DESALTECH 2015

Saturday, August 29, 2015 (Day Two)

Process Hybrids, Material Science, and Industrial Applications

ORAL PRESENTATION ABSTRACTS

9:10 AM – 9:40 AM	**Plenary Presentation: Desalination Needs and Opportunities in the Oil and Gas Industry.** Samer Adham, Ph.D., ConocoPhillips (Qatar)	
9:40 AM – 10:10 AM	**Plenary Presentation**: **Polymeric Membranes for Clean Water and Osmotic Power Generation.** Neal Chung, Ph.D., National University of Singapore (Singapore)	
	Track A *Industrial Applications*	Track B *Other Emerging Technologies*
10:40 AM – 11:10 AM	**A401. Keynote Presentation: Extraction of Water and Minerals from Coal Seam Gas Produced Water for Beneficial Uses.** Neil Palmer, National Centre for Excellence in Desalination Australia (Australia)	**B401. Keynote Presentation: Adsorption Desalination.** Kim Choon Ng, Ph.D., P.E., National University of Singapore and King Abdullah University of Science and Technology (Saudi Arabia)
11:10 AM – 11:30 AM	**A402. Influence of Draw Solution on Performance of Forward Osmosis Process for Shale Gas Wastewater Treatment.** Sungyun Lee, Ph.D., Korea Institute of Machinery & Materials (Korea)	**B402. Electrodialysis Metathesis to Prevent Scaling in Desalination of Gypsum-Rich Groundwater.** Thomas Davis, Ph.D., University of Texas at El Paso (USA)
11:30 AM – 11:50 AM	**A403. Use of Membrane Distillation for Treatment of Produced Water from Unconventional Onshore Gas Extraction.** Omkar Lokare, University of Pittsburgh (USA)	**B403. Electro-Distillation with Brine Bulb Technology–An Emerging Treatment Technology for Aggressive, High TDS Waste Streams.** Eric Dole, P.E., Hazen and Sawyer (USA)
11:50 AM – 12:10 PM	**A404. Zero Liquid Discharge Desalination of Oilfield Produced Water: Survey of Likely-Feasible Systems by Simplified Computations and Experimental Testing.** Essam El-Sayed, Ph.D., Kuwait Institute of Scientific Research (Kuwait)	**B404. Effect of Transverse Vibration and Aeration on the Mass Transfer and Crystal Formation in Submerged Vacuum Membrane Distillation and Crystallisation.** Helen Julian, University of New South Wales (Australia)
	Track A *Commercialization Landscape*	Track B *Process Hybrids*
1:10 PM – 1:40 PM	**A501. Keynote Presentation: The Singapore Commercialization Ecosystem.** Harry Seah, Public Utilities Board (Singapore)	**B501. Keynote Presentation: Challenges in Future Desalination: Brine Management.** Seung-Hyun Kim, Ph.D., Kyungnam University (Korea)
1:40 PM – 2:00 PM	**A502. Going Big with Forward Osmosis.** MaryTheresa Pendergast, Ph.D., Oasys Water (USA)	**B502. Polymer Enhanced Forward Osmosis: Exploration of the Potential of Branched Polyethyleneimine as Draw Solute.** Manki Cho, Korea Advanced Institute of Science and Technology (Korea)

2:00 PM – 2:20 PM	**A503. Process Commercialization Landscape for Forward Osmosis.** Erik Desormeaux, Porifera, Inc. (USA)	**B503. Design of Forward Osmosis/Reverse Osmosis Hybrid System for Saving Energy Consumption at Desalination.** Sangho Lee, Ph.D., Kookmin University (Korea)
2:20 PM – 2:40 PM	**A504. Aquaporin-Based Biomimetic Membranes for Reverse Osmosis and Forward Osmosis.** Jiang Wei, Ph.D., Aquaporin (Denmark)	**B504. Integrating Tunable Anion Exchange with Reverse Osmosis for Enhanced Recovery During Inland Brackish Water Desalination.** Ryan Smith, Ph.D., Lehigh University (USA)
	Track A Rooms 15a/15b *Commercialization Landscape*	Track B Rooms 14a/14b *Process Hybrids and Biofouling*
3:10 PM – 3:40 PM	**A601. Keynote Presentation: Brine Management and Zero Liquid Discharge Options.** Tom Pankratz, Water Desalination Report (USA)	**B601. Keynote Presentation: Role of Pressure Retarded Osmosis in the Mega-ton Project.** Masaru Kurihara, Ph.D., Toray Industries (Japan)
3:40 PM – 4:00 PM	**A602. High Recovery, Low Fouling, Low Energy Reverse Osmosis.** Rick Stover, Ph.D., Desalitech (USA)	**B602. Self-Sustained Microbial Electro-deionization Cell for Desalination and Wastewater Treatment.** Noura Shehab, Ph.D., King Abdullah University of Science and Technology (Saudi Arabia).
4:00 PM – 4:20 PM	**A603. Brine Reuse Desalination Using Forward Osmosis Technology.** Sophie Walewijk, Ph.D., Trevi Systems (USA)	**B603. Magnetic Pickering Emulsions Coupled to Membrane Filtration for Fouling Free Oil/Water Separation.** Alexander Dudchenko, University of California, Riverside (USA)
4:20 PM – 4:40 PM	**A604. Pilot Testing of an Integrated Mechanical and Membrane System in a Steam-Flood Produced Water Treatment Application.** Arian Edalat, Ph.D., Water Planet Engineering (USA)	**B604. Radioluminescence Membrane Biofouling Control: Generating Germicidal UV Radiation Inside Membrane Modules Using X-rays.** Ezra Cates, Ph.D., Clemson University (USA)
4:40 PM – 5:00 PM	**A605. Membrane Distillation: Ready for the Market? Comparative Assessment of Commercial Systems.** Guillermo Zaragoza, Ph.D., Plataforma Solar de Almería – CIEMAT (Spain)	**B605. Forward Osmosis/Low Pressure Reverse Osmosis Hybrid for Indirect Desalination of Seawater.** Zhenyu Li, Ph.D., King Abdullah University of Science and Technology (Saudi Arabia)

9:10 AM – 10:10 AM

PLENARY SESSION

Moderated by **David Furukawa**, National Centre of Excellence in Desalination Australia (NCEDA)

Desalination Needs and Opportunities in the Oil and Gas Industry
Presented by Samer Adham, Ph.D., Manager of Water Solutions, ConocoPhillips (Qatar).

Water management touches most segments of the petroleum industry, including upstream extraction and downstream refining operations. ConocoPhillips (COP) produces oil and gas from its diverse portfolios including: conventional and unconventional reservoirs, oil sands, and liquefied natural gas (LNG) production. Examples of water technologies being applied or under evaluation by COP include: (1) LNG operations: Gas field operations in Australia and Qatar produce large volumes of produced and processed waters (PPW). Due to regulatory constraints on water disposal, the PPW streams are being treated to reduce disposal volume and/or permit reuse as irrigation or process water. Treatment technologies include MF/RO in Australia and MBR/RO in Qatar. (2) Oil sands: The hot produced water (HPW) generated from oil sands operations in Canada is treated by warm lime softeners and weak acid cation exchange before the once through steam generator (OTSG). There is a recent paradigm shift for desalinating the HPW using thermal evaporators to feed drum boilers for improved efficiency and reduced operating cost. (3) Conventional: During water flooding to enhance oil production, seawater can be partially desalinated by RO/NF membranes to reduce salinity/sulfate levels and maximize oil recovery while minimizing scale and biogrowth when injected into the reservoir. (4) Unconventional: There is a growing interest in utilizing hypersaline groundwater and/or flowback for fracking operations. Various membrane and non-membrane technologies are being evaluated for partial or complete desalination of such challenged waters. This presentation will also provide COP test data from recently evaluated technologies including membrane distillation, forward osmosis and humidification-dehumidification.

Polymeric Membranes for Clean Water and Osmotic Power Generation
Presented by Neal Chung, Ph.D., Professor and Provost's Chair, National University of Singapore, Singapore (Singapore).

Clean water, clean energy, global warming, and affordable healthcare are four major concerns globally resulting from clean water shortages, high fluctuations of oil prices, climate changes and high costs of healthcare. Clean water and public health are also highly related, while energy is essential for sustainable prosperity. Among many potential solutions, advances in membrane technology are one of the most direct, effective and feasible approaches to solve these sophisticated issues. Membrane technology is a fully integrated science and engineering discipline which consists of materials science and engineering, chemistry and chemical engineering, separation and purification phenomena, environmental science and sustainability, statistical mechanics-based molecular simulation, process and product design. In this presentation, we will introduce our efforts on membrane development for clean water production and osmotic power generation to solve water scarcity issues and enhance energy generation from reverse osmosis (RO) brine. Our recent technology breakthroughs on UF, NF, FO, MD, draw solutes, and osmotic power will be highlighted.

10:40 AM – 12:10 PM

TRACK A – INDUSTRIAL APPLICATIONS

Abstract #A-401

Neil Palmer, CEO, National Centre for Excellence in Desalination Australia (Australia)

Extraction of Water and Minerals from Coal Seam Gas Produced Water for Beneficial Uses

Australia's eastern states suffered the worst drought on record from 1997 to 2010. Decisions to build $A13b worth of seawater desalination infrastructure from 2004 to 2012 in all mainland state capital cities were questioned following flooding rains in 2011 and above average rainfall that has followed. The program of construction was rapid (8 years for all plants including permitting), the plants are all able to be powered by renewable energy (wind and solar) and the high environmental standards have protected the marine environment from harm from intakes or concentrate return. Economic modelling for NCEDA undertaken by Deakin University has shown that in the long term (100 years) the desalination plants will significantly reduce the unit cost of water. Increasing demand and competition for traditional fresh water means the provision of water from the sea mitigates the risk of higher cost of water from market forces and new, harder to get supplies. The high cost of water restrictions is also avoided with climate independent supplies. Then there is impact of climate change: warmer temperatures, longer and more severe droughts interspersed with more extreme storm events: more uncertainty. Desalination plants will be increasingly seen as essential components of the portfolio of supplies to modern coastal cities. However, in Perth, the drought never broke and the two large seawater desalination plants operating at 100% are seen as base load, supplying half of Perth's drinking water. The NCEDA's first five year tranche of research projects covering pretreatment, reverse osmosis, novel desalination, concentrate management and social, environmental and economic issues is heading towards completion. Advances in understanding of common operating problems including biofouling and higher recovery, and innovations with commercialisation pathways including membrane coatings, forward osmosis, use of novel materials like graphene for capacitive deionisation, use of renewable energy to power desalination and biomimetics will be described in a summary of the research effort.

Abstract #A-402

Sungyun Lee, Ph.D., Senior Researcher, Korea Institue of Machinery & Materials (Korea)

Influence of Draw Solution (sodium chloride, ammonia-carbon dioxide) on Performance of Forward Osmosis Process for Shale Gas Wastewater Treatment

Exploration of shale gas industry has rapidly expanded in recent years with improvements in horizontal drilling and hydraulic fracturing technologies. Water demands and wastewater treatment during shale gas production are main challenges for economical and environmentally sound gas production. Because of high salinity of the wastewater ranging from 10,000 to 200,000 mg/L, it is difficult to treat wastewater with conventional treatment processes. In this study forward osmosis (FO) process was investigated for shale gas wastewater treatment. FO process yields concentrated wastewater and diluted draw solution. The reduction of wastewater volume can save truckloads for disposal at an offsite underground injection wells. In addition, the diluted draw solution can be directly reused for hydraulic fracturing or purified water is produced from draw solute recovery system depending on the type of draw solution. Typically,

shale gas wastewater contains high salinity, suspended solids, emulsified hydrocarbons and hardness. Although FO process is considered less susceptible to fouling compared to pressure driven membrane processes such as NF and RO, water flux of FO membrane could decline due to inorganic fouling such as CaCO3 by hardness of the wastewater. Considering reverse salt diffusion of draw solute, severe inorganic fouling is expected when ammonia-carbon dioxide draw solution is used for draw solution. The effect of draw solution on performance of FO process was investigated using two representative draw solutions, sodium chloride and ammonia-carbon dioxide. Reversibility of scaling and strategy for FO process application in shale gas wastewater treatment were discussed.

Abstract #A-403

Omkar Lokare, Doctoral Student, University of Pittsburgh (USA)

Use of Membrane Distillation for Treatment of Produced Water from Unconventional Onshore Gas Extraction

Hydraulic fracturing used for natural gas extraction from unconventional onshore resources generates large quantities of produced water that needs to be managed efficiently and economically to ensure further development of this industry. The most common solution for produced water management is disposal by deep well injection, which has led to increasing number of seismic events. The industry is now striving to reuse the produced water for hydraulic fracturing, which is feasible only if there are sufficient numbers of new gas wells. This study is designed to evaluate membrane distillation technology to meet this objective. The total dissolved solids content of produced water can reach as much as 350,000 mg/L with sodium and chloride being the primary ions followed by calcium, barium, strontium, magnesium, some organics and heavy metals at low concentrations. Membrane distillation can achieve complete rejection of ions and dissolved non-volatile organics provided that the membrane pores are not wetted. It also has lower energy demand as it can be operated at near atmospheric pressure and below 100°C. Initial tests with synthetic and actual produced water from unconventional Marcellus Shale wells in Pennsylvania yielded permeate flux that are comparable to that obtained with NaCl only. No serious irreversible fouling or wetting of the membrane was observed in tests with real flowback water and clean water permeability was restored after membrane washing. The results of ongoing studies to further demonstrate the feasibility of MD for flowback/produced water treatment at different feed compositions and temperature gradients will be presented at the conference.

Abstract #A-404

Essam El-Sayed, Ph.D., Senior Research Scientist and Program Manager, Kuwait Institute for Scientific Research (Kuwait)

Zero Liquic Discharge Desalination of Oilfield Produced Water: Survey of Likely-Feasible Systems by Simplified Computations and Experimental Testing

Oilfield produced water is the largest inconvenient unfavorable waste stream associated with oil and gas production. The rapid growth in quantities and increase in salinities of oilfield produced waters pose immense environmental challenge to the future of the oil production business. Several of the oil producing countries, especially in the Arabian Peninsula are water starving and rely on their very limited natural brackish water resources for the oilfield operations. Zero liquid discharge (ZLD) desalination

seems to offer convenient multifaceted solution to this complex situation. The advantage of this solution is the conversion of such environmentally undesirable waste stream into useable water and compact solid discharge that might be of commercial value. The Water Research Center of the Kuwait Institute for Scientific Research has devoted a good part of its R&D resources and activities during the past five years along this line. The concern was to seek feasible treatment and desalination systems and to assess their potentiality, especially in terms of efficiency and effectiveness of separation, specific energy consumption, operability and environmental acceptance. The focus was on waters containing oil, H2S, and TDS between 130,000 to 250,000 mg/kg. This paper outlines the integrated process-sequencing approach that was systematically developed and adapted while seeking the likely feasible system(s). The first step in this three-step process sequencing was the pretreatment for separating H2S and oil whereas the last step was purification of the salt produced and its subsequent processing for production of useful byproducts. One exemplary process will be presented for each of those two steps; i.e., a unique microfiltration membrane for oil removal and electrolysis for final salt processing. The middle step is the desalination process and it is the key in this integrated sequencing and also it is the most challenging one. Five likely-feasible desalination systems will be presented here. These include four thermally-driven processes suitable for ZLD desalination; namely membrane distillation, eutectic freezing, humidification with energy recycling (patent pending), and low-temperature flash evaporation. The fifth system is pressure-driven and it is basically a hybrid reverse osmosis/pressure retarded osmosis (patent pending), which can be used for desalting and producing low-sulfate water for reinjection in oil-producing wells for pressure maintenance and enhancing oil recovery. Results of the simplified exploratory computational modeling and experimental testing for these systems will also be presented in this paper.

10:40 AM – 12:10 PM

TRACK B – OTHER EMERGING TECHNOLOGIES

Abstract #B-401

Kim Choon Ng, Ph.D., P.E., Professor, National University of Singapore (Singapore) and King Abdullah University of Science and Technology (Saudi Arabia)

Adsorption Desalination

Adsorption (AD) cycle has been recently pioneered by the authors for cooling and desalination applications. In this paper, a review of the recent development of AD cycle is presented along its hybrid cycles such as the MED and MSF. We begin by looking at the basic sorption theory for different adsorbent-adsorbat pairs, namely the silica gel-water and the zeolite-water pairs. Under the IUPAC categorisation, there are 6 types of isotherm behaviour that capture almost all types of adsorbent-adsorbate behavors and many isotherm correlations have been developed to described their uptake patterns, namely the Henry, Langmuir, Toth, etc. A correlation has been proposed that can universally capture all six types of isotherms of IUPAC and it requires only a minimum set of regression coefficiencts. We present also the basic AD cycle for seawater desalination as well as its hybridization with known conventional thermally-driven cycles. The performances of the basic AD pilot is presented, powered by low temperatures heat source such as the renewable solar. Owing to thermodynamic synergy between the thermally-driven cycles, the AD cycle can be hybridized with the robust multi-effect distillation cycle to improve the water production yields. The hybrid cycle is called the “MED+AD” or MEDAD in short. With hybridization, it allows the bottom-brine temperature of the MED to operate below ambient temperature, as low as 5°C, in contrast to the conventional MED which is limited by the

ambient, resulting in a quantum increase of distillate production by 2 to 3 times. We demonstrate this efficiency improvement in a pilot comprising a 3-stage MED and AD plant and the top-brine temperature is maintained at 70°C. Lastly, the concept of exergy is applied to the fuel cost apportionment in a cogeneration plant where both electricity and water are being produced simultaneously. This concept gives a more accurate method than the conventional enthalpic approach because it considers the quality of the expanding steam.

Abstract #B-402

Thomas Davis, Ph.D., Director, Center for Inland Desalination Systems, University of Texas at El Paso (USA)

Electrodialysis Metathesis to Prevent Scaling in Desalination of Gypsum-rich Groundwater

Groundwater rich in calcium sulfate (gypsum) is difficult to treat by reverse osmosis (RO), because calcium sulfate levels in the RO concentrate can exceed saturation. Groundwater near Alamogordo, New Mexico, is nearly saturated in calcium sulfate, and the yield of fresh water by RO is limited to 75%. An emerging technology called Zero Discharge Desalination (ZDD) obtains recoveries as high as 98%. This high recovery is achieved by treating the RO concentrate with electrodialysis metathesis (EDM) to remove troublesome ions like calcium and sulfate. The EDM product is returned to the RO for additional recovery. The ZDD technology has been demonstrated at 20-40 gpm production rates in Alamogordo, and has been demonstrated at locations in in Florida, Colorado and California. The EDM process utilizes four membranes and solution compartments in a repeating cell, called a quad. Each quad has two diluting streams, RO concentrate and NaCl, and two distinct concentrate streams. The cations removed from the feed combine with Cl- ions from the NaCl to produce a concentrate stream of mixed Cl- salts. The anions removed from the EDM feed combine with Na+ ions to produce a concentrate stream of mixed Na salts. The EDM concentrate solutions can be mixed to precipitate gypsum and release NaCl, which can be concentrated, purified, and used in the EDM. Since silica is essentially uncharged, it is not removed by the EDM and becomes trapped in the RO-EDM concentrate loop. Nanofiltration with silica-permeable membranes performs better than RO for groundwater similar to Alamogordo.

Abstract #B-403

Eric Dole, P.E., West Regional Energy Efficiency Practice Lead, Hazen and Sawyer (USA)

Electro-Distillation with Brine Bulb Technology: An Emerging Treatment Technology for Aggressive, High TDS Waste Streams

Brine Bulb Treatment Technology (BBT) (US Pat. No. 8,273,156) is a multiple-effect vacuum distillation system that incorporates alternating current electro-coagulation into one unit process to produce high quality condensate from high TDS water. This technology typically achieves a 99+% reduction of TDS levels associated with RO concentrate, produced/flowback water, seawater, spent IX brine and cooling tower blow-down water. BBT removal mechanisms are as follows: 1) Oxidation (anode) /reduction (cathode) reactions; 2) Emulsion breaking; 3) Halogen complexing; 4) Seeding; 5) Electron flooding resulting in virus and bacteria removal, heat generation, expedited reaction kinetics, 35% reduction in specific heat and 84% reduction in latent heat of vaporization; 6) No external latent heat of condensation required due to multiple effects. Treatment efficiency is a function of voltage, amp density, residence time, blade material, pH and solids separation technique. The low operating temperatures of the BBT electro-distillation system allow the use of PVC and standard metal components. The only consumables

are the metal electrodes and electricity. The utilization of a micro-turbine, multiple effect heat transfer (3 effects), constant vacuum technology and AC electro-coagulation allows for the low energy intensity and high treatment efficacy. Mr. Dole entered into a royalty agreement with a water treatment technology investor in Sept 2014 to build units to recover the spent brine from IX systems. Field trials are earmarked for Q1 2015. Arizona State University and Colorado School of Mines have agreed to perform academic evaluations of the BBT efficacy in spent IX brine recovery and flowback/produced water treatment.

Abstract #B-404

Helen Julian, Doctoral Student, University of New South Wales (Australia)

Effect of Transverse Vibration and Aeration on the Mass Transfer and Crystal Formation in Submerged Vacuum Membrane Distillation and Crystallisation

Submerged Vacuum Membrane Distillation and Crystallisation (SVMDC) systems have the potential to address the inland brine water disposal problem due to their ability to handle high solids feeds and even temperature distribution on the bulk feed flow. However, the major drawbacks of this process include localized temperature polarization, concentration polarization and crystallization at membrane surface that may lower the permeate flux and cause the membrane pores blockage. This study evaluates the operational strategies that can be applied to reduce temperature polarization and concentration polarization through transverse vibration of membrane modules and aeration to enhance turbulence at membrane surface. Aeration has the added effect of providing competitive nucleation sites for crystallization away from the membrane surface. The experiments were conducted by using polypropylene membrane with model inland brine water as the feed solution at 70° C. At the selected vibration frequency and feed TDS=11.13 g/L, the SVMDC could maintain stable operation for more than 700 h. Both transverse vibration and aeration were able to increase the initial flux. However, at high feed concentrations (TDS=33.39 g/L), flux reduction was observed at much earlier with the transverse vibration possibly due to the accelerated crystallization of CaCO3 at the membrane surface. When the aeration was introduced in the operation, the higher flux was sustained for longer than transverse vibration operation, followed by eventual collapse. These results suggest an inevitable formation of crystals in the feed solution and their attachment to the membrane surface. Keywords: membrane distillation, crystallization, temperature polarization, concentration polarization, transverse vibration, aeration.

1:10 PM – 2:40 PM

TRACK A – COMMERCIALIZATION LANDSCAPE

Abstract #A-501

Harry Seah, Chief Technology Officer, Public Utilities Board (Singapore)

The Singapore Commercialization Ecosystem

With water as a strategic growth area, the Singapore government aims to strengthen and accelerate the development, commercialisation, and adoption of innovative water technologies solutions. In addition to

an R&D budget of S$20M/year from PUB, Singapore's national water agency, there are other funding schemes under the Environment Water & Industry Programme Office (EWI) to catalyse technological development from idea conceptualisation to commercialisation. These schemes include the Environment and Water Research Programme (EWRP), which comprises the Innovation Development Scheme (IDS) and Incentive for Research & Innovation Scheme (IRIS), to support the basic and applied research projects; and schemes supporting commercialisation, namely Fast Tech, TechPioneer & Test-Bedding with PUB, to support test-bedding and commercialisation of the innovative technologies. With the support of these funding schemes, PUB hopes to be the first large scale adopter of new technologies, leading to wider adoption and greater acceptance of the technologies in other utilities and industries. One technology that has benefitted from these schemes is the electrochemical desalting project that looks at low energy desalination. Besides looking into the adoption of new technologies, we are also tapping on the Energy–Water–Waste (EWW) Nexus through co-location of facilities to create opportunities for more sustainable use of resources; reduction in cost involved in transmission of resources between facilities; and for waste to be utilised as a resource. Studies that are of interest include anaerobic co-digestion of food waste, used water sludge, and pressure retarded osmosis (PRO) for energy recovery.

Abstract #A-502

MaryTheresa Pendergast, Ph.D., Technical Program Manager, Oasys Water (USA)

Going Big with Forward Osmosis

The frontier of water treatment technologies is being defined by hybrid processes and thoughtful design integration within treatment trains. The use of increasingly sophisticated process trains is driven by the need to treat dramatically impaired water supplies while maintaining low cost, high utilization, and high operational flexibility. Integrating forward osmosis (FO) and thermal technologies is one notable, emerging opportunity to realize substantial advantages in cost and performance compared to the use of either conventional membrane processes or thermal technologies. RO technologies remain ideally suited to desalinate low fouling streams to moderate levels of recovery. Spray dryers or crystallizers employing mechanical or thermal vapor compression cycles are still best used to convert saturated or organic rich liquours to solid products. But what of the multitude of waters, especially industrial streams, that are too saline or high in foulants to be well treated by RO and are not of high enough value to warrant direct crystallization? The traditional answer defaults to a 90+ year old technology in the thermal brine concentrator. In this discussion we will see how thermolytic draw solutions enable FO processes and treatment trains to challenge these traditional treatment paradigms in diverse commercial applications on two continents.

Abstract #A-503

Erik Desormeaux, Director of Process Development, Porifera, Inc. (USA)

Process Commercialization Landscape for Forward Osmosis

Forward osmosis (FO) membranes have been available for more than 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: (1) Innovations in FO membranes, elements,

and draw solutions that reduce cost and footprint, (2) New and existing companies entering the market, (3) Marketing FO for reuse, food and beverage, oil and gas, and high salinity instead of desalination, (4) Regulations that promote near zero liquid disharge and industrial reuse, and (5) 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 systems as RO pretreatment. By 2017, FO+RO systems will cost less than UF+RO systems, with lower operation costs and producing higher quality water. Also, FO Concentrators will cost >70% less than 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: Desalination is not the ideal application for FO. 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.

Abstract #A-504

Jiang Wei, Ph.D., Vice President, Production, Aquaporin (Denmark)

Aquaporin-Based Biomimetic Membranes for Reverse Osmosis and Forward Osmosis

Aquaporins are water channel proteins found in the cells of all organisms. These integral membrane pore proteins facilitate rapid, highly selective water transport through water-impermeable lipid membranes of living cells driven by osmotic pressure differences. Inspired by the fascinating properties of aquaporins, ideas of incorporating aquaporin molecules into polymeric membranes were suggested and pursued for achieving higher water permeability and selectivity. Researchers at Aquaporin A/s already filed a patent in 2005, disclosed novel water membranes comprising lipid bilayers incorporating functional aquaporins. Prototype of aquaporin based FO membrane manufactured by R&D machines was already developed, and prototype of RO membranes are currently under development. This presentation will first present the preparation of aquaporin based biomimetic membranes. Some examples of the applications of such membranes for 1) Desalination of seawater by fertilizer drawn forward osmosis, 2) NASA application will also be discussed. Finally, the company's strategy and plans will be presented.

1:10 PM – 2:40 PM

TRACK B – PROCESS HYBRIDS

Abstract #B-501

Seung-Hyun Kim, Ph.D., Professor, Kyungnam University (Korea)

Challenges in Future Desalination: Brine Management

Challenges that desalination plants face can be summarized in two issues of energy efficiency and brine management. Since desalination is an energy intensive process, there have been many efforts made to improve the energy efficiency of desalination plants. Unlike energy issue, brine issue has not received much attention which it deserves from academia and industry, although it becomes more critical as the plant size gets larger. Therefore, a research project focusing on desalination plant concentrates is

introduced in this presentation. Global MVP (GMVP) is a five year (2013~2018) research project, financially supported by the Korean government of MoLIT (Ministry of Land, Infrastructure, and Transportation) and its research managing agency of KAIA. Here, MVP represents three research themes; membrane distillation (MD), valuable resource recovery (VRR), and pressure retarded osmosis (PRO). GMVP has a vision to make a desalination plant more environment friendly. Unlike conventional desalination plants, brines in GMVP are regarded not as wastes, but as resources. By applying MD, PRO, and VRR techniques on RO brines, GMVP envisions the future desalination plant of discharging less brine and with more value. In this presentation, an idea of GMVP, and the results obtained so far will be discussed.

Abstract #B-502

Manki Cho, Doctoral Student, Korea Advanced Institute of Science and Technology (Korea)

Polymer Enhanced Forward Osmosis: Exploration of the Potential of Branched Polyethyleneimine as Draw Solute

Forward osmosis (FO) is a promising membrane-based separation technology which has a potential to offer more energy-efficient processes than pressure-driven membrane processes (e.g., reverse osmosis) for various environmental and industrial applications including (i) water reclamation, (ii) desalination, and (iii) resource recovery (e.g. nutrient extraction/concentration from wastewater). However, a major and unresolved challenge in FO remains the availability of efficient draw solutions that can be separated and reconstituted using a low-energy separation process. This study investigates the potential use of a branched polyethyleninime (PEI) macromolecule (Mn: 10000 Da and Mw: 25000 Da) as osmotic agent to formulate new FO draw solutions that could be separated and reconstituted utilizing low-pressure membrane filtration. To assess the potential of aqueous solutions of branched PEI as FO draw solutions, we combine (i) osmotic pressure measurements using a custom-built membrane osmometer with (ii) water flux and reverse solute permeation measurements using two commercial membranes (HTI-CTA and HTI-TFC) in both the FO and PRO modes and (iii) ultrafiltration (UF) and nanofiltration (NF) separation/concentration experiments using a polyethersulfone UF membrane (MWCO: 5k Da) and a DOW-Filmtech NF 270 membrane. The overall results of this study suggest that branched PEI macromolecules are promising building blocks for the preparation and formulation of FO draw solutions with high osmotic pressures and very low reverse solute permeation. However new FO membranes and draw solution reconstitution processes will be required to advance the applications of polymer-based osmotic agents such as PEI.

Abstract #B-503

Sangho Lee, Ph.D., Associate Professor, Kookmin University (Korea)

Design of Forward Osmosis/Reverse Osmosos Hybrid System for Saving Energy Consumption at Desalination

Desalination technologies have spread rapidly in the world as an option to solve the water shortage problem. The reverse osmosis (RO) process is usually more efficient than thermal processes with respect to energy consumption. Therefore, RO technology is increasingly used in the desalination market. However, the RO process also requires high energy consumption (about 4 kWh/m3) as compared to other

water treatment processes. Forward osmosis methods developed to save energy consumption in desalination used the difference of chemical energy between the feed and draw solution. In this study, we designed a new hybrid FO/RO system for reducing energy consumption as compared with the reverse osmosis process. We calculated the energy consumption in various feed concentration changes to determine the optimum ratio FO/RO system.

Abstract #B-504

Ryan Smith, Ph.D., Postdoctoral Researcher, Lehigh University (USA)

Integrating Tunable Anion Exchange with Reverse Osmosis for Enhanced Recovery During Inland Brackish Water Desalination

Ion Exchange (IX) and Reverse Osmosis (RO) are universally recognized as two fundamentally different processes for treating water. Although seemingly unrelated, we present the results of an investigation that acts as a bridge between RO and IX processes to mitigate the problems associated with inland brackish water desalination and the management of concentrate disposal. Enhanced recovery and reduction in the reject volume is usually limited by the solubility of calcium sulfate. Reducing or eliminating the presence of sulfate would allow the process to operate at higher recoveries without threat to membrane scaling. By using an appropriate mixture of self-regenerating anion exchange resins, sulfate can be selectively removed and replaced by chloride prior to the RO unit. The effluent from the IX column is then desalinated using RO but at higher than previously possible recoveries. Eventually, the resin will be exhausted and need to be regenerated, but instead of using a prepared regenerant brine, the reject from the RO process may be used as a regenerant thus requiring no addition of external chemicals. By properly "tuning" the mixture of anion exchange resins, both high sulfate removal and efficient regeneration by the RO reject brine is possible. Results of a lab-scale study show that this Hybrid Ion Exchange-RO (HIX-RO) process can achieve increased recovery and a 50% reduction in the volume of the reject without the threat of sulfate scaling. This process can be extended to nearly any composition of brackish water for enhanced recovery only by changing the mixture of resins.

3:10 PM – 5:00 PM

TRACK A – COMMERCIALIZATION LANDSCAPE (CONTINUED)

Abstract #A-601

Tom Pankratz, Consultant and Editor, Water Desalination Report (USA)

Brine Management and Zero Liquid Discharge Options

Over the past 40 years, technological improvements have led to significant changes in the way water and wastewater is treated. New, high-rate processes and the widespread use of membrane technologies have reduced plant footprints and dramatically improved the process and energy efficiency of treatment processes. Although these changes have improved effluent quality, they usually lead to an increase in the "strength" of the resulting concentrated waste streams, which complicates disposal, especially in inland locations and for many industrial wastes. Brine concentration and management systems have historically

relied upon evaporators and/or crystallizers to achieve reduced liquid discharge (RDL) or zero liquid discharge (ZLD). With energy requirements that can range well beyond 30 kWh/m3, brine concentration technologies are the most energy intensive treatment processes. In some cases, further complications occur when concentrated salts cannot be crystallized in traditional systems or may be difficult to dewater. This paper will review traditional brine management options and will consider several of the newer and more innovative technologies and systems employed to achieve RDL/ZLD. It will also compare the capital and operating costs of the systems and present examples of their use in municipal, power and oil and gas industry applications.

Abstract #A-602

Richard Stover, Ph.D., Executive Vice President, Desalitech (USA)

High Recovery, Low Fouling, Low Energy Reverse Osmosis

Desalination and water reuse using reverse osmosis (RO) are viable new water supply resources, however traditional RO systems often create excess brine waste, do not fully utilize source water supplies and consume too much energy. Newly emerging closed-circuit RO processes improve RO performance and reduce its cost by increasing recovery, reducing fouling and scaling, and reducing energy consumption. This performance has been documented in dozens of RO installations in a range of applications. In particular, a closed-circuit RO unit operated on groundwater with a silica concentration of 59 ppm at recovery rates of up to 93.5%, producing brine silica concentrations exceeding 900 ppm. This recovery rate was sustained at neutral pH, with modest anti-scalant dosing and no scaling-related CIP requirements. A traditional RO system operating in feedwater with this concentration of silica would be limited to 76% recovery or less, corresponding to more than 3 times the production rate of brine concentrate. At another site, seawater with a total dissolved solids (TDS) content of 35,329 ppm was desalinated with 5.5 kWh/1000gal (1.45 kWh/m3) of RO pump energy. This represents the lowest energy consumption ever reported for seawater RO at a comparable recovery rate and flux.

Abstract #A-603

Sophie Walewijk, Ph.D., Senior Chemical Engineer, Trevi Systems (USA)

Brine Resuse Desalination using Forward Osmosis Technology

Forward Osmosis (FO) is a natural process and occurs in the cells of all living things when liquids of differing solute concentrations are separated by a semi-permeable membrane. FO differs from Reverse Osmosis (RO) in that natural osmotic pressure, resulting from the difference in solute concentration in the two liquids, is the sole driving force for the transport of pure water across a membrane. Water is driven through a semi-permeable membrane in the RO process, using hydraulic pressure resulting in significant energy expenditure, and hence cost in producing the desalinated product. With FO, osmosis is allowed to occur naturally, without external force, resulting in a very low energy method for desalinating water. FO provides a number of advantages over RO for seawater desalination in addition to the energy savings. Lower fouling of the membrane provides longer lifetime and lower maintenance costs. Other advantages of FO include higher maximum feed water recoveries and a reduced level of pretreatment. Trevi Systems has engineered a unique proprietary draw solution that allows for a high TDS water stream, enabling Trevi to participate in a trial with Orange County Water District, with the Department of Energy, focusing

on brine wastewater reuse. This trial will enable OCWD to reuse their brine coming off of their RO wastewater treatment plant, in an energy efficient manner. If successful, the pilot will enable for a 75,000 M3 forward osmosis system, using waste heat from a peaker plant. The scientific data from this trial will be the focus of the presentation.

Abstract #A-604

Arian Edalat, Ph.D., Vice President of Commercial Projects, Water Planet Engineering (USA)

Pilot Testing of an Integrated Mechanical and Membrane System in a Steam-Flood Produced Water Treatment Application

Reuse and recycle of oil and gas produced water constitutes a new frontier of desalination. Application of reverse osmosis for desalination in such scenarios is currently impractical, as the influent water cannot be treated reliably to a sufficient level of purity to enable its use as an RO feed. A major shortcoming of conventional oil-field pre-treatment processes is their inability to sustain a consistently low-level of free oil and grease, turbidity and SDI in their effluent. Water Planet Engineering (WPE) has developed a patent-pending, integrated mechanical and membrane separation platform (process) for oil and gas produced water treatment. The mechanical components (1) remove free oil and suspended solids and (2) capture and de-water the oil product (i.e., oil product recovery). The UF membrane then filters out the remaining suspended solids, bacteria, clay fines and any hexane extractable oil hydrocarbons from the water. Field-testing was performed over five weeks at a California steam-flood oil production site (~15 API) employing a wide range of temperature (up to 85° C), with various oil concentrations in the influent (up to 15%) and solids (up to 5%). Typical operating throughput of the pilot was up to 800 barrels per day. Under every operating condition, the treated water consistently showed non-detectable oil and grease, turbidity below 1 NTU, and SDI below 1. This presentation will describe details of the pilot tests, highlighting the performance of the system toward production of consistent quality tertiary treated water, summarizing the performance metrics. In conclusion, it appears that WPE's platform can perform as a robust, modular, low footprint oil-field produced water pre-treatment system that can render the downstream water polishing and desalination applications more reliable in many conventional, EOR, and thermal EOR oilfields.

Abstract #A-605

Guillermo Zaragoza, Ph.D., Senior Researcher, Plataforma Solar de Almería-Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas CIEMAT (Spain)

Membrane Distillation: Ready for the Market? Comparative Assessment of Commercial Systems

Membrane Distillation (MD) has shown great potential as a desalination technology in many laboratory studies. Niche opportunities for application of MD are also increasing and several modules are already available in the market. This paper analyzes the state of the art of MD as a commercial technology based on tests performed with real modules in pilot plant scale. Practically all the different MD systems available commercially have been tested at Plataforma Solar de Almería (Spain), and their performance compared in terms of water production and quality, energy consumption, maintenance requirements and reliability. The influence of several operational parameters like temperatures, flow rate, and feed water salinity has also been examined. All the commercial modules evaluated use flat-sheet membranes, with

different configurations. Plate and frame modules are favoured by companies like Scarab and Keppel-Seghers, the former in air-gap and the latter in permeate-gap MD configuration. Spiral-wound modules are fabricated by Solar Spring and Aquastill using permeate-gap and air-gap configurations respectively. Vacuum multi-effect membrane distillation modules manufactured by Memsys have also been analyzed using two units built by Aquaver. Based on the experimental tests, the different MD technologies are compared in order to identify their strengths and weaknesses. An assessment of the commercial modules is made in the context of existing desalination technologies and the challenges and opportunities for their market implementation are discussed.

3:10 PM – 5:00 PM

TRACK B – PROCESS HYBRIDS AND BIOFOULING

Abstract #B-601

Masura Kurihara, Ph.D., Fellow, Toray Industries (Japan)

Role of Pressure Retarded Osmosis in the MEGATON Project

Today water treatment systems that convert seawater into freshwater or recycle wastewater are under development and in use. Since 2000, huge plants capable of producing 100,000 cubic meters of freshwater per day are rapidly being built. However, even larger plants will be required in the future. This has led to urgent needs of developing innovative water treatment systems which address the problems caused by the construction of huge plants, such as massive energy consumption and environmental destruction. The Mega-ton Water System project is aiming to develop 21st century key technology for water treatment with Japanese initiative and contribute to global water problem solutions. The missions of the project are 1) Energy reduction, 2) Low environmental impact, and 3) Low water production cost. The outputs of Mega-ton Water System Technology are newly developed Material & Equipment, and System as follows. Materials & Equipment: 1) Low Pressure Seawater RO Element, 2) Next-Generation ERD, 3) New High Pressure Resin Pipes –System, 4) Low pressure Multi-Stage System (LMS) with High Recovery, 5) Bacteria Friendly RO System (BFRO), and 6) Pressure Retarded Osmosis (PRO) System. This system is operated at (a) Low pressure operation below 5.0 Mpa, (b) High water recovery system (up to 65%), (c) Advanced energy recovery system, energy reduction, (d) Bio friendly Pretreatment. In conclusion, (i) Only SWRO system afford 20% energy reductions; SWRO-PRO system afford 30%, and (ii) Role of PRO in Mega-ton Water System works as 10% energy reduction from the brine and the concentration for the discharging brine will be same as feed seawater.

Abstract #B-602

Noura Shehab, Ph.D., Postdoctoral Scholar, King Abdullah University of Science and Technology (Saudi Arabia)

Self-Sustained Microbial Electro-deionization Cell for Desalination and Wastewater Treatment

Global increases in water demand and decreases in both the quantity and quality of fresh water resources have served as the major driving forces to develop sustainable use of water resources. One viable

alternative is to explore non-traditional (impaired quality) water sources such as wastewater and seawater. The current wastewater treatment is energy intensive and fails to recover the potential resources (water and energy) in wastewater. Also, conventional desalination technologies like reverse osmosis (RO) are energy intensive. Therefore, there is a need for the development of sustainable wastewater treatment and desalination technologies for practical applications. Processes based on microbial electrochemical technologies (METs) such as microbial desalination cells (MDCs) hold promise for the treatment of wastewater with recovery of the inherent energy, and for desalination of brackish water and seawater. One of the main challenges of using MDCs for desalination is that progressive salt ion removal leads to a build-up of ohmic resistance, which will limit electricity generation and desalination rates. To address this issue, ion exchange resins (IXRs) were used in the MDC to improve desalination efficiency, in a developed device called a microbial electrodeionization cell (MEDIC). Using IXRs in the MEDIC, the desalination efficiency was significantly improved by 31% for brackish water and by 25% for synthetic seawater compared to MDCs. One could imagine this technology to be used in the future as a pre-treatment to RO. A pre-treatment step before the RO system, in which the salinity is partially reduced, could significantly reduce energy consumption in the subsequent (low pressure) RO.

Abstract #B-603

Alexander Dudchenko, Ph.D., Doctoral Student, University of California, Riverside (USA)

Magnetic Pickering Emulsions Coupled to Membrane Filtration for Fouling Free Oil/Water Separation

The ever increasing demand for oil throughout the world has resulted in increased production of oil and produced water. The produced water can be challenging to treat, due to presence of free and emulsified oil. Gravity-based separation can effectively remove the free oil, but not the emulsified fraction. Membrane filtration has been demonstrated to be an effective method of oil removal, producing high quality water. However, membranes suffer from a high degree of irreversible fouling. Here, we present a novel approach to oil/water separation using magnetic Pickering emulsions coupled to ultrafiltration membranes. We demonstrate that crude oil/water mixtures, with concentrations as high as 100 ml/L, can be treated at high fluxes of 100L/m2 hr for extended periods of time with no significant fouling. The efficacy of this process is independent of water chemistry, with no decrease in performance even at the high ionic strengths (2 Molar) associated with some produced waters. The process employs ferromagnetic nanoparticles, which coat oil droplets, creating a physical barrier preventing coalescence and subsequent membrane fouling. We explore the coated oil droplet properties with atomic force microscopy, demonstrating the presence of the physical barrier separating the oil. The ferromagnetic properties of the emulsions allow for their recovery using a magnetic force, leading to nanoparticle recycling and reuse. The ability to rapidly treat oily wastewater can open new alternatives to deep well injections and evaporation ponds, allowing for reuse in oil extraction operations, discharge into the environment or further post treatment, such as desalination.

Abstract #B-604

Ezra Cates, Ph.D., Assistant Professor, Clemson University (USA)

Radioluminescence Membrane Biofouling Control: Generating Germicidal Ultraviolet Radiation Inside Membrane Modules Using X-rays

While the current industry practice for managing membrane biofouling relies mainly on a combination of chemical treatment and physical scouring, recent research has gravitated toward development of membrane materials that possess inherent antimicrobial or anti-adhesion properties. Many such materials perform admirably in the lab, but achieving a lasting anti-fouling mechanism that continues to deter bacteria after the surface has been coated with chemical foulants remains a major challenge. We have recently begun studying the feasibility of utilizing UVC radioluminescence (UVC-RL) for biofouling control; therein, phosphors may be incorporated within a membrane module and excited via an externally-situated X-ray source to achieve germicidal UVC emission within the module feed channels. The goal is thus to allow microbial inactivation even when the membrane active layer has undergone cake formation, with the added advantage of intensity and temporal tunability, controlled by the X-ray excitation. Preliminary results of UVC-RL materials development and module X-ray penetration characteristics will be presented.

Abstract #B-605

Zhenyu Li, Ph.D., Research Scientist, King Abdullah University of Science and Technology (Saudi Arabia)

Forward Osmosis/Low Pressure Reverse Osmosis Hybrid for Indirect Desalination of Seawater

Indirect forward osmosis (FO) desalination of seawater uses natural seawater as the draw solution (DS) while an impaired-quality water is the feed solution (FS). The osmotically diluted seawater can be treated by low pressure reverse osmosis (LPRO) to recover fresh water with reduced energy consumption as compared with conventional RO desalination of seawater. Therefore, the hybrid FO-LPRO has been assessed in terms of potential niches for wastewater treatment and seawater desalination in coastal area. In this paper, most work has focused on the FO process. The effect of FS quality, process performance, membrane fouling propensity, and contaminant rejection was comprehensively studied. The primary and secondary wastewater effluents and urban runoff were used as the FS while natural seawater was the DS. The difference in process performance (i.e. water flux) and fouling propensity due to the FS quality is clearly visible. FO membrane showed high rejection to COD, phosphate, trace metals, ionic micropollutants, and polycyclic aromatic hydrocarbons, and moderate rejection to ammonia, total nitrogen, and neutral micropollutants. Additionally, a commercial pilot spiral wound FO module was tested to study the fouling at DS (seawater) side. The membrane autopsy revealed that the spacer at the DS side and pretreatment of seawater are crucial for module performance. Although the permeated water may drag the foulant away from the membrane surface at the DS side, the biofouling at the DS side was still observed. This study explores a possible integration of wastewater reuse and seawater desalination for sustainable water resources management in coastal regions.