Novel Thin Film Nanocomposite Membranes with Improved Properties for Enhanced Desalination Performance

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Dedication

This thesis is deeply dedicated to:

My lovely parents, Parvin and Naser, for their great supports and continuous care

My amazing husband, Alireza, for his love, understanding, encouragements and sacrifices

Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Masoumeh Zargar Date: 01.10.2015

List of Publications

The doctoral thesis is prepared in “Publication” style according to the “specifications for Thesis (2015)” of the University of Adelaide. It includes publications that have been published, submitted for publication, or ready to be submitted:

- M. Zargar, B. Jin and S. Dai*, In Membrane Processing for Dairy Ingredient Separation, ed. J. D. Kang Hu, Wiley-Blackwell, 2015, Ch. Development and application of reverse osmosis for separation p. 139 (ISBN: 978-1-118-59017-1).
- M. Zargar, B. Jin* and S. Dai*, An integrated statistic and systematic approach to determine synthesis-performance correlation of thin film composite reverse osmosis membranes, submitted to Industrial & Engineering Chemistry Research (IE-2105-019756).
- M. Zargar, Y. Hartanto, B. Jin* and S. Dai*, Understanding functionalized nanoparticle incorporation in thin film composite membranes: interaction and desalination performance, submitted to Journal of Membrane Science (JMS-15-1287)
- M. Zargar, Y. Hartanto, B. Jin* and S. Dai*, Hollow mesoporous silica nanoparticles: a peculiar structure for thin film nanocomposite membranes, submitted to the ACS Applied Materials & Interfaces (am-2015-094259).
- M. Zargar, Y. Hartanto, B. Jin* and S. Dai*, Polyethylenimine modification of silica nanoparticles: a positive approach to develop sustainable thin film nanocomposite membranes, will be submitted.

Some relevant components of the work have been presented in conferences and symposiums:

- M. Zargar, B. Jin, S. Dai, Static protein adsorption on nanocomposite membranes: the contribution of nanofillers’ surface functionality, ICONN 2016 - International Conference on Nanoscience and Nanotechnology, 7-11 Feb 2016, Canberra, Australia.
- M. Zargar, Y. Hartanto, S. Dai, B. Jin, Thin film nanocomposite membranes:

which medium to choose for nanoparticle integration, 12th International Conference on Membrane Science and Technology (MST2015), 1-3 November 2015, Tehran, Iran.

- M. Zargar, S. Dai, B. Jin, Thin film composite reverse osmosis membranes hybridized with surface modified silica nanoparticles for enhanced desalination performance, 2nd International Conference on Desalination using Membrane Technology, 26-29th July 2015, Singapore.
- M. Zargar, S. Dai, B. Jin, An optimization strategy to investigate the structure-performance correlation of thin film composite reverse osmosis membranes, 2nd International Conference on Desalination using Membrane Technology, 26-29th July 2015, Singapore.
- M. Zargar, S. Dai, B. Jin, An optimization strategy to fabricate thin film composite reverse osmosis (TFC-RO) membranes, RACI SA Student polymer & Bionanotechnology Symposium (SASPBS14), 29th August 2014, Adelaide, South Australia.
- M. Zargar, S. Dai, B. Jin, Effect of solid and porous nanoparticles' incorporation at low concentration into the polymeric membranes' structure, RACI SA Student polymer & Bionanotechnology Symposium (SASPBS14), 29th August 2014, Adelaide, South Australia.
- M. Zargar, S. Dai, B. Jin, Fabrication and characterization of uniform mesoporous silica nanoparticles with the average particle size of 100 nm, The International Conference on Nanoscience and Nanotechnology (ICONN 2014), 2-6 February 2014, Adelaide Convention Centre, South Australia.
- M. Zargar, B. Jin, S. Dai. Fabrication and characterization of polyamide thin film composite membranes, RACI SA Student polymer & Bionanotechnology Symposium (SASPBS13), 4th October 2013, Adelaide, South Australia.

I have also co-authored the following publications during my PhD candidature:

- Y. Hartanto M. Zargar, H. Wang, B. Jin* and S. Dai*, Thermo-responsive acidic microgels as functional draw agents for forward osmosis desalination, submitted to Environmental Science & Technology (es-2015-04123d).

- Y. Hartanto, M. Zargar, B. Jin*, S. Dai*, Cationic thermos-responsive microgels as functional draw agents for forward osmosis desalination, will be submitted.

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Abstract

Nowadays, polymeric thin film composite (TFC) membranes have received increasing applications for separation and purification processes such as desalination and wastewater treatment. The development of nanotechnology has opened new frontiers in the advancement of TFC membranes. The incorporation of nanomaterials into the thin film polyamide (PA) layer of TFC membranes, making a structure known as thin film nanocomposite (TFN) membrane, can offer the advantages of both inorganic nanofillers and organic polymeric membranes. However, the possibility of nanoparticles' leakage and their low compatibility with organic membranes make the successful fabrication of TFN membranes challenging. Hence, investigating the structure-performance correlation of TFC/TFN membranes and their interactions with the incorporated nanomaterials is of great importance.

In my PhD project, a serial of TFC membranes incorporated with variously sized, structured and surface functionalized silica nanoparticles have been developed and extensively characterized with the aim to advance the knowledge of interfacial interactions between inorganic nanomaterials and the thin film PA layer of TFC membranes.

A statistical analysis was applied to study some key fabrication parameters of TFC membranes including PSF concentration in phase separation and aqueous phase soaking time and heat curing time in the interfacial polymerization course. Our findings highlighted the importance of considering interactions when devising a strategy to fabricate TFC membranes in order to optimize the overall desalination performance.

After the study of the TFC fabrication parameters, fabrication of TFN membranes was performed to get a better understanding on the interfacial interactions between nanoparticles and TFC membranes. SN with different sizes (50 nm and 100 nm) and surface functionalities (hydroxyl, amine or epoxy) were synthesized and successfully incorporated into TFC membranes. Desalination performance evaluation of the TFN membranes showed that no matter which functional group was present on SN, the resulting TFN membranes had higher water flux and comparable or higher salt rejection compared with the TFC membrane without nanoparticles. In addition, nanoparticle surface functionalization using epoxy and amine moieties facilitated the chemical interaction between SN and the TFC membranes, resulting in TFN membranes with higher crosslinking density of their PA selective layer and improved performance stability.

After studying the solid SN, hydrophilic hollow mesoporous silica nanoparticles (HMSN) have been used to fabricate novel TFN membranes in order to study the contribution of this peculiar porous structure on the properties and desalination performance of the resulting TFN membranes. The HMSN with an average particle size of ~ 68 nm were synthesized and incorporated into TFC membranes. The performance evaluation results revealed that with 0.03 wt % HMSN incorporation, water flux could improve up to 40 percent without obvious alteration of the salt rejection. Moreover, the compaction resistance of the resulting membranes was enhanced after HMSN incorporation.

To enhance the compatibility of introduced SN with the PA layer, polyethyleneimine (PEI) modified SN (SN-PEI) were fabricated and incorporated into the TFC membranes. Introduction of SN-PEI to the TFC membranes could facilitate the formation of strong covalent bonds between SN-PEI and PA layer, improve the compatibility of SN with the organic PA and enhance the physicochemical properties of the resulting TFN membranes. The cross-flow filtration performance evaluation of the fabricated membranes showed improved water flux and salt rejection capability in addition to a higher compaction resistance for the developed TFN membranes.

This thesis project has attempted to advance fundamental knowledge of the nanocomposite formation and fundamental processes governing water transport through reactive nanostructure to guide the development of nanoparticle-enabled multifunctional membranes.

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