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Research Article

Effect of Mass Flow Rate and Temperature on the Performance of PEM Fuel Cell: An Experimental Study

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Abstract

The paper shows the Experimental study of the performance of the PEM fuel cell with varying mass flow rate of hydrogen and oxygen. It also focuses the effect of fuel cell temperature on the performance of the fuel cell. Fuel cell performance is increased by proper water management on the membrane. Basic parameter which enhances the fuel cell performance is Relative humidity, Flow Field design, Temperature, Stoichiometric ratio. With the help of this studies, we observe that the fuel cell performance improve by Increasing the relative humidity, temperature, pressure, stoichiometric ratio and using the split serpentine flow field instead of single serpentine flow field. The effects of different fuel cell operating temperatures and mass flow rates on the performance of proton exchange membrane (PEM) fuel cell have been studied experimentally, using pure hydrogen on the anode side and air on the cathode side. The objective of this study is to explore the research in the field of PEM fuel cell and to make it cost effective for sustainable power supply.

Keywords: *PEM fuel cell, Mass flow rate, Different cell operating temperatures, Efficiency*

1. Introduction

Proton Exchange Membrane, also called Polymer Electrolyte Membrane, Fuel Cells (PEMFC)s are electrochemical energy conversion devices. PEMFCs produce electricity by combining hydrogen and oxygen, typically from the air, to form water and a small amount of heat. The heart of PEMFCs is the polymer electrolyte membrane.

The splitting of hydrogen into protons and electrons takes place at the anode catalyst layer. Protons crossing the membrane combine with oxygen and electrons at the cathode catalyst layer to generate water. The membrane provides a barrier to keep the hydrogen and oxygen separated. It must conduct protons easily, yet be electronically insulating to force the electrons through an external circuit and provide useful work. The polymer membranes have low melting temperatures, which limit operating temperature below 100^0C. Typical operating temperatures range from 50^0C to 70^0C. PEMFCs have several attributes, including low operating temperature and high efficiency (typically 50-70% for the fuel cell stack and 40-60% for the overall system), which make them good candidates for automotive and portable power applications. For proton exchange membrane (PEM) fuel cell designs, reactant gases are feed into the fuel cell through the gas flow fields grooved on the collector plates.

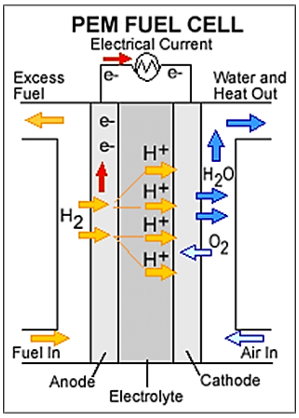

Fig. 1.1: Principle of PEM fuel cell

There are different designs of gas flow fields. The traditional design is the serpentine flow field with this type of flow field, the reactant gases are transported from the gas channels to the catalyst layers mainly by diffusion.

Interest has been growing in proton exchange membrane (PEM) fuel cells due to their unique characteristics of *low operation temperature*, *low emission and quick startup*. However, various irreversible losses existing in an operating PEM fuel cell affect its performance and reduce its efficiency. Ohmic loss is one

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of the main losses in normal fuel cell operation. The contribution from the contact resistance to the ohm loss has been reported to be approximately equal to that from the proton conduction resistance in the membrane. Proton exchange membrane (PEM) fuel cells have been widely recognized as the most promising candidates for future power generating devices in the automotive, distributed power generation and portable electronic applications.

2. Experimental Setup

The experimental set up used for this study is shown in figure 3.1. It consists of PEM Fuel cell, oxygen cylinder, acetylene cylinder, flow regulator, flow meter, suction blowers, ammeter, voltmeter, electronic control circuit, bulb as a load and a heater. PEM fuel cell is the combination of two major plates such as, anode plates and cathode plates, which has been well design and construction as per using per our specification. A single unit cell with active surface aria of 7.2 x 7.2 c. m. was used for experiment in this study. The membrane electrode assembly (MEA) consists of a *Nafion* in combination with platinum loadings of *0.4 mg/cm^2* per electrode. The gas diffusion layers are made of carbon fiber cloth. The MEA positioned between two graphite plates is pressed between two gold-plated copper plates. The graphite plates are grooved with serpentine gas channels. In the test station, reactant gases are humidified by passing through external water tanks. Regulating the water temperature controls the humidification of the reactant gases.

3. Experimental Procedure

The procedure for each experiment is as follows:

Figure 3.1: Experimental Setup with PEM Fuel cell

Figure 3.2: Cylinders of Hydrogen and Oxygen gas

Figure 3.3: Ammeter and Voltmeter

Figure 3.4: Flow Meter

1. Power on the Fuel Cell Test Station and open the valves of the gas cylinders of hydrogen, oxygen.
2. Before starting experiments, purge the anode side with hydrogen to ensure no oxygen is present.
3. Set the experimental parameters of mass flow rate of the gas cylinders of hydrogen, oxygen.
4. Set the maximum voltage, minimum voltage and voltage increment step of the fuel cell polarization data by Ammeter and Voltmeter.
5. Set the delay between every two voltage and current data points.

4 Experimental Results and Discussion

4.1 Effect of fuel cell temperature

The effect of the cell temperature on the cell performance with the inter-digitated flow fields has been studied. Figure 4.7- 4.9 shows that the performance of the fuel cell increases with the increase of the cell temperature from 40^{0}C to 80^{0}C. The exchange current density increases with the increase of fuel cell temperature, which reduces activation losses. This may explain the improvement of the performance. The polarization curve for fuel cell temperature at 80^{0}C is lower than the other curves. The experiments were carried out with the anode and cathode humidification temperatures of 70^{0}C. The anode and cathode backpressures were 4 atm. The hydrogen mass flow rate was and the air mass flow rate was 1.0 ml/s and Oxygen flow rates 2.0 ml/s. The experiments were carried out at different cell temperatures ranging from 40 to 800C, with an increment of 200C.

4.2 Effect of mass flow rate

Mass flow rates ranges are used to in our experimental setup because it has very positive effect on fuel cell. Experiment for different hydrogen mass flow rates curves ranging from1.0 to 6.0 ml/s with different cell operating temperatures vs. cell voltage at fixed current density. Results show that mass flow rate of reactant gases (H_2 and O_2). H_2 mass flow rate range is 1 to 3 ml/s. and O_2 mass flow rate range is 2 to 6 ml/s at fixed current density (0.2 A/cm^2 to 1.2 A/cm^2) with an increment of 0.2 A/cm^2, which shows that when it increases then performance of fuel cell also increased as per figures. Mass flow rate of H_2 presents the best results for 3 ml/s which produced voltage approximate 1 volt. At 0.2 A/cm^2 (current density) and show lowest voltage as high current density (1.2 ml/s). Results find out at constant cell temperature of 70^{o}C.

Table 01: Experimental data at 0.2 A/cm2 Current Density

Cell Temp. (^{0}C)	Voltage at Mass flow rate 1 ml/s (V)	Voltage at Mass flow rate 2 ml/s (V)	Voltage at Mass flow rate 3 ml/s (V)
40	0.75	0.9	0.98
60	0.76	0.91	0.99
80	0.77	0.92	1.01

Table 02: Experimental data at 0.4 A/cm2 Current Density

Cell Temp. (^{0}C)	Voltage at Mass flow rate 1 ml/s (V)	Voltage at Mass flow rate 2 ml/s (V)	Voltage at Mass flow rate 3 ml/s (V)
40	0.7	0.78	0.96
60	0.71	0.8	0.97
80	0.73	0.82	0.98

Table 03: Experimental data at 0.6 A/cm2 Current Density

Cell Temp. (^{0}C)	Voltage at Mass flow rate 1 ml/s (V)	Voltage at Mass flow rate 2 ml/s (V)	Voltage at Mass flow rate 3 ml/s (V)
40	0.6	0.7	0.91
60	0.64	0.71	0.92
80	0.68	0.73	0.93

Table 04: Experimental data at 0.8 A/cm2 Current Density

Cell Temp. (^{0}C)	Voltage at Mass flow rate 1 ml/s (V)	Voltage at Mass flow rate 2 ml/s (V)	Voltage at Mass flow rate 3 ml/s (V)
40	0.68	0.75	0.93
60	0.7	0.76	0.93
80	0.71	0.77	0.96

Table 05: Experimental data at 1.0 A/cm2 Current Density

Cell Temp. (^{0}C)	Voltage at Mass flow rate 1 ml/s (V)	Voltage at Mass flow rate 2 ml/s (V)	Voltage at Mass flow rate 3 ml/s (V)
40	0.54	0.68	0.8
60	0.57	0.7	0.82
80	0.6	0.71	0.84

Table 06: Experimental data at 1.2 A/cm2 Current Density

Cell Temp. (^{0}C)	Voltage at Mass flow rate 1 ml/s (V)	Voltage at Mass flow rate 2 ml/s (V)	Voltage at Mass flow rate 3 ml/s (V)
40	0.48	0.6	0.76
60	0.52	0.64	0.77
80	0.55	0.68	0.78

Table 07: Variation of voltage with temperature when Hydrogen flow rate is 1.0 ml/s and Oxygen flow rate is 2.0 ml/s.

Sr. No.	Current density (A/cm^2)	Voltage at fuel cell Temp. 40^{0}C (V)	Voltage at fuel cell Temp. 60^{0}C (V)	Voltage at fuel cell Temp. 80^0 C (V)
1	0.2	0.75	0.76	0.77
2	0.4	0.7	0.71	0.73
3	0.6	0.68	0.7	0.71
4	0.8	0.6	0.64	0.68
5	1	0.54	0.57	0.6
6	1.2	0.48	0.52	0.55

Table 08: Variation of voltage with temperature when Hydrogen flow rate is 2.0 ml/s and Oxygen flow rate is 4.0 ml/s.

Sr. No.	Current density (A/cm^2)	Voltage at fuel cell Temp. 40^{0}C (V)	Voltage at fuel cell Temp. 60^{0}C (V)	Voltage at fuel cell Temp. 80^{0}C (V)
1	0.2	0.9	0.91	0.92
2	0.4	0.78	0.8	0.82
3	0.6	0.75	0.76	0.77
4	0.8	0.7	0.71	0.73
5	1	0.68	0.7	0.71
6	1.2	0.6	0.64	0.68

Table 9: Variation of voltage with fuel cell temperatures. (Hydrogen flow rate is 3.0 ml/s and Oxygen flow rate is 6.0 ml/s.)

Sr. No.	Current density (A/cm^2)	Voltage at fuel cell Temp. 40^{0}C (V)	Voltage at fuel cell Temp. 60^{0}C (V)	Voltage at fuel cell Temp. 80^{0}C (V)
1	0.2	0.98	0.99	1.01
2	0.4	0.96	0.97	0.98
3	0.6	0.93	0.94	0.96
4	0.8	0.91	0.92	0.93
5	1	0.8	0.82	0.84
6	1.2	0.76	0.77	0.78

5. Calculations for Voltage Improvement

The Table 5.1 shows the Improvement in Voltage with variable Mass Flow Rate and Current Density of Fuel Cell.

Current Density (A/cm^2)	Mass flow rate of H_2 (ml/s)	Mass flow rate of O_2 (ml/s)	Voltage Increases (%)
0.2	1	2	(1.01-0.77)/0.77
	3	6	31.16
0.4	1	2	(0.98-0.73)/0.73
	3	6	34.24
0.6	1	2	(0.96-0.71)/0.71
	3	6	35.21
0.8	1	2	(0.93-0.68)/0.68
	3	6	36.76
1	1	2	(0.84-0.60)/0.60
	3	6	40
1.2	1	2	(0.78-0.55)/0.55
	3	6	41.81

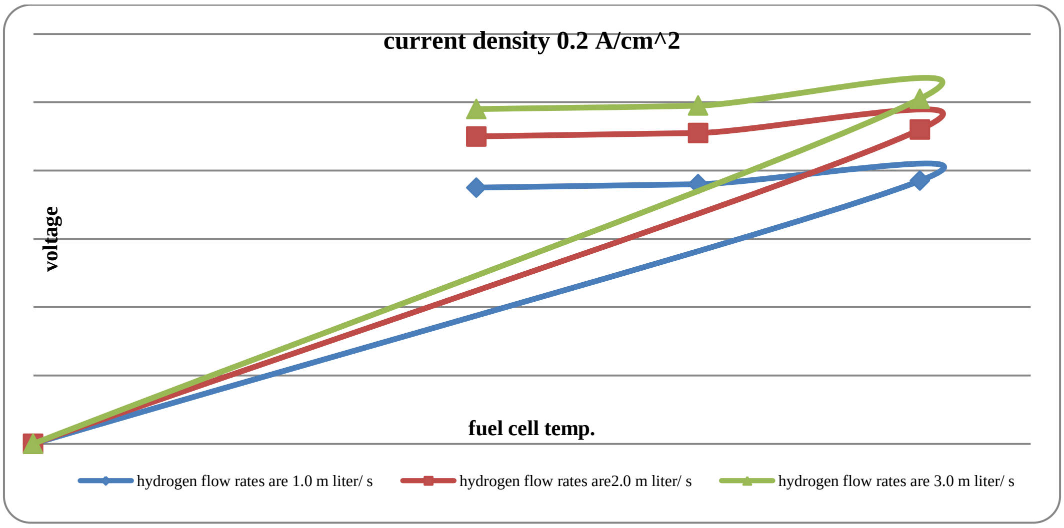

Figure 4.1: Variation of voltage with Fuel cell temperatures at constant current density of 0.2 A/cm^2

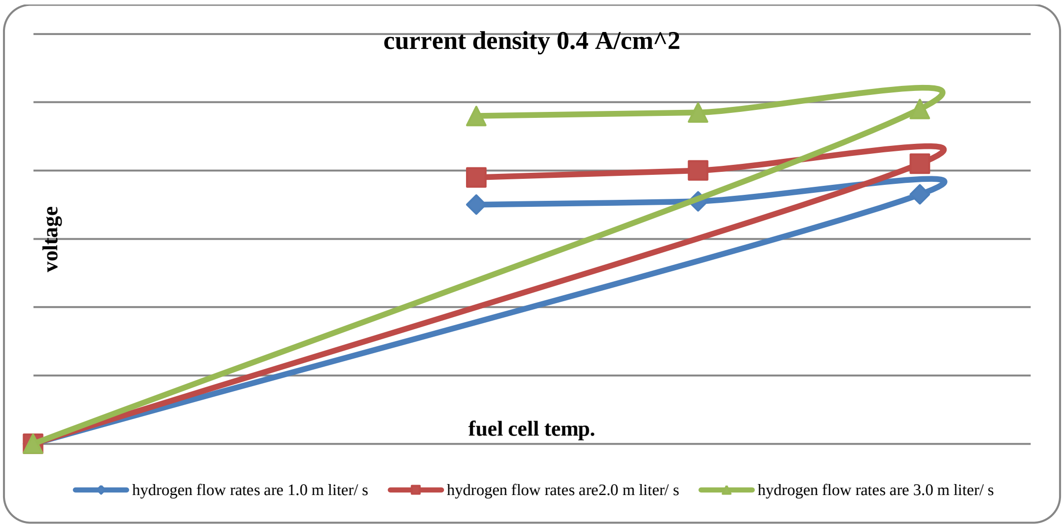

Figure 4.2: Variation of voltage with Fuel cell temperatures at constant current density of 0.4 A/cm^2

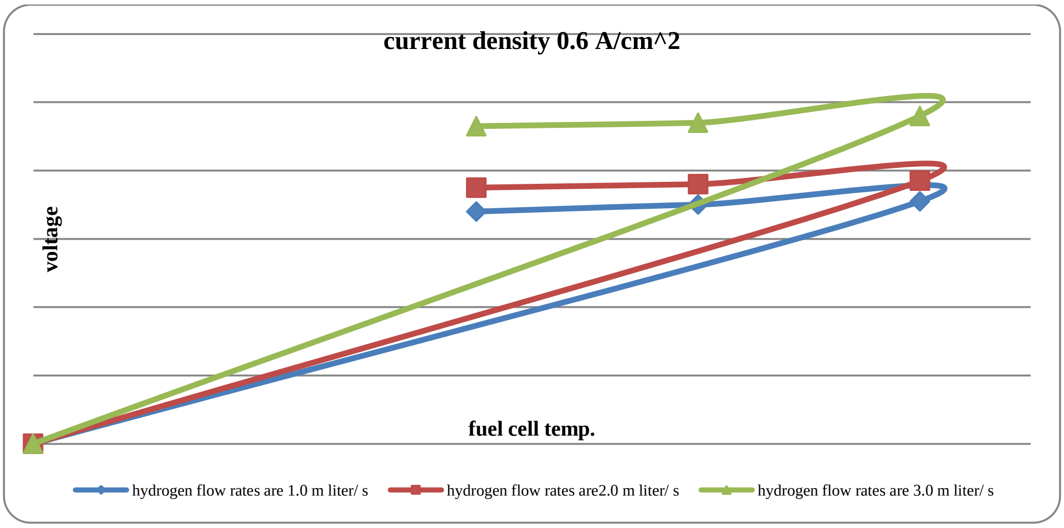

Figure 4.3: Variation of voltage with Fuel cell temperatures at constant current density of 0.6 A/cm^2

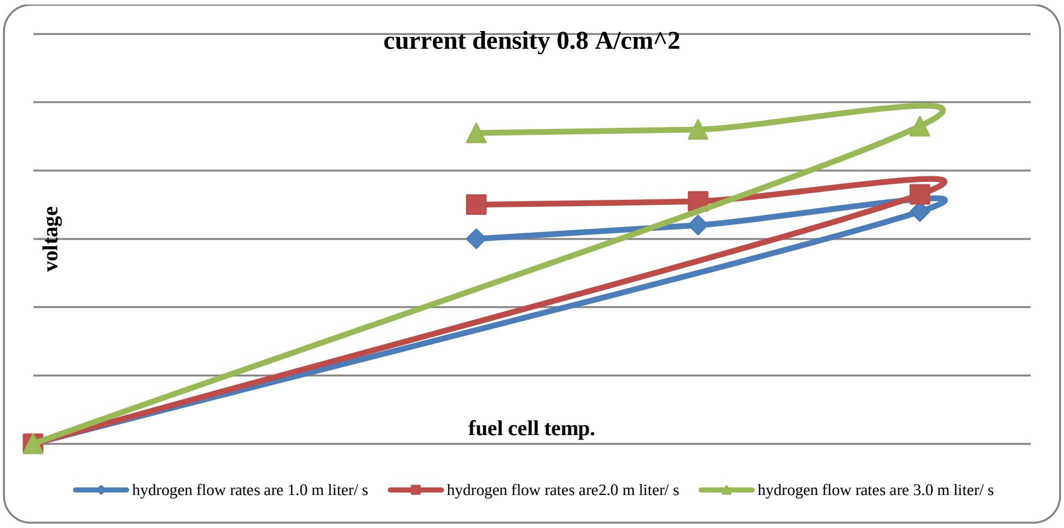

Figure 4.4: Variation of voltage with Fuel cell temperatures at constant current density of 0.8 A/cm^2

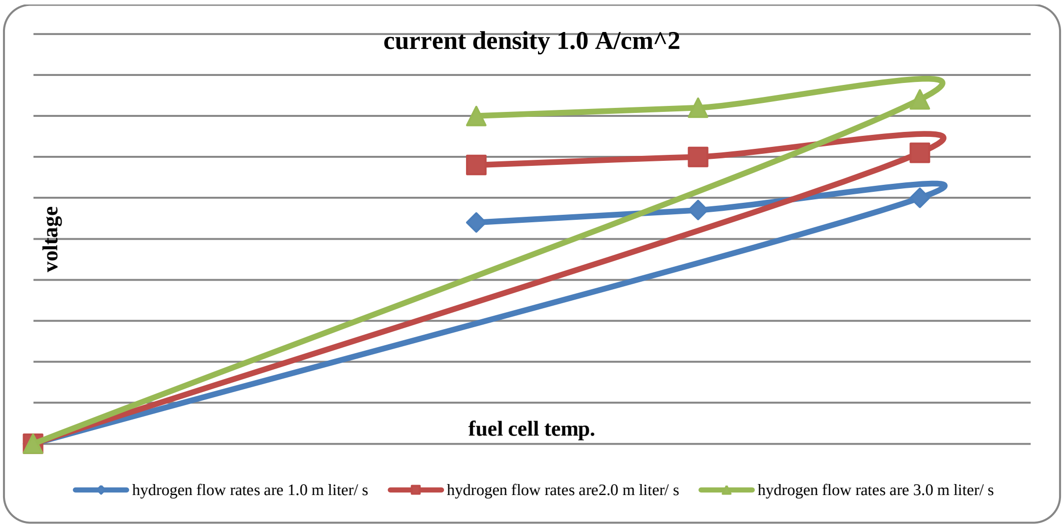

Figure 4.5: Variation of voltage with Fuel cell temperatures at constant current density of 1.0 A/cm^2

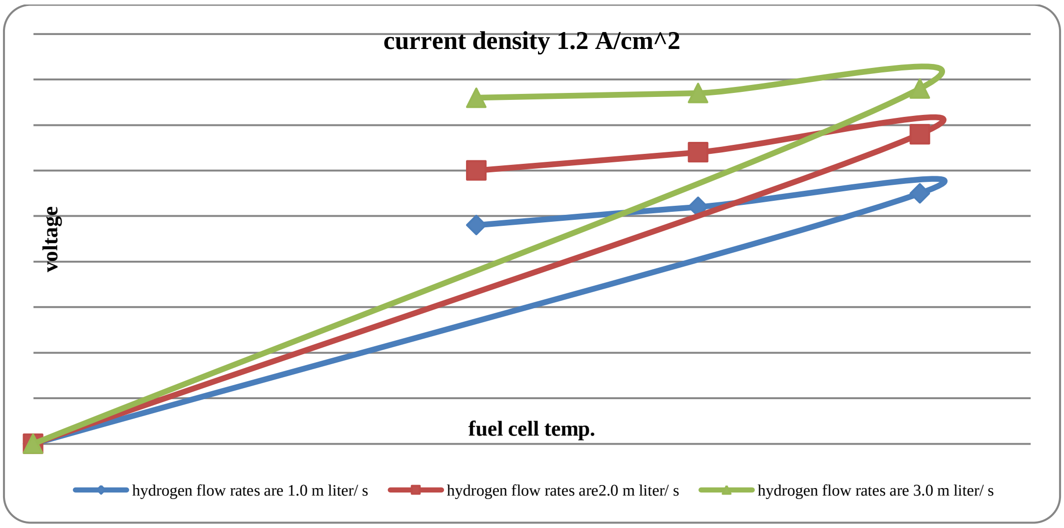

Figure 4.6: Variation of voltage with Fuel cell temperatures at constant current density of 1.2 A/cm^2

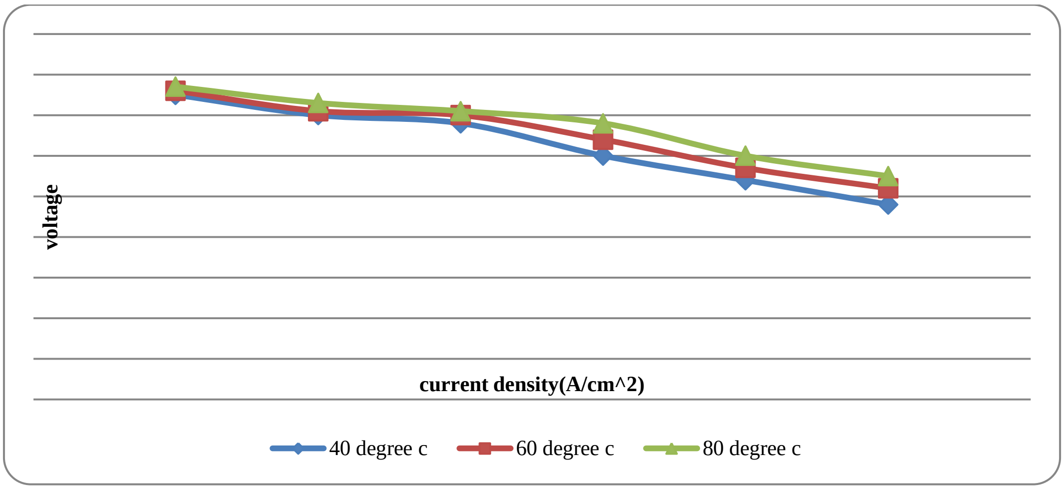

Figure 4.7: I-V characteristics for different fuel cell temperatures. (H_2 and O_2 flow rates are 1.0 ml/s and 2.0 ml/s respectively)

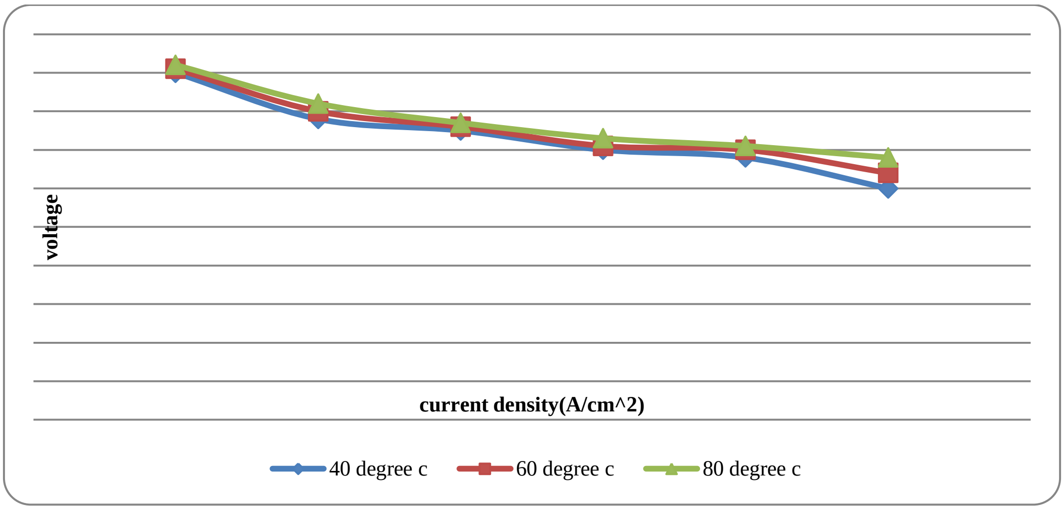

Figure 4.8: I-V characteristics for different fuel cell temperatures. (H_2 and O_2 flow rates are 2.0 ml/s and 4.0 ml/s respectively)

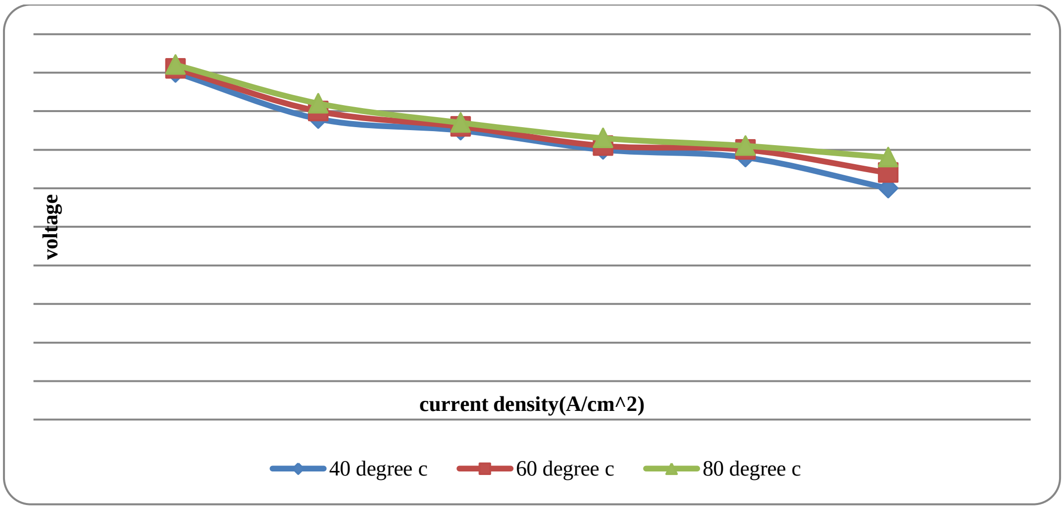

Figure 4.9: I-V characteristics for different fuel cell temperatures. (H_2 and O_2 flow rates are 3.0 ml/s and 6.0 ml/s respectively)

Conclusion

In this work, experimental approach is used to show the improvement in the performance of the fuel cell with variable operating parameters of PEM Fuel cell such as mass flow rates, different fuel cell temperatures. After analyzing the results, it is concluded that the fuel cell performance is improved by increasing the fuel cell operating temperature, mass flow rate, and stoichiometric ratio. After experimentation, some other important conclusions have been drawn:

1. If H_2 mass flow rate is increased from 1ml/s to 3 ml/s and O_2 mass flow rate from 2 ml/s to 6 ml/s the improvement in voltage is found by 41.81% at fixed fuel cell temperature of 80^0C and at fixed Current density of 1.2 A/cm^2.
2. If H_2 mass flow rate is increased from 1ml/s to 3 ml/s and O_2 mass flow rate from 2 ml/s to 6 ml/s the improvement in voltage is found by 40.00% at fixed fuel cell temperature of 80^0C and at fixed Current density of 1.0 A/cm^2.
3. If H_2 mass flow rate is increased from 1ml/s to 3 ml/s and O_2 mass flow rate from 2 ml/s to 6 ml/s the improvement in voltage is found by 36.76% at fixed fuel cell temperature of 80^0C and at fixed Current density of 0.8 A/cm^2.
4. If H_2 mass flow rate is increased from 1ml/s to 3 ml/s and O_2 mass flow rate from 2 ml/s to 6 ml/s the improvement in voltage is found by 35.21% at fixed fuel cell temperature of 80^0C and at fixed Current density of 0.6 A/cm^2.
5. If H_2 mass flow rate is increased from 1ml/s to 3 ml/s and O_2 mass flow rate from 2 ml/s to 6 ml/s the improvement in voltage is found by 34.24% at fixed fuel cell temperature of 80^0C and at fixed Current density of 0.4 A/cm^2.

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