Effect of cathode end plate on passive direct methanol fuel cell performance

K Deepak
Professor, Mechanical Engineering Department, Vardhaman College of Engineering, Hyderabad-INDIA
E-mail: deepak045@gmail.com

Abstract. Direct methanol fuel cell (DMFC) belongs to the class of fuel cells that use polymer electrolyte membrane and operate on methanol-water mixture. The low overall performance of passive DMFC compared to active DMFC is due to the slow anode reaction combined with inefficient cathode reaction. In this work, an attempt was made to augment the passive DMFC performance by modifying the structural design of the cathode end plate (CEP). The passive DMFC was fabricated and the performance was investigated experimentally. Three different CEP duct configurations were studied using 1 to 5 M methanol mass fraction. The results indicated higher performance for square duct CEP configuration, with 5 M methanol mixture.

1. Introduction
DMFC is an energy conversion device that directly converts the stored chemical energy of methanol into electrical energy. Owing to ease in storage and delivery, high energy density, and longer life, DMFC is considered as a viable alternative to batteries in portable device applications [1]. DMFCs are of two types, active and passive [2]. The active type DMFC functions with the provision of an auxiliary pump and a blower to supply methanol on the anode side and air on the cathode side. In passive systems, methanol is supplied without an external device and depends on utilizing atmospheric air. The active DMFC has high reliability, yields high performance and easy to regulate the operating parameters such as temperature, methanol mass fraction and flow rate. In passive type DMFC, fuel supply depends on the fuel diffusion in the built-in tank while the atmospheric air is utilized for oxidant. The passive system is more compact and offers a unique feature for fuel cell size reduction.

Structural parameters influence the performance of DMFCs significantly. The use of high open ratio current collector (CC) exhibits high performance due to enhanced methanol flow rate from the fuel chamber to the gas diffusion film [3]. Methanol concentration is one of the vital parameter that has substantial effect on the fuel cell performance. Structural adaptions influence the degree of methanol concentration and the open circuit voltage (OCV) characteristics [4]. Methanol mass fraction, cell positioning and temperature influence the OCV values. Horizontal cell positioning is ideal for higher methanol mass fraction and vertical positioning is chosen for lower mass fraction to limit methanol crossover and carbon dioxide gas blockage [5]. Structural parameters such as current collector open ratio, gasket, and assembly shape influence the contact resistance effect between the current collector and gas diffusion film [6]. Light weight CCs were developed and feasibility for using in a 3-cell DMFC module was demonstrated, that has full possibilities for a variety of applications. Multiple cells can be incorporated to produce high voltage [7]. The Faraday efficiency of DMFC can be increased substantially by modifying the system layout and operating strategy [8]. The passive DMFCs are associated with the challenges such as methanol crossover, species management, heat and water management, slow kinetics, stability and durability. Various methanol transport barriers are used to control the methanol crosswise flow from anode side to cathode.
Working temperature boosts the electrochemical action and hence the fuel cell performance. It is important to enhance the air and water flow on the cathode side for reducing water flooding [9]. The cathode CC design is very crucial for efficient functioning of the fuel cell. A good cathode CC facilitates efficient oxygen flow for reaction; evacuate water bubbles besides electron collection [10].

2. Methodology

2.1. Cell Fixture and Membrane Electrode Assembly (MEA)

The experiment was conducted on passive DMFC. A single cell arrangement was designed that has 45 cm$^2$ effective cross-sectional area. Fig. 1 shows detailed view and assembled image of the passive DMFC module. The cell was molded in a polymethyl methacrylate (also known as acrylic glass) frame, and was positioned between a set of CC and diffusion layer. In this system, grooves were provided on the end plates for methanol mixture and oxygen flow. The provisions to tap current and voltage measurement were provided. A Nafion 117 electrolyte membrane that has good proton conductivity, no electron conductivity and good mechanical strength was used in MEA preparation. The polymer electrolyte film separates the anode and the cathode. Fig. 2 shows the proposed CEPs with three different configurations.

![Fig. 1 Passive DMFC Module](image1.png)

![Fig. 2 CEP with (a) Square duct; (b) Hexagonal duct; (c) Circular duct](image2.png)
2.2. Operation and Parameters
Methanol mixture was filled into the fuel chamber of the cell adjacent to anode; the area adjacent to cathode was kept exposed to the atmospheric air. The complete reactions were taken place leading to the formation of water and carbon dioxide as reaction by-products. Methanol mixture with 1 to 5 molarities was used in the experiment and the performance parameters were calculated for three different CEP configurations. Following reactions occur in the DMFC.

\[
\text{Anode: } \text{CH}_3\text{OH} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + 6\text{H}^+ + 6\text{e}^- \quad E_0=0.02\text{V} \\
\text{Cathode: } 3/2\text{O}_2 + 6\text{H}^+ + 6\text{e}^- \rightarrow 3\text{H}_2\text{O} \quad E_0=1.23\text{V} \\
\text{Complete: } \text{CH}_3\text{OH} + 3/2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \quad E_0=1.21\text{V}
\]

2.3. Measurement Procedure
A DC power load bank was used for loading and the voltage-current data was noted. For stable voltage values, 1 minute time interval was considered for two consecutive readings. Methanol mixture was filled using a pipette on the anode side. The atmospheric oxygen was made to flow naturally to reaction sites on the cathode side. Before beginning the experiment, a fresh MEA was activated using 1 M methanol mixture for 16 hours. The experiments were conducted at atmospheric conditions. Three observations were noted for each CEP configuration using 1 to 5 M methanol solution. The average values were plotted.

3. Results and Discussion
To determine the power density of DMFC for different CEP configurations, voltage is measured corresponding to different current density values with 10 mA/cm\(^2\) increment. The experiments were conducted using 1 to 5 M methanol mixture separately and the results of 5 M methanol mixture were plotted. The voltage decreases with current density. As depicted in Fig. 3, voltage is highest for the square configuration followed by the hexagonal configuration. The power density variation with current density, illustrated in Fig. 4 shows highest power density for the square configuration and least for the circular configuration.

![Fig. 3 Variation of voltage with current density using 5 M methanol solution](image-url)
4. Conclusion

This experimental work deals with the performance of a passive DMFC, with different CEP configurations. From the experimental results, it is depicted that, the CEP with square duct gives high performance. For this duct configuration, the methanol concentration for high performance is determined experimentally. The following conclusions were drawn based on the experimental results.

- The use of CEP improves the cell performance.
- The CEP with square duct gives high cell performance in comparison with hexagonal and circular ducts.
- Methanol mass fraction influences the cell performance significantly. For DMFC with square duct CEP, 5 M methanol mixture yields high performance.

References

[1] Zhao T S, Chen R, Yang W W and Xu C, 2009, Small direct methanol fuel cells with passive supply of reactants (Journal of Power Source, Vol.191, issue 2) p.185
[2] Kamarudin, S K, Achmad F, and Daud W R W, 2009, Overview on the application of direct methanol fuel cell (DMFC) for portable electronic devices (International Journal Hydrogen Energy, Vol. 34, issue 16) p.6902
[3] Lai Q, Yin G P, Wang Z, 2009, Effect of Anode Current Collector on the Performance of Passive Direct Methanol Fuel Cells (International Journal of Energy Research, vol. 33) p.719
[4] Yuan W, Tang Y, Wana Z, Pan M, 2011, Operational Characteristics of a Passive Air-Breathing Direct Methanol Fuel Cell under various Structural Conditions (International Journal of Hydrogen Energy, vol. 36) p.2327
[5] Yousefi S, Shakeri M and Sedighi K, 2014, The Effect of Operating Parameters on the Performance of a Passive DMFC Single Cell (World Applied Sciences Journal, vol. 22, issue 4) p.516
[6] Borello D, Calabriso A, Cedola L, Zotto L D, 2014, Simone Giovanni Santori, Development of Improved Passive Configurations of DMFC with Reduced Contact Resistance (Energy Procedia, vol. 61) p.2654
[7] Kuan Y D, Lee S M and Sung M F, 2014, Development of a Direct Methanol Fuel Cell with Lightweight Disc Type Current Collectors (Energies vol. 7) p.3136
[8] Na Y, Zenith F and Krewer U, 2015, Increasing Fuel Efficiency of Direct Methanol Fuel Cell Systems with Feed forward Control of the Operating Concentration (Energies vol. 8) p.10409
[9] Munjewar S S, Thombre S B, Mallick R K, Approaches to Overcome the Barrier Issues of Passive Direct Methanol Fuel Cell – Review (Renewable and Sustainable Energy Reviews vol. 67) p.1087
[10] Boni M, Rao S S, Srinivasulu G N, 2020, Performance Evaluation of an Air Breathing–Direct Methanol Fuel Cell with Different Cathode Current Collectors with Liquid Electrolyte Layer (Asia-Pacific Journal of Chemical Engineering, vol. 15, issue 4) e.2465.