Biofuel Cells – Alternative Power Sources

Sofia Babanova[1], Yolina Hubenova[2], Mario Mitov[1,3]

[1]Department of Chemistry, South-West University "Neofit Rilski", 66 Ivan Mihajlov Str., 2700 Blagoevgrad, Bulgaria
[2]Department of Biochemistry and Microbiology, "Paisii Hilendarski" University of Plovdiv, 24 Tzar Asen Str., 4000 Plovdiv, Bulgaria
[3]Institute of Electrochemistry and Energy Systems, Bulgarian Academy of Sciences, Acad. G.Bonchev Str., bl.10, 1113 Sofia, Bulgaria

***Abstract**: Energy generation from renewable sources and effective waste treatment are two key challenges for the sustainable development. Microbiological (or Bio-) Fuel Cells provide an elegant solution by linking both tasks. Biofuel cells, which can directly generate electricity from biodegradable substances, have rapidly gained increasing research attention. Widely available fuel sources and moderate operational conditions make them promising in renewable energy generation, wastewater treatment, power sources for remote devices, etc. This paper reviews the use of microorganisms as biocatalysts in microbiological fuel cells. The principle of biofuel cells and their construction elements are discussed.*

***Keywords:** alternative power sources, biofuel cells, biocatalysts.*

1. INTRODUCTION

The need of using alternative power sources, which can gradually replace the traditional energy fuels, is widely discussed. At the present, fossil fuels such as coal, oil, natural gas and their derivatives satisfy almost 85% of the energy demands. Unfortunately, the earth reserves of these fuels are limited. As a result of technical revolution and increasing people's population, exploitation of these sources intensified, and for about one and a half century almost a half of the existing fossil fuels on our planet have been consumed. The conventional carbon fuels shortage combined with the rising content of greenhouse gases in the atmosphere, leading to global warming, enforce the necessity of new alternative energy sources utilization. From another hand, the increasing consumption of petrol products leads not only to energy crisis, but also to decrease of the raw materials for synthesis of carbon-containing products such as polymer materials, food, drugs, etc.

Biofuel cells, more popular as microbial fuel cells (MFCs), could be a potential solution of all these problems. MFCs possess a number of advantages over the currently used technologies for generating energy from organic matter [11]. The most important is that, they use substrates from renewable sources and have high conversion efficiency. The MFCs operate at ambient temperatures and do not pollute the environment. This is the reason why they have the potential for application in locations lacking electrical infrastructure. Except for getting energy, in the same time, they can be used for wastewater treatment; powering marine devices with oxidation of sea sludge; as bio-batteries; in space crafts, etc.

For the progress of this innovative technology, which is most intensively developed in the last five years, the generalization of achievements is of a big importance. In this paper, the principles and construction elements of biofuel cells are reviewed and discussed.

2. *MFC BASIC PRINCIPLES*

*MFCs are devices that co*nvert the chemical energy of natural available organic substrates directly into electricity by using different microorganisms as bio-microreactors [9, 11]. The most investigated bacteria for application in biofuel cells are Escherichia coli [12, 13], Geobacter sulfurreducens [7, 12, 13], Pseudomonas aeruginosa [7, 12, 13], Rhodoferax ferrireducens [12, 13], Shewanella oneidenis, Shewanella putrefaciens [12, 13], Enterobacter cloacae [9, 13], etc.

In principle, biofuel cells can be divided into three major components: anaerobic anode chamber, cathode chamber and separator (fig. 1). In the anode compartment the organic matter is oxidized through the catabolic metabolism of the microorganisms and the gained electrons are then transferred to the electrode [12]. Abundant organic substances such as carbohydrates, organic acids, methanol, etc., can be used as substrates for the oxidation process [1, 2]. The electrons that reach the anode pass through the external load circuit to the cathode, where the electron acceptor is reduced. The protons diffuse from the anode through a separator to the cathode, where with oxygen, provided by air, produce water [6]. In most cases, the resulting products are carbon dioxide (at the anode) and water (at the cathode). Other oxidizers such as hydrogen peroxide, potassium ferricyanide, etc., can also serve as final electron acceptors.

The operational characteristics of biofuel cells, as other electrochemical power sources, depend on numerous factors including anode potential, cathode potential, internal cell resistance, etc.

The anode potential controls the liberation of electrons from different stages of metabolic pathways. Changing the anode potential we could varying the amount of electrons flow, produced *in vivo* in the processes of glycolysis, fermentation or respiration, to the electrode.

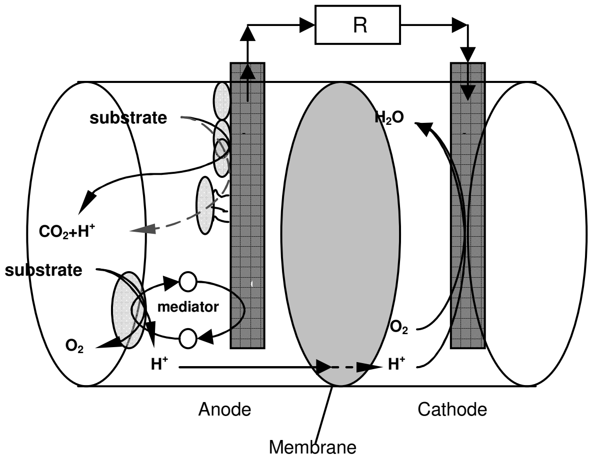

Fig. 1: The working principle of a two-chamber microbial fuel cell

The dependence of the anode potential upon material determines the type of material used. The anodic material of MFC must be conductive, biocompatible and chemically stable. The most appropriate one is the carbon. Graphite plates, rods, felt, cloth, paper, fibers are performed. The conduction characteristics of carbon electrodes are arranged in the ascending order: graphite plates and rods< carbon cloth< carbon foam< carbon felt, besides current density increase with the overall internal surface area [6]. It is supposed, that carbon felt has the best characteristics. Modifications including electrocatalysts performance such as Mn(IV), Fe(III), Pt, tungsten carbide, polyanilins/Pt composites, covalently linked mediators [6, 12] could increase the anode quality. However, difficulties concerning the biocompatibility of the electrocatalysts, chemical and electrochemical stability and cellular non toxicity are lowering their widely utilization.

From one hand, the choice of anode material, leading to suitable anode potential will increase the electrical current. The decrease of the anode potential forces the microorganisms to give electrons via taking part of complexes with low potentials. The aim is to apply such an anode potential by which the cells grow and develop normally, i.e. to use the electrons from the terminal stages of their metabolic pathways. However, for higher current density generation the electrochemical rules require lower anode potential in comparison with the cathode one [1, 12]. From the other hand, the composition of the anolyte is from crucial meaning. The select biocatalysts and substrates necessary for microorganisms' development are of primary significance. The nutrition ingredients include sources of organic carbon, nitrogen, phosphorus, sulfur and metal ions. A lot of varying parameters such as medium components proportion, cell density, carbohydrate exhausting during cultivation, etc., influence the MFCs-performance. The maintaining of suitable pH, once for the growth of microorganisms, and second for increasing the solution conductivity, requires a buffer solution usage. Neutral phosphate buffer (pH 7,0) is the most appropriate and commonly used for a two-chamber MFCs.

The choice of a proper cathode is also of big importance for the performance of MFCs. In general, for obtaining good operational characteristics, the cathode should possess high positive potential, which provides a high voltage of the power source. The oxygen is the most suitable electron acceptor for biofuel cells. It has high oxidation potential, availability, low cost and gives as end product water. To increase the rate of oxygen reduction, Pt catalysts could be applied. However, the high price of the product makes it inapplicable in the non labor production. [6]. Replacing Pt catalysts, the potassium ferricyanide acts as an oxidant [2, 10] and increases the power by 1.5 to 1.8 times compared to a Pt-catalyst cathode [6]. Using permanganate as the cathodic electron acceptor, a two-chamber MFC generate 4.5 and 11.3-folds higher maximum power density than that produced by using ferricyanide and oxygen, respectively [15]. The cathode reaction kinetics can be improved once, by choosing the suitable electrolyte and second, by electrode modifications incorporating metals, surfactants, organic substances or addition of mediators [10].

The separator is the third important component in MFC. It connects and at the same time physically separates the anode and cathode compartment while allowing protons to pass through to the cathode in order to sustain an electrical current. The major requirement to the separator is to allow the passing through only of the protons arresting other substances. Examples for separators most commonly used are the proton exchange membrane such as Nafion, the cation exchange membrane such as Ultrex or a simple salt bridge [2, 5, 6, 8].

Many different configurations are possible for MFCs. A widely used and inexpensive design is a traditional two-chamber MFC. It is constructed from two separate chambers, connected with a tube containing a separator or a salt bridge. The improved construction today leads to distribution of the single-chamber MFC with air-cathode. In this case the cathode is placed in direct contact with air, either in the presence or absence of membrane, so that the anode and the cathode are in the same compartment.

Other types of biofuel cells are those using enzymatic electrodes, the so-called enzymatic microbial fuel cells [4, 11]. The redox enzymes from the main metabolic pathways - oxidases, dehydrogenases, etc., can be isolated and purified from living cells and immobilized on the electrode surface. In such a manner the enzymes serve as biocatalysts rather than whole microbial cells.

Independently on the MFC type, the improvement of the electron transport efficiency takes an important part of investigations in the field. Three mechanisms of electron transfer from living cells to the anode are possible [6, 12]: by artificial exogenous mediators; by using natural mediators produced by bacteria; direct electron transfer - by bacterial nanowires or respiratory enzymes. The oxidized and the reduced forms of the mediator should easy penetrate the cell membrane, should possess potential positive enough to pro-vide fast electron transfer and of course be non toxic [6, 12]. The most common used organic compounds as electron transport mediators are: thionine, methylene blue, neutral red, viologen, etc. [3, 4, 14]. Their concentration should not cause bacteria poisoning and apoptosis.

The examinations of natural mediators are in progress. Microorganisms such as Shewanella putrefaciens, Geobacter sulfurreducens, Geobacter metallireducens and Rhodoferax ferrireducens have active redox enzymes in their outer membrane, which can transfer electrons directly to the anode and because of that they do not require the use of exogenous mediators. These preferable biofuel cells are called mediatorless MFCs.

3. PERSPECTIVES FOR MFC APPLICATION

In principle, the current and power density output of MFCs is much lower than those of chemical fuel cells such as hydrogen-powered ones, so it is unrealistic to expect that they will have a large input in the future energy budget. However, the extremely increasing R&D in this field is indicative for its perspectives.

MFCs can potentially be used for different applications. The most realistic of them are as power sources for implantable devices within humans and as power supplies for use in remote areas. For large-scale applications such as wastewater treatment and remediation, development of inexpensive large surface area electrodes that resist fouling is needed.

A lot of further R&D, concerning improvement of current and power density output, cell design, long-life operation, etc., is required for the real commercial application of this innovative technology.

Acknowledgements: The authors would like to thank the National Science Fund of the Ministry of Education and Science of Bulgaria for the financial support through contract D002-163/2008.

4. REFERENCES

[1] Aelterman, P., Freguia, S., Keller, J., Verstraete, W. and Rabaey, K. (2008) The anode potential regulates bacterial activity in microbial fuel cells, *Applied Microbiology and Biotechnology*, 78, 409-418.

[2] Chae, K.J., Choi, M., Ajayi, F.F., Park, W., Chang, I.S. and Kim, I.S. (2008) Mass transport through a proton exchange membrane (Nafion) in microbial fuel cells. *Energy and Fuels*, 22(1), 169-176.
[3] Fan, Y, Hu, H, Liu, H. (2007) Sustainable Power Generation in Microbial Fuel Cells Using Bicarbonate Buffer and Proton Transfer Mechanisms. *Environmental Science & Technology*, 41(23), 8154-8158.
[4] Katz, E, Shipway, A, Willner, T. (2003) *Handbook of Fuel Cells – Fundamentals, Technology and Applications*, USA: John Wiley & Sons Ltd.
[5] Kim, J.R., Oh, S.E., Cheng, S., Logan, B.E. (2007) Power generation using different cation, anion and ultrafiltration membranes in microbial fuel cells, *Environmental Science & Technology*, 41(3), 1004-1009.
[6] Logan, B.E., Hamelers, B., Rozendal, R., Schröder, U., Keller, J., Freguia, S., Aelterman, P., Verstraete, W., Rabaey, K. (2006) Microbial fuel cells: Methodology and technology. *Environmental Science & Technology*, 40, 5181-5192.
[7] Lovley, D.R. (2006) Microbial fuel cells: Novel microbial physiologies and engineering approaches. *Current Opinion in Biotechnology*, 17, 327-332.
[8] Min, B., Cheng, S., Logan, B. (2005) Electricity generation using membrane and salt bridge microbial fuel cells. *Water Research*, 39(5), 942-952.
[9] Mohan, Y., Kumar, S., Das, D. (2007) Electricity generation using microbial fuel cells. *International Journal of Hydrogen Energy*, 33, 423-426.
[10] Pham, H., Jang, J., Chang, I., Kim, B. (2004) Improvement of Cathode Reaction of a Mediatorless Microbial Fuel Cell. *Microbial Biotechnology*, 14(2), 324-329.
[11] Rabbaey, K., Verstraete, W. (2005) Microbial fuel cells: biotechnology for energy generation. *TRENDS in biotechnology* 23(6), 292-298.
[12] Rinaldi, A., Mecheri, B., Garavaglia, V., Licoccia, S., Nardo, P., Traversa, E. (2008) Engineering materials and biology to boost performance of microbial fuel cells: a critical review. *Energy & Environmental Science*, 1, 417-429.
[13] Schaetzle, O., Baronian, K. (2008) Bacteria and yeasts as catalysts in microbial fuel cells: electron transfer from micro-organisms to electrodes for green energy. *Energy & Environmental Science*, 1, 1-24.
[14] Schröder, U. (2007) Anodic electron transfer mechanisms in microbial fuel cells and their energy efficiency. *Physical Chemistry Chemical Physics*, 9, 619–2629.
[15] You, Sh., Zhao, Q., Zhang, J., Jiang, J., Zhao, Sh. (2006). A microbial fuel cell using permanganate as the cathodic electron acceptor. *Journal of Power Sources*, 162, 1409-1415.