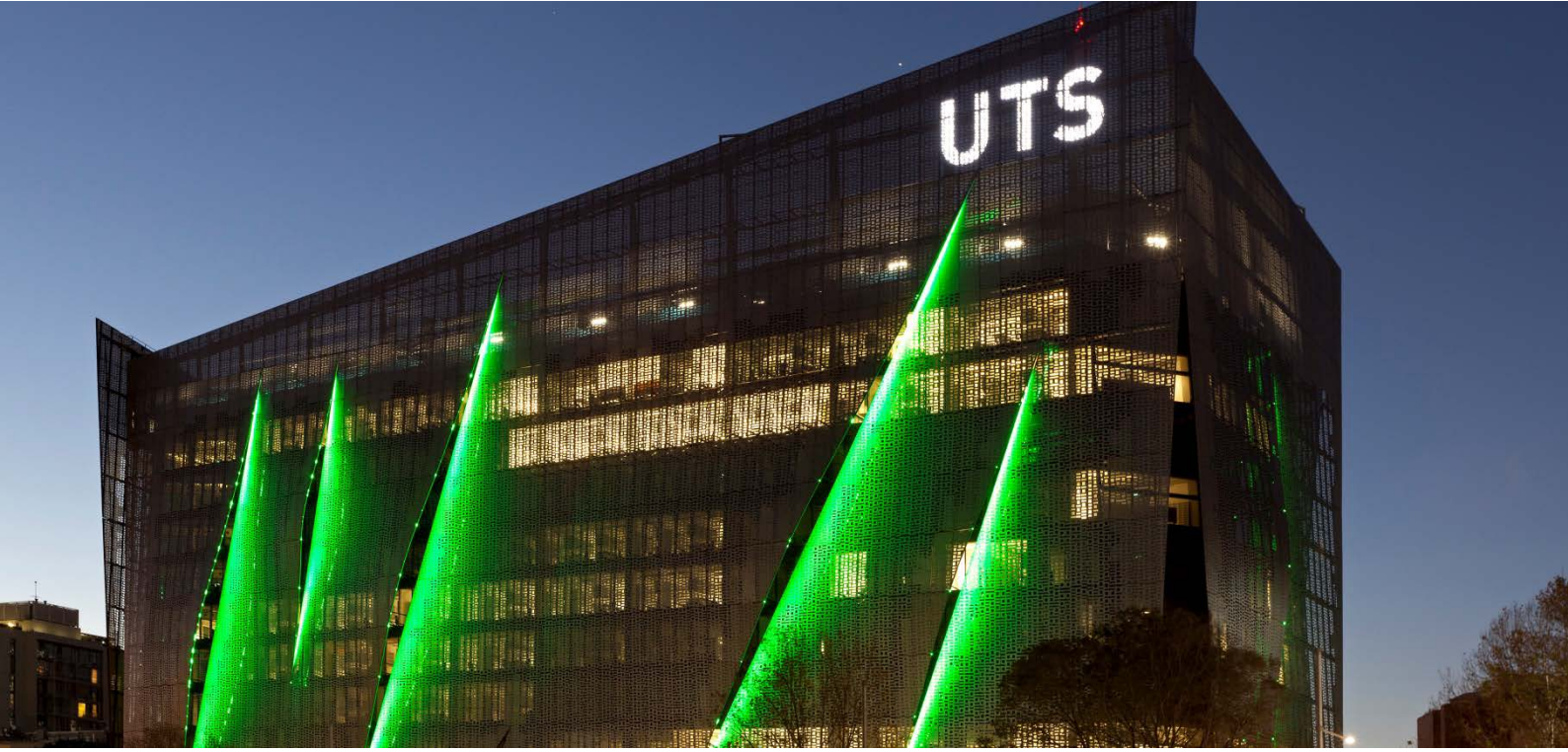

2016 Fenner Conference on the Environmen

Australian Academy of Science

International Forward Osmosis Summit

IFOS 2016 Abstract Book

University of Technology Sydney (UTS)

15 Broadway, Ultimo, NSW 2007, Australia

2-4 December 2016

Contributors of IFOS 2016 Abstract Book

Dr. Sherub Phuntsho
Associate Prof. Ho Kyong Shon
Dr. Laura Chekli
Mr. Minwei Yao

University of Technology Sydney 2016
15 Broadway, Ultimo,
New South Wales 2007
Australia

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Welcome to Sydney

On behalf of the organising committee of the IFOS 2016, I am delighted to welcome you to the IFOS 2016, being held in the vivid and dynamic city of Sydney and the University of Technology Sydney (UTS). I thank the delegates of the IFOS 2016 and greatly appreciate most of your continued support to the IFOS series.

Inspired by the natural osmotic process, ubiquitous to all living cells, FO and pressure retarded osmosis (PRO) are now emerging as alternative membrane technologies for desalination and energy generation. During two days, those with a professional interest in FO from around the world will meet and share new ideas about the latest progress, the future perspectives and beyond within the academia and industries. There will be opportunities to connect with other FO professionals, build your networking and form collaborations to address the growing challenges facing FO technologies around the world.

During the weekend, the critical debates creating our FO future with about 100 researchers and industries coming from 17 different countries that are taking part in the summit will take place in 43 oral presentations and 31 posters. Besides, the participants will have a very relaxing cruise dinner during which you will have ample time to interact and socialise with the other researchers from all around the world. Three technical tours will help you improve your digestion and health after lunch. This exciting and unprecedented FO program will help you update your knowledge and skills, provide a perfect opportunity for networking and exchange information on the latest FO trends in best practice, breakthrough, and pioneering research and science.

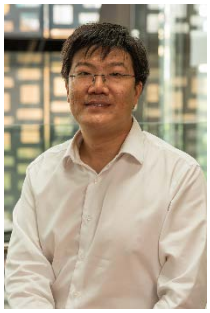
IFOS 2016 is organised and hosted by UTS in collaboration with the University of New South Wales, University of Wollongong, Shanghai Advanced Research Institute, Korea University, International Forward Osmosis Association, National Centre for Excellence in Desalination Australia, FO-RO Hybrid Desalination Research Centre (FOHC), Hyorim Industries and Porifera. I wish to thank the financial support of the Australian Academy of Sciences, Membrane Society of Australasia, other partners and UTS volunteers.

The next IFOS 2018 will be organised by Prof. Jin-Sik Sohn who is a director of FOHC in Korea. The FOHC centre will demonstrate a large-scale FO-RO hybrid system during the period and this will be attractive for the delegates and FOHC to continue the momentum of one of the best FO practices.

The IFOS 2016 is ready to address the FO challenges we collectively face. We could set some targets for implementation. Let us do this while enjoying your stay together in Sydney during this weekend.

Associate Professor Ho Kyong Shon
IFOS2016 Convenor
University of Technology Sydney

Organizing Committee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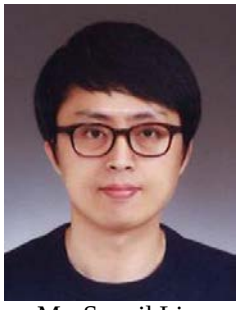
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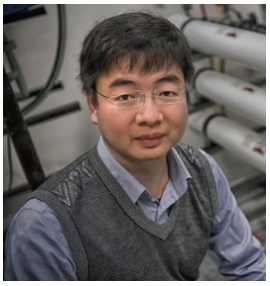
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member


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Prof. Jin-sik Sohn
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Dr. Joon Young Choi
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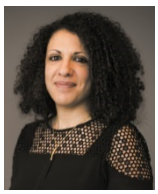
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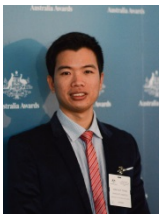
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UTS Security Office:

Dial 6 (from any UTS internal phone)

1800-249-559 from any phone/mobile (free call)

NSW Ambulance

0,000 (from UTS internal phones)

000 (from any other phone/mobile)

In case of fire emergency

Call UTS Security. Dial 6 from any UTS internal phone

Call UTS Security at 1800-249-559 (free call from any phone/mobile)

EMERGENCY Evacuation procedures

UTS Security Services has established procedures for the evacuation of buildings in an emergency.

In the case of a fire:

- the smoke detectors will activate the evacuation system and
- Fire & Rescue NSW is called automatically.

The Evacuation system alarm consists of two tones:

1. Standby tone – a ***Beep...Beep...Beep...*** **sound** [Prepare to evacuate]
2. Evacuate tone – a ***Whoop...Whoop...Whoop...*** sound accompanied by a voice message advising evacuation of the building.

- Do not attempt to combat the fire – this should be left to professionally trained personnel.
- Staff should take any students or visitors with them during an evacuation of the building.
- Assist any person with a disability.
- Only take your immediate belongings – do not waste time!
- Evacuate the building via the fire stairs or signed exits. Do not use lifts.
- Obey directions from security officers or fire wardens.
- Move quickly, but do not run.
- Do not return to the building until the 'all clear' is given. This would normally be advised by the security officer on duty on the advice of the emergency services personnel in attendance.

More details on emergency can be found from the following link:
http://www.uts.edu.au/about/maps-and-facilities/safety-and-security/during-emergency

Summit partners and sponsors

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National Centre of Excellence in Desalination Australia (NCEDA)

Shanghai Advanced Research Institute, Chinese Academy of Sciences

International Forward Osmosis Association

FO-RO Hybrid Desalination Research Centre, South Korea

Hyorim Industry, South Korea

Korea University

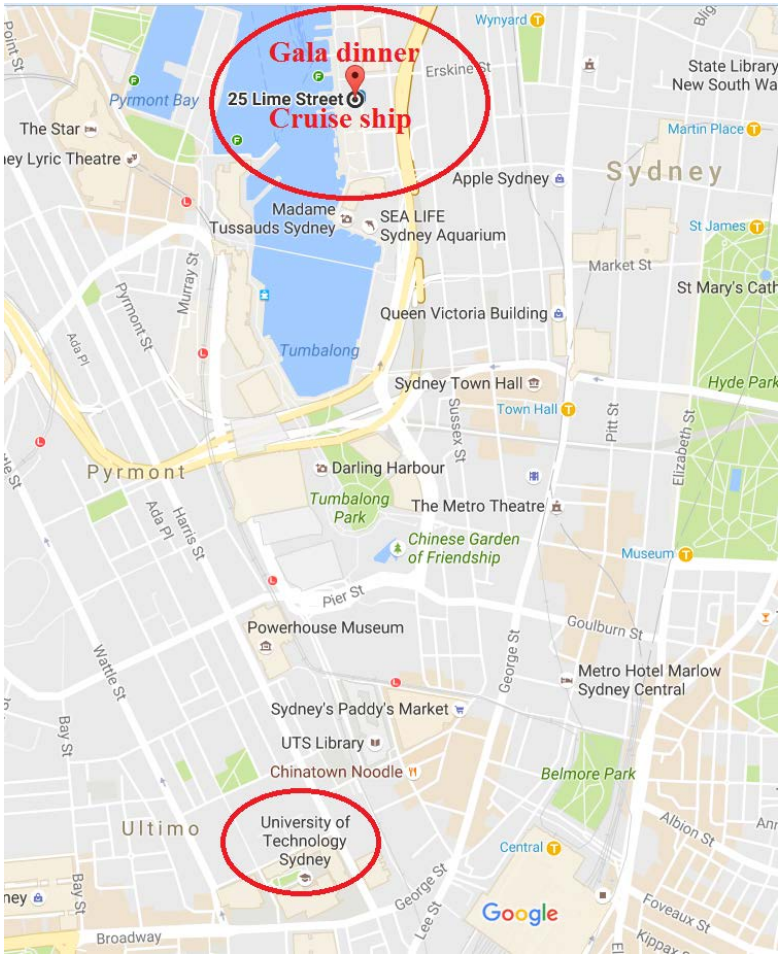
Directions of Cruise Ship Gala Dinner

6:15-6:30 PM	Delegates board the chartered Sydney bus from the bus stop located near UTS
6:30 PM	Bus departs UTS to Darling Harbour
6:45-7:00 PM	Bus arrives and drops delegates at Lime Street behind King Street Wharf
7:00-7:30 PM	Boarding Cruise Ship from King Street Wharf 5
7:30 PM	Cruise ship for gala dinner starts
9:30 PM	Arrive back to Darling Harbour

Delegates to arrange their own transport

For those delegates travelling to the Dinner venue on their own, please see the address and the map shown below:

Australian Cruise Group Pty Ltd,
32 The Promenade,
King Street Wharf 5, Sydney NSW 2000, Australia
Phone: +61 2 8296 7296. Or Call any of the IFOS organisers



IFOS2016 Program

Overview

	December 2, Friday	December 3, Saturday	December 4, Sunday
Activities	Arrival and Registration	Oral/poster Presentation	Oral/poster Presentation
Evening	Welcome drinks	Cruise dinner/firework	--

December 2, 2016 (Friday) 16:00~20:00

16:00 - 18:00	Registration
17:00 - 19:00	Welcome drinks

December 3, 2016 (Saturday) 09:00~20:00

Time	Oral Presentation	Pg.
8:00-9:00	**Registration**	
	Chair: Sherub Phuntsho	
9:00-9:20	Opening **A/Prof. Ho Kyong Shon** **Prof. Tao He** **CEO Neil Palmer**	
	Chair: Torove Leiknes	
9:20-9:50	Forward Osmosis and Pressure Retarded Osmosis: Challenges and Opportunities **Menachem Elimelech, Yale University**	14
9:50-10:10	Forward Osmosis Aquaporin Inside TM hollow fiber membranes for water re-use in dairy industry **Krzysztof Trzaskus, Aquaporin**	17
10:10-10:30	Thin-film nanocomposite and vertically embedded carbon nanotube composite membrane for forward osmosis **Heechul Choi, GIST**	17
10:30-10:50	Effects of polysulfone (psf) support layer on the performance of thin-film composite (tfc) forward osmsis membranes **Ben Schwegler, Disney Research China**	18
10:50-11:20	**Photo time, coffee break and poster presentation**	
	Chair: Long Ngheim	
11:20-11:50	Developments in FO membranes and processes at the Singapore Membrane Technology Centre **Tony Fane, Nanyang Technological University**	14
11:50-12:10	FO-RO process treating wastewater from coal power plant: pilot-scale evaluation **Seungkwan Hong, Korea University**	26
12:10-12:30	Fouling of forward osmosis membranes during phosphorus recovery from wastewater **Katie Charlotte Kedwell, Aalborg University**	18
12:30- 12:50	Inorganic Scaling in Forward Osmosis: Gypsum and Reactive Silica **Ming Xie, Victoria University**	19
12:50- 01:10	Polyvinyl Chloride and Layered Double Hydroxide Composite as a Novel Substrate Material for the FO Membrane **Alka Muntray, Sardar Vallabhbhai National Institute of**	19

	Technology	
13:10-14:30	**Lunch break (three tours included)**	
	Chair: Xiao-Lin Wang	
14:30-14:50	What is the next for forward osmosis? **Neal Chung, National University of Singapore**	15
14:50-15:10	Taking advantage of the reverse salt flux **Long Nghiem, University of Wollongong**	20
15:10-15:30	Practical considerations for the scalability of forward osmosis based on pilot scale testing **Gaetan Blandin, University of Girona**	20
15:30-15:50	Transport of OMPs through FO membranes: influence of OMP and draw solute properties **D'Haese Arnout, Ghent University**	21
15:50-16:20	**Coffee break and poster presentation**	
	Chair: Am Jang	
16:20-16:40	FO–RO hybrid Desalination Research Center: Progress and Challenges **Jin-Sik Sohn, FOHC director**	21
16:40-17:00	Pressure assisted forward osmosis for volume minimization of reverse osmosis concentrate from a water reclamation plant **Saravanamuthu Vigneswaran, University of Technology Sydney**	22
17:00-17:20	Development of a SWRO-PRO Hybrid Desalination System: Pilot Plant Investigations **In-Ho Yeo, GS Engineering & Construction**	18
17:20-17:40	Pressure build-ups and drops of an 8040 spiral-wound FO membrane element **In S. Kim, GIST**	22
17:40-18:00	Forward Osmosis Process for microalgae separation from water **Li-Hua Cheng, Zhejiang University**	23
18:10	Bus to Darling Harbor	
19:00-09:30	**Sydney Cruise dinner**	

December 4, 2016 (Sunday)

Time	**Oral Presentation**	**Pg.**
	Chair: Xia Huang	
9:00-9:30	FO applications: porifera's technical advances and current update **Olgica Bakajin, Porifera Inc.**	15
9:30-9:50	Membrane Fouling Mechanisms in Osmotically Driven Membrane Processes **Qianhong She, Nanyang Technological University**	24
9:50-10:10	Pressure assisted osmosis: advantages, opportunities and challenges **Pierre Le-Clech, University of New South Wales**	24
10:10-10:30	Performance evaluation of a Semi-pilot scale forward osmosis-reverse osmosis (fo-ro) hybrid SYSTEM **Sung Ju Im, Sungkyunkwan University**	25
10:30-10:50	Forward osmosis for dairy processing – pre-concentration of dairy whey **George Chen, University of Melbourne**	25
10:50-11:20	**Coffee break and poster presentation**	

	Chair: Olgica Bakajin	
11:20-11:40	Influence of draw solution in causing severe scaling in the feed side of a forward osmosis system **Noreddine Ghaffour, King Abdullah University of Science and Technology (KAUST)**	23
11:40-12:00	Fertiliser-drawn forward osmosis: progresses and challenges **Ho Kyong Shon, University of Technology Sydney**	26
12:00-12:20	Resource recovery from municipal wastewater by forward osmosis based process: Opportunities and Challenges **Xiwang Zhang, Monash University**	27
12:20- 12:40	Coal mine water treatment by combined forward and reverse osmosis (FO-RO) **Ramesh Thiruvenkatachari, CSIRO**	27
12:40- 13:00	Enhanced Performance Dual Stage Pressure Retarded Osmosis **Ali Altaee, University of Technology Sydney**	28
13:00-14:20	**Lunch break (three tours included)**	
	Chair: Xiwang Zhang	
14:20-14:40	Thin-film composite Hollow fiber forward osmosis membrane by using aliphatic polyketone support **Hideto Matsuyama, Kobe University**	28
15:00-15:20	Effects of high salt concentrations on activated sludge used to treat concentrates from forward osmosis **Jihyang Kweon, Konkuk University**	29
15:20-15:40	Forward Osmosis for the concentration of apple juice **Netsanet Shiferaw, CSIRO**	29
15:40-16:00	Forward osmosis process for the treatment of different mass flows in a dairy plant **Anita Haupt, Technische Universität Dresden**	30
16:00-16:20	Hydrogel composite monolith as forward osmosis draw agent **Ranwen Ou, Monash University**	30
16:20-16:50	**Beer/coffee break and poster presentation**	
	Chair: Pierre Le-Clech	
16:50-17:10	Investigation of the Transmembrane Electrical Potential of a Forward Osmosis Membrane **Xiao-Lin Wang, Tsinghua University**	31
17:10-17:30	Effluent organic matter (EfOM) removal and energy consumption of various pretreatment systems for osmotic dilution seawater RO desalination **June-Seok Choi, Korea Institute of Civil Engineering and Building Technology (KICT)**	31
17:30-17:50	Impact of reverse diffusion on membrane biofouling of fertilizer driven forward osmosis **Sheng Li, King Abdullah University of Science and Technology (KAUST)**	31
17:50-18:10	Application of forward osmosis process in oilfield wastewater treatment under high salinity conditions **Pengfei Lin, China University of Petroleum (East China)**	32
	Chair: Laura Chekli	
18:10-18:30	**Closing ceremony (Poster award, next IFOS 2018)**	

Poster presentation

Poster presenters need to prepare a poster which can be displayed on a **LCD screen**.

December 3, 2016 (Saturday) 09:00~18:00

No	Poster Presentation	Name	Pg.
P-1	A refined draw solute flux model in forward osmosis	D'Haese Arnout	33
P-2	Fertiliserdrawn forward osmosis process: Pilot-scale desalination of mine impaired water for fertigation	Jungeun Kim	33
P-3	Numerical Investigation of hollow fiber forward osmosis membrane	Joon Ha Kim	34
P-4	Relating the Solute properties of contaminants in emerging concern (cec) and their rejection in the forward osmosis process	Duksoo Jang	34
P-5	Osmotic versus conventional membrane bioreactors integrated with reverse osmosis for water reuse: Biological stability, membrane fouling, and contaminant removal	Wenhai Luo	34
P-6	Recovery of fresh water from magnesium chloride solutions	Ryan Lefers	35
P-7	Integral Forward Osmosis-Membrane Distillation Process: Research Hype or Sustainable Solution for Water Reuse?	Tao He	35
P-8	Developing Energy-Efficient Seawater Desalination Processes by integrating forward osmosis membranes	Tae-Hyun Bae	36
P-9	Development of Pressure Retarded Osmosis (PRO) hollow fiber membrane modified with graphene oxide	Myoung Jun Park	36
P-10	Fertilizer driven forward osmosis as a low energy technology for sodium removal in greenhouse applications	Federico Volpin	37
P-11	Investigating fertilizer drawn forward osmosis process for groundwater desalination for irrigation in Egypt	Peter Nasr	37
P-12	Performance of a novel fertilizer-drawn forward osmosis aerobic membrane bioreactor (FDFO-MBR): Mitigating salinity build-up by integrating microfiltration	Jin Wang	38
P-13	Forward osmosis membrane module optimization in forward osmosis - reverse osmosis hybrid process	Joon Young Choi	38
P-14	Forward osmosis membrane fouling index	Byeong-Gyu Choi	38
P-15	Economic feasibility of osmotic power generation at the Gold coast desalination plant	Abdelrahman Azzuni	39

December 4, 2016 (Sunday)

Keynote Speakers

Prof. Menachem Elimelech

Environmental Engineering, Yale University, USA
Email: menachem.elimelech@yale.edu

Title: FORWARD OSMOSIS AND PRESSURE RETARDED OSMOSIS: CHALLENGES AND OPPORTUNITIES

Abstract

The presentation will describe key challenges for the successful implementation of forward osmosis (FO) and pressure retarded osmosis (PRO) and highlight opportunities for research and development to overcome these challenges. We will first discuss the energy efficiency of FO compared to reverse osmosis (RO) and highlight applications where FO can excel. Such niche applications of FO are generally for treatment of feed waters with very high salinity (TDS) or fouling potential where RO cannot be used. We will later discuss the desired properties of FO membranes to be successful in these applications and future research directions to develop such membranes. The second part of the presentation will focus on PRO. We will present a framework to determine the energy efficiency of PRO and apply this methodology to analyze the viability of PRO for three scenarios: (i) seawater – river water pairing, (ii) RO desalination brine – wastewater pairing, and (iii) incorporation of PRO in RO desalination plants. Based on this analysis, we will propose potential viable applications of PRO and highlight the required properties of PRO membranes to meet these applications.

Biography

Menachem Elimelech is the Roberto Goizueta Professor at the Department of Chemical and Environmental Engineering at Yale University. Prof. Elimelech received his B.Sc. and M.Sc. degrees from the Hebrew University in Israel and Ph.D. from the Johns Hopkins University in 1989 in Environmental Engineering. His research interests include (i) engineered osmosis for sustainable production of water and power, (ii) environmental applications and implications of nanomaterials, (iii) membrane separations for desalination and water reuse, and (iv) water and sanitation in developing countries. Prof. Elimelech has received numerous awards in recognition of his research and teaching. Notable among these are his election to the United States National Academy of Engineering in 2006, the Eni Prize for 'Protection of the Environment' in 2015, the Simon W. Freese Environmental Engineering Award and Lecture from the American Society of Civil Engineers in 2011, the American Institute of Chemical Engineers Lawrence K. Cecil Award in Environmental Chemical Engineering in 2008, and the Clarke Prize for excellence in water research in 2005.

Prof. Anthony G. Fane

Nanyang Technological University, Singapore
Singapore Membrane Technology Centre (SMTC)
Email: agfane@ntu.edu.sg

Title: DEVELOPMENTS IN FO MEMBRANES AND PROCESSES AT THE SINGAPORE MEMBRANE TECHNOLOGY CENTRE

Abstract

This presentation describes research in membranes and processes based on forward osmosis and pressure retarded osmosis at the Singapore Membrane Technology Centre. FO membrane development includes preparation of aquaporin (water channel) based membranes which exhibit enhanced performance and long term stability. In another development thin film nanocomposite FO membranes have been prepared using nanofibrous substrates reinforced by carbon nanotubes. This design provides improved substrate strength allowing us to increase its porosity and thereby reducing its structure parameter to mitigate ICP. Pressure retarded osmosis membranes have special needs and we have developed several options, including composite flat-sheet membranes, flat-sheet nanofiber membranes and composite hollow fibres. In terms of PRO module design the spiral wound module is challenged by flow maldistribution and spacer effects; there could be benefits to use of hollow fibres. However elevated pressures in the fibre lumen are a problem owing to membrane creep. Our efforts to understand and mitigate this will be described, along with a report on our PRO pilot plant studies. For FO there is a need for engineered draw solutes and our studies include three types of DS; this work will be summarized. In terms of applications we have developed FO membranes for reduction of produced water volume thermal brines. A 50% reduction in produced water volume looks feasible. We have also trialed a simple anaerobic bioreactor coupled to a FO-MD system that produces good quality effluent at acceptable fluxes. Finally, the presentation will conclude with a brief discussion of FO fouling issues, including a comparison of FO and RO fouling characteristics.

Biography

Tony Fane is Visiting Professor at SMTC (Founding Director) and Former Director of the UNESCO Centre for Membranes (UNSW). His research interests are in sustainable water processing using membrane technology.

Prof. Tai-Shung (Neil) Chung

Department of Chemical and Biomolecular Engineering, National University of Singapore, 4 Engineering Drive 4, Singapore 117585 (Phone: 65 6516 6645)
Email: chencts@nus.edu.sg

Title: WHAT IS THE NEXT FOR FORWARD OSMOSIS (FO)?

Abstract

Forward osmosis (FO) has received extensive attention during the last decade as one of the emerging technologies for water reuse and seawater desalination. The purposes of this presentation are to summarize (1) the current status of FO membrane development, (2) what we have learned in the last decade on FO and pressure retarded osmosis (PRO) technologies, and (3) share our understanding and perspectives in order to develop useful technologies and applications for clean water and clean energy production. [1–7)]

References

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2) G. Han, S. Zhang, X. Li, T. S. Chung, *Prog. Polym. Sci.* 51, 1–27 (2015).
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Biography

Dr. Tai-Shung (Neal) Chung is the Provost's Chair Professor at the Department of Chemical and Biomolecular Engineering, NUS. His research focuses on polymeric membranes for clean water and clean energy.

Dr. Olgica Bakajin

Porifera Inc., 3502 Breakwater Court, Hayward, CA 94545;

Email: olgica@porifera.com

Title: FO APPLICATIONS: PORIFERA'S TECHNICAL ADVANCES AND CURRENT UPDATE

Abstract

FO membranes have been available for over 20 years, but the market has been small with desalination as the target application. Advancements in FO technologies and changes in target markets are rapidly changing the FO landscape. The total addressable markets for FO systems are now estimated to be in the tens of billions of dollars as a result of:

- Innovations in FO membranes, elements, and draw solutions that reduce cost and footprint
- New and existing companies entering the market
- Marketing FO for reuse, food and beverage, oil and gas, and high salinity instead of desalination
- Regulations that promote near zero liquid disharge and industrial reuse
- Increased interest in potable reuse and emerging contaminant removal

Recent innovations are the key drivers for increased interest in FO based solutions because they address: 1) cost, 2) footprint, and 3) target markets.

Cost: Previously, FO equipment would cost on the order of 6-8 times more than competing ultrafiltration (UF) systems as reverse osmosis (RO) pretreatment. FO+RO systems will cost less than UF+RO systems in the near future, with lower operation costs and producing higher quality water. Also, FO Concentrators will provide equivalent water treatment at <70% less cost than the competing evaporators.

Footprint: FO systems were previously large, however, recent innovations have significantly reduced system footprints to be

similar to or smaller than competing systems.

Target markets: Sales have grown rapidly in the last 2 years with the majority of successful case studies coming in the food and beverage, oil and gas, mining, and industrial water reuse markets.

The talk will provide latest information on Porifera's products and discuss results of Porifera's recent piloting activities.

Biography

Olgica Bakajin currently serves as CEO at Porifera, Inc. She received her BA in Physics and Chemistry from the University of Chicago in 1996 and her Ph.D. in Physics from Princeton University in 2000. Dr. Bakajin received the NanoTech Briefs Award in 2007, R&D 100 Award in 2010 and has been elected Fellow of the American Physical Society in 2011. She also serves on the Board of Directors of the International Forward Osmosis Association. Dr. Bakajin has co-authored more than 50 US and international patents and patent applications and her publications, have been cited over 10,000 times. Prior to founding Porifera, Dr. Bakajin led a research team at Lawrence Livermore National Laboratory that performed seminal work on fluid flow through carbon nanotubes. She left LLNL in 2009 to co-found Porifera with the mission of creating advanced membrane systems for water treatment and product concentration.

ORAL PRESENTATIONS DAY 1 Saturday 3 December 2016

Forward osmosis aquaporin inside [tm] hollow fiber membranes for water re-use in dairy industry

Krzysztof Trzaskus[1], Mads Friis Andersen[1], Sylvie Braekevelt[1], Dorrit Thaysen[2] and Oliver Geschke[1]

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[2] *Arla Foods Ingredients Group P/S, Sønderupvej 26, 6920 Videbæk, Denmark, Phone: +45-7217-7914.*

Presentation author: *oge@aquaporin.dk*

Brief Bio of the presenting author

Dr. Geschke is vice president of Aquaporin A/S. His work focuses on a development of biomimetic membranes for RO and FO applications.

Abstract

Forward Osmosis (FO) is a relatively novel water purification technology drawing more and more attention to the industry as an effective technique capable of up-concentrating feed and diluting draw solutions. Especially, for feed solutions such as whey processing effluents or dairy waste water, application of FO can be beneficial.

Dairy plant discharge volumes of such effluents are often large compared to water intake, meaning that plants may have net production of water. The whey processing effluent studied here is characterized by high levels of non-protein-nitrogen (primarily containing urea), posing a challenge to currently available separation techniques. Here, FO can be successfully applied in order to extract water with re-usable quality and at the same time reduce wastewater volumes.

Aquaporin Inside™ hollow fiber membranes were tested for re-use water extraction from the dairy effluent. The membrane performance was evaluated based on membrane water flux and urea rejection. The preliminary results revealed that the treatment of the dairy wastewater using the Aquaporin Inside™ hollow fiber membrane in FO mode and NaCl as a draw solution can effectively reduce volume of these wastewaters. Moreover, the significantly high urea rejection obtained in these tests (from 47% up to 95% depending on the process conditions), makes FO operations promising for re-use of dairy effluents. Based on the promising preliminary results, a demonstration FO-RO plant will be constructed in order to determine commercial feasibility of using FO in dairy industry.

Thin-film nanocomposite and vertically embedded carbon nanotube composite membrane for forward osmosis

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Brief Bio of the presenting author

Moon Sonis PhD student in Gwangju Institute of Science and Technology (GIST). He is doing research on nano-enhanced membrane for fresh water and energy harvesting.

Abstract

Forward osmosis (FO) for desalination is receiving remarkable attention due to its low energy consumption and simple operation compared to reverse osmosis. Here, we propose a thin-film nanocomposite (TFN) membrane with vertically-embedded carbon nanotubes (CNT) in the active layer and support layer to maximize membrane permeability without significantly sacrificing selectivity.

We first attempted a spray-assisted electromagnetic field alignment technique to vertically embed CNT in the active layer of the TFN membrane (M. Son and H. Choi et al, 2016). After vertically embedding the CNT, the developed TFN membrane exhibited 20% increased water flux when 0.5 M NaCl solution was used as draw solution. When chemical etching of the active layer was further applied, increase of water flux was over 300% (40 LMH). Meanwhile, the increased reverse salt flux was mild most likely due to the steric effect of CNT in the active layer. The developed TFN membrane thus showed even higher water flux and lower reverse salt flux when compared to recently-provided commercial FO membrane.

In addition, TFN with CNT positioning in support layer was also successfully synthesized and tested. The water flux increase of the TFN membrane was promoted by CNT-induced porosity and the hydrophilicity of the support layer as well as by the chemical etching of the active layer. The water flux of the developed TFN membrane was found to be 130% greater than for bare thin-film composite membranes (M. Son and H. Choi et al, 2016). This method is easy to up-scale with a one-step fabrication process, and it is cost-effective due to its simplicity and the low concentration of CNT solution used. Therefore, these findings could contribute to fresh water production using the FO process to overcome global water scarcity.

Effects of polysulfone (psf) support layer on the performance of thin-film composite (TFC) forward osmosis membranes

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Abstract

Forward osmosis (FO) as a new membrane process has attracted much attention, In this study, a new FO membrane was specifically developed for treating grey water. We formed two types of Polysulfone (PSf) membranes by the phase inversion process using two different additives. Polyethylene glycol (PEG) and Plournic F127, were used as support layers to prepare polyamide (PA) TFC membranes by the interfacial polymerization (IP). The resulting effects of PEG and Plournic F127 concentrations on pure water flux, mean pore size, and porosity were investigated. The overall performance of these TFC membranes was evaluated in terms of water flux and reverse salt rejection ratio. For both these two additives, the pure water flux showed a similar trend with increasing concentration in support layers. There is an optimal concentration value for both additives; at this value, the pure water flux of the support membrane reached the highest rate. The support membrane with Plournic F127 showed a large increase on the pure water flux with decrease on the mean pore size. For the resulting TFC membrane, the water flux of FO membrane with PEG support layer showed a similar trend as that of pure water flux of the support membrane, which indicated that the separation performance of support membrane was an important factor affecting the separation performance of overall TFC membrane. However, the resulting TFC membrane using Plournic F127 support membrane did not show better performance than that of support membrane. Comparing two different support layers, in addition to the differences of the separation performance, there were also substantial differences between the surface characteristics, such as the hydrophobic/hydrophilic ratio, and the chemical composition, which might affect the formation of PA layer during IP process. The observed decreased in water flux could be attributed to the change of the PA layer structure. Therefore, TFC layer is an import factor affecting the separation performance of the TFC FO membrane.

Development of a SWRO-PRO hybrid desalination system: pilot plant investigations

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Abstract

The Seawater Reverse Osmosis (SWRO) desalination technology covers 78% of annual new contracted desalination capacity from 2006 to 2012 owing to its lower electrical power consumption (3-5 kWh/m3) compared to thermal desalination technologies(up to 18 kWh/m3) such as MSF, MED, etc. However, existing SWRO desalination systems are still required to be further improved to lower their energy consumption required. Recently, a novel hybrid SWRO desalination system utilizing Pressure Retarded Osmosis (PRO) technology has been studied, which can recover a large amount of osmotic power from concentrated brine with 60,000 to 80,000 ppm of TDS. In this study, GS E&C evaluated and created an advanced engineering approach to the economically feasible SWRO process with PRO implementation. The ultimate goal of this research project is to create an engineering scheme where the SWRO-PRO technology is applied to a seawater desalination process in a gradual scale-up plan from pilot plant to full scale plant. In this paper, the technology implementation feasibility and some pilot study results are discussed.

Keywords: SWRO, PRO, Pressure Retarded Osmosis

Fouling of forward osmosis membranes during phosphorus recovery from wastewater

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Brief Bio of the presenting author

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Abstract

Known phosphorus (P) reserves around the world will be depleted in 80 years. Consequently, it is necessary to find a solution to recover P. One source of recovery is wastewater. Presently, sludge is spread on fields as fertilizer, alternatively, the use of struvite ($NH_4MgPO_4.6H_2O$) or calcium phosphate could be preferable. However, this reaction requires a higher concentration of phosphates than is in wastewater in order to be efficient, therefore, sludge reject water can be used since it contains higher concentrations of phosphates than

raw wastewater. Forward osmosis (FO) can be utilized to increase the concentration of phosphates further, thus giving a higher concentration of phosphates and magnesium ions during struvite crystallization. However, sludge contains high concentrations of organic and inorganic polymers and other particulates, which have potential to cause a high degree of fouling on the membrane.

This study aims to analyse the effects of polymer fouling on a carbon nanotube FO membrane (Porifera Inc., Hayward, USA), determine the degree to which fouling occurs, and its potential to be reversed. Sludge reject water collected from Aaby WWTW (Denmark) was used as feed solution, and seawater and NaCl solution as the draw. Data is shown for experiments initially run for 6 hours, followed by a 6 hour cleaning period with DI water as the feed solution, which was then changed back to sludge reject water, and the experiment was left to run for another 5 hours. During the first run the flux decreased to 47%, and was restored to 98% of its original capacity during cleaning, during the second run the flux fell to 34%, as shown in Figure 1. Analysis of the fouling layer and optimal cleaning techniques/times will be discussed during the presentation. FO is still a viable technology for P recovery, since the decrease in flux caused by fouling could be reversed considerably without the use of chemical cleaning.

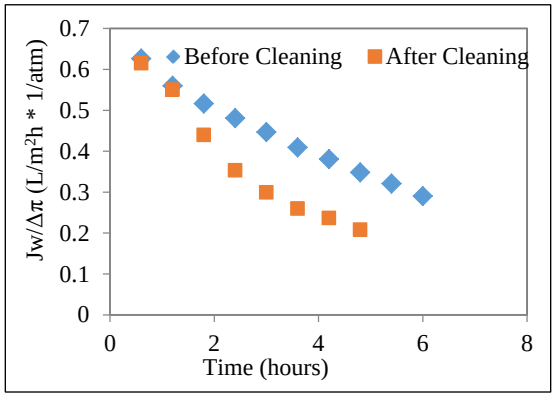

Figure 1. Effects of membrane fouling and cleaning

Inorganic Scaling in Forward Osmosis: Gypsum and Reactive Silica

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Abstract

Membrane silica scaling hinders sustainable water production. In this study, we elucidated silica scaling mechanisms on an asymmetric cellulose triacetate (CTA) membrane and polyamide thin-film composite (TFC) membrane. Scaling filtration showed that TFC membrane was subjected to more severe water flux decline in comparison with the CTA membrane, together with different scaling layer morphology. To elucidate the silica scaling mechanisms, silica species in the aqueous solution were characterised by mass spectrometry as well as light scattering. Key thermodynamic parameters of silica surface nucleation on the CTA and TFC membranes were estimated to compare the surface nucleation energy barrier. In addition, high resolution X-ray photoelectron spectroscopy resolved the chemical origin of the silica-membrane interaction via identifying the specific silicon bonds. For CTA membrane, silica scaling was promoted by the aggregation of mono-silicic acid into large silica aggregates, followed by the deposition from bulk solution onto the membrane surface; by contrast, silica surface polymerisation on the TFC membrane was the dominant mechanism where the majority of mono-silicic acid interacted with TFC membrane surface. This hypothesis was supported by monitoring of aqueous silica species with mass spectrometry and light scattering techniques; as well as confirmed by the estimation of key silica nucleation parameters and high-resolution XPS analysis of Si 2p binding energy on the CTA and TFC membrane. For the CTA membrane, the aggregation of monomer silicic acid proceed via formation of dimmer – linear trimer – cyclic trimer, which resulted in a continuous increase in hydrodynamic radii as well as the weight-average molecular weight. However, for the TFC membrane, the major species of silica oligomers in the solution remained as cyclic trimer after ten-hours of scaling experiment, which was compounded by a largely unchanged hydrodynamic radii and weight-average molecular weight. Estimation of thermodynamic parameters of silica surface nucleation demonstrated a significant reduction of surface nucleation energy (more than 50%) for the TFC membrane in comparison with the CTA. In addition, the Si 2p binding energy suggested different silicon bonds for the CTA (Si=O) and TFC (Si-O) membranes, which supported the proposed chemical origins of silica scaling on these two membranes.

Polyvinyl chloride and layered double hydroxide composite as a novel substrate material for the FO membrane: thermodynamic study

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Brief Bio of the presenting author

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Abstract

In this study, a composite of the polyvinyl chloride (PVC) and layered double hydroxide (LDH) has been used as

substrate material for the forward osmosis (FO) membrane preparation. Different concentrations of LDH (0, 0.5, 1, 1.5, 2, 2.5 and 3 wt %) were incorporated into PVC to fabricate FO substrates. The substrate morphology was evaluated by scanning electron microscope (SEM) and thermodynamic aspect. The thermodynamic study involves the ternary phase diagram which helps to demonstrate the main two path of the phase inversion process. These are: (i) liquid-liquid phase separation, in which binodal boundary separates the triangle into two region: homogeneous solution region, and two phase region, and (ii) solidification, in which movement of polymer precipitation restrained by increasing viscosity of polymer solution to fix the membrane structure. By increasing the LDH concentration into the casting solution, the binodal line shifted nearer to the polymer/water axis. Shifting of the binodal line toward the polymer/water axis indicated that more water required for precipitation of PVC in the quaternary system. Hence, this study reveals the importance of thermodynamic study to design of forward osmosis substrate.

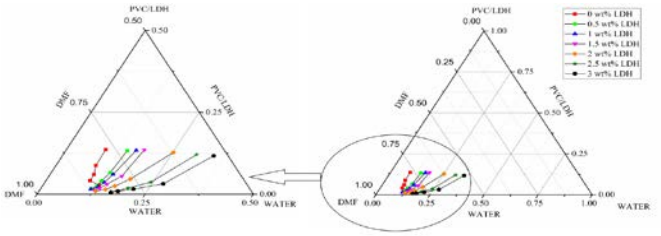

Fig. 1 Ternary phase diagram of PVC/LDH/DMF/water system

Taking advantage of the reverse salt flux

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Abstract

Forward osmosis can be an important building block as part of an integrated system for resource recovery from waste and wastewater. Since commercially available FO membranes cannot achieve complete retention of the draw solution, the reverse salt flux has often been seen as the Achilles heel of the process. In this presentation, several examples in which the reverse salt flux can be exploited to enhance the process performance. These include (i) the retarded diffusion phenomenon that utilizes the reverse salt flux to enhance the rejection of trace organic contaminants by FO membranes, (ii) the reverse salt flux of magnesium or calcium into a phosphate rich feed solution to facilitate phosphorus recovery, and (iii) the bidirectional transport of proton (H^+) and cations for pH adjustment during FO operation. Potential applications of each of these examples are discussed. Results from our work demonstrate that a fundamental understanding of the transport phenomena in FO can used to take advantages of some of the seemingly problematic issues to facilitate innovative FO applications.

Practical considerations for the scalability of forward osmosis based on pilot scale testing

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Abstract

Forward osmosis is a promising process for water reuse and desalination but its implementation requires significant water flux increase for more attractive economics. The development of novel FO membranes and the application of hydraulic pressure in FO under the form of pressure assisted osmosis (PAO) have both proven to be able to tackle current FO flux limitation. However, most FO studies have been conducted on lab scale using a cross-flow cell, and very little is known about pilot scale operation which is the necessary next step towards successful full-scale implementation. In this extensive study, we evaluated various cross flow FO module configuration (plate and frame, spiral wound from 2.5 up to 8'') as well as submerged plate and frame configuration (for osmotic membrane bioreactor). Those tests allow comparing (1) cross flow cell performance vs. pilot scale (2) different membranes types for similar design and (3)

the impact of design on performance and associated practical limitations. Typically, water and salt fluxes, impact of operating cross flow velocity on pressure drop, fouling and cleaning strategies were extensively evaluated and will be presented. Among the key results, it has been observed that novel thin film composite membranes (and modules) can provide 3 times higher flux with better membrane selectivity than the state of the art cellulose triacetate membrane from HTI. Moreover, feed and draw flowrate can be severely limited by the type of spacer used due to pressure-drop in the draw side of the module. In that context plate and frame module appeared less sensitive than spiral wound modules and allowed to operate at similar feed and draw flowrates. Fouling occurred in all configurations but the combination of osmotic backwash and physical cleaning proved to be an effective strategy for both cross flow and submerged configurations.

Transport of OMPs through FO membranes: influence of OMP and draw solute properties

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Bio of Arnout D'Haese

Ir. Arnout D'Haese is an academic assistant at the PaInT lab at Ghent University, currently finalizing his PhD. His research focusses on solute transport phenomena in FO.

Abstract

In this work, the rejection of 27 OMPs with different physico-chemical properties was studied. CTA membranes, operated in AL-FS (FO) mode, were used. 4 draw solutes (NaCl, MgCl2, Na2SO4 and MgSO4) were tested at 5 concentrations, as well as simple diffusion (no salts present). In a separate set of experiments, the flux behaviour of the draw solutes was evaluated as well.

It was found that the draw solute influences OMP rejection through charge effects: neutral and anionic OMPs were better rejected by sulfate draw solutes, while cationic OMPs were better rejected by chloride draw solutes. Other draw solute effects were noted as well. For uncharged OMPs, the membrane permeability during diffusion was as high as during FO operation with chloride draw solutes, but was reduced when sulfate draw solutes were used. No relation was found between the draw solute permeabilities and OMP permeabilities. The draw solute permeability decreased in the following order: NaCl > MgCl2 > Na2SO4 > MgSO4. The hypothesis that a higher draw solute permeability hinders OMP transport is thus not supported by this study.

Certain OMPs showed a different permeability depending on the draw solute, but this was not the case for every OMP. Those OMPs whose membrane permeability were influenced by the draw solute, were predominantly smaller compounds in terms of molecular weight and surface area, showing an overall lower rejection. It is therefore hypothesized that adsorption of certain draw solutes causes subtle structural changes in the membrane active layer. The permeability of relatively large compounds would not be impacted to a large extend, as transport through the membrane active layer of these compounds is strongly hindered in any case. The influence of structural changes would be larger on smaller compounds, with a size closer to the "pores" of the active layer.

FO–RO hybrid desalination research center: progress and challenges

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Abstract

Forward osmosis (FO) has been increasingly studied in the past decade for its potential as a low-energy water and wastewater treatment process. FO coupled with RO process, so-called hybrid FO-RO system, is drawing much attention in the desalination area because it has a great potential to decrease the energy demand significantly in the RO process. The real concern is whether the energy reduction in the FO-RO hybrid system can compensate for the increase of the capital cost and the energy demand of the overall system.

Korea has been conducting several big R&D projects on desalination since 2006. One mega R&D project, named SeaHERO project, built the capacity of 45,000 ton/day SWRO plant in 2014. In the following years, several subsequent desalination projects based on MD, FO, and RO technologies started. The FO-RO hybrid desalination project funded by Korea Ministry of Land, Infrastructure and Transport (MOLIT) was started on Dec. 2014. The main objective of the project is to achieve higher energy efficiency through combining FO and RO processes. In order to evaluate the effectiveness of the FO-RO hybrid system, pilot plant (1,000 ton/day) will be established.

The presentation provides a brief introduction of the project including background, research contents, and some research results.

Pressure assisted forward osmosis for volume minimization of reverse osmosis concentrate from a water reclamation plant

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Abstract

The use of forward osmosis (FO) is growing both in water desalination and wastewater treatment due to use of natural osmotic pressure of draw solution. In this study pressure assisted forward osmosis (PAFO) was used. The performance of FO and PAFO was investigated for the treatment of reverse osmosis concentrate (ROC) from a water reclamation plant in terms of volume minimization and safe water discharge. The water production was higher in PAFO by 9% and 29% at applied pressures of 2 and 4 bar than FO based on 90 hours of experiments with ROC. Granular activated carbon (GAC) pretreatment and HCl softening were used prior to application of FO and PAFO to reduce organic fouling and scaling. It reduced total organic carbon and total inorganic carbon by about 90% and about 85 %, respectively from ROC. This also resulted in a higher permeate flux. GAC pretreatment also adsorbed almost all organic micropollutants from ROC to below detection limit. In this study low concentration of draw solution (0.25 M KCl) was applied to directly use the KCl diluted by PAFO operation for fertigation. Studies showed successful use of 10 Kg/m^3 (0.13 M KCl) for fertigation. The diluted KCl was also concentrated from 0.13 M back to 0.25M KCl by membrane distillation process.

Pressure build-ups and drops of an 8040 spiral-wound FO membrane element

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Mr. Seungho Kookis a Ph.D. candidate at Gwangju Institute of Science and Technology (GIST). His research interest is mainly devoted to pressure-assisted forward osmosis in hybridization with reverse osmosis (PAFO-RO hybrid).

Abstract

Practical applicability of forward osmosis and reverse osmosis (FO-RO) hybrid process has been widely studied yet there are unknown hurdles in implementing FO membrane elements in the field. This study investigated the effects of initial feed (20–50 L/min) and draw flowrates (2–5 L/min) on the pressure build-ups and pressure drops (i.e. pressure differences between an inlet and an outlet) within an 8040 spiral-wound FO membrane element in serial configuration up to 3 elements employing single element-based tests. All tests were conducted at a fixed hydraulic pressure difference of 0.2 bar between the feed outlet and the draw inlet (higher pressure at the feed outlet) to prevent the FO element from rupturing (i.e. damaging the membrane leaves in the FO element). Then, desired flowrates were put into test. Averaged water fluxes of the FO element (i.e. $J_{w,ave}$) for varying feed and draw flowrates were found to be 20.93, 19.38 and 18.71 LMH at E1, E2 and E3 (first, second and third elements in a serial configuration), respectively, with averaged water retrieval of 5.23, 4.85 and 4.67 L/min. At fixed draw flowrates, feed flowrates did not affect the pressure drops in both the feed and draw channels. On the other hand, at fixed feed flowrates, the feed pressure drops showed a relatively consistent value regardless of draw flowrates and the element numbers in series whereas the draw pressure drops showed a significantly escalating pattern as the draw flowrate and the element number increase despite of such smaller flowrate variations than those of feed flowrates. These results critically address the importance of controlling and optimizing the draw flowrates for implementing FO membrane elements in FO-RO applications. Higher initial draw flowrate yields higher volumetric flow of diluted draw streams yet with higher feed and draw pressures required for proper and stable operation of the hybrid process, which in turn leads to the increase in operating expenditure (OPEX) of FO. Critical economic feasibility analysis should be conducted

to determine the maximum draw flowrate by minimizing the potential surcharge in FO OPEX.

Forward osmosis process for microalgae separation from water

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Abstract

The process of forward osmosis, characterized in low-energy consumption and low membrane fouling, has been increasingly penetrated into the field of microalgae separation from water. In this work, the permeate flux of microalgae is found not decreased with the increase of biomass density. To understand the effect of microalgae growth on separation of biomass from water, the chemical composition, Zeta potential, and secretion of extracellular polymeric substances (EPS) of *Chlorella vulgaris* cultured in the secondary water, are fully characterized during the whole period of cell growth. The results show that not only the protein content of cell, but also the polysaccharide content in the soluble EPS (SEPS) are the highest for those in adaptation growth phase, enabling that the water flux decline is the highest. The consistent increase of negative zeta potential of cell increases the stability of microalgae-water system, and the possible reduced reverse diffusion due to the initial inner membrane fouling allows that the water flux of biomass at exponential growth is higher even than the baseline with only the culture medium. The increase of cell density together with the variation of cell composition then allows the slightly lower permeate flux for microalgae growth at plateau phase than that during exponential growth phase, but still higher than the baseline. This work is endeavored to propel the integration of forward osmosis with traditional field of microalgae separation from water.

Influence of draw solution in causing severe scaling in the feed side of a forward osmosis system

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Abstract

Forward Osmosis (FO) is an osmotically driven membrane process. The driving force is being created by the difference in the osmotic pressure between a low concentration solution (feed side) and a highly concentrated draw solution (DS) flowing on both sides of a semi-permeable FO membrane, preferably on a counter current direction flow. Naturally-driven, the flux permeates through the membrane from the feed solution (FS) to the DS side. However, one the main problems facing the FO process development is the reverse salt flux (RSF) which consists of a transport of salt from the DS to the FS.

This study presents a new $CaCO_3$ scaling phenomenon occurred in the feed side of the FO membrane where there is no tendency of scaling to happen due to the nature of the feed water quality and the operating conditions. The main reason behind this finding was attributed to the type of the DS used. It was found that using ammonium bicarbonate as DS caused a severe scaling in the FS (seawater) due to the interaction between an anion reversely diffused from the DS and a cation present in the FS, causing a significant flux decline. The composition of the scaling layer was dominated by the solubility of salt formed by the paired anion and cation. A low solute concentration is actually enough to create scaling in an early stage of the experiments.

A deep characterization of the scale formed on the membrane surface has been performed and is presented in detail. Different membrane cleaning methods such as hydraulic cleaning have been investigated to recover the water flux. Hydraulic cleaning was very efficient (82%) when the scaling occurred on the top of the membrane surface of the active layer, however, when occurred on the back surface of the FO membrane, the hydraulic cleaning efficiency was significantly lower (36%).

Results of this investigation revealed that scaling in the FO scaling is quite different from the one typically observed in the reverse osmosis process which is mainly due to supersaturation of salts present in the feed side. These results will help to better select the most suitable DS for each specific FS in FO application.

Keywords: Scaling; Forward osmosis; Water desalination; Scaling; Draw solution, Reversible salt flux.

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Membrane fouling mechanisms in osmotically driven membrane processes

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Abstract

Osmotically driven membrane processes (ODMPs), represented by forward osmosis (FO) and pressure retarded osmosis (PRO), show great promise to leverage the global water-energy nexus and have drawn considerable attention in recent years. However, the performance of ODMPs in practical applications is significantly affected by membrane fouling that is a complex problem and associated with the foulant deposition, concentration polarization and reverse solute diffusion (RSD). This study is (1) to systematically elaborate the ODMPs fouling factors and mechanisms through a comprehensive review of existing literature from our group to the whole research community in this field, and (2) to explore intrinsic interrelationships among those fouling mechanisms with the assistance of a novel osmotic-resistance filtration model. The fouling factors and mechanisms in ODMPs are also compared with those in pressure-driven reverse osmosis (RO) and nanofiltration (NF). Among those fouling factors and mechanisms for ODMPs, some are also applicable for RO/NF, such as the cake-enhanced concentration polarization (CE-CP) mechanism. Some care unique for ODMPs, such as the effects of draw solution composition and membrane orientation, the internal concentration polarization (ICP) self-compensation effect, and the RSD-enhanced fouling. This study provides significant implications for the development of effective fouling-control strategies for ODMPs. Based on this study, future research needs are proposed for further studying the membrane fouling in ODMPs.

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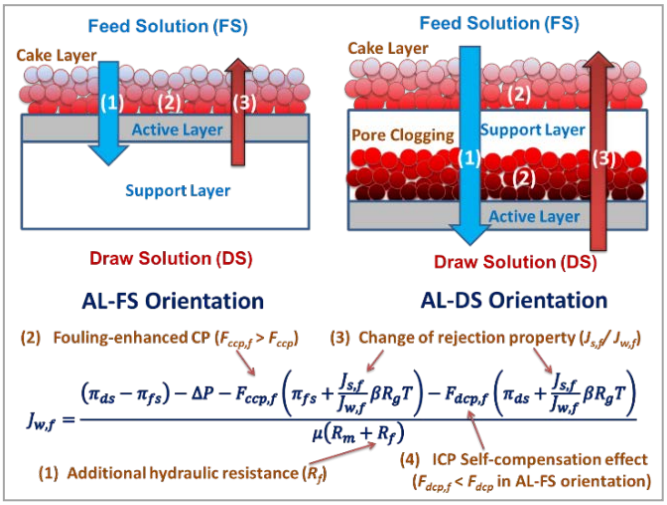

Figure 1. Comparison of the water permeability (J_w) in the two types of the HF membrane

Pressure assisted osmosis: advantages, opportunities and challenges

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Brief Bio of the presenting author

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Abstract

This presentation aims at evaluating the potential and limitations to improve flux in FO through the implementation of hydraulic pressure in the feed stream (i.e. pressure assisted osmosis (PAO)). PAO allowed for higher water flux and lower reverse salt diffusion (RSD). Membrane deformation was observed for all membranes in PAO operation; and the assessment of membrane mechanical resistance will be a key parameter to consider for further membrane development. Fouling tests demonstrated that the low fouling behaviour often mentioned for FO was due to operation so far at low permeation fluxes. With higher initial fluxes obtained in PAO, the fouling cake was found to be more compacted on the membrane surface and consequently significant flux decline was observed over time. Also, it was demonstrated that, at similar initial fluxes, fouling was more severe when a moderate hydraulic pressure (4 bar) was applied. To tackle the higher extent of fouling

observed, osmotic backwashing proved to be a promising cleaning strategy. Interestingly, novel FO membranes demonstrated improved rejection of the whole range of tested trace organic contaminants (TrOC) by steric rejection. Operation in PAO mode led to a general decrease of TrOC rejection, as a result of membrane deformation and less RSD. The PAO concept was implemented in as a pretreatment of desalination by reverse osmosis (RO), whereby an osmotic dilution of the seawater with wastewater occurs, offering the benefit of combining water recycling with a decreased energy demand of seawater RO. In that case, the economic model developed highlighted that further flux improvement is needed (>30 L.m-2.h-1) to lower investment costs down to an economically acceptable level for FO-RO hybrids to become beneficial, comparatively to standalone seawater RO.

Performance evaluation of a semi-pilot scale forward osmosis-reverse osmosis (FO-RO) hybrid system: various operation conditions

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Abstract

A FO-RO hybrid system has gained attention as novel energy saving water treatment and desalination technology. However, the most of previous FO-RO researches have focused on lab-scale or unit process because of high installation and operation cost of the semi pilot-scale FO-RO hybrid system, suitable area, lengthy duration and legislation problem. For optimization and commercialization of a full scale FO-RO hybrid system, the performance evaluation of a semi-pilot scale FO-RO hybrid system is required.

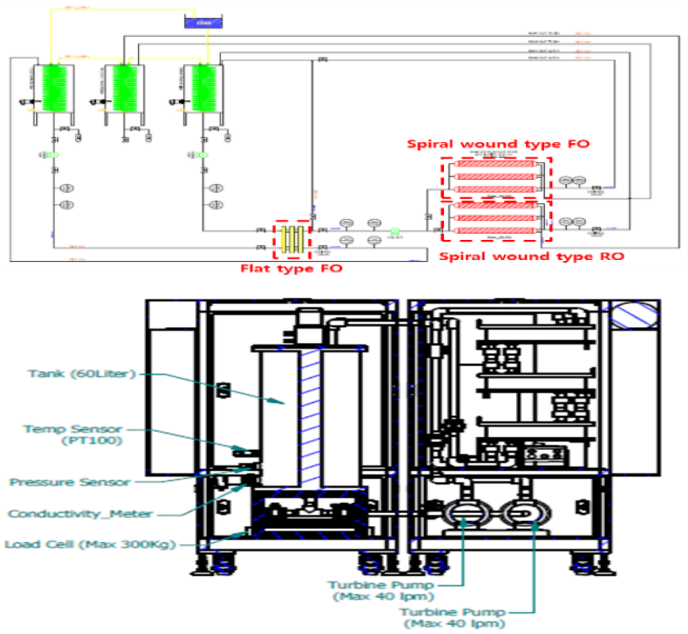

Fig.1. The design of semi-pilot scale FO-RO hybrid system

In this study, a semi-pilot FO-RO hybrid system was designed as a continuous operating mode (final RO permeate: 1 m^3/d) to find out the optimal operation conditions such as flow rate, draw solution concentration, etc. It will be useful to provide basic information (design and operation factors) of the FO-RO hybrid system for pilot plant engineers.

Forward osmosis for dairy processing – pre-concentration of dairy whey

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Brief Bio of the presenting author

Dr. Chen is a postdoctoral research fellow within the ARC Dairy Innovation Research Hub at the University of Melbourne. His research interests include separation and membrane technologies for dairy processing, wastewater treatment and gas separation.

Abstract

Dairy processing is the third largest rural industry in Australia where almost 10 billion litres of milk is produced annually, generating $13 billion in turnover. Each year, large quantities of milk and whey are processed to powder. In dairy processing, concentration and drying are the most energy intensive processes, demanding ~25% of the total energy consumption. Conventionally evaporative operations are utilized to remove 90% of the water during the concentration step, while the remaining 10% is removed during the drying process. As a result, there is a great interest in increasing

the total solids concentration prior to drying by means of less energy consuming unit operations. Conventional pressure driven membrane processes such as ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) are often applied as a pre-concentration step. Due to the rising osmotic pressure and the extensive fouling issues caused by the formation of protein deposits, these processes are limited by the maximum achievable total solid concentrations and the declining filtration efficiency.

Forward osmosis has been widely researched for desalination purposes, but only very limited studies have considered dairy applications. The approach has been reported to be more energy efficient and less susceptible to fouling compared to reverse osmosis. In this work, forward osmosis is used to pre-concentrate a variety of whey streams prior to thermal evaporative concentration and drying, for the production of whey protein concentrate, demineralized whey powder and lactose. The dairy streams are processed by Aquaporin flat sheet as well as cellulose acetate hollow fibre membranes using magnesium chloride as the draw solution. Although magnesium ions are known to be beneficial to human health, the reverse flux of magnesium ions is monitored carefully as it plays also an important role in potential membrane scaling. While total solids concentrations obtained from these membranes exceed what is generally achieved by NF and RO, the differences in membrane performance between the two membrane configurations will be addressed. To evaluate the reduction in energy consumption of the overall concentration step, the system efficiency of forward osmosis in response to feed stream total solids content and membrane fouling will be discussed.

FO-RO process treating wastewater from coal power plant: pilot-scale evaluation

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Choi is Ph.D. student at Korea University. His current research interest is seawater desalination and wastewater reuse using FO-RO integrate system.

Abstract

Forward osmosis (FO) is an osmotically driven membrane processes that can be used to simultaneously facilitate water reclamation and wastewater concentration with low energy consumption. Many previous studies of forward osmosis for wastewater reuse were conducted at bench scale, and should be further investigated in pilot scale to demonstrate its feasibility. The former studies highlighted the benefits of FO process to treat highly impaired water without incurring substantial irreversible membrane fouling. The main objectives of this study were to investigate, at a pilot scale, the performance of future osmotic dilution process in a dual barrier FO-RO configuration and the robustness of a commercial flat sheet FO membrane. Long-term water flux, fouling reversibility, permeation of dissolved organic matter (DOM) and energy consumption were evaluated during more than 3 months of continuous operation with wastewater feed of coal power plant. Comprehensive membrane autopsy and energy efficiency were also performed at the conclusion of the study. The SDI values of the seawater and the wastewater from the coal power plant were 5.4±0.4 and 6.4±0.5, respectively, showing that the fouling potential of both waters are critically high. Therefore, these waters need to be pretreated for sustainable desalination using RO. The high potential of membrane fouling of the wastewater was significantly decreased to 1.2±0.1 of SDI by FO filtration, whereas the SDI of seawater was lowered to 2.9±0.2 attributing to its dilution. The declined water flux induced by the organic fouling layer on the FO membrane due the wastewater feed solution was readily recovered (80%) by physical cleaning. Different from prior literature and modeling experimental data, to validate the feasibility of FO-RO integrating system, this study first reported energy consumption data at pilot scale. The energy consumption during the FO-RO hybrid process was around 15% lower than a typical single SWRO system at both bench- and pilot-scale. We also have investigated the quality of final permeate through the dual barrier process at pilot scale. The quality of final product satisfied all the water quality standards of cooling water in coal power plant. In conclusion, the results of FO-RO pilot study demonstrate that the sustainable FO-RO operation could be achieved for wastewater treatment from power plant in practical industry due to its easy fouling control, low energy use and high quality of the final product.

Fertiliser drawn forward osmosis process: processes and challenges

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Dr. Shon is an Associate Professor and ARC Future Fellow at the University of Technology Sydney (UTS). His research interests include physic-chemical water treatment, membrane processes for water purification and desalination.

Abstract

Operation of forward osmosis (FO) process at a pilot-scale level is still limited. In this study, fertiliser drawn FO-Nanofiltration (FDFO-NF) system was operated in the filed for about six months at a pilot-scale level for the desalination of saline groundwater water produced during the coal mining activities. Long-term operation of the FDFO-NF system indicates that although, high turbidity feed water could reduce the FO water flux for a short-term

however, the water flux can be almost fully recovered through simple physical cleaning without the need of a chemical cleaning. No fouling or scaling issues were encountered with the NF post-treatment process due to excellent quality of the feed water from the FDFO process. Test fertigation of the final product water from the FDFO-NF desalination system was carried out on the turf farm and potted tomato plants and the results indicate that, FDFO-NF is suitable for fertigation. However, loss of fertiliser nutrients through reverse solute flux was observed significant and hence could be one of the major challenges for in-land desalination especially for the concentrate management. High rejection FO membranes are therefore essential not only to reduce loss of fertiliser nutrient but also to reduce the eventual accumulation and build-up of feed salts such as Na^+ and Cl^- that reaches the DS during the continuously recycling and reuse of the DS by the NF post-treatment process which could affect the final water quality. A brief economic analysis indicates that, the application of FDFO-NF desalination system could be commercially viable for the turf farm during the time of drought compared to do-nothing scenario. However, the study shows that FO membrane need significant improvement to make the cost of FDFO-NF desalination system comparable to low pressure RO desalination process for similar saline feed water quality.

Resource recovery from municipal wastewater by forward osmosis based process: opportunities and challenges

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Brief Bio of the presenting author

Xiwang Zhang is currently Associate Professor at Monash University. His research interests focus on membrane and oxidation technologies for water and wastewater treatment.

Abstract:

Currently, aerobic biological processes are dominant in municipal wastewater treatment which consumes about 0.5-1.5 kWh/m^3 [1]. This poses a long-term threat to water industry. On the other hand, the major component of pollutants in municipal wastewater are organics, which are actually an energy source. The calorific value of wastewater is 0.0041 kWh/g COD [2]. This means that the energy present in wastewater is more than the energy consumed in the treatment process. In addtion, municiapl wastewater also contains large amount of nitorgen and phophorous, which cuase entrophication problem. To remove them requires complex process and additional energy. Therefore, to recover these nutirents which are the key compoments of fertilisers may be more desirable. However, the concentrations of organic, nitrogen and phophrous in municipal wastewater are too low so that it is not ecominically feasible to recover them directly. Forward Osmosis (FO) provides a possiblity to preconcentrate organic, nitrogen and phorphorous in wastewater into a small volume of concentrate, which makes it possible to economically fesible to convert organics to biogas and recover nitirents from the concentrate [3]. The permeate of FO unit also can be further treated to produce high quality fresh water and regenrate draw solution. The study summarizes the recent progress in wastewater preconcentration by FO for energy and resource recovery, and discusses the challenges in the field.

Coal mine water treatment by combined forward and reverse osmosis (FO-RO)

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Abstract

Environmental constraints prevent untreated mine water being discharged into water ways. Water management initiatives on site help to maximise the amount of water being reused and to minimise the volume discharged off site without harming the environment. Currently, reverse osmosis (RO) is one of the most commonly adopted and mature desalination technologies in Australia. Application of forward osmosis for coal mining impacted water treatment is limited. This study presents the development of an integrated pilot FO-RO system with 1 m^3/d capacity and evaluation of its performance in treating two actual coal mine waters. Both asymmetric cellulose acetate (CA) and thin film composite (TFC) FO membranes were used. Operational experience, optimum operating parameters, and considerations required for scale up are also evaluated. This study showed that The FO unit served as an effective pre-treatment system prior to RO by eliminating direct contact of the RO membranes with the raw mine water. The integrated FO-RO systems has a strong potential to successfully minimise conventional pre-treatment processes for RO in treating mine impacted water. Treated mine water was consistently well below 1 g/L of total dissolved solids that can be safely discharged or reused for some mine operations. The results obtained from the pilot trial strongly suggests that the choice of the FO membrane is one of the key aspects for successful application and development of FO technology.

Enhanced performance dual stage pressure retarded osmosis

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Abstract

Pressure Retarded Osmosis (PRO) has been proposed for power generation using high-concentration salinity gradient resource. To enhance the performance of PRO process, a second stage of PRO membrane was proposed for the treatment of diluted draw solution from first stage using a fresh feed solution. A computer model developed and validated using experimental data to evaluate the performance of a Dual Stage PRO (DSPRO) process using a variety of salinity gradient resources. Model results revealed that power density of the first and second stage of the DSPRO process was more than the minimum threshold of 5 W/m2 recommended for an economical PRO process. The net total power generation was also improved by 30% when a second stage DSPRO process was added. Furthermore, DSPRO process performed better when the membrane operated at PRO mode than at Forward Osmosis (FO) mode. However, reverse salt diffusion was higher when the DSPRO operates in PRO mode. The power consumption associated with the second stage of the DSPRO process was estimated 25% or less of the total power consumption in the DSPRO process. Therefore, DSPRO has the potential of improving the performance of conventional PRO process in the osmotic power plant.

Thin-film composite hollow fiber forward osmosis membrane by using aliphatic polyketone support

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Prof. Matsuyama is Professor at the Kobe University and Director at the Center for Membrane and Film Technology. His research interests include membrane technology for water treatment and gas separation.

Abstract

Forward osmosis (FO) is one of the attractive technology for the water treatment. FO process will begin to be installed a part of their processes. However, it still has some serious issues to prevent practical applications such as low water permeation rate resulting in higher initial cost. Therefore, FO membrane development is one of important factor to improve the FO emerging technology because the water flux is usually relatively low due to internal concentration polarization (ICP) in FO system. Consequently, the development of FO membrane was required in order to decrease ICP effect. In previous work, we have already successful fabricated high water permeability FO membrane of flat sheet type by using porous polyketone support [1)].

In this study, we fabricated hollow fiber (HF) type TFC FO membrane using same polymeric support. The active layer was formed on the shell-side of the support HF membrane *via* interfacial polymerization. To investigate the effect of HF support membrane diameter on FO performance of the prepared TFC-HF-FO membrane, two types of HF support (HF-A and HF-B) were used. Both diameter and thickness of HF-A were smaller than those of HF-B. Fig. 1 shows the FO flux (J_w) of HF-A- and HF-B-based TFC FO membranes in active layer facing to DS (AL-DS) orientation. Theoretical lines were also described using the intrinsic parameters of the prepared FO membrane calculated by FO fitting method [2)]. The HF-A-based FO membrane showed higher J_w because lower ICP effect was caused by smaller thickness.

Reference

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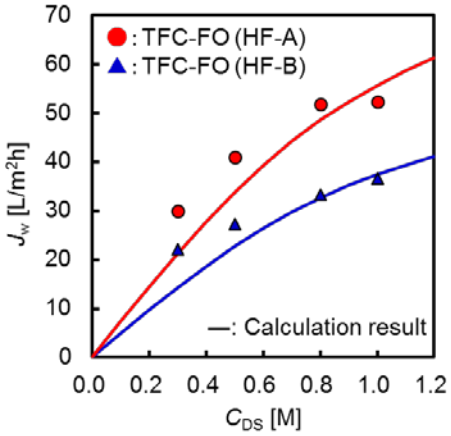

Fig 1. Comparison of the water permeability (J_w) in the two types of the HF membrane.

Effects of high salt concentrations on activated sludge used to treat concentrates from forward osmosis

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Abstract

Operation of forward osmosis (FO) process produces two water streams, i.e., diluate and concentrate. The hybrid system with FO and reverse osmosis (RO) frequently applies seawater as a draw solution and wastewater as a feed solution in FO process. Water molecules in the wastewater are drawn to the seawater, which generates wastewater concentrates. During the process, high strength of salts would be yielded in the FO concentrates due to the reverse salt flux (RSF) through membrane. Therefore, the high salts and also organic matter might have an effect on the biological process to treat the concentrates. In general, microbial activity is maintained stable with approximately 10g/L of salt concentrations in activated sludge process. The salt concentrations might be greater than 10 g/L in the FO concentrates depending on the specific membrane property. In this study, effects of salt concentrations on activated sludge in a membrane bioreactor are investigated. The concentrate produced from a pilot scale FO process is collected and analyzed for total dissolved salt (TDS), organic properties such as biochemical oxygen demand and chemical oxygen demand, and nutrients. The TDS concentrations are also compared with calculated values based on RSF of the membrane used in the pilot plant. A bench scale MBR will be operated to examine the treatability of the concentrates with high TDS concentrations.

Forward osmosis for the concentration of apple juice

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Brief Bio of the presenting author

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Abstract

Fruit juices are usually concentrated to reduce storage, transport and packaging cost and to extend their storage life. The concentration of fruit juices is mainly conducted using multi-stage vacuum evaporators. Nevertheless, the high temperature applied during the process results in significant degradation of juice flavor, color and nutritional quality. The capital and operating costs of vacuum evaporators are also considerably high. Thus, alternative concentration processes such as membrane based processes are being explored for the production of high quality fruit juice concentrates. One such technology that is completely non-thermal is forward osmosis (FO) membrane technology. This study investigated the feasibility of FO for the concentration of apple juice using NaCl, $MgSO_4$ and $MgCl_2$ as draw solutes. The influence of processing parameters such as draw solute type, concentration and temperature on process performance as well as reverse solute diffusion were studied. In addition, the effect of the process on juice quality parameters such as color, total polyphenol content, individual polyphenols, and flavor volatiles were evaluated. The highest flux at ambient temperature was obtained with $MgCl_2$ as a draw solute, closely followed by NaCl while the opposite was observed at higher temperatures. The reverse solute diffusion was the highest with NaCl, whereas very low reverse solute diffusion was observed both with $MgSO_4$ and $MgCl_2$, perhaps due to the higher diffusivity of Na^+ compared to Mg^{2+} ions. About 60% increase in the average flux was observed with increase in operating temperature to 40 °C, although further increase in temperature did not have significant effect. Reverse solute diffusion also increased with increase in temperature. Change in draw solute concentration had relatively less effect with about 28% reduction in the average flux observed when the draw solute concentration and hence the osmotic pressure difference was reduced by 50%. FO was effectively used to concentrate apple juice from 11°Brix to 45 °Brix, with no significant impact on color, individual and total polyphenol content as well as volatile profile, indicating that the process as a better alternative to evaporation for the production of high quality apple juice concentrates.

Forward osmosis process for the treatment of different mass flows in a dairy plant

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Brief Bio of the presenting author

Ms. Haupt is a research assistant and PhD student at the Technische Universität Dresden in Germany. Her research interest includes industrial wastewater treatment by membrane processes, especially forward osmosis.

Abstract

Research on forward osmosis (FO) covers many fields of application ranging from sea water desalination and drinking water production to the treatment of produced water and landfill-leachate. However, there are only few studies on forward osmosis being utilised in manufacturing industries.

The presentation will show our investigation on FO applications in a dairy plant. First, different mass flows typically found in dairy plants were analyzed and the potential for the use of FO was evaluated. This step included the determination of the osmotic pressure. As a result, the following fluids were found to be further pursued either as feed solution (FS) or draw solutions (DS) for the FO process:

- biologically treated wastewater which is currently reused after ultrafiltration and reverse osmosis (pretreated wastewater),
- salt water solution from cheese production (cheese brine),
- whey which is presently further treated by ultrafiltration, reverse osmosis, and evaporation to gain whey powder.

As a second step, various FO scenarios will be studied and presented at the conference. For this purpose, the identified dairy mass flows, deionized water, and sodium chloride solution will be utilized as FS or DS in different combinations. The investigations will be run at laboratory scale with an experimental set-up containing a FO test cell. Different FO membranes will be used, including a commercial TFC-FO-membrane and an Aquaporin-based FO-membrane. Furthermore, the influence of membrane orientation will be examined. As a result, the FO application potential in a dairy plant will be determined. Especially possibilities to improve existing water and mass flow cycles will be considered which would enable an ecologically and economically optimized production process.

Hydrogel composite monolith as forward osmosis draw agent

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Brief Bio of the presenting author

Ms. Ranwen Ou is a PhD candidate at Monash University. Her research interests include stimuli responsive membranes for water treatment, stimuli responsive materials for forward osmosis draw agent.

Abstract

Water desalination and purification are critical to address the global issue of the shortage of clean water. Forward osmosis (FO) desalination is an emerging low-cost technology for clean water production from saline water. The lack of a suitable draw agent is one of hurdle for the commercialization of FO desalination technology. Recently, the thermos-responsive hydrogel has been demonstrated to be a potential draw agent for the FO process. However, the commonly used hydrogel powder shows a much lower flux than other kind of draw agent such as inorganic salts.

The swelling pressure of hydrogel and the effective contact area between FO membrane and hydrogel are key parameters for achieving high water flux. In this work, we have demonstrated that the forward osmosis performance of hydrogels can be significantly improved by producing composite hydrogel monoliths containing commercial polyurethane foam (PUF), or thermoplastic polyurethane (TPU) microfibers to introduce capillary effect for enhancing water transport inside the monolith, as well as the swelling pressure of hydrogel. On the other hand, using of monolith form hydrogel as draw agent improves the effective contact area. By introducing PU foam, the hydrogel-polyurethane interpenetrating network (HPIPN) was formed. These HPIPN composites show a flux as high as 17.9 LMH, which is nearly 8 times than that of hydrogel powders (2.2 LMH). The high flux is attributed to the 3-D continuous hydrogel-polyurethane interpenetrating network, which can effectively enhance the water transport inside the monolith. By introducing TPU microfibers, microchannels were formed around the microfibers, resulting in much quickly water transport through monolith due to their hydrophilicity and capillary forces. The 1st hour FO water flux and dewatering flux of TPU-PSA are 1.81 and 3.51 $Lm^{-2}h^{-1}$, respectively, twice of those for PSA particles alone. The swelling property study indicates that addition of microfibers enhance water diffusion through the draw agent and sustain high swelling pressure, resulting in improved FO performance.

Investigation of the transmembrane electrical potential of a forward osmosis membrane

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Abstract: Understanding the simultaneous transmembrane electrical potential (TMEP) accomplished with the transport of water and reverse draw solute through a forward osmosis (FO) membrane is essential for the development and application of the emerging FO technology. The influences of membrane orientations, electrolyte species (NaCl, KCl, $CaCl_2$ and $MgCl_2$), draw solution concentration and concentration ratio of solutions at both sides of membranes on the TMEP in single electrolyte solutions were investigated. The TMEPs under different membrane orientations didn't completely coincide, which indicated the effect of membrane asymmetry on the TMEP. The TMEP increased with the increase in concentration ratio of draw solution to feed solutions. Diffusion coefficients of ions had remarkable effects and electrolyte species on TMEPs. The higher the difference of diffusion coefficients between cations and anions, the higher the TMEP for all four electrolytes. Furthermore, the TMEPs of univalent and bivalent salts showed diverging trends with the increase in draw solution concentration.

Keywords: forward osmosis; transmembrane electrical potential

Effluent organic matter (EfOM) removal and energy consumption of various pretreatment systems for osmotic dilution seawater ro desalination

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Brief Bio of the presenting author

Dr. Kim is a Researcher at the Korea Institute of Civil Engineering and Building Technology (KICT). His research interests include membrane processes for water purification and desalination.

Abstract

In these days, the recognized water production costs and energy requirements of seawater desalination by reverse osmosis (RO) have continued to be a hindrance to its application. Therefore, wastewater secondary effluent is used for osmotic dilution of seawater. It can be beneficial to make the RO system more energy-efficient by decreasing energy consumption and reducing the environmental adverse effects due to the dilution of RO brine. However, the effluent organic matter (EfOM), type of dissolved organic, which comprises proteins, polysaccharides, humic acid, was contained in the wastewater secondary effluent. The EfOM has caused organic fouling in the RO process. For the successful application of osmotic dilution process, several aspects regarding fouling are needed to be delineated and examined. In this study, the fouling behavior in the osmotic dilution process was studied and cost analysis of overall desalination processes including membrane cleaning was compared. Various processes including forward osmosis (FO) were used for pretreatment of enriched synthetic wastewater. Recovery of wastewater was set up 30, 50 and, 70%. SWRO was operated with the blending of treated solution and seawater. With applying above fouling control strategies, RO fouling tests were conducted for 12 to 48 hrs until recovery reached 50% and then flux decline rates were compared based on the initial flux of each case. Energy consumption during each RO with the pretreatments was calculated by operated pressure and measured feed water flux. Our results suggest that EfOM fouling can be effectively controlled by pretreatment processes such as NF or FO system. Particularly the osmotic dilution process by FO system is a non-pressurized membrane system and, thus, the energy consumption of overall desalination system was the lowest. In addition, the structure of fouling layer on FO membrane is relatively weak and reversible enough to be disrupted by simply hydrodynamic washing. Therefore, RO process with low salinity feed water through FO system is possible as a less energy consuming desalination system with efficient membrane fouling control.

Impact of reverse diffusion on membrane biofouling of fertilizer driven forward osmosis

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Abstract

Biofouling of fertilizer driven forward osmosis (FDFO) was investigated by spiking pure bacteria species *Pseudomonas aeruginosa PAO1+ GFP* into a FDFO system driven by two different fertilizers, namely KNO_3 and KH_2PO_4. The performance of FO system treating synthetic wastewater was determined, and the membrane fouling caused by different fertilizer draw solutes was

evaluated. FO membrane using KNO_3 as draw solute exhibited more severe flux decline (63%) than using KH_2PO_4 (30%). Correspondingly, both amounts of organic foulants and biomass on fouled membranes using KNO_3 as draw solute (947.5 mg/m^2 biopolymers, 72μL biofilm thickness and 3.5 mMol/L adenosine triphosphate) were significantly higher than that using KH_2PO_4 (440 mg/m^2 biopolymers, 35μL biofilm thickness and 2.2 mMol/L adenosine triphosphate). That was probably due to the higher reverse diffusion of KNO_3 (19.6 mMoL) than KH_2PO_4 (0.8 mMoL), which provided more nutrients for the bacteria to grow on the feed side of the FO membranes. Although FO membranes using KNO_3 and KH_2PO_4 draw solutes showed different membrane fouling, biopolymers are found to be the main component of fouling layer for both draw solutes.

KEYWORDS: Forward osmosis, Fertilizer, Reverse diffusion, Biofouling

Application of forward osmosis process in oilfield wastewater treatment under high salinity conditions

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Brief Bio of the presenting author

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Abstract

Forward osmosis (FO), as a developing type of osmotic driving membrane separation process, compared to other membrane separation processes, can be directly used in oilfield wastewater treatment under high salinity conditions. The pretreatment process is simple and can reduce the cost effectively, shorten the process flow, and has broad application prospects. Treatment effect of three membrane materials includes cellulose acetate membrane, sulfonated polyethersulfone membranes and polysulfone thin film composite membrane in oilfield wastewater under high salinity conditions was studied in this paper. The results showed that polysulfone membrane was preferentially selected with higher water flux and low solute backmixing flux. With the laboratory water distribution system, this paper studied the effects of the factors such as the concentration and type of the draw solution, the flow velocity, the operation mode and other factors on oilfield wastewater treatment under high salinity conditions. The results showed that the inorganic salt draw solution was more suitable for the oilfield water treatment system. In order to meet the industrial application, the paper took sea water as the draw solution, and the experimental results showed that the sea water is an ideal solution. The effect of oily wastewater treatment with different concentrations and the concentration degree of the high salt wastewater were studied in this paper so as to provide reference for the pretreatment process. A combined treatment process with forward osmosis as the core was built in laboratory in order to lay a theoretical foundation for the industrial application of oilfield wastewater treatment under high salinity conditions.

POSTER PRESENTATION DAY 1

A refined draw solute flux model in forward osmosis

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Bio of the presenting author

Ir. Arnout D'Haese is an academic assistant at the PaInT lab at Ghent University, currently finalizing his PhD. His research focusses on solute transport phenomena in FO.

Abstract

A detailed study of water and draw solute transport through FO membranes is presented. Flux tests were performed using CTA and TFC membranes (HTI) in both orientations using four draw solutes (NaCl, Na_2SO_4 , $MgCl_2$, $MgSO_4$). Fluxes were modeled using a novel model and using an FO-only approach. The membrane permeability coefficients and structural parameter were determined by model fitting for each draw solute and each membrane orientation, allowing a detailed comparison of membrane and draw solute properties.

It was found that the TFC membrane had a 6-fold higher water permeability (A coefficient) than the CTA membrane, but the draw solute permeabilities (B coefficients) were higher as well. This resulted in similar A/B ratios for both membranes, and conversely, measured fluxes were of similar magnitude. Furthermore, a decreasing water permeability of the CTA membrane was noticed with increasing draw solution osmotic pressure, however, draw solute permeabilities remained constant. The TFC membrane on the other hand showed variability for both water and draw solute permeability depending on the draw solute: Mg draw solutes caused a marked decrease in water permeability.

Draw solute flux across the active layer was described using novel equations, taking into account the concentration-dependence of draw solute diffusivity. This yielded improved model convergence, especially for AL-DS tests. The improvements were larger as the draw solute diffusivity in function of concentration showed more variability. Membrane characterization furthermore allowed the calculation of the apparent tortuosity. The apparent tortuosity was dependent on draw solute and membrane orientation, clearly showing that the apparent tortuosity is not only dependent on membrane properties. For the CTA membrane, realistic tortuosity values were obtained in AL-FS mode but were overestimated in AL-DS mode. For the TFC membrane, tortuosity was less dependent on membrane orientation but more on draw solute. It is hypothesized that this can be explained by a combination of electrokinetic effects and steric hindrance of draw solute transport in the active layer - support layer interface. The electro-viscous effect could partially explain the different behaviour between AL-FS and AL-DS modes, as the highest apparent tortuosity was obtained when the draw solute concentration in the support layer was the lowest. Finally, electrostatic interactions of the draw solutes with the active layer were considered and found to be small, although they yielded improved predictions of the J_w/J_s ratio.

Fertiliser drawn forward osmosis process: pilot-scale desalination of mine impaired water for fertigation

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Abstract

The forward osmosis (FO) process is a promising and emerging low energy desalination technology that works on the principles of natural osmotic process. Recently, FO has been investigated for a wide range of applications including desalination, wastewater treatment, reverse osmosis concentrate treatment, food processing, emergency nutritious drinks, pharmaceutical industries, etc. However, the application of the FO process for potable water desalination is still a challenge due to lack of an ideal draw solution (DS) that can be easily separated from the pure water and recover for regeneration and reuse. It irrefutably requires an additional process, which could consume energy. However, FO has been found to be ideal for those applications where the separation of draw solute and the water is not essential and where in fact the presence of the draw solutes adds value to the product water from the FDFO process. Fertiliser drawn forward osmosis (FDFO) process is one such applications where fertilisers are used as the DS and the diluted fertiliser solution can be directly applied for fertigation, therefore avoiding the need for separation and recovery of the DS.

Numerical investigation of hollow fiber forward osmosis membrane

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Brief Bio of the presenting author

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Abstract

Forward osmosis process draws attention as one of the promising membrane technology for desalination. To popularize forward osmosis process, novel membrane module is critical. Plate-and frame module, spiral-wound module, and hollow fiber module are widely researched for forward osmosis process. In this study, hollow fiber forward osmosis membrane was investigated using numerical modeling. Navier-stokes and convection-diffusion equations were used to evaluate solvent and solute transport. Using developed hollow fiber forward osmosis model, flow and concentration distribution were calculated considering internal concentration polarization and external concentration polarization. Based on the developed model, optimization of the hollow fiber membrane can be conducted in future study

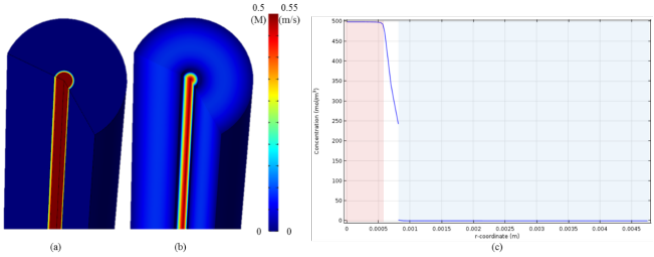

Figure1. (a) Concentration, (b) velocity distribution in membrane module and (c) concentration in according to radial direction

Relating the Solute propertiees of contaminants in emerging concern (cec) and their rejection in the forward osmosis process

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Mr. Jang is a Ph.D. candidate at the Korea Advanced Institute of Science and Technology (KAIST). His research interests include biofouling mechanisms and antifouling strategy for membrane processes.

Abstract

Utilizing unconventional water resources such as reclaimed wastewater has been widely accepted as a feasible alternative to augment water supply. However, the occurrence of contaminants of emerging concern (CECs) such as pesticides and pharmaceuticals in treated effluent is a major obstacle for the implementation of water reuse due to potential negative effects on aquatic ecosystems and human health. During the last decade, forward osmosis (FO) has received extensive attention as emerging technologies for water reuse and seawater desalination. Even though some researches have been carried out focusing on the rejection of CECs in FO, little knowledge is available on the interaction between solute properties and FO membrane. In this study, we investigated the rejection mechanism of hydrophilic (caffeine, acetaminophen, sulfamethoxazole) and hydrophobic compounds (naproxen, diclofenac, 2, 4-D) during the operation of FO process to reuse wastewater effluents. These compounds were fractionated further into different molecular weight. Overall, the flux decline was accelerated with low molecular weight CECs in FO membrane. The rejection efficiencies were higher than 98 % in tested CECs, and the solute hydrophobicity was not significant effect on the selected CECs rejection efficiency in FO process. The relatively high rejection of these CECs in the FO could be explained by the phenomenon of retarded forward diffusion of solutes. The reverse salt flux of NaCl hinders the diffusion and subsequent adsorption of the trace organic compounds within the membrane.

Osmotic versus conventional membrane bioreactors integrated with reverse osmosis for water reuse: biological stability, membrane fouling, and contaminant removal

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research topic is “water reuse by novel osmotic membrane bioreactors”.

Abstract

In this study, we systematically compared the performance of osmotic membrane bioreactor – reverse osmosis (OMBR-RO) and conventional membrane bioreactor – reverse osmosis (MBR-RO) for wastewater treatment and reuse. Results show that these two hybrid systems effectively removed bulk organic matter, nutrients, and all 31 trace organic contaminants investigated here. As a result, both of them could produce high quality water suitable for recycling applications. While stable biological performance was observed with conventional MBR operation, salinity build-up in the bioreactor was significant during OMBR operation. The observed salinity build-up was due to the reverse draw solute flux and the high salt rejection by the forward osmosis (FO) membrane. Salinity build-up in OMBR caused a reduction in water production and negatively affected the biological treatment by altering biomass characteristics and microbial community structure. In addition, the elevated salinity also increased soluble microbial products and extracellular polymeric substances in the mixed liquor, which in turn induced the FO membrane fouling. Nevertheless, microbial analysis suggested that salinity stress led to the development of halotolerant bacteria, thus restoring the biological performance of OMBR. In the OMBR-RO hybrid system, FO effectively prevented foulants from permeating into the draw solution and therefore significantly reduced the RO membrane fouling. By contrast, organic matter, including humic- and protein-like substances, as well as inorganic salts accumulated considerably in the MBR effluent, which caused severe membrane fouling to the downstream RO process during conventional MBR-RO operation.

Recovery of fresh water from magnesium chloride solutions via hollow fiber based vacuum membrane distillation

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Brief Bio of the presenting author

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Abstract

Magnesium chloride solution can be used in forward osmosis and liquid desiccant applications. The recovery of fresh water from the magnesium chloride solution is a critical step towards application of this technology. In our experiments, magnesium chloride solutions was pumped through PVDF hollow fibers subjected to varying feed inlet temperature, flow rate and vacuum set points in membrane distillation. Results showed that fresh water can be recovered from the system and the magnesium chloride solution can be regenerated/concentrated with high salt rejection in the separation process.

Integral Forward Osmosis-Membrane Distillation Process: Research Hype or Sustainable Solution for Water Reuse?

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Abstract

Water scarcity has been the growing concerns worldwide due to quick expanding in domestic, industrial, agricultural consumption, as well as climate change, water mismanagement, and water pollution caused by the human activities. Many countries and regions are now focusing on the non-conventional water source, such as seawater, wastewater from municipal, food and beverage, chemical, steel, mining and oil/gas industries. Conventional treatment technologies and processes, e.g. coagulation/sedimentation, cyclone, media filter, are difficult to satisfy the more and more stringent environmental regulations. Membrane technologies, such as reverse osmosis (RO), nanofiltration are limited to desalinate low saline and extensively pre-treated feed due to constraints in the osmotic pressure, fouling/scaling.

Forward osmosis (FO) is a desalination process driven by high osmotic pressure of a draw solution. Recent studies demonstrated that forward osmosis (FO) is intrinsically fouling reversible (compared to RO), suitable for high salinity feed, and requires low hydraulic pressure. However, the recovery of pure water from the draw cost much more energy than FO alone. Utilizing membrane distillation (MD) driving by the solar power or waste heat, FO-MD hybrid process has been used for a variety of wastewater streams.

When treating high salinity feed, the internal concentration polarization of FO membrane is crucial because the draw efficiency is low. Therefore, design of the forward osmosis (FO) membrane is important. In this paper, we will discuss a systematic research on designing of hollow fiber FO membranes to achieve a high flux of 20 LMH at a feed solution of 10 wt.% total dissolved salt from oil/gas industry. On the MD part, the MD membrane is in direct contact with an engineered simple draw solution, frequently composed of water and salt. Therefore, fouling or scaling is in principal not a major concern. However, the membrane flux and salt leakage is critical. We will report the state-of-the-art development

of superhydrophobic membrane as the potential candidate. The cost of FO-MD process will be evaluated in comparison to the distillation and RO processes.

Developing Energy-Efficient Seawater Desalination Processes by Integrating Forward Osmosis Membranes

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Brief Bio of the presenting author

Dr. Bae is an assistant professor of chemical engineering at Nanyang Technological University. His main research area is energy-efficient separation processes.

Abstract

Pressure-driven membrane-based processes, such as Reverse Osmosis (RO), is gaining worldwide acceptance in the desalination market due to their energy efficiency compared to other desalination processes. However, pressure-driven processes require energy input in the form of hydraulic pressure to drive the process, and the driving force also accelerates fouling issues. Forward Osmosis (FO), on the other hand, utilizes an osmotic gradient as driving force for water flux, and presents a solution that consumes less energy and has a lower fouling propensity. However the use of FO alone is limiting due to an energy intensive draw solution regeneration process. In this study done in collaboration between Hyundai Engineering and Construction Co. Ltd and Nanyang Technological University, FO-based seawater desalination processes are aimed to be designed and optimized for energy-efficient seawater desalination. In one of the potential configurations, seawater is used as draw solution and wastewater as feed to FO to produced dilute seawater which is then fed into RO that can be operated with low energy consumption. This system allows a simultaneous processing of wastewater reclamation and seawater desalination. In this project, various commercial FO and RO membranes have been tested and screened at the conditions relevant to real applications. After integrating membranes selected to a lab-scale hybrid FO-RO system, optimization of operation parameters has been carried out. Based on this preliminary work, we will also explore other configurations to develop energy-efficient seawater desalination processes. Subsequently, the potential feasibility of the system will be demonstrated by a pilot plant operation with the support from Public Utility Board in Singapore.

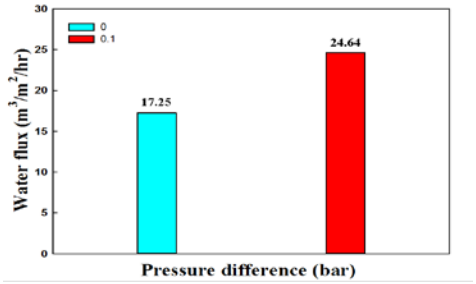

Fig.1 Difference of water flux according to pressure differ ences between feed inlet and draw inlet

Development of Pressure Retarded Osmosis (PRO) hollow fiber membrane modified with graphene oxide (GO)

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Brief Bio of the presenting author

Myoung Jun Park is a PhD candidate at the University of Technology Sydney (UTS). His research interests include thin film composite (TFC) membranes development for osmotically driven process such as forward osmosis (FO) and pressure retarded osmosis (PRO).

Dr. Shon is an Associate Professor and ARC Future Fellow at the University of Technology Sydney (UTS). His research interests include physic-chemical water treatment, membrane processes for water purification and desalination.

Abstract

Operation of forward osmosis (FO) process at a pilot-scale level is still limited. In this study, fertiliser drawn FO-Nanofiltration (FDFO-NF) system was operated in the filed for about six months at a pilot-scale level for the desalination of saline groundwater water produced during the coal mining activities. Long-term operation of the FDFO-NF system indicates that although, high turbidity feed water could reduce the FO water flux for a short-term however, the water flux can be almost fully recovered through simple physical cleaning without the need of a chemical cleaning. No fouling or scaling issues were encountered with the NF post-treatment process due to excellent quality of the feed water from the FDFO process. Test fertigation of the final product water from the FDFO-NF desalination system was carried out on the turf farm and potted tomato plants and the results indicate that, FDFO-NF is suitable for fertigation. However, loss of fertiliser nutrients through reverse solute flux was observed significant and hence could be one of the major

challenges for in-land desalination especially for the concentrate management. High rejection FO membranes are therefore essential not only to reduce loss of fertiliser nutrient but also to reduce the eventual accumulation and build-up of feed salts such as Na^+ and Cl^- that reaches the DS during the continuously recycling and reuse of the DS by the NF post-treatment process which could affect the final water quality. A brief economic analysis indicates that, the application of FDFO-NF desalination system could be commercially viable for the turf farm during the time of drought compared to do-nothing scenario. However, the study shows that FO membrane need significant improvement to make the cost of FDFO-NF desalination system comparable to low pressure RO desalination process for similar saline feed water quality.

Fertilizer driven forward osmosis as a low energy technology for sodium removal in greenhouse applications

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Brief Bio of the presenting author

Federico Volpin did his master thesis at *Technical University of Denmark in collaboration with* Aquaporin A/S. From December 2016 he will be a PhD fellow under Prof. Ho Kyong Shon at School of Civil and Environmental Engineering, University of Technology, Sydney (UTS).

Abstract

With the increasing pressure on the limited fresh water resources, good quality irrigation water is often not available for greenhouse growers, which increasingly are forced to use water with high sodium content. Sodium concentration particularly affects the quality of fertigation water, often decreasing yield and quality of the growing crops. Forward osmosis technology has recently emerged, among other membrane technologies, for its low fouling and low energy consumption. The concept of Fertilizer Driven Forward Osmosis (FDFO) has been investigated due to advantages of avoiding draw solution recovery. If successful, FDFO technology could be introduced as a low energy solution in the for water treatment in the greenhouse industry.

The objective was to investigate if FDFO has the potential to be a viable low energy solution for the removal of sodium in the fertigation water of the greenhouse industry. A proof-of-concept of the FDFO technology was conducted, using a commercial fertilizer, together with a feasibility study to test the hypothesis.

The results show that FDFO, as a standalone technology, has insufficient driving force to provide enough dilution of the fertilizer to meet the greenhouses requirements. Especially when high water recovery is targeted. Assisting the process with additional hydraulic pressure (PA-FDFO) has been deemed necessary to fulfill the water treatment targets. Pressure assistance, of up to 6 bar, was found necessary to overcome the expected range of osmotic pressure in the feed water. Moreover, positive effects on the membrane footprint and losses of fertilizer have been found by applying the additional hydraulic pressure. The FDFO set-up with Aquaporin Inside™ biomimetic hollow fibers membrane have shown 99% sodium rejection. However, the HF module used faced challenges in sufficiently retaining NH_4^+ and NO_3^-, resulting in a significant reverse salt flux. These results have been achieved using a commercial Ammonium Calcium Nitrate fertilizer. However, it is suspected that the loss of NH_4^+ ions have led to an increase in diffusion of NO_3^- anions to the feed side, as a result of maintaining the electro-neutrality of the system. In fact, by removing the NH_4+ and using pure Calcium Nitrate as draw solution, the SRSF decreased by 80% (0.08 g/L) meaning a significantly lower SRSF compared to published data on other commercial membranes.

The outcomes of a preliminary feasibility study show that the PA-FDFO technology could offer significant energy savings, up to 75%. However, these savings could potentially be offset by the cost due to fertilizer losses.

Investigating fertilizer drawn forward osmosis process for groundwater desalination for irrigation in Egypt

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Brief Bio of the presenting author:

Peter Nasr is an Environmental Engineering Researcher at the American University in Cairo (AUC). His research interests include Forward Osmosis, Desalination for Irrigation and water treatment.

Abstract

Groundwater desalination could be a possible solution to Egypt's scarcity problem through applying state-of-the-art desalination technologies. This work investigated a recently developed sustainable desalination technology which is Fertilizer Drawn Forward Osmosis (FDFO). In this work, ammonium sulphate was selected as a draw solution being a commercial, inexpensive and efficient Egyptian fertilizer. Three commercially available Forward Osmosis (FO) membranes were tested for baseline flux. Best membrane was selected for further experimentation. A real Egyptian brackish groundwater sample from El Tor in Sinai was used as the feed solution. Performance has been assessed by the water flux, reverse permeation and the forward rejection of the feed solutes. Porifera's commercial FO membrane proved to be the best

membrane with respect to baseline flux. It was chosen for further experimentation. Water flux and ammonium sulphate concentration can be correlated logarithmically. Further increase in ammonium sulphate concentration decreases water flux gradually due to increased severity of concentration polarization effects that take place at high draw solution concentration. Specific Reverse Solute Flux (SRSF) values did not exceed 0.18 g/l for both NH_4^+ and SO_4^{2-} ions, indicating high membrane selectivity. At flux exceeding 20 $Lm^{-2}h^{-1}$, NH_4^+ ion reported higher SRSF values than that of SO_4^{2-} ion, a phenomenon that could be justified thermodynamically. SRSF is almost constant irrespective of ammonium sulphate concentration. While increasing draw solution concentration lead to increasing Na^+ ion rejection, it caused a significant decline in Cl^- ion rejection. This phenomenon could be probably associated to an ion exchange mechanism and the membrane surface charge. In conclusion, the scheme studied showed that ammonium sulphate is an efficient draw solution for FDFO process using Porifera's commercial FO membrane exhibiting high osmotic pressure, low reverse solute permeation and remarkable rejection of feed solute.

Performance of a novel fertilizer-drawn forward osmosis aerobic membrane bioreactor (FDFO-MBR): Mitigating salinity build-up by integrating microfiltration

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Abstract: In this paper, three different fertilizer draw solutions were tested in a novel forward osmosis-microfiltration aerobic membrane bioreactor (MF-FDFO-MBR) hybrid system and their performance were evaluated in terms of water flux and reverse salt diffusion. Results were also compared with a standard solution. Results showed that ammonium sulfate is the most suitable fertilizer for this hybrid system since it has a relatively high water flux (6.85 LMH) with a comparatively low reverse salt flux (3.02 gMH). The performance of the process was also studied by investigating different process parameters: draw solution concentration, FO draw solution flow rate and MF imposed flux. It was found that the optimal conditions for this hybrid system were: draw solution concentration of 1M, FO draw solution flow rate of 200 mL/min and MF imposed flux of 10 LMH. The salt accumulation increased from 834 to 5400 μS /cm during the first 4 weeks but after integrating MF, the salinity dropped significantly from 5400 to 1100 μS /cm suggesting that MF is efficient in mitigating the salinity build up inside the reactor. This study demonstrated that the integration of the MF membrane could effectively control the salinity and enhance the stable FO flux in the OMBR.

Forward osmosis membrane module optimization in forward osmosis - reverse osmosis hybrid process

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Brief Bio of the presenting author

Dr. Choi is an executive director and head of Hyorim Industrial Technology Research Institute. His research interests include water treatment and seawater desalination. Also, he participated many national policy research.

Abstract

Nowadays, reverse osmosis (RO) is the most widespread technology in desalination market. However, RO require high energy consumption and it takes large portion of operating expenditure. To overcome this, numerous studies have been conducted to reduce energy cost in RO system. Among many studies, forward osmosis (FO) - RO hybrid system is the most promising technology since this process use osmotic pressure as a driving force. Therefore, in this study, we investigate optimized module arrangement in FO process in order to apply this technique to FO-RO hybrid system. We conducted semipilot experiment with three 8 inch FO module, see water and wastewater effluent are used as draw and feed solution. And we evaluate membrane performance with two different module arrange system.

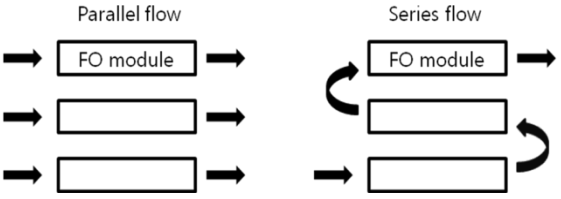

Fig. 1 Schematic diagram of FO module evaluation system

Forward osmosis membrane fouling index

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Brief Bio of the presenting author

Choi is Ph.D. student at Korea University. His current research interest is seawater desalination and wastewater reuse using FO-RO integrate system.

Abstract

Although the method (e.g., SDI and MFI) to assess fouling of the pressure-driven membranes (RO) is available, there is no measurement method and device to simulate fouling of forward osmosis (FO) membrane

accurately. Current methods, however, have considerable limitation because it could not reflect the actual non-pressurized FO operating conditions (i.e., driven by osmotic pressure). When FO membrane was operated by pressurization, the consolidation of fouling layer occurred, and the fouling reversibility which is one of FO membrane characteristics, was not observed. In addition, it is difficult to operate FO process by negative pressure as driving force. The non-pressurized FO operation could be simulated and the fouling reversibility could be measured by method and equipment in this study. It was demonstrated that FO membrane fouling was accurately simulated at appropriate osmotic pressure and the reversibility of fouled FO membranes was measured in a short time by accelerating fouling phenomena using high-concentration draw solution (DS). Accordingly, the FO membrane fouling could be quantified using so called osmotic fouling index (OFI).

Economic feasibility of osmotic power generation at the Gold Coast desalination plant

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Brief Bio of the presenting author

Mr. Azzuni is a Higher Degree Research Candidate at Griffith University. His research is focused on the generation of osmotic power through salinity differences as part of sustainability development.

Abstract

The Gold Coast Desalination Plant is a seawater reverse osmosis desalination facility designed to produce drinking water for the Gold Coast region and for the cities of Brisbane and Logan. The plant has a capacity of 125 ML day^{-1} and is located approximately 1.5 kilometers inland from the Tasman Sea. Previous studies have suggested that an osmotic power generation unit (Pressure Retarded Osmosis -PRO) could assist the Gold Coast desalination plant to reduce its huge external energy supply by generating power on-site from the mixing of desalination brine and seawater streams using a PRO system. In this study, the economic feasibility of osmotic power generation at the Gold Coast Desalination Plant is investigated assuming the use of commercially available membranes for PRO. This theoretical investigation is based on estimated values of the capital and running costs of a PRO unit, combined with the actual capital and running costs of the existing desalination plant. This study demonstrated that membranes are the main components of the capital and running costs of the PRO facility. The main conclusion falls in the category of recommending the development of a lower cost membrane to make PRO unit more profitable.

POSTER PRESENTATIO DAY 2

Ionic liquid used as draw solute for forward osmosis

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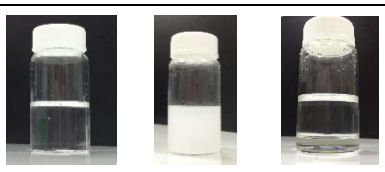
Brief Bio of the presenting author

Chih-Hsiang Fang is an Associate Research Fellow at Industrial Technology Research Institute (ITRI). His research interests include pressure driven processes, forward osmosis, membrane distillation and capacitive deionization.

Abstract

Forward osmosis (FO) is a novel desalination technology. The driving force of the water permeation from feed solution to draw solution through membrane is the osmotic difference between these two solutions. In considering the energy consumption and safety, development of a novel draw solute that have high osmotic pressure, non-toxic, low salt reverse diffusion and easy separation is critical. To meet these requirements, a $[P_{4444}][Mal]$ ionic liquid, which can induce phase separation spontaneously above some water concentration, was investigated as draw solute for forward osmosis in this study. The osmotic pressure of $[P_{4444}][Mal]$ ionic liquid, analyzed by Osmometer is 2~5 times higher than that of seawater. Moreover, the experimental results indicate $[P_{4444}][Mal]$ ionic liquid show that increasing water content will reduce its self-assembly to increase the conductivity at small water content. The results indicate $[P_{4444}][Mal]$ ionic liquid draw solution could phase separation spontaneously in the range of 50 wt% to 70 wt% water content at room temperature. In synthetic brine FO test, thin film composite (TFC) membrane (from Hydration Technology Innovations) was used and $[P_{4444}][Mal]$ ionic liquid was used as draw solute. In pressure retarded osmosis (PRO) orientation mode (active layer faced to draw solution, AL-DS), the water flux reached 3.7 and 2.5 $L/m^2/h$ when feed solution was 2000 ppm and 0.5M NaCl, respectively.

Table 1. Phase separation of different concentrations $[P_{4444}][Mal]$ ionic liquid at room temperature (partly)

IL concentration	10%	20%	30%
Photo			

Understanding the possible underlying mechanisms for low fouling tendency of the forward osmosis and pressure assisted osmosis processes

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Brief Bio of the presenting author

Mrs. Fezeh Lotfi is a PhD candidate at the University of Technology Sydney (UTS). Her research interests include physic-chemical water treatment, membrane processes for water purification and desalination.

Abstract

We investigated the possible underlying mechanism of the low fouling potential in the forward osmosis (FO) process during the osmotic dilution of seawater as part of the simultaneous desalination and wastewater reuse by FO and reverse osmosis hybrid system. Long-term experiments revealed an interesting water flux pattern highly dependent on the different operating parameters. The most interesting observation made was the spontaneous increase in the FO permeate flux at regular time interval during the FO operation using synthetic wastewater as feed and seawater. This sinusoidal FO flux pattern related well with the build-up of loose fouling layer and their natural peel-off from the membrane surface upon reaching certain layer thickness due to crossflow velocity shear. This flux pattern was more prominent at higher cross-flow velocity rates, lower feed water pH, for a smoother membrane surface and at lower operating pressure during pressure assisted osmosis (PAO) mode. Based on these results, membrane cleaning strategies were proposed by targeting a higher cross-flow velocity shear at a time when the permeate flux started to just increase. The approach of physical membrane cleaning was observed efficient and was able to almost fully restore the initial flux even under the PAO operation at 4 bar.

Effect of chlorine dioixde used for an alternative disinfectant agent on seawater reverse osmosis (swro) desalination process

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Brief Bio of the presenting author

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chlorine and chlorine dioxide on reverse osmosis membrane performance.

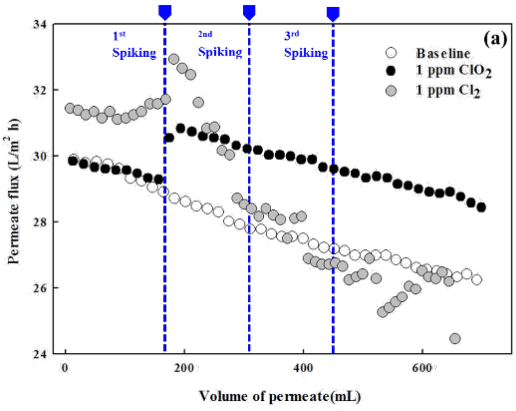
Abstract

One of the major concerns of the decrease in performance of RO membrane in seawater desalination process is biofouling. The most popular disinfecting agents used for biofouling control in the RO system include oxidizing biocides such as chlorine, chloramines, chlorine dioxide. Among them, chlorine is a traditional water disinfecting agent of choice, and it has been used effectively in cellulose acetate membrane systems. However, it has been informed that chlorine causes an irreversible deterioration on polyamide RO membranes in a very short time. Alternatively, chlorine dioxide concentrations of < 1.0 ppm were found to be much less damaging to the membrane than for chlorine. Thus, it may be that low concentrations of chlorine dioxide are effective for biogrowth control, and less damaging to the membrane. In addition, chlorine dioxide is known to produce less DBPs as compared to chlorine. In order to apply chlorine dioxide disinfection to actual SWRO process, the operation data, such as results of membrane performance test and of biofouling reduction test, is needed to be accumulated and analyzed. As preliminary experiments, we already examined the effect of chlorine dioxide on RO membrane performance. In this study, therefore, the other applicability assessment of chlorine dioxide in SWRO process was performed, and the assessment contents are below:

1) Reduction effect of biofouling in RO membrane.

2) Reduction effect of disinfection by-products (DBPs) in RO system.

As a beginning stage, several RO membrane performance tests were conducted.



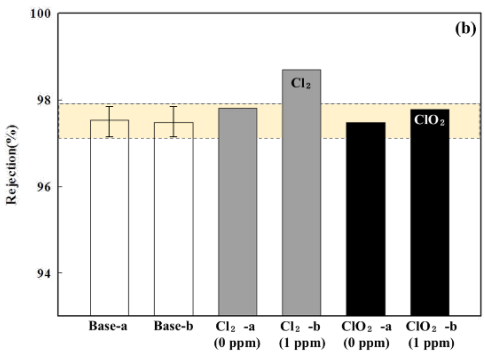


Fig. 1 (a) Permeate flux decline curves under 1 ppm Cl_2 and ClO_2 conditions, (b) comparison of salt rejection under 1 ppm Cl_2 and ClO_2 conditions

The permeate flux curves obtained through the test are shown in Fig. 1 (a). An instantaneous flux increase was observed right after the first Cl_2 spiking, but the permeate flux was severely decreased. The apparent aspect of permeate flux change by ClO_2 exposure on the RO system was remarkably different from that of the case of Cl_2. The ClO_2 spiking rapidly increased permeate flux, but the flux was not dropped down afterward. Each salt rejection was described in Fig.1 (b). Even though salt rejection changes in ClO_2 spiking case is shown to be increased, this is within the standard error range of the baseline cycle. Exceptionally, salt rejection in the Cl_2 spiking case was clearly increased.

Opportunities and challenges in application of forward osmosis in food processing

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Brief Bio of the presenting author

Dr. Rastogi is Senior Principal Scientist and Professor, Academy of Scientific & Innovative Research (AcSIR) at the Department of Food Engineering, Central Food Technological Research Institute, Mysore, India. His research interests include membrane processes for food processing.

Abstract

Food processing and preservation technologies must maintain the fresh like characteristics of the food while providing an acceptable and convenient shelf life as well as assuring safety and nutritional value. Besides, the consumers demand for highest quality convenience foods in terms of natural flavor and taste, free from additives and preservatives necessitated the development of a number of membrane based nonthermal approaches to the concentration of liquid foods, of which forward osmosis has proven to be most valuable. A series of recent publications in scientific journals have demonstrated novel and diverse uses of this technology for food processing, desalination, pharmaceuticals as well as for power generation. Its novel features, which include the concentration of liquid foods as at ambient temperature and pressure without significant fouling of membrane made the technology commercially attractive. This review aims to identify the opportunities and challenges associated with this technology. At the same time, it presents a comprehensive account of recent advances in forward osmosis technology as related to the major issues of concern in its rapidly growing applications in food processing such as concentration of fruits and vegetables juices (grape, pineapple, red raspberry, orange, tomato

Juice and red radish juices) and natural food colorants (anthocyanin and betalains extracts). Several vibrant and vital issues such as recent developments in the forward osmosis membrane and concentration polarization aspects have also been addressed. The asymmetric membrane used for forward osmosis poses newer challenges to account both external and internal concentration polarization leading to significant reduction in flux. The recent advances and developments in forward osmosis membrane processes, mechanism of water transport, characteristics of draw solution and membranes as well as applications of forward osmosis in food processing have been discussed.

Evaluating the membrane fouling formation and chemical cleaning in a forward osmosis membrane filtration process treating domestic sewage

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Brief Bio of the presenting author

Nur Hafizah is a PhD student at the University of Queensland (UQ). Her research interests include forward osmosis membrane based technology and wastewater treatment.

Abstract

Forward Osmosis (FO) is a new membrane filtration technology and recently has drawn lots of interests from the industry due to its ability to treat wastewater with lower operating cost, lower propensity of fouling formation and comparable contaminant rejection performance as Reverse Osmosis (RO) and nanofiltration (NF) technologies. This study has been conducted to analyse the characteristics of the membrane fouling formation in a long-term running FO unit to directly concentrate raw domestic wastewater. The efficiency of different chemical cleaning strategy (cleaning with deionised water, ethanol and Free Nitrous Acid (FNA)) on fouling control was also evaluated. The result of the preliminary study shows that both reversible and irreversible fouling formed while treating the raw domestic wastewater, in which deionised water flushing did not fully recover the membrane performance. The result of this study also suggested FNA was the most efficient cleaning reagent due to its higher flux recovery and ability in killing the microorganisms in comparison to deionised water without affecting the membrane structure. In addition, the exposure of the membrane to ethanol severely affected the membrane structure and stability, which eventually reduce the performance of the membrane in rejecting the contaminants. The outcomes of this study provide new insights for sewage filtration, resource recovery and chemical cleanings using FO membrane based technologies.

Utilization of Donnan potential induced by reverse salt flux in pressure retarded osmosis systems

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Brief Bio of the presenting author

Dr. Park is a scientist at the Korea Institute of Energy Research (KIER). His research interests include salinity gradient system and membrane fabrication of various types for pressure-retarded osmosis, forward osmosis, and various water purification including desalination.

Abstract

Pressure retarded osmosis systems extract the mixing energy of different salinities using water-semipermeable membranes. To recover the electrical energy from mixing energy, a PRO membrane sufficiently provides the mass transfer of water molecules exerted by driving force due to the difference in effective osmotic pressure. However, since actual PRO membranes cannot perfectly exclude salts, the salt flux reduces the energy efficiency as the irreversible energy loss. However, this study states for the first time that the salt flux can be directly converted into electrochemical potential. The electrochemical pressure retarded osmosis (E-PRO) system is analogues to geometries of PRO modules except for use of two electrodes. E-PRO extracts simultaneously both water mixing energy based on osmotic pressure (PRO) and electrochemical energy based on the Donnan potential of salt diffusion. The pumping energy loss is reflected to clarify the efficiency improvement of E-PRO. Using a single flat sheet PRO membrane coupon, the efficiency of E-PRO is improved higher than 7% at the positive net power. If E-PRO systems consists of alternative cation/anion selective membranes like reverse electrodialysis, its energy efficiency could be more improved by suppling sufficient electrochemical redox potential.

Dual-layered nanocomposite membrane based on polysulfone/graphene oxide for mitigating internal concentration polarization in forward osmosis

Sungil Lim[1], Myungjun Park[1], Sherub Phuntsho[1] and Ho Kyong Shon[1,*]

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Brief Bio of the presenting author

Mr Lim is a PhD student at the University of Technology Sydney (UTS). His research interests include fabrication of novel nanocomposite membranes for pressure-driven and osmotic-driven processes using carbon-based materials.

Abstract

A novel thin-film composite (TFC) forward osmosis (FO) membrane with dual-layered substrate support was fabricated by a double-blade casting technique using different polysulfone (PSf) concentrations for top (15 wt%) and bottom (7 wt%) substrate layers. Graphene oxide (GO) was incorporated in the substrate layer, and the dual casting approach resulted in a membrane support with a highly porous bottom structure and a dense top skin layer on which the polyamide active layer was effectively formed. The dual-layered TFC PSf/GO membrane (TFC-PSf_dGO) exhibited high water permeability, and ion selectivity was enhanced by the presence of well dispersed hydrophilic GO in the PSf substrate. The TFC-PSf_dGO also exhibited lower specific reverse solute flux (J_s/J_v=0.19 gL^{-1}) and a more favorable structural parameter (S=130 μm) compared to GO-free membranes. Using deionized water as feed solutionand1 M NaCl as draw solution (DS), TFC-PSf_dGO had J_v=33.8 $Lm^{-2}h^{-1}$ and J_s=6.9 $gm^{-2}h^{-1}$ under AL-FS mode, and J_v=61.5 $Lm^{-2}h^{-1}$ and J_s=14.0 $gm^{-2}h^{-1}$ under AL-DS mode. The potential of TFC-PSf_dGO for commercial application was further evaluated by fabricating it with a fabric backing support (denoted as TFC-PSf_dGO_f). Compared to TFC-PSf_dGO, TFC-PSf_dGO_f exhibited only 14% decline in its water flux. The overall results reveal that, fabrication of TFC membrane support via co-casting approach along with GO incorporation produced high-performance TFCFO membranes which likely reduced the internal concentration polarization effects.

Novel fabrication techniques for forward osmosis applications

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Brief Bio of the presenting author

Mr. Mehmet E. Pasaoglu (MSc) is a Res. Assist. in ITU Depart. of Environmental Eng. and Researcher at MEM-TEK. His main research interests include forward osmosis processes for PRO applications.

Abstract

Nowadays membrane design of reverse osmosis (RO) thin-film composite (TFC) membranes mainly required perm-selectivity, chemical resistance and better mechanical properties. However, RO membranes which have support layers limit performance in engineered osmosis through internal concentration polarization. Support layer structure will cause internal concentration polarization is valued by the structural parameter, S, given by $S= t\cdot\tau/\varepsilon$, where t, τ, and ε are respectively the thickness, tortuosity, and porosity of the membrane support layer. Membrane support layers can be produced via electrospinning technique with required mechanical transport properties. Micro or nanoscale fibers with high strength-to-weight ratios can be produced using electrospinning technique. Optimizing material selection and post-treatment of these fiber mats chemical and mechanical properties can be improved .

In order to produce nanofiber support layer sPSf polymer were used. Commercial Solvay-Udell® Polysulfone were synthesized using trimethylsilyl chloro- sulfonate because of lower chain scission characteristic and side reactions. While fabrication of TFC layer on nanofiber support layer meta-phenylene diamine (MPD) and trimesoyl chloride (TMC) solution were prepared using certain rations and required post treatment.

In this present study, nanofiber supported TFC FO membranes were successfully produced and tested under various pump ratios. Higher water flux (J_w) were obtained against low reverse salt flux (RSF) were measured using a standard FO test set-up.

Performance of a hybrid baffled ombr-mf system for simultaneous wastewater treatment and mitigation of ro brine discharge

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Brief Bio of the presenting author

Nirenkumar is a research student in the School of Environmental Engineering at the University of Technology Sydney (UTS). His research interests include wastewater treatment including membrane processes for water purification and desalination.

Abstract

Sustainability of water sources are threatened due to population growth, urbanization, climate change and environmental pollution. Also, there is an increasing

demand for better quality of effluents from wastewater treatment processes. The problem of eutrophication in closed water bodies, mainly caused by nitrogen and phosphorus in wastewater effluents, remains unsolved in many places. In this context, development of more efficient wastewater treatment process is crucial. In recent years, the concept of osmotic membrane bioreactor (OMBR) has been introduced and presents many advantages such as low fouling potential resulting in minimum cleaning and low energy consumption. The present study investigates the performance of an integrated osmotic and microfiltration membrane bioreactor system for wastewater treatment employing baffles in the reactor. Thus, the single-stage reactor design employed here combines both anoxic and aerobic processes to reduce the footprint and decrease energy costs of continuous aeration. The process performance has been evaluated in terms of water flux, salinity build up in the bioreactor, organic and nutrient removal and microbial activity using synthetic RO brine as draw solution. The incorporation of MF membrane was effective in maintaining a reasonable salinity level in the reactor (i.e. 672-1450 mg/L) which resulted in a much lower flux decline as compared to previous studies (i.e. 11.48 to 8.5 LMH in 10 days). This combined system can effectively remove organic matter (> 95%) and nutrient (PO_4-P > 90% and TN > 77%) respectively. The dissolved oxygen profile during the aerobic-aerobic cycle confirmed a level of < 0.5 mg/L oxygen concentration which was favourable for denitrification. The results obtained in this study clearly demonstrated the applicability of the proposed combined MF-OMBR baffled reactor.

The temperature-sensitive polymer With upper critical solution temperature (UCST)--Application and Development IN draw solution

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Brief Bio of the presenting author

Ms. Hsu served as an associate research fellow at the Materials and Chemical Laboratories, ITRI, Hsinchu, Taiwan. Her research interests mainly focus on the design and development of polymer materials/particles.

Abstract

The driving force for osmosis distillation (OD) depends on vapor pressure difference, whereas forward osmosis (FO) was driven by osmotic pressure, which could be processed with limited pressure or even without any external pressure.

The FO is a low-cost green separation and purification process with low-energy consumption. The OD/FO system depends on the research and development of draw solution. Currently, the FO has been applied to desalination, water purification, food processing, pharmaceutical industry and electricity generation. Thus, it is urgent to research and develop adequate draw solution.

In this study, we developed a biocompatible material with upper critical solution temperature (UCST), which has higher osmotic pressure than seawater. After drawing, the concentration of draw solutionwas decreased then the phase change temperature was increased to form a gel-type , which could facilitate water production.

The draw solution used in this study is PDMAPS. For FO system, the concentration (>30 wt%) and osmotic pressure are relative higher, and phase change temperature is lower than room temperature. The draw solution become sol-type and could draw water. While the concentration decreased (<30 wt%) and phase change temperature close to room temperature, it changed as gel-type, which could be recycled and produced water with low-energy consumption.

The water flux of this material is about 1 ~ 1.5 LMH, and has a low reverse diffusion properties (conductivity 25 ~ 150 μS / cm). On the other hand the osmotic pressure could rise 3 times via material modification experiments. We expected the capacity of water flux could be enhanced.

Comparison of submerged and side-stream osmotic membrane bioreactors in short term operation

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Brief Bio of the presenting author

Dr. Eyvaz is research assistant at Gebze Technical University. His research interests include physic-chemical water and wastewater treatment, membrane processes for water purification and desalination and membrane manufacturing and modification.

Abstract

Forward osmosis membrane bioreactors (FOMBR) can be designed and operated in submerged or side-stream configuration similar to conventional membrane bioreactors (MBR). In this study, submerged and side-stream MBRs in lab-scale were operated with novel tubular nanofiber FO membrane (TuNFO) for the treatment of high-strength synthetic domestic wastewater in 90-day-period. The both systems were coupled with a reverse osmosis (RO) system to polish the FO permeate (diluted draw solution-DDS). However, the concentrate of RO (concentrated DS) was transferred again to the TuNFO membrane as draw solution and the both systems

had no waste discharge during the operation. In submerged FOMBR, the membrane was immersed into the bioreactor and the draw solution was circulated through the inner part of the tubular membrane. However, in side-stream operation, a commercial ultrafiltration membrane (UF) employed in bioreactor and the UF permeate was sent to the external TuNFO membrane module as feed solution flowing through the outer surface of the tubular membrane. In both system, sodium chloride solution (0.5 M) was used as DS. In submerged mode, no fouling effect was observed, therefore no cleaning was made and high constant flux (~11 LMH) was obtained compared to conventional MBRs. In side-stream operation, the flux value of TuNFO membrane was very high (~90 LMH) and the membranes were cleaned using chemicals periodically because of the salt concentration in membrane due to the high water flux. High removal efficiencies were obtained for whole system for COD, TN and TP, 99%, 88 %, 100 % (for submerged), 99%, 92%, 100 % (for side-stream), respectively. There was no salt accumulation which is a big problem for osmotic MBRs in both configurations. The reason of that is the low reverse salt flux and salt permeability of TuNFO membrane from outside into the inside of the membrane.

Assessing fertilizer-drawn forward osmosis for coal seam gas (CSG) reverse osmosis (RO) brine treatment

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Brief Bio of the presenting author

Youngjin Kim is a Ph.D student at Korea University and University of Technology Sydney (UTS). His research interests include RO, FO and MD for water purification and desalination.

Abstract

Three processes including reverse osmosis (RO), fertilizer-drawn forward osmosis (FDFO) and the RO-FDFO hybrid process were investigated for treating coal seam gas (CSG) produced water to produce nutrient rich solution for irrigation and compared in terms of specific energy consumption and nutrient concentrations in the final product water. The results showed that FDFO has the lowest SEC followed by the RO-FDFO hybrid process and RO. The final nutrient concentration simulation suggests that the RO-FDFO hybrid process has lower final concentration, higher maximum recovery and lower nutrient loss than FDFO. Simulation results show that the RO-FDFO hybrid process is the most promising process for both CSG RO brine treatment and favorable nutrient supply. Membrane fouling in FDFO during CSG RO brine treatment was further investigated and the strategies for controlling membrane fouling were then evaluated. During CSG RO brine treatment, KNO_3 exhibited the highest flux decline due to the highest reverse salt flux while the most severe membrane scaling was observed with calcium nitrate, due to the reverse transport of calcium ions. To control membrane fouling in FDFO process, both physical cleaning and chemical cleaning were examined. Membrane cleaning with citric acid of 5% resulted in a complete flux recovery.

Effect of the functionalized carbon nanotube on performances of the thin-film nanocomposite membrane for the application of Integrating seawater desalination and Wastewater reclamation forward osmosis process

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Brief Bio of the presenting author

Dr. Choi is a senior research scientist at the Korea Research Institute of Chemical Technology. His research interests include environmental nanotechnology-based membrane and process for water purification, desalination, and gas separation.

Abstract

Development of forward osmosis (FO) membrane is a challenging study for a field application. FO membrane basically requires 1) high permeability and selectivity, and 2) high fouling resistance. Recently, a nano-enhanced membrane (NEM) is actively studied to an application of not only FO but also other membrane-based processes for water purification and desalination, which demonstrated a great potential to improve the membrane requirements as described above. Various nanomaterials were used for FO NEM fabrication. However, there is still a lack of studies for a field application of FO. In this study, thin-film nanocomposite membrane was fabricated via non-solvent induced phase separation and interfacial polymerization. A carbon nanotube (CNT) was chosen as a nanomaterial and this was functionalized before blending it in polyethersulfone support layer of the membrane. The membrane was characterized using scanning electron microscopy, Fourier infrared spectroscopy, zeta potential analysis, and water contact angle measurement. In lab-scale test, it was operated in integrating seawater desalination and wastewater reclamation FO process in order to evaluate membrane performances in the

integrating FO process, which was conducted for the first time. This study mainly investigated that the functionalized CNT conducted a dominant role of enhancement of permselectivity and effluent organic matter fouling resistance due to its hydrophilicity and negative charge.

Integrated management of olive fermentation brine and disgester centrate wastewaters by forward osmosis

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Brief Bio of the presenting author

J.L. Soler-Cabezas is PhD student at the Chemical Engineering Department of the Universitat Politècnica de València (Spain). His area of expertise is membrane technology; he is specialized in forward osmosis.

Abstract

In the processing of table olives there is a step in which sodium chloride is added to the olives. As a result, a fermentation brine of very high conductivity is produced. This fact makes its biological treatment very difficult.

On the other hand, in some Municipal Wastewater Treatment Plants the sludge produced in the primary and secondary settlers is treated in anaerobic digesters in order to stabilize the organic matter. As a result, a sludge with high water content is produced. This sludge is treated in a centrifuge and it is separated into two streams (solid fraction and liquid fraction). The liquid fraction resulting from the centrifugation is called digester centrate. Digester centrate is rich in nitrogen and phosphorus, compounds that can cause eutrophication if discharged to rivers or lakes causing an environmental problem. As these compounds can be used as fertilizers (for example, by estruvite formation), concentration of digester centrate could be advantageous.

Forward osmosis is a membrane technique than could be suitable to treat simultaneously olive fermentation brines and digester centrate. In this way, nutrients from digestate could be concentrated and fermentation brine could be diluted simultaneously. In this work, experiments with these streams as draw and feed solution, respectively, were carried out in a Sterlitech CF042 module with a HTI CTA-ES (cellulose triacetate; embedded support) membrane. Results showed that flux values ranged between 7.46 and 8.74 $L \cdot m^{-2} \cdot h^{-1}$ and no salt reverse flux was observed. Fouling was completely reversible and membrane permeability were restored after rinsing.

Study on the influence of the membrane orientation on the removal of boron in forward osmosis

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Brief Bio of the presenting author Dr. Yi is a PhD student at CSIRO. His research interests include membrane synthesis and membrane processes for water purification and desalination.

Abstract

In this paper, CTA-ES, CTA-NW and TFC-ES forward osmosis membranes in FO mode (active layer against FS) and PRO mode (active layer against DS) were respectively investigated with water flux, reverse draw solute flux, boron flux and boron rejection as index in order to study the influence of membrane orientation on the Removal of Boron. The results indicated that the water flux and reverse solute flux in PRO mode were 62.91%~260.56% and 0.85%~19.89% higher than those in FO mode, respectively, nevertheless, the boron rejection rate in PRO mode was 0.85%~19.89% lower than that in FO mode. In order to ensure the efficiency of boron removal and the quality of draw solution, the FO mode was preferred.

FORWARD OSMOSIS MEMBRANE COMBINED WITH ANAEROBIC BIOREACTOR FOR SEWAGE RECLAMATION AND ENERGY RECOVERY

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Brief Bio of the presenting author

Dr. Xia Huang is a Professor and State Key Joint Laboratory Director at the Tsinghua University. Her research interests include membrane and bio-electrochemical processes for wastewater treatment and resource recovery.

Abstract

With the rapid growth of economy and population, one of the limiting factors for sustainable development is water resources shortage. Sewage reclamation is one of countermeasures for solving this problem. Forward osmosis (FO) membrane is a potential and effective

process to water reclamation since it can exhibit remarkable removal efficiency for different contaminants, such as organics, nitrogen, phosphorus, salts and so on. Energy can be further recovered from sewage if FO membrane is combined with anaerobic digestion. In this research, forward osmosis membrane combined with anaerobic bioreactor (FO-AnMBR) was set up for sewage reclamation and energy recovery. Different concentration of NaCl solution was used as draw solution. The biogas production, effluent water quality and FO water flux changes during the operation were investigated. COD concentrations in the draw solution at different draw solution concentrations were in the range of 10-20 mg/L, with removals > 90% compared the raw sewage. Ammonia, TN, and TP concentrations in the draw solution were lower than 5 mg/L, 6 mg/L, and 0.3 mg/L, with removals higher than 85%, 90%, and 90%, respectively. Lower draw solution concentration benefited prevention the migration of organic matter, ammonia and total nitrogen from the anaerobic bioreactor to the draw solution side. Water flux decline over the operation was found, which implied membrane fouling occurred. The higher the concentration of draw solution was, the severer the membrane fouling happened. However, the higher draw solution concentration enabled higher treatment ability of the system at the same time. Based on the above results, draw solution concentration with 1 M was selected during the long-term operation. Stable membrane effluent quality can be maintained. Membrane fouling behaviour, biomass activity, and microbial community changes were investigated during the long-term operation.

Centre for Technology in Water and Wastewater (CTWW)

Overview of CTWW

The Centre for Technology in Water and Wastewater (CTWW) is a leading research centre in the field of alternative water sources. Our team is focused on the development of innovative technologies that deliver abundant supplies of recycled, desalinated and harvested storm water. While CTWW projects focus largely on urban water supplies, we also undertake research projects that respond to rural and regional water issues.

The growing global population and the relative scarcity of water as a resource is the driving force behind CTWW research. We seek to develop innovative and cost-effective water and wastewater technologies that can be applied in residential, commercial and industrial environments. CTWW has been consistently recognised for the development of world-class research in the water and wastewater field.

Our People

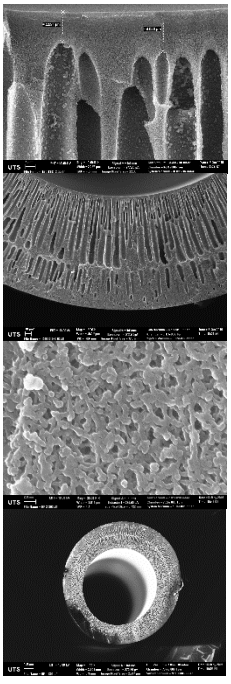
CTWW is composed of 14 full time core members and 5 associate members with Prof. S. Vigneswaran leading as the Centre Director with Prof. Hu Hao Ngo and Associate Prof. Hokyong Shon as the deputy centre directors. The centre has about 40 higher degrees by research students.

Forward Osmosis research at UTS

Forward osmosis is one of the major research activities at CTWW. Led by Associate Prof. Hokyong Shon and Dr. Sherub Phuntsho, this team has been working on this area for the last six years particular in the fertiliser drawn forward osmosis process for fertigation application. In this approach, fertiliser solution is used as a natural draw solution to extract water from the saline or impaired water sources to convert into nutrient rich water for fertigation of hydroponic greenhouse crops. The first FO pilot-scale test operation was carried out at one of the coal mining sites in Australia for the desalination of coal mine impaired saline water. Test fertigation was carried out on the nearby turf grass farm and potted tomato plants which yielded promising results indicating the technical feasibility of commercial applications. This project was funded by the National Centre for Excellence in Desalination Australia (NCEDA).

The work on the forward osmosis is now expanded to membrane fabrications including both flat-sheet and hollow fibre FO membranes including through the incorporation of nanomaterials such as graphene oxide and holloysite nanotube. The group also works on the application of forward osmosis for the wastewater treatment and reuse including through osmotic membrane bioreactors using fertilisers as draw solution for fertigation. Recently, the pilot scale fertiliser drawn forward osmosis process was applied for the treatment of secondary wastewater effluent using hydroponic solutions and tested its application for the successful growth of hydroponic lettuce in collaboration with the Sydney Royal Botanical Garden. Currently led by Associate Prof. Shon, there are two postdoctoral research fellows and 8 PhD students working in the forward osmosis and related field. CTWW also works on the application of FO process for the treatment of RO concentrate and this work is led by Prof. Vigneswaran.

The work on forward osmosis at UTS is also carried out in collaboration with other overseas universities and industries including King Abdullah University of Science & Technology, Korea University and Yale University.



Wastewater Treatment and Re-use Technologies

Research in this stream is divided into two key areas: storm water and wastewater. Our team is focused on the development of sustainable small to medium-scale decentralised water treatment systems. Unlike other research centres in this field, CTWW couples advanced membrane processes with advanced materials characterisation. We characterise a range of materials that pollute existing water supplies, including:

- pharmaceutical products
- poly-aromatic hydrocarbons
- heavy metals
- other organic compounds

Alternative Water Sources and Advanced Membrane Processes

Research in the Alternative Water Sources stream seeks to develop appropriate treatment systems for stormwater and saline water brackish/seawater. We are experts in the development of new desalting systems, including forward osmosis and membrane distillation. In the last six years, the centre has worked extensively in the application of forward osmosis process for irrigation. Our team also developed innovative pre-treatment systems that reduce the biofouling in the reverse osmosis membranes.

Catchment Water Resources and Socio-Hydrology

Researchers in this stream are part of a multi-institution, multidisciplinary collaboration into water catchment processes. Led by the University of Illinois at Urbana-Champaign, this socio-hydrology project looks at the relationship between humans and water flow patterns. The research team seeks to study, quantify, model and transport historical water catchment trends. Socio-hydrology expertise supports the delivery of sustainable water solutions in developing countries.

New Membranes and Materials Fabrication

New membranes and materials fabrication research looks at new generation membranes for water purification in desalination and wastewater projects. These include flat-sheet and hollow fibre forward osmosis membranes that use polymers and nanoparticles for increased efficiency. Our research team is also investigating the use of graphene as an emerging material for more efficient purification tools.

Technical Tour

A brief technical tour is organised during lunch session on the first day and second day. There are three optional short trips (30-45 min) which the delegate can choose from. Please remember to give your choice at the registration desk. The trip to the Central Park wastewater recycling plant is limited to 10 persons only and hence preference is given to first come first serve basis. If more delegates want to join this trip, it will be organised on the second day during the lunch time.

Technical tour to the CWTT lab

The CTWW environmental engineering labs facilitate high impact water and wastewater research. These laboratories are home to world-class equipment, which we share with a number of other universities and research organisations.

As well as bench and laboratory scale systems, we have a significant number of pilot scale installations. These allow our team to test their research and technology developments in real-world environments. We have also installed pilot scale facilities at the Sydney Institute of Marine Sciences.

Analytical instruments

- Total/dissolved organic carbon analyser
- Ion chromatography (IC)
- High performance liquid chromatography (HPLC)
- Inductively coupled plasma mass spectrometry (ICP-MS)
- Atomic absorption spectrometer (AAS)
- Microwave plasma-atomic emission spectrometer (MP-AES)
- Gas chromatography mass spectrometer (Triple quad) (GS-MSMS)
- Liquid chromatography mass spectrometer (Single quad) (LC-MS)
- UV-analyser
- Zetasizer
- Fourier transform infrared spectrometer (FTIR)
- Field-flow fractionation (FFF)
- Malvern 2000 particle size analyser
- Contact angle analyser
- Automatic sieving system
- Vacuum drying oven
- Drying oven
- Furnace oven
- Ultrasonic bath
- Merck spectrophotometer
- HACH spectrophotometer
- Inline pressure measurement system
- Automated titration system

Membrane and media filtration systems

LAB SCALE SYSTEMS

- Reverse osmosis system
- Lab scale direct contact membrane distillation system
- Lab scale cross flow micro-filtration, ultra-filtration and nano-filtration system
- Lab scale dead-end micro-filtration, ultra-filtration and nano-filtration system
- Lab scale modified fouling index and silt density index measurement system
- Lab scale electro spinning system for membrane fabrication
- Lab scale membrane bioreactor system
- Lab scale forward osmosis system
- Lab scale bio-filtration system
- Lab scale media filtration system
- Pilot scale stainless steel membrane filtration system

PILOT SCALE SYSTEMS

- Pilot scale membrane bioreactor system
- Pilot scale ultra-filtration system
- Pilot scale reverse osmosis system
- Pilot forward osmosis system
- Pilot scale vacuum membrane distillation system

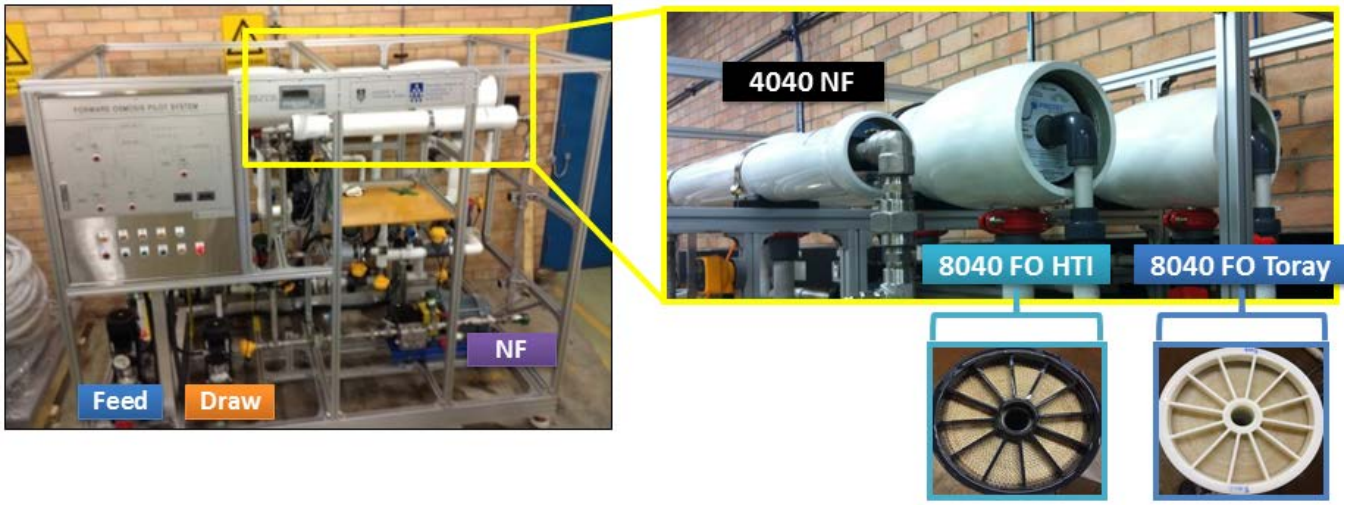
For further information:

Please visit the website http://www.uts.edu.au/research-and-teaching/our-research/technology-water-and-wastewater
Or contact the Director Professor Saravanamuth Vigneswaran (Saravanamuth.Vigneswaran@uts.edu.au) for further information.

Environmental Engineering Chemical and Biological Research Laboratories

Technical tour to the FO pilot-scale unit

The pilot unit consists of microfiltration (MF), forward osmosis (FO) and nanofiltration (NF) processes together to work independently. MF can be used as a pre-treatment of feed water or concentrated draw solution. Commercial grade fertiliser often contains some impurities including silt and some other suspended particles which need to be removed. FO process is made up of two numbers of 8040 FO membrane modules with single element each which can operate in parallel or in series. NF process consists of single element 4040 NE 90 NF module. The pilot unit was operated both at UTS lab and also in the filed at one of the coal mining sites that produce saline wastewater.



Technical tour to the Central park wastewater recycling facilities

Central Park Water

Central Park Water is wholly owned by Flow Systems and services approximately 5,000 residents and more than 15,000 workers and visitors daily.

Residents are saving about 50% of drinking water, saving money and precious drinking water supplies.

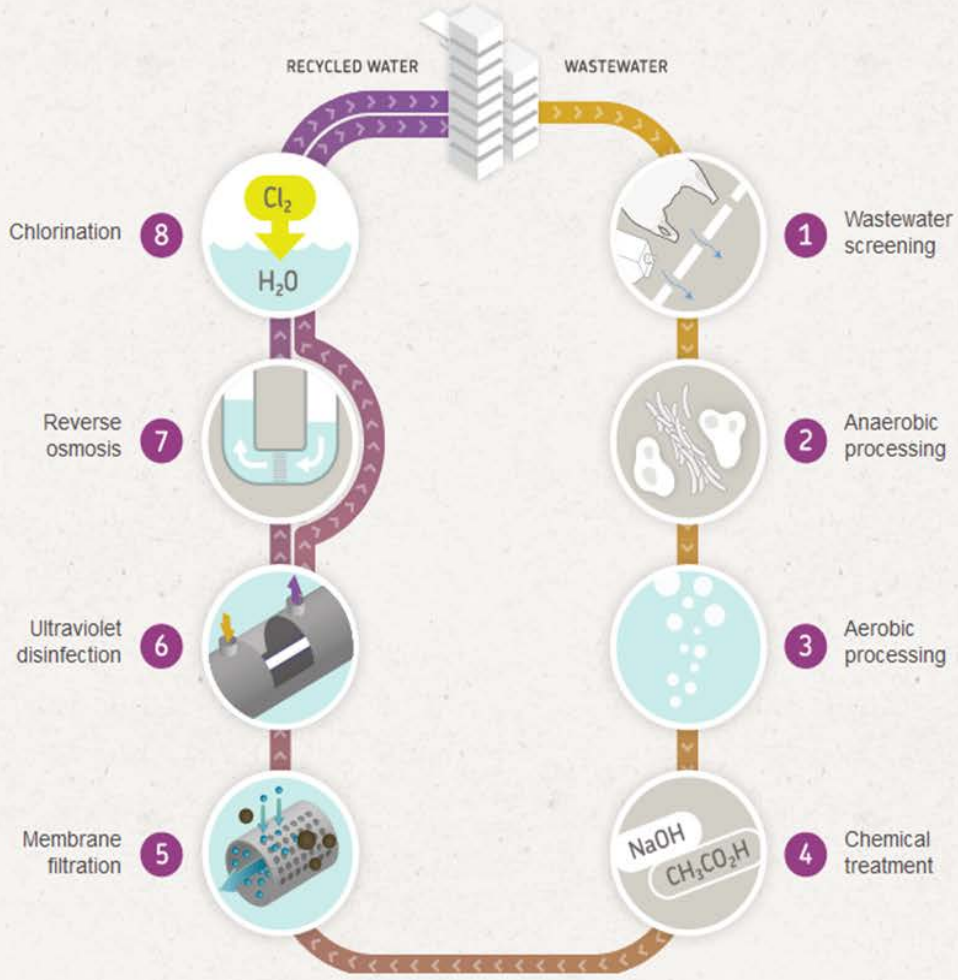
The plant is fully controlled remotely, it requires minimal space and does not smell or make any disturbing noise.

The recycled water network harnesses multiple water sources with varying qualities and creates multiple water supplies, covering all the water requirements of the community. The main water sources include rainwater from roofs, sewage from an adjacent public sewer and sewage from all buildings within the Central Park community. The main use of recycled water is for toilet flushing, washing machines, greenwall irrigation, car washing and cooling tower.

a local utility from flow systems

The purification process

Central Park Water's processes meet strict Australian Guidelines for Water Recycling set out by Federal and State Governments. Wastewater is cleaned to the highest Australian standards, undergoing eight extensive filtration and purification processes including Membrane Bioreactor (MBR), Ultraviolet (UV) and Reverse Osmosis (RO).



Ultimate plant capacity: **1 Megaliter/day**
3 critical control points: MBR, UV and Chlorination
MBR membranes get chemically cleaned every week
RO membranes get chemically cleaned every 2 months

a local utility from flow systems

Authos Index

NOTES FOR YOUR CONVENIENCE

International Forward Osmosis Summit 2016
University of Technology Sydney