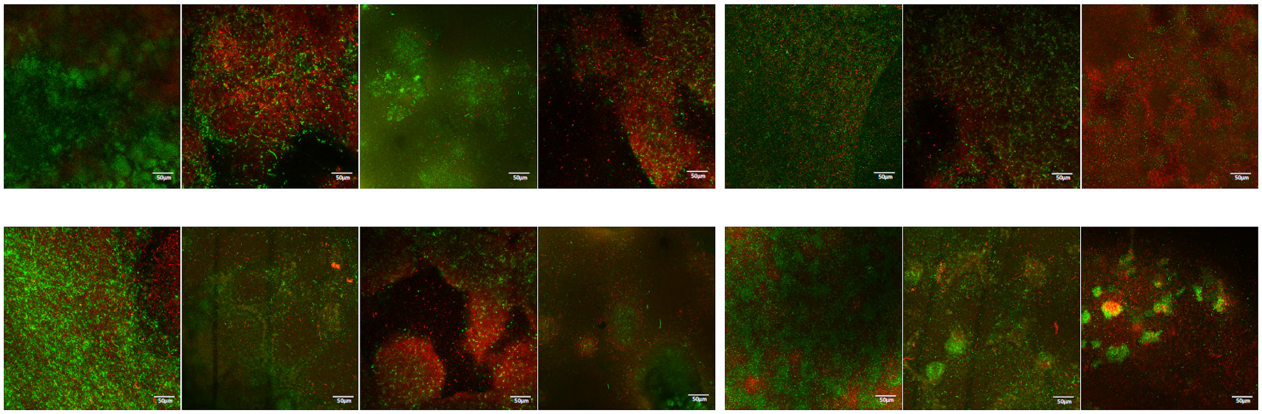


"Confocal image of biofilm"

Water Desalination and Reuse Center – Environmental Microbial Safety and Biotechnology Lab

(Prof. Peiying Hong)

Research activities performed by The Environmental Microbial Safety and Biotechnology Lab at KAUST is driven by the need to address water scarcity issues worldwide, particularly in Saudi Arabia. Saudi Arabia is a water-stressed country that has non-renewable supplies of water at an amount insufficient to meet the demands of the growing population. The problem is further aggravated by the need to utilize up to 80% of the freshwater to irrigate agricultural crops to produce food. The large amount of water required for irrigation in an arid country is a key bottleneck when ensuring food security.

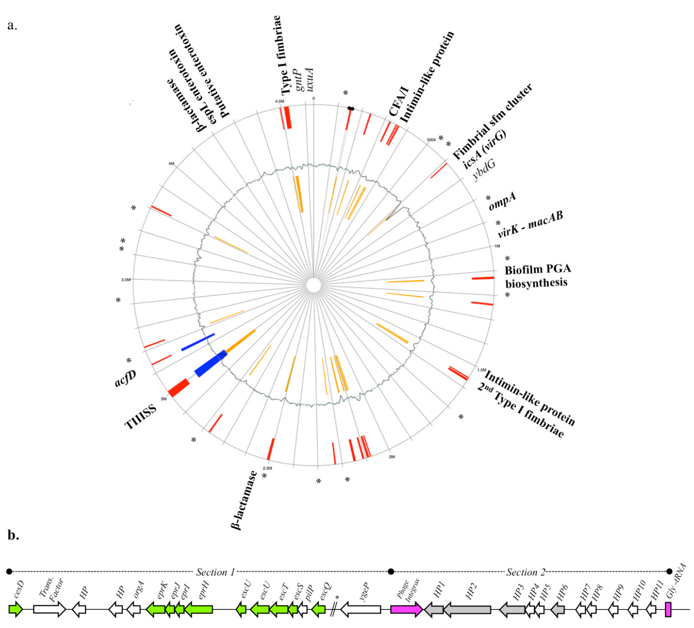
A solution to overcome water scarcity issues would be to look into the use of alternative water sources, one of which would be the treated wastewater. Unfortunately, as of now, only 50% of Jeddah is connected to a centralized wastewater treatment plant, while the remaining 50% relies on septic tanks for waste management and disposal [1]. This means that the wastewater cannot be fully captured for treatment prior to reuse. Instead, septic tanks are designed to discharge partially treated wastewater into the surrounding area after a certain period, which would contribute to fecal contamination of the groundwater supplies and impose a public health concern.

This is of special relevance for Saudi Arabia, with Mecca and its neighboring cities serving as locations for Hajj and Umrah pilgrimages, both of which are carried out by approximately 2 million pilgrims from over 80 different nationalities per year [2]. Human activities such as international tourism and pilgrimage can contribute to the spread of these emerging biological pollutants, as visitors might carry multi-resistant infectious agents that can ultimately be disseminated via the local sewage system [3].

With this background problem, our group aims to understand the microbial safety concerns related to wastewater. This is done primarily though monitoring and characterizing the pathogens or other emerging contaminants that may be present in the wastewater and groundwater. Through this effort, we have isolated a pathogenic *E. coli* that exhibit resistance against a wide spectrum of antibiotics from the wastewater in Saudi Arabia. In order to determine the fate and persistence of this pathogen, we have inserted a fluorescent tag into the bacterium, which would allow one to determine this fluorescent bacterium under the microscope.

Given that our monitoring surveillance suggests the presence of pathogens and other emerging threats in untreated wastewater [4, 5], a good water reuse program can only be safely adopted with an efficient treatment process. An efficient treatment process will also aid in convincing the agricultural farmers to reuse treated wastewater. For this, our group aims to develop anaerobic membrane bioreactor as a green and sustainable biotechnology to treat wastewater [6-8]. This is stemmed from the various advantages of using anaerobic processes to reduce the organic carbon load in the wastewater. Firstly, anaerobic processes generate energy which can be harvested to operate the process itself. This is significant as most agricultural fields are off the infrastructure grid. Secondly, anaerobic processes do not produce a large amount of sludge and hence diminish the need for solid disposal. Thirdly, anaerobic processes produce effluents that retain the original concentration of nitrogen and phosphorus. This nutrient-rich effluent can be used to irrigate and fertilize the crops. Fourthly, by coupling with the membrane separation unit, the effluent is of improved quality compared to those obtained from conventional wastewater treatment plants.

In summary, pursuit of these goals set out by our research group will result in impactful knowledge that can assist the local regulatory agencies (e.g. Ministry of Agriculture, Ministry of Water and Electricity) to devise meaningful water reuse quality standards. These standards will provide guidance to agricultural farmers and would empower them to use treated wastewater safely; and to produce food supplies that can be consumed without any compromise to public health. Our research activities will also result in decentralized anaerobic membrane bioreactors that can be placed on agricultural sites to provide a ready access of treated wastewater for reuse.



References

1. Program, K. I. C. (2010) The KICP Annual Strategic Study - Promoting Wastewater Reclamation and Reuse in the Kingdome of Saudi Arabia: Technology Trends, Innovations Needs, and Business Opportunities. KAUST: Thuwal, Saudi Arabia
2. Ahmed, Q. A., Y. M. Arabi, and Z. A. Memish (2006) Health risks at the Hajj. The Lancet 367:1008-1015.
3. Ahammad, Z. S., T. R. Sreekrishnan, C. L. Hands, C. W. Knapp, and D. W. Graham (2014) Increased waterborne blaNDM-1 resistance gene abundances associated with seasonal human pilgrimages to the upper ganges river. Environ Sci Technol 48:3014-3020.
4. Alsalah, D., N. Al-Jassim, K. Timraz, and P.-Y. Hong (2015) Assessing the Groundwater Quality at a Saudi Arabian Agricultural Site and the Occurrence of Opportunistic Pathogens on Irrigated Food Produce. International journal of environmental research and public health 12:12391-12411.
5. Al-Jassim, N., M. I. Ansari, M. Harb, and P. Y. Hong (2015) Removal of bacterial contaminants and antibiotic resistance genes by conventional wastewater treatment processes in Saudi Arabia: Is the treated wastewater safe to reuse for agricultural irrigation? Water Res 73:277-290.
6. Xiong, Y., M. Harb, and P.-Y. Hong (2016) Characterization of biofoulants illustrates different membrane fouling mechanisms for aerobic and anaerobic membrane bioreactors. Separation and Purification Technology 157:192-202.
7. Harb, M., Y. Xiong, J. Guest, G. Amy, and P.-Y. Hong (2015) Differences in microbial communities and performance between suspended and attached growth anaerobic membrane bioreactors treating synthetic municipal wastewater. Environmental Science: Water Research & Technology 1:800-813.
8. Wei, C. H., M. Harb, G. Amy, P. Y. Hong, and T. Leiknes (2014) Sustainable organic loading rate and energy recovery potential of mesophilic anaerobic membrane bioreactor for municipal wastewater treatment. Bioresour Technol 166:326-334.

KAUST – Red Sea Research Center- Reef Genomics Lab

Our research area is coral reef genomics, an integrative discipline combining ecological, environmental, microbial, and molecular approaches to understand coral animal and reef ecosystem function. Corals are metaorganisms composed of the coral host, intracellular photosynthetic dinoflagellate symbionts, and associated microbiota. Together these so-called coral holobionts form the keystone species of reef ecosystems. Their carbonate skeletons provide the structural habitat complexity necessary to maintain millions of vertebrate and invertebrate species. Coral reefs are biodiversity reservoirs, provide a significant source of nutrition to coastal people, and represent the medicine cabinets of the 21st century, but their existence is threatened by anthropogenic impact.

Our research aims to develop an integrated understanding of the ecology and evolution of the coral metaorganism on a molecular and ecosystem level to predict adaptive capabilities and biotic response to environmental change. The Red Sea provides a natural laboratory that allows us to study mechanisms of adaptation to future ocean scenarios. The ability to gain insight into coral resilience will provide critical guidance for improving strategies to support the sustainable use of coral reef resources and the conservation of ecosystem function. One of these resources is the rich array of molecules with bioactive potential derived from organisms living on coral reefs that we are beginning to characterize. We have furthermore started to characterize a 'new' ecosystem, Red Sea deep-sea corals, that warrant further investigation. Our research follows a hierarchical approach based on a genomics framework covering four research areas, which are outlined in Figure 1. Interactive links providing further info: Frontiers Science Hero - http://blog.frontiersin.org/2016/02/12/scientist-at-red-sea-research-center-looks-at-the-role-of-bacteria-in-3d-coral-reefs-ecosystems/ ; Reef Future Genomics

ReFuGe 2020 - https://vimeo.com/106256176

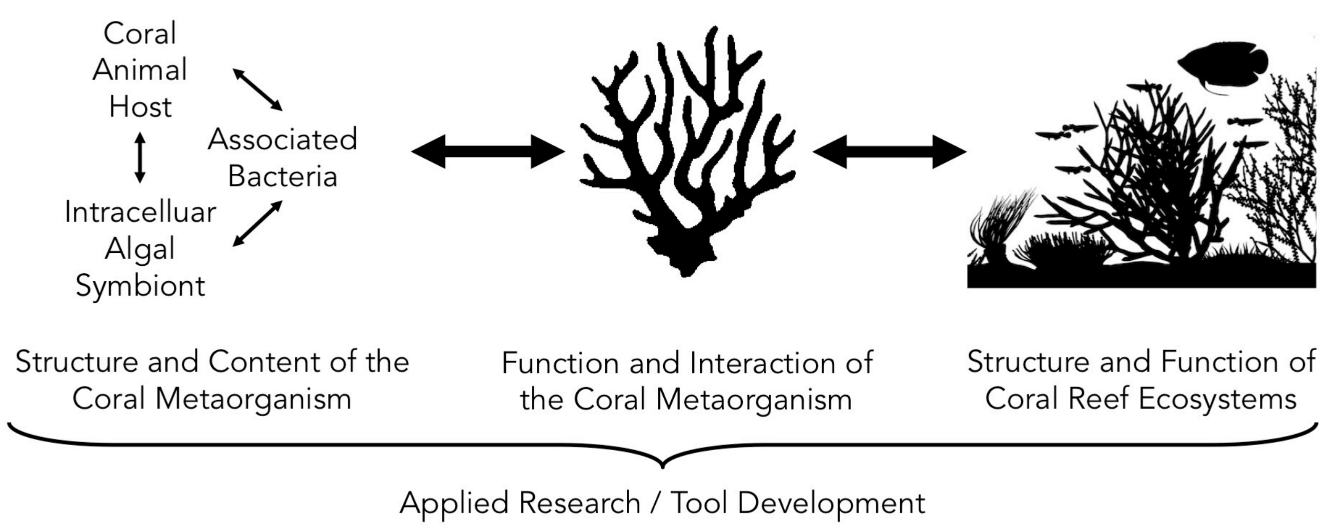


Figure 1: Hierarchical approach to the study of the structure and function of the coral metaorganism on a molecular and ecosystem level.

Integrated Ocean Processes Research Group KAUST

Building the first ocean observatory for the Red Sea

Overview

The Red Sea has been significant to Saudi Arabia and the Arabian Peninsula since time immemorial. From food, to transport and trade, to cultural exchange, the Red Sea has been linked to the diet, health and wellbeing of the region. Today, the Red Sea faces an array of pressures from coastal development, increasing population, fishing, shipping, oil exploration, desalination, terrestrial run-off, plastic waste and climatic changes. The reliance on the Red Sea in the present day has not diminished and stewardship of this national treasure is essential.

At KAUST, located on the shores of the Red Sea, the Integrated Ocean Process (IOP) research group is providing a holistic, integrated understanding of the Red Sea marine ecosystem, including the physical, chemical and biological components. By building the first ocean observatory in the region with real-time modeling and forecasting capability, this 15-year research effort will revolutionize our understanding of the Red Sea. Tools and resources for Saudi Arabia and the region will be provided to effectively steward the long-term ecosystem health of the sea.

The people of the IOP research group are a multidisciplinary, multinational cooperative. Our disciplines straddle biology, ecology, genomics, physics, chemistry, geography, computer science and modeling. Our group of 27 people spans 18 nationalities, bringing with it a breadth of perspectives and depth in expertise. Our perspectives and methods stretch from the microscale: genetic research to identify and classify new and known species, cycling of nutrients in the sea, which form the foundation for productivity to the macro-scale: where underwater autonomous vehicles (gliders), floats and terrestrial-based radars scan the sea and send vital data back to our labs via satellite communication.

Research Topics

The IOP website features current research, people and publications. Three of our synergistic research areas are highlighted below:

a) Ecological Assessment

The ecological assessment effort will provide baseline data regarding the biodiversity patterns of the Red Sea ecosystem, aiming to identify and characterize habitats that are unique, valuable, and sensitive to environmental pressures.

b) Operational Oceanography and Modeling

The operational oceanography research includes the following key components:

1. Surface current mapping (land-based radar systems)
2. Autonomous vehicle hydrographic mapping and monitoring (sea gliders)
3. Moored sensors for currents, waves and hydrographic variables
4. Ocean modeling
    - Physical oceanographic models that provide 3-dimensional, time varying distributions of temperature, salinity, currents and waves.
    - Biogeochemical modeling.

c) Marine Geographic Information System and Database To archive the raw data collected via observations and modeling, we are establishing an archival database and a marine GIS system that can be used for analysis and display of the acquired data sets. Resulting products will include visual, statistical and management services.

As a sub-tropical sea, the Red Sea is warm and very salty. Many of the marine inhabitants of the sea have adapted to these conditions in surprising ways. The Red Sea, therefore, is an optimal laboratory for studying and applying discoveries to the changes that will be experienced with climate change. This living laboratory is a window to the future.

Invitation

Given the pioneering research being undertaken, we would welcome collaboration with artists embracing our interdisciplinary approach to research of the Red Sea in their art practice. We can offer field trips on, below and/or beside the sea, and our upcoming International Conference on the Marine Environment of the Red Sea (14-16 November 2016 at KAUST) would be another opportunity to engage trans-disciplinarily with the wider regional and international Red Sea research community. As an integrated effort, the IOP group collaborates closely with the Earth Fluid Modeling and Prediction laboratory of Prof. Ibrahim Hoteit and we would encourage interaction and interpretations amongst our respective, cross-divisional research groups.

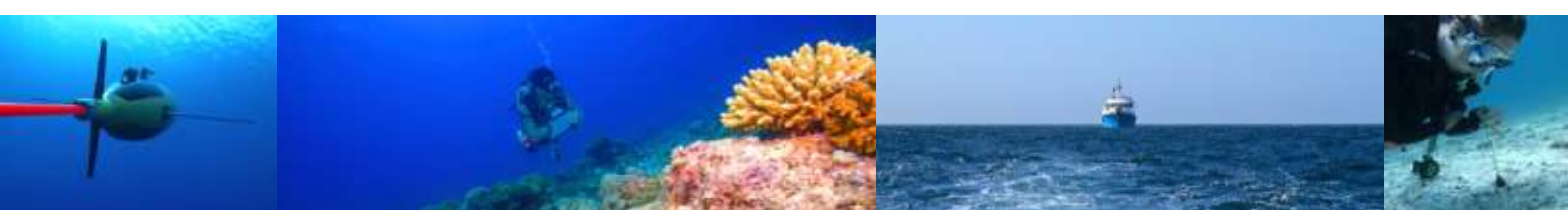
Web site: https://iop.kaust.edu.sa; Integrated Ocean Processes Group led by Professor Burton H. Jones

Selected Papers

1. Brewin, R., Raitsos D., Dall'Olmo G., Zarakenellos, N., Jackson T., Jones B., Hoteit I., *Regional ocean-color chlorophyll algorithms for the Red Sea*. Journal of Remote Sensing of Environment, accepted, 2015.
2. Carvalho S., Cúrdia J., Pereira F., Guerra-García J.M., Santos M.N., Cunha M.R. 2014. Biodiversity patterns of epifaunal assemblages associated with the gorgonians *Eunicella gazella* and *Leptogorgia lusitanica* in response to host, space and time. Journal of Sea Research, 85: 37-47.
3. Carvalho S. et al. 2013. How complementary are epibenthic assemblages in artificial and nearby natural rocky reefs? Marine Environmental Research, 92: 170-177.
4. Jones, B., E. Teel, B. Seegers, and M. Ragan. 2015. Observing, Monitoring and Evaluating the Effects of Discharge Plumes in Coastal Regions, in *Intakes and Outfalls for Seawater Reverse-Osmosis Desalination Facilities*, edited by T. Missimer, B. Jones and T. Pankrantz, Springer International Publishing, Switzerland, doi:10.1007/978-3-319-13203-7_22.
5. Kürten B. et al. 2014. Ecohydrographic constraints on biodiversity and distribution of phytoplankton and zooplankton in coral reefs of the Red Sea, Saudi Arabia. Marine Ecology, doi: 10.1111/maec.12224.
6. Pearman, J.K & Irigoien X. 2015. Assessment of Zooplankton Community Composition along a Depth Profile in the Central Red Sea. PLOS ONE 10(7): e0133487. doi:10.1371/journal.pone.0133487
7. Pearman J., Irigoien X., Carvalho, S. 2016. Extracellular DNA amplicon sequencing reveals high levels of benthic eukaryotic diversity in the central Red Sea. Marine Genomics, 26: 29-39. doi: 10.1016/j.margen.2015.10.008
8. Zhan P., Yao F., Kartadikaria A., Viswanadhapalli Y., Gopalakrishnan G., and I. Hoteit. 2014. *Far-field ocean conditions and concentrate discharges modeling along the Saudi coast of the Red Sea*. in *Intakes and Outfalls for Seawater Reverse-Osmosis Desalination Facilities*, edited by T. Missimer, B. Jones and T. Pankrantz, Springer International Publishing, Switzerland, doi:10.1007/978-3-319-13203-7_22.

Media

KAUST Discovery article on ‘An ocean observatory for the Red Sea’
KAUST Discovery article, ‘Unlocking the mysteries of the Red Sea eddies’.
KAUST Beacon article, ‘KAUST glides into the future of oceanography’. (pages 12-13)



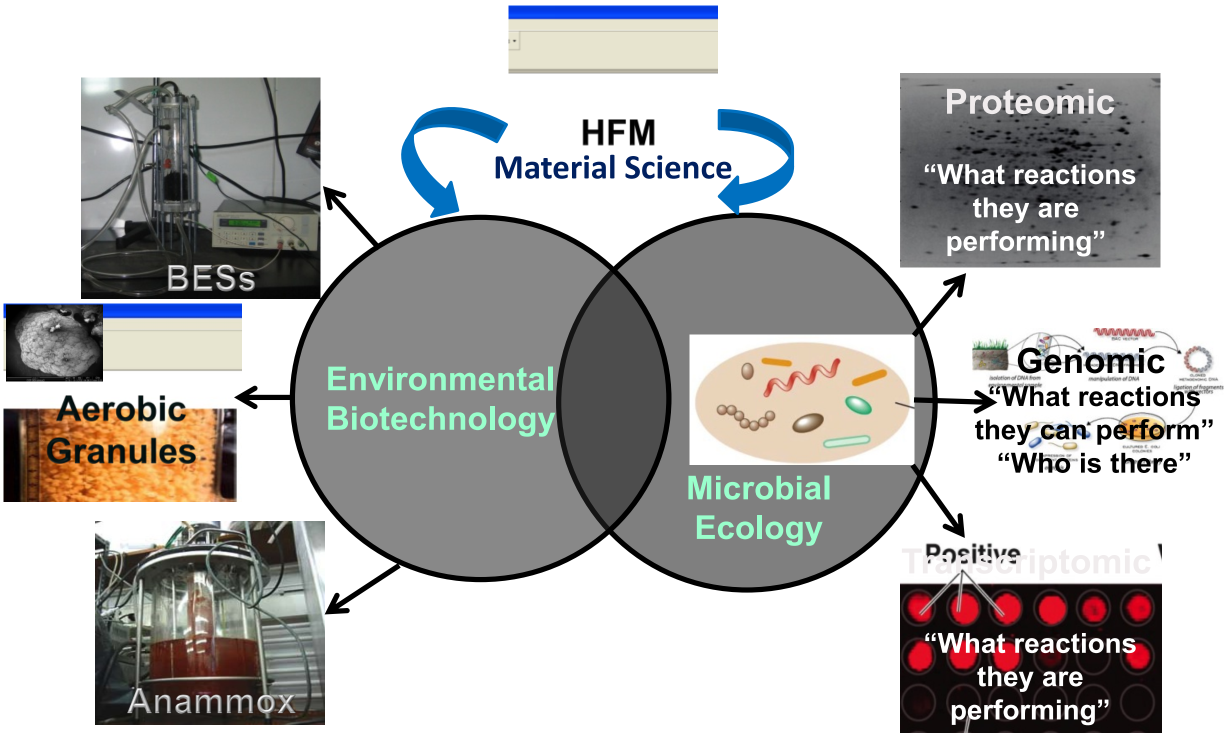
Water Desalination and Reuse Center – Waste Water Reuse

(Prof. Pascal Saikaly)

Water and energy resources are inter-dependent; a relationship commonly referred to as the water-energy nexus. 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 through reclamation and reuse of domestic wastewater. The current paradigm for wastewater treatment is based on technologies that are energy-and resource-intensive. To meet the water demands of a growing population and the economic realities of energy resources, there is a clear need to develop sustainable and low-energy demanding technologies for wastewater reclamation and water reuse. To achieve this goal my research group at KAUST is conducting fundamental and goal-oriented research to optimize and create sustainable biotechnologies (**Bioelectrochemical systems; Aerobic granular sludge process; Anammox process**) for wastewater reclamation and reuse that are robust, scalable, and capable of providing tailored water quality with minimization of energy, resources and carbon footprint.

My research group employs various omic tools (genomic, proteomic, and transcriptomic) to study the microbial ecology of engineered microbial systems (bioelectrochemical systems, aerobic granular sludge, Anammox). Also we innovate in the development of new engineered microbial systems and dedicate efforts in understanding their microbial ecology. We strongly collaborate with Faculty at KAUST, exploring their complementary expertise in synthesizing new membranes specifically tailored for our applications. We are guided by the vision that convergence of environmental biotechnology, microbial ecology and material science will provide viable solutions to the two greatest challenges facing society in the 21st century, i.e. water and energy (Scheme 1).

https://wdrc.kaust.edu.sa/Pages/WDRC-PhD.aspx



Scheme 1

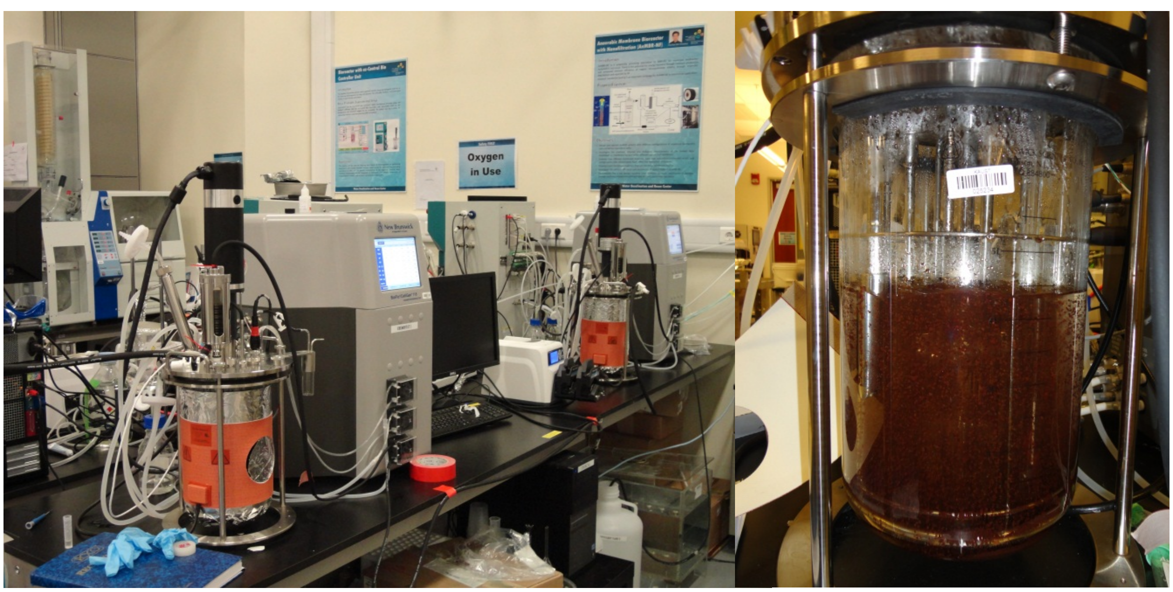


Figure 1. Anammox reactors in the WDRC.

Figure 2. Aerobic granular sludge set-up in the WDRC.