

## Experimental analysis of a two-cell passive direct methanol fuel cell stack

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**Abstract**—Passive direct methanol fuel cells (DMFC) are applicable for charging portable electronic devices. In passive DMFC, fuel and oxidants are supplied through diffusion and natural convection process. The present experimental work analyzed the effect of the membrane electrode assembly (MEA) activation, methanol concentration, bolt tightening torque and stability of the fuel cell stack. Newly fabricated MEA were activated for different time durations of 0, 6, 12 and 18 hrs at 1 M of methanol concentration with a constant load. The concentration of methanol varied from 1 M to 6 M and also bolt torque varied from 4 N-m to 8 N-m. Further, open circuit voltage (OCV) and voltage stability with respect to time were analyzed. From the results, it is observed that the fuel cell performance was enhanced from 1 M to 5 M and then decreased. From 0-12 hrs, the cell performance increased with respect to time and then continued the same performance at the 18<sup>th</sup> hr. From the results, it is also observed that increased bolt torque from 4 N-m to 7 N-m enhanced the fuel cell performance and then decreased. The fuel cell performance was analyzed in terms of maximum power density and maximum current density.

Keywords: Passive DMFC stack, Fuel Cell Performance, Methanol Concentration, Bolt Torque, Open-circuit Voltage

### INTRODUCTION

DMFC, which is mostly useful for charging of small electronic devices [1], has the higher energy density, is lightweight and has low fuel cost. Passive DMFC can be considered as more attractive power source for charging of small power applications than active DMFC, as the parasitic losses are eliminated in passive DMFC [2]. Single fuel cell produces much less voltage and it may be enhanced by connecting the number of fuel cells in series. The present work analyzed the two cell stack operated at different methanol concentrations and durability issues.

Wang et al. [3] experimentally evaluated the impact of concentration of methanol on the passive DMFC performance. It was identified that the fuel cell generated a higher MPD of  $27 \text{ mW}\cdot\text{cm}^{-2}$  at 5 M concentration of methanol. Feng et al. [4] conducted experiments on the ten cell passive DMFC stack for analyzing stability and methanol concentration. It was observed that after 300 hours operation at 60 mA current, the faradic and energy efficiencies were decreased about 8%. Jing et al. [5] experimentally investigated the performance and stability issues of the passive DMFC. It was identified that the fuel cell performance was decreased during long term operation due to the increased internal resistance and catalyst degradation.

Guo and Faghri [6] designed a 1 W prototype passive DMFC stack with inserted air filter used as a methanol storage medium. It was observed that an air filter successfully implemented the methanol storage medium and the stack produced 1.5 W power at diluted methanol solution. Martin et al. [7] developed different configurations of series and parallel connections of the passive DMFC stack.

They concluded that the series connection fitted cell produced maximum MPD compared to parallel connection. Baglio et al. [8] analyzed the impact of Pt loading and methanol concentration of passive DMFC stack performance. They concluded that  $4 \text{ mg}\cdot\text{cm}^{-2}$  Pt loading gave maximum cell performance than  $1.54 \text{ mg}\cdot\text{cm}^{-2}$  Pt loading and maximum power was produced by a cell at 5 M methanol concentration, which was 225 mW. Yuan et al. [9] examined the impact of different Nafion membranes (Nafion 115, Nafion 117 and 212) with current collector OR of 38.5% and 49% on the performance of a passive DMFC. They concluded that among all, the Nafion 117 with current collector OR of 49% combination produced the MPD of  $8 \text{ mW}\cdot\text{cm}^{-2}$ .

Kuan et al. [10] developed a different free open ratio of current collector with  $5\times 5$ ,  $7\times 7$ ,  $10\times 10$  and open ratio of 30%, 40%, 50%, 60%. It was observed that higher free openings of  $10\times 10$  produced the higher MPD. Boni et al. [11] observed that the combination of perforated CC (PCC) and wire mesh CC fitted passive DMFC gave maximum cell performance over the only PCC fitted fuel cell. Yuan et al. [12] conducted experiments on the passive DMFC fitted with circular-hole-array (CHA) current collectors, with OR of 50.24% & 28.26% and parallel-fence (PF) current collectors with an open ratio 75.04% & 63.49%. It was identified that CHA with an OR of 50.24% on the cathode side and PF with an OR of 63.49% on anode side generated the higher MPD. Boni et al. [13] observed that CC with an OR of 55.40% at 3 M methanol gave maximum fuel cell performance.

Lai et al. [14], from their experimental studies on a passive DMFC, concluded that parallel CC effectively removed  $\text{CO}_2$  bubbles compared to circular CC. Mallick et al. [15] concluded that the fuel cell performance improved with increase in bolt torque from 5 N-m to 8 N-m and then decreased. The cell with uniform bolt torque reduced the ohmic losses and simultaneously enhanced the passive DMFC performance. Shrivastava et al. [16] experimentally analyzed

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the impact of bolt torque on the single passive ethanol fuel cell performance. It was concluded that the cell performance increased with increase of bolt torque from 4 N-m to 8 N-m and then decreased. Boni et al. [17] evaluated the impact of liquid electrolyte (LE) layer thickness and concentration of methanol on the performance of a passive DMFC. They concluded that 2 mm thickness LE gave maximum cell performance and also observed that the fuel cell performance increased from 1 M to 5 M and then decreased.

From the literature survey, much work has been carried out on a greater number of fuel cells with a small active area. The present study deals with the two cell passive DMFC stack with a total active area of 50 cm<sup>2</sup> and analyzes the effect of methanol concentration and durability of the passive DMFC.

## EXPERIMENTATION

### 1. Fuel Cell Stack Assembly

The fuel cell stack is composed of two Nafion 117 membranes

with an active area of 25 cm<sup>2</sup> each. The Pt-Ru/black+ Pt-Ru/C of two-layer catalyst and Pt/C catalyst with a loading of 4 mg-cm<sup>-2</sup> and 2 mg-cm<sup>-2</sup> are used on the anode and cathode side, respectively. The common methanol reservoir with a capacity of 60 ml is placed in the middle of the fuel cell. This has a provision for holding anode current collectors and is made of PMMA material. The anode CC with an OR of 45.40% is placed between the methanol reservoir and two MEAs. Cathode current collectors are fixed between cathode end plate and two MEAs. The complete assembly is fixed by bolts and nuts with an applied torque of 5 N-m. The assembly of the two cell fuel cell stack is shown in Fig. 1.

#### 1.a Catalyst Physico-chemical Properties

The catalyst is made of Pt-Ru/black+ Pt-Ru/C of two-layer catalyst and Pt/C catalyst are used on the anode and cathode sides, respectively. The properties of the catalyst are given below.

Porosity-0.3

Permeability-  $1.0 \times 10^{-14}$  m<sup>2</sup>

Thickness-0.2 mm

Electrolyte volume fraction-0.4 m<sup>2</sup>

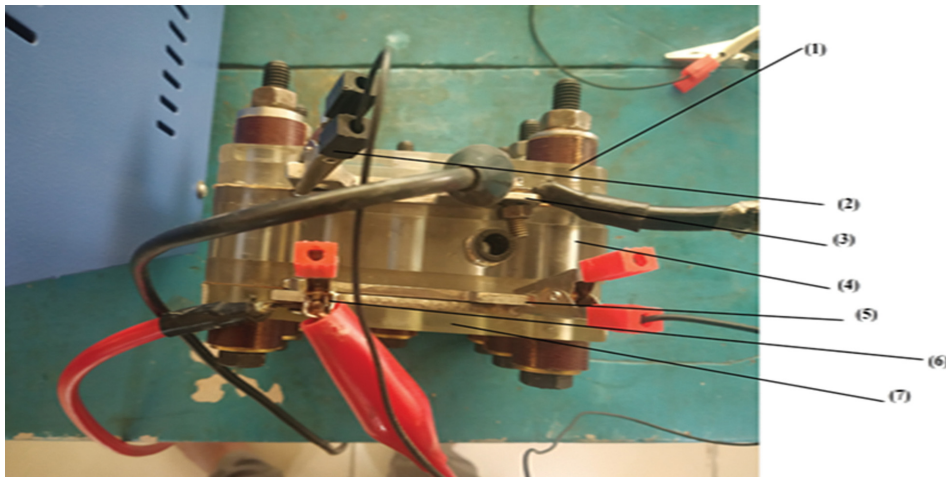


Fig. 1. Assembly of two cell passive DMFC stack. (1) and (7) Cathode end plates (2) and (6) Cathode current collectors, (3) and (5) Anode current collectors, (4) Methanol reservoir.



Fig. 2. Experimental setup.

## 2. Experimental Setup and Test Conditions

DC electronic load bank was used to record the current-voltage data. Recording of every voltage at a time gap of 60 seconds was considered between two successive for achieving stable voltage. Prior to conducting the study, a new MEA was activated for 12 hours of period at 1 M concentration of methanol at cell assembly torque of 5 N-m. Before starting the experiment, we waited for 60 minutes for getting voltage stability conditions. Each experiment was repeated three times to ensure repeatability of experimental data. The average values were considered for drawing of polarization curves. All the experiments were conducted at a temperature of 27 °C and 65% relative humidity. The experimental setup of the passive DMFC stack as given in Fig. 2.

## RESULTS AND DISCUSSION

The experiments were conducted on the two cell passive DMFC stack and its performance evaluated with newly fabricated MEA at different time durations: 0 h, 6 h, 12 h and 18 h. Further, we examined the effect of methanol concentration from 1 M to 6 M and also studied the OCV and voltage stability with respect to time on the passive DMFC stack performance. The DMFC stack performance was evaluated in terms of MPD and MCD.

### 1. Effect of Activation of the MEA

The newly fabricated MEA was fixed in the two cell passive DMFC stack. The total cell active area was 50 cm<sup>2</sup>. After fixing of the MEA, the methanol chamber was filled with 1 M of methanol concentration and then the voltage and current values were noted to plot polarization curves at 0 hour period. After that at a constant load of 0.3A, the DMFC stack was run for 6 hours and the voltage and current values were noted down. Similarly, polarization curves were drawn for the 12 hour and 18 hour period. It is observed that at 18 h activation, the voltage drop was almost similar to 12 h activation. For this reason, the data points of the 12 h and 18 h activation periods are overlapped as shown in Fig. 3. From Fig. 3, it is observed that a quick voltage drop occurs at 0 hours'

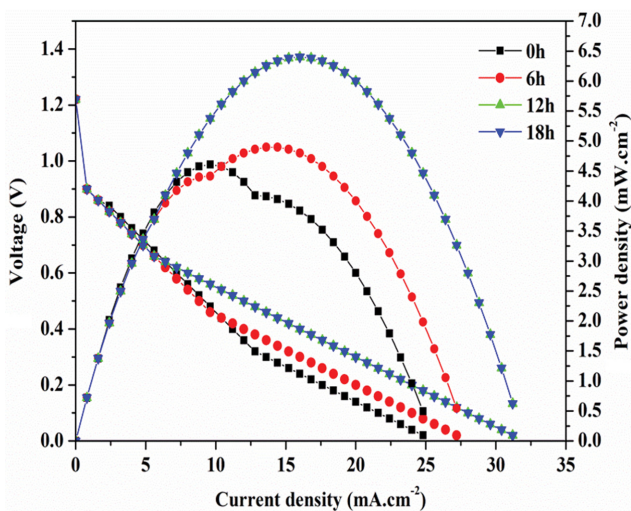


Fig. 3. Polarization curves of the newly fabricated MEA with different operating durations.

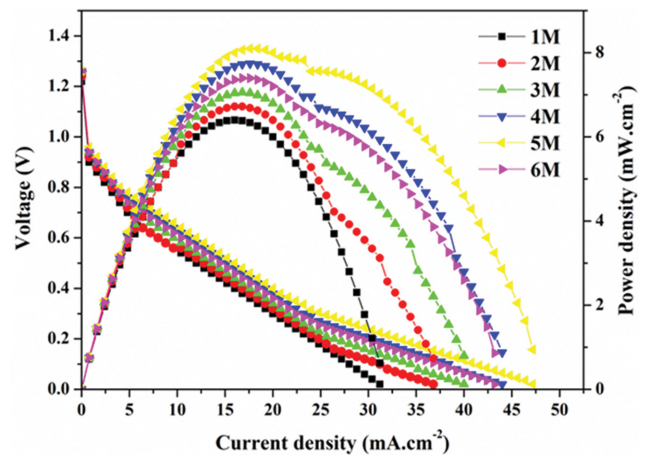


Fig. 4. Effect methanol concentration on the passive DMFC two-cell stack.

time period due to increase in activation losses. At 12 hours the voltage drop is less compared to 0 hours and 6 hours period activation, and after 12 hour time period the same voltage drop remains. This is because the catalyst is ready for the reaction after 12 hours of the period. Because of this activation, ohmic and mass transfer losses are decreased compared to other activation periods. Above the 12 hours of the period of activity catalyst is emerged compared to the initial stage. Fast reactions took place and the fuel the consumption, heat generation increased. These are main factors for the increment of stack performance. The MPD and MCD produced by 0 hour time period operated cell at 1 M concentration of methanol were 4.608 mW·cm<sup>-2</sup> and 24.8 mA·cm<sup>-2</sup>. Similarly, for 12 hours activated fuel cell is 6.4 mW·cm<sup>-2</sup> and 31.28 mA·cm<sup>-2</sup>.

### 2. Effect of Methanol Concentration

Fig. 4 depicts the polarization curves of the two cell passive DMFC stack at different methanol concentration. The concentration of methanol varied from 1 M to 6 M. For this experimentation, 12 hours of active MEA was used. The stack performance increased from 1 M to 5 M of methanol concentration [17]. The diluted methanol fuel was filled in the fuel chamber; it was placed in the middle of the fuel cell assembly. Methanol fuel was reaching the anode reaction sites through the diffusion layer by the diffusion process. The diffusion layer is a porous material, so it allows the methanol fuel. Similarly, oxygen reaches to the cathode reaction sites through the cathode diffusion layer. Sufficient amount of oxygen is required for oxygen reduction reaction (ORR). The quantity of oxygen requirement depends on the electrons and protons reaching the cathode reaction area. For higher methanol concentration, a greater number of protons and electrons are produced during the anode reaction process. So, the higher the methanol concentration, the greater the amount of oxygen required.

Three main factors are decided the DMFC stack performance: (i) amount of methanol fuel availability increased on the anode catalyst area; this resulted in enhanced reaction kinetics and decreased concentration losses. (ii) Methanol mass transport is enhanced with an increase in concentration of methanol. This results in methanol flows from anode to the cathode side. This will increase the fast voltage drop. (iii) Due to the MCO, oxygen reacts

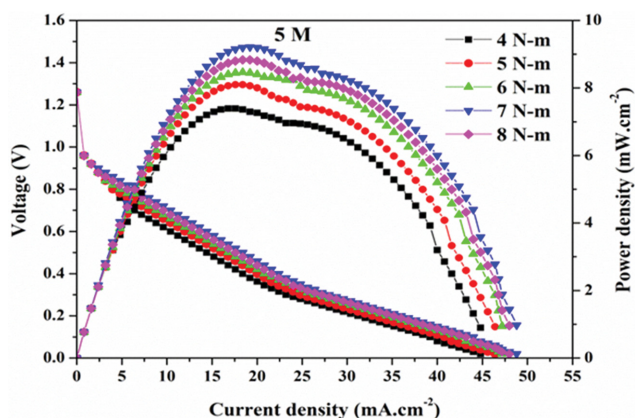


Fig. 5. Polarization curves of the different bolt torques applied on the fuel cell stack.

with methanol on the cathode side and in this exothermic reaction process, heat is released. This produced heat on the cathode side enhances the reaction kinetics. The cell performance increases with an increase in concentration of methanol from 1-5 M and then decreases. The fuel performance enhancement is due to the dominating factors (i) and (iii) compared to (ii). The cell performance decrement is due to the factor (ii) dominated compared (i) & (iii). The MPD and MCD produced by fuel cell at 5 M concentration of methanol are  $8.096 \text{ mW}\cdot\text{cm}^{-2}$  and  $46.4 \text{ mA}\cdot\text{cm}^{-2}$ , respectively.

### 3. Effect of Bolt Torque

In a passive DMFC assembly, all components are held together by bolts and nuts. The applied torque on the bolts is adjusted by a torque wrench. The bolt torque is a very important factor for arresting the liquid leakage and reducing the ohmic resistance. Fig. 5 depicts the polarization curves of the impact of bolt torque applied on the passive DMFC. The bolt torque is varied from 4 N-m to 8 N-m and experiments were carried out at 5 M of methanol concentration. Three main factors influence the fuel cell performance at different bolt torques. Factors are (i) contact resistance between the diffusion layer and current collector decreases; this results in decreasing the ohmic losses and fuel cell performance increases; (ii) in-plane electron conductivity of the diffusion layer increases; this leads to decrease in ohmic resistance, (iii) diffusion layer has a highly porous material, pore volume and porosity of the diffusion layer decrease as an applied bolt torque, which results in increases in the mass transport losses. Because of this the fuel cell performance is decreased. The stack performance increases from 4 N-m to 7 N-m [16]. This is due to the dominant factors of (i) and (ii) compared to (iii). Again, increasing bolt torque from 7 N-m to 8 N-m. The stack performance deteriorates due to dominating the factor (iii) compared to (i) and (ii).

### 4. Stability of Fuel Cell Stack

The 5 M of methanol solution was filled in the passive DMFC stack and then we waited for some time to get steady-state conditions. Fig. 6 shows the variation of the OCV with the reference of time. The OCV is decreased from 1.39 V-1.29 V at 5 M of methanol concentration. At lower current density reasons, activation losses are dominating and this results in decreasing the OCV.

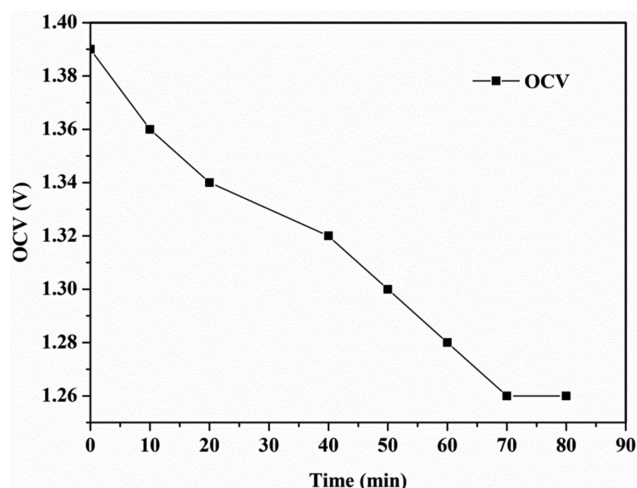


Fig. 6. Open circuit voltage (OCV) variation with respect to the period at 5 M of methanol concentration.

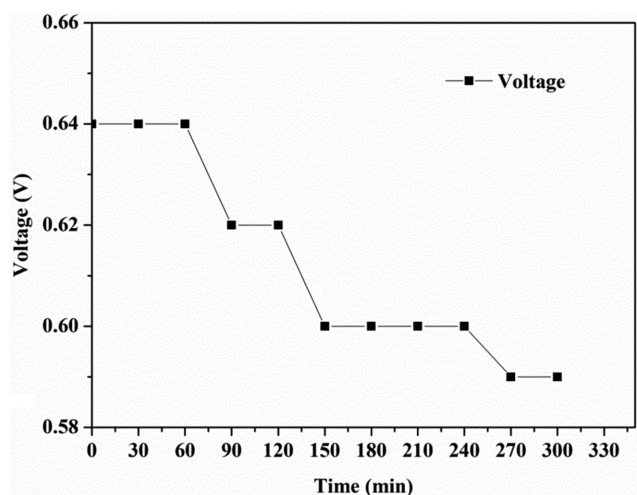


Fig. 7. Voltage stability of the passive DMFC stack.

Fig. 7 depicts the voltage stability of the passive DMFC stack at a constant load of  $10.6 \text{ mA}\cdot\text{cm}^{-2}$  with 5 M concentration of methanol. The stack is operated at temperature of  $27^\circ\text{C}$  and 65% relative humidity and the cell is assembled with a uniform torque of 5 N-m. The fuel cell stack is operated for a 6 hour period at constant load. The voltage is decreased from 0.64 V-0.59 V. Poisoning of the catalyst and Ru crossover from anode to the cathode side can be observed. The MCO at the cathode side obstructs the oxygen flow from atmosphere to reaction sites.

## CONCLUSIONS

This study deals with the experimental analysis of passive DMFCs tack. The Pt-Ru/carbon black+ Pt-Ru/C of two-layer catalyst and Pt/C catalyst with a loading of  $4 \text{ mg}\cdot\text{cm}^{-2}$  and  $2 \text{ mg}\cdot\text{cm}^{-2}$  are used on the anode and cathode side, respectively. The following conclusions have been drawn:

- Newly fabricated MEA, activation time varied from 0-18 h.

The fuel cell had better fuel cell performance at 12 hours of the period and then retained the same.

- The fuel cell performance is enhanced with an increase in concentration of methanol from 1-5 M and then decreases.
- The stack performance increased with bolt torque applied on the fuel cell stack from 4 N-m to 7 N-m and then decreases.
- During short term stability of the fuel cell stack, voltage decreased from 0.64 to 0.59 for 6 hours of the period.

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### ABBREVIATIONS

DMFC	: direct methanol fuel cell
CC	: current collector
OR	: open ratio
MPD	: maximum power density
MCD	: maximum current density
MCO	: methanol crossover

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