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Journal
UC Merced Undergraduate Research Journal, 6(1)

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Publication Date
2014

DOI
10.5070/M461022684

Undergraduate

Microbial Fuel Cell Coupling: Clean, renewable energy generated from wastewater amongst other potential uses

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May 20, 2014

Abstract

Microbial fuel cells (MFCs) are novel power generation alternatives. The significance lies in its ability to house anaerobic bacteria that effectively consume organic matter in a fuel cell to generate electricity. The process is rather versatile in a bioremedial sense because the bacteria can be used to treat wastewater and to detect contaminants in liquids, amongst other application. Additionally, utilizing the eager microorganisms as a biocatalyst has a significantly lower carbon footprint in comparison to burning fossil fuels and coals. Although full scale implementation worldwide is unlikely at the current moment, selected research publications demonstrate the vast potential of MFCs, particularly in developing nations. Moreover, given the nature of the urgent need to adapt or mitigate the effects climate change, I argue it would be illogical to consider the practical implications of this compelling innovation.

Introduction

Advancements in environmental engineering and sustainable science, both increasingly growing fields in recent decades, are the sole measure to promote ecological conservation and preservation. Skilled individuals in these equally important fields possess critical knowledge, which when collaborating with other experts, can stimulate a critical reevaluation of several environmental processes that either directly or indirectly affect the protected resources within. A notable development that is gaining attention due to the vast number of uses and implications that are associated with it is the topic of microbial fuel cells (MFCs).

One of the primary influential and early pioneers in the topic of MFCs is Dr. Bruce E. Logan of Pennsylvania State University. Dr. Logan began publishing work on MFCs in the early 2000s and has more recently obtained a patent for what is described as substrate-enhanced MFCs, the central topic of interest for this release (Google.com/Patents, 2007). Other notable researchers whose work and statistics will be discussed is that of a team from Oregon State University led by Dr. Hong Liu.

How does a MFC work and what is needed to operate one?

An elemental description of how the timely innovation generates electricity from an electrophysical standpoint is no different than how conventional fuel cells operate (i.e an electrical current flowing from a negatively charged anode to a positively charged cathode). However, it is the source of the electrons that supply this current that differs in a MFC. Instead of a controlled reaction involving a fuel (e.g propane, octane, ethanol, etc.) and an oxidative species (e.g oxygen gas), a MFC utilizes a mixture of bacterial colonies grown under anaerobic conditions that are housed on the anode (Logan, 2006). It is here in which the bacteria ultimately oxidizes (i.e “strips” or removes electrons from) organic matter to generate the electric current. Essentially, the bacteria act as a biocatalyst in which the energy output is effectively made possible by virtue of the bacterial colonies gaining nutrition. MFCs have gained notoriety mostly due to the numerous applications they can be coupled with to ultimately provide an array of insight to future problems worldwide. All that is required for continual electricity generation is an MFC itself, a substrate such as acetone or glucose to house the bacteria on the anode, and consistent source of organic matter.

Anaerobic conditions in the anode chamber are critical to the overall electric current generation. This is because without oxygen, which would normally act as the final electron acceptor in aerobic strains of bacteria, the electrons oxidized need to find elsewhere to be contained. In the instance of a MFC, they travel nearby to the cathodic wiring, via electron carriers and medicators, which is most often constructed from platinum. The significance of the metal wire is since platinum is a transition metal, it is able to hold more electrons in its outer shell as opposed to other common elements such as carbon, nitrogen, and noble gases for example. The underlying reason for this is because transition elements operate under the 18-electron rule as opposed to the octet rule as attributed to the transition element having an extra d orbital shell (Zener, 1951).

MFCs and wastewater treatement

The prime potential a MFC holds can be demonstrated as a solution to definitive energy woes. This is because, inevitably, the human society is destined to be plagued with pressing energy issues that require dire innovation in the near future. Examples that will obligate attention include peak oil extraction in addition to the depletion of fossil fuels and water, which are now becoming very pragmatic due to exponential population growth and a variety of other factors (Hirsch, 2013). Research findings from the aforementioned MFC focused research groups show a shared interest in utilizing the MFCs for a dual wield of highly sought after necessities: maintaining renewable energy generation while simultaneously treating wastewater to ultimately be recycled for future use. The treatment of water is made possible through the use of a proton exchange membrane (PEM) that separates the anode and cathode chambers. This electrochemical conversion proceeds because the PEM allows protons to pass from the anode chamber to the cathode chamber, where natural oxygen gas is being circulated through, to combine and form the treated water (Logan, 2004). Considering the example of a MFC treating wastewater as the source of organic matter, such a utilization allows for a much more cost efficient process as opposed to the conventional "sludge" method due to the fact that it eliminates the need to consistently aerate wastewater, a feat that frees up almost 4/5 of the biochemical oxygen demand (Logan, 2005).

MFC design and electricity measurements

Analogous to how different circuit set ups (i.e parallel vs. series) and anode/cathode materials affect overall Columbic efficiency, different MFC design and construction materials generate different energy data. Knowledge of this paves the way for future research to be centralized on design modifications to current prototypes in an effort to maximize energy output. In a noteworthy 2005 study from Dr. Logan and his team, they tested a variety of energy parameters based upon different designs: a single chambered MFC, a double chambered MFC, and a flat plate MFC. Each has their own benefits and disadvantages. For example, the single chamber MFC eliminates the need for aeration but has a slightly worse overall power density than a double chambered MFC (26 mW/m2 vs. 28 mW/m2). However, the double chambered MFC has its own singular advantage in the sense that it has better separation of the anode and cathode, thus decreasing the possibility of oxygen adversely affecting any of the chemical reactions in the anode necessary for electricity production (Logan, 2005).

Comprehending the statistics available, the prototype of interest for this report that has the most potential for use in wastewater treatment is the flat plate MFC. The reason for this is because the flat plate MFC has all the benefits of the double chambered MFC, plus the minimal spacing between the anode and cathode acts to minimize the resistance generated during the reactions. The flat plate design additionally generates more than two times the power density either the single chamber or double chamber would produce (Logan, 2005).

Suggested modifications to maximize MFC efficiency

The implications behind the use of current MFC prototypes in wastewater treatment are earth-shattering alone. However, after reviewing research transcripts from the Pennsylvania State University and Oregon State University teams, it is speculated that certain constructional alterations can be made to further maximize energy output and worldwide accessibility: Firstly, in an effort to combat the costliness of such a wide scale implementation, an alternative cathode wiring material is needed. This is because the current most widely used wiring material in similar operations has been the metal platinum which is an expensive and rare precious metal. Recent projects investigating possible cathodic wiring alternatives determined that the best choices in regards to improved power density and overall recovered energy would be nickel foam and molybdenum disulfide (Ribot-Llobet, 2013). Another alternative they had tested was stainless steel wool which, although inexpensive and easily manufactured, did not perform up to par in comparison to the three previously mentioned materials.

Secondly, a problem the Penn State team encountered during MFC assisted wastewater treatment was that the source of organic matter (wastewater in this example) was too dilute. If an additional measure to further concentrate the organic matter was used, more power density and Coulombic efficiency would be generated (Logan, 2005). A technique that would be applicable is the Niro Freeze Concentration method. This process consists of crystallization and subsequent recrystallization that is first achieved by solid and liquid separation in a wash column. Wastewater is then pumped into a heat exchanger where it forms needle shaped ice crystals in the column. Once the crystals are formed, it is then mixed with larger ice crystals. This mixture's ultimate fate is to enter a last column wash that leads to the separation of purified water and concentrated organic matter (Lemmer, 2001).

The final improvement to be made involves understanding the bacteria and their individualistic mannerisms on a deeper genetic and hereditary level. Since the process of converting the high energy electrons in organic matter to an electrical current is essentially just a single step on the redox ladder for anaerobic microorganisms; discovering which taxa and/or mutants have the most efficient oxidation rates would be of great aid in getting the most from a MFC, electrically speaking. Strains from the following taxa Shewanella putrefaciens, Geobacter sulfurreducens, Geobacter metallireducens, and Rhodoferax ferrireducens have the most potential in regards to this matter as discussed by Dr. Logan in a 2004 interview (Logan, 2004). In addition to selecting for the most energy efficient species, using various sterile techniques such as autoclaving the wastewater and/or spraying N2 gas in the anode chamber of a MFC prior to treatment would be beneficial as it would ensure that the competitors (i.e methanogens and denitrifiers, respectively) would be eliminated along with further preventing aerobic oxidation from occurring. The former is important for competitive reasons but the latter is critical also such that the substrate the bacteria grow on (e.g glucose or acetone) does not become depleted.

MFCs and their potential role in developing countries' economies

Due to the ease of explanation, the aforementioned designs are only select experiments that were performed during the mid 2000s. Dr. Logan and the Pennsylvania State University team continued to attempt to improve their prototypes with various alterations and distinct bacterial taxa up until about the end of the decade. Hereafter, their research began to fixate towards the production of hydrogen gas instead of electricity, which by definition would make the prototype identified as a Microbial Electrolysis Cell (MEC) rather than a MFC. Both methods hold extreme value, energetically speaking. However, it is my belief that it is more logical to find an alternative to a convention that already has the infrastructure to support its growth, such as electricity does, in comparison to other debated alternatives such as hydrogen, solar/wind, or nuclear energy, for example.

The most sought after goal would be to implement MFC coupled wastewater treatment plants in developing countries, for such nations would surely gain the most. It is speculated that it would allow viable economic growth which could ultimately lead to infrastructure stabilization, more accessible health care/diagnosis, and better overall wellbeing, amongst other advantages. Surely, it is envisioned that the cost associated with such a wide scale incorporation would be expensive at first. To further elaborate on potential expenses, the research team at Oregon State University estimated that the cost of engineering a single operation and continued maintenance would be nearly equivalent to the conventional "sludge" operation cost, nearly $25 million (Stauth, 2012).

When contemplating the funding of such an operation, one must keep in mind that this is a long term investment. Albeit quite costly, thus decreasing the probability that many developing nations' officials may opt for the innovation, the long-term benefits would surely outweigh the initial costs. Verification of such a claim is made possible by realizing that the aforementioned Oregon State estimate fails to take in consideration the possible profit gained from the subsequent retail of the net gain in energy a MFC produces during operation. According to Dr. Logan in an editorial about his work with MFCs, current municipal and industrial wastewater plants' infrastructures comprise about 5% of the total electrical power used in the United States. each year [Logan, 2004- From the 2004 Paul L. Busch Award Ceremony at the WERF Subscriber Luncheon (2004)]. Therefore, the clear logic behind the possible energy transition is why would we, as a society whose successes are based heavily on innovation, continue to support an energy intensive operation to treat wastewater instead of MFC-coupled wastewater treatment that holds the potential to generate electricity and subsequent profits instead of consuming them both substantially.

Additional MFC coupled projects

Looking ahead towards the future with MFCs being coupled to other operations besides wastewater treatment, a number of other feats can be accomplished. For example, breaking the dependence the general population worldwide has on batteries, generators, natural gas, etc. would be highly sought after from an environmental standpoint. Moreover, utilizing MFCs for more than powering means can be observed if utilizing a MFC as a contamination detector. For example, if monitored consistently, an anomaly in the bacterial consumption of the organic matter would insinuate there is a potential toxin or major contamination in a environmentally protected area such as a stream or a patch of soil in a national park (Raebay et. al, 2010).

The global implications and potential crises MFC coupled processes can provide insight on in the present are copious. With further research on other MFC prototypes and additional design modifications, more knowledge will become readily available within the next couple of decades in order to maximize the efficiency of energy generation, granted the proper measures are taken. Timely reexaminations such as this in all societal actions are pivotal not just because a fraction of the population may feel change is necessary; it becomes important because when dealing with essentials such as energy and water, conservation and sustainability need to be considered in every aspect to ensure the essentials we care so much about can persist for future generations.

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Mark Reynolds is a fourth year Biological Sciences student emphasizing in Microbiology & Immunology with a minor in Environmental Science & Sustainability. Raised in Tehachapi, CA, he had always envisioned himself attending medical school and ultimately becoming a physician. Plans changed upon enrolling at the University of California Merced where a firm interest now lies in understanding the basics of various life and earth science sub-disciplines. He hopes to apply these skills to a career by either performing research to discover and/or teaching to inform those who also have a desire to learn. He plans to pursue graduate studies to obtain either a PhD in Environmental Microbiology or a Masters degree in Scientific Writing. Recently, Mark has been selected as a 2014 California Alliance of Minority Participant (CAMP) scholar at UC Merced. Additionally, he was selected as one of ten students and the only undergraduate to receive a scholarship to attend the UC sponsored 9th Biennial Association of Natural Resource Extension Professional (ANREP) Conference in Sacramento, CA. Non-academic hobbies of Mark's include watching/playing basketball, listening to music, traveling, reading, and spending time with those important in his life.