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Review

Microbial fuel cells as pollutant treatment units: Research updates

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HIGHLIGHTS

- Recent R&D works for microbial fuel cells process were reviewed.
- Oxidization, reduction and combined systems on pollutant treatment were covered.
- Challenge and ways forward for MFC process were discussed.

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ABSTRACT

Microbial fuel cells (MFC) are a device that can convert chemical energy in influent substances to electricity via biological pathways. Based on the consent that MFC technology should be applied as a waste/wastewater treatment unit rather than a renewable energy source, this mini-review discussed recent R&D efforts on MFC technologies for pollutant treatments and highlighted the challenges and research and development needs. Owing to the low power density levels achievable by larger-scale MFC, the MFC should be used as a device other than energy source such as being a pollutant treatment unit.

1. Introduction

The microbial fuel cells (MFC) are a device that oxidizes fed substrates in reduced forms by biofilm on anode to deliver electrons and protons, and then transfer yielded electrons and protons to cathode for reduction of externally supplied oxidants via an external circuit (Wang et al., 2015a). Hence, the MFCs are regarded as a promising energy source when treating waste/wastewater (Tamakloe, 2015; Sakdaronnarong et al., 2015). Multidisciplinary sciences involved in MFC studies. The basic architecture of an MFC is shown in Fig. 1. Kim et al. (2015a) reviewed the current status of development and challenges for MFC technologies, including on nano-scales involving electron transfer mechanisms, the micro-scales with biofilm formation and associated transport processes, and the macro-scales with electrodes and separators in bio-anode are discussed.

The Web of Science™ database search using topic of "microbial fuel cell" on 2015.Dec.22 led to a total of 5090 papers, in fields of biotechnology applied microbiology (1644), energy fuels (1361), electrochemistry (964) and environmental sciences (804). The authors from United States and China contributed 54% of these published papers. The number of these papers had received 118,104 citations, with relevant articles at >700 citations as follows (Logan et al., 2006; Bond and Lovley, 2003; Rabaey and Verstraete, 2005; Liu and Logan, 2004; Barton et al., 2004; Gorby et al., 2006). The MFC paper numbers monotonically increase with time in the last decade (89, 149, 235, 270, 410, 504, 550, 709, 758, 926 over year 2006–2015). In all platforms, Bioresource Technology ranked top in number of MFC papers published (543), followed by Environmental Science & Technology (222) and Journal of Power Sources (215). Table 1 lists the top 15 journals in 2015 and their numbers of MFC papers published and those regarding pollutant treatments, with Bioresource Technology published 58.4% of these pollutant treatment papers, followed by RSC Advances and Water Research (7.9% each).

This mini-review provides a snapshot of recent development on MFC technologies for pollution treatments. The arguments of using MFC for purpose other than a practical energy source are first

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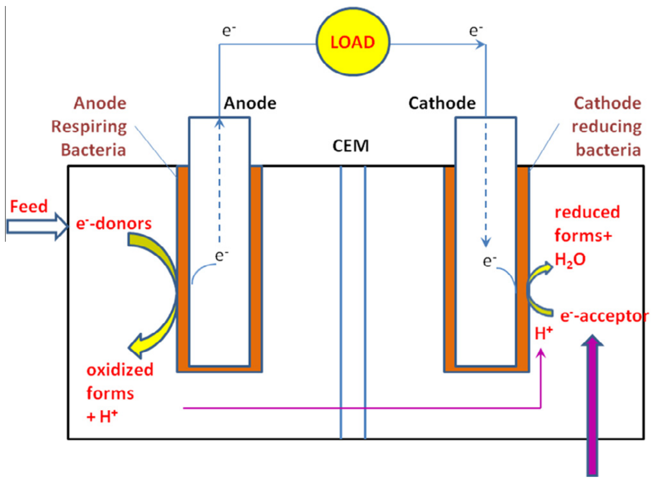

Fig. 1. Schematic of microbial fuel cells. Electron donors in feed are oxidized at anode to form reduced form and electron and proton, while the latter two are transferred to cathode to yield the reduced forms of electron acceptors in the catholyte.

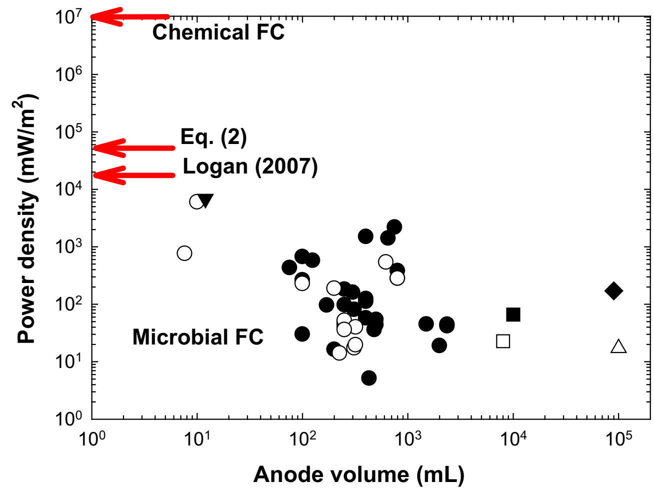

Fig. 2. Power density versus anodic chamber volume data. Solid circles: data from references cited in Table 1 of ElMekawy et al. (2015); open circles: data from references cited in Rahimnejad et al. (2015); solid triangle: Fan et al. (2008) (0.012 L); open triangle: Ge et al. (2015) (100 L); open square: Zhuang et al. (2012) (8 L); solid square: Jiang et al. (2011) (16 L); solid rhombus: Dong et al. (2015) (90 L).

discussed (Section 2). Then the current studies for MFC pollutant treatment works were briefly discussed (Section 3). Since Bioresource Technology, RSC Advances and Water Research journals are the major platforms reporting the MFC research progress, the present mini-review summarizes 2015 papers in these journals for demonstrating the current R&D trends in pertinent literature works on MFC technologies for pollutant treatments. In Section 4, the challenges and prospects of MFC studies on pollutant treatment are discussed.

2. MFC as energy source

To use MFC as a renewable energy source, the power density deliverable is a key performance parameter. Logan (2007) and Fan et al. (2008) estimated the ultimate power generation from an MFC without internal resistances to be 17–19 W/m^3. A human body of volume 0.1 m^3 could generate 100 W heat, leading to a volumetric power generation of 1 kW/m^3. There are 3.73×10^{13} cells in a typical human body (Bianconi et al., 2013); therefore, the energy generation by a single cell can be estimated as 2.68×10^{-12} W (=100 W/3.73×10^{13} cells). A packed bed with random or regular packings can have specific surface area up to a few hundred m^2/m^3. Assuming that biofilms with 20 layers of the cells of projected area of 1 μm^2 occupy whole surface area of the MFC with specific surface area of 100 m^2/m^3, then the ultimate volumetric energy generation and the power density can be estimated as follows:

$$[(100\ \mathrm{m^2/m^3})/(1\ \mu\mathrm{m^2/cell})] \times 20\ (\mathrm{layers})(2.68 \times 10^{-12}\ \mathrm{W/cell}) = 5360\ \mathrm{W/m^3} \quad (1)$$

$$[2.68 \times 10^{-12}\ \mathrm{W/cell} \times 20\ \mathrm{cells}]/(1\ \mu\mathrm{m^2}) = 53.6\ \mathrm{W/m^2} \quad (2)$$

Interestingly, the volume fraction of these biofilm only accounts on 0.2% of the total reactor volume ([(100 m^2/m^3)/(1 μm^2/cell)] × 20 × 1 μm^3/cell = 0.002 m^3/m^3). The space left for the electrodes, connecting wires, channels for fluid flow etc will take >99% of the reactor space. Without sufficient flow channels, the pressure drop over an MFC will be too high to be practically implemented.

In practice, Logan (2009) provided a figure (his Fig. 2b) a dramatically increasing trend of MFC power density reported in literature from lower than 0.1 W/m^2 in 1999 to up to 6.9 W/m^2 in 2008, from which one can expect a promising prospect for the use of MFC as a practical energy source in near future. Fig. 2 shows the power

Table 1
Top 15 Journals that published more than 10 papers in 2015 according to Web of Science™ database search using topic of "microbial fuel cell" on 2015.Dec.22. These journals published 408 MFC papers in 2015, with 101 papers on pollutant treatment.

Journal	Number of MFC papers in 2015	Number of pollutant treatment MFC papers in 2015 (A)	A/101 (%)
Bioresource Technology	108	59	58.4
RSC Advances	50	8	7.9
Journal of Power Sources	40	2	2.0
Bioelectrochemistry	30	4	4.0
International Journal of Hydrogen Energy	29	5	5.0
Water Research	20	8	7.9
Electrochimica Acta	20	1	1.0
Scientific Reports	18	2	2.0
Biosensors Bioelectronics	17	3	3.0
Environmental Science Technology	16	0	0.0
Frontiers in Microbiology	14	1	1.0
Chemical Engineering Journal	14	4	4.0
International Journal of Electrochemical Science	11	0	0.0
Biotechnology for Biofuels	11	0	0.0
Desalination and Water Treatment	10	4	4.0
Sum	408	101	100.0