Newcastle University
School of Engineering

ISSUE 13 | October/November 2018

pig MONTHLY

process intensification group | www.pig.ncl.ac.uk | www.pinetwork.org

In This Issue

GHGT-14

The 14th International Conference on Greenhouse Gas Control Technologies (GHGT-14) was held from 21—26th October in Melbourne, Australia. This conference has been established as the principle international conference on greenhouse gas mitigation technologies, especially on CCS, and formed in 1997 following the merger of the earlier ICCDR series and the Greenhouse Gas: Mitigation options conference. The IEA Greenhouse Gas R&D Programme (IEAGHG) is the guardian of this conference series, with GHGT conferences being held every two years in IEAGHG member countries. The main themes at this year's meeting were: capture technologies (20 sessions) and storage methods (26 sessions). Other themes included: alternative storage methods (1 session), industrial GHG sources (4 sessions), transport (2 sessions), negative emissions (2 sessions), CO_2 utilization (3 sessions), demonstration (4 sessions), technology assessment (5 sessions), public perceptions (1 session), policy (2 sessions) and legal (1 session). A summary of the full programme is available here.

Dr Jon Lee, Dr James Hendry and Warm In-Na represented the PIG at the 2018 meeting, presenting the following research under the "capture" theme:

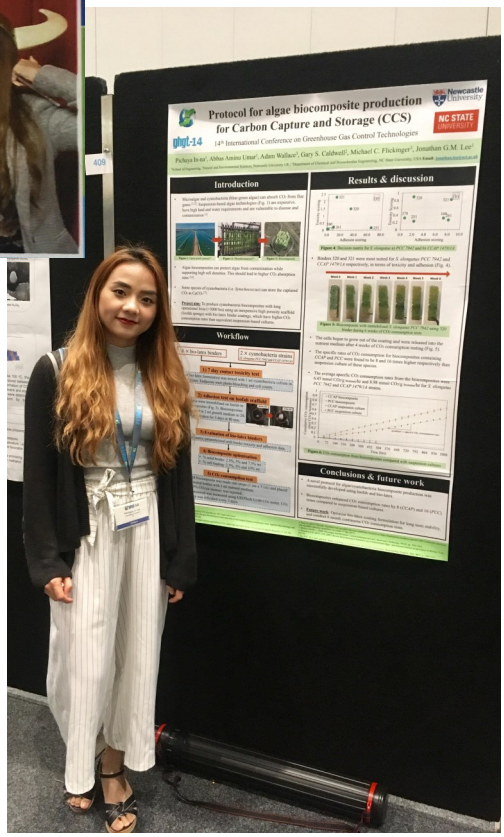
J. Lee, M. Flickinger, A. Umar, **W. In-Na** | "Protocol for algae biocomposite production for Carbon Capture and Storage (CCS)" | Poster (see image below)

J. Lee, P. Attidekou, T. Kolawole, **J. Hendry** | "Comparative study of CO2 capture using counter, co and cross flow configurations in a rotating packed bed absorber using mono ethanol amine (MEA)" | Oral Presentation (see image below)

Upcoming Conferences

- **2019 AIChE Spring Meeting and 15th Global Congress on Process Safety** (31 Mar-4 April 2019, New Orleans, Louisiana, US).
- **4th Green and Sustainable Chemistry Conference** (5-8 May 2019, Dresden, Germany). Early registration deadline: 8th March 2019
- **International Symposium on Green Chemistry, ISGC2019** (13-17 May 2019, La Rochelle, France). Abstract Deadline: 15th April 2019
- **2nd International Process Intensification Conference (IPIC²)** (27-29 May 2019, Leuven, Belgium). Abstract Deadline: 15th Jan 2019
- **13th International Workshop on Polymer Reaction Engineering** (11-14 June 2019, Hamburg, Germany)
- **International Congress of Chemical Engineering** (19-21 June 2019, Santander, Spain)
- **12th European Congress of Chemical Engineering** (15-19 Sep 2019, Florence, Italy). Abstract Deadline: 15th Jan 2019
- **2019 AIChE Annual Meeting** (10-15 Nov 2019, Orlando, Florida, US). Call for abstracts will open in January 2019

GHGT-14 Photos



PIG News

- Dr Anh Phan recently produced an article in The Conversation that discusses the process of converting plastics directly into useful forms of energy and chemicals for industry
- The Wastewater Network Conference is an annual conference that aims to bring innovative and new technologies to light across the water sector. The 6th meeting was this year hosted at Cranfield University on 28th November, where PhD student Harry Laing was invited to attend as one of the representatives of Newcastle University and Northumbrian Water. Harry won the prize for best poster, which can be viewed here.
- Harry Laing recently published an article titled "Embracing the 'Digital Revolution' doesn't have to be complex, or costly" in the 200th edition of the Institute of Water magazine, which was dedicated to "Energy, Efficiency and Traffic Management". A pre-print version of the article can be read here.
- Prof Adam Harvey will give a presentation to the Scottish Branch of the IChemE at Heriot Watt University on the 6th December on "Process Intensification and why you should be doing it"
- All PI group members are encouraged to submit abstracts to the Second International Process Intensification Conference (IPIC^2), which will be held from 27—29th May 2019 in Leuven, Belgium. This is the first time this conference series is being run as a stand-alone event, and will be the pinnacle platform for disseminating PI-orientated research.
- Dr Fernando Russo-Abegao recently helped to organize and successfully deliver a two half-day event at Newcastle University on 22nd—23rd November that focused on novel catalytic materials and novel reaction technologies. This forum was run in collaboration with the IChemE Catalysis Special Interest Group (CatSIG) and Prof Ian Metcalfe, head of the Applications of Ion Transport Group
- The TUV SUD NEL laboratory in East Kilbride, near Glasgow, has excellent experience and facilities for flow measurement and numerous related activities. Prof David Reay used to work closely with them, and Marietta would be happy to help PIG members interested in involvement in the event/webinar opportunities in their regular Newsletter. The latest one is available here.

New Publications

- Z. Ahmad, A. Bahadori, J. Zhang. Prediction of equilibrium water dew point of natural gas in TEG dehydration systems using Bayesian Feedforward Artificial Neural Network (FANN). Petroleum Science and Technology 20 (2018) 1620-1626
- M.A.S. Alkarawai, G.S. Caldwell, J.G.M. Lee. Continuous harvesting of microalgae biomass using foam flotation. Algal Research 36 (2018) 125-138
- P. Livotov, A.P.C. Sekaran, Mas'udah, R. Law, D. Reay, A. Sarsenova, S. Sayyareh. Eco-innovation in process engineering: Contradictions, inventive principles and methods. Thermal Science and Engineering Progress 9 (2019) 52-65
- J.R. McDonough, S. Murta, R. Law, A.P. Harvey. Oscillatory fluid motion unlocks plug flow operation in helical tube reactors at lower Reynolds numbers (Re ≤ 10). Chemical Engineering Journal 358 (2019) 643-657
- G.A. Oliveira, I. Monje-Ramirez, E. Carissimi, R.T. Rodrigues, S.B. Velasquez-Orta, A.C.C. Mejía, M.T.O. Ledesma. The effect of bubble size distribution on the release of microalgae proteins by ozone-flotation. Separation and Purification Technology 211 (2019) 340-347
- F.N. Osuolale, J. Zhang. Exergetic optimisation of atmospheric and vacuum distillation system based on bootstrap aggregated neural network models. In: Exergy for a Better Environment and Improved Sustainability; 1: Fundamentals. Cham: Springer Verlag (2018), pp. 1033-1046
- J. Palmer, C.J. O'Malley, M.J. Wade, E.B. Martin, T. Page, G.A. Montague. Opportunities for Process Control and Quality Assurance Using Online NIR Analysis to a Continuous Wet Granulation Tableting Line. Journal of Pharmaceutical Innovation (2018). In-Press
- S. Velasquez-Orta, E. Utuk, M. Spurr. Microbial fuel cell sensors for water and wastewater monitoring [Book Chapter]. In: Microbial Electrochemical Technologies, CRC Press (2018)
- S. Wang, W. Lee, C. Li, B. Kuan, N. Burke, J. Patel. The pyrolysis of natural gas - A study of carbon deposition and the suitability of reactor materials. AIChE Journal (2018). In-Press

Recent PIG Seminars

Introductions to New PhD Students

- **Guanqi Wang** | 5th Oct
  "Dynamics of a Levitated Object"
- **Olatunde Akinbuja** | 5th Oct
  "Algae Based Bioelectrochemical Systems"
- **Abdullahi Adamu** | 5th Oct
  "Photocatalytic CO_2 Reduction to Chemical and Fuel"
- **Hafsat Ibrahim** | 12th Oct
  "Ultrasound-assisted Ozone pretreatment of biomass waste to chemical platforms (5-hydroxymethyl furfural)"
- **Abubakar Halidu** | 12th Oct
  "Production of Bio-Hydrogen from Agricultural Residues (Spelt Husks) using Gasification Process"

Regular/Guest Meetings

- **Wissam Muhsin** | 29th Oct
  "Modelling and Multi-Objective Optimisation of a Crude Oil Hy drotreating Process Using Bootstrap Aggregated Neural Networks"
- **Jose Munoz** | Visiting PhD Student | 19th Oct
  "Analysis of the heat transfer, power consumption and flow patterns in baffled tubes under oscillatory flow"
- **Dr Lyes Kahouadji** | Guest Speaker from Imperial | 2nd Nov
  "Vortex formation and aeration in an air-water mixing system using a pitched blade turbine"
- **Faisal Saleem** | 9th Nov
  "Conversion of benzene to methane"
- **Mohamad Faiz Gunam Resul** | 16th Nov
  "Continuous epoxidation of renewable terpenes using novel "mesoscale" 3D-printed oscillatory baffled reactors"
- **Harry Laing** | 23th Nov
  "Investigation of control and on-line optimization of a wastewater treatment plant"
- **Jonathan Harris** | 30th Nov
  "Cold plasma initiated valorization of waste glycerol"

TSEP Special Issue:

Thermal Energy Use in the Agricultural Sector

Dr. habil. Barbara Sturm, Head of Process and Systems Engineering in Agriculture at the University of Kassel (and previously at Newcastle University) has organized a Special Issue of Thermal Science and Engineering Progress, an Elsevier Journal (edited by Prof David Reay of PIG) where she is Executive Editor, on thermal energy use in agriculture.

Of particular interest to our Chemical Engineering area is her message that papers on bio-based processes will be very welcome. As the Special Issue is a 'virtual' one, papers do not need to meet the deadline shown in the call, (1 January 2019) and this allows a degree of flexibility. Full data on the SI are given in the flyer that can be viewed here.

Other Information

- Full contact details and research profiles for the PI group members can be found at the website: *http://pig.ncl.ac.uk*
- For enquires about collaborations or PhD study, see the website: *http://pig.ncl.ac.uk*
- If anyone would like to contribute any articles, or if anyone has any ideas regarding the newsletter please contact Jonathan McDonough: jonathan.mcdonough@ncl.ac.uk

UK National Heat Transfer Committee

The 16th UK Heat Transfer Conference, organised under the auspices of the UK National Heat Transfer Committee, will be held at the University of Nottingham on 8-10th September 2019.

The Conference Chairman, Professor Yuying Yan is pleased to invite researchers and practitioners from academia and industry to submit extended abstracts describing original research in line with one of the Conference themes.

The deadline for abstract submission is on Tuesday 15th January 2019.

More information is available on the conference website.

We are looking forward to seeing you in Nottingham!

The Second International Process Intensification Conference (IPIC2) will take place as a stand-alone conference, unlike IPIC[1] which was held in conjunction with the 10th World Congress of Chemical Engineering (Barcelona 2017). IPIC[2] will be an excellent opportunity to learn about recent implementations in industry, the latest advances in research, and the current offer from technology providers. Furthermore, discussions on the state of the art and future perspective of process intensification will keep you updated on future trends. We specifically reach out to our colleagues in other continents to build a global PI community.

A number of presenters in IPIC2 will be invited to publish their results in a Special Issue of Chemical Engineering and Processing: Process Intensification (CEP:PI) and a Special Issue of the Journal of Advanced Manufacturing and Processing (JAMP).

The call for abstracts is currently open (deadline: 15th Jan 2019).

HORIZON 2020 Call for Proposals on 'Efficient Integrated Downstream Processes'

Newcastle University, in conjunction with a number of partners in Europe, many of whom collaborated on the recently-completed €10 million 'Intensified by Design' project - see http://ibd-project.eu/ - is seeking industrial 'end users' who would be interested in joining us to bid for this SPIRE project. Within SPIRE the process industries targeted are: Cement, Ceramics, Chemicals, Minerals, Steel and Water.

It is believed that this call will be of interest to several of the **PIN members who receive the PIG Newsletter.** The budget is such – an EU contribution of €10-14 million is suggested – that an end user could expect a substantial prototype demonstration unit at the end of the project. In terms of Technology Readiness Level (TRL) the European Commission expects the project to commence at TRL 5 – "Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)" and achieve TRL 7 level – "A system prototype demonstration in an operational environment". We read this as allowing the validation to take place in a research laboratory ideally with process streams mirroring those in the selected industrial sector(s), but ending up at an industrial site, either as essential components of the product process stream, or, perhaps more sensibly, located in a bypass stream, at least initially.

Information on the Call for Proposals can be found at H2020-NMBP-ST-IND-2018-2020 and data given there are summarized below. The deadline for proposal submission is 21 February 2019, and Grant Agreements would be signed by the end of October 2019, at the latest.

The specific challenge, as set out in the Call, is as follows:
"Today, process industry operations for downstream processing represent on average 50-60% of the total capital (CAPEX) and operating costs (OPEX) and they account for up to 45% of the process energy in industrial operations. These high costs for downstream processing are often linked to the inefficiencies in the upstream process, due to low conversion and formation of co-products, by-products and/or impurities. Hybrid processing technologies (including chemical and biochemical steps) can provide major advantages in terms of primary process selectivity and sustainability. However, they have not been widely deployed in industry so far. The development of novel technologies for upstream and downstream unit operations, as well as their better integration, could provide significant resource and energy efficiency gains."

The scope is such that proposals are "expected to provide novel solutions for a deeper integration of upstream and downstream processing operations."

Of particular interest and relevance to the Process Intensification Group in Chemical Engineering at Newcastle, and to many of the other 21 partners in IbD is the emphasis on PI technologies as set out in the Call:

- Intensified process technologies presenting multistep upstream processes, potentially exploiting hybrid chemo and bio catalytic technologies as well as process analytical techniques (PAT), in order to maximise production efficiency, selectivity and mitigation of downstream processing;
- Complex downstream operations, integrating different separation techniques and purification steps;
- Modularity and flexibility of the solutions, as well as, potential for transition from batch to continuous operations;

- The technologies proposed should enable increased productivity, purity and quality of products, while lowering the process environmental footprint and increasing resource and energy efficiency;
- The potential for integration in the current industrial scenario, and the replicability of the concept in different sectors of the process industry;
- Increased safety of the work environment.

The IbD project took some of the more challenging PI applications – those where solids are present – and successfully demonstrated six Case Studies of intensified unit operations in three of the six sectors identified in SPIRE. We addressed challenges relevant to all of the bullet points above, but did not venture into the bio-catalytic area – although we did work in the pharma sector.

Pointers towards what might be addressed in a successful proposal are summarized in the Call document as:

> *"Proposals should provide proof of economic and industrial feasibility of the technologies involved; and should consider the potential integration in existing installations, as well as their retrofitting. Reduction of production costs and time to market is also expected.*
>
> *"Significant demonstration activities in industrial environments are expected. Demonstration activities in real industrial settings, showing the potential for integration into existing plants and industrial operations, represent a clear added-value to the proposals.*
>
> *"Proposals submitted under this topic should include actions designed to facilitate cooperation with other projects; to enhance user involvement; and to ensure the accessibility and reusability of data produced in the course of the project."*

From these it can be seen that our emphasis on seeking end users is particularly important if the proposal is to be taken seriously by the Commission assessors.

Expected Impact: In the proposal, as well as giving details of the ways in which the challenges above will be addressed, the EC will expect us to show how our solutions will meet the quantified criteria set out below:

- 20% decrease in greenhouse gas emission;
- Increased in resource and energy efficiency by at least 20%;
- Novel modular and scalable integrated (upstream-downstream) pilot line technologies with 10% decrease in CAPEX and OPEX;
- Effective dissemination of major innovation outcomes to the current and next generation of employees, through the development of learning resources with flexible usability. These should be ready to be easily integrated in existing curricula and modules for undergraduate level and lifelong learning programmes.

For PIN Members: Please contact David Reay on DAReay@aol.com or David.Reay@newcastle.ac.uk if you would like to discuss in more detail the opportunities for joining our proposal.

Bioelectrochemical Systems

Dr Sharon Velasquez-Orta, Eka Utuk, Olatunde Akinbuja, Tobechi Okoroafor

Bioelectrochemical Systems, known as BES, are a biotechnology that can be used for resource recovery of waste biomass (wastewater) or the removal of inorganic waste from a stream (CO_2, metals). BES undertake waste transformations through selective interactions involving waste, microorganisms and conducting electrodes. Here, redox reactions facilitate the transport of electrons from microorganism to carbon electrodes. The operation of BES depend on the waste transformation and product of interest. As such, there are numerous subdivisions of bioelectrochemical systems. The ones we have studied in the PIG include: Microbial Fuel Cells (MFC), Microbial ElectroSynthesis cells (MES) and Microbial Electrolysis Cells (MEC). Applications studied of each type of technology can be seen in Figure 1.

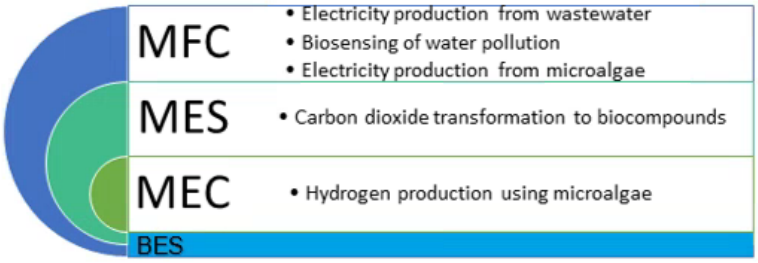


Figure 1. Types of Bioelectrochemical Systems. Studied applications are shown in bullet points.

It was in Armstrong Building located in the centre of Newcastle University where Prof. Potter in 1911 first published the idea of producing electricity from microorganisms. About a centenary later, researchers reported the use of MFCs to obtain electricity from the hydrolysis and fermentation of organic matter using bacteria. MFCs are relevant as the technology only uses one unit operation to obtain electricity, competing with current anaerobic digesters that produce biogas which is then fed to a generator for electricity production. Figure 2 shows a traditional MFC system which consists of an anode and a cathode connected by a load (usually a resistor in laboratory studies). The anode contains mixed or pure cultures of microorganisms that are used to catalyse the decomposition of the organic matter into electrons and protons. An electric current is facilitated through the reduction of oxygen or another chemical at the cathode. A metal is usually used to catalyse oxygen reduction, though it has been shown that microorganisms (e.g. microalgae) can be used for this purpose as well.

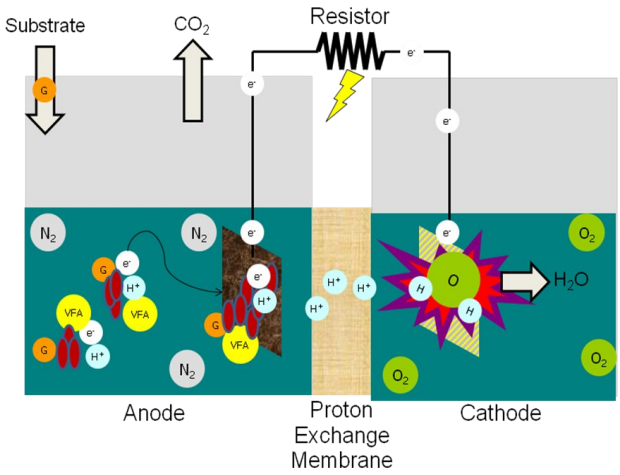


Figure 2. Schematic representation of a microbial fuel cell (Taken from Velasquez-Orta, 2010). In the anode: orange circles are the substrate glucose(G), yellow circles are volatile fatty acids (VFA), white circles are electrons (e-), blue circles are hydrogen protons (H+), grey circles are nitrogen molecules (N_2), brown circles are bacteria that may be either attached to the anode or suspended in the electrolyte, and the brown rectangle is the anode electrode. In the cathode: green circles are oxygen molecules (O_2).

Through our research we have collaborated with groups in Manchester University, UK; and PennState University, USA. This has led to several well-cited articles that uncover microbial electron transfer mechanisms (7) and guide the standardisation of an important lab-technique called polarisation (6). Polarisation is used to define the maximum power output delivered by a MFC. Dr Velasquez-Orta's initial work has now branched into several related areas in the search of proving different industrially feasible technologies. This includes the use of MFC biosensors to create low-cost devices that can be used to monitor waste biomass pollution. Here, a novel way to monitor faecal pollution events in groundwater wells was proposed using a technology described in an article in the Water Research Journal in 2017 (3). This work was funded by NERC and helped initiate collaboration with academics from Ardhi University, Tanzania. The technology was recognised in 2015 by MIT as a world leading innovation. The same year, Dr Velasquez was invited by the United Nations to their Annual Water Theme Conference to discuss with a panel of experts the sensing technologies available to improve global water management. A chapter on MFC biosensors for the book titled Microbial Electrochemical Technologies has been produced with the input of Ekaete Utuk (a PhD student in the PIG) and it will be published in March of 2019 by CRC Press, Taylor & Francis Group (1). Our research in this area continues, by studying the development of other types of biosensors to detect microbial pollution.

Twelve years ago it was discovered that MFCs could be turned into a MECs by adding a small supplement of electricity at the cathode to produce products such as hydrogen gas. Since then, the technology has spurned much excitement and research into increasing the performance and gas yield of MECs. In this field most of the cathode materials used include precious metals such as platinum. Our research focuses on the use of biocatalysts in the cathode to enhance hydrogen production. Olatunde Akibunja is currently investigating the use of MEC systems to facilitate the synthesis of hydrogen using microalgae as an alternative sustainable biocatalyst:

Algae Based Bioelectrochemical Systems

Olatunde Akinbuja

This research seeks to investigate the role of *Synechocystis sp* PCC 6803 and *Chlorella vulgaris* as biocatalysts in bioelectrochemical systems and to increase their catalytic function through optimization and intensification. One of the strategies for intensification will be the use of biocomposite electrodes to be tested in MFC and MEC. In bioelectrochemical systems, the formation of a biofilm has been liked to higher system performance. Immobilization of microbes on electrodes, helps provide an "artificial" biofilm. An algae paper electrode will be created and applied to bioelectrochemical systems to investigate how this influence electricity production and hydrogen production. Finally, a comparison will be made between the performance of *Chlorella Vulgaris* (green algae) and *Synechocystis* (cyanobacteria).

MES also use power to perform processes or product formations. In contrast with MFC, that produce electrical energy, MES reverse this process to product formation by applying an electric current. Here, we are interested in investigating microbe-electrode interactions that drive bio-production from CO_2. We have studied the economic and sustainability of MES technologies (4,5). Plus our recent alumna, Dr Xenia Christodoulou, researched the ability of using *Shewanella Oneidensis* MR-1 as biocatalyst to facilitate the conversion of CO_2 to biocompounds. We discovered the main products formed from CO_2 as acetate, formic, propionic and butyric acids. This, along with other outcomes, suggested that *Shewanella Oneidensis* MR-1 are able to biosynthesize hydrocarbons from CO_2. Tobechi Okoroafor has now concluded his work on the sustainability analysis of MES technology using a full life cycle analysis, proposing which products are industrially and environmentally viable.

Our group has participated in several activities in the UK and other parts of the word. Highlights include the set-up of an MFC system in the London Science Museum, and a demonstration for children in the Hancock Museum. Members of our group engage in interdisciplinary research attending electrochemical, water (2) and chemical engineering conferences. Dr. Velasquez has chaired or co-organised 6 other European or International events including this years' 4th European Meeting in Bioelectrochemical Technologies held at Newcastle, UK and the World Water Day celebration and workshop held at the Institute of Engineering, Mexico.

Recent research outcomes for PIG Bioelectrochemistry Research:

1. Velasquez-Orta S, Utuk E, Spurr M. Microbial fuel cell sensors for water and wastewater monitoring. In: Microbial Electrochemical Technologies. CRC Press, 2018. In Press.
2. Velasquez-Orta SB, Heidrich O, Black K, Graham D. Retrofitting options for wastewater networks to achieve climate change reduction targets. Applied Energy 2018, 218, 430-441.
3. Velasquez-Orta SB, Werner D, Varia J, Mgana S. Microbial fuel cells for inexpensive continuous in-situ monitoring of groundwater quality. Water Research 2017, 117, 9-17.
4. Christodoulou X, Velasquez-Orta SB. Microbial electrosynthesis and anaerobic fermentation: An economic evaluation for acetic acid production from CO_2 and CO. Environmental Science and Technology 2016, 50(20), 11234–11242.
5. Christodoulou X, Okoroafor T, Parry S, Velasquez-Orta S. The use of carbon dioxide in microbial electrosynthesis: Advancements, sustainability and economic feasibility. Journal of CO2 Utilization 2017, 18, 390-399.
6. Velasquez-Orta SB, Curtis TP, Logan BE. Energy From Algae Using Microbial Fuel Cells. Biotechnology and Bioengineering 2009, 103(6), 1068-1076.
7. Velasquez-Orta SB, Head IM, Curtis TP, Scott K, Lloyd JR, von Canstein H. The effect of flavin electron shuttles in microbial fuel cells current production. Applied Microbiology and Biotechnology 2010, 85(5), 1373-1381.
8. Velasquez Orta SB, Head IM, Curtis TP, Scott K. Factors affecting current production in microbial fuel cells using different industrial wastewaters. Bioresource Technology 2011, 102(8), 5105-5112.