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# A novel pilot-scale stacked microbial fuel cell for efficient electricity generation and wastewater treatment

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ABSTRACT

A novel stacked microbial fuel cell (MFC) which had a total volume of 72 L with granular activated carbon (GAC) packed bed electrodes was constructed and verified to present remarkable power generation and COD removal performance due to its advantageous design of stack and electrode configuration. During the fed-batch operation period, a power density of 50.9 ± 1.7 W/m$^3$ and a COD removal efficiency of 97% were achieved within 48 h. Because of the differences among MFC modules in the stack, reversal current occurred in parallel circuit connection with high external resistances (>100 Ω). This reversal current consequently reduced the electrochemical performance of some MFC modules and led to a lower power density in parallel circuit connection than that in independent circuit connection. While increasing the influent COD concentrations from 200 to 800 mg/L at hydraulic retention time of 1.25 h in continuous operation mode, the power density of stacked MFC increased from 25.6 ± 2.5 to 42.1 ± 1.2 W/m$^3$ and the COD removal rates increased from 1.3 to 5.2 kg COD/(m$^3$ d). This study demonstrated that this novel MFC stack configuration coupling with GAC packed bed electrode could be a feasible strategy to effectively scale up MFC systems.



## 1. Introduction

Microbial fuel cells (MFCs) are bioelectrochemical devices that utilize exoelectrogenic microorganisms as catalysts to convert chemical energy of organic substrate into electricity (McCarty et al., 2011; Wang et al., 2015). Due to its capacity to recover energy by degrading pollutants in wastewater and produce less excessive sludge, MFC could become a promising wastewater treatment technology with great environmental friendly benefits (Rabaey and Verstraete, 2005). In order to bring MFC into practical applications, MFC must be scaled up to a certain extent to treat large amount of wastewater. However, studies revealed that as the dimension of an individual MFC enlarged, the power density declines due to the increase of volumetric ohmic resistance and inactive reactor volume, leading to a low power generation performance of scaled-up MFC (Clauwaert et al., 2008).

Combining multiple small MFC modules to form a larger stack may be a more feasible and efficient strategy to scale up MFC systems than merely increasing the size of an individual reactor (Ieropoulos et al., 2008). So far, there have been a variety of researches focusing on the performance of scaled-up MFC stack, but the reported power densities were still too low to make MFC system comparable with conventional anaerobic treatment in terms of energy recovery (Rabaey and Verstraete, 2005). For example, Dekker et al. (2009) constructed a 20 L stacked MFC fed by synthetic wastewater and produced a low power density of 11 W/m$^3$ due to the detrimental impact of reversal voltage in some cell units under series electrical connection on the MFC stack. Kim et al. (2011) constructed a 1 L tubular MFC stack also fed by synthetic wastewater and achieved a lower power density of 5.6 W/m$^3$ which might be attributed to the limited biomass contents on the carbon veil anode and limited active surface area on the carbon cloth cathode. Feng et al. (2014) invented a 250 L plug flow stacked MFC to treat municipal wastewater but only achieved a power density of about 0.47 W/m$^3$ owing to the increased area-specific-resistance of the stack configuration. Therefore, more efficient MFC stack and electrode configuration are needed to improve the power output of scaled-up MFC system and more information should be obtained to reveal the impact of external circuit connection on MFC stack performance.

To enhance the power output of MFC, the internal resistance

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which mainly involves ohmic, kinetic and transportation resistance (He et al., 2005), should be reduced as much as possible. In regard of scaled-up MFC systems, ohmic resistance usually becomes higher with the increase of electron and ion transport distances. The kinetic reaction rate per volume which is closely related with the effective surface area of electrode usually decreases with the enlargement of MFC reactor. Transportation resistance will become significant when MFCs are to treat the low substrate concentrations of real wastewater, such as domestic wastewater (Clauwaert et al., 2008; He et al., 2006). Therefore, strategies to lower the internal resistance of scaled-up MFC stack should be invented on the basis of reducing these three resistance components.

In this study, a novel stacked MFC with a total volume of 72 L has been constructed and exhibited a higher power generation and organic removal performance than most of the reported scaled-up MFCs thus far. It was designed on the basis of the following three hypothesis: (1) the stack configuration should possess larger ion exchange membrane areas per volume to facilitate ion transport efficiency and the electrode chambers were fabricated as narrow and flat (90 cm height, 40 cm length with only 5 cm width) to reduce electron transfer distances and be easily stacked together to a larger dimension; (2) granular activated carbon (GAC) packed bed electrodes were employed since their higher available surface area could provide more active sites for the attachment of anode and cathode biofilms, which greatly enriched biomass contents and thus enhanced the kinetic performance of MFC electrodes. (Jiang and Li, 2009; Wei et al., 2011); (3) the adsorptive effect of GAC was pre-verified to significantly reduce mass transfer resistance of MFC anode at low substrate concentrations and improve the bioactivity in anode biofilms (Wu et al., 2015; Herzberg et al., 2003). Then, power generation and chemical oxygen demand (COD) removal performance of this pilot stacked MFC were investigated in both fed-batch and continuous operation modes. Impact of the external circuit connection on the performance of individual MFC modules and the whole MFC stack were examined to give more insights into how the MFC modules interact with each other in the stack. Performance differences among anode chambers were further investigated to characterize the influence of the structural design of this stack configuration.

## 2. Materials and methods

### 2.1. Stacked MFC

The stacked MFC (SMFC) consisted of three anode chambers, three biocathode chambers and two blind plates of the same size (90 × 40 × 5 cm), all of which were made of polyvinyl chloride and clamped transversely together by stainless steel bolts (Fig. 1A&B). The working volume of each electrode chamber was 12 L (80 × 30 × 5 cm), amounting to a total volume of 72 L in an MFC stack. Both anode and biocathode chambers were packed with activated carbon granules (2–3 mm in diameter, 4–6 mm in length, Beijing Chunqiudingsheng Environmental Science and Technology Co. Ltd., China) as electrode. The porosity of packed bed was about 42% and thus the liquid volume of each electrode chamber was about 5 L. Three anode chambers and three biocathode chambers were stacked alternately with each other and separated by cation exchange membranes (CEM) (Tianwei Company, Shandong, China). Titanium meshes (80 × 30 cm) were used as inner current collectors and inserted adjacently on both sides of each CEM, and two titanium meshes were set on the side near to the blind plates. A CEM with two titanium meshes on its sides and the activated carbon granules in the adjacent anode and biocathode chambers can be equivalently regarded as an individual MFC module. The structural design of this stack configuration indicated that each anode or

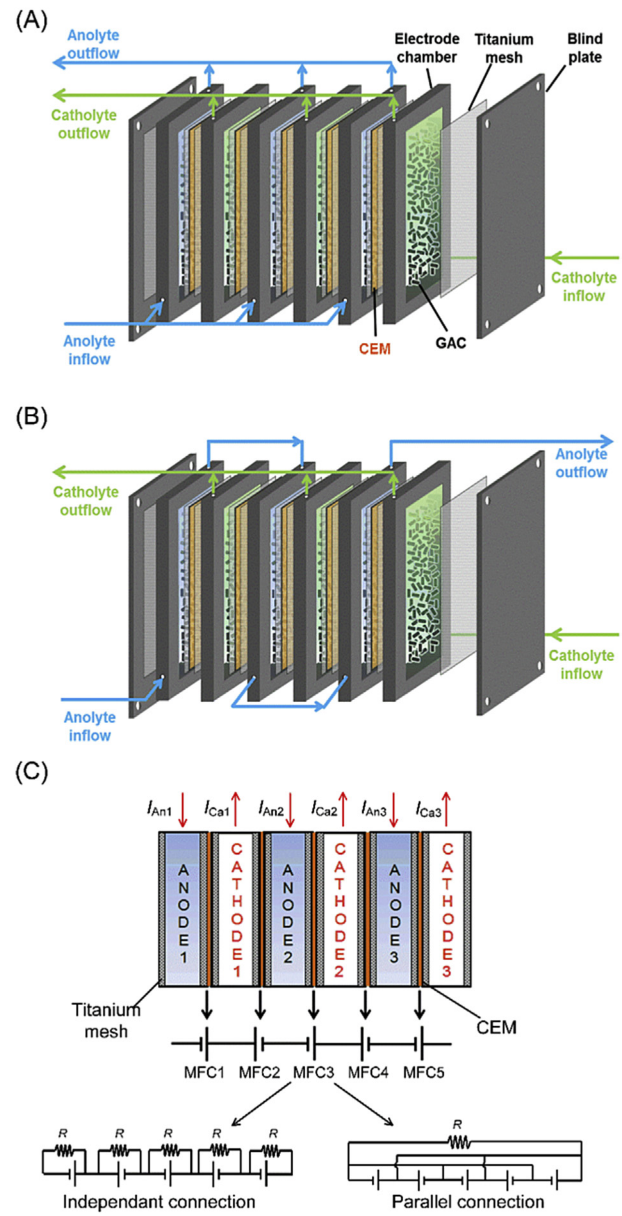


**Fig. 1.** Schematic of the 72 L pilot SMFC operated in fed-batch (A) and continuous mode (B) and its equivalent circuit at different external electrical connection (C) (The direction of red arrows in Fig. 1C represented the direction of current flows outside the electrode chambers.).(For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

cathode chamber of SMFC simultaneously served as the anodes or cathodes of two MFC modules except the chambers on the two sides of SMFC (Fig. 1C). There were two kinds of external circuit connection: independent circuit connection (ICC), where each MFC module was connected with a separate external resistance, and parallel circuit connection (PCC), where each MFC module in the stack was connected in parallel together with a single resistor (Fig. 1C).

### 2.2. Inoculation and medium

In order to ensure the stable working condition of SMFC system and the parallelism of experimental results in this study, synthetic wastewater was used as anode medium which contained