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Hybrid Ion Exchange-Nanofiltration Process to Desalinate Seawater and Brackish Water

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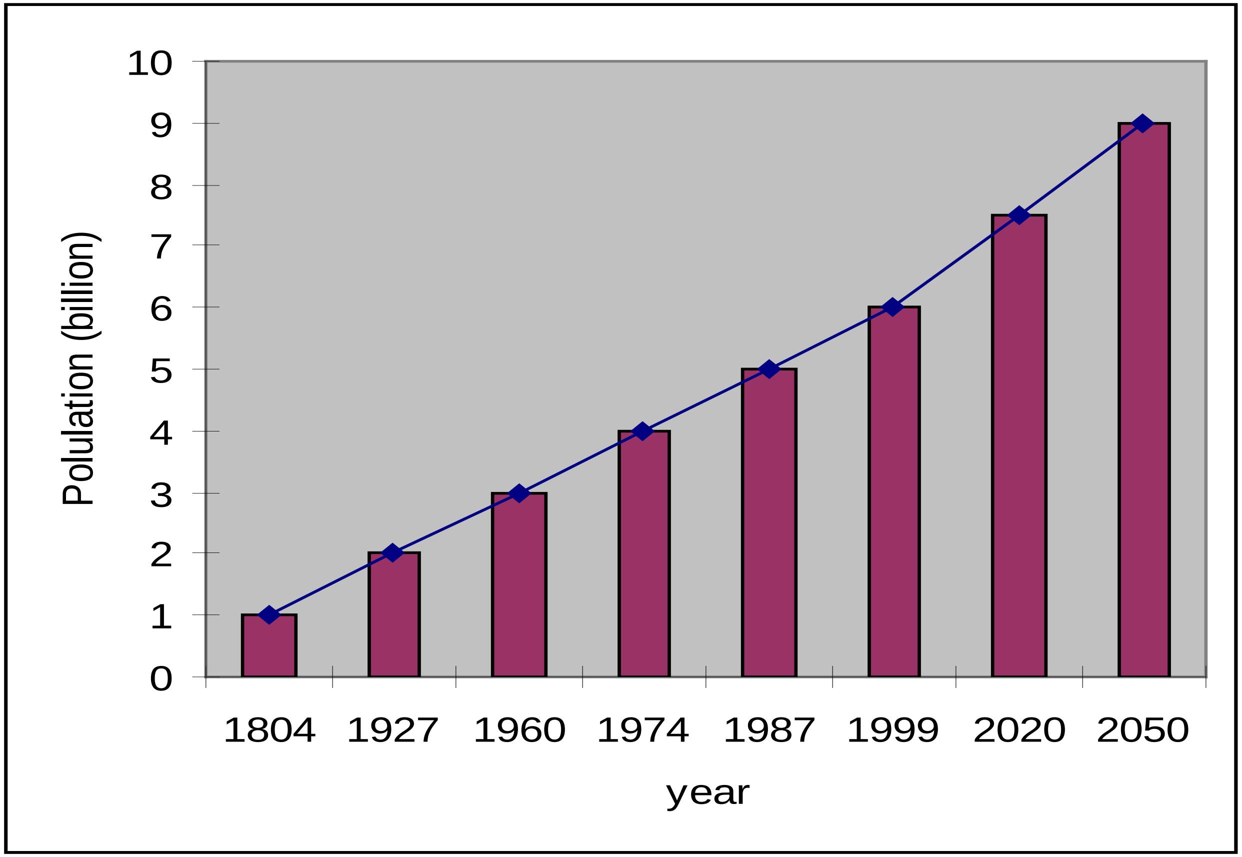
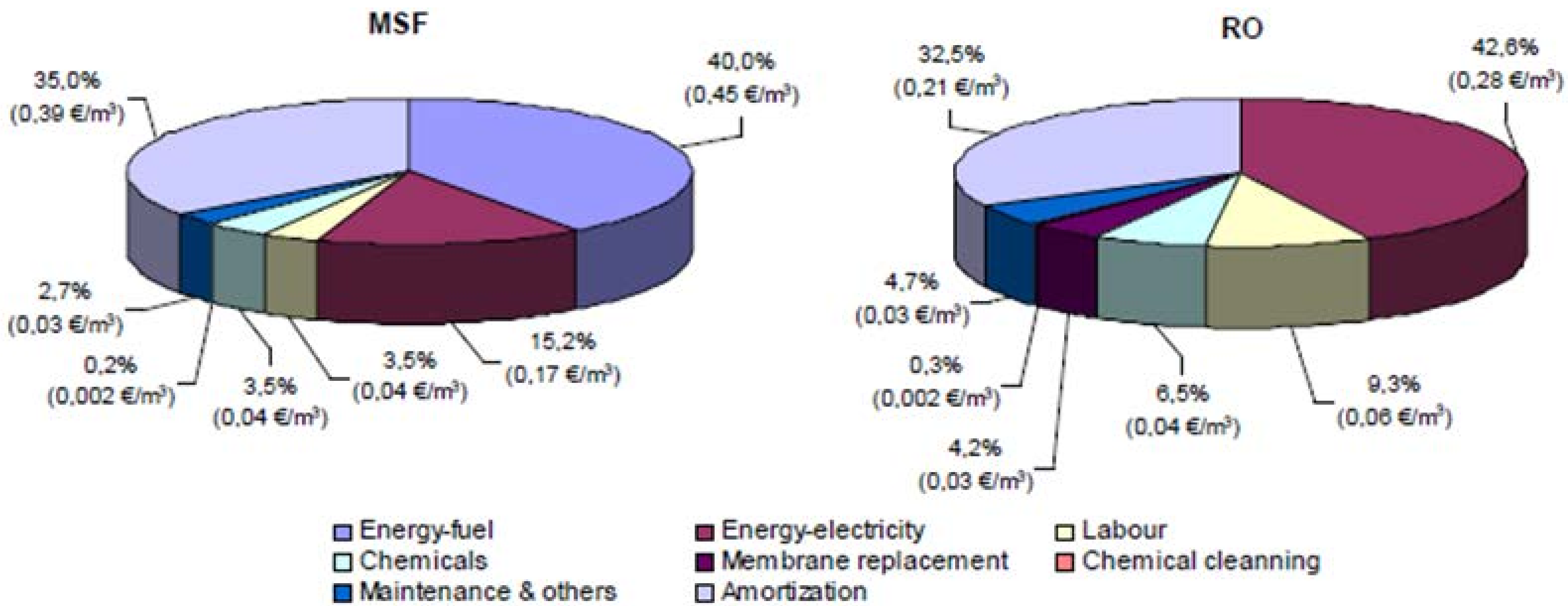
Demand for fresh water



El-Dessouky and Ettouney, Fundamentals of Salt Water Desalination, Elsevier, 2002

Breakdown of desalination cost for multistage flash distillation (MSF) and reverse osmosis (RO)

Energy consumption represents the most significant portion of the total cost for the most widely used desalination processes :
up to 50.2 % for MSF and to 42.6 % for RO



Source: GW Desal Data, 2012

There is a need for development of novel desalination processes for water desalination with lower energy consumption

Background of Hybrid Ion Exchange –Nanofiltration Process of Water Desalination

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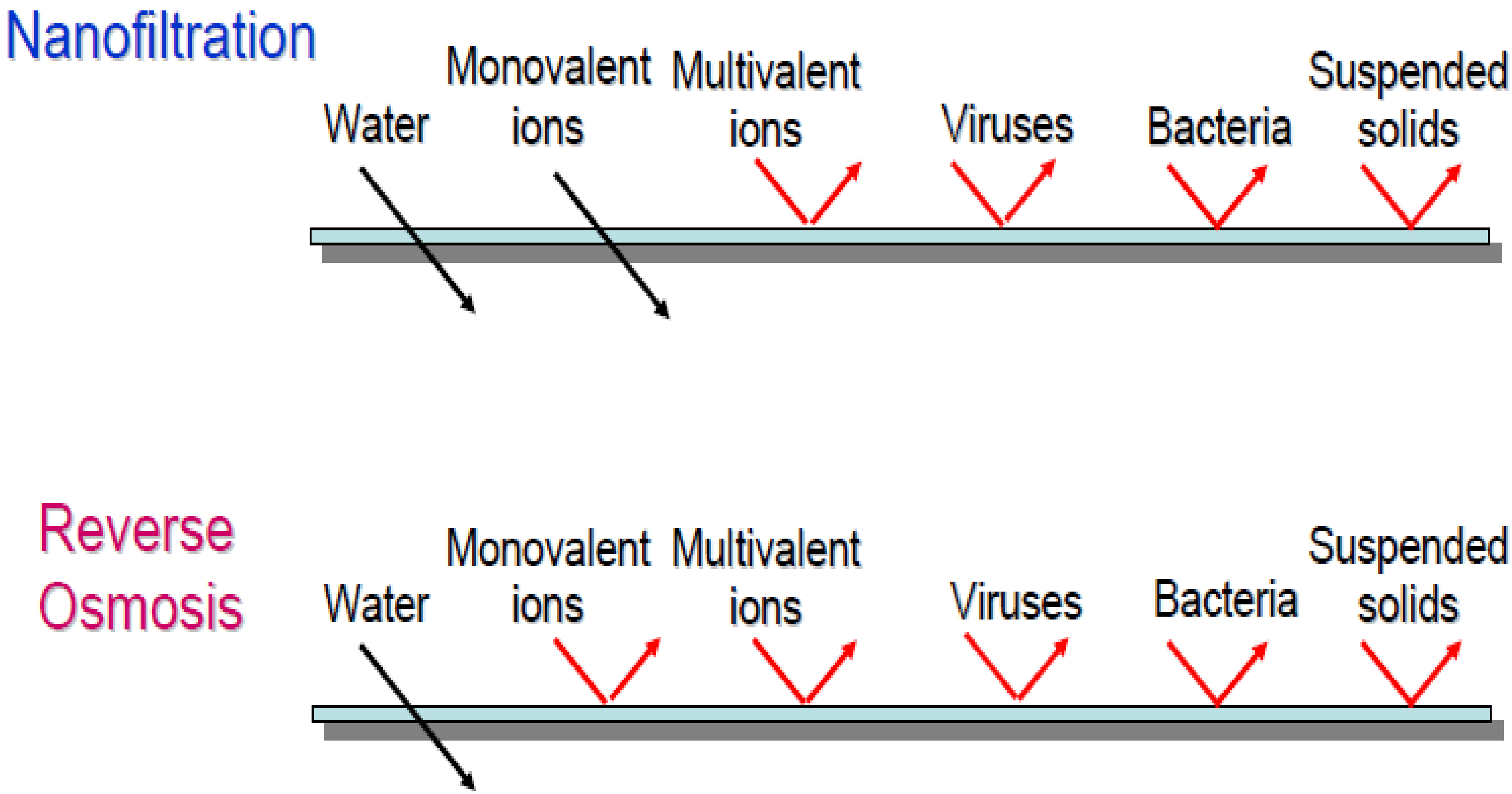
If monovalent chloride ions in salty water are converted into divalent sulphate ions then more energy efficient NF membranes may be used instead of energy consuming RO membranes for water desalination

$$2Cl^- \Leftrightarrow SO_4^{2-}$$



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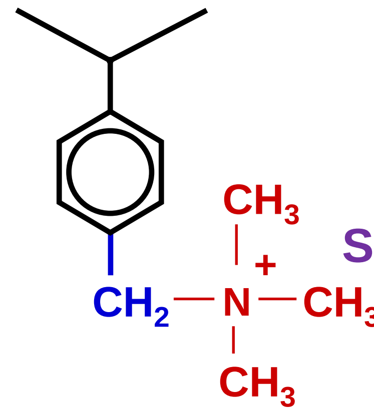
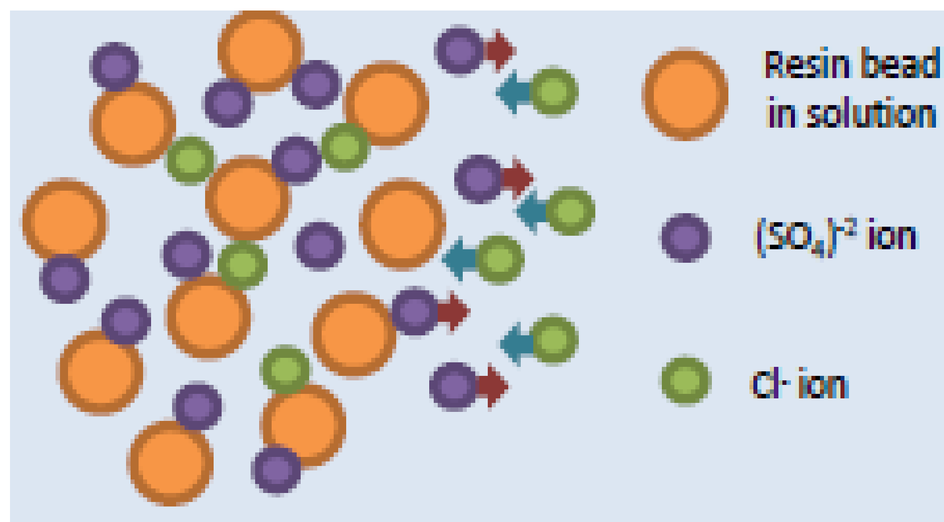
SO_4^{2-}/Cl^- exchange with anion exchange resin

$$(RN^+)_2SO_4^{2-} + 2Na^+ \ +2Cl^- \Leftrightarrow 2(RN^+)Cl^- + SO_4^{2-} + 2Na^+$$



$SO_4^{2-} \Leftrightarrow Cl^-$



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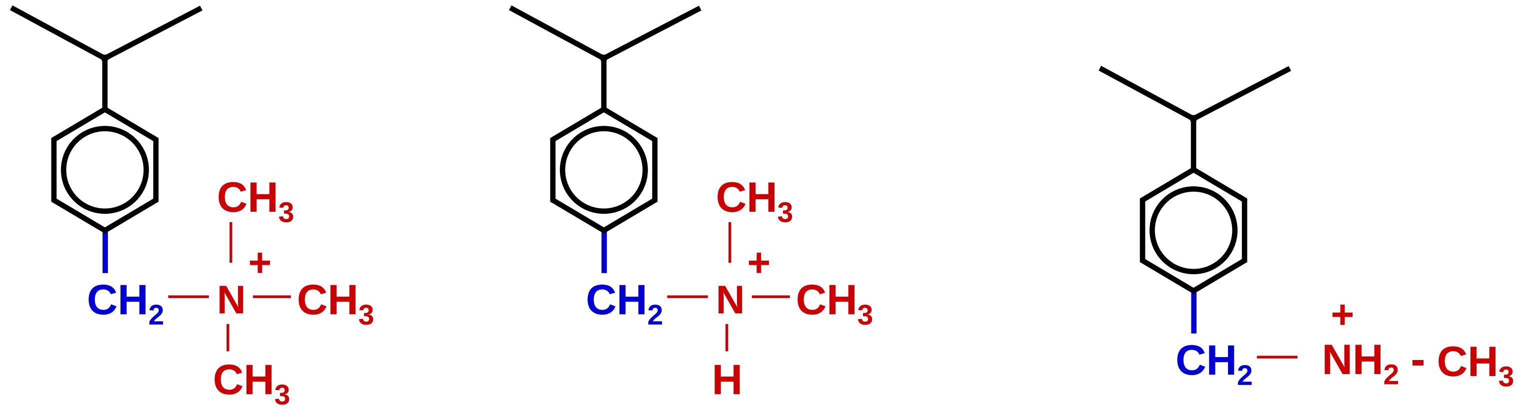
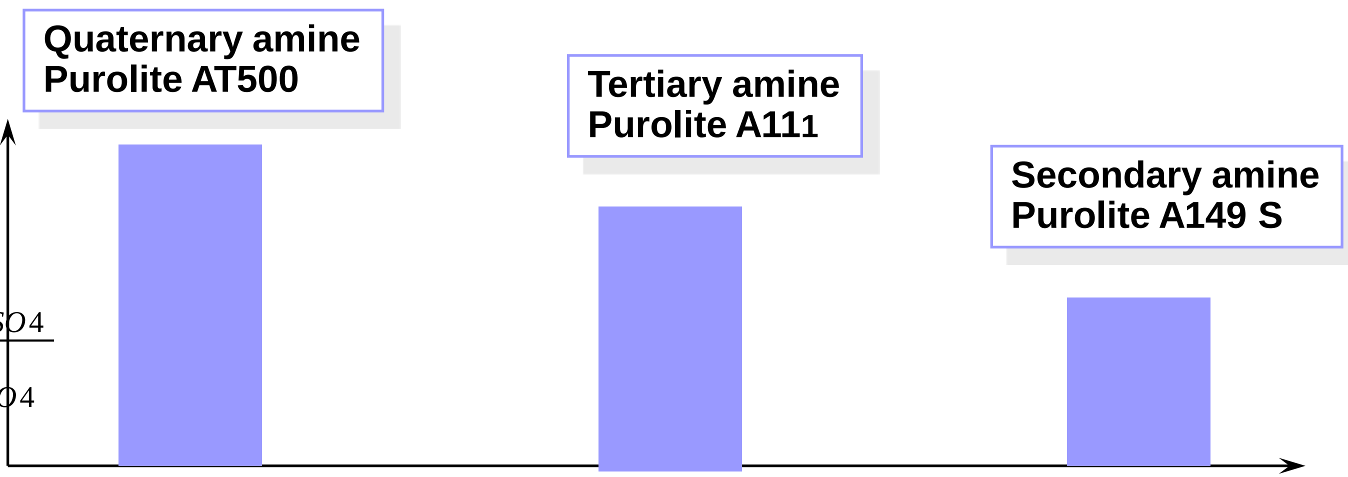
Tuning sulphate-chloride selectivity: effect of amine group



$$\alpha^{Cl}_{SO4} = \frac{Y_{Cl}}{X_{Cl}} \times \frac{X_{SO4}}{Y_{SO4}}$$



The chloride-sulphate separation factor increases with degree of substitution in amine functional group of anion exchange resin

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Anion exchange resins with different amine functional groups have been used in the work

Resin name	Ambersep 900SO_4	A500TLSO_4	A400TLSO_4	A850
Manufacturer	Dow Chemical	Purolite international	Purolite international	Purolite international
Matrix	Styrene divinylbenzene copolymer	Polyacrylic crosslinked with divinylbenzene	Gel polyacrylic crosslinked with divinylbenzene	Polyacrylic crosslinked with divinylbenzene
Functional groups	Trimethyl ammonium	Quaternary Ammonium	Quaternary Ammonium	Quaternary Ammonium
Ionic form as shipped	$SO4^{=}$	$SO4^{=}$	$SO4^{=}$	Cl^{-}
Total exchange capacity	1.00 eq/L (Cl^{-} form)	1.15 eq/L (Cl^{-} form)	1.3 eq/L (Cl^{-} form)	1.25 eq/L (Cl^{-} form)
Particle size	-	425 - 850 µm	425 - 850 µm	300 - 1200 µm

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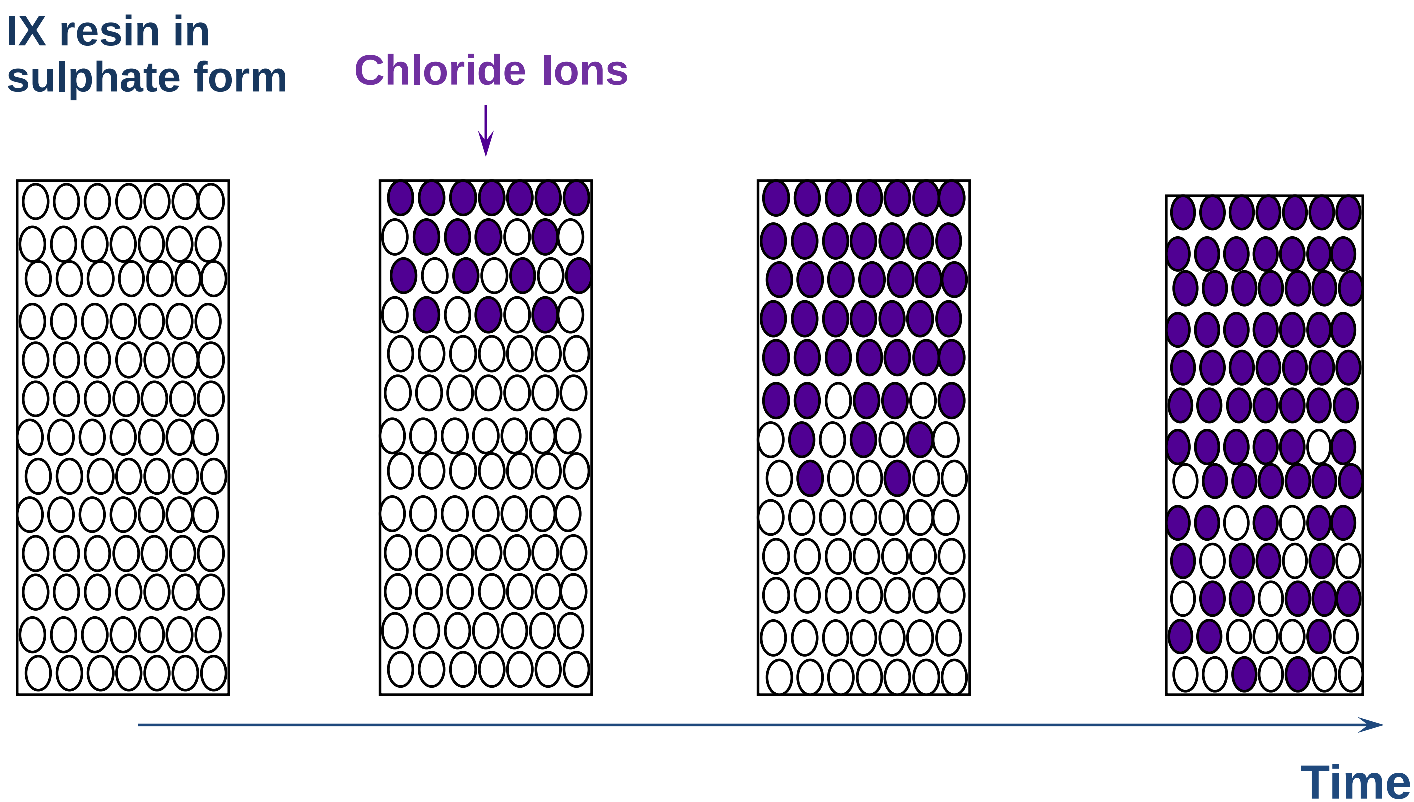
Ion exchange (IX) studies have been performed in batch and column modes both on the laboratory and the semi pilot scales



SO_4^{2-}/Cl^- exchange in an IX column with time

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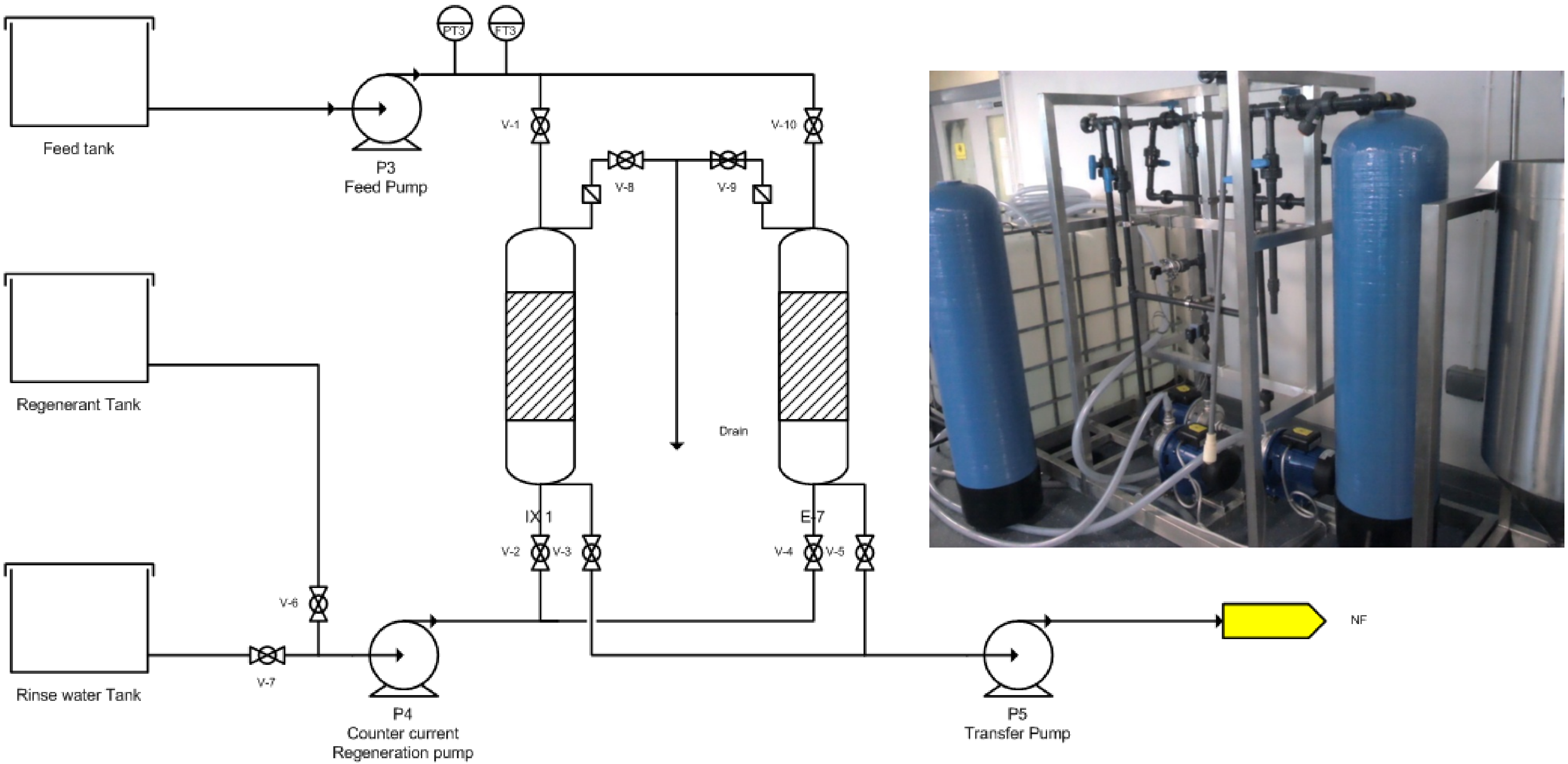
Design and photo for IX section of the developed pilot scale IX-NF plant for water desalination



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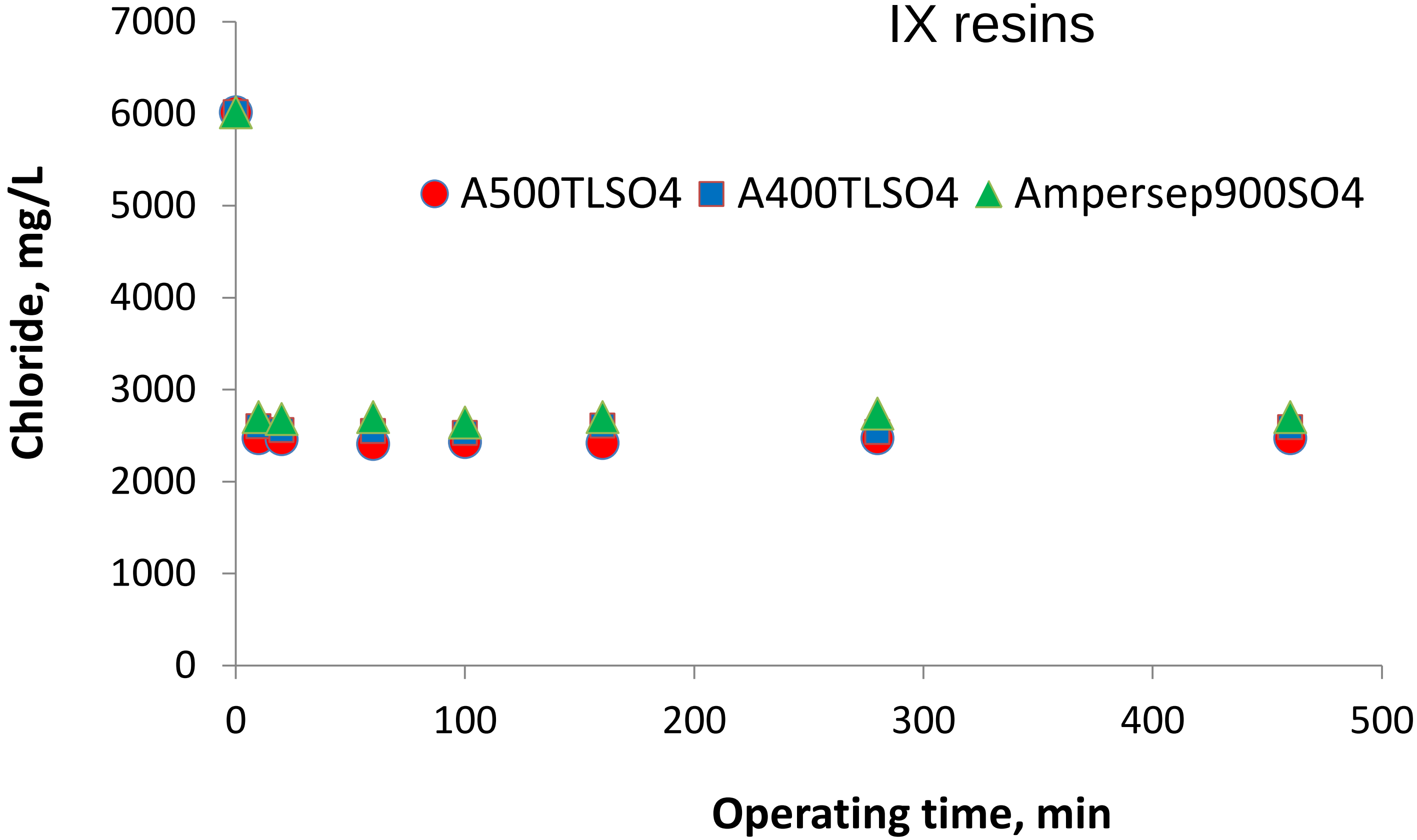
Equilibrium studies on SO_4^{2-}/Cl^- exchange with different IX resins



Concentration of Cl^- ions versus operating time during IX treatment of 10 g/L NaCl solution with Purolite A500TLSO$_4$, Purolite A400TLSO$_4$ and Ambersep 900SO$_4$ resins

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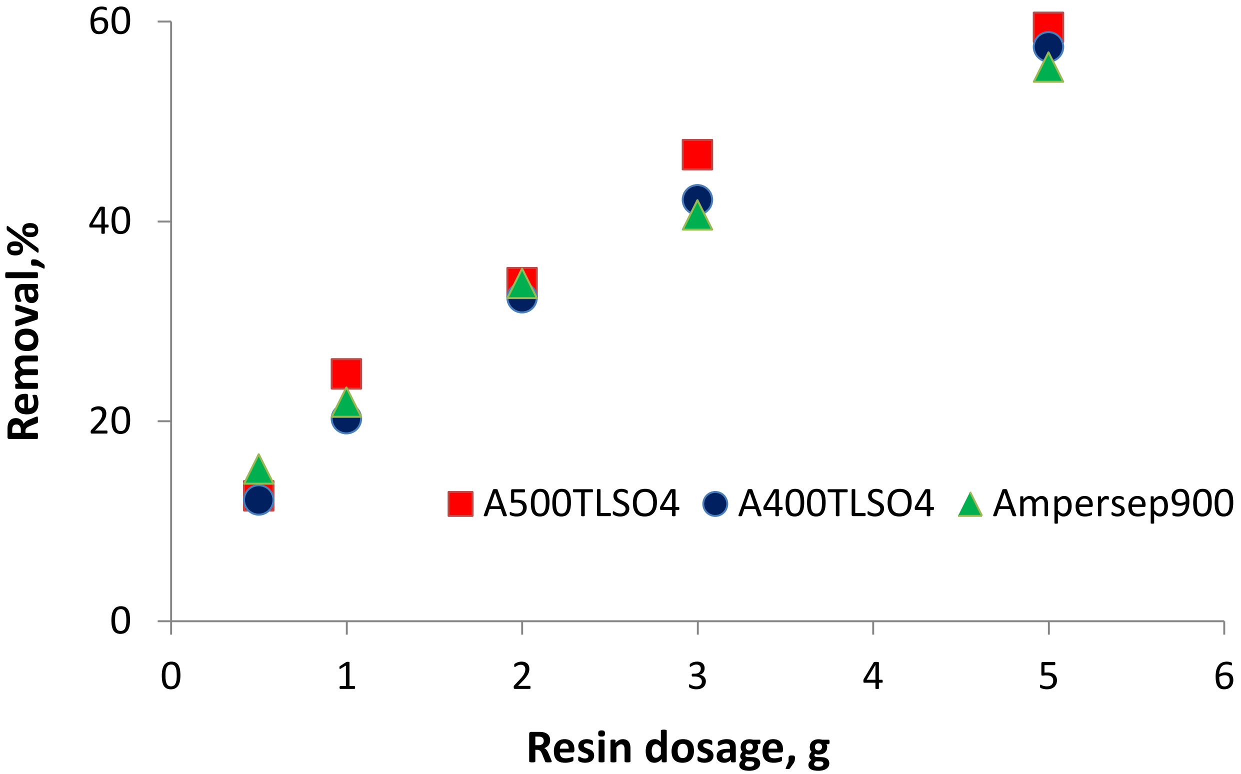
Effect of the resins dosage on IX removal of chloride ions



Removal of Cl^- in 10 g/L NaCl solution with Purolite A500TLSO_4, Purolite A400TLSO_4 and Ambersep 900SO_4 resins at various resin's dosage

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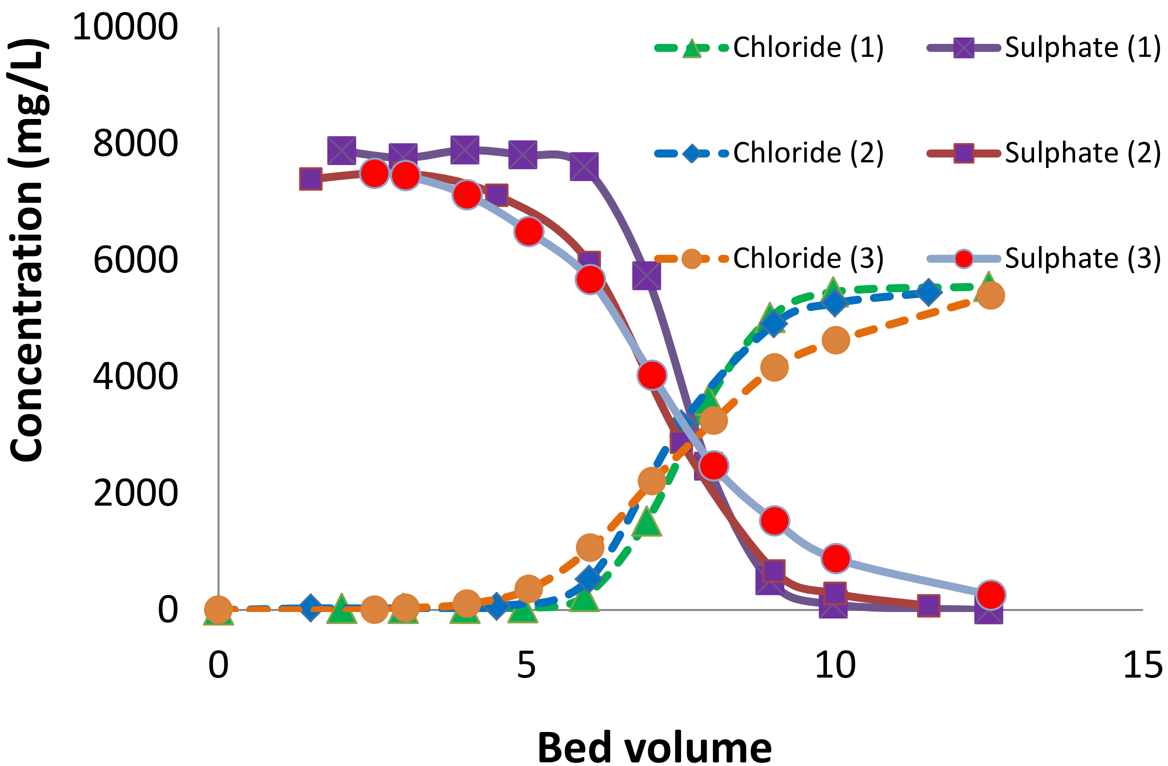
SO_4^{2-}/Cl^- exchange at various flow rates through the IX column



The breakthrough curves of chloride and sulphate ions during treatment of NaCl solution with concentration of 10000 mg/L with Purolite A500TLSO_4 resin at various flowrates: (1) 0.2 L/h, (2) 0.45 L/h and (3) 1.0 L/h

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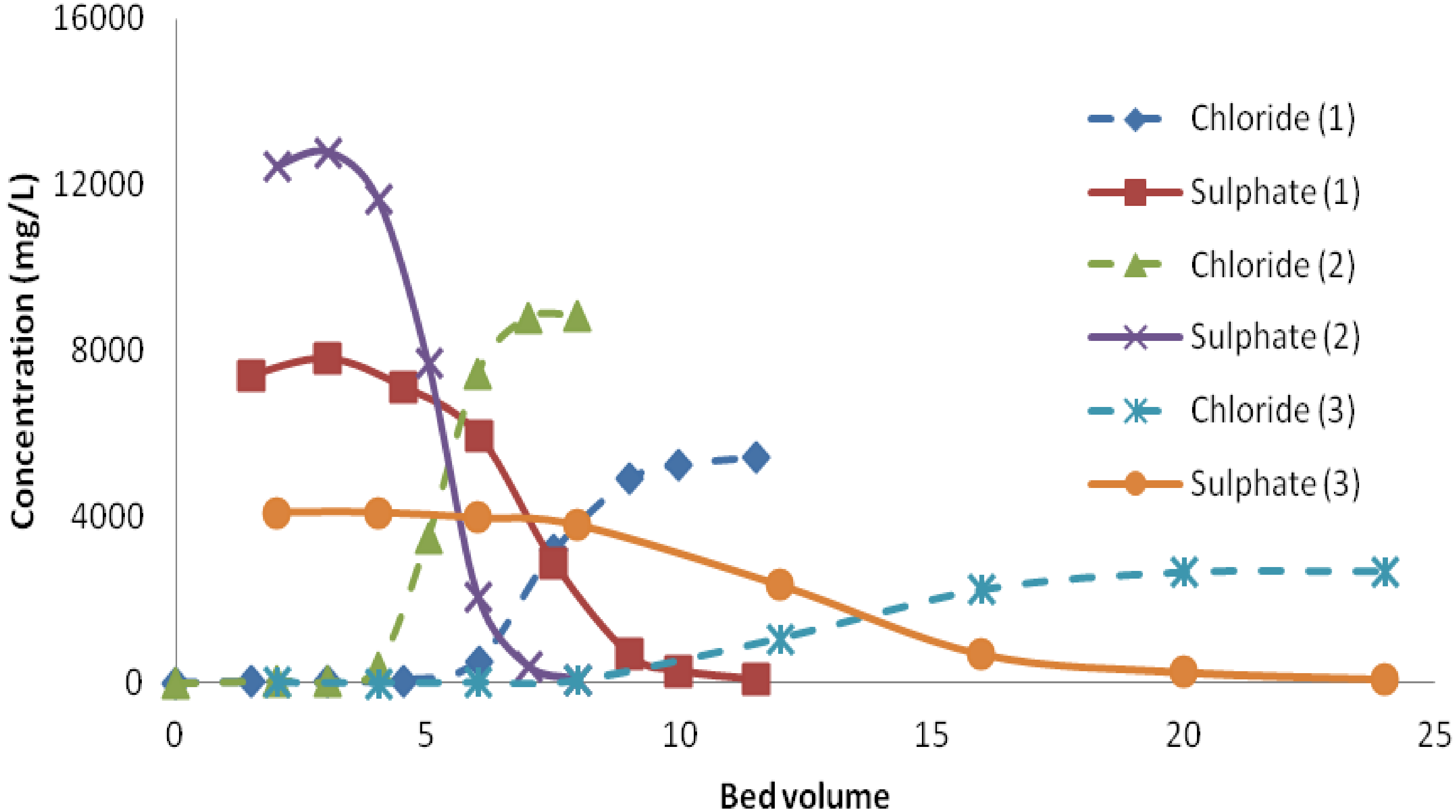
SO_4^{2-}/Cl^- exchange at various salinity of feed water



The breakthrough curves of the chloride and sulphate ions during filtration of NaCl solution through the column with Purolite A500TLSO4 resin at various feed concentrations, g/l. 10 (1), 15 (2) and 5 (3).

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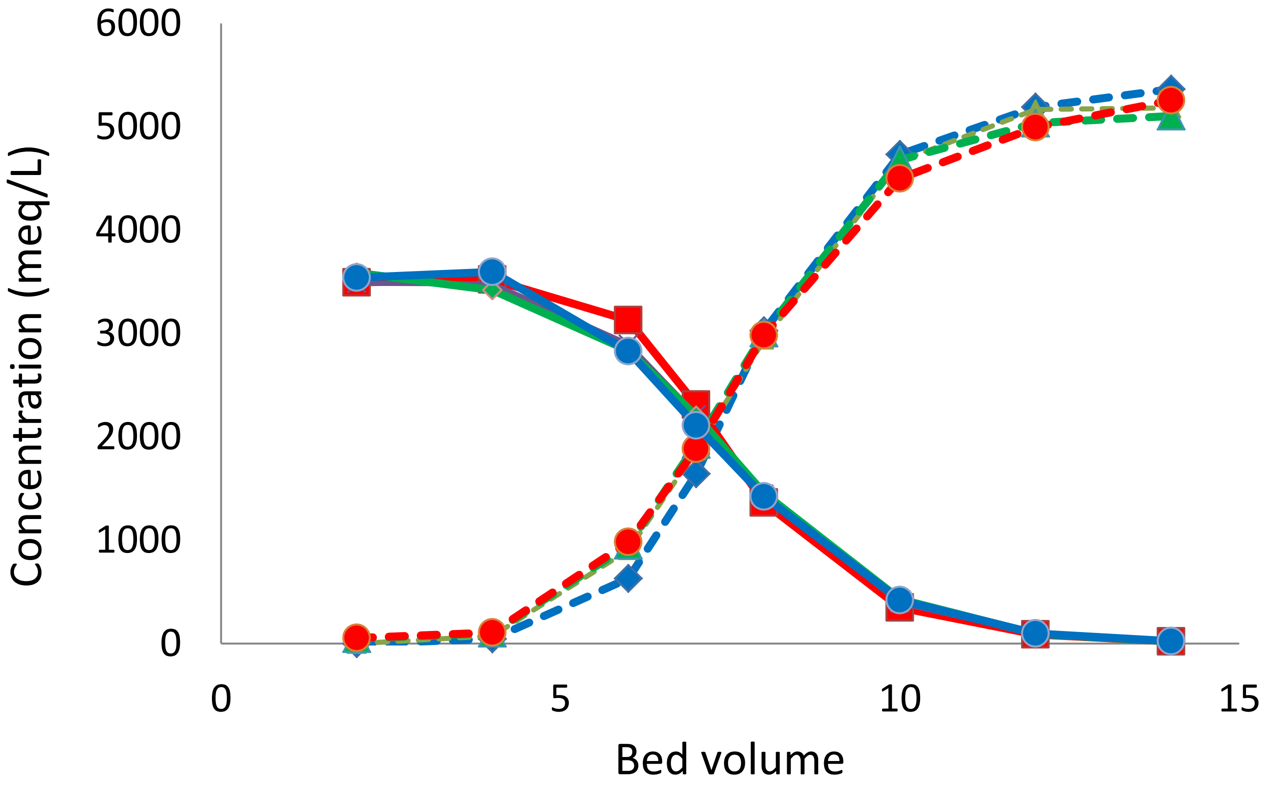
Sulphate-chloride reversibility: multiple IX cycles



Breakthrough curves of chloride and sulphate ions with regenerated Purolite $A400TLSO_4$ resin during treatment of 10 g/L NaCl solutionf (four exhaustion runs). 0.2 M Na_2SO_4 solution has been used for regeneration.

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Centre Director: Professor Nidal Hilal

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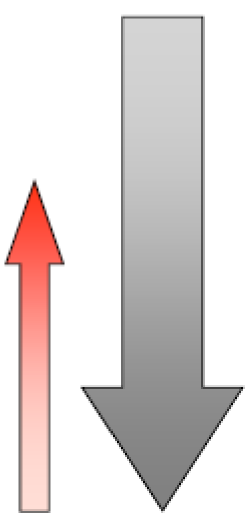
$$(RN^+)_2SO_4^{2-} + 2Na^+ + 2Cl^- \Leftrightarrow 2(RN^+)Cl^- + SO_4^{2-} + 2Na^+$$

Driving Pressure



Osmotic Pressure

Osmotic pressure

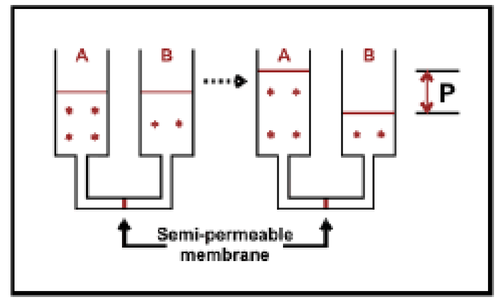


Figure from: http://www.bbc.co.uk/dna/h2g2/A686766

$$\boxed{\Pi = n \cdot C \cdot R \cdot T}$$

Osmolarity

Π: osmotic pressure in kPa

n: number of OAP per mole

C: molar concentration in mol/l

R: universal gas constant ($8.31441\ N.m.mol^{-1}.K^{-1}$)

T: temperature in K

Conversion of chloride to sulphate ions reduces the osmotic pressure of feed water as a result a lower operating pressure for water desalination with membranes can be used

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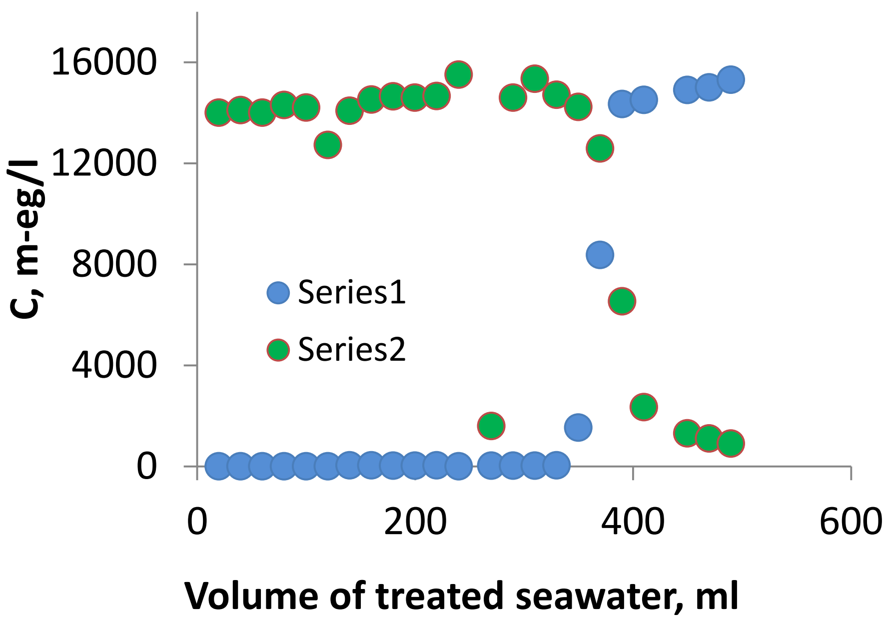
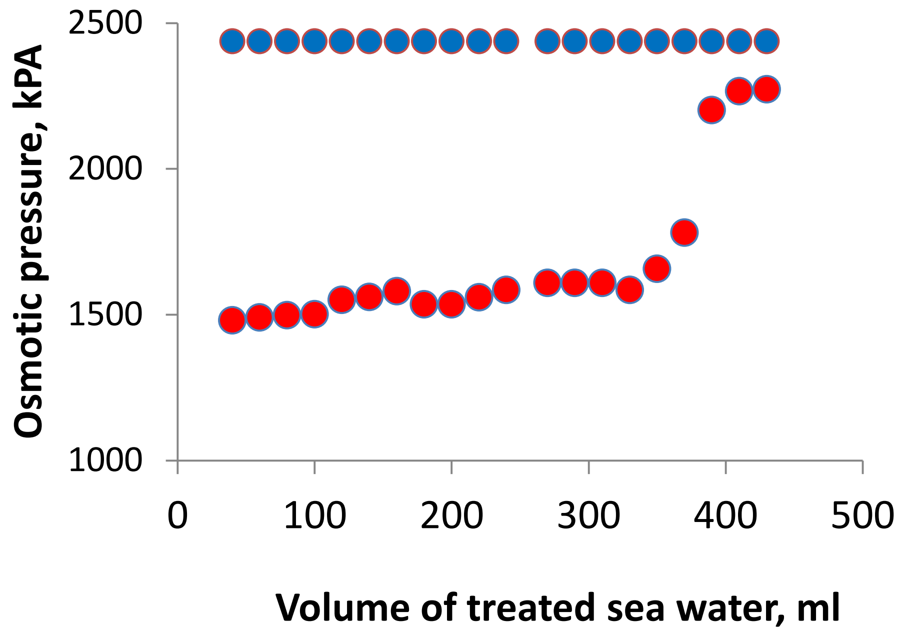
Sea water treatment with Purolite AT500SO4 resin



Content of chloride (1) and sulphate (2) ions in IX-treated sea water



Osmotic pressure of sea water before and after IX treatment

Due to decrease in osmotic pressure of salty water after SO_4^{2-}/Cl^- exchange, NF membranes can be used for water desalination

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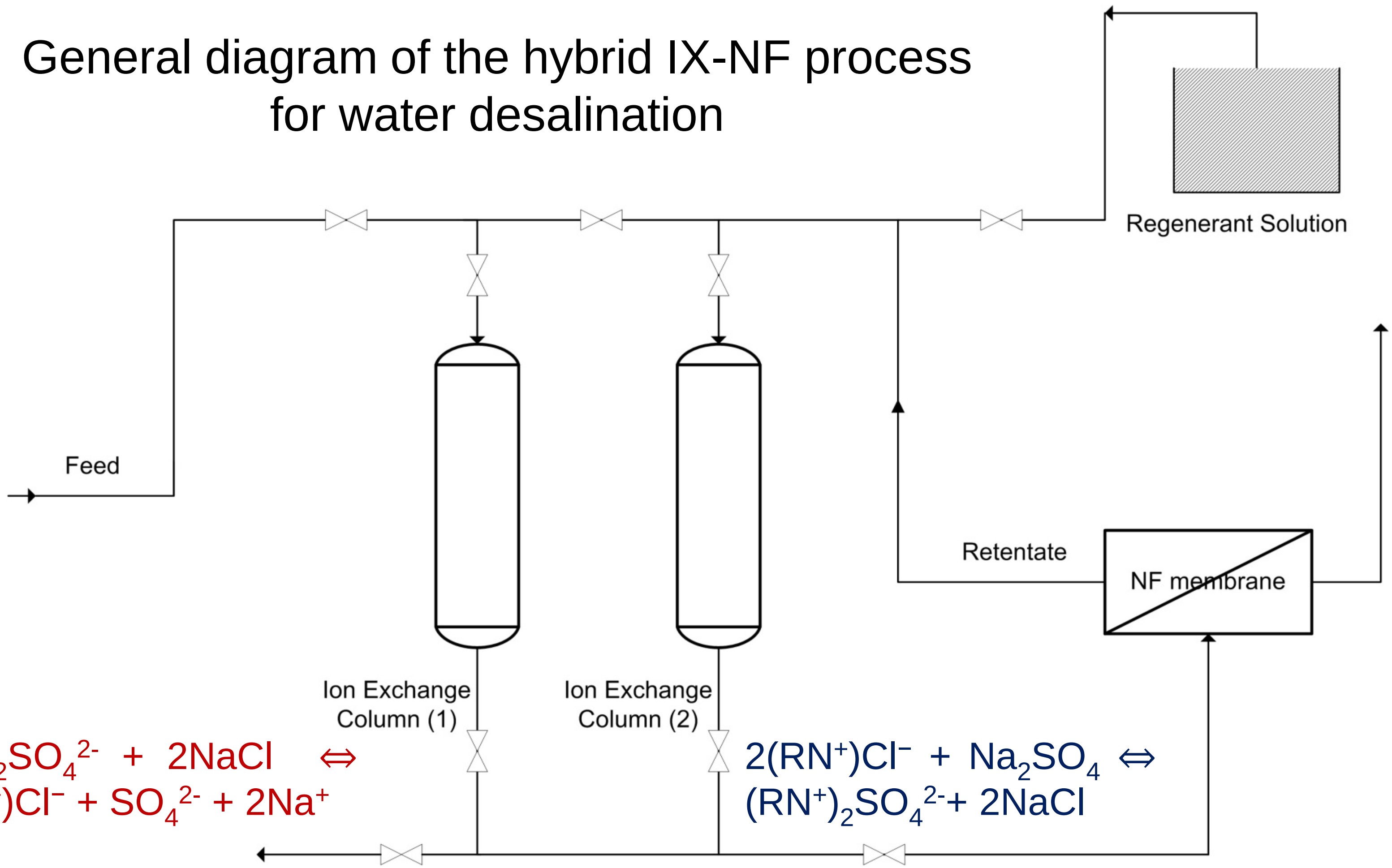
General diagram of the hybrid IX-NF process for water desalination



$(RN^+)_2SO_4^{2-} + 2NaCl \Leftrightarrow 2(RN^+)Cl^- + SO_4^{2-} + 2Na^+$

$2(RN^+)Cl^- + Na_2SO_4 \Leftrightarrow (RN^+)_2SO_4^{2-} + 2NaCl$

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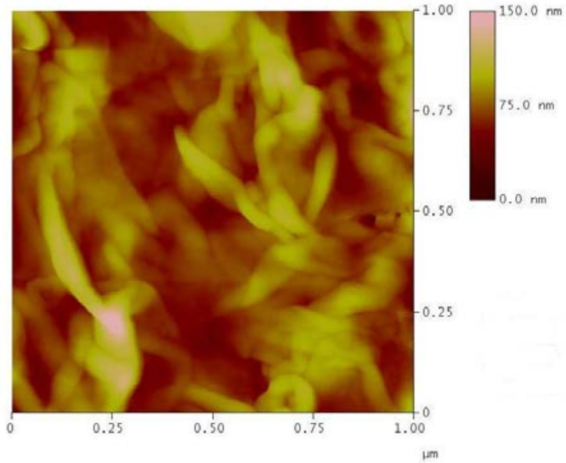
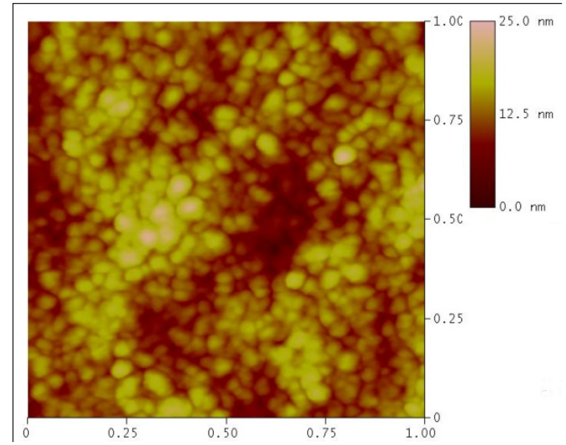
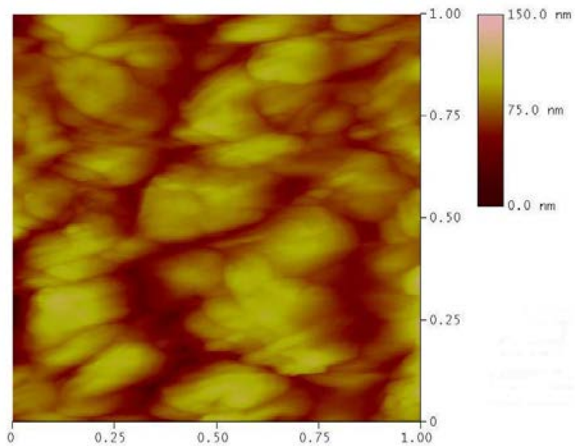
Selection of NF membranes for hybrid process of water desalination



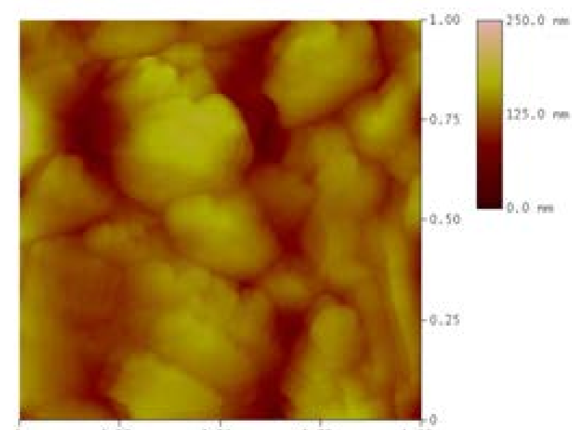
NF-90 (Dow FilmTec)



NF-270 (Dow FilmTec)



BW-30 (Dow FilmTec)



SW-30 (Dow FilmTec)

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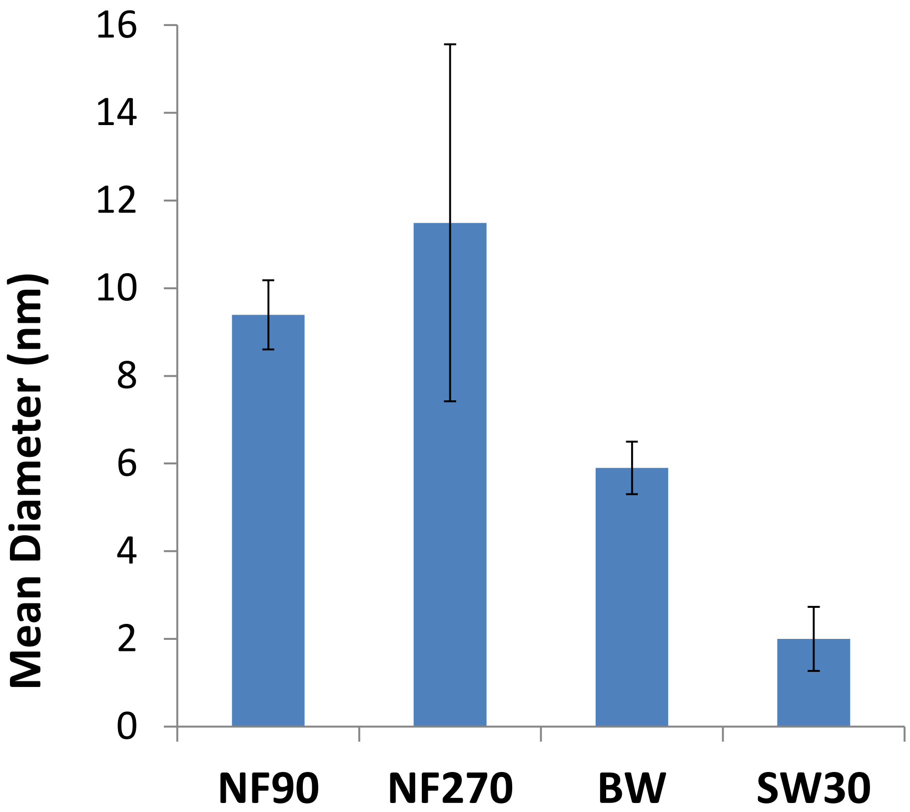
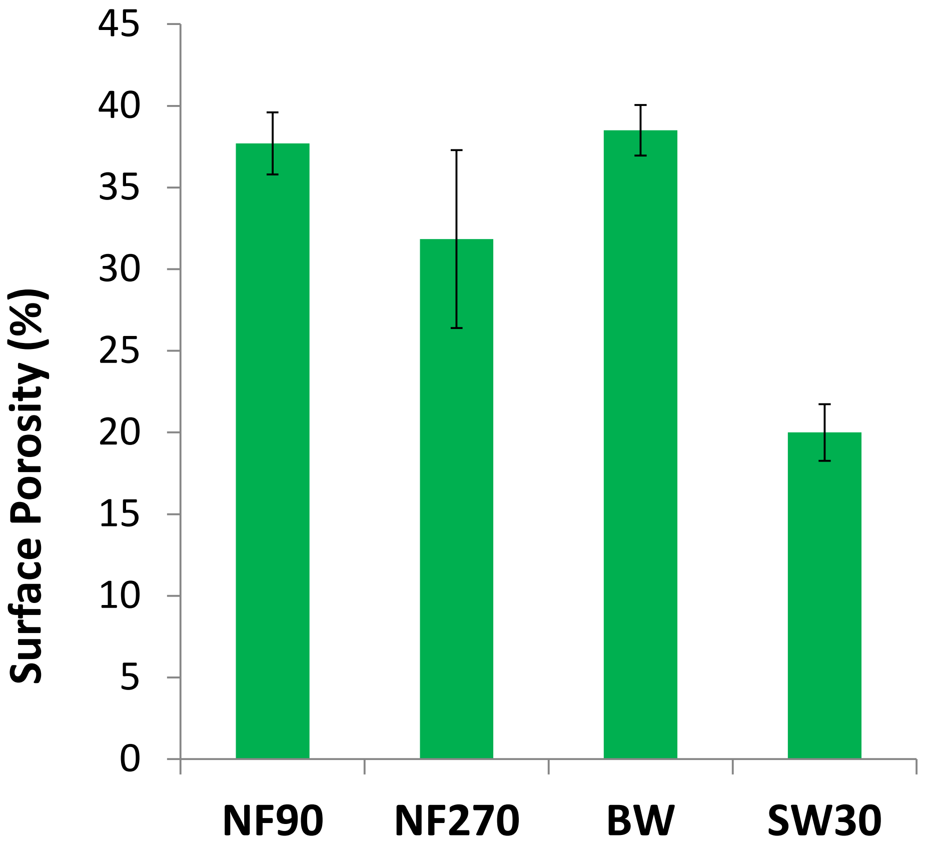
AFM measured pore diameter and surface porosity of different NF membranes





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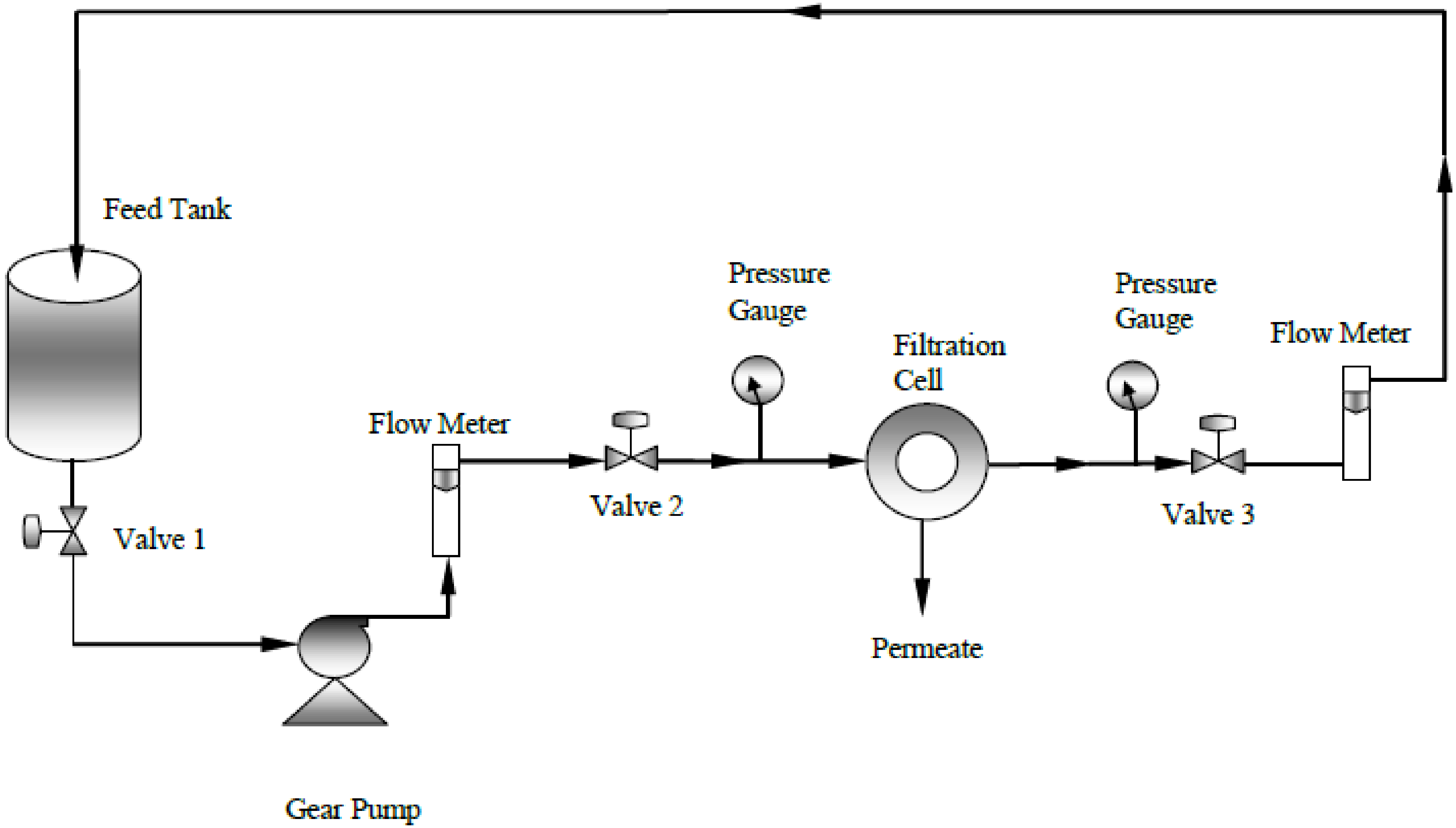
Experimental cross-flow unit for membrane testing



Rejection: $R = (1 - C_p/C_f) \times 100\%$

Flux: $J = \dfrac{V}{At}$

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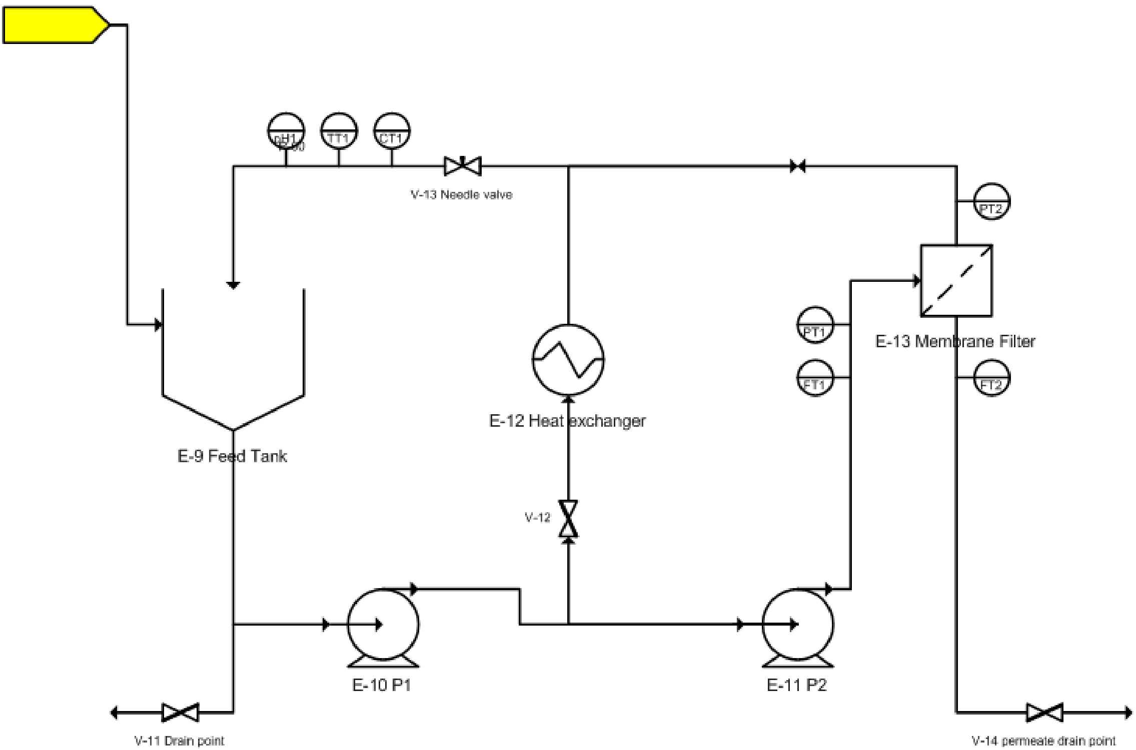
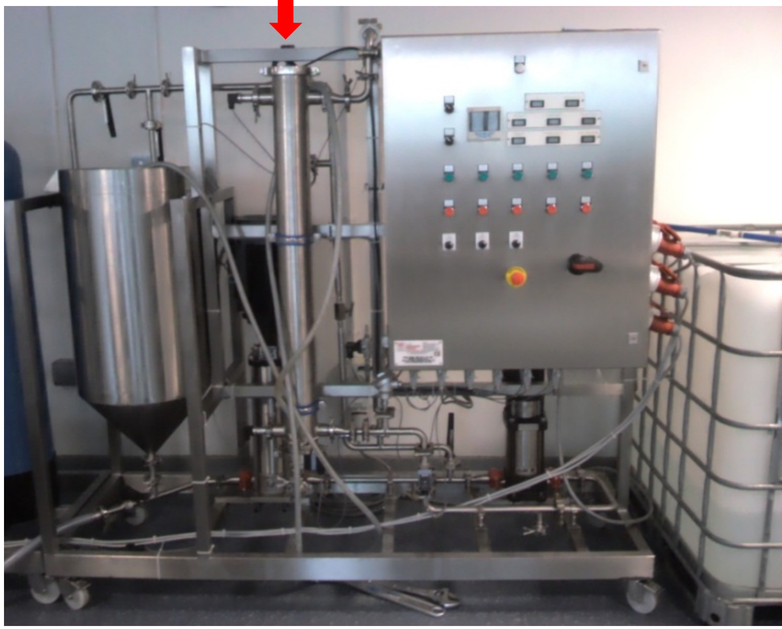
P&ID and photo for NF section of the developed pilot scale IX-NF plant for water desalination

4040 NF membrane element





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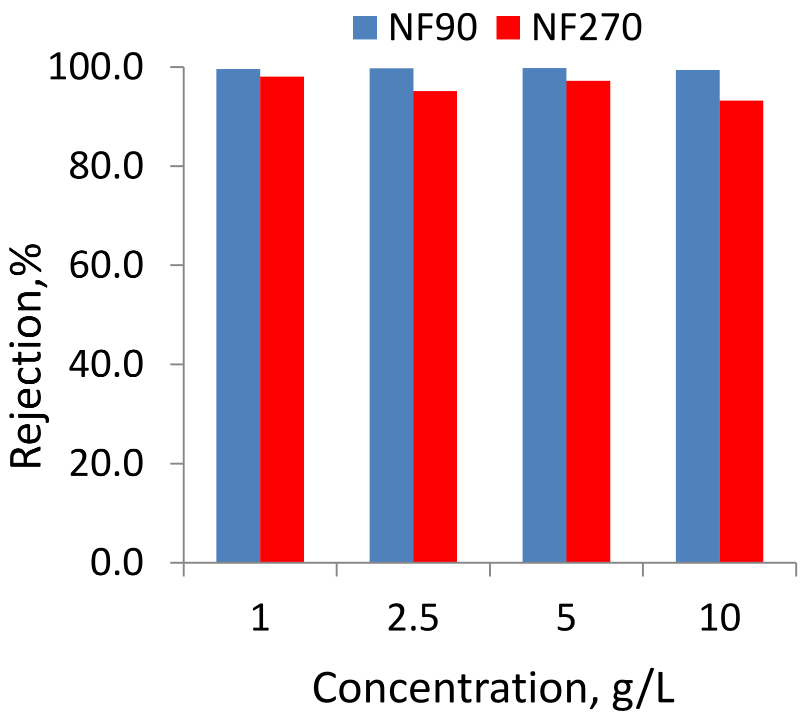
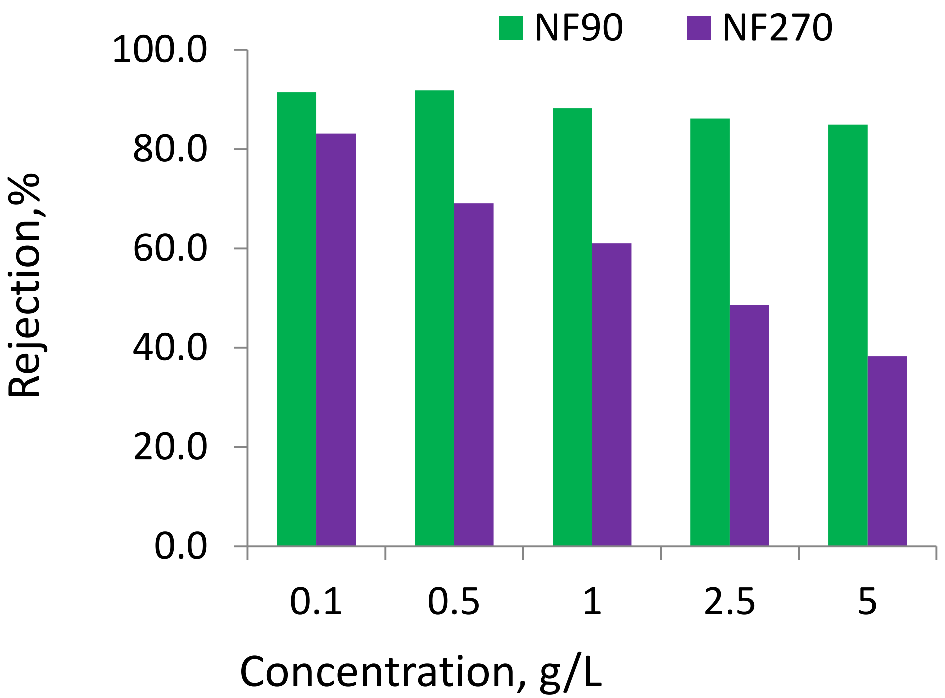
Flux and rejection of chloride and sulphate ions with NF90 and NF270 membranes during filtration of single NaCl and Na_2SO_4 solutions



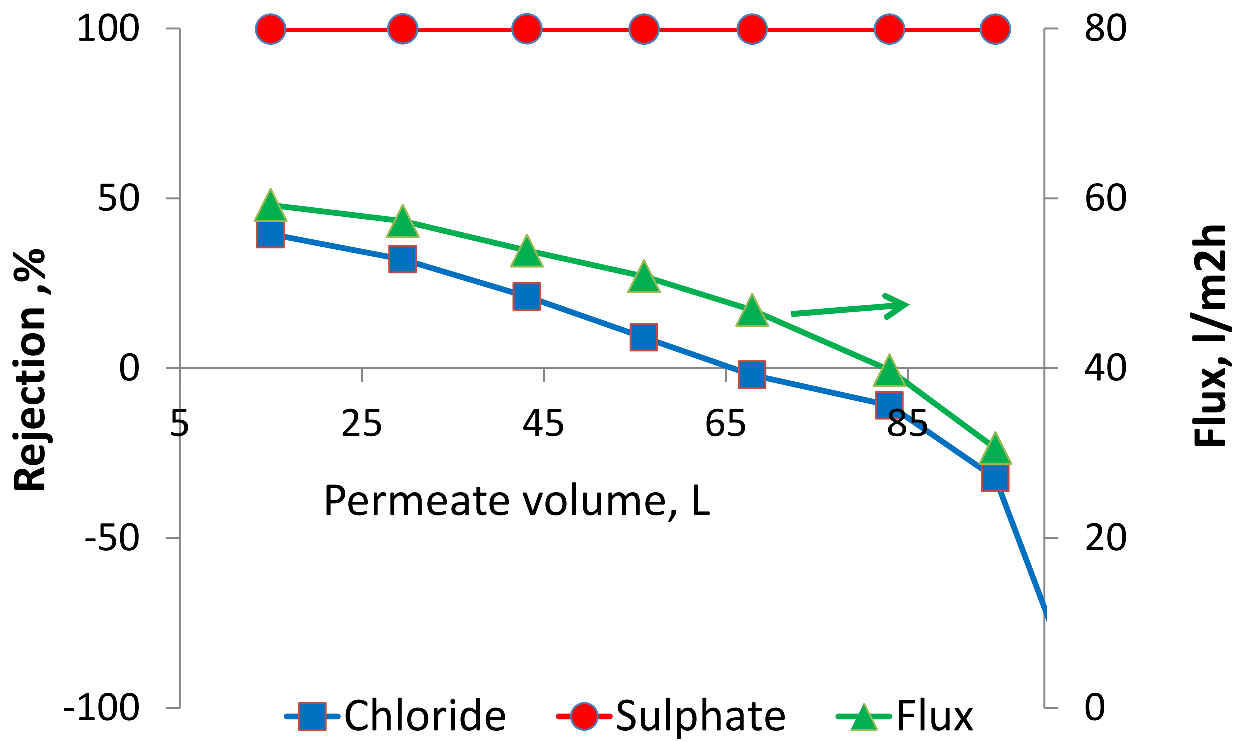
Sulphate rejection with NF90 and NF270 membranes at different Na_2SO_4 concentration



Chloride rejection with NF90 and NF270 membranes at different NaCl concentrations

Hybrid Ion Exchange - Nanofiltration Process to Desalinate Sea Water and Brackish Water

Flux and ions rejection with NF270-4040 membrane element at filtration of 5 g/L mixture (95:5%) of Na_2SO_4 and NaCl salts at operating pressure of 12 bars



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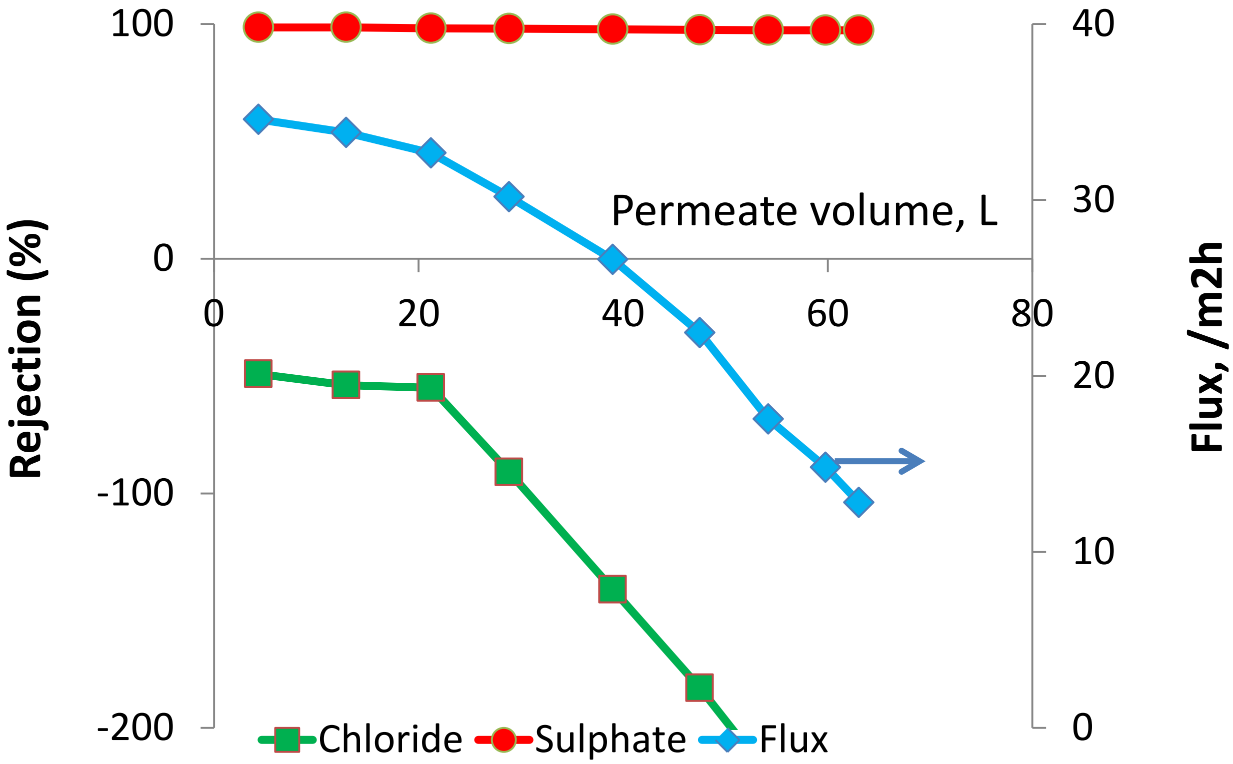
Flux and ions rejection with NF270-4040 membrane element during filtration* of seawater after IX treatment with Purolite AT500SO4 resin



*Operating pressure is 12 bars

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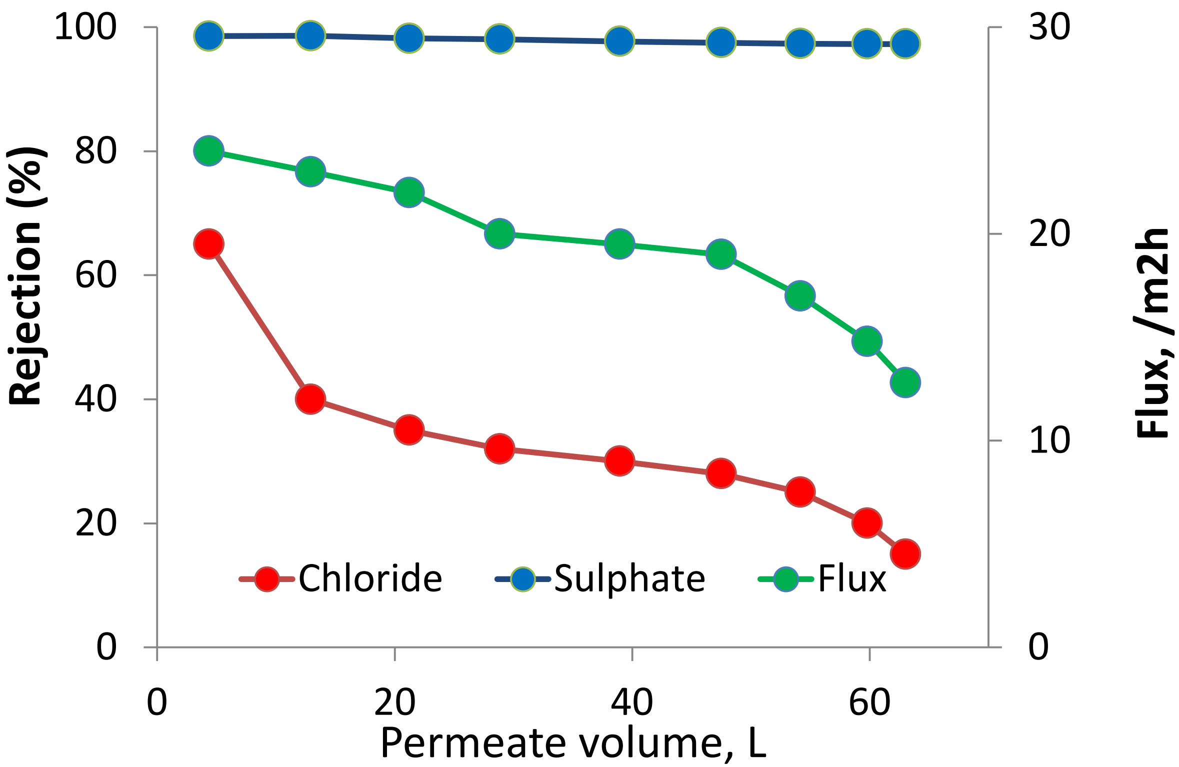
Flux and ions rejection with NF90-4040 membrane element during filtration* of seawater after IX treatment with Purolite AT500SO4 resin



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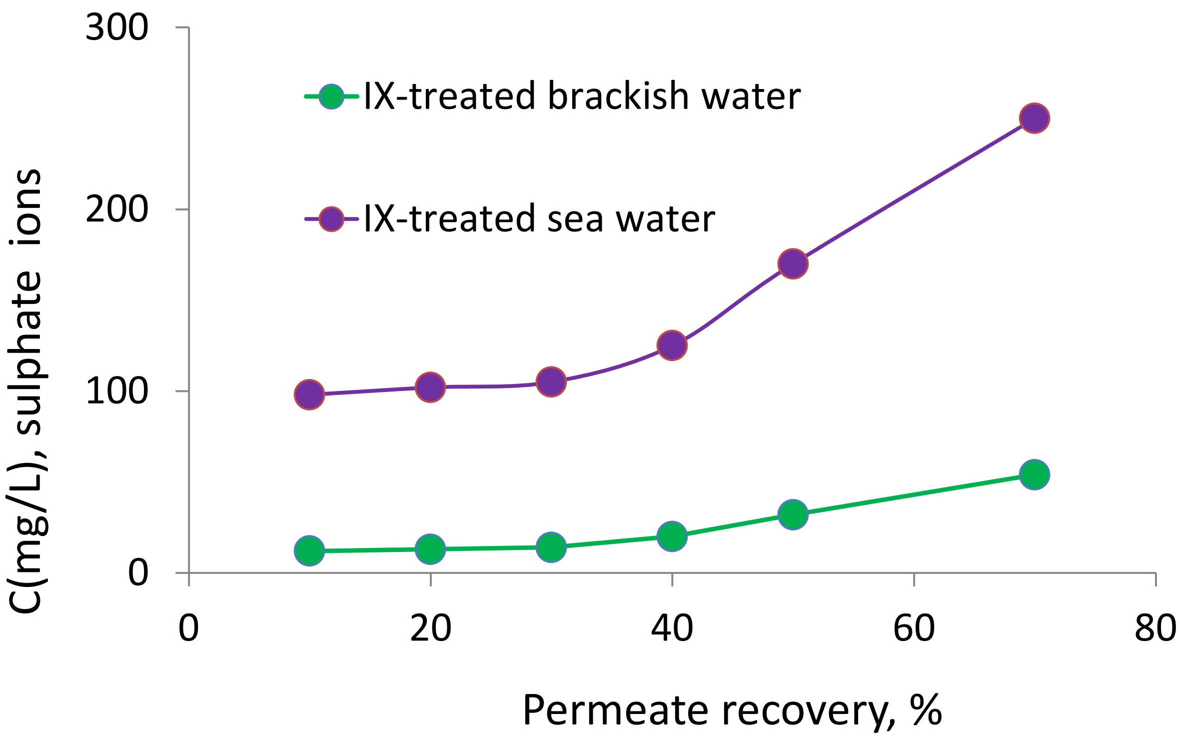
Concentrations of sulphate ions in permeate during filtration of IX-treated* brackish water** and IX-treated sea water *** through NF90-4040 membrane element at 12 bars



*Purolite AT 500 SO4 resin; flowrate through the column is 2 L/min
** Initial brackish water concentration: 6690 mg/L Cl^- and 173 mg/L SO_4^{2-}
*** Initial sea water concentration: 17464 mg/L Cl^- and 2433 mg/L SO_4^{2-}

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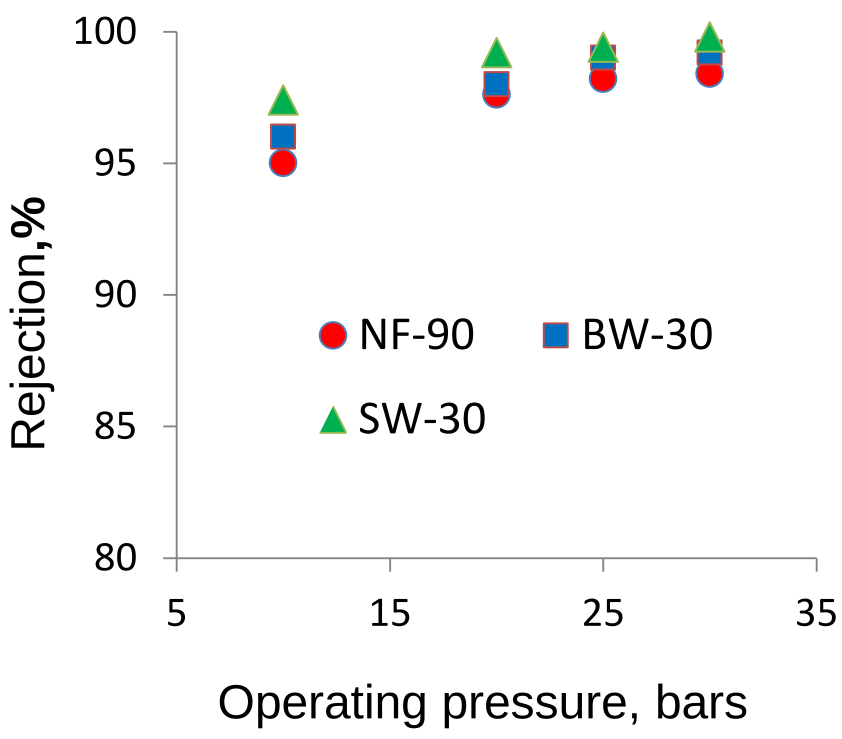
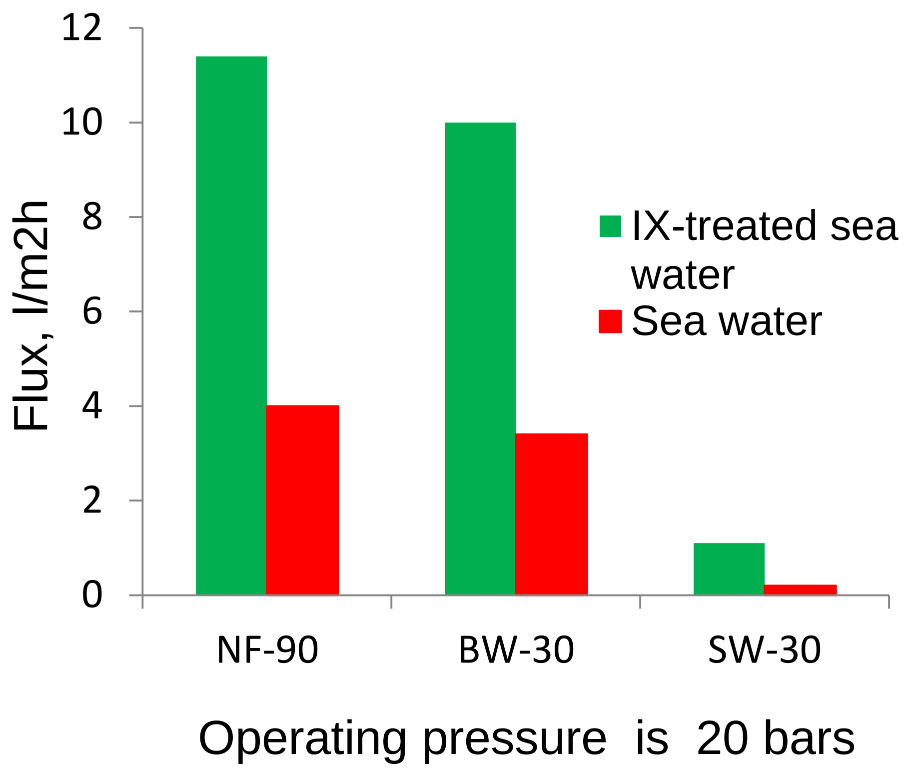
Rejection of sulphate ions and membrane fluxes during filtration of IX-treated sea water through NF/RO membranes





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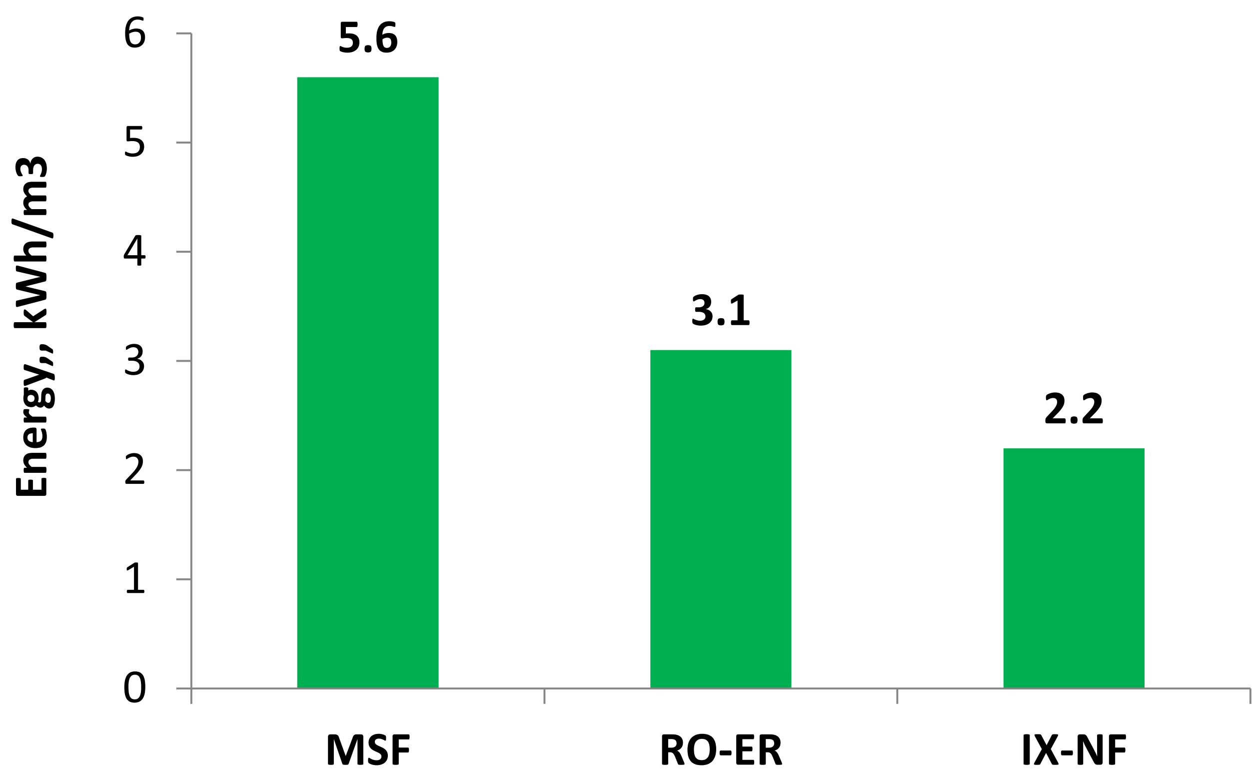
Comparison of energy consumption for different processes for water desalination



Data for MSF and RO-ER (reverse osmosis with energy recovery) processes are from *Sarkar and SenGupta, J. Membr. Sci., 324 (2008)*

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Photo of the developed pilot IX-NF plant for water desalination

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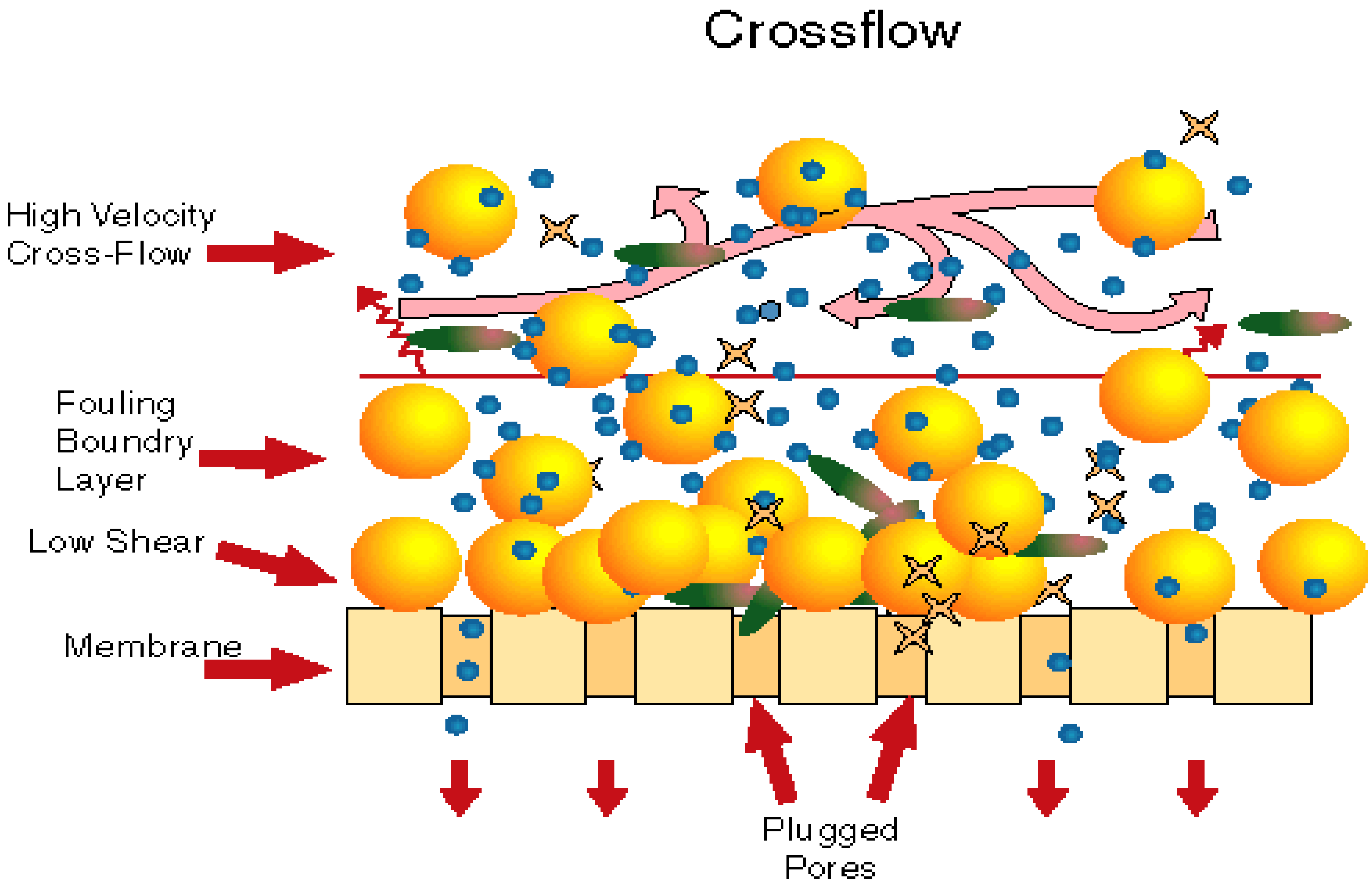
Development of composite low fouling membranes



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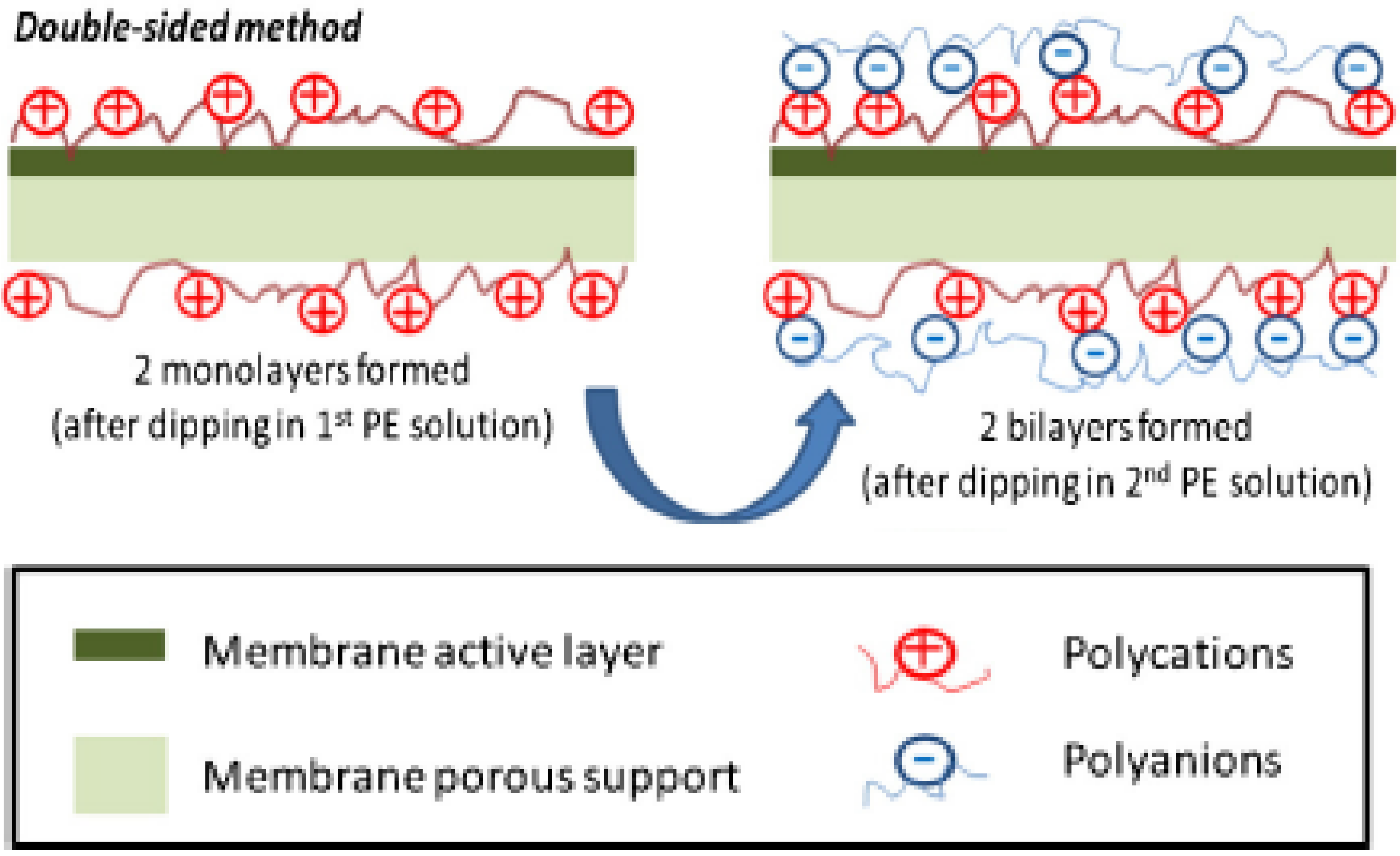
Development of composite low fouling membranes

Layer-by-layer (LbL) deposition of polyelectrolytes multilayers on the membrane surface



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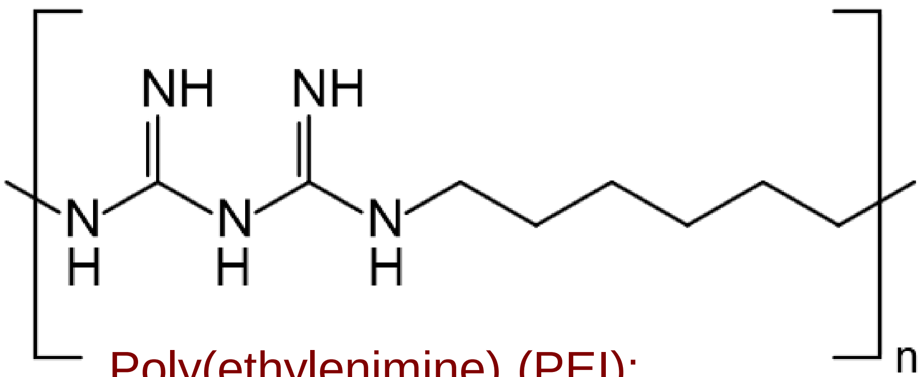
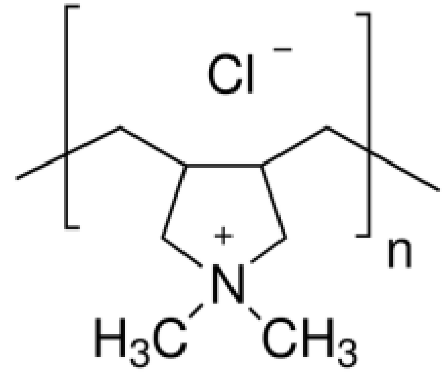
Development of composite low fouling membranes

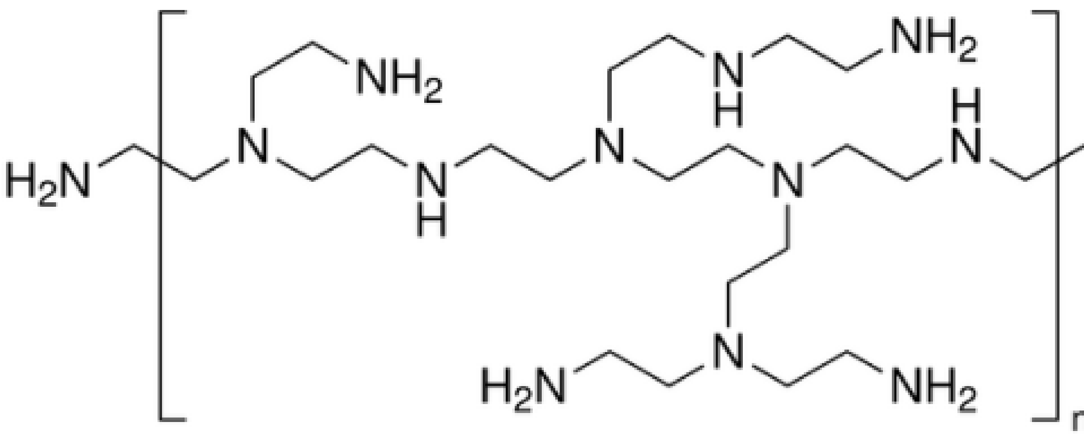
Cationic polyelectrolytes used for membrane modification



Poly(ethylenimine) (PEI);
MW 60 kDa



Poly(diallyldimethyl-ammonium chloride) (PDMAC);
MW <100 kDa



Poly(hexamethylene biguanide (PHMB)

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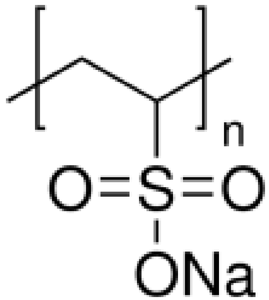
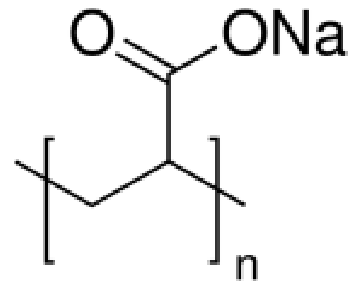
Development of composite low fouling membranes

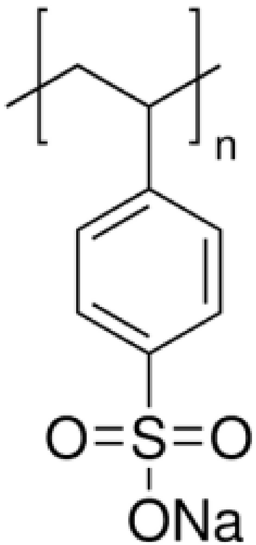
Anionic polyelectrolytes used for membrane modification



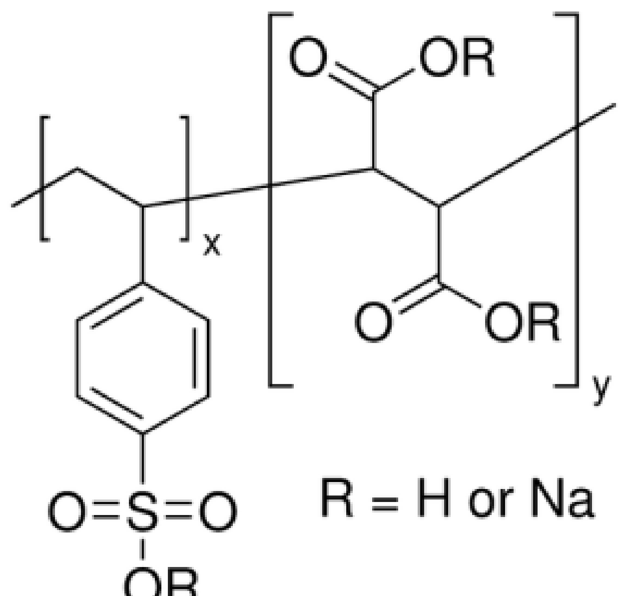
Poly(vinylsulfonic acid) (PVS); MW 4-6 kDa



Poly(acrylic acid) (PAA); MW 1.2 kDa

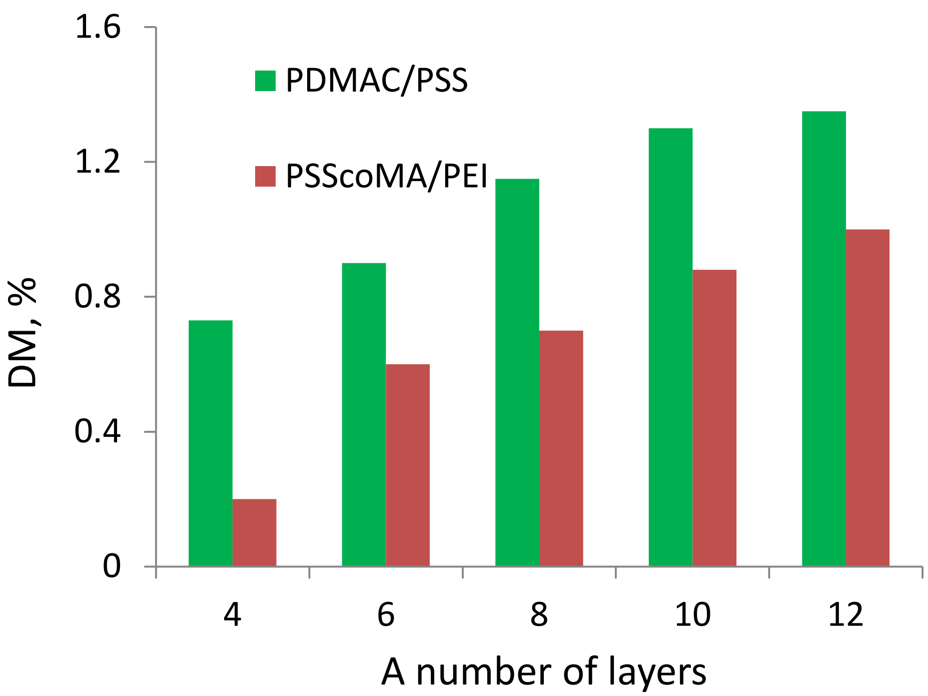


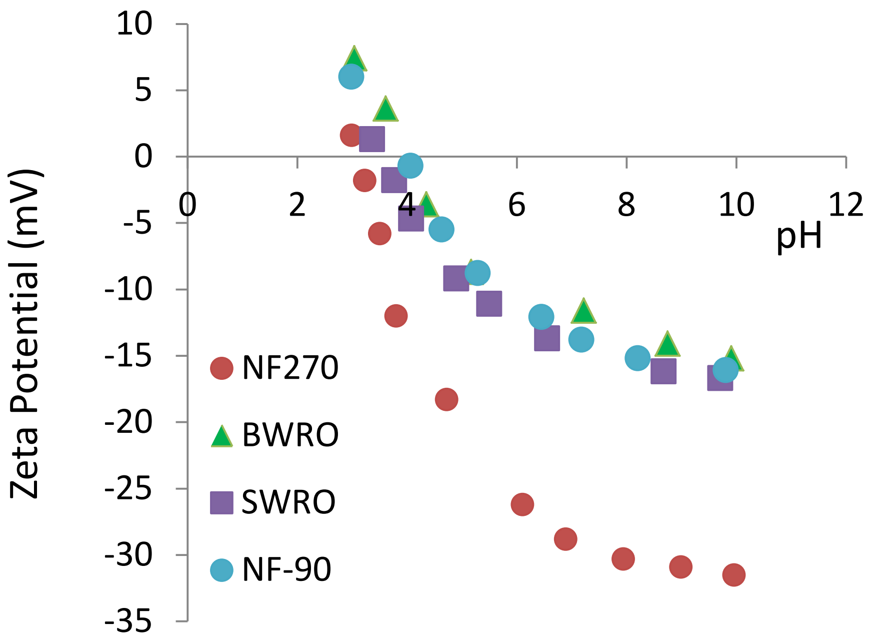
Poly(sodium 4-styrene sulfonate) (PSS) ; MW 70 kDa



Poly(4-styrene sulfonic acid-co-maleic acid) (PSScoMA); MW 20 kDa

Development of composite low fouling membranes





Modification of NF-90 membrane via LbL assembly using PDMAC/PSS and PSScoMA/PEI polyelectrolyte pairs:
DM versus the layer number

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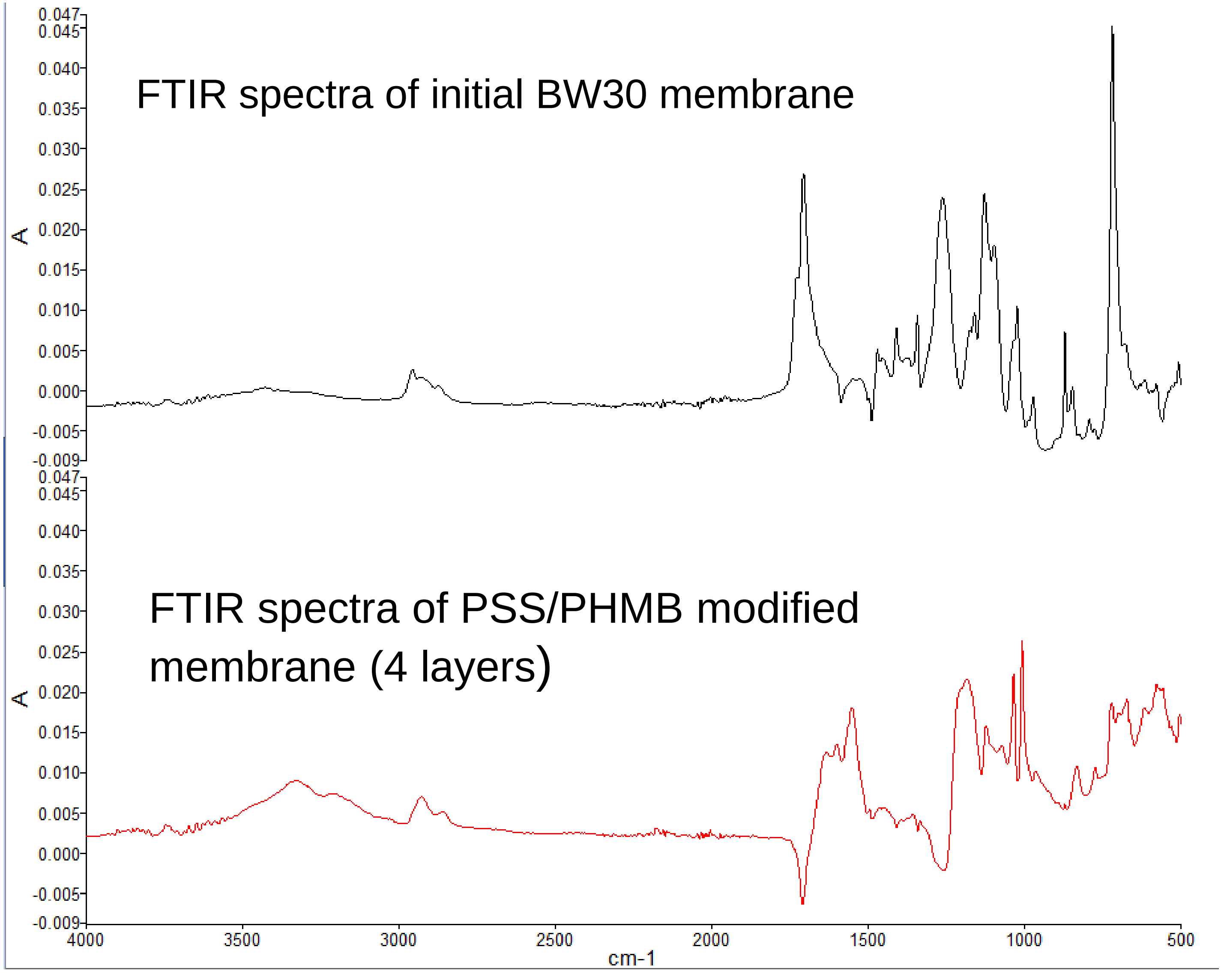

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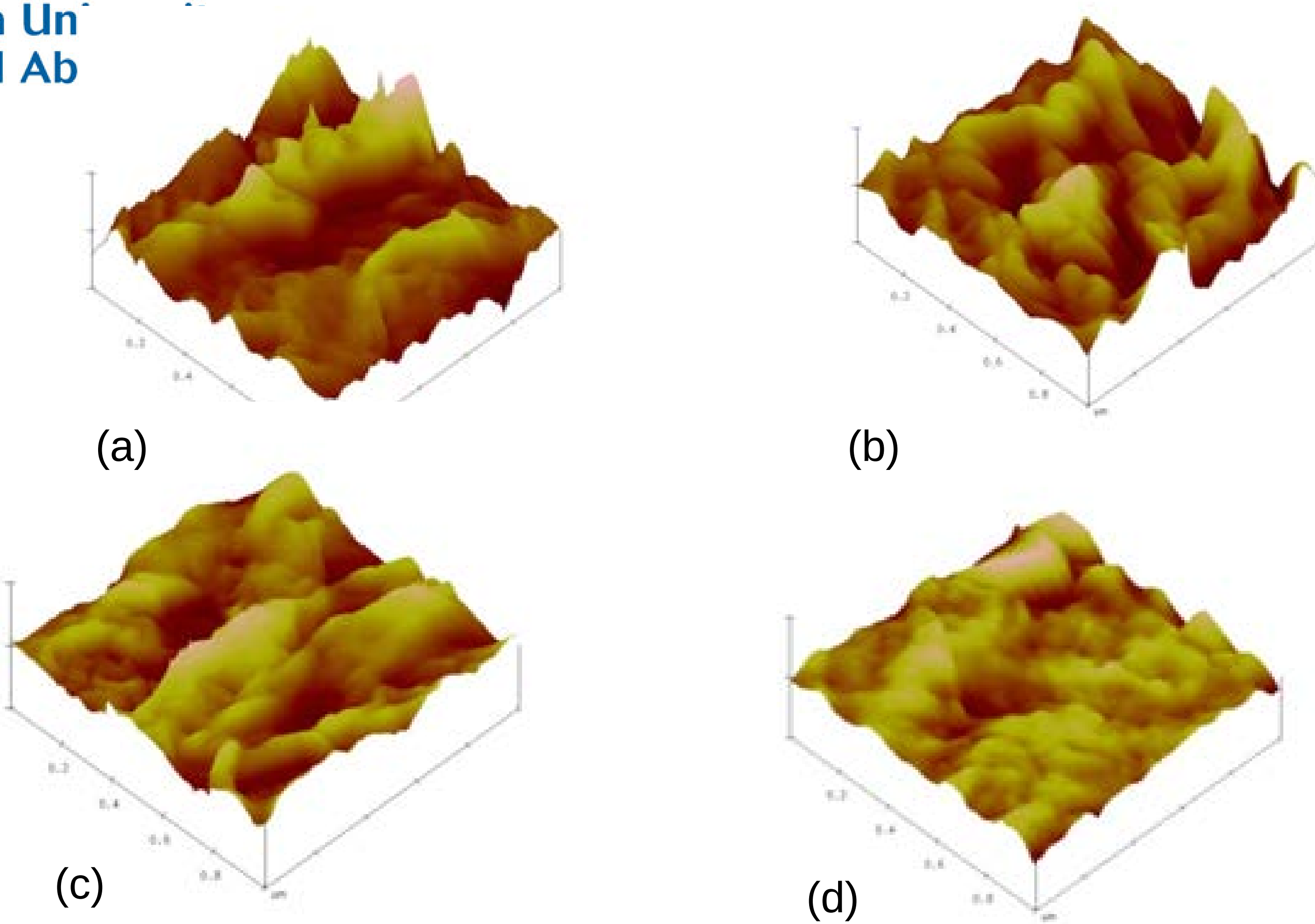

(a) (b) (c) (d)

AFM images of initial NF90 membrane (a) and LbL modified samples with a different number of PSScoMA/PEI layers: (b) - 4 layers; (c) – 8 layers; (d) – 12 layers.

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Mean roughness (R_a) of the surface of polyelectrolyte multilayered NF-90 membranes

Membrane	R_a, (nm)
Neat NF-90 membrane	28.623
4 layered membrane	24.141
8 layered membrane	17.558
12 layered membrane	10.794

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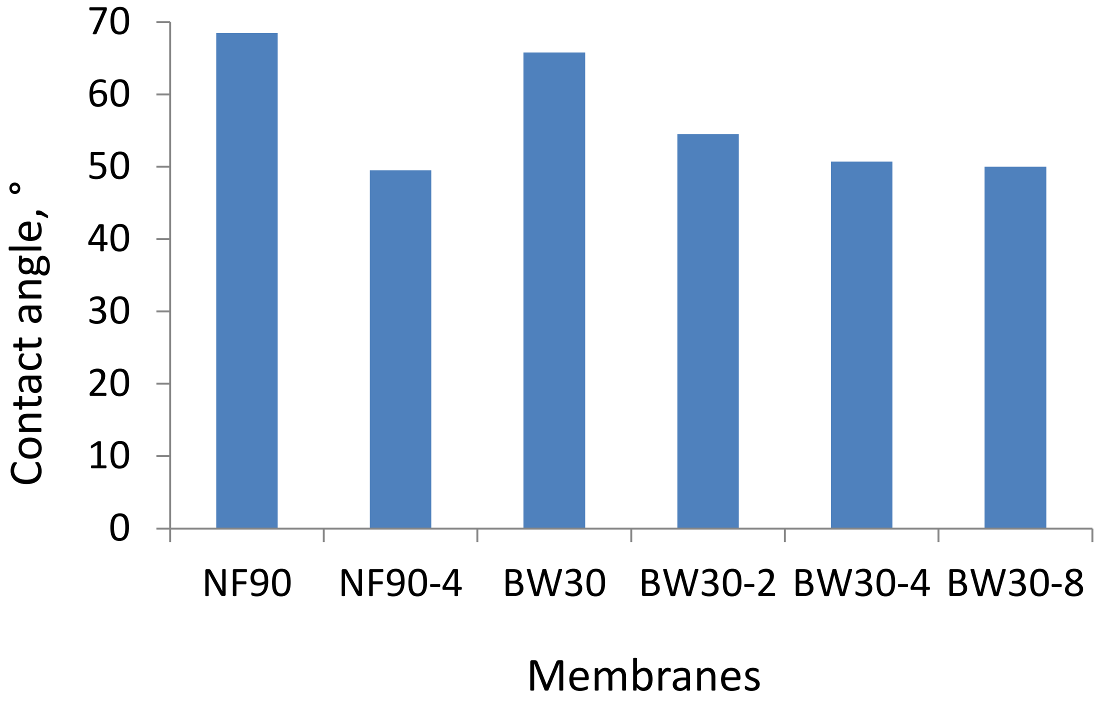
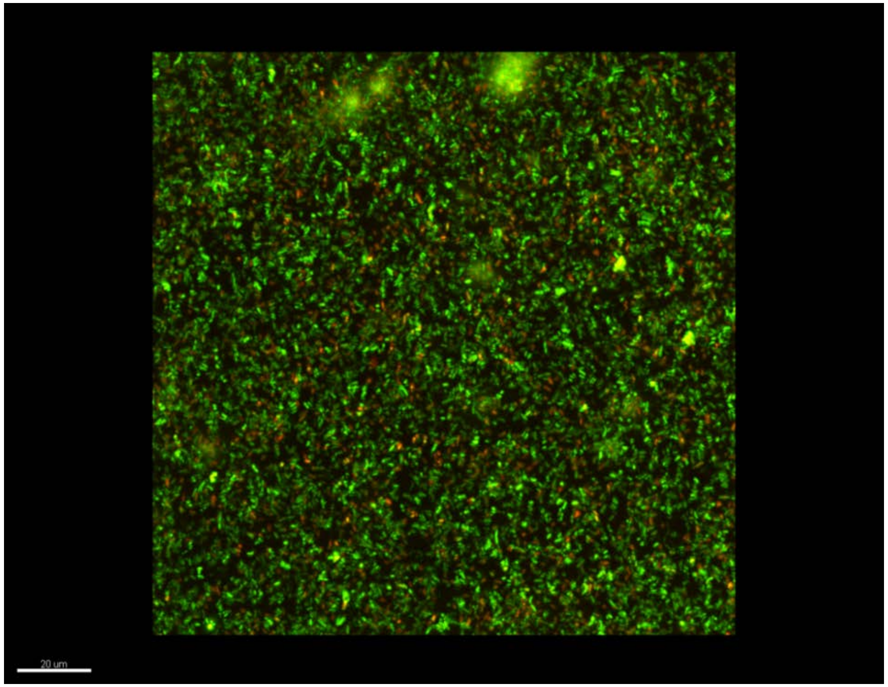


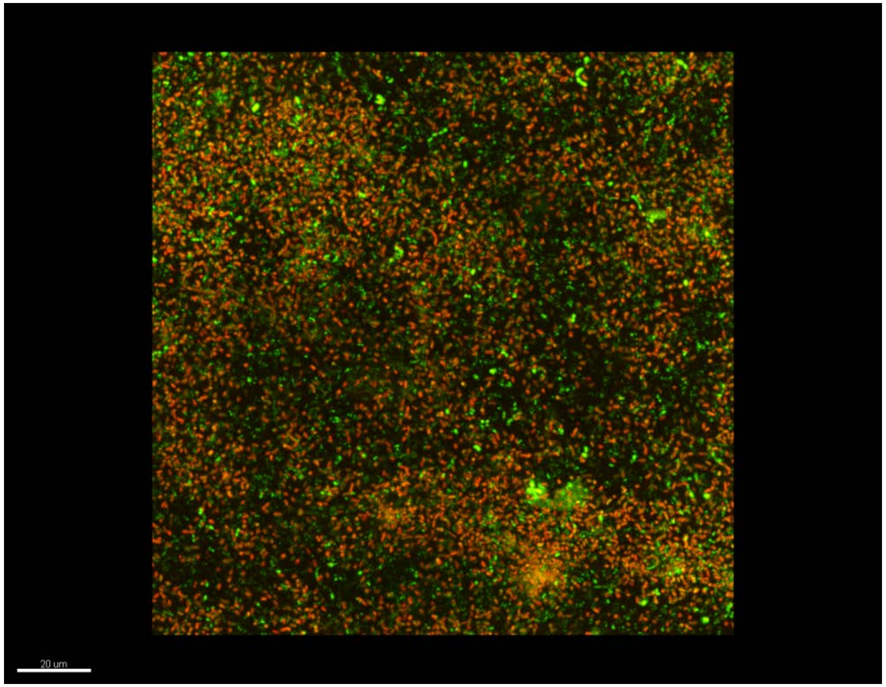
Water contact angles on the surface of NF90 and BW30 membranes and PSS/PEI modified samples with a different number of polymer layers:
2 (BW30-2); 4 (NF90-4 and BW30-4) and 8 (BW30-8)

Development of composite low fouling membranes

Confocal images of the membrane surface after *Pseudomonas aeruginosa* PAO1 growth: initial NF-90 membrane (a) and composite membranes modified via LbL approach with PHMB (b)



(a)



(b)

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Thank you for
your attention!