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Engineering advance

Advances in forward osmosis membranes: Altering the sub-layer structure via recent fabrication and chemical modification approaches

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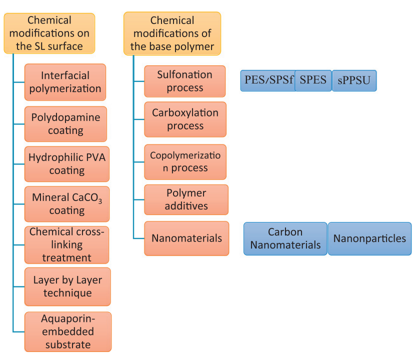
GRAPHICAL ABSTRACT



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ABSTRACT

The forward osmosis process has obtained renewed interest nowadays and it might become an alternative solution for many industrial applications to meet the current and future requirements for potable water. The FO process depends on the osmotic pressure gradient between a high salinity draw solute and low salinity feed solution across a semi-permeable membrane to extract pure water. Despite the potential advantages of FO, there are some technical drawbacks that hinder FO application for water desalination. One of the most significant critical challenges is the need for membrane compatible with the FO process. To improve FO desalination feasibility, membrane development is required to obtain maximum water permeability and minimum reverse solute flux over long-term operations. Therefore, this review starts by demonstrating the fundamentals and membrane development over the years. Fabrication modifications for the support layer of FO membranes and the crucial challenges of the FO process are summarized. Recent trends of the chemical modifications of the bulk and substrate are discussed. The advantages and disadvantages of the modifications on the FO membrane productivity are also addressed. Finally, concluding with future perspectives.

1. Introduction

The growth of the global population and the rise in water consumption has increased the already great pressure on water and energy systems [1]. Two alternatives for increasing water supplies involve desalination of sea or brackish water or the reclamation of wastewater [2]. A promising emerging membrane technology for purification of water is forward osmosis process which has gained immense interest

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List of abbreviations

FO	Forward osmosis
RO	Reverse osmosis
TFC	Thin film composite
PA	Polyamide
CA	Cellulose acetate
CTA	Cellulose triacetate
MMM	Mixed matrix membranes
PSf	Polysulfone
AqpZ	Aquaporin
NIPS	Non-solvent induced phase separation
L-b-L	Layer by layer technique
MPD	2-methyl-2,4-pentanediol
TMC	1, 3, 5-trimesoylchloride
FS	Feed solution
DS	Draw solution
ICP	Internal concentration polarization
ECP	External concentration polarization
PES	Polyether sulfone
pNE	Norepinephrine
HTI	Hydration Technology Innovations
SDS	Sodium dodecyl sulfate
Zn_2GeO_4	Nanowires
IER-Na	Na type ion exchange resin
PEM	Polyelectrolyte multilayer
SA	Sodium alginate
LiCl	Lithium chloride
PI	Phase inversion technique
PEG	Polyethylene glycol-electrolyte
PRO	Pressure retarded osmosis
NaCl	Sodium chloride
PBI	Polybenzimidazole
NF	Nanofiltration
IP	Interfacial polymerization
PBI-PES	Polybenzimidazole-polyethersulfone
CNTs	Carbon nanotubes
PAI	Poly(amide–imide)
PET	Polyethylene terephthalate
PAN	Polyacrylonitrile
ZnO-SiO_2	Zinc oxide-Silicon dioxide
TiO_2-g-PHEMA	Titanium dioxide grafted poly(2-hydroxyethyl methacrylate)
MWCNTs	Multiwalled carbon nanotubes
f-CNTs	Functionalized multi-walled carbon nanotubes
PVDF	Polyvinylidene fluoride
SiO_2	Silicon dioxide
TiO_2	Titanium dioxide
PVA	Polyvinyl alcohol
MA	Maleic acid
PAA	Polyacrylic acid
CP	Concentration polarization
CEOP	Cake-enhanced osmotic pressure
sPPSU	Sulfonated poly phenylene sulfone
sPSf	Sulfonated polysulfone
sPES	Sulfonated polyether sulfone
NPs	Nanoparticles
SO_3H	Sulfonic acid groups
MMT	Montmorillonite
PESU E6020P	Polyethersulfone
PPSU	Polyphenyl sulfone
CPSF	Carboxylated polysulfone
CPES	Carboxylic polyethersulfone
PTA–POD	Polytriazole-*co*-polyoxadiazole
SPEK	Sulfonated poly(ether ketone)
PFSA	Perfluorosulfonic acid
NMP	N-Methyl-2-pyrrolidone
GO	Graphene oxide
CN/rGO	Graphene oxide based graphitic carbon nitride
HNTs	Alumina-Silicates
MWf	Functionalized Multiwalled Carbone Nanotubes
GOT or MWfT	Carbon-TiO_2 composite
PVP	Polyvinyl pyrrolidone
PAH	Polyallylamine hydrochloride
$CaCO_3$	Calcium Carbonate
HCl	Hydrochloric acid
LDH-NPs	layered double hydroxide nanoparticles
PDA	Phenylenediamine
SW	Seawater
BW	Brackish water
GA	Glutaraldehyde
CMBA	4-(chloromethyl) benzoic acid
EDC	N-ethyl-N(3-dimethylamino) carbodiimide
$MgSO_4$	Magnesium sulfate
Na_2SO_4	Sodium Sulfate
$MgCl_2$	Magnesium Chloride
PEI	Polyethyleneimine
NaOH	Sodium hydroxide
PEI	Polycationethyleneimine
PSS	Polyanion polystyrene sulfonate
H-PAN	Hydrolyzed polyacrylonitrile
DOPC	1,2-dioleloyl-*sn*-glycero-3-phosphocholine
DOTAP	1,2-dioleoyl-3-trimethylammo-nium-propane (chloride salt)
T-PSS	PSS-terminated double-skinned
SLB	Supported lipid bilayer
SO_3	Sulfonic group

List of symbols

$\Delta\pi$	Osmotic pressure gradient
π	Osmotic pressure
V	Solution volume
R	Ideal gas constant
$8.314\ J\ K^{-1}\ mol^{-1}$	Ideal gas constant unit
T	Absolute temperature in Kelvin
B2, B3, B4	Virial empirical coefficients
σ	Reflection coefficient
π_D	Bulk osmotic pressures of the draw solute
π_F	Bulk osmotic pressures of the feed solution
B	Salt permeability coefficient
A	Water permeability coefficient
E	Global error
EXP	Experimental flux
CALC	Calculated flux
k/k_F	Mass transport coefficient of the feed solution/solute resistance
D	Bulk diffusion coefficient of the draw solute
SS_{err}	Residual sum of squares
SS_{TOT}	Total sum of squares
$R2_s$	Coefficient of determination for the solute flux
τ	Membrane support layer tortuosity
t_s	Thickness
A/B	Selectivity ratio of membrane active layer: water permeability/salt permeability
S	Membrane support layer structure parameter
ε_{eff}	Effective porosity
PH	Potential of hydrogen
$D\epsilon_{eff}$	Effective diffusion constant
M	Molar concentration