Journal of Energy Storage 7 (2016) 136–146

Contents lists available at ScienceDirect

Journal of Energy Storage

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

Equivalent circuit modeling of microbial fuel cells using impedance spectroscopy

M. Sindhuja[a], N. Saravana Kumar[b], V. Sudha[c], S. Harinipriya[d,*]

[a] Junior Research Fellow, Electrochemical Systems Lab, SRM Research Institute, SRM University, Kattankulathur, Chennai 603203, India
[b] B.Tech Physics and Nanotechnology, SRM university, Kattankulathur, Chennai 603203, India
[c] Assistant Professor, Department of Chemistry, SRM University, Kattankulathur, Chennai 603203, India
[d] ECS member, Research Assistant Professor, Electrochemical Systems Lab, SRM Research Institute, SRM University, Kattankulathur, Chennai 603203, India

ARTICLE INFO

Article history:
Received 7 April 2016
Received in revised form 13 June 2016
Accepted 14 June 2016
Available online xxx

Keywords:
Microbial fuel cells
Activation polarization
Internal resistance
Biofilm formation
Electrochemical impedance spectroscopy

ABSTRACT

The effect of internal resistance on the electrochemical processes of microbial fuel cell is demonstrated by Electrochemical Impedance Spectroscopy. The decrease in solution resistance and increase in charge transfer resistance influenced the performance of microbial fuel cell over time. To understand the effect of the parameters on the electrochemical processes a lumped equivalent circuit model for activated charcoal based microbial fuel cell and the Equivalent circuit fitting model of Nyquist plot for graphite based microbial fuel cell is adopted. The Equivalent circuit models predicted negligible activation polarization for activated charcoal electrode assembly and significant activation polarization for graphite electrode assembly. The rationale behind this observation could be due to the higher affinity for biofilm formation on activated charcoal in comparison to graphite. The efficiency of the microbial fuel cell went down with time as the electrochemical kinetics predominates over biochemical kinetics. The Maximum power density and current density measured are (i) 8 mW/m^2 and 103 mA/m^2 respectively for activated charcoal based microbial fuel cell, (ii) 1015 mW/m^2 and 11803.5 mA/m^2 respectively for graphite electrodes based microbial fuel cells. The power density is 7.6 times higher than the literature data of 133 mW/m^2 for graphite based microbial fuel cells.

1. Introduction

Microbial fuel cells (MFCs) are alternative means of energy production from organic matter [1–3]. However, the high inherent voltage loss and low power density ouput hinder the real time application of this technology. Many researchers have focused on minimizing voltage loss to increase electrical power density and enhance the utility of MFCs [4,5]. In MFCs, electrochemical reactions include electron transfer at the electrode surface and mainly involve (i) electrolyte resistance, (ii) adsorption of electro-active species, (iii) charge transfer at the electrode surface and (iv) mass transfer from the bulk solution to the electrode surface. Each process can be considered as an electric component or a simple electric circuit. The reaction process as a whole can be represented via an electric circuit composed of resistance, capacitance, or constant phase elements combined in parallel or in series [6,7]. Thus Electrochemical Impedance Spectroscopy (EIS) is a powerful nondestructive technique that can be used to study MFCs. EIS studies of MFCs can further be explored in the analysis of the internal resistance of MFCs, electrode materials, catalyst coatings on electrodes, biofilm development and electrochemical reactions on the anode and the cathode [8]. The key issue in the studies of MFCs is to analyze, understand and overcome the biological and/or the abiotic factors that limit power output. These limiting factors can be represented by the internal resistance (R_{in}) of MFCs or reflected by the impedance of its individual electrodes. R_{in} consists of three components: I. Activation (charge transfer) resistance, II. Ohmic resistance (R_s, also called solution resistance, representing the resistance from solution, electrode materials and membrane) and III. Concentration (diffusion) resistance which can be measured by EIS [8–10]. As Microbial reactions result in changes of the charge transfer resistance, which is affected by kinetically controlled electrochemical reactions, the charge transfer resistance measured from EIS can be used as a parameter for the evaluation of microbial activities in MFCs [11–14]. The concept of internal resistance is recognized as a vital parameter for voltage loss in MFCs [15,16]. Several techniques including EIS have been applied to determine the components of internal resistance [17,18].

* Corresponding author.
E-mail address: harinipriya.s@res.srmuniv.ac.in (S. Harinipriya).

http://dx.doi.org/10.1016/j.est.2016.06.005
2352-152X/

EIS is a standard tool employed for in situ characterization of fuel cells and to identify internal resistance components such as: Ohmic resistance, charge transfer resistance and diffusion resistance [19]. Recently, EIS is applied to determine individual resistances [20–22], the electrochemical behavior of redox mediators [23] as well as anode performance characterization in MFCs [24,25]. The notable property of EIS is that, it does not interrupt the establishment or activity of the microbial community during the experiments [26]. The results of EIS are analyzed in combination with equivalent electrical circuit (EEC) fitting models which consist of common electric elements such as resistors (R), capacitors (C), constant phase elements (CPE or Q) and inductors (W). Till date, several EECs have been developed to suit a variety of MFCs [27–31]. A simulation of EEC R(QR)(QR) is reported to determine the internal resistance in upflow MFCs [19,26,32,33]. You et al. [34] reported a simulation of EEC R(QR)(CR) to determine the internal resistance of MFCs. The components of internal resistance of MFCs have been the focus of the aforementioned studies in recent years [32–35]. Equivalent circuit modelling and its experimental validation via EIS is well known in the literature for energy storage devices such as Lithium ion batteries [36,37] and MFCs [38,39]. Thus in the present work, EIS of dual chambered MFCs (Fig. 1) is carried out to understand (i) the effect of internal resistance on the performance of MFCs, (ii) the lifetime of membrane employed via charge transfer resistance and (iii) comparison between the performance of activated charcoal and graphite as electrode material via lumped equivalent circuit model and fitting equivalent circuit model employing EIS respectively.

2. Materials and methods

2.1. Electrodes

Two types of electrodes (i) activated charcoal from used water cartridges; the rationale behind this choice is that, owing to the affinity towards microbes, activated charcoal cartridges behave as the optimized material for microbe filtration in commercial water filters, (ii) commercially available graphite rods for comparison of the efficiency with activated charcoal. In the present case anodic chamber is completely sealed to maintain anaerobic condition. The electrons generated in anodic chamber will be transferred to cathodic chamber by the external circuit. The proton transfer occurs through the salt bridge to the cathode to complete the circuit (ref. Fig. 1). The value of voltage is recorded in 60 min interval. EIS experiments were conducted with the help of Biologic Electrochemical Workstation in the frequency range of 200 kHz

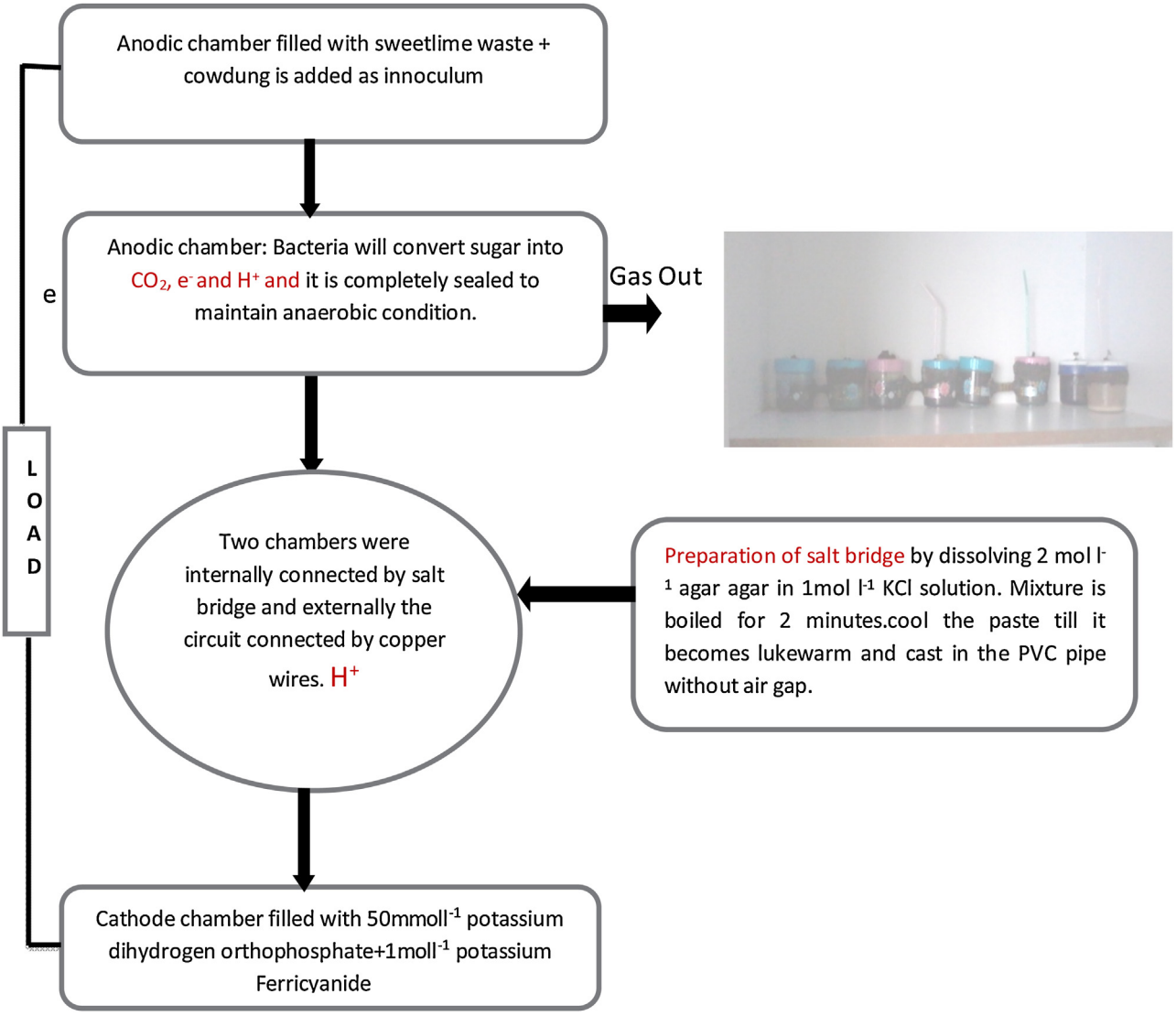

Fig. 1. Flow chart for the fabrication of MFCs and picture of MFCs fabricated.