Journal of Membrane Science & Research

journal homepage: www.msrjournal.com

Editorial Note

Membrane Science and Research: A Tribute to Professor Takeshi Matsuura

Dipak Rana

Guest Editor

Department of Chemical and Biological Engineering, University of Ottawa, 161 Louis Pasteur Street, Ottawa, ON, K1N 6N5, Canada

Email: rana@uottawa.ca (D. Rana)

This special issue is dedicated to honoring Professor Takeshi Matsuura for his vision that has embraced many aspects of membrane science and research. Professor Matsuura is currently an emeritus professor at the University of Ottawa, Department of Chemical and Biological Engineering. He has occupied this position since 2003, and Professor and Industrial Research Chair-holder of the British (Consumers) Gas/National Science & Engineering Research Council (NSERC) at the University of Ottawa and Director of Industrial Membrane Research Institute (IMRI) during the period of 1992-2002. He also worked at the National University of Singapore, in 2003; at Myongji University, Yongjin, South Korea, in 2008 as a visiting professor; at the University Technology Malaysia (UTM), Johor Bahru, Malaysia, in 2007 and 2009-2019, as a distinguished professor. A symposium of membrane gas separation held at the Eighth Annual Meeting of the North American Membrane Society (NAMS), May 18−22, 1996, in Ottawa, Canada, honored Dr. Matsuura together with Dr. Srinivasa Sourirajan. He was a recipient of the Research Award of the International Desalination and Environmental Association in 1983. He was also presented with the George S. Glinski Award for Excellence in Research from the Faculty of Engineering, the University of Ottawa in 1998. He was also the recipient of the honorary Ph.D. in engineering from UTM in April 2017. He is a fellow of the Chemical Institute of Canada (CIC) and a member of the North American Membrane Society (NAMS). He has routinely delivered many lectures at overseas research institutions and international conferences. He has published over 625 articles in refereed journals, authored and co-authored 6 books and edited 8 additional books. Professor Matsuura was born in Shizuoka, Japan, in December 1936, and he was awarded B.Sc. in 1961 and M.Sc. in 1963 from the Department of Applied Chemistry at the Faculty of Engineering, University of Tokyo, Japan. He received his Doktor-Ingenieur at the Institute of Chemical Technology at the Technical University of Berlin, Germany, in 1965. His works included the Department of Synthetic Chemistry, the University of Tokyo as a staff assistant and the Department of Chemical Engineering at the University of California at Davis, US, as a post-doctorate research associate. He also worked at the Division of Chemistry, National Research Council (NRC) at Ottawa, during 1969-1992.

This special issue consists of three letters of appreciation; Professor William J. Koros, Georgia Institute of Technology, Atlanta, US; Professor Nidal Hilal, Swansea University, Swansea, UK; Professor Ahmad Fauzi Ismail, University Technology Malaysia, Johor Bahru, Malaysia, as well as two review articles and ten research articles. A brief summary of the articles follows:

Kurihara and Ito conducted a review of the seawater reverse osmosis (SWRO) desalination that requires less energy compared with the distillation method and so is an important emerging technology. Recently, the Middle Eastern countries have been adopting the RO method in new desalination plants of the Mega-SWRO. By bringing together, a low-pressure SWRO membrane and a low-pressure two-stage high recovery SWRO system, 20% of energy reductions are possible. Less chemical along with less chemical cleaning enabling more reliable operation also leading to lower environmental impact particularly with green desalination. Harnessing low-cost renewable energy, particularly solar energy, will reduce the cost of seawater desalination to \$ 0.50/m^3/day or even less. The research concludes that the requirements for sustainable SWRO desalination as green desalination in the 21st century involve four key challenges as follows: (a) Energy saving, (b) Low environment impact, (c) Reliable plant operation, and (d) Low water production cost.

Chang and co-workers reviewed phenomena involving the fouling of membrane distillation (MD) in wastewater treatment and desalination. The biofouling of MD covered less significance compared to the organic and inorganic fouling. However, this was limited to operations nearing the boiling point of water. At elevated temperatures, the fouling of MD by inorganic materials became a serious issue due to deteriorating ion solubility. The membrane and system design from the perspective of materials and processes involved were addressed to provide insight into current and future advancements in MD technology for water recovery. The future trends for MD were projected based on current developments involving the MD process.

Li and co-workers investigated the summaries R&D activities, and progress on the preparation and testing of thin palladium (Pb)-based membranes and their applications. Hydrogen permeability, selectivity and stability were considered as important properties of membranes for hydrogen separation applications. This research included the work improving key properties of perm-selective membranes and developing reactors and processes utilizing such membranes. Albeit that both niobium and tantalum offer higher H_2 permeability and lower cost than palladium, their low resistance to oxidation and hydrogen embrittlement, even after being coated with Pd on their surfaces, prevented their practical use for purposes of hydrogen separation. A standard manufacturing process has been developed for large Pd-Ag alloy foil-based membrane modules, including a suitable sealing technique. The membrane module, which involves a double-sided panel of 0.15 m x 0.3 m surface area, was immersed in a fluidized bed reactor for the production of hydrogen from natural gas by the process of steam reforming.

Frappa and co-workers researched the application of a membrane condenser (MC) for water recovery as well as the removal of micro-particles from gaseous streams. The recovery of water depended upon the temperature and relative humidity of the fed gaseous stream, upon the temperature differential between the feed and the membrane module, and on the ratio between the rate of feed flow and the membrane area. Experimental tests performed on gaseous streams containing micro-particles demonstrated that these do not affect MC performance, either in terms of water recovery or in terms of fouling. The tests concluded that the complete retention of particles can only be done through the correct choice of the membrane, particularly with pore size lower than particle diameter.

Ebadi Amooghin and co-workers focused their research on a time-dependent 2D axisymmetric model of a multilayer hollow fiber (HF) composite membrane for gas separation. A HF type membrane module with four zones of feed, support, dense membrane and permeate was used to model the transport phenomena. Governing equations for species transport were developed for model domains and then solved by utilizing a finite element method. Gas permeation properties of pure H_2, O_2, N_2, CH_4, CO_2 and He are calculated and validated employing experimental data with a high level of conformity. The results demonstrated that, with increasing the temperature, the permeability and the diffusion coefficient of the pure gas components increased while solubility decreased.

Chen co-workers synthesized three different graphene-based materials, namely graphite oxide, thermally reduced graphite oxide and ascorbic acid multi-phase reduced graphene oxide, and used this to produce mixed matrix membranes (MMM) based on polyimide for gas separation using H_2, CO_2, O_2, N_2, and CH_4. The results revealed that the gas molecules were transported through the MMM in differing pathways depending upon the gas molecular size and MMM morphology, mainly involving the interlayer distance. The CO_2/CH_4 and H_2/CH_4 ideal selectivity's are reached values of up to 79.8 and 231, respectively. The expectation is that these membranes would be a good starting point to optimize a methane separation process or biogas upgrading/natural gas purification system. High selectivity for H_2/CH_4 and H_2/N_2 are signaling that these new membranes hold significant potential for several future applications, including hydrogen recovery from ammonia plants.

Xu and co-workers focused on research involving the use of commercial polypropylene (PP) and polyvinylidene fluoride (PVDF) HF membranes to explore the effects of their physicochemical properties on long-term CO_2 absorption performances in a bench-scale gas-liquid membrane contactor device. This research revealed that PP HF membranes with a pore size of 19 nm, the thickness of 0.046 mm, and porosity of 58% demonstrated a high CO_2 flux whereas PVDF HF membranes with a pore size of 24 nm, thickness of 0.343 mm, and porosity of 84% achieved good CO_2 separation performance from the simulated biogas. The PP membranes revealed a high CO_2 flux with pure CO_2 as feed whereas the PVDF membranes showed good CO_2 separation performance when using biogas. When water is used, there is a resultant flux drop, and using monoethanolamine as an absorbent for long term operation membranes resulted in a flux decline. However, for better performance using water as absorbent, omniphobic membranes should be developed to prevent wetting and fouling.

Kaya and co-workers research studied the applicability of nanofiltration (NF) membranes as a pre-treatment prior to reverse osmosis (RO) in seawater desalination using a mini pilot-scale located in Urla Bay-Izmir, Turkey. The membranes utilized were NF270 and NF90 as the NF membranes while the brackish water (BW) RO membrane BW30 was used as the RO membrane. The seawater desalination performance of the BW30 membrane was addressed both separately and involving integrated systems for the applicability of NF as a pre-treatment stage for BWRO for seawater desalination. The performance enhanced by the NF+BW30 integrated system combination was better than that of a single BW30 system. The calculated permeate fluxes for single BW30-35 bar, NF270-30 bar + BW30-35 bar, NF90-30 bar + BW30-25 bar, and NF90-30 bar + BW30-35 bar were 6.7, 11.3, 24.3, and 36.6 L/m^{2}h, respectively. The average boron rejection values for the BW30-35 bar, NF90-30 bar + BW30-25 bar, NF90-30 bar + BW30-35 bar were 49.6, 59.3 and 60.2%, respectively. The results revealed that the quality of product water obtained using single BWRO did not meet irrigation standards. Therefore, it can be concluded that the amount of water withdrawn from underground sources, especially for agricultural purposes, can be reduced by producing irrigation water from seawater.

Figueiredo and co-workers looked at integral asymmetric cellulose acetate (CA) membranes cast by phase-inversion with varying formamide content; 22, 30 and 34%, acting as pore promoter. The hydraulic permeability and molecular weight cut-off values of CA-22, CA-30, and CA-34, were 3.5, 32, and 81 kg.m^{-2}.h^{-1}.bar^{-1}, and 4.17, 8.32, and 31.43 kDa, respectively. The experimental apparent rejection coefficients for neutral solutes of increasing molecular weight were related to their intrinsic rejection coefficients through the film model. In reference to salts rejection, CA-22 displays rejection coefficients higher than 50% for the sulfate salts and lower than 20% for the chloride salts. However, both CA-30 and CA-34 membranes revealed very low values for all salts. For the CA-22 membrane, there were more free carbonyl groups and a larger fraction of free water, which were both able to interact with solutes, such as hydrated sulfate ions. The membranes with larger pores, CA-30 and CA-34, had water molecules that were organized with a liquid-water-like structure, in which most molecules were hydrogen-bonded to four or to two others. A fraction of water molecules was also strongly bonded to the CA carbonyl groups. Therefore, it was revealed that a CA ultrafiltration membrane had the capability for differentiating anionic species.

Amin and co-workers researched the effect of organoclay in the substrate layer on the performance of RO membranes. The polyamide selective layer was created on top by modifying the polysulfone substrate with different loading capacities of organoclay. The modified membranes showed significantly enhanced pure water flux and salt solution permeability, with values of 60.5 and 44.3%, respectively, without sacrificing salt rejection. The authors concluded that the addition of organoclay in the membrane matrix has improved water transport since it can provide more water pathways by making additional void space for water transport.

Shirazi and co-workers addressed some niches of the sweeping gas membrane distillation (SGMD) process opportunities applied to the bioethanol process in their research. Here, the SGMD process was performed using three commercial membranes made of PP, PVDF, and polytetrafluoroethylene (PTFE). The effect of operating parameters, specifically feed temperature, feed flow rate, feed concentration, and gas flow rate on the distillate flux have been studied and optimized. Moreover, the influences related to flow arrangement, specifically co-current, counter-current and cross-current, in the SGMD module were also minutely studied. The best performance was achieved utilizing a feed temperature of 65ºC, feed flow rate of 600 mL/min, a gas flow rate of 0.453 Nm^3/h, feed flow channel depth of 2 mm, and upon using a cross-current flow arrangement. Furthermore, this method has been used for sugar syrup concentration prior to the fermentation step in the bioethanol production process. Based on the results, it's clear that the PTFE membrane with a 0.22 μm pore size achieved the best performance.

Sengupta and Wickramasinghe studied the ability to selectively graft glycidyl methacrylate (GMA) from the external surface of regenerated cellulose (RC) ultra-filtration (UF) membranes using activator generated electron transfer (AGET) atom transfer radical polymerization (ATRP). Selective grafting from the external membrane surface was demonstrated by using an appropriate pore filling solvent prior to modification. Interactions of the pore filling solvent with the reaction solvent and initiator molecules were determined by the level of selectivity. These Dextran and BSA rejection tests revealed the selective modification of the external surface of the RC-UF membranes. The optimization of the experimental parameters for surface-initiated AGET ATRP demonstrated that an increase in the relative concentration of the reductant, ascorbic acid, to Cu provided sufficient control of the ratio of the two oxidation states of Cu to sustain the AGET-ATRP.

Hopefully, the readers will gain inspiration from this research and be impressed to excel in this fascinating research field, *Membrane Science and Research*. Lastly, we would like to thank Professor Matsuura for his pioneering contributions to this field of membrane research and wish him continuing good health and well beings.