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REVIEW ARTICLE

Bio-electroactive fuel cells and their applications

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ABSTRACT

Bio-electroactive fuel cells are systems that produce useful products from renewable sources without causing environmental pollution and treating waste. In this study, general design properties, operation mechanisms, application areas, and historical advancement of the bio-electroactive fuel cell was reviewed. Electricity generating microbial fuel cells offer new opportunities as with hydrogen and methane-producing microbial electrolysis cells due to their attractive variety of electroactive microorganisms and operating situations. This article provides an up-to-date review for Bio-electroactive fuel cells and outlines instructions for future studies.

Keywords: Bioelectronics, biofuel cells, microbial fuel cell, microbial electrolysis cell, microbial desalination cell

1. INTRODUCTION

Bio-electroactive fuel cells are described as fuel cells based on enzymatic catalysis for a certain part of their activity [1, 2]. Basically, Bio-electroactive fuel cells are devices that can convert chemicals directly into electrical energy through electrochemical reactions involving biochemical stages and the bio-electroactive fuel cell may be of micro size because it uses chemical energy sources [3, 4, 5]. These fuel cells consist of 2 parts as anode and cathode compartments. Oxidation and reduction reactions occur at anode and cathode, respectively. Oxidation releases electrons that is transferred owing to the external circuit to the cathode by doing electrical work. The circuit is completed by moving a compensating charge along the electrolyte, usually in the form of positive ions [6, 7]. Traditionally, fuel cells systems utilizes hydrogen or methanol (MeOH) as fuel and produce energy, water, and carbon dioxide (in the presence of MeOH) [8]. Biodegradable organic matters supply essential nutrients for living organisms [9, 10]. Consequently microbial catalytic oxidation of degradable organic compounds, free electrons are released through the electron transport chain (ETC) [11]. Under anaerobic conditions, the released electrons are transferred to compounds such as nitrate or sulfate, which are different from oxygen. In the Microbial Electrochemical System (MES), bacteria utilize their catalytic activities to transfer the released electrons to an electrode (as an electron acceptor) and hereby, electric current is produced [12, 13].

Increasing consumption as the world population increases threatens natural resources and the earth. For this reason, research teams continue to work to obtain sustainable and renewable energy. Currently, alternative fuel sources such as solar energy, hydrogen, biomass, biofuels, and fuel cells [14, 15]. These devices consist of a system capable of generating electrical energy from electrochemical reactions involving oxidation and reduction of chemical species [16, 17]. Great interest in the field of biofuels can be considered as a mission to produce sustainable green energy from living systems to set against the global energy crisis in the future. These devices consist of a system capable of generating electrical energy from electrochemical reactions involving oxidation and reduction of chemical species [18]. Great interest in the field of biofuels can be considered as a mission to produce sustainable green energy from living systems to withstand the global energy crisis in the future [19]. Bio-electroactive fuel cells technology is considered a renewable and environmentally friendly technology that aims to be applied as a small power source for common applications [20]. The main advantages of Bio-electroactive fuel cells are that they can be operated at room temperature, have high fuel conversion

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efficiency and scale up. Microorganisms are the main point of modern bio electrochemical systems.

Fuel cells can be classified according to the biocatalyst as Microbial Fuel Cell (MFC), microbial electrolysis cell (MEC), microbial desalination cells (MDCs), and microbial solar cells (MSC).

2. ANALYTICAL APPLICATIONS OF BIO-ELECTROACTIVE FUEL CELLS

2.1. Microbial fuel cell

The idea of producing electricity from bacteria was first proposed by Potter in 1911, which is the basis of the MFC system [21]. With these initial studies, significant progress was achieved in understanding electron transfer mechanisms, developing efficient bio-electrocatalytic interfaces, and developing new, low-cost and resistant electrode materials, but there is still deficiencies that should be improved. Prior to full-scale applications of MFCs, advancement of the system was made with the participation of NASA, some national agencies, and vehicle manufacturers [22].In the 1960s Biofuel cells (BFC) gained some popularity due to NASA's interest in these units. NASA aimed to convert organic waste into electricity in space missions. But the interest ended in a short time .Since the start of the 21st century, increase in the number of scientific studies on MFC indicates that there is an increasing interest on the topic. Accordingly, several fuel cells have been developed and classified according to the function of utilized electrolyte (polymeric membrane, ceramic, liquid electrolyte). MFC is a bio-electrochemical utility that converts bio-sources into electricity [23]. MFC can be treat wastewater and generate electricity at the same time. This is the most known property of the system. MFC system consists of anode and cathode departments separated by a cation-specific membrane. The bacterias in the anode zone oxidizes the substrate [24, 25]. Electrons are transferred to the cathode through an external circuit, whereas protons are transferred to cathode from anode through a proton exchange membrane. Due to the fact that many MFCs are electrochemically inactive, electron transfer from MFC to the electrode can be expedited by mediators something like thionine, methyl cello, humic acid and etc. A MFC system is shown in Fig 1.

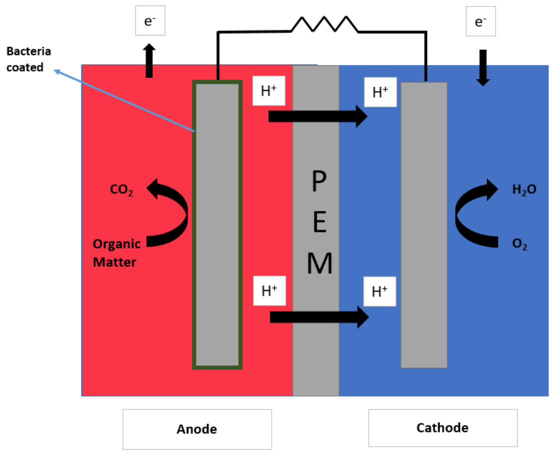

Fig. 1. The principle for microbial fuel cell [26]

In MFC applications, substrates (eg wastewater) are oxidized by exoelectrogenic microorganisms. The highest current densities to date usually generated by mixed cultures dominated by *Deltaproteobacteria*of the *Geobacter* genus. However, many other microorganism can transfer electrons to an anode.

MFCs represent a next-generation technology that allows not only energy generation but also recovery of useful products with wastewater treatment. MFCs allow the conversion of conventional wastewater treatment processes, which are characterized as energy intensive and purification-oriented, into integrated systems that allow the production of value-added products when wastewater treatment.

2.2. Microbial electrolysis cell (MEC)

MECs are a comparatively new method to produce hydrogen from electrohydrogenesis, acetate and other fermentation end products. In MEC, bacteria called exoelectrogens oxidize a substrate and release electrons on the anode [27, 28]. Generally, in the existence of oxygen at the cathode in an MFC, the current is produced by oxygen reduction, but in the MEC, the cathode is anaerobic and therefore, without oxygen, spontaneous current production is not possible [29]. MEC system is shown in Fig 2.

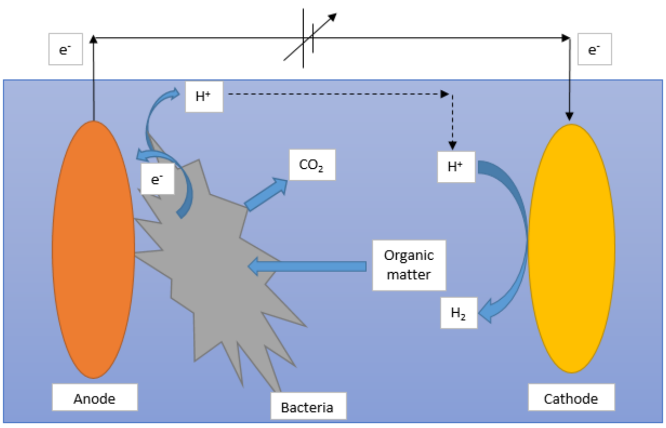

Fig. 2. The mechanism for a MEC system [30]

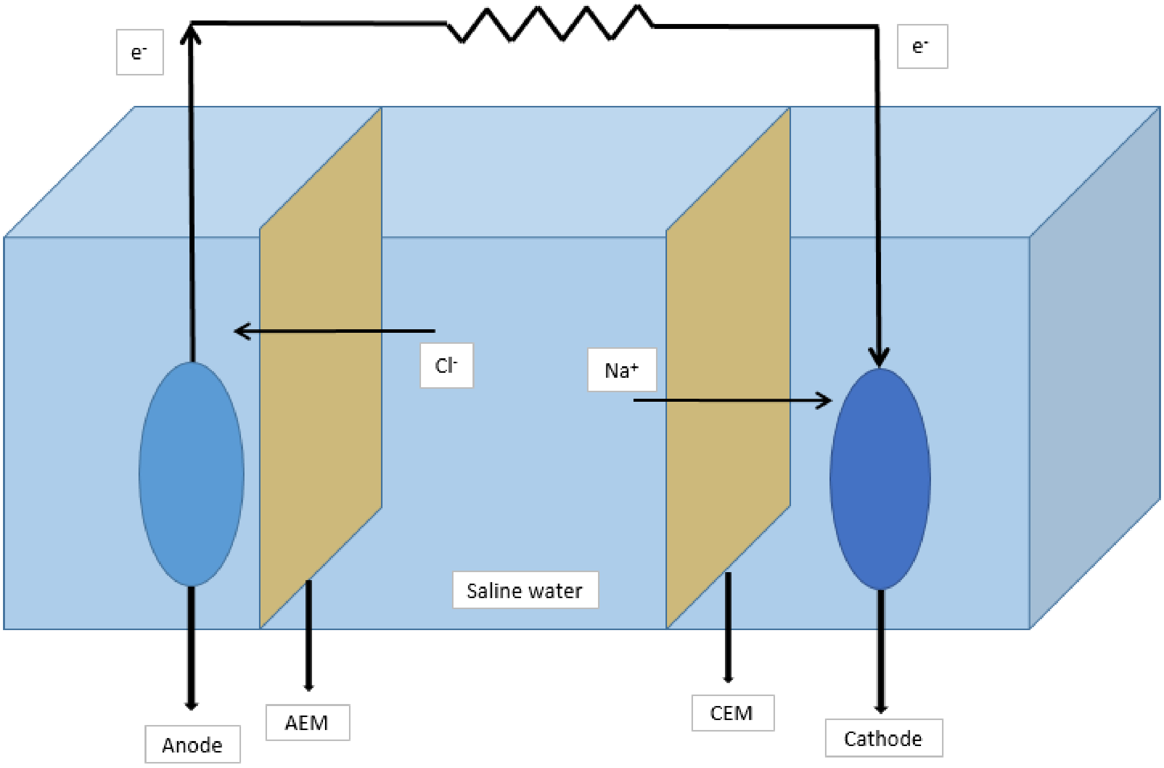

Fig. 3. General scheme of Microbial Desalination Cell [32]

Thus, a small voltage is applied externally to the circuit and allows the production of hydrogen at the cathode by reducing the proton. In MEC, hydrogen is produced at the cathode by electrolysis. However, an external electricity source is required for this production. Fortunately, this energy requirement is a relatively small amount. Because, most of the energy produced by the chemical energy at the anode during the oxidation of substrates.

2.3. Microbial desalination cell (MDC)

The microbial desalination cell (MDC) has been successfully developed for decisive purposes in order to purify wastewater, generate electricity and desalinate water simultaneously [31]. A general diagram of the microbial desalination cell is shown in Fig 3.

The increasing number of publications in MDC shows the growing interest to this topic. General accepted configurations in MDCs in current studies are air breathing, bio-cathodes and osmotic membranes. MEC systems are commonly used in studies with bio-cathodes and osmotic membranes [32, 33].

3. CONCLUSIONS

In the past two decades, researchers have tried to use more complex and higher energy containing fuels for conventional products. Bioelectroactive fuel cells can generate electric current in the presence of biological substances.Bio-electroactive fuel cells are released as microbial electro synthesis devices, where the production of valuable products from other compounds, including CO_2 or gas conversion, with the help of specific bacteria. In order to make an easy-to-use and practical biofuel cell, many efforts have been made. These efforts include improving immobilization, electrode structure and electrolyte, and introducing multi-enzyme system and stabilization. This relatively new method, attracts attention of the researchers due to its off-grid energy supply potential.

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