Electronic Supplementary Information (ESI*)

Resource-efficient Pre-Treatment with Partial Desalination Approach Using Graphene-MXene Coated Cellulose Filters for Desalination Plants

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Sl. No	Method used	Principle	Advantages	Disadvantages	Ref.
1	Coagulation & Flocculation	Addition of chemicals (e.g., $FeCl_3$, $Al_2(SO_4)_3$) to destabilize particles and form flocs	Removes suspended solids, Cost-effective, Improves downstream filtration	Produces sludge, requires precise chemical dosing	[1]
2	Cartridge Filtration	Depth filtration using porous cartridges (typically 5 µm)	Compact, Easy replacement, protects RO membranes	Requires frequent replacement, Limited capacity for large volumes	[2]
3	Ultrafiltration (UF)	Membrane filtration that removes particles, colloids, and bacteria (pore size ~0.01 µm)	High efficiency, removes viruses, Stable feed for RO	High initial cost, Membrane fouling, needs cleaning	[3]
4	Microfiltration (MF)	Membranes with larger pore size (~0.1 µm) for particle and microorganism removal	Reduces biofouling, Low-pressure operation	Cannot remove dissolved salts or organics, Fouling risk	[4]
5	Dissolved Air Flotation (DAF)	Air bubbles attach to suspended particles, which float and are skimmed	Effective for algae and oil, Less sludge than coagulation	Requires a large area, not efficient for very small particles	[5]
6	Chlorination/Dichlorination	Chlorine is added to kill microorganisms; sodium bisulfite is used before RO to neutralise chlorine	Controls biofouling, Cost-effective	Chlorine damages RO membranes, generates harmful by-products	[6]
7	Acid Addition (pH Adjustment)	Acid (e.g., H_2SO_4) lowers pH to reduce scale formation	Prevents scaling (especially $CaCO_3$), Enhances antiscalant performance	Corrosive, pH must be carefully controlled	[7]
8	Antiscalant Dosing	Polyphosphates or polymers inhibit the crystal formation of scale-forming salts	Minimises scaling, Enhances RO recovery	Potential biofouling must be dosed precisely	[8]
9	Our method	Gravity-driven filtration, modified adsorbates with a hybrid sandwich-like arrangement.	Zero energy requirement, no hazardous chemicals, eco-friendly, dual purpose and cost-effective.	Relatively low water flux, need for replacement of the materials.	--

Table S1. Commercially available pretreatment methods and their working principle, along with pros and cons.

Pretreatment method	Parameters studied	Results	Advantages	Limitations	Ref.
Ultrafiltration (UF)	SDI, turbidity, particle removal, biofouling	- SDI <3 - Effective particle/microbe removal - Stable flux	- High particle/microbe removal - Improved RO feed quality	- Membrane fouling over long-term - Chemical cleaning needed	[9]
Pilot-scale dual-media filtration	SDI, MFI, RO performance, fouling	- SDI <3 - Satisfied pilot-scale performance	- Proven pilot-scale - Low fouling risk	- Site-specific - Chemical addition may be needed	[10]
Dual media rapid filtration	Fouling fractionation, turbidity	- >80% particulate fouling removed	- Simple - Proven technique	- Limited organic removal - Fouling can occur	[11]
Ceramic UF	SDI, DOC, particle removal	- Robust removal of particulates - SDI < 3	- High chemical/thermal stability - Long life	- High initial cost - Energy demand	[12]
Gravity-driven membrane (GDM) filtration	Permeate flux, AOC removal, biofilm	- Flux ~9.1 L/m^{2}h - AOC removal ~50–55%	- Low energy - Biofilm enhances organics removal	- Lab-scale only - Low flux - Long-term biofilm control	[13]
Pre-chlorination + GDM	Flux, fouling, microbial removal	- Flux increased 15–68% - Reduced EPS	- Enhanced flux - Microbial safety	- Long-term stability issues - Chemical addition	[14]
Softening + Ballasted Flocculation (SBF)	Ca^{2+}/Mg^{2+} removal, SDI, settling velocity	- Settling velocity ~3.5 cm/s - SDI <3 - Sludge reduced 76.5%	- Rapid removal of Ca^{2+}/Mg^{2+} - Reduced RO fouling	- Chemical addition - Sludge handling required - Other foulants not fully removed	[15]
Fibre media filtration	SDI, MFI, turbidity, organics	- SDI ~2.6 - MFI ~1.4 s/L^2 - Turbidity <0.35 NTU	- High velocity - Compact footprint - Organic/particle removal	- Maintenance and chemical dosing required	[16]
Graphene oxide (GO/rGO) membrane-based filtration	Ca^{2+}/Mg^{2+} rejection, flux, TBT	- TBT increased to 166 °C - Improved divalent rejection	- Reduced scaling - Improved thermal efficiency	- Limited to lab-scale - Cost - Other fouling not addressed	[17]
Flat sheet PVDF GDM	Flux, biofilm properties, DOC	- Flux ~7.3–8.4 L/m^2.h - Biofilm porosity correlates with flux	- Low-energy - Biofilm can enhance flux stability	- Modest flux - Limited DOC removal - Pilot scale	[18]
Fibre filter + Dual media	SDI, MFI, DOC, turbidity	- SDI ~2.6 - MFI ~1.4 s/L^2 - DOC reduced ~70% - Turbidity <0.35 NTU	- High feedwater quality - Compact footprint - Coagulation improves performance	- Chemical addition - pilot scale - Other fouling agents are not fully addressed	[19]
Submerged membrane hybrid system	Flux, fouling mechanisms, SDI	- Pore blocking & cake formation dominate - Optimized operation reduced fouling	- Improved RO feedwater quality - Understanding fouling mechanisms	- Pilot scale - Complex - Higher CAPEX/maintenance	[20]
Hybrid filtration setup consisting of natural adsorbents, GO/MXene-coated cellulose filters working on gravity-driven filtration	SDI, pH, TDS, conductivity, salinity, COD, BOD, TSS, turbidity, total hardness, MPN	- SDI = 2.6 - Satisfactory reduction in all the tested parameters - Partial desalination up to 17.7% along with the pretreatment	- No energy requirement - Cost-effective - Simple and scalable - Dual functioning	- Comparatively low water flux - Components of the hybrid filter need to be replaced regularly	Present work

Table S2. Comparison of the present study with similar seawater pretreatment studies.

Sample	pH	TDS (PPT)	Conductivity (mS/cm)	Salinity (PPT)	Decrease in salinity (%)
Unfiltered seawater	7.97	36.3	48.01	34.4	---
Filtered through hybrid filters with:					
Uncoated cellulose filter	7.94	35.2	47.82	34.1	0.87
0.25 mg/mL GO-coated filter	7.86	33.6	46.68	33.4	2.91
0.50 mg/mL GO-coated filter	7.54	31.8	44.93	31.9	7.27

0.75 mg/mL GO-coated filter	7.33	30.4	43.04	30.2	12.21
1.00 mg/mL GO-coated filter	7.10	29.1	41.20	28.3	17.73
0.25 mg/mL Ti_3C_2-coated filter	7.90	34.0	47.56	34.0	1.16
0.50 mg/mL Ti_3C_2-coated filter	7.76	33.4	46..24	33.1	3.77
0.75 mg/mL Ti_3C_2-coated filter	7.61	32.9	44.11	32.5	5.52
1.00 mg/mL Ti_3C_2-coated filter	7.43	31.8	43.19	31.1	9.59

Table S3. Water quality parameters of seawater before and after the filtration

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