MEEP 2022

Book of Abstracts

Special Symposium on

Microbial, Enzymatic & Bio-Photovoltaic Electrochemical Reactors, Fuel Cells and Electrolyser Systems

Sessions

M03: Microbial Reactors: Fuel Cells & Hydrogen Syntrophy
M04: Bioelectrochemical systems: Reactors, design and insights
M05: Biofilms with a Keynote
M06: Microbial dynamics: traits and fuel cell reactions
M08: Electrode materials and surface interactions
M09: Bioelectrochemical Systems with a Keynote on Up-scaling

Compiled and edited by

Prof. Johannes Gescher Prof. Ioannis Ieropoulos Fiona Moore Dr. Michael Spirig

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M0104

Technologies and nature-based solutions in sustainable actions on European Unionô cities

Minas Angelidis
National Technical University of Athens, Athens/Greece
Tel.: +30 6972308416
angelimi763@gmail.com

Abstract

Scope of the presentation is to discuss: (a) the role of technologies in sustainable city actions (b) the advantages of [illegible] sustainability. Both constitute important points of the COST PHOENIX rationale. The investigation refers to the smart and green city actions implemented in European Uni[illegible] cities.
At first, we present and comment briefly the conceptual framework of smart cities and green cities as well as the relationships among them.
Next, we discuss the role of technologies [illegible] the cit[illegible] concept of nature-based city solutions and what advantages they present compared to other city solutions. Then, we look at the classifications of smart and green city actions by categories and sub- categories (see, for instance, the classification proposed by Vienna University of Technology / VUT) and distinguish those in which the role of technologies is more important. Next, from the subcategories selected we present in detail some examples of city actions and we comment on their environmental footprint on cities and their socioeconomic impact as well. We are taking similar steps regarding nature-based city solutions.
The whole investigation has as a starting point (based on the relevant state of the art) the fact that urban actions based on appropriate technologies and leading to nature-based city solutions have a better environmental footprint and a better socioeconomic impact on cities. Therefore, it is worth giving them priority in funding and support from local and national authorities as well as by the respective EU programs. Consequently, research in the above fields also needs to be supported as a priority.
From this point of view, it is worth examining whether EU policies (especially for cities and in general) follow this priority. To this end, we proceeded to a critical evaluation of the EU urban agendas as well as of the EU [illegible] instrumentô objectives and tools [illegible] to p[illegible] both the above strategies and the relevant tools have weaknesses and need appropriate adjustments.

M0105

A bioelectrochemical system for flexible biogas production

Janek R. Weiler[1,*], Melanie T. Knoll[1,*], Nikolai Jürgensen[2], An-Ping Zeng[2], Johannes Gescher[1]

1 Institute of Technical Microbiology, University of Technology Hamburg, Hamburg, Germany
2 Institute of Bioprocess and Biosystems Engineering, University of Technology Hamburg, Hamburg, Germany

Tel.: +49- (0)40- 42878 ï3963
janek.weiler@tuhh.de

Abstract

Biogas plants in which biomass is converted by microorganisms to biogas are already widely applied. However, the biogas production is rather sensitive to an accumulation of organic acids that inhibits methanogenesis. To optimize this process, one approach is to integrate microbial electrolysis cells (MEC) into existing biogas plants. In the envisioned MEC-biogas-hybrid reactor, exoelectrogenic organisms will oxidize organic acids in a respiratory process to carbon dioxide. The terminal electron acceptor of the microorganisms is the MEC-anode while hydrogen is produced on the cathode side. By adjusting the potential of the anode it will be possible to direct electron flow from organic acids in the biogas reactor either towards cathodic hydrogen or biogas production.

A 10 L MEC-reactor was developed for scalable process development. The reactor was constructed according to the blueprint of a biological contactor with rotating discs as anodes of the MEC system. A model biofilm was pre-grown on the rotating discs consisting of the exoelectrogenic organisms *Shewanella oneidensis* and *Geobacter sulfurreducens*. After reaching a stable current production, linear sweep voltammetry was used to determine the limits of potential-controlled electrode transfer. Here, a potential below -0.24 V vs. normal hydrogen electrode (NHE) led to a complete inhibition of anodic electron transfer. Alternating potentials of -0.2 V and 0.2 V vs. NHE were applied over different time periods to determine how exoelectrogenic organisms can cope with rapid changes in the applied anode potentials. The conducted experiments revealed that these rapid potential variations did not interfere with long-term activity of the anode biofilms as it was possible to regain maximum current densities shortly after readjusting the potential towards maximum electron transfer kinetics. The experimental data is currently evaluated to identify kinetic parameters for the development of a mathematical MEC model that can be integrated into existing models for anaerobic digestion.

M0301

Revealing hydrogen syntrophy of human gut microbes with a bioelectrochemical system

Ulrike Biehain (1), Dr. Sofia Esquivel-Elizondo (2), Dr. Tianran Sun (1), Nils Rohbohm (1), Prof. Dr. Ruth E. Ley (2) , Prof. Dr. Ir. Largus T. Angenent (1)
(1) Center for Applied Geosciences, Environmental Biotechnology, University of Tübingen, Tübingen/Germany
(2) Max Planck Institute for Biology Tübingen, Tübingen/Germany
Tel.: +49 7071-29-74733
ulrike.biehain@uni-tuebingen.de

Abstract

The fermentation of carbohydrates is one of the major functions of the gut microbiome, which results in the production of short-chain carboxylic acids and gasses such as hydrogen (H_2) and carbon dioxide (CO_2) (Oh *et al.*, 2003). Fermentative H_2 production and interspecies H_2 transfer predominantly drive colonic H_2 metabolism rather than respiration (Waters & Ley, 2019). Accumulation of H_2 disrupts the gut function, is harmful for humans, and needs to be prevented. However, H_2 is an important energy source for gut microbes such as sulfate-reducing bacteria, acetogens, and methanogens (Carbonero *et al.*, 2012). The family *Christensenellaceae* are heritable members of the human gut and are associated with human health. *Christensenalla minuta,* which is one prominent member of *this family, was already isolated from the human gut and is an H_2-producing microbe.* In co-cultures of *C. minuta* and *Methanobrevibacter smithii*, H_2 production supports CH_4 formation by the methanogen (Ruaud *et al.*, 2020). Due to thermodynamic limitations, H_2 accumulation predicts a microbial syntrophy in which carbohydrate degradation can only occur when a microbial partner consumes H_2 simultaneously (Smith *et al.*, 2021). The major question is: how do these syntrophic microbes transfer molecular H_2 in the gut, and how do they benefit from it? For this investigation, we developed a bioelectrochemical system (BES) that mimics a syntrophic microbial partner that takes up H_2. The BES provides a Platinum-doped carbon anode (Pt/C) and further a close interaction site of microbes with the anode where H_2 is actively removed by oxidation. Thus, it provides an environment favored by H_2-producing, carbohydrate-degrading bacteria. For a proof-of-concept, *C. minuta* as an H_2-producing microbe was used. We found a shift of the fermentation products of *C. minuta* towards more acetate and less butyrate.
Furthermore, we found that *C. minuta* attached to the Pt/C anode and formed a biofilm by scanning electron microscopy. The outcomes of this study are essential to developing an isolation approach for gut microbes without the requirement of a microbial (syntrophic) partner. The cultivation of *C. minuta* in the BES will help further technical BES development and support our ultimate goal to understand human gut microbes better.

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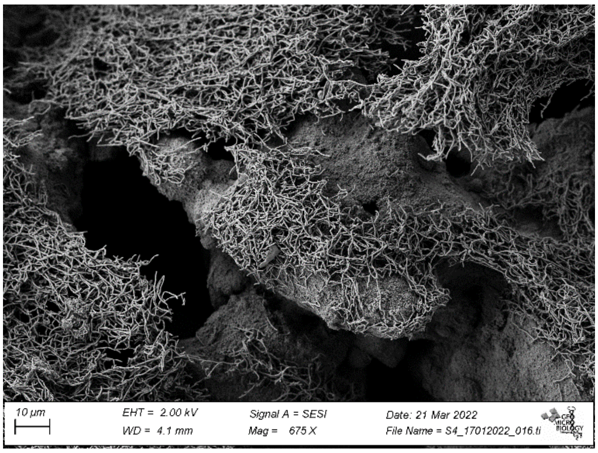

M0302

Dynamic configuration assessment of a Microbial Fuel Cell stack/cascade fed on human urine.

George Papaharalabos (1), John Greenman (2), Andrew Stinchcombe (1), Ioannis A. Ieropoulos (1)*

(1) Bristol BioEnergy Centre, Bristol Robotics Laboratory, University of the West of England, Bristol BS16 1QY, United Kingdom

(2) Faculty of Applied Sciences, University of the West of England, Bristol, United Kingdom

* Current contact details: Civil, Maritime and Environmental Engineering
Faculty of Engineering and Physical Sciences, Boldrewood Campus, Southampton, SO16 7QF, UK

Tel.: +44 (0) 23 8059 2845

email: i.ieropoulos@soton.ac.uk

Abstract

Urine is an inexhaustible by-product of human metabolism. It accounts for 75% of the nitrogen, 50% of the phosphorous and 10% of the chemical oxygen demand (COD) content found in municipal wastewater, primarily involved in water eutrophication and poisoning the water table. Microbial Fuel Cells (MFCs) consist of microorganisms capable of reducing the organic content in urine whilst generating reasonable amounts of electricity with the added benefit of recycling chemicals harmful to the environment. An effective way to enhance the capabilities of individual MFC units is stacking them in fixed electrical and hydraulic configurations. A suggested approach is MFCs assembled in a cascade manner achieving a higher active surface area of microbes for processing the effluent as in a trickling filter treatment process. This study focuses on the remediation aspect of 24 MFCs reconfigured hydraulically and electrically under a fixed flow rate creating a gradual nutrient deficiency along the cascade. The stack reduced COD up to 34%, with the electrical and hydraulic shuffling revealing a correlation between R_{int} and COD removal and a feedback loop among the number of cascaded units and urine quality. Each configuration displayed performance attributes that allow the MFC stack to adapt to variable nutrient conditions, which is crucial in specifying systems design and configuration.

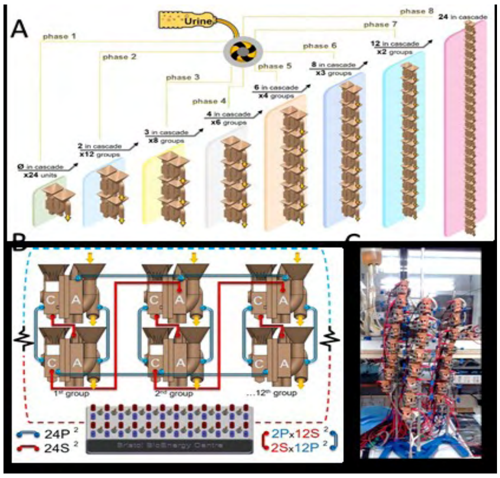

Figure 1. A) Eight cascade scenarios under constant flow rate, B) electrical interconnection of *stacked MFCs with*

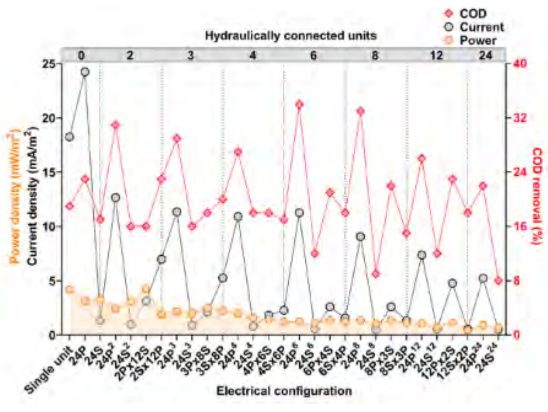

Figure 2. *COD readings along with current and power output under a dynamic hydraulic and electrical*

M0303

Comparative study of different cathode strategies in single chamber microbial fuel cells

Asimina Tremouli (1), Theofilos Kamperidis (1), Pavlos K. Pandis (1), Christos Argirusis (1), Vassilis N. Stathopoulos (2), Ioannis Ieropoulos (3), Gerasimos Lyberatos (1,4)

(1) School of Chemical Engineering, National Technical University of Athens, Athens, Greece.

(2) Laboratory of Chemistry and Materials Technology, Department of Agricultural Development, Agrofood and Management of Natural Resources, National and Kapodistrian University of Athens, Psachna Campus, 34400 Evia, Greece.

(3) Civil, Maritime and Environmental Engineering, Faculty of Engineering and Physical Sciences, Building-178, Boldrewood Campus, Southampton, SO16 7QF, UK

(4) Institute of Chemical Engineering Sciences, Stadiou Str, Platani, 26504 Patras, Greece

Tel.: +302107723124

atremouli@chemeng.ntua.grmailto:jsample@fastmail.com

Abstract

Different cathode assemblies were investigated as a means of enhancing the performance of a four air-cathode single chamber microbial fuel cell (MFC). In this context, three cells were constructed using three different cathode assemblies (C1, C2, C3). Each system consisted of one chamber filled with graphite granules with the cathode assemblies running through the chamber. For the C1 case, four mullite tubes were coated internally with MnO_2 catalyst. For the C2 case, four Plexiglas tubes were wrapped with GoreTex cloth coated internally with MnO_2. For the C3 case, four mullite tubes were tested, using fly ash as the catalyst. Each MFC operated in batch mode using glucose (~1 g COD/L) as the substrate.

For the C1 case the MFC operated with an average cycle duration of 200 ± 60 h. The maximum current output ($I_{max)}$was 2.3 mA and the lowest was 1.9 mA. The highest coulombic efficiency (CE) calculated was 40.6%. The maximum volumetric power density (P_{vmax} / calculated by dividing power output with the anodic liquid volume of 150 mL) produced during C1 was 5.5 W/m^3. For the C2 case the MFC operated with an average cycle duration of 85 ± 42 h. I_{max} was 3.1 mA and the lowest was 2.7 mA. The highest CE was 11.3% whereas the P_{vmax} for C2 was 10.2 W/m^3. The average cycle duration for the C3 case was 120 ± 52 h whereas the current output ranged between 1.6 mA and 2.4 mA with the highest CE being equal to 18% and P_{vmax} equal to 5.4 W/m^3. The COD removal was high with an average percentage of 95 ± 4%, 89 ± 3% and 84 ± 11%, for the C1, C2 and C3 case, respectively.

Acknowledgments

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M0304

Assessment of different configuration of microbial fuel cells to enhance bioelectricity production

Carlotta Cosentini, Gabriele G. Gagliardi, Domenico Borello
University of Rome, La Sapienza, Rome/Italy
Tel.: +
gabriele.gagliardi@uniroma1.it

Abstract

Microbial Fuel Cells (MFCs) are a promising tool that exploits microorganisms for generating electricity from a variety of reduced materials, including organic matter. Soil is a suitable substrate to be used in microbial fuel cells as it is characterized by a complex microbial community, including electrogenic bacteria needed for electron transport. Terrestrial Microbial Fuel Cells (TMFCs) are a class of MFCs operating with soil as the electrolyte and the source of organic substance.
However, this technology has some technical and operating constraints that limit its application as energy supply system. In particular, the low output voltage and the low power density are the major restrictions. Previous works demonstrated that organic matter amendment significantly increases the electricity generation of MFCs. Therefore, TMFCs were assembled with the addition of an agricultural composting product (3% by weight).
Furthermore, the scaling up can be reached by developing bigger reactors and by connecting different MFCs in series and/or parallel configurations.
In this work, two stacked configurations (series and parallel connections) have been developed and tested to analyse how the energy performances could be enhanced. This study aims to assess an optimum configuration, corresponding to the lowest internal resistance, to satisfy the energy demand of small electrical devices. Experimental tests are currently ongoing.

M0305

Comparative analysis of electrical performance and degradation rate in PMFC exposed to Malachite Green contamination

Domenico Borello (1), Gabriele Gagliardi (1), Andrea Pietrelli (1,2), Naoufel Haddour (2), Michele Martone (1,2), Grégory Bataillou

(1) Universit¨ di Roma ñ La Sapi Rome/Italy

(2) Université de Lyon, UCBL, INSA, ECL, CNR UMR 5005, Lyon/France

Tel.: +

gabriele.gagliardi@uniroma1.it

Abstract

In recent years humanity is facing challenges never seen before such as geopolitical disputes, global warming, pandemics, and mounting energy requirements. In this regard the energetic engineering research, to achieve the goals that these enormous tasks impose, identifies, as one of the main solutions, the efficient use of the available energy sources even if not traditional. Among the non-conventional sources, the scientific community has identified in the Microbial Fuel Cells (MFCs), and in the Plant Microbial Fuel Cells (PMFCs), one of the smartest and most flexible solutions adoptable in the near future for the exploitation of the living or and energetic fields. These Bio-Electrochemical Systems (BES), thanks to the latest advances in low power electronics, are green energy production devices which, through the biocatalytic activity of exo-electrogenic microorganisms, convert the chemical energy stored in the organic compounds present in the soil into electrical energy by means of redox reactions. In this work, indeed, the electrical and decontamination performance of the BES are analyzed from an experimental point of view with the aim of demonstrating their effectiveness in the two different fields simultaneously. From the studies conducted on two different experimental setups of single-chamber MFC and PMFC, an in-depth comparative analysis has been carried out to or not of a highly persistent organic dye, the Malachite Green (Figure 1). This work reports preliminary data concerning the effects of performance leading to interesting conclusion outputs. During the 30 days working period stable voltage supply has been obtained for MFCs with maximum peak power of 13,70 mW/m^2 realized when the *Papyrus* was planted. Some average trend related to the sy drawn from the results in object which see the plant as power growth driver in blank soil and the Malachite Green as feeding compound with stabilizing effects in MFCs.

Figure 1. Initial setup with three cells for each of the four

M0306

A scalable Rotating Disc Bioelectrochemical Reactor (RDBER) suitable for the cultivation of both cathodic and anodic biofilms

Max Hackbarth (1), Johannes Reiner (2), Harald Horn (1,2)
(1) DVGW Research Centre, Water Chemistry and Water Technology, Karlsruhe/Germany
(2) Karlsruhe Institute of Technology (KIT), Engler-Bunte-Institut Water Chemistry and Water Technology, Karlsruhe/Germany
Tel.: +49 721 608 - 47893
hackbarth@dvgw-ebi.de

Abstract

Reduction of CO_2 into value-added chemicals as well as the recovery of energy from waste streams is considered one of the cornerstones towards a sustainable circular economy. For this purpose, a scalable and membrane-less rotating disc bioelectrochemical reactor (Fig. 1) with a working electrode surface of 1 m^2 was constructed and operated as both microbial electrosynthesis (MES) and microbial electrolysis cell (MEC). In MES mode the cathodic growing thermoacidophilic Knallgas bacterium *Kyrpidia spormannii* EA-1 was cultivated on the rotating discs and visualized in situ and online via optical coherence tomography (OCT). To supply the biofilm with the gaseous substrates, the reactor was continuously pressurized with a gas mixture of CO_2 and O_2 while the cathode served as the sole electron donor. In MEC mode the model organisms *Shewanella oneidensis* and *Geobacter sulfurreducens* were cultivated to oxidize non-essential organic acids into carbon dioxide leading to a cathodic hydrogen production. Early experiments prove a significant influence of the working electrodes rotational speed on the degradation rate of the organic acids as well as on the achieved current densities. Furthermore, changes in cathode design lead to higher hydrogen yields due to less shuttling between cathode and hydrogen consuming biofilm.

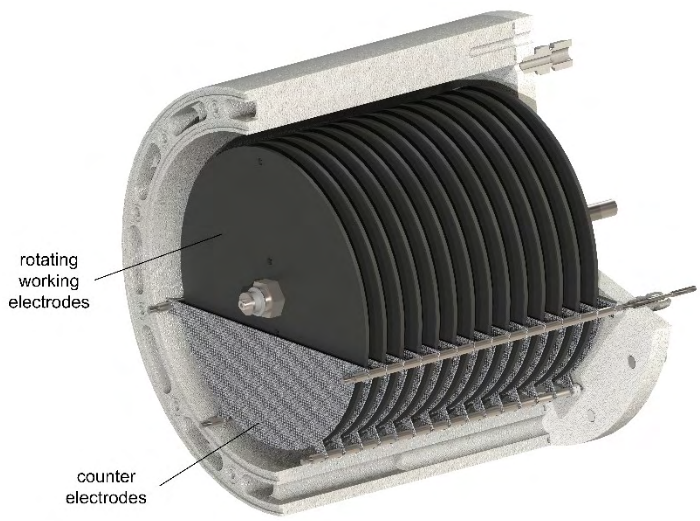


Fig. 1: RDBER equipped with 14 rotating working electrodes

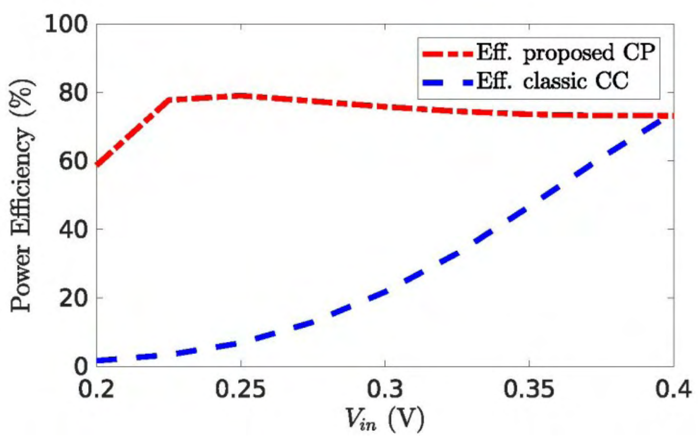
M0310

Ultra-low power consumption charge pumps for electrochemical reactors

P. López (1), Ó. Pereira-Rial (1), L. Vicente-García (1), Juan M. Carrillo-Calleja (2)
(1) Centro Singular de Investigación en Tecnoloxías Intelixentes (CiTIUS), Santiago de Compostela/Spain
(2) Universidad de Extremadura, Badajoz/Spain
Tel.: +34-881816406
p.lopez@usc.es

Abstract

Bio-photovoltaic, enzymatic and microbial fuel cells are among the different types of electrochemical reactors commonly used to harvest energy from the environment. They can produce energy by means of organic substances present in living cells and environmental wastes and hence constitute a widely-available, affordable and green source of energy with application in several fields such as wastewater and contaminated soils treatment or the production of fresh water from sea water. However, the main drawback of these techniques from a practical perspective is the small magnitude of the harvested voltages, which severely limits their applicability. Since most electrochemical reactors deliver output voltages in the range of mVs and common electronic components work at 3.3 V and above, the use of charge pumps to increase the regulated output voltage is mandatory. On the other hand, their low power density, ranging from µW/cm^2 to mW/cm^2, requires the use of circuitry with ultra-low power consumption characteristics as well as dedicated power management units.



The classic cross-coupled (CC) voltage doubler charge pump is known to have good power efficiency for moderate and large input voltages. As we will show, a gate-boosting approach can be used to increase the drive capability of the charge pump switches when the input voltage is below the transistorsô thresh effectively counteracting the on-resistance increase. As a result, the power efficiency for low voltage input conditions is increased. In so doing, we are able to work using input voltages below 400 mV and input powers as low as nWs while maintaining a good overall efficiency. In the figure, we show a comparison of the power efficiency of classic CC devices with our proposed charge pump. As can be seen, the gate-boosting approach offers significant improvements at low input voltage conditions. The same fly capacitors and switching transistorsô sizes are considered in both ca additional hardware increases the charge pump power consumption by only a 5%.

M0311

Investigation of the optimal design to produce biosurfactants and electricity from waste vegetable oil in air-cathode microbial fuel cells

Aleksander de Rosset, Grzegorz Pasternak
Wroclaw University of Science and Technology, Wroclaw, Poland
grzegorz.pasternak@pwr.edu.pl

Abstract

Microbial fuel cells (MFC) are devices that use microorganisms as biocatalysts for the oxidation of organic matter to generate electricity and/or synthesise valuable compounds. The low currents obtained in the MFC limit their use as an alternative energy production process only for low energy applications. The use of MFC for the synthesis of valuable products is currently one of the development ways. In this study, the effects of electrode alignment and agitation on power and biosurfactant production from waste vegetable oil was assessed in single-chamber air-cathode microbial fuel cells. The production of biosurfactants and electricity generation in the vertical MFC design with continuous mixing was compared to the horizontal MFC design of without agitation. The MFCs were investigated using real time temporal analysis, linear sweep voltammetry measurements, surface tension measurements, foaming properties measurements and gas chromatography with mass spectroscopy analysis. No significant change in surface tension was observed in the anolyte of the agitated vertical MFC. At the same time, the maximum power density produced was 2.36 W m^{-3}. The horizontal MFC system led to increased electricity production by 104.7% to 4.84 W m^{-3}. Furthermore, an increased production of biosurfactants was observed, which led to reduced surface tension of the anolyte to 50.7 mN m^{-1}. Therefore, we showed that production of biosurfactants through electrofermentation process can be achieved by using waste vegetable oils and through of an appropriate MFC system design, which improves contact of the organic substrate with the anode surface.

M0312

Describing polarization curves and potential changes of a Microbial Electrolysis Cell

Nikolai Jürgensen (1,2), An-Ping Zeng (1), Johannes Gescher (2)
(1) Institute of Bioprocess and Biosystems Engineering, University of Technology Hamburg, Hamburg, Germany
(2) Institute of Technical Microbiology, University of Technology Hamburg, Hamburg, Germany
Tel.: +49 4042878 3963
niko.juergensen@tuhh.de

Abstract

A kinetic model was used to represent experimental data of polarization curves and applied potential changes within Microbial Electrolysis Cells (MEC). To describe the produced current density of electrochemically active microorganisms on a bio-anode, the Butler-Volmer-Monod model was used and compared to the Nernst-Monod model. Using the Butler-Volmer-Monod model it was possible to describe the experimental polarization curves of the MEC more accurate compared to the Nernst-Monod model. Moreover, the kinetic model was implemented for application in Matlab (The MathWorks, Inc., USA). In that software environment, parameter estimation was conducted to determine by sum of least squared error between measurements and corresponding simulation results values for the kinetic model. The fitted parameters were well applicable to describe applied potential changes of the system and could be used to even predict potential changes. Accordingly, the Butler-Volmer-Monod model was capable to predict a theoretical potential change of 35% which showed a very realistic simulation result compared to experimental data.

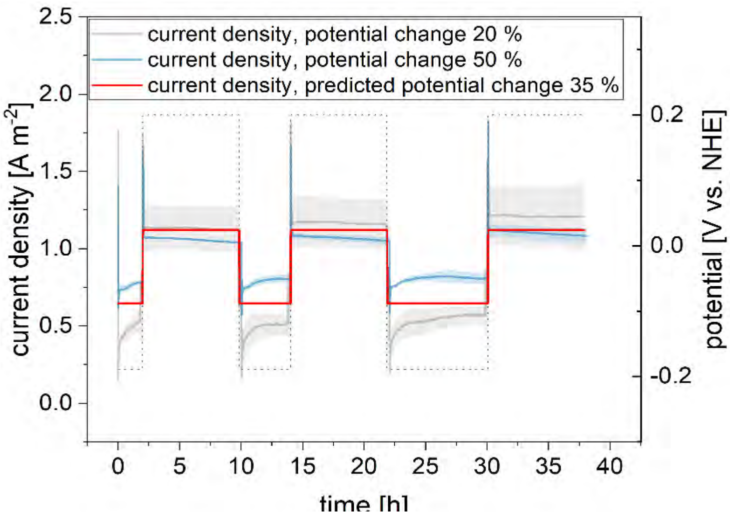


Figure 2: Predicted potential change at 35% in comparison to 20% and 50%

M0313

Microbial Gardens: A design-led proposal for the creation of a human-bacteria cohabitation unit for inhabiting extreme environments based on microbial fuel cell and benthic fuel cell technologies.

Anna Vershinina, Rachel Armstrong
KU Leuven, Dep. of Architecture, Campus Sint Lucas, Ghent/Belgium

Tel.: +32 45 63 00 193
anna.vershinina@student.kuleuven.be

Abstract

A third of the planetôs land is severely de
fertile soil is being lost at the rate of 24bn tonnes a year, according to the United Nations (2017), with the annual desertification rate at 1.3%. Exacerbated by climate change, the essentially man-made process of desertification is leading to further land degradation, consequently, a system for inhabiting barren areas of our land and even other planets, is pressing. This design-led paper proposes a microbial toolset for the formation of specific microbiomes implemented as microbial gardens that establish the infrastructure, metabolisms, and protocols for living that are essential for human inhabitation. Situated in Antarctica, one of the most barren areas on the Earth, the design draws on electroactive microbes via the use of microbial fuel cells and benthic microbial fuel cells to establish a human-microbial symbiosis through wastewater processing and lake sediment. Exploring a range of prototypes printed from different clays, human/microbial symbioses are optimised, where microbes provide clean water and electricity for human inhabitants in exchange for food, heat and running water, by altering the geometry and efficiency of the bioelectrical cells.