OUTLOOK OF SEDIMENT MICROBIAL FUEL CELL FOR POWER GENERATION AND BIOREMEDIATION OF CONTAMINANTS

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Abstract - Due to lack of a membrane and completely anoxic, sediment microbial fuel cells (SMFCs) are different from microbial fuel cells. The simultaneous production of renewable energy, bioremediation of contaminants and moderate functioning parameters, SMFCs have attracted the attention of many researchers. For power generation, many exoelectrogens in SMFCs have the ability to transfer electrons from electrodes by using four ways of natural electron shuttles. The most dominant mechanism is long-range electron transfer via conductive pili. The powering by microbes is an emerging technique for the remediation of contaminants from sediments. The pathways for transferring electrons in electrotrophs operate in the opposite direction from those in exoelectrogens.This review briefly targets on the SMFC prototype, power generation and contaminants remediation.

Keywords - Electrodes, Electrotrophs, Exoelectrogens, Power generation

I. INTRODUCTION

In general, sediment is recognized a major “sink” for contaminants, specifically for some persistent organic pollutants and heavy metals. These pollutants may accumulate to concentrations many fold above than those in the water column. In recent years, the pollution of the aquatic environment has become a global problem because of its toxic effects on living organisms. Due to their bio-accumulation in the ecosystem and their toxic effects, heavy metals are of particular concern among environmental pollutants [1]. Many conventional methods have been used for the remediation of sediments, such as ozonation, dredging, and electro-chemical degradation, but their high cost and harsh nature limits their widespread application [2]. Thus, the natural degradation of sediments by microorganisms, including methods such as immobilization, degradation, and decomposition, has received much interest due to its reduced cost and environmentally benign nature. The microorganisms have many diverse metabolic routes by which they can easily degrade/transform the sediment pollutants into less toxic forms [3]. However, the natural degradation/transformation of sediment heavy metals by microorganisms is a very slow process because there is a lack of proper electron donors and acceptors. Thus, to boost this metabolic process, a system is needed that can easily provide a proper electron acceptor and donor for simultaneous sediments heavy metal remediation and electricity generation.

There are many types of fuels cells. Many reports that environmental microbes can easily build electrochemical signaling with solid electrodes have rapidly led to the microbial fuel cells (MFCs) development [4]. An MFC is a device that converts the chemical energy of organic and inorganic compounds into electricity using bacteria, and in this device, pollutant treatment and electricity generation are simultaneously achieved [5]. Sediment microbial fuel cells (SMFCs) are a special application of MFCs for sediment remediation and electricity production. There are many advantages of SMFCs for sediment remediation to remove various contaminants while producing renewable energy: 1) for the natural bioconversion mechanisms, the electrode can provide a less aggressive, inexhaustible, clean and flexibly portableelectron acceptor or donor; 2) SMFCs cause minimum distraction to the native aquatic habitat; and 3) controllable electrochemical parameters can be easily monitored for the remediation processes [6].

II. SEDIMENT MICROBIAL FUEL CELLS (SMFCs)

Electricity production by bacteria was first observed by Potter. Very few practical advances were achieved in the field of MFC for the next 55 years. In the early 1990s, researchers were primarily using exogenous chemical mediators (natural red, methyl viologen, potassium ferricyanide, thonin, anthraquinone 2-6, disulfonate, and others) for the transfer of electrons from inside bacteria to electrodes, but these exogenous chemical mediators (electron shuttles) are often toxic and unstable . Kim et al. achieved the first breakthrough in the field of MFCs when they found that without the addition of exogenous mediators, the bacteria could transfer the electrons to electrodes [7].

The prototype SMFCs consist of a graphite anode placed in an anaerobic sediment and a graphite cathode placed in water containing dissolved oxygen. The performance of SMFCs depends on the potential gradient of the sediment-water interface. Around both the anode and cathode, copper wires are tangled because they are very good electrical conductors. To make the SMFCs efficient, a multi-anode system is typically used; approximately 11 anodes are sufficient for a single cathode [8]. Thus, both electrodes are connected with the external circuit that is attached to a multi-meter data logger to monitor the system. SMFCs provide an appropriate model to examine how energy flows through microbial consortia and how we can collect the energy from a natural system; their potential role in power generation and the bioremediation of contaminants in the environment can be explored. Some potential SMFC types that can easily degrade/transform sediments containing heavy metals with simultaneous electricity production are discussed in the next sections. The prototype of general SMFCs is shown in Figure 1. Following are the possible forms of SMFCs.

2.1. Aerobic non-stimulated SMFCs

The prototype for this SMFC is the same as mentioned above. This SMFC type is very similar to a natural aquatic environment because it is not stimulated externally, and an oxygen sparger is inserted in the cathode chamber to create the aerobic environment [9].

2.2. Aerobic stimulated SMFCs

This SMFC is stimulated by an external battery, and the main difference is that the multi-cathode system is developed by opposing the direction of the external battery terminals because heavy metals normally require high potential for reduction or degradation [10].

2.3. Anaerobic non-stimulated SMFCs

The prototype of this SMFC is the same as for the aerobic SMFC with the only difference that there is no external oxygen supply [11]. The entire system is tightly closed, which prevents the introduction of oxygen into the system and maintains an anaerobic environment for the fermentation activities of anaerobic bacteria.

2.4.Anaerobic stimulated SMFCs

The structure of this SMFC is the same as for the non-stimulated anaerobic SMFC except that it is stimulated by an external battery, and a multi-anode system is created by opposing the direction of the external battery terminals. This step is used because the initial current in the external battery from the positive terminal and heavy metals in the sediments is easily reduced by the external current due to the integration of the cathode into sediments [12].

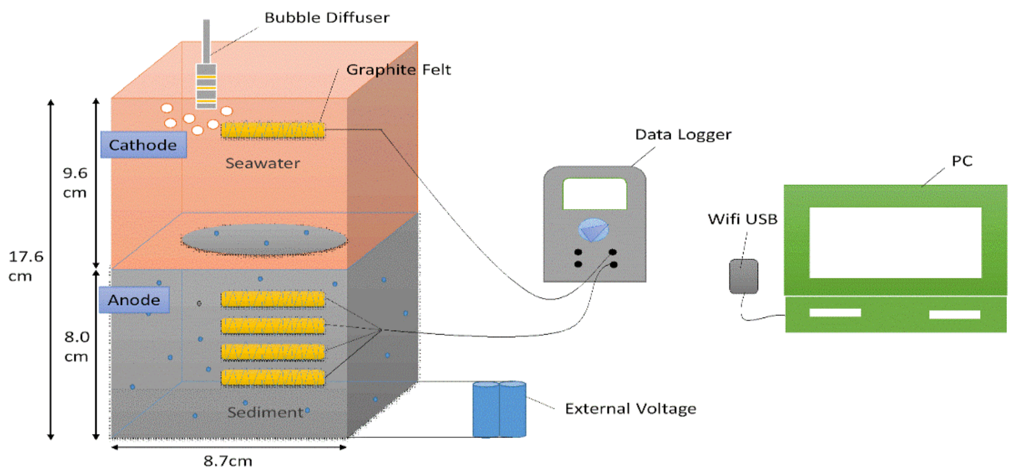

Fig.1. The schematic prototype of a general double-chamber SMFC.

III. EXOELECTROGENS

Many exoelectrogenic bacterial strains are known that can easily transfer electrons to electrodes, e.g., Rhodopseudomonaspalustris, Geobactersulfurreducens, Geobacterloveleyi, Anaeromyxobacterdehalogenas, Pseudomonas aeruginosa, Geothrixfermentas, Thermincolacarboxydophila, Shewanellaoneidensis, Shewanellaputrefaciens, Escherichia coli, and Thermincolapotens. Recently, some pathogenic bacterial strains, such asOchrobactrum anthropic and Klebsiella pneumonia [13], have been reported to produce current in SMFCs.The electrons are transferred from bacteria to SMFC electrodes through four mechanisms like Electron transfer by soluble electron-shuttling molecules, short-range direct electron transfer by redox-active proteins, long-range electron transport through conductive pili and direct interspecies electron transfer.

IV. ELECTROTROPHS

Microbes that have ability to accept electrons from electrodes are called electrotrophs. The electrotrophs discovery opened a new research direction for the remediation of heavy metals through reduction. To date, many microbial consortia have shown the properties of electrotrophs. Many bacteria such as Staphylococcus carnosus, Enterococcus faecalis, Lactobacillus farciminis, Kingelladenitrificans, Shigellaflexneri, Streptococcus Mutans, Dechlorospirillum anomalous, Clostridium ljungdahlii[14], and Acinetobactercalcoaceticus have different redox-active molecules that can act as electrons shuttles, accept the electrons from electrodes, and deliver them to bacteria to promote the reduction of inorganic substrates and fermentation.

CONCLUSIONS

SMFCs have created a new research direction that may prove to be environmentally sustainable and more controllable and cost-effective for power generation and the bioremediation of contaminated sediments. The electron transfer mechanisms of exoelectrogens and electrotrophs are well investigated mostly in Shewanella spp. and Geobacterspp.; so research about electron transfer mechanisms in other exoelectrogens and electrotrophs are also needed. The challenges of SMFCs will be overcome by joint endeavors from researchers in many disciplines such as environmental studies, biotechnology, electrochemistry, computer science, electronics, materials science, and biology.

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