Borneo Journal of Resource Science and Technology (2024), 14(1): 69-79
DOI: https:doi.org/10.33736/bjrst.6163.2024

Simulation of Hybrid Microbial Fuel Cell-Adsorption System Performance: Effect of Anode Size on Bio-Energy Generation and COD Consumption Rate

NUR FARUNITA MOHAMAD[1], IVY AI WEI TAN*[1], MOHAMMAD OMAR ABDULLAH[1], NORAZIAH ABDUL WAHAB[1] & DEVAGI KANAKARAJU[2]

[1]Department of Chemical Engineering and Energy Sustainability, Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia; [2]Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300, Kota Samarahan, Sarawak, Malaysia
*Corresponding author: awitan@unimas.my
Received: 11 October 2023 Accepted: 23 March 2024 Published: 30 June 2024

ABSTRACT

Landfill leachate discharged into watercourse without proper treatment can pollute the water source due to its high chemical oxygen demand (COD). The high pollutant load in landfill leachate has become one of the potential substrates in bio-energy generation by using microbial fuel cell (MFC). MFC integrated with adsorption system has been introduced as an approach to overcome the limitation of stand-alone MFC, which is able to treat the landfill leachate more effectively while simultaneously generating bio-energy. Anode size has been reported to have a significant influence on the power generation of MFC via lab-scale experiments, however the simulation studies on MFC are still limited. This study aimed to develop a simulation model to predict the effect of graphite fiber brush anode size on the performance of a single chamber air-cathode hybrid MFC-Adsorption system, in terms of COD removal and bio-energy generation. The highest power density of 1.33 mW/m^2 was achieved with 20% anode brush removed. The highest current generation of 2.37 mA and voltage of 7.11 mV was obtained with the largest anode surface area of 0.1288 m^2 and resistance of 2.76 Ω. The highest COD consumption by electrogenic microorganisms was 4.96 x 10^{-9} Lmol/mg, and predicted to decrease with decreasing anode size. The efficiency of the simulation model could be further improved by incorporating parameters such as charge transfer kinetic at anode and cathode, adsorption effect by activated carbon as well as the substrate and microbial population behaviour. The simulation model developed was significant towards enhancing the bio-energy generation and reducing the cost of MFC for industrial application.

Keywords: Bio-energy; chemical oxygen demand; landfill leachate; microbial fuel cell; simulation model

INTRODUCTION

Landfill leachate consists of various components characterised as high chemical oxygen demand (COD), biochemical oxygen demand (BOD), BOD/COD ratio, suspended solids, pH, turbidity, ammonium-nitrogen (NH_3-N) and heavy metals. Energy production from landfill leachate has become a recent interest due to the potential of this highly polluting wastewater as the source of bio-electricity generation (Tan *et al*., 2023). MFC has demonstrated advantages as compared to other wastewater treatment processes as MFC can convert substrate energy to electricity directly, and operate at ambient or low temperatures, thus producing less amount of excessive sludge (Sorgato *et al*., 2023). The MFC design for practical application as it single chamber air-cathode is the most suitable produces higher power generation, low cost and simple design (Samudro *et al*., 2022; Li *et al*., 2023). In terms of voltage generation and treatment efficiency, hybrid system is generally more reliable and efficient than a stand-alone MFC (Tee *et al*., 2016). Yazdi *et al*. (2016) obtained a higher power density of 2400 mW/m^2 by using 2.5 cm^2 graphite fiber brush (GFB) as an anode electrode material. However, the optimization of bio-energy through the MFC design still needs to be further researched for industrial application. Numerical studies on MFC can be extensively used to offer deeper insights into MFC performance (Gadkari *et al*., 2019a).

The performance of MFC depends on the improvement through modifying system architecture, materials and better understanding of the solution chemistry (Liang *et al*., 2022). The metabolic pathway of the microorganism and the potential of anode are the key parameters for cell potential determination. The anode used in MFC should be able to reduce the internal resistance and increase power density when placed together with the cathode. According to Sakai *et al.* (2018), the surface area of anode has an important role in energy production. Rossi *et al*. (2019) reported an 18% reduction in the power density with a larger anode due to increasing in the internal resistance. A shorter anode-brush diameter was found to maintain a closer spacing of electrodes which reduced the internal resistance and improved MFC performance (Lanas *et al*., 2014). In a single chamber MFC, a carbon brush with 27 cm^2 produced 48 mW/m^3 whereas an anode with 9 cm^2 produced 41 mW/m^3 (Houghton *et al*., 2016). As the number of experimental studies on MFC has been increasing, it is not the same for mathematical modelling and simulation studies. Mathematical models are able to help in understanding the influence of different operational, design and biological parameters affecting the MFC performance, and to optimize the new reactor configurations as well as aiding in up-scaling the technology (Ortiz-Martínez *et al*., 2015). Improvement in simulation design is crucial as the innovation of MFC for industrial application is restricted by the electrode material cost, requirement of precious metal, low power density and low performance of the system. These issues can be overcome at the lab scale, however the vital part is the performance on a large scale particularly when managing wastewater that does not have steady conditions with time (Logan, 2010). A few mathematical models have been developed to study the influence of anode on MFC performance, such as the model on bioanode (Gadkari *et al*., 2019b) and two-dimensional model of air-cathode MFC with GFB as anode (Gadkari *et al*., 2019a). Gadkari *et al*. (2019a) used Nelder-Mead Simplex algorithm for prediction of power generation to estimate the parameters in the model, which reported little change in power density around 15% to 60% of brush removed in which the power density was reduced by 21%.

Table 1 shows the development of MFC numerical studies. Limited numerical studies have focused on air-cathode MFC. Additionally, optimisation using simulation on hybrid MFC-Adsorption system has not been reported up to date, and the study on the effect of anode size in hybrid MFC-Adsorption system has not been found. Simulation study is significant towards the development of MFC for industrial application as the system is currently in its infancy stage due to the challenges on reducing the high cost and improving the power generation. Anode generally should have the characteristics of larger surface area, best chemical and microbial stability, high electrical conductivity, biocompatibility and inexpensive in cost (Liang *et al*., 2022). The power output of the system is determined by the wellness of biofilm attached to the anodic surface area. Thus, the best method to enhance the performance of the MFC is by increasing the affinity of the biofilm through anode modification (Banerjee *et al*., 2022). Therefore, the main focus of the present study was to develop a simulation model using Microsoft Excel 365 Proplus by correlating the anode size of a single chamber hybrid MFC-Adsorption system with the bio-energy generation of the system and COD consumption rate, by using landfill leachate as the MFC substrate. In addition, the current and voltage generated in the hybrid MFC-Adsorption system with different anode size were predicted through simulation of the maximum power densities.

MATERIALS AND METHODS

Simulation Design

The simulation used in this work was adopted from Gadkari *et al*. (2019a) which was the two-dimensional simulation focusing on single chamber air-cathode MFC. Microsoft Excel 365 Professional Plus was used to develop the simulation in predicting the bio-energy generation and COD consumption rate. GFB anode was represented in the simulation and was connected using twisted titanium wire and placed at the central of the closely packed-bed of granular activated carbon (GAC). The air-cathode existed as activated carbon fiber felt (ACFF) and was connected to the circuit by a copper rod. The electrode was exposed to air on its outer surface while being in contact with the earthen pot and hydrogel was applied evenly between them, following the configuration of the hybrid MFC-Adsorption system of Tee *et al*.