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Factors Affecting the Performance of Single Chamber Microbial Fuel Cell Using a Novel Configuration

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Abstract: In this study, the single chamber microbial fuel cell (MFC) with annular configuration and spiral anode geometry is proposed for future large-scale applications. Dairy wastewater containing complex organic matter was used as substrate. Factors affecting power generation and internal resistance of this MFC such as substrate injection, electrode surface area, and substrate concentration were investigated to elucidate the effects of the MFC configuration and operating conditions on its performance. The results show that with decreasing anode surface area output current is reduced. With decreasing anode surface area from 2×63 to 2×38 cm, output current is reduced about 34%. In measurement of open circuit voltage, replacement of old wastewater by fresh ones the open circuit voltage significantly increased. Also, enhancement of wastewater concentration shows an increase in the MFC power density. The MFC which was fed with wastewater with lower COD had a shorter batch time than that of the higher wastewater COD.

Key words: Single chamber microbial fuel cell · Spiral anode · Operating conditions · Dairy wastewater

INTRODUCTION

Microbial fuel cells (MFCs) represent a promising candidate as a new method for wastewater treatment, because of high efficiency, electricity generation and low cost in comparison with other methods of wastewater treatment. Actually, the major obstacles for practical applications of MFCs in a wastewater treatment plant concerns mainly difficulties in the scaling-up process and the very high capital costs [1]. Scaling up of microbial fuel cells (MFCs) requires a better understanding of the importance of different factors such as electrode surface area, MFC configuration, and parameters related to solution conditions such as conductivity and substrate concentration. Lorenzo et al. [2], investigated effect of three dimensional anode surface area on power generation of single chamber MFC. They showed that with increasing anode surface area, MFC performance improved. In several studies, effect of substrate concentration as a main factor in the MFC efficiency was investigated [3, 4].

Among different wastewaters that were used in MFCs, dairy wastewater contains complex organics, such as polysaccharides, proteins, and lipids, which on hydrolysis form sugars, acids, and fatty acids. Dairy wastewater treatment in MFCs produce lower power density in comparison with other wastewaters [5, 6].

This study reports the fabrication of a novel annular single chamber MFC (ASCMFC) assembly by using a graphite coated stainless steel mesh anode electrode with spiral geometry in single chamber microbial fuel cell. There were two objectives in present work. First, the stainless steel mesh anode with graphite coating to grow biofilm was developed and compared with the air cathode MFCs in order to elucidate the effect of surface porosity on MFC efficiency. Second, factors affecting the performance of single chamber microbial fuel cells for wastewater treatment were investigated. The anode material and its configuration represent an important parameter in a MFC, as it influences the development of the microbial community involved in the electrochemical bio-reactions. The aim of this work was to evaluate

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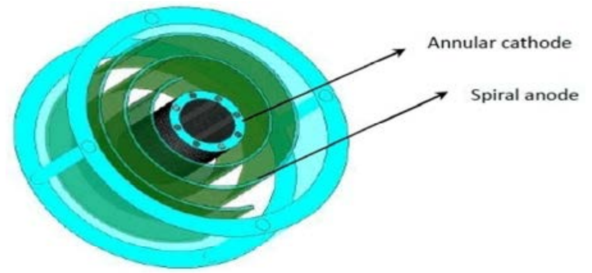

Fig. 1: Schematic diagram of annular single chamber microbial fuel cell (ASCMFC) with spiral anode

ASCMFC with high anode surface area, achieved by using stainless steel mesh in spiral geometry. In this work, we evaluated the effect of anode surface area on the performance of a ASCMFC using dairy wastewater as substrate. Moreover, effect of dairy wastewater concentration is an important parameter that needs to be addressed before MFCs successfully scaled up for wastewater treatment. The aim of this research is to investigate the effects that different parameters on power production from dairy wastewater.

Microbial Fuel Cell Assembly: The annular single chamber microbial fuel cell (ASCMFC) with spiral anode and annular cathode were constructed using Plexiglas cylindrical chamber as the main body. The anode electrode (63 × 2 cm) was made of stainless steel mesh (with mesh 300) as a porous surface with graphite coating to minimize electrical resistance. Because of spiral geometry, the anode surface was increased and electrode spacing in compare to other single chamber microbial fuel cell construction was decreased. The cathode was made of type B carbon cloth (30% wet-proofing; E-Tek, USA) and treated by 0.5 mg platinum loading per cm^2. The cathode (3 × 12 cm) was placed in annular configuration as the inner pipe in the main body. The schematic diagram of ASCMFC is shown in Fig. 1.

Dairy wastewater was collected from Pegah-Isfahan Dairy Industrial Corporation. It was highly conductive and turbid. The ASCMFC was inoculated with activated sludge collected from dairy wastewater treatment of Pegah–Isfahan Dairy Industrial Corporation. After inoculation, diluted raw dairy wastewater with a COD of 1000 mg/l was fed into ASCMFC. Cell voltages (V) were recorded in every 15 minutes across a variable external resistance (30-50,000 Ω) using a multimeter with a data acquisition system connected to a personal computer. Power (P=IV), was normalized by the projected anaerobic volume.

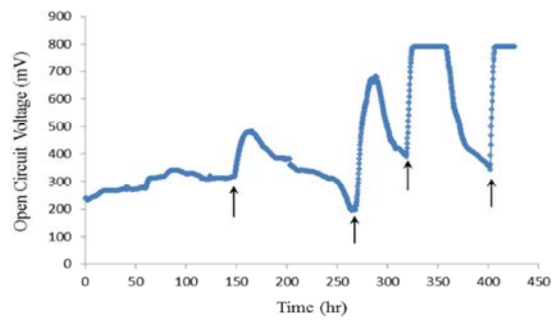

Fig. 2: Open circuit voltage (OCV) during MFC operation as function of time

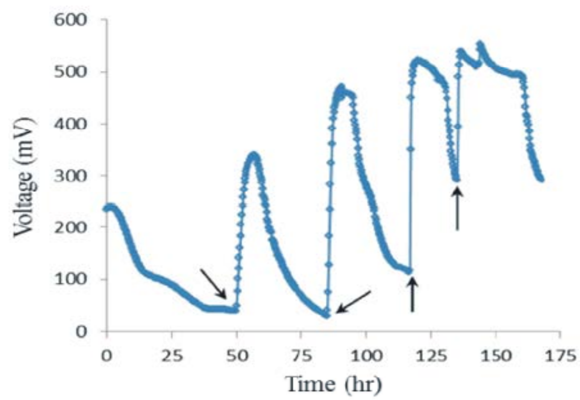

Fig. 3: MFC voltage at 500 Ω resistance as function of time (dynamics response of cell).

RESULTS AND DISCUSSION

Effect of Wastewater Fed Batch on OCV: Fig. 2 depicts open circuit voltage (OCV) during the operation period of the ASCMFC. Experiments illustrated that the power generated in ASCMFC depends on substrate concentration of dairy wastewater. Alos, Fig. 2 shows the behaviour of the ASCMFC while four feed injections were performed. In each batch, the used wastewater was replaced with fresh wastewater that is shown with arrow. Interestingly, this figure illustrates high OCV with dairy wastewater compared to previously published data [5, 7]. Because of dynamic state in measurement of open circuit voltage, replacement of old wastewater by fresh ones significantly increases OCV. In other words, these results showed that wastewater consumed in the MFC system was coupled to current generation. After the replacement of fresh wastewater, the voltage returned to peak voltage.

Fig. 3 shows the variation in voltage response of the anode with the biofilm formed in previous tests (OCV measurement) at a 500 Ω resistance. Data showed that the replacement of wastewater in the ASCMFC produced a non-linear increase in maximum voltage

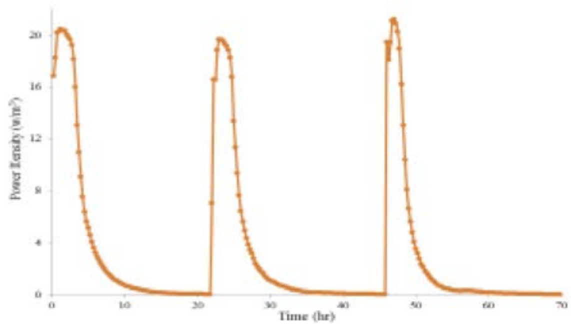

Fig. 4: MFC voltage at 50 Ω resistance as function of time (sustained response of cell)

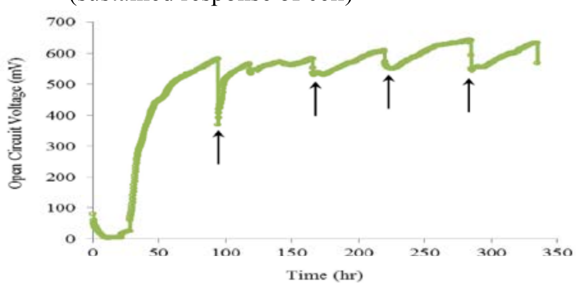

Fig. 5: Open circuit voltage (OCV) during MFC operation with anode surface area 2×38 cm

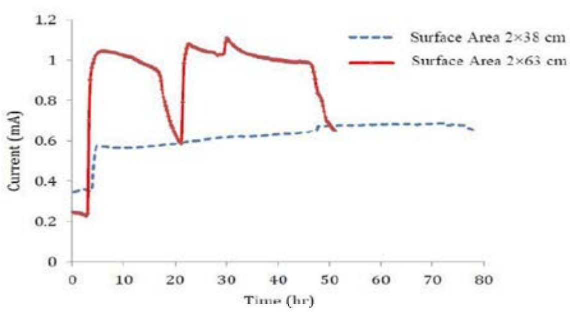

Fig. 6: Comparison of output current of ASCMFC with two anode surface area

reached during four injections of fresh wastewater which are showed with arrows. The time to reach the peak current decreased with injection of fresh wastewater; varying approximately from 3 to 1 h for first and final injection of wastewater. The cell response is linked to the dynamic process of active biofilm attachment and their metabolic process [8].

When this process is sustained, replacement of dairy wastewater in the ASCMFC will not lead to increase in the maximum voltage reached in each test. Resistance of 50 Ω is last resistance that used to measurement of ASCMFC response during different resistances. In this resistance, the process of active biofilm attachment was sustained, so the maximum voltage reached in each wastewater injection did not vary significantly (Fig. 4).

Effect of Varying Spiral Anode Surface Area: The influence of anode surface area was investigated to elucidate the effects of the spiral configuration on power generation. Anode surface area reduced from 2×63 to 2×38 cm. After graphite coating, inoculation was performed to develop biofilm over new electrode surface. Similarly, ASCMFC with new spiral anode surface area (2×38 cm) was fed with the dairy wastewater at same concentration. The open circuit voltage of ASCMFC with new anode surface area was compared with previous ASCMFC. The evolution of OCV is plotted in Fig. 5.

Also, Fig. 5 shows that with decrease in anode surface area, open circuit voltage of ASCMFC is reduced; in addition, four times wastewater injections did not increase the maximum voltage.

The output current of ASCMFC with new anode surface area was compared with previous ASCMFC. In Fig. 6, evolution of current from MFC with both anodes at external resistance of 500 Ω is illustrated.

As it can be noticed in Fig. 6, with decreasing anode surface area from 2×63 to 2×38 cm, output current is reduced about 34%. Also, the ASCMFC with the smaller anode surface area has a much longer stationary phase –the phase which current evolution is constant- than that with the larger anode surface area and stationary phase period is increased from 67 to 23 hours.

Anode geometry and its configuration in the ASCMFC affect specific area and electrodes spacing. The high specific area and low space with cathode increased MFC efficiency [9]. Clearly, with reduction of anode surface area, biofilm development decelerates compared to greater anode surface area. This leads to reduction of substrate degradation. Moreover, by decreasing anode surface area in spiral geometry, electrode spacing is increased that leads to increase in internal resistance of the cell. By increasing MFC resistance including external and internal resistances, the duration of stationary phase increases. Both phenomena can be observed in Figs. 5 and 6.

Effect of Wastewater Concentration: The wastewater concentration is an important parameter on MFCs performance. To investigate the effect of wastewater concentration, an experiment initially conducted using wastewater with a COD of 1000 mg/l and then MFC was fed with wastewater with COD of 500 mg/l. Fig. 7 shows the output current at external resistance of 100 Ω with two different wastewater concentrations for duration of 350 hours.

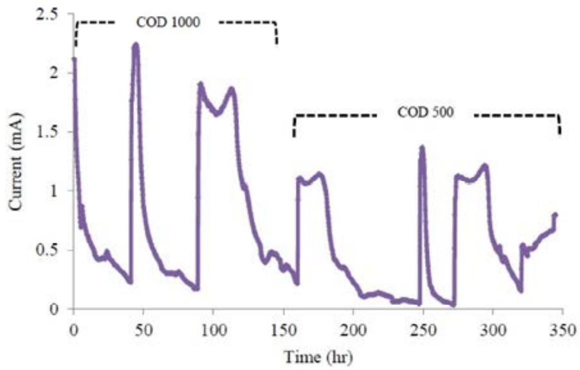

Fig. 7: Current evolution at external resistance of 100 Ω with two different concentrations of dairy wastewater (Spiral anode surface area: 2×38 cm)

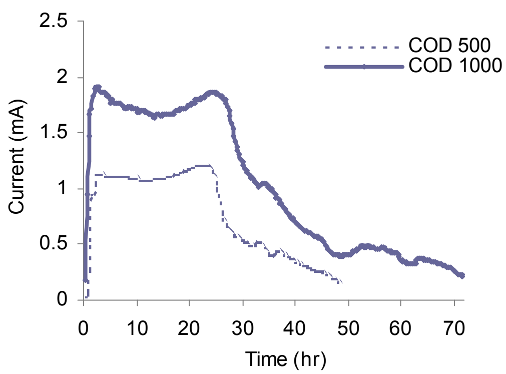

Fig. 8: ASCMFC current vs. time behavior at external resistance of 100 Ω when using wastewater with two chemical oxygen demands.

As it can be observed from Fig. 7, with decreasing dairy wastewater concentration, output current is reduced due to reduction of organic contents in the anolyte. This reduction is specified for two batch cycles in Fig. 8.

Fig. 8 shows current vs. time in ASCMFC in two separate batch cycles with 49 and 72 hours of batch operation time. The COD of wastewaters in these batch cycles were equal to 500 and 1000 mg/l. By reduction of initial dairy wastewater COD which was fed to ASCMFC from 1000 to 500 mg/l, maximum output current is decreased from 1.89 to 1.2 mA. In addition, the MFC which was fed with wastewater with COD 500 mg/l had a shorter descending phase – the phase which current evolution is descending - than that of the higher wastewater COD. Moreover, the output current from the MFC fed with dairy wastewater with less COD, reached to 0.17 mA after 49 hours while the period of current reduction for the MFC fed with dairy wastewater with higher COD is longer than 72 hours.

CONCLUSION

The effect of anode's surface area shows that spiral geometry of anode plays a significant role in power generation. The ASCMFC with the small anode surface area had a much longer stationary phase than that with the large anode surface area. Anode geometry and its configuration in the ASCMFC affect specific area and electrodes spacing. The high specific area and low space with cathode increase ASCMFC efficiency. Because of dynamic state in measurement of open circuit voltage, replacement of old wastewater by fresh ones significantly increases OCV. Replacement of wastewater in the ASCMFC produced a non-linear increase in the maximum voltage reached during dynamics state of ASCMFC. These results showed that wastewater consumed in the MFC system was coupled to current generation. With decreasing dairy wastewater concentration, output current is reduced due to reduction of organic contents in the anolyte. In addition, replacement or injection of fresh wastewater significantly increased OCV.

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Persian Abstract

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چکیده

در این تحقیق پیل سوختی میکروبی (MFC) تک محفظه برای کاربردهای آتی در مقیاس بزرگ پیشنهاد گردید. پساب صنایع لبنی حاوی مواد آلی پیچیده بوده که بعنوان سوبسترا استفاده گردید. فاکتورهای تاثیر گذار بر تولید توان و مقاومت درونی MFC از قبیل تزریق سوبسترا، مساحت سطح الکترود و غلظت سوبسترا بررسی شد در جهت اینکه اثرات پیکربندی MFC و شرایط عملیاتی بر روی عملکرد آن مشخص شود. نتایج نشان داد که با کاهش مساحت سطح آند از ۶۳×۲ به cm ۳۸×۲، جریان خروجی در حدود ۳۴ درصد کاهش یافت. با جایگزینی پساب قدیمی با پساب تازه ولتاژ مدار باز به طرز قابل توجهی افزایش یافت. همچنین افزایش غلظت پساب موجب افزایش دانسیته توان شد. MFC در حالت تغذیه با پساب با COD پایین زمان ماند ناپیوسته کوتاهتری نسبت به حالت تغذیه با COD بالا داشت.