FROM THE DIRECTOR

I am pleased to welcome you to peruse this second edition of the WDRC newsletter, covering the fourth quarter of 2012. We at the WDRC were very busy during this last quarter with initiation of new research activities, hosting various academic and industrial visitors, and participation in international and regional conferences and workshops.

Our most significant activity was hosting the third annual WDRC Center Industrial Affiliates Program (CIAP) meeting held on November 27-28. At the meeting, we updated 12 CIAP partners on progress being made and future plans for the WDRC strategic research agenda. The research update was presented according to newly defined research clusters, corresponding to areas/topics in which the WDRC has achieved/can achieve international visibility. These (five) clusters include: (i) membrane (bio)fouling; (ii) novel and sustainable (treatment) processes; (iii) membranes and materials (for water applications); (iv) chemical and microbial water quality; and (v) monitoring, sensing, and modeling.

We continued to host industrial delegations (e.g., Pall, Inge, and Schlumberger) and welcomed new academic visitors (e.g., Prof. Joan Rose, Michigan State University (USA); Prof. TorOve Leiknes, NTNU (Norway); Prof. Hans-Curt Flemming, University of Duisburg (Germany); Prof. Chris Buckley, University of Kwa-Zulu Natal (South Africa); Prof. Jeremy Guest, UIUC (USA); Prof. Mamadou Diallo, KAIST (Korea)). WDRC faculty and research scientists participated in various international and regional conferences, and the WDRC organized a special pre-conference session on Moving Water Reuse Forward in Saudi Arabia at the Saudi Water and Power Forum (December 2).

Two proposals submitted by the WDRC were selected as KAUST Seed Fund winners: (i) Hybrid Osmosis Process for Water Desalination and Reuse and (ii) Multi-Stage Membrane Distillation Desalination. The Seed Fund is a product development funding mechanism for moving promising ideas further toward commercialization, and ultimately leading to the formation of a new business.

The WDRC is continuing to grow. We are recruiting new faculty to join the WDRC in the areas of membrane processes and technology, and environmental toxicology/eco-toxicology. Construction has commenced on a 1,000 m² expansion of the WDRC laboratory.

—Prof. Gary Amy, Director, WDRC
NEW FACULTY Q&A

Dr. Matthew McCabe joined the WDRC as an Associate Professor in November 2012. Prior to joining, he was an Associate Professor in the School of Civil and Environmental Engineering at the University of New South Wales in Sydney, Australia.

Q: Why did you choose to join the WDRC?
A: I was not actively looking for a new position, but after hearing more about the opportunities supporting research, the high quality of the faculty and the vision and motivation for KAUST, I was intrigued. These concepts became more evident when I visited in early 2012. I was impressed not only with the campus itself, but also by the energy and attitude of the individuals I spoke to, from graduate students all the way up to senior management. The “idea” of KAUST is quite unique and it has huge potential to make real contributions to issues of both national and international importance. I wanted to be a part of that.

Q: Tell us about your research interests.
A: Essentially, my research involves describing how water moves through the Earth system and monitoring the changes as it does so. Water is always moving from one phase to another or from one “place” to the next (evaporation > rainfall > groundwater > stream-flow) and keeping track of this is hard.

To do so, I run numerical models that describe the processes and also instruments that measure them directly. From the measurement side, I have ground-based sensors that measure aspects of the hydrological cycle and data from space-based satellites that provide information on these processes. With modeling, we can simulate using a range of approaches, spanning simple empirical representations to complex fully-coupled physical descriptions that provide a complete account of water movement.

Apart from using observations to evaluate how well (or not) our models are performing (do we get the right answers for the right reasons), combining these approaches allow us to answer important real-world problems. For instance, how much water do crops require from irrigation, or what is the risk of flooding from a rainfall event, and even should we expect drier or wetter conditions in a changing climate (and what are the hydrological implications of these?). There are important local, regional, and global scale water resource related issues that require improved understanding.

Q: What are your short- and long-term goals at KAUST?
A: In the short-term, I need to set-up a new group to answer the many open questions in this research area. I need groundwater and land surface modelers, remote sensing specialists, field technicians, and scientists and researchers with skills that bridge the traditional observation-model divide. My “lab” is quite unique in this way, as we are really interested in a whole systems approach, rather than focusing on just one small area of research, so having a multi-disciplinary team is key. Long-term, I want KAUST hydrology to be recognized internationally for undertaking research of regional and global importance. I also want students and postdocs to recognize KAUST as the place to learn about and undertake research that addresses the water challenges we face now and in the coming decades.

Q: What makes your research relevant to the WDRC and KSA?
A: The Kingdom has some unique, but not isolated, problems related to both water quality and water quantity. These are issues that the WDRC is seeking to address directly in a way that few other places are attempting. While my research falls on the “quantity” side, the two are inherently linked, so there is great opportunity to work with the excellent faculty here.

Solving the water problems for the Kingdom involves not only the development of new sources of water, but also identifying efficient ways to use existing sources. Agriculture accounts for more than 80% of total water used in the KSA, most of which comes from unsustainable fossil aquifers. There is a real need to better quantify the water use and the available water sources in the Kingdom: something that I hope to assist through my role here.

Q: One of the pleasures of scientific research is discovering the unknown; what drives you to discovery?
A: We are all so familiar with water that we often take it for granted. You turn the tap on, and there it is. However, for much of the world’s population, water and its quality are issues of major importance and uncertainty. Water is such an essential component of sustaining life, that our search for it (and storage of it) has provided a continuous thread through human development. Today, water and food security present two of the most important social and geopolitical issues of our time – and they are inherently linked. What better motivation is there then to try and better understand and address these issues?
ENVIRONMENTAL BIOTECHNOLOGY: RESEARCH GROUP ACTIVITIES

Introduction
An increase in demand for fresh water and global decreases in both 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 water sources through reclamation and reuse of wastewater. In arid and semi-arid regions (e.g., southwestern USA, sub-Saharan Africa, Gulf Cooperation Council (GCC), and the Middle East and North Africa (MENA) region), wastewater can provide an important renewable water source if it can be treated biologically to an effluent quality that is suitable for reuse (agriculture, irrigation, industrial use (e.g., processing and cooling), recreation, landscaping and aquifer recharge) with minimization of energy, resources and carbon footprint.

To achieve this goal, the Environmental Biotechnology Group in the WDRC is conducting fundamental and goal-oriented research by integrating cutting-edge omic tools (genomic, proteomic, and transcriptomic) with bioprocess engineering to optimize and create sustainable biotechnologies (Anammox processes; Aerobic granular sludge process; Bioelectrochemical systems) for wastewater reclamation and reuse that are robust, scalable, and capable of providing tailored water quality with minimization of energy, resources, and carbon footprint.

Anammox processes for mainstream wastewater treatment and reuse
Anaerobic ammonia oxidation (Anammox) process is recognized as a cost-effective and sustainable solution for the removal of nitrogen from high-strength ammonia containing wastewater. In this process, ammonia is directly converted into dinitrogen gas by using nitrite as an electron acceptor under anaerobic conditions. Anammox processes have several advantages compared to conventional nitrification/denitrification processes including 60% reduction in energy costs due to aeration, 90% reduction in CO\textsubscript{2} emissions, and 50% reduction in required space. However, most of the high ammonia containing wastewater is often associated with high organic carbon, which adversely affects the anammox process.

Therefore, to capture the full potential of anammox processes for mainstream wastewater treatment, it is important to have a fundamental knowledge on the functional stability of anammox community to organic carbon perturbation. The anammox team at the WDRC is currently running chemostat reactors to optimize and better understand this technology for the treatment of mainstream wastewater. An interdisciplinary approach that combines bioprocess engineering, genome-
enabled molecular biology tools and bioinformatics is being used to decipher the anammox community structure and function under normal (no organic carbon) and organic carbon perturbation conditions. The fundamental new knowledge obtained from this study will assist environmental engineers to improve the design of anammox processes for mainstream wastewater treatment.

**Aerobic granular sludge (AGS) process for biological nutrient removal**

Aerobic granulation is an emerging biotechnology for the removal of nutrients from wastewater. Aerobic granules are microbial aggregates that are normally formed in sequencing batch reactors seeded with biological flocs and operated under high selective pressure (e.g., low settling time), leading for the formation of granules. Compared to flocular activated sludge process, AGS has a variety of merits including excellent settling properties, compact microbial structure, high biomass retention, and ability to withstand shock and toxic loadings. Also, the aerobic outer layer and anoxic/anaerobic core structure of the granules allow for simultaneous nitrification, denitrification and phosphorus removal (SNDPR) to occur in one tank. Thus, a significant reduction (75%) in footprint and energy consumption (25%) due to aeration could be achieved by AGS process. However, the nutrient removal capability and granule stability of AGS process are challenged when environmental conditions (salinity, temperature, substrates) change. Also, the microbiological and ecological bases (e.g., eco-physiological response and microbial interaction, and biochemical pathways) behind the formation of aerobic granules remain to be further investigated.

The aerobic granulation team at the WDRC is currently focusing their research on providing a fundamental knowledge on the formation and stability of aerobic granules for nutrient removal in laboratory-scale simulations of AGS process under varying environmental and operating conditions. This knowledge is essential for: (1) providing fundamental understanding of the mechanism of granule formation and (2) linking engineering design and operation to the successful start-up and stability of AGS for full-scale application.

**Bioelectrochemical systems: microbial fuel cells; microbial electrolysis cells; microbial desalination cells**

Microbial fuel cell (MFC) is an emerging biotechnology for the simultaneous treatment and electricity generation from wastewater. In MFCs, a certain group of bacteria called exoelectrogens transport electrons generated from the oxidation of organic matter in wastewater outside their cells to the anode. The electrons and protons that are generated at the anode ultimately get reduced to H$_2$O at the cell cathode. To date, most MFC studies have been motivated by power generation. However, for MFC to be envisaged as a cost–effective biotechnology for wastewater treatment it is essential to: i) guarantee the quality of treated wastewater in terms of carbonaceous and nitrogenous compounds and ii) address practical up-scaling configurations of MFCs for wastewater treatment. In an attempt to address these points, the bio-electrochemical team at the WDRC has successfully developed a new hybrid, air-biocathode microbial fuel cell (MFC)-membrane bioreactor (MBR) system for achieving simultaneous wastewater treatment, water reclamation, and energy recovery. Substantial permeate quality comparable to conventional MBRs was achieved, with more than 90% removal of COD, NH$_3$-N, PO$_4^{3-}$, and bacteria. Additionally, the team successfully demonstrated the feasibility of integrating MFCs with other existing technologies such as forward osmosis (Microbial Osmotic Fuel Cell) and rotating biological contactors (MFC-RBC).

In addition to MFCs, the bio-electrochemical team at the WDRC has been actively conducting fundamental and goal-oriented research in the last year to optimize and have a better fundamental understanding of other bio-electrochemical systems such as microbial electrolysis cells (MECs) for hydrogen production and microbial desalination cells (MDCs) to desalinate brackish water.
1938 year oil was discovered in Saudi Arabia

The commercially viable source of oil was discovered by an American company, the Standard Oil Company (Socal), in Dhahran on March 4, 1938. On January 31, 1944, Saudi Arabia renamed the company the Arabian American Oil Company (Aramco), and in 1988, it became a state-owned enterprise and was named Saudi Aramco. The estimated market value of Saudi Aramco in 2005 was $781 billion.

11 million barrels of oil per day produced

Saudi Arabia is the world’s largest producer and largest net exporter of oil. However, the domestic demand of its oil is increasing rapidly, primarily due to electricity production. As of 2009, the Kingdom consumed about 2.4 million bbl/day of crude oil internally. This figure increased by 50% since 2000, so if this trend continues, it could exceed 8 million bbl/day by 2030, which would take a significant toll on its ability to export, jeopardizing the economy.

265.4 billion barrels proven reserves

This is the amount of oil that the Kingdom has in its oil reserve as of 2011. It is holding about 1/5 of the world’s oil reserve, the second largest in the world. Oil is a non-renewable resource and needs to be handled carefully and strategically.

46 gigawatts (GW) electricity requirement per day

Saudi Arabia’s current peak electricity demand is 46GW per day which is expected to triple within 20 years to 120GW by 2030. Oil is used primarily in generating electricity in the Kingdom, and as the energy demand increases, the amount of resources used will also increase. This will certainly take a toll on oil exports unless significant steps are taken in diversification of energies (geothermal, solar, wind).

$80 billion loss in revenue from domestic oil subsidies

Saudi Arabia is losing potential export revenue by selling oil domestically at $5 to $15 a barrel when international buyers pay more than $100. As a result of these subsidies, it is estimated that Saudi Arabia lost over $80 billion in revenue in 2011.

#1 world rank for oil consumption per capita

Saudi Arabia consumes around 3 million bbl/day, which is about 1 billion barrel per year or around 40 barrel of oil person per year, the highest rate in the world. This is four times higher than United States, five times higher than that of South Korea, and eight times the rate of Japan.

2030 year Saudi Arabia may begin importing oil

A Citigroup analyst predicted that Saudi Arabia could begin importing oil from other countries as its internal demand grows, and this could happen in less than 20 years. In order to avoid this, the Kingdom must diversify its energy supply and decrease its energy demand.
IN NUMBERS: ACHIEVEMENTS

The WDRC has grown significantly since its inception in 2009 and has achieved a lot in since then. This graph demonstrates the increase that we have realized in both journal publications and conference proceedings in the past three calendar years.

Table 1. Achievements Growth

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<th>Patents</th>
<th>Book Chapters</th>
<th>Conference Proceedings</th>
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This figure summarizes the total contributions of WDRC researchers since its beginning.

Figure 1. Total Achievements

UPCOMING EVENTS

Continued from p. 1

Third Annual SAP Meeting
TBA

The WDRC’s Scientific Advisory Panel will meet with faculty and research staff to discuss the ongoing and new research topics and critique the Center’s research and knowledge transfer in order to align the center with its strategic agenda and goals. To learn more about the SAP, visit the WDRC’s website.

Thermal Workshop
March 12–13, 2013

The WDRC will host the second Thermal Workshop at KAUST. People from various industries and academic institutions will be invited to participate in the expert workshop, which will focus on operational and knowledge gaps in thermal desalination that dominate the desalination capacity and market of the Kingdom.
SPRING SEMINAR SERIES

February 9: Dr. Nabil Nada, Nomac, KSA. “An introduction to thermal desalination plant Multistage Flash (MSF).”
February 23: Prof. Wolfgang Uhl, Technical University of Dresden, Germany. “Pretreatment for desalination of secondary effluent.”

March 2: Dr. Regis Vilagines, Aramco, KSA. “Produced water management at Saudi Arabian oilfields – An overview.”
March 9: Prof. D. Bhattacharyya, University of Kentucky, USA. “Functionalized and responsive membranes for environmental applications.”
March 16: Prof. Simon Judd, Qatar University, Qatar / Cranfield University, UK. “Oil and gas industry wastewater treatment using membrane technology.”
March 23: Prof. Jean-Claude Block, University of Lorraine, France. “Drinking water biofilms: Cohesiveness, adherence and resistance to environmental constrains.”

April 6: Prof. Herve Gallard, ENSIP University of Poitiers, France. “Aquatic surface chemistry of manganese oxides: Production of iodinated organic compounds and interactions with xenobiotics.”
April 13: Prof. Robert Field, University of Oxford, UK.
April 20: Dr. Samer Adam, Global Water Sustainability Center, Qatar. “Advanced treatment of produced water for recycling or reuse applications.”

April 27: Sophie Bertrand, Degremont, France.

May 4: Prof. Tanju Karanfil, Clemson University, USA. “Adsorption of contaminants by CNTs, graphenes, activated carbons.”

THIRD ANNUAL CIAP MEETING

We would like to thank our Center Industry Affiliate Program partners for a productive third annual meeting on November 27-28, 2012.

Industry partners and WDRC researchers

Prof. Hans Vrouwenvelder

Water Desalination and Reuse Center
King Abdullah University of Science and Technology
Thuwal 23955–6900, Saudi Arabia

Contact: Dr. Shahnawaz Sinha
shahnawaz.sinha@kaust.edu.sa
+966 (2) 808 4905