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APPLICATION OF MICROBIAL ELECTROCHEMICAL TECHNOLOGIES IN THE WASTE WATER TREATMENT AND BIOSENSOR DEVELOPMENT

Imre L. BICZÓ[1], Claudiu Iulian BARBU[2]

[1]Environmental Engineering Institute, Faculty of Light Industry and Environmental Protection Engineering, Óbuda University, Budapest Hungary,
[2]Faculty of Food Engineering, Tourism and Environmental Protection, and Institute of Research, Development, Innovation in Technical and Natural Sciences, Aurel Vlaicu University, Arad, Romania

Abstract

The advance of Microbial Fuel Cells makes use of natural, cost efficient materials scalable from the single home use to industrial waste water treatment and energy production. Hydrogen and electrical energy are the main byproducts by conversion of the energy in the organic matter from the substrate, using electrochemically active bacteria such as Shewanella and Geobacter. Advances in cathode and anode design has reached the stage of inexpensive carbon fiber material, easy to mold into shape and size, this optimizes the hydrogen and electricity production. Use of MFC's as a biosensor to detect different types of toxicity is a main advantage, short response times and online monitoring is possible. Different pollutants require the use of different microorganisms in the detection of heavy metals, organic waste, pesticides etc. The current rise in environmental awareness has developed the use of biosensors and biomonitoring. In wastewater the removal of BOD in a main factor, conventional BOD monitoring is not suitable for use due to the long response time (up to 5 days). With the use of MFS biosensor the response time can be reduced at a fraction of 3 to 6 hours, with a grater dynamic range and accuracy and using a multi stage coupled MFC system. The use of a multi-stage MFC system allows for precise differentiation of BOD and toxicity, with possibility of online monitoring. The different types of application of MET (Microbial Electrochemical Technologies) results in a wide range of possible determinations in and off situ. Variations of MET's include: microbial desalination cells, microbial electrolysis cell, microbial electrosynthesis system, microbial fuel cell, sediment microbial fuel cell (benthic) and microbial methanogenesis cell.
Keywords: *Waste water treatment, Algae technology, Microbial Fuel Cell, Circular Economy, Bioelectrochemical systems, Biosensor development*

1. INTRODUCTION

Current advances in technology pave the way for better understanding in how we see renewable energy. Energy demand in rising and sustainable approaches are to be used that integrate not only the production of clean energy but the ability to harness this energy in a way that we can have a positive impact on the environment.

Pollution has proven a challenge in many aspects as clean air, water and land define the quality of life as urban population is expected to reach more than 5 billion in the next decade.

Waste is a main concern in so many areas of our industry, the ability to harness clean energy and regulate environmental concerns in waste management will prove essential in coming years.

The European Union has presented the directive to aid in this step to reuse, recycle and manage resources in adopting the Circular Economy package. This includes revised legislative proposals on waste for sustainable economic growth also generating green jobs from production to consumption and waste management.

Water and energy are a main concern to our lifestyle as traditional methods of water treatment are energy consuming (between 950 and 2850 kJ/m^3 of water treated) and often costly. A new approach to wastewater treatment is harness the energy potential available, estimated at 9.3 times more energy in the wastewater than was used to treat it. [1] The concentration of organic compounds found in municipal wastewater and can be a source of energy, however high strength industrial wastewater has a concentration above 2000 mg (BOD)/L [2] and higher energy density. Wastewater generated in the food industry provides a good source of easily degradable carbohydrates and organic acids and have a low concentration of organic nitrogen. The highest organic compounds found in wastewater come from the animal industry (approx. 100.000 mg (COD)/L) [2]. Despite considerable variability in the characteristics of wastewater depending on their sources, the following general characterization parameters were defined:

– "Soluble" wastewater, non-settleable and non-coagulable, composed of readily biodegradable COD, readily hydrolysable COD, and inert substrates.

– "Colloidal" wastewater, non-settleable, composed of heterotrophic biomass, inert substrates, and slowly-biodegradable COD substrate.

– "Particulate" wastewater, settable, composed of biomass, slowly-biodegradable COD, and inert substrates. [2]

The common technology used today for biological treatment is activated sludge, in which microorganisms (aerobic) metabolize the organic waste. This is an energy consuming process, pumping and aeration only demands for 30 to 55 % of the total energy consumption. Recently a new technology emerged in the form of membrane, this is an expensive technology used for non-renewable fossil fuels. Because of the greenhouse gas production these are harmful to the environment and not a cost effective method for waste water treatment.

The interest in MFC as an effective waste water treatment method comes as an answer to the more demanding market for technology that has a low impact on the environment is self-powering and capable of offering a standalone unit, scalable for home, mobile or industrial use. [3]

2. MICROBIAL ELECTROCHEMICAL TECHNOLOGIES, BIO-ELECTOCHEMICAL SYSTEMS (BES)

In the following a model setup is provided for a better understanding of the technology and modular possibility of a BES system. Description of the system and types of modules is provided in the work of Bruce E. Logan and the group of researchers that have analyzed the potential of different BES. Used as a modular system, these can harness not only sustainable energy but also a great number of chemicals from the organic matter found in wastewater. The process removes, transforms and provides treatment for the organic substances via oxidation-reduction reaction.

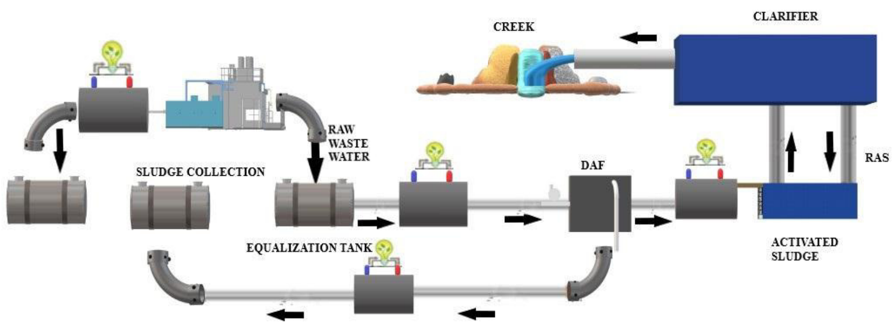

Figure 1: Integration of BES in wastewater treatment [graphics by Claudiu Iulian Barbu]

2.1 Examples of Different Microbial Electrochemical Technologies (METs)[4]:

- MDC: - microbial desalination cells can use electrodialysis stacks (MEDC, microbial electrodialysis cell), or forward osmosis (MOFC, microbial osmotic fuel cell) membranes.
- MEC - microbial electrolysis cell typically used for hydrogen gas production from the cathode, but also used for metal reduction.
- MEDCC - microbial electrolysis desalination and chemical production cell (MEDCC) includes a bipolar membrane, so energy must be input for chemical production.
- MES - microbial electrosynthesis system an MEC that is designed to produce soluble organics such as acetate.
- MFC - microbial fuel cell electrical power production.
- MxC-MBR - MFC with a cathode membrane, the cathode serves a dual function, reduction and filtration of the water using either MFCs or MECs.
- MMC - microbial methanogenesis cell methane production from the cathode.
- MREC - microbial reverse electrodialysis, RED stack inserted into an MEC electrolysis cell.
- MREEC - microbial reverse electrodialysis, electrolysis and chemical production cell. An MEDCC that includes a RED stack and is used for production of acid and bases; can be used for carbon capture; can produce hydrogen gas; can also be used for desalination
- MRFC - microbial reverse electrodialysis fuel cell, RED stack inserted into an MFC
- MSC - microbial struvite production cell, designed to precipitate struvite on the cathode
- sMFC - sediment microbial fuel cell also known as a benthic MFC [4]

2.2 Microbial Fuel Cells

Given the potential of converting organic waste into electricity and scalable, flexible design of the technology MFC (Microbial Fuel Cells) have been tested and further developed by the scientific community. The process of converting the chemical energy of organic matter in the substrate into electrical energy is a main opportunity for the demand in green energy and treatment of wastewater.

This conversion can be obtained when bacteria oxidize the substrate (electron donors, such as oxygen, nitrate or Sulphur species), in the anodic chamber and generate electrons and protons. The electrons are absorbed by anode and flowed through a resistant or a power user to the cathode, where they can reduce the electron acceptor. Cations, preferably protons, flow from the anodic to the cathodic chamber through an ion selective membrane such as salt bridge or proton exchange membrane (PEM) to complete the charge balance. In the cathodic chamber, the protons combine with oxygen and form water. Anodic chamber is anaerobic and carbon dioxide is produced as an oxidation product. [3]

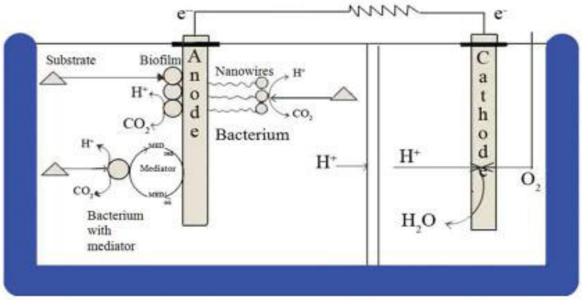

Figure 2: Design of a two-chamber MFC, M. Aghababaie et al. [3]

MFC uses electrochemically active bacteria such as *Shewanella* and *Geobacter*, by transporting electrons extracellularly in the process of organic carbon consumption they flow to the cathode delivering electricity.

Temperature, pH, the materials use for the construction of the parts as well as the ionic strength of the medium are key factors for optimal results. Advances have been made in the design and materials used in MFC in recent years that lead to better performance and results of the systems developed.

Fermentation and respiratory chain are the main pathways in the anodic chamber. The MFC electrical potential depends on the positive redox potential of the substrate, the high energy gain is given by the higher positive redox.

The use of microorganism allows for a multiple substrate with multiple enzymes, these are optimal for biofuel cells. One other option is purified enzymes, these can be used better I biosensor application, as described in later pages of this article. In laboratory testing and modelling MFC have made use of organic matter substrates that vary from glucose, cellulose, butyrate, acetate to lactate in the work done so far.

Anode material and characteristics

Choice of material for the anode is essential conductivity, stability, biocompatibility, non-corrosive manner and surface area are main characteristics that ensure operational stability and potential. Previously used materials (Au, Ag, Pl) have a weak adhesion to microbes and high cost, alternative electrodes that report better performance include Ni, Cu, Rh, Ir. Recent advances have made use of flexible carbon-based anodes, these output best results in conductivity and durability in combination with a titanium core wire.

Cathode and biocathode

Platinum has long been used as the primary material for the electrode however these have proven unsustainable and costly, recent research had made use of carbon and graphite based electrodes. Biological cathodes are inexpensive and sustainable, enzymes and microorganisms can be used as biological catalysts for oxygen reduction however they prove limited capacity of electron transfer fo rm the cathode to the microorganisms.

Marzieh Aghababaie has detailed the process implemented in his research with MFC. In recent models the anodic and cathodic chambers are separated by a salt bridge or membrane, Nafion used as material, newly tested separators include disulphonated poly(arylene ether sulphone), carbon nanofibre/Nafion nanocomposite, activated carbon nanofibre/Nafion nanocomposite membranes, earthen pot and sulphonated poly(ether ether ketone) (SPEEK) in poly(ether sulphone) (PES) membranes at various compositions of SPEEK. [3]

Biosensor development in MFC technology

By use of an MFC-based biosensor, the bacteria can sense the analyte and then give a corresponding response on its output electric current, in which the sensing step and electrical signal transition step are integrated and can be completed in one step without a signal transducer and external power source. [8] As a result this gives opportunity for a portable biosensor device for use in long term and remote measurements. In testing it has proven to be superior operational stability to conventional BOD sensors.

For the detection of toxic components an MFC-based biosensor makes use of all control methods (resistance, anode potential, current control). The given response depends on the method utilised and the control level of each method. A noticeable change in signal is observed when using >0.5 mA current and >-0.4V anode potential. In the case of the two mentioned methods (current control and anode potential control) there is a long recovery time, this lead to the observation for choosing the specific settings of control level of the sensor. A faster recovery is possible by use of bacteria that can adjust anode potential and current. When using an external resistor there is benefit in recovery time and signal change.

Sumaraj and Ghangrekar M. M [5] publish the results from there study on MFC as a biosensor using 2 units for testing. In the first unit (MFC -1) the response rate was 120 minutes for detection of 22.43 mg/L COD concentration. The second unit took the same time to detect a concentration of 64.28 mg/L COD. The research and findings can be found in the cited publication.

Conclusions

A rapid development of the MFC technology can be observed from the existing research and findings. The technology is a basis for scaling models directed at home and industrial use. The necessity of a easy to use system in wastewater treatment has come to the awareness of the scientific community for some time. Current development of the technology is aiming for use as a biosensor and further development is necessary.

In his publication of Z. Baicha provides insight to the use of microalgae as a substrate and also the growing use of phototrophic microorganisms in the cathode of an MFC. Increased use is caused because of their numerous advantages such as oxygen production and ability to capture the CO_2 generated. Photosynthesis allows phototrophic microorganisms to produce oxygen, which is consumed at the cathode, while carbon dioxide is used as carbon source during the process. The use of bio-cathodes based on algae allows expensive noble catalysts usually employed for the oxygen reduction to be replaced with natural materials. [7]

MFC technology has become a sustainable option in wastewater treatment as one of the most promising MET applications, a primary use in wastewater of the MFC is as biosensor. Application of MFC as a biosensor for BOD measurements and toxicity can prove a viable solution for online chemical toxicity detection. Conventional BOD measurement methods are time consuming with a response rate of 3 to 5 days, the response delay is improper for monitoring use and information processing. As BOD is directly converted to electricity by the MFC this accounts for a fast response rate between 2 to 5 hours.

References

[1] Dannys E, Green T, Wettlaufer A, Madhurnathakam CMR, Elkamel: Wastewater Treatment with Microbial Fuel Cells: A Design and Feasibility Study for Scale-up in Microbreweries. J Bioprocess Biotech, 2016 6:267. DOI:10.4172/2155- 9821.1000267

[2] Fornero J. Jeffrey, Miriam Rosenbaum, Largus T. Angenent: Electric Power Generation from Municipal, Food, and Animal Wastewaters Using Microbial Fuel Cells. Electroanalysis, 2010, 22(7-8): 832 – 843. DOI: 10.1002/elan.200980011

[3] Marzieh Aghababaie, Mehrdad Farhadian, Azam Jeihanipour & David Biria: Effective factors on the performance of microbial fuel cells in wastewater treatment – a review, Environmental Technology Reviews, 2015, 4:1, 71-89

[4] Bruce E Logan, Maxwell J Wallack, Kyoung-Yeol K, Weihua He, Yujie Feng and Pascal E Saikaly: Assessment of Microbial Fuel Cell Configurations and Power Densities. Environ. Sci. Technol. Lett., 2015, 2: 206–214. DOI:10.1021/acs.estlett.5b00180.

[5] Sumaraj and Ghangrekar MM.: Development of microbial fuel cell as biosensor for detection of organic matter of wastewater. Recent Research in Science and Technology, 2014, 6(1): 162-166.
[6] Carlo Santoro, Catia Arbizzani, Benjamin Erable, Ioannis Ieropoulos, Microbial fuel cells: From fundamentals to applications. A review, In Journal of Power Sources, 2017, 356, 225-244, ISSN 0378-7753, https://doi.org/10.1016/j.jpowsour.2017.03.109.
[7] Z. Baicha, M.J. Salar-García, V.M. Ortiz-Martínez, F.J. Hernández-Fernández, A.P. de los Ríos, N. Labjar, E. Lotfi, M. Elmahi: A critical review on microalgae as an alternative source for bioenergy production: A promising low cost substrate for microbial fuel cells, In Fuel Processing Technology, 2016, 154, 104-116, ISSN 0378-3820, https://doi.org/10.1016/j.fuproc.2016.08.017.
[8] Sun, Jianzhong & Peter Kingori, Gakai & Si, R.-W & Zhai, D.-D & Liao, Z.-H & Sun, D.-Z & Zheng, Tao & Yong, Yang-Chun: Microbial fuel cell-based biosensors for environmental monitoring: A review. Water Science and Technology. 2015, 71. 801-809. 10.2166/wst.2015.035.
[9] Ogrinc, David & Vodovnik, Masa & Marinšek Logar, Romana: Microbial biosensors for environmental monitoring. Acta agriculturae Slovenica. 2015. 106. 67-75. 10.14720/aas.2015.106.2.1.
[10] S.B. Velasquez-Orta, D. Werner, J.C. Varia, S. Mgana: Microbial fuel cells for inexpensive continuous in-situ monitoring of groundwater quality, Water Research, 2017, 117, 9-17, ISSN 0043-1354, https://doi.org/10.1016/j.watres.2017.03.040.

Corresponding author:
Dr. Imre L. BICZÓ
Environmental Engineering Institute
Faculty of Light Industry and Environmental Protection Engineering
Óbuda University
1034 Bécsi út 96/B
Budapest Hungary
+36- 1-666-5944
biczo.imre@rkk.uni-obuda.hu