification process, TGA/DSC experiments were conducted for pure precursor, membrane, and membrane-precursor combinations. The membrane-precursor mixture (1 to 5 mass ratio) mimics membrane modification with mass ratio modified to minimize the initial reactant mass effects on the TGA behavior. Equal amounts of precursor, membrane, and their mixture were heated from room temperature to 400 °C at a rate of 5 °C/min under 30 ml/min of flowing air. To simulate the precursor thermal behavior under membrane modification protocol, TGA-DSC experiments were performed in two successive steps. First, $Fe(NO_3)_{3^2}9H_2O$ precursor was heated from ambient temperature to 200 °C using 5 °C/min under 30 ml/min of flowing air. Then, the sample was kept at 200 °C, and the isothermal weight loss and heat flow were recorded for 12 h.

NP type and crystalline structure were investigated by XRD analysis. The AR membrane, MM membranes (MM0.5 – MM2.0), and HT product samples were gently crushed into fine micron-sized powder. XRD analyses operating at 40 kV were performed in a 2θ range from 20° to 80° using a counting time of 1.0 °/min, and a 0.02° step.

The distribution of in situ generated NPs on the membrane surface and within its porous structure, potential NP agglomeration, and approximate NP loading on the membrane surface were evaluated by SEM/EDX analyses. Different arbitrary spots were thoroughly analyzed during the experiment to best evaluate and characterize the AR and MM membranes.

TEM/EDX analyses were applied to obtain the approximate size of in situ deposited NPs. The active layers of the MM membranes with various NP contents were meticulously separated and gently crushed into micron-sized particles. The powders were then dispersed in ethanol, deposited on carbon girds, and left to dry for analysis.

Membrane surface topology and roughness parameters were evaluated by atomic force microscopy (AFM) (Nano Wizard® 4, JPK). An aluminum coated conical tip was used for all the measurements, and the analysis was performed in QI (quantitative imaging) mode. To evaluate the potential effects of membrane modification on its surface roughness characteristics, AR and MM membranes were analyzed in terms of average roughness (R_a), root mean square (RMS) roughness (R_q), and relative roughness (r) using AFM techniques. Relative roughness, also known as Wenzel roughness, is defined as the ratio of actual membrane surface area to the projected area ¹.

Membrane wettability properties were investigated by the spreading-penetration process of a sessile droplet released onto the dry membrane surface from a very short distance. All the measurements are performed at macroscopic levels, including contact radius, contact angle, and droplet volume. Only small droplet volumes (approximately 3 μ L) are considered, hence the effect of the gravitational force on the droplet dynamics is negligible since small Bond number is encountered. Moreover, the very low impact velocity minimizes the influence of inertia on the process (Weber number < 1). Thus, the process is controlled by surface tension, viscous and wetting effects ².

SI – 2: Membrane regeneration

For membrane regeneration after each fouling cycle, fouled membranes were hydrodynamically cleaned by forward flushing with DI water to remove contaminants loosely attached to the membrane surface ³. Then, the

cake was gently removed from the membrane surface. Backwashing was avoided to prevent membrane collapse and failure. Following cake removal, steady water flux was obtained at the corresponding TMP and cross-flow rate conditions. As physical washing did not fully regenerate the membrane in most cases (i.e., F_{RR} less than 95%), the membranes were also chemically cleaned by flushing with aqueous *NaOH* solution (15 – 20 wt%) for 30 min at 60 °C. Then, the membranes were well rinsed until neutral pH was achieved and stored in DI water. Storage time did not affect the membrane performance, as confirmed by resistance measurements. Membrane integrity was not influenced by alkaline chemical cleaning, as previously reported ^{4, 5}.

SI - 3: TGA, DSC, and XRD analyses

For the $Fe(NO_3)_3$, $9H_2O$ precursor, TG/DSC curves exhibit four major endothermic reactions corresponding to stepwise dehydration processes and a final decomposition step occurring at 55, 88, 145, and 157 °C, respectively (Figure 2a). The small mass loss observed after 200 °C can be attributed to the release of volatile products ⁶. The (TG) and DSC profiles of the membrane confirm that the membrane is thermally stable in the temperature range used here (up to 400 °C), and no change in mass is observed. Lastly, the (TG) and DSC profiles of the membrane-precursor suggest that the precursor thermal decomposition is not significantly influenced by the presence of membrane material.

Considering Fe_2O_3 as the final product (Figure 2b), the mass loss after 12 h (78.4 wt%) is in good agreement with the theoretical stoichiometric calculation (80.2 wt%). The slight discrepancy can be due to the loss of water of dehydration during precursor storage and transportation ⁷.

SI – 4: NP identification by TEM/EDX analysis

Individual deposited NPs on the membrane surface are nearly impossible to detect by SEM analysis due to the fine particulate nature of the membrane active layer (as shown in Figures S4 and S5) and the limited accuracy of the EDX technique at the required high magnifications. Hence, TEM/EDX analysis is performed for membranes with various loads of deposited NPs (MM0.5 and MM1.0). HRTEM images of membranes represented in Figure

S7 show a mixture of cubic ZrO_2 and $\alpha - Fe_2O_3$ NPs. The images reveal that in both 15 kDa and 150 kDa membranes, the active layer is mainly composed of monophasic cubic ZrO_2 particles between 5 and 25 nm in size. TEM/EDX analysis of MM membranes shown in Figure S8 reveals uniformly distributed $\alpha - Fe_2O_3$ NPs with very limited agglomeration sites with an upper limit of 15 nm. The agglomeration sites were identified considering spots particularly rich in iron (denser population of green spots) coupled with lower content of zirconium, especially since zirconium is the main element of the active layer.

SI – 5: The influence of membrane modification on its intrinsic characteristics

Membrane modification did not have a significant effect on the membrane porosity, regardless of membrane MWCO and NP concentration. This may be explained by the fact that the membrane active layer, where most of the in situ NPs reside, as confirmed by EDX mapping of Figure 3b and S2b, contributes to a small portion of the total membrane porosity. The active layer thickness (less than 0.4% of the overall membrane thickness) and pore size are much smaller than the intermediate and support layers, as evident from SEM analysis (Figure S6). Hence, porosity change of the active layer is overshadowed by the total porosity of the membrane. Moreover, assuming surface pore size distribution can adequately estimate the active layer pore size, the SEM results revealed similar pore size of as-received and modified membranes for loose pore size membranes loaded with low NP content, i.e., 150 kDa – AR and 150 kDa – MM0.5⁸, which is also confirmed by the natural resistance measurements. Lastly, while the possibility of a tradeoff, i.e., smaller pores caused by NP deposition, and larger pores as a result of heat treatment, cannot be entirely overruled, dramatic changes in the membrane porous structure and larger pore sizes at relatively low temperature of 200 C is highly unlikely.

The membrane hydraulic resistance, on the other hand, is significantly affected by the deposition of NPs. Except for 150 kDa – MM0.5, membrane resistance generally increased as a result of modification, especially for higher NP concentration, i.e., MM1.0, for which the MM membrane resistance is almost two times higher than the AR membranes. As per Figure 3 and S2, NPs are deposited not only on the membrane surface but also in the pore space of the active layer. The active layer contributes the most in determining membrane resistance. The NPs

narrow down the pore diameter, which increases membrane resistance. This influence is more pronounced at higher NP population. The relatively invariant resistance for the 150 kDa membrane at low NP population can be attributed to the small change in membrane active layer average pore size after the deposition of small NPs ⁸.

According to surface roughness data summarized in Table S1, membranes exhibit relatively rough surfaces with a significant degree of roughness heterogeneity. NP deposition on the membrane surface decreases the surface roughness, which might be attributed to the very small size of the NPs relative to the pristine membrane surface roughness, as confirmed by TEM analysis. Under this scenario, the NPs tend to mostly reside within the surface valleys ⁹. This effect becomes more pronounced at higher NP content until micron-sized agglomeration at large NP population, i.e., MM2.0, contributes to the membrane roughness. Interestingly, comparable trends are observed for both 15 and 150 kDa membranes at similar modification concentrations. Surface roughness, nevertheless, is significantly lower for 15 kDa membranes in all cases. Relative roughness is not much affected by surface modification

SI – 6: Membrane wetting characteristics

The antifouling characteristics of a membrane are strongly dependent on its wetting characteristics. Membrane wettability was evaluated by dynamic contact angle measurements. The physics of deposited droplets on the membrane surface was investigated from two viewpoints: droplet spreading on the membrane surface and capillary penetration into the membrane pores. Three stages can be identified in Figure S11a,b corresponding to the spreading/penetration process of the water droplet on/into the porous membrane surface, as typically observed in a partially wetting case ¹⁰. During the first stage, the droplet spreads on the membrane surface until the maximum droplet base radius (R_{max}) is achieved and the apparent dynamic contact angle plunges to the static advancing contact angle decreases linearly with time until the static receding contact angle (θ_R) is reached, follows. The third stage includes droplet base shrinkage at constant contact angle until complete penetration (Figure S12). Contact angle hysteresis ($\Delta \theta = \theta_A - \theta_R$) and pinned droplet edge, i.e., stage 2, are the main characteristics of

partial wetting as predicted by disjoining/conjoining pressure isotherm ¹¹. Hysteresis and pinned droplet edge are attributed to surface imperfections such as roughness and chemical heterogeneity.

Regarding droplet volume and liquid penetration into the layered porous membrane (Figure S11c), two distinct stages, distinguished by different slopes, are observed. In the first stage, the liquid penetrates the pores beneath the droplet contact area. During the second stage, there is radial penetration through porous matrices beyond the droplet base (Figure S12)¹². The liquid penetration rate in stage 1 is typically determined by the characteristics of the first layer, i.e., the active layer, whereas in stage 2 by the combination of all layers ¹³.

Analysis of the wetting behavior for membranes with different pore sizes reveals that the 15 kDa and 150 kDa membrane have relatively similar surface wetting properties. In the case of penetration process, however, 15 kDa and 150 kDa membranes behave differently. Liquid penetration time is significantly lower for the 150 kDa membranes (Figure S12). The 150 kDa membranes with higher permeability provide more capillary paths for liquid penetration, which considerably reduces the penetration time (increases the penetration flux.). Capillary pressure, which is considered the primary driving force, is enhanced by higher pore wettability. Note that larger pore size inhibits the penetration by decreasing the capillary force while at the same time enhances the penetration by reducing viscous friction resistance ¹⁴. Therefore, the penetration process is controlled by a balance between these two opposing effects.



Figure S1: Schematic diagram of membrane modification process; (a) As – received membrane, (b) Membrane saturation with precursor solution via filtration and immersion, (c) Heat treatment at 200 C for 12 h, (d) In situ modified membrane.



Figure S2: XRD analysis of MM membranes and HT product; F, R, and Z denote $\alpha - Fe_2O_3$, rutile TiO_2 , and ZrO_2 , respectively.



Figure S3: SEM images of 150 kDa membranes with different NP loading with the corresponding EDX mappings; (a) membrane surface, (b) membrane cross-section featuring the active layer. Scale bar = $4 \mu m$.





Figure S4: SEM images of membrane surface for 15 kDa membrane with various nanoparticle loading displaying its rough, fine particulate structure; (a) 15 kDa – AR, (b) 15 kDa – MM0.5, (c) 15 kDa – MM1.0.



Figure S5: SEM images of membrane surface for 150 kDa membrane with various nanoparticle loading displaying its rough, fine particulate structure; (a) 150 kDa – AR, (b) 150 kDa – MM0.5, (c) 150 kDa – MM1.0.



Figure S6: SEM images of membrane cross-sections showing that the pore space in the intermediate and supporting layers is much higher than the active layer; (a) 15 kDa – AR, (b) 150 kDa – AR.



Figure S7: HRTEM images of nanoparticles collected from membrane active layer; (a) 15 kDa – MM0.5, (b) 150 kDa –

MM0.5, (c) 15 kDa - MM1.0, (d) 150 kDa - MM1.0



Figure S8: Figure S : STEM image/EDX mapping of membrane active layer particles; (a) 15 kDa – MM0.5, (b) 150 kDa – MM0.5, (c) 15 kDa – MM1.0, (d) 150 kDa – MM1.0. Aggregated iron oxide NPs are shown with green circles. Scale bar = 20 nm.



Figure S9: AFM analysis of membrane surfaces with various nanoparticle loading; (a) 15 kDa – AR (R_a = 150 ± 45 nm), (b) 15 kDa – MM0.2 (R_a = 130 ± 20 nm), (c) 15 kDa – MM0.5 (R_a = 100 ± 45 nm), (d) 15 kDa – MM1.0 (R_a = 80 ± 40 nm), (e) 15 kDa – MM2.0 (R_a = 90 ± 65 nm).



Figure S10: AFM analysis of membrane surfaces with various nanoparticle loading; (a) 150 kDa – AR ($R_a = 260 \pm 110$ nm), (b) 150 kDa – MM0.2 ($R_a = 230 \pm 50$ nm), (c) 150 kDa – MM0.5 ($R_a = 200 \pm 50$ nm), (d) 150 kDa – MM1.0 ($R_a = 150 \pm 50$ nm), (e) 150 kDa – MM2.0 ($R_a = 320 \pm 50$ nm).



Figure S11: Spreading/penetration parameters for various membranes; (a) droplet contact radius, (b) apparent contact angle, (c) droplet volume over the membrane surface.



Figure S12: Demonstration of the three stages of droplet spreading/penetration process for a liquid droplet on partially wettable porous medium; (a) droplet contact radius, (b) apparent contact angle. R_{max} is the maximum contact radius. θ_A and θ_R are advancing and receding contact angles, respectively. t_A , t_R , and t_P are the times at which the advancing contact angle, the receding contact angle, and the end of spreading/penetration are reached, respectively. Experimental data are for 15 kDa – AR; (c) Demonstration of the evolution of droplet volume over a multi-layered porous medium; The penetration flux of liquid during stage 1 is controlled by the first layer and depends on the combination of all layers (mainly first and

second in the case of relatively small droplets) during stage 2; Experimental data are for 150kDa - AR.



Figure S13: Normalized permeate flux evolution during membrane fouling for various membrane/feed/TMP combinations; (a) Synthetic PW (HA – 0.6 g/l), (b) Synthetic PW (HA – 2.4 g/l)



Figure S14: Experimental data and model predicted permeate flux as a function of time for field PW; (a) 150 kDa – AR, and (b) 150 kDa – MM0.5 membranes.



Figure S15: Experimental data and model predicted permeate flux as a function of time for field PW; (a) 15 kDa – AR, and (b) 15 kDa – MM0.5 membranes, (c) 15 kDa – MM1.0 membranes.



Figure S16: Experimental data and model predicted permeate flux as a function of time for HA – 0.6 g/l; (a) 150kDa – AR, and (b) 150kDa – MM0.5 membranes, (c) 150kDa – MM1.0 membranes.



Figure S17: Experimental data and model predicted permeate flux as a function of time for HA – 0.6 g/l; (a) 15 kDa – AR, and (b) 15 kDa – MM0.5 membranes, (c) 15 kDa – MM1.0 membranes.



Figure S18: Experimental data and model predicted permeate flux as a function of time for HA – 1.5g/l; (a) 150 kDa – AR, and (b) 150 kDa – MM0.5 membranes, (c) 150 kDa – MM1.0 membranes.



Figure S19: Experimental data and model predicted permeate flux as a function of time for HA – 1.5 g/l; (a) 15 kDa – AR, and (b) 15 kDa – MM0.5 membranes, (c) 15 kDa – MM1.0 membranes.



Figure S20: Experimental data and model predicted permeate flux as a function of time for HA – 2.4 g/l; (a) 150 kDa – AR, and (b) 150 kDa – MM0.5 membranes, (c) 150 kDa – MM1.0 membranes.



Figure S21: Experimental data and model predicted permeate flux as a function of time for HA – 2.4 g/l; (a) 15 kDa – AR, and (b) 15 kDa – MM0.5 membranes, (c) 15 kDa – MM1.0 membranes.



Figure S22: Schematic representation of combined fouling mechanisms; (a) standard blocking – cake formation, (b) complete blocking – cake formation, (c) intermediate blocking – cake formation.



Figure S23: Static adsorption of HA – 0.6 g/L on membranes modified with various NP contents; (a) 15 kDa membranes,

(b) 150 kDa membranes



Figure S24: Number/Volume based particle size analysis of synthetic PW: (a) HA – 0.6 g/l, (c) HA – 1.5 g/l, (e) HA – 2.4 g/l and permeate samples of different membranes: (b) HA – 0.6 g/l, (d) HA – 1.5 g/l, (f) HA – 2.4 g/l.

Table S1: Surface roughness data obtained from AFM analysis; R_a , R_q , and r are average roughness, RMS roughness, and relative (Wenzel) roughness, respectively.

Membrane	R_{a} (nm)	R_q (nm)	r
15 kDa – AR	150 ± 45	175 ± 40	1.07 ± 0.03
15 kDa – MM0.2	130 ± 20	160 ± 20	1.10 ± 0.03
15 kDa – MM0.5	100 ± 45	125 ± 50	1.07 ± 0.04
15 kDa – MM1.0	80 ± 40	95 ± 40	1.10 ± 0.07
15 kDa – MM2.0	90 ± 65	110 ± 50	1.11 ± 0.06
150 kDa – AR	260 ± 110	310 ± 120	1.18 ± 0.01
150 kDa – MM0.2	230 ± 50	280 ± 50	1.18 ± 0.01
150 kDa – MM0.5	200 ± 50	235 ± 50	1.18 ± 0.01
150 kDa – MM1.0	150 ± 50	195 ± 45	1.17 ± 0.01
150 kDa – MM2.0	320 ± 50	375 ± 65	$1.2^{0} \pm 0.04$

Membrane	Feed _	Fouling Characteristics		
		Flux Decline (%)	Dominant Fouling Mechanism	
15kDa – AR	HA - 0.6 g/L	5.2 ± 0.3	Standard – Cake	
	HA - 1.5 g/L	15.0 ± 0.4	Intermediate – Cake	
	HA - 2.4 g/L	12.8 ± 0.3	Complete – Cake	
	PW – Field	30.3 ± 0.7	Intermediate – Cake	
	HA - 0.6 g/L	7.1 ± 0.4	Complete – Cake	
15kD - MM0 5	HA - 1.5 g/L	$4.9~\pm~0.3$	Complete – Cake	
15KDa – MINIO.5	HA - 2.4 g/L	$10.9~\pm~0.4$	Complete – Cake	
	PW – Field	$14.9~\pm~0.6$	Intermediate – Cake	
	HA - 0.6 g/L	6.2 ± 0.3	Complete – Cake	
15LD. MM10	HA - 1.5 g/L	$10.4~\pm~0.4$	Complete – Cake	
15KDa – MINI1.0	HA - 2.4 g/L	$8.2~\pm~0.2$	Complete – Cake	
	PW – Field	$12.7 ~\pm~ 0.4$	Intermediate – Cake	
	HA - 0.6 g/L	11.7 ± 0.3	Standard – Cake	
150LD	HA - 1.5 g/L	28.1 ± 0.4	Standard – Cake	
150kDa – AR	HA - 2.4 g/L	37.4 ± 1.1	Intermediate – Cake	
	PW – Field	65.4 ± 3.1	Intermediate – Cake	
	HA - 0.6 g/L	9.4 ± 0.2	Intermediate – Cake	
	HA - 1.5 g/L	5.6 ± 0.1	Intermediate – Cake	
	HA - 2.4 g/L	4.5 ± 0.3	Complete - Cake	
	PW – Field	50.0 ± 1.6	Intermediate – Cake	
150kDa – MM1.0	HA - 0.6 g/L	6.2 ± 0.3	Complete – Cake	
	HA - 1.5 g/L	6.6 ± 0.2	Complete – Cake	
	HA - 2.4 g/L	5.5 ± 0.3	Intermediate – Cake	
	PW – Field	-	-	

Table S2: Fouling characteristics for various membrane–feed systems at TMP = 0.5 bar.

Membrane	Feed -	Fouling Characteristics		
		Flux Decline (%)	Dominant Fouling Mechanism	
	HA - 0.6 g/L	$10.0~\pm~0.4$	Complete – Cake	
	HA - 1.5 g/L	10.3 ± 0.3	Complete – Cake	
	HA - 2.4 g/L	16.4 ± 0.3	Complete – Cake	
	PW – Field	$20.6~\pm~0.7$	Standard – Cake	
	HA - 0.6 g/L	6.8 ± 0.2	Complete – Cake	
15kDo MM0.5	HA - 1.5 g/L	7.7 ± 0.2	Complete – Cake	
ISKDa – MIMU.S	HA - 2.4 g/L	8.4 ± 0.1	Complete – Cake	
-	PW – Field	8.0 ± 0.3	Intermediate – Cake	
	HA - 0.6 g/L	4.0 ± 0.2	Complete – Cake	
15kDo MM1 0	HA - 1.5 g/L	2.4 ± 0.1	Complete – Cake	
15KDa – WIWI1.0	HA - 2.4 g/L	7.6 ± 0.1	Complete – Cake	
	PW – Field	6.9 ± 0.2	Intermediate – Cake	
-	HA - 0.6 g/L	29.8 ± 1.4	Standard – Cake	
	HA - 1.5 g/L	37.8 ± 2.5	Standard – Cake	
150KDa – AK	HA - 2.4 g/L	22.1 ± 0.8	Intermediate – Cake	
-	PW – Field	57.3 ± 1.4	Intermediate – Cake	
	HA - 0.6 g/L	17.3 ± 0.6	Intermediate – Cake	
	HA - 1.5 g/L	24.3 ± 2.4	Intermediate – Cake	
	HA - 2.4 g/L	17.0 ± 0.5	Intermediate – Cake	
	PW – Field	47.2 ± 0.9	Intermediate – Cake	
	HA - 0.6 g/L	13.7 ± 0.3	Intermediate – Cake	
	HA - 1.5 g/L	26.4 ± 1.6	Intermediate – Cake	
	HA - 2.4 g/L	$20.0~\pm~0.2$	Intermediate – Cake	
	PW – Field	-	-	

Table S3: Fouling characteristics for various membrane–feed systems at TMP = 1.0 bar.

Membrane	Feed _	Fouling Characteristics		
		Flux Decline (%)	Dominant Fouling Mechanism	
15kDa – AR	HA - 0.6 g/L	16.1 ± 0.5	Intermediate – Cake	
	HA - 1.5 g/L	15.9 ± 0.4	Intermediate – Cake	
	HA - 2.4 g/L	31.9 ± 1.2	Intermediate – Cake	
	PW – Field	$31.9~\pm~0.9$	Intermediate – Cake	
	HA - 0.6 g/L	13.4 ± 0.5	Intermediate – Cake	
15kDa MM0.5	HA - 1.5 g/L	$14.0~\pm~0.3$	Complete – Cake	
15KDa — WIWI0.5	HA - 2.4 g/L	$29.4~\pm~0.8$	Intermediate – Cake	
	PW – Field	$29.1~\pm~0.5$	Intermediate – Cake	
	HA - 0.6 g/L	4.1 ± 0.2	Intermediate – Cake	
15kDa MM1.0	HA - 1.5 g/L	5.0 ± 0.2	Complete – Cake	
15KDa – MM1.0 -	HA - 2.4 g/L	$15.6~\pm~0.5$	Intermediate – Cake	
	PW – Field	$22.3~\pm~0.7$	Intermediate – Cake	
	HA - 0.6 g/L	13.4 ± 0.3	Intermediate – Cake	
	HA - 1.5 g/L	$28.9~\pm~1.1$	Intermediate – Cake	
150kDa – AR -	HA - 2.4 g/L	21.3 ± 1.2	Complete – Cake	
	PW – Field	$41.2~\pm~0.7$	Intermediate – Cake	
- 150kDa – MM0.5 -	HA - 0.6 g/L	16.8 ± 0.5	Intermediate – Cake	
	HA - 1.5 g/L	$22.4~\pm~0.9$	Intermediate – Cake	
	HA - 2.4 g/L	$20.8~\pm~0.7$	Intermediate – Cake	
	PW – Field	36.6 ± 1.2	Intermediate – Cake	
	HA - 0.6 g/L	13.0 ± 0.4	Complete – Cake	
	HA - 1.5 g/L	27.7 ± 1.2	Complete – Cake	
	HA - 2.4 g/L	27.1 ± 1.1	Intermediate – Cake	
	PW – Field	-	-	

Table S4: Fouling characteristics for various membrane–feed systems at TMP = 1.5 bar.

Table S5: Organic percent rejection ($^{\%}R$) values for different membrane/feed/TMP combinations; The values in parentheses represent the total organic content in the feed. The values in parentheses show feed TOC.

Membrane	TMP (bar)	Percent Rejection (%R)			
		HA - 0.6 g/L (^{206 ± 9} mg/L)	HA - 1.5 g/L (530 ± 17 mg/L)	HA - 2.4 g/L (836 ± 32 mg/L)	PW – Field (433 ± 11 mg/L)
- 15kDa – AR -	0.5	99.2	98.9	97.8	32.6
	1.0	99.1	99.0	97.9	32.2
	1.5	98.7	98.9	97.9	33.4
	0.5	99.4	99.2	99.2	35.3
15kDa – MM0.5	1.0	99.3	99.2	98.9	37.6
-	1.5	98.9	99.1	98.9	37.1
15kDa – MM1.0	0.5	97.6	98.7	98.9	39.6
	1.0	97.3	98.7	98.8	39.7
	1.5	96.8	98.7	98.8	41.3
150kDa – AR	0.5	97.6	94.4	91.5	27.9
	1.0	95.8	94.4	91.5	29.2
	1.5	95.9	94.7	91.1	31.1
150kDa – MM0.5	0.5	98.7	98.7	97.1	39.1
	1.0	97.8	98.0	97.4	38.6
	1.5	97.9	97.6	98.0	41.6
150kDa – MM1.0	0.5	97.6	98.1	96.8	-
	1.0	96.0	96.8	96.8	-
	1.5	96.0	96.9	96.2	-

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