Journal of the Taiwan Institute of Chemical Engineers 56 (2015) 148–153

Contents lists available at ScienceDirect

Journal of the Taiwan Institute of Chemical Engineers

journal homepage: www.elsevier.com/locate/jtice

Performance of sulfate reducing bacteria-microbial fuel cells: reproducibility

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ARTICLE INFO

Article history:
Received 3 February 2015
Revised 12 April 2015
Accepted 18 April 2015
Available online 8 May 2015

Keywords:
Microbial fuel cell
Linear sweep voltammetry
Cyclic voltammetry
Electrochemical impedance spectroscopy (EIS)

ABSTRACT

Reproducibility of performances of microbial fuel cells (MFC) started up in sulfur-containing wastewaters was examined. Four identical dual-chambered MFCs cultivated with identical inoculum, feed, cell geometry and cultivation protocol yielded distinct cell performances. Imposing positive or negative potential on anode did not enhance the performance reproducibility. Two anodes in the same anodic compartment could behave very differently. Both biofilms and anodic suspensions held specific substances with redox activities that may relate to the electron transport process. The electrolyte resistance in anodic compartment was found to principally determine the MFC power output. This study noted that the MFC performance depends heavily on biofilm, cell geometry (including anode position) and internal hydrodynamic environment.

1. Introduction

Microbial fuel cell (MFC) is a device that can convert electron donors such as organic matters in wastewaters to their oxidized form (such as CO_2) with external electricity generation [1–5]. Although MFC technologies are widely studied, the performances are not generally consistent amongst cells that were started up at identical conditions (discussed later).

The sulfur derivatives in industrial effluents can be reduced to sulfide by sulfate-reducing bacteria (SRB) under anaerobic condition to cause corrosion, which needs intensive treatment before safe disposal to receiving waters. The methods to remove sulfide species in waters are reviewed [6], including chemical oxidation by chlorine, chemical removal by metal salts, increasing redox potential to control by sulfide formation by air injection, and biological oxidation by sulfur-oxidizing bacteria. Novel treatment technologies for cost-effective sulfur removal from industrial effluents are desired [7,8]. Following the pioneering work by Habermann and Pommer [9], sulfide removal in microbial fuel cell (MFC) was studied [10–19]. Zhang et al. [16] proposed the possibility to utilize the sulfate-reducing bacteria (SRB) to convert sulfate to sulfide, then use MFC to convert the formed sulfide to elementary sulfur. Lee et al. [20] experimentally confirmed the concept with SRB to convert sulfate to sulfide, then with MFC anode biofilm to oxidize the formed sulfide to elementary sulfur with electricity generation.

This study started up four SRB-MFCs using abiotic cathodes to examine the reproducibility in cell performance for treating sulfate and citrate-laden wastewaters. We demonstrated herein that the MFC performance is very sensitive to biofilm characteristics hence leading to difficulty for maintaining process reproducibility in applications.

2. Materials and methods

2.1. Inoculation and medium

Activated sludge was collected from a bakery factory in Taoyuan County, Taiwan. The sludge was filtered using coarse screen and incubated anaerobically to enrich sulfate reducing consortium for 1 month in a medium of: Na_2SO_4, 1.15 g/L; sodium citrate, 5.0 g/L; NH_4Cl, 1.0 g/L; K_2HPO_4, 0.5 g/L; sodium lactate, 5.0 g/L; $Fe(NH_4)_2(SO_4)_2$, 1.0 g/L; Wolf's vitamin solution, 1 mL; Wolf's mineral solution, 1 mL. The pH of the medium was adjusted to 7.5 by 1 N HCl or 1 N NaOH. The Wolf's vitamin solution has the following composition (g/L): biotin, 0.2; folic acid, 0.2; pyridoxine HCl, 1.0; riboflavin, 0.5; thiamin, 0.5; nicotinic acid, 0.5; pantothenic acid, 0.5; B-12, 0.01; *p*-aminobenzoic acid, 0.5; thioctic acid, 0.5. The Wolf's mineral solution contained (g/L): NTA, 1.5; $MgSO_4$, 3.0; $MnSO_4$ H_2O, 0.5; NaCl, 1.0; $FeSO_4$ $7H_2O$, 0.1; $CaCl_2$ $2H_2O$, 0.1; $CoCl_2$ $6H_2O$ 0.1; $ZnCl_2$, 0.13; $CuSO_4$ $5H_2O$, 0.01; $AlK(SO_4)_2$ $12H_2O$, 0.01; H_3BO_3, 0.01; Na_2MoO_4, 0.025; $NiCl_2$ $6H_2O$ 0.024; Na_2WO $2H_2O$, 0.025.

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http://dx.doi.org/10.1016/j.jtice.2015.04.028
1876-1070/

2.2. MFCs

Four identical MFCs (SRB A–D) comprised anode and cathode cylindrical chambers, each with inside diameter of 5 cm and length 4 cm, connected with a proton exchange membrane (Ultrex CMI-7000; Membrane International, Inc., Glen Rock, NJ, USA). The anodes were made of carbon felt (C0S3002; CeTech Co., Taichung, Taiwan), and the cathodes were made of carbon cloth (W0S1002; CeTech Co., Taichung, Taiwan) with 1 mg/cm^2 Pt catalyst. The sizes of the carbon cloths and the carbon felts were 1 cm × 1 cm. In each anodic compartment, two identical carbon felt electrodes (1 and 2) were installed at the center to compare the difference in electrode performances under the same electrochemical environment. For comparison sake, for certain tests a 3 cm ×3 cm carbon felt was placed at the edge of the compartment for demonstrating the possible internal transport resistance inside the compartment. Before inoculation, all electrodes were first immersed in 1 M NaOH then in 1 M HCl for 1-h each to remove microbial residues on the electrodes surface.

The enriched sulfate-reducing bacteria consortium was fed into the MFC anodic chamber with synthetic sulfate-laden wastewater of composition as follows: Na_2SO_4, 1.15 g/L; NH_4Cl, 1.0 g/L; K_2HPO_4, 0.5 g/L; sodium lactate, 5.0 g/L; Wolf's vitamin solution, 1 mL; Wolf's mineral solution, 1 mL. The pH of the medium was adjusted to 7.5 by 1 N HCl or 1 N NaOH. 50 mM ferricyanide was used in this experiment and phosphate buffer was added to regulate the pH change in the cathode. The composition of this cathodic solution was as follows: NaH_2PO_4 H_2O, 17.77 g/L; Na_2HPO_4, 32.33 g/L; $K_3Fe(CN)_6$, 16.46 g/L at pH 6.9. Biofilms would grow on anode but would not on cathode. During the test a −0.3 V potential was posed on anode 1 in SRB A (termed as SRB A1), and a +0.3 V was posed on anode 1 of SRB B (termed as SRB B1), to observe the effect of anode potential on MFC performances. In these two MFCs, Ag/AgCl electrode was applied as the reference electrodes.

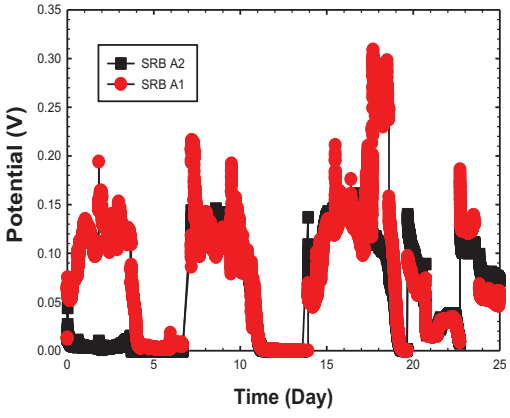

Fig. 1. Potential (over 1000 ohms) *vs.* time for SBR A. Anode 1 with + 0.3 V imposed potential; anode 2 with no external potential.

Table 1
OCV, P_{max} and internal resistance of tested MFCs.

	OCV (*V*)	P_{max} (mW/m^2)	Resistance (ohm)
SRB A1	632	20.7	3650
SRB A2	640	29.1	3060
SRB B1	680	15.0	6220
SRB B2	684	9.9	14,100
SRB C1	627	15.0	6900
SRB C2	642	9.9	14,400
SRB D1	626	2.3	26,700
SRB D2	654	73.8	1340

2.3. MFC tests

The voltage drop over an external load 1000 ohms of individual MFC was recorded at 180 s intervals using a data acquisition system (Advantech Co., Taipei, Taiwan). Linear sweep voltammetry (LSV), cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS) of tested MFC were conducted using an

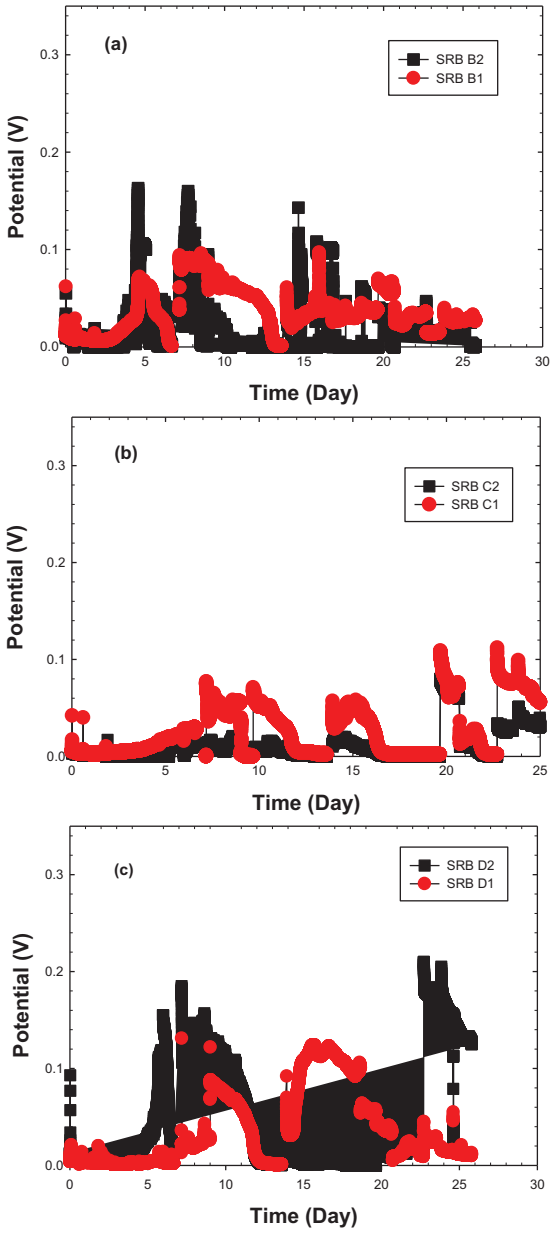

Fig. 2(a–c). Potential *vs.* time data for SRB B (a), SRB C (b), SRB D (c).

Table 2
Fit parameters for spectra of anodes in SRB D2.

Element	Edge anode	Center anode
R1	7.2 ohms	16.5 ohms
CPE1-T	1.27×10^{-4} F	5.08×10^{-5} F
CPE1-P	0.78	0.80 F
R2	453 ohms	433.7 ohms
CPE2-T	4.81×10^{-3} F	8.46×10^{-4} F
CPE2-P	0.979	0.95
R3	77,300 ohms	34,700 ohms