



Electrified biofilms: A special issue on microbial electrochemistry

The journal *Biofilm* launched at the beginning of 2019 with the aim of bringing together biofilm research from various (micro)environments, disciplines, and levels of technological readiness. A year later, as much of the world was locking down for what we thought would be a six-week attempt to stop the spread of a burgeoning pandemic, we issued a call for a virtual special issue on biofilms of electroactive bacteria called “Electrified Biofilms”. We invited authors to submit articles that focused on the biology of electroactive biofilms, either associated with natural environments or in bioelectrochemical systems. Despite the unexpected challenges for the global research community in the intervening 18 months, we received a strong response, and we are pleased to present six papers representing a diverse selection of exciting new research into electroactive biofilms. These papers included some familiar organisms, such as the bacterium *Geobacter sulfurreducens*, and found some relative newcomers, such as *Zoogloea* spp. There were papers that asked more applied questions such as “How do reaction kinetics affect scale up of oxygen reducing biocathodes?” and more basic questions such as “How does a bacterium use electric fields to sense a surface?”

The field of microbial electrochemical systems started with the observation that microbes could generate electricity in what would later become known as microbial fuel cells (MFCs). In a sense, MFCs have provided the framework (and funding) that enabled the fundamental discoveries of how microbes interact electrochemically with their surroundings. Greenman et al. [1] provide a nice overview of the history, design and key species involved in MFCs. This is a great article to start with for anyone new to the field. They point out many of the areas where improvements have been made, and places where much is still not understood.

Three papers described organisms and communities that perform EET. Speers and Reguera described *Geobacter sulfurreducens* PCA mutants that had a competitive advantage when exposed to oxygen [2]. Most of the mutations they found actually inactivated reactive oxygen species detoxification pathways, which the authors hypothesize triggered a compensatory response in the form of an increase in expression of other oxidative stress response pathways. These then reduced aerobic respiration, and prevent loss of electrons to oxygen. Berger et al. explored enrichments of a community dominated by the anaerobic methanotroph “*Candidatus Methanoperedens BLZ2*” and found that it was in fact the non-methanotrophic bacteria that were responsible for anodic current [3]. The authors suggest that rather than deriving electrons directly from methane, the likely electroactive organisms (*Zoogloea* sp., *Dechloromonas* sp., two members of the phylum *Bacteroidetes*, and *Leptonema* sp.) are instead using acetate produced by the methanotroph as an electron donor. This electrochemical characterization of an ANME consortium helps us understand a fascinating cross domain

metabolic partnership. Finally, our group contributed an article describing the ways that *Marinobacter atlanticus* regulates its gene expression when confronted with different environmental conditions, from electrode potential to growth as a biofilm [4]. This also helps to understand a possible mechanism for EET, by identifying some genes that may be involved in oxidation or reduction of the hypothesized redox shuttling metal ions in this growth medium.

There is an exciting contribution to the field of electrotaxis, investigating how bacteria are able to find a polarized surface upon which to live. Chong et al. found that the electric fields of poised electrodes cause the formation of cationic gradients, which the authors propose underlies the mechanism of chemotactic movement toward the electrodes [5]. This linking of electrode potential to bacterial sensors provides a framework for experiments to test hypotheses involving known electrotaxis behaviors and bacterial physiology, along with providing more information that may help fields as diverse as wound healing and biomanufacturing.

On the more applied side, Mohamed et al. examined the factors that may limit scale up of biocathodes and found that physical limitations such as ohmic losses and dissolved oxygen concentration have more impact on cathodic current than the community structure that can develop within large systems [6]. Their results highlight the importance of finding ways to minimize the impact of the low ionic conductivity in microbial electrochemical wastewater systems will be a key step toward scaling these technologies up. This also suggests that microbial communities in these systems are capable of adapting to whatever size of system is developed.

These papers represent advances that will help move the study of electroactive biofilms forward, facilitating both top down and bottom up approaches to engineering microbial electrochemical technologies. They also raise some interesting questions about the role ions may play beyond simply counter balancing electron flow in observed microbial current, such as enabling colonization and imposing limits on biofilm development, suggesting new avenues of research for electromicrobiology.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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