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Review

Challenges in the application of microbial fuel cells to wastewater treatment and energy production: A mini review

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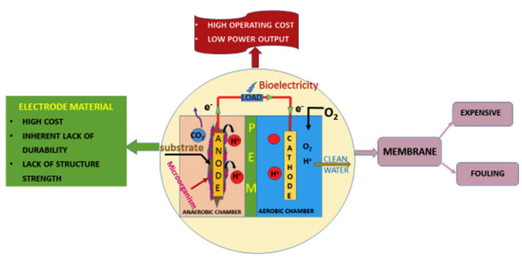
HIGHLIGHTS

- MFCs are a promising technology for wastewater treatment and energy production.
- Costs of MFC material fabrication and electricity production are challenged.
- Current instability and high internal resistance are also problematic issues.
- Membrane fouling and low rate of growth of microbes limit the MFCs' application.
- Practical version of tonne scale MFC is proposed and tested with real wastewaters.

GRAPHICAL ABSTRACT



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ABSTRACT

Wastewater is now considered to be a vital reusable source of water reuse and saving energy. However, current wastewater has multiple limitations such as high energy costs, large quantities of residuals being generated and lacking in potential resources. Recently, great attention has been paid to microbial fuel cells (MFCs) due to their mild operating conditions where a variety of biodegradable substrates can serve as fuel. MFCs can be used in wastewater treatment facilities to break down organic matter, and they have also been analysed for application as a biosensor such as a sensor for biological oxygen which demands monitoring. MFCs represent an innovation technology solution that is simple and rapid. Despite the advantages of this technology, there are still practical barriers to consider including low electricity production, current instability, high internal resistance and costly materials used. Thus, many problems must be overcome and doing this requires a more detailed analysis of energy production, consumption, and application. Currently, real-world applications of MFCs are limited due to their low power density level of only several thousand mW/m^2. Efforts are being made to improve the performance and reduce the construction and operating costs of MFCs. This paper explores several aspects of MFCs such as anode, cathode and membrane, and in an effort to overcome the practical challenges of this system.

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Contents

1. Introduction

Wastewater is now recommended as a vital resource for water reuse and saving energy. Conversely, traditional treatment technologies such as conventional aerobic activated sludge (CAAS) require large amounts of energy and generated residuals; there is also the problem of not recovering enough or any potential resources available in wastewater (He et al., 2017). Currently, anaerobic digester (AD) technology is widely accepted as a vital treatment strategy in that it saves energy sources and is highly effective in converting organic chemicals into methane (CH_4) gas. This in turn can be changed into electricity by CH_4-driven engines or chemical fuel cells. However, some research indicates that treated wastewater does not always meet stringent regulatory standards, and more technical advances are demanded for the post-treatment scenario. Despite these problems, water reuse has already been widely implemented especially in some dry areas. However, it invariably requires more energy for treatment, principally arising from the increased water quality requirements for reuse (Venkata Mohan et al., 2011).

Microbial fuel cells (MFCs) have been recognized as an encouraging and challenging technology in saving energy and simultaneous wastewater treatment, overcoming environmental problems (Pandey et al., 2016). This is particularly the case in isolated areas that are supplied with biosensors, bio hydrogen production, as well as in-situ power sources for bioremediation and wastewater treatment (He et al., 2017; Surya Ramadan and Purwono, 2017).

In recent years, the number of papers on MFCs being published in journals has markedly increased. The Web of Science ™ database searching with keyword of “microbial fuel cell” on December 25, 2016 leaded to a total of 6198 papers, in the field of “biotechnology applied microbiology” (1896), “energy fuels” (1664), “electrochemistry” (1154) and “environmental sciences” (1006) (Hu et al., 2017). In the last few years, MFCs as a new source of bioenergy have been extensively reviewed with different emphasis, such as designs and configurations, electrodes and electrode surface modifications, microbial communities, operation conditions for performance and biofilm formation, challenges and possibilities, fundamental electron transfer mechanisms and applications (Pandey et al., 2016; Surya Ramadan and Purwono, 2017).

He et al. (2017) indicated there are many reasons why MFCs are more sustainable when applied to wastewater treatment. The first advantage is their ability to directly convert substrate energy into electricity. Second, using MFCs allows wastewater processes to reduce activated sludge compared to anaerobic digestion and CAAS processes. The third advantage is insensitivity to the operational environment. The fourth one is that MFCs do not require any treatment for gas because of the recycling and conversion. Much more energy can be saved by MFCs without any energy input required for aeration. Fifth and finally, MFCs can be used widely in locations where there is insufficient electrical infrastructure.

Despite of the fact that, MFCs technology is an innovation strategy for improving waste/wastewater treatment and energy product. However, many challenges must be addressed including electron transfer mechanism, the microscales with biofilm formation and associated transport process, and the macro-scales with electrodes and separators in bioanode (Kim et al., 2015).

Despite the MFCs' application at lab level, researchers have proved their suitability in industrial contexts such as the reactor volume operational time and wastewaters investigated in MFCs (He et al., 2017).

With these possibilities in mind, this study aims to discuss the MFC concept and its practical application for wastewater treatment and energy production. By introducing a wide range of MFCs and looking at each one in detail, the challenges of MFCs are highlighted. Moreover, the combination of MFCs with other treatment processes is explained in terms of practicality and effectiveness. Furthermore, the challenges and opportunities for scaling up and future applications of MFC in wastewater are also discussed in this paper.

2. General features of microbial fuel cells

Recently, a type of technology using microbial fuel cells (MFCs) that converts the energy stored in chemical bonds in organic compounds into electrical energy has been achieved through the catalytic reactions generated by microorganisms. This process has aroused considerable interest among academic researchers since the early 1990s (Allen and Bennetto, 1993; Choi et al., 2003; Gil et al., 2003; Moon et al., 2006). Microbial fuel cell technology has become an innovation renewable energy resource by degrading organic pollutants in wastewater (Mustakeem, 2015; Wang et al., 2015).

Microbial fuel cells (MFCs) are devices that use bacteria as catalysts to oxidize organic and inorganic matter and generate electrical current. Microbes in the anodic chamber of an MFC oxidize added substrates and generate electrons and protons in the process. Carbon dioxide is

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