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Prediction of sustainable electricity generation in microbial fuel cell by neural network: Effect of anode angle with respect to flow direction

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ABSTRACT

This study aimed to investigate for the first time the effect of anode inclination on electricity generation integrated with biodegradation of organic substrate in a mediator-less microbial fuel cell continuously fueled with actual dairy wastewater. The influence of anode inclination was investigated at angles 0, 45 and 90° with respect to the flow direction on the MFC performance with respect to power generation and COD removal, alternatively at 1 and 2 mL/min wastewater flow rate. Results revealed that maximum power generation of 486 and 369 mW/m^2 and COD removal efficiencies of 92 and 89% were observed when the anode was positioned perpendicularly with the flow direction at steady state conditions using wastewater flow rates of 1 and 2 mL/min, respectively at external resistance of 40 Ω. Lower COD removal and power generation were observed for MFCs designed with anodes positioned at 0° and 45° with respect to the feed flow direction. A three-layer artificial neural network (ANN) model was investigated in this study to predict the efficiency of the MFC in regard to power generation. Results of prediction indicated a good fitting between actual and predicted data with a high correlation coefficient (R^2) of 0.99889 with negligible mean square error.

1. Introduction

Microbial fuel cell (MFCs) technology represents a promising approach for generating electricity from biomass using bacteria. A typical MFC consists of the anode and cathode chambers, physically separated by a proton exchange membrane (PEM). Microorganisms in the anode oxidize the organic substrates and produce electrons and protons [1, 2]. Extensive studies and research works considering the design of MFCs with different electrode arrangements and contact areas in addition to the electrode material modification have been developed to improve the MFC performance. Park & Zeikus [3] and Park & Zeikus [4] designed both NR-woven graphite and Mn (IV) graphite electrodes that served as mediators in MFC bioreactors. Scott & Murano [5] demonstrated the importance of electrode position in a cell for enhanced power output. Niessen et al. [6] and Niessen et al. [7] reported that using modified electrode with fluorinated polyanilines poly (2-fluoroaniline) and poly (2, 3, 5, 6-tetrafluoroaniline) could improve the electricity of an MFC. Ahn & Logan [8] designed a single chamber MFC with multiple graphite fiber brush anodes and a single air-cathode cathode chamber with a separator electrode assembly (SEA) to minimize electrode spacing. Wang et al. [9] utilized a new material of electrode; carbon nanotube/polyaniline carbon paper utilized and compared it with other traditional carbon paper/cloth. Ahn and Logan [10] studied altering the anode thickness to improve the power production in the MFC with different electrode distances. However, none of the previously reported studies dealt with investigating the effect of anode inclination on the performance of MFC. On the other hand, for scientists working on MFC, the computational models help by pointing to the most important MFC parameter that should be experimentally measured and reported. Many kinds of neural networks are available such as multi-layer perceptron (MLP), radial basis function (RBF) networks and recurrent neural network (RNN) ,but all of them consist of the same basic features; nodes, layers and connections [11]. Artificial neural networks are computational tools which have the ability to describe the behavior of a process and the relationship between groups of variables without any phenomenological model of the system. They are a powerful tool for discovering relationships between sets of data. This artificial intelligence method has attracted considerable attention because it can handle complex, nonlinear problems and requires less processing time than conventional methods [12]. However, very limited studies have been reported on using ANN to describe the performance of MFCs. Feng et al. [13] demonstrated that microbial fuel cell (MFC)-based biosensing can be integrated with artificial neural networks (ANNs) to identify specific chemicals present in water samples. The ANN predicted the concentration of COD without error with just one layer of hidden neurons. King et al. [14] studied the integration of artificial neural network (ANN) processing with microbial fuel cell (MFC)-based biosensing in the detection of three organic pollutants: aldicarb, dimethyl-methylphosphonate (DMMP), and bisphenol-A (BPA).

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Overall, the use of the ANN proved to be more reliable than direct correlations for the determination of both chemical concentration and type. Garg et al. [15] modeled the performance microbial fuel cell (MFC) using three potential artificial intelligence (AI) methods such as multi-gene genetic programming (MGGP), artificial neural network and support vector regression. Esfandyari et al. [16] used artificial neural network (ANN) and adaptive neuro-fuzzy inference system (ANFIS) modeling to investigate the effect of power density and Columbic efficiency (CE) in a microbial fuel cell. Four influential factors, including ionic strength, initial pH, medium nitrogen concentration, and temperature were selected as operating variables. Five levels are used for every factor. The results revealed that for predicting power density and CE values both ANN and ANFIS models have acceptable performance (R^2 > 0.99), but ANN model has simpler structure and tuning procedure. Anyhow, none of the previously reported studies have concerned about the effect of anodic electrode inclination on the performance of MFC fueled with actual industrial wastewater. Also, knowing that artificial neural network (ANN), genetic programming (GP), and other computational intelligence methods are useful tools for predicting the relationship between generated output properties and the input parameters [17] makes it a good available option for predicting the performance of MFC.

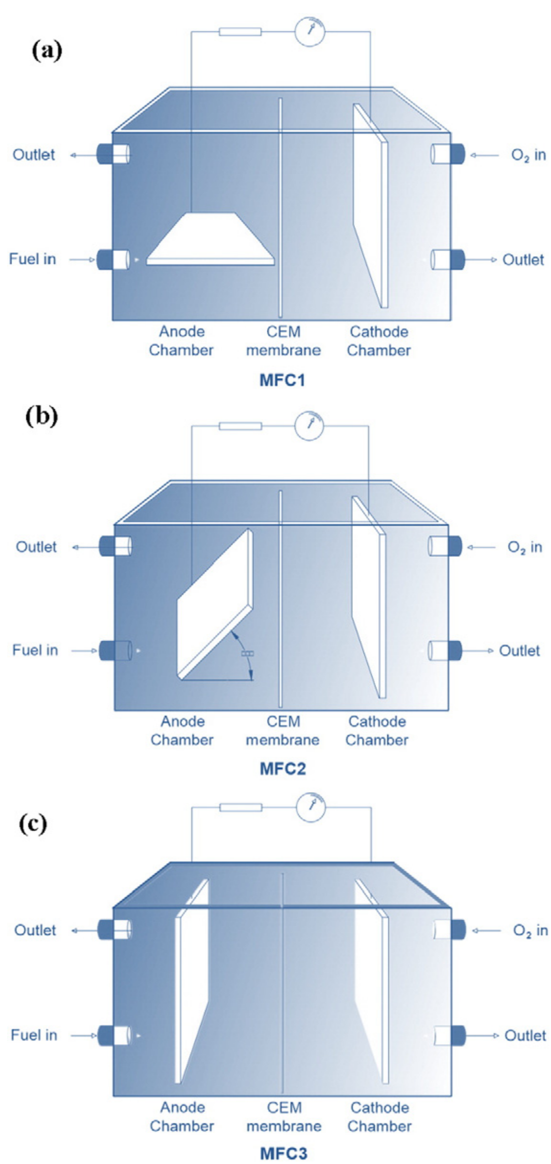

Fig. 1. Schematic diagram of MFC with different angles of inclination between the anodic electrode plain and flow direction, (a) MFC1 (θ = 0°), (b) MFC2 (θ = 45°), (c) MFC3 (θ = 90°).

This study aimed to: (1) evaluate for the first time the effect of angle inclination of the anodic electrode on the efficiency of dual-chamber MFCs for treatment of actual dairy wastewater simultaneously with power generation, (2) investigate the performance of the suggested MFCs with respect to COD removal and power generation at two different feed flow rates, and (3) use the artificial neural network (ANN) to describe the behavior of the MFCs with respect to power generation.

2. Materials and methods

2.1. Wastewater and inoculum

Actual dairy wastewater obtained from a local dairy manufacturing factory located in Al Kut city (Iraq) was used in this study to fuel the MFC. The composition of the primarily clarified actual dairy wastewater performed in this study with their constituent average concentrations expressed in (mg/L) was as follows: BOD (875), COD (1650), TSS (241), total phosphorus (17.8), NO_3^- (9), Cl^- (34), conductivity (1550), and pH (7.2).The anodic chamber of the MFC was inoculated with anaerobic sludge collected from the bottom of a local septic tank. The sludge was sieved through 1 mm sieve opening before use.

2.2. Microbial fuel cell system

Three identically designed microbial fuel cells were used in the present investigation. Each MFC consisted of a dual rectangular chamber made of transparent Plexiglas parallelepiped having dimensions of 15 cm × 15 cm × 8 cm. One side of each chamber (15 cm × 8 cm) was perforated with 20 pores of size 5 mm. A cation exchange membrane (CEM) type CMI-7000 supplied by membrane international INC., NJ was placed between two perforated glass sheets. The net surface area of the membrane was 393 mm^2. The type of anode and cathode electrodes was plain graphite; each of dimensions 4 cm × 4 cm × 0.5 cm. Before use, the graphite electrodes were abraded with sand paper to enhance bacterial growth. Also, the CEM was treated with sodium chloride solution for 6 h, and then rinsed with deionized water to ensure good conductivity for protons. The three identically designed MFCs were labeled as MFC1, MFC2, and MFC3 with the anode electrodes positioned

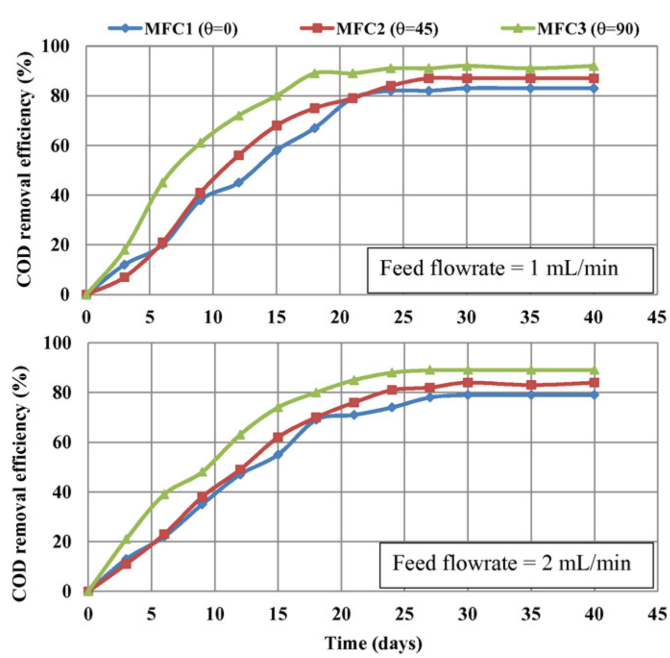

Fig. 2. Profiles of COD removal efficiencies.