

# The Performance of PEM Fuel Cell Using Platinum-Ruthenium Alloy Catalyst With Variable Catalyst Loading

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**Abstract-** Fuel cells are regarded as a promising alternative for a clean and green energy source in the context of depleting fossil fuels. A fuel cell is an electrochemical energy conversion device that converts chemical energy of a fuel directly into electrical energy. Among the different fuel cell variants, the proton exchange membrane (PEM) variant was preferred due to quick startup, low operating temperature and better efficiency. In a PEM fuel cell, the membrane electrode assembly (MEA), which is considered as the 'heart' of the fuel cell, is primarily fabricated using electrocatalysts supported on carbon materials with higher surface area. In this study, three MEAs were fabricated for a PEM fuel cell of 25 cm<sup>2</sup> active area using 30% Pt-Ru catalyst supported on carbon for anode and 20% Pt supported on carbon for cathode with a various catalyst loading. MEA-1 is fabricated with a loading of 0.6 mg of Pt/cm<sup>2</sup> for anode and 0.4 mg of Pt/cm<sup>2</sup> for cathode. MEA-2 is fabricated with a loading of 0.6 mg of Pt/cm<sup>2</sup> for anode and 0.5 mg of Pt/cm<sup>2</sup> for cathode. MEA-3 is fabricated with a loading of 0.6 mg of Pt/cm<sup>2</sup> for anode and 0.6 mg of Pt/cm<sup>2</sup> for cathode. Experimental analysis was conducted to investigate the PEM fuel cell performance using the fabricated MEAs under the influence of variable operating parameters such as cell temperature, Anode gas humidification temperature, Cathode gas humidification temperature, Anode gas flow rate and Cathode gas flow rate. The experimental results were presented in the form of polarization curves and power curves which shows the impact of variable catalyst loading and flow field plates on the performance of PEM fuel cell.

**Keywords-** PEM Fuel cell, MEA, Pt-Ru alloy catalyst, 17 & 13 path flow field plate.

## I. INTRODUCTION

The fossil fuel depletion, increase in energy consumption and environmental pollution have resulted scientists to focus on alternative clean and energy solution. A Fuel cell is the one which promises to fulfil the above problems. fuel cell is an electrochemical device where the

energy of a chemical reaction is converted directly into electricity by combining hydrogen fuel with oxygen. Water and heat are the only by products, if hydrogen is used as fuel source. Individual fuel cells are inherently low voltage in nature. Hence, total voltage is increased by stacking individual fuel cells together in series, forming a system capable of providing voltages necessary for commercial use. No other energy generation technology offers the combination of benefits that fuel cells do. In addition to low or zero emissions, benefits include high efficiency and reliability, multi-fuel capability, flexibility, durability, scalability and ease of maintenance. Fuel cells operate silently, so they reduce noise pollution as well as air pollution and the waste heat from a fuel cell can be used to provide hot water or space heating for a home or office. Proton exchange membrane (PEM) fuel cells are currently regarded as promising energy conversion devices for the 21st century because of their high efficiency, low emission, and quick start-up capability, making them suitable for mobile, stationary and portable device power applications. However, cell performance is determined by several factors, including the geometry and morphology of transport components, as well as the operating conditions such as pressure, temperature, and humidification of the reactant gases. The reaction in a PEM fuel cell is chemically simple, with hydrogen molecules splitting into hydrogen ions and electrons on the anode while protons recombine with oxygen and electrons into water and release heat at the cathode.

Experimental studies verified the performance of a PEM fuel cell using different back pressures and flow field designs. Experiments were conducted with three different flow field plates, 4-serpentine, inter-digitated and dual inlet single outlet, at three different back pressures created by immersing the outlet tube in a cylinder at three different depths with each flow field plate[1].The influence of variable operating parameters including operating cell temperature, anode and cathode humidification temperature, pressure and various combination of these parameters have been studied[2].The behaviour of a single PEM fuel cell was studied under various operating parameters. The author has studied the performance

of the fuel cell with an active area of  $25 \text{ cm}^2$  fabricated with 20%Pt on carbon support catalyst on both sides with a loading of  $0.5 \text{ mg of Pt/cm}^2$ [3].The effect of multi-walled carbon nanotubes supported platinum catalyst for proton exchange membrane fuel cells on the performance of PEM Fuel cell was studied. Experimental analysis was conducted to investigate the effect of nano catalyst loading under the influence of variable operating parameters such as cell temperature, gas humidification temperatures on the output performance of the PEMFC[4].The comparison of Pt and Pt-Ru catalyst on catalysing the hydrogen oxidation reaction for alkaline polymer electrolyte fuel cells operated at  $80^\circ\text{C}$ .The author reported a transformational finding that the Pt anode can actually be as good as the Pt-Ru anode for APEFCs operated at elevated conditions. At  $80^\circ\text{C}$  with appropriate gas backpressure, the cell with a Pt anode can exhibit a peak power density very close to that with a Pt-Ru alloy catalyst on anode[5].The study on the physical and morphological characteristics and electrochemical behaviour in a PEM Fuel cells of Pt-Ru supported on carbon[6].The effects of nitrogen and carbon monoxide concentrations on performance of proton exchange membrane fuel cells with Pt-Ru anodic catalyst. The author reported that a larger dilution effect of nitrogen is noted for cases with lower hydrogen stoichiometric ratios. Furthermore, increasing the carbon monoxide concentration reduces the cell performance because the elevated carbon monoxide adsorption rate results in a severer poison effect[7].The behaviour of a single PEMFC with variation of cell temperature, anode and cathode flow temperatures in saturation and dry conditions and reactants pressure were studied[8].Pt-based electrocatalysts are usually employed in PEMFCs as cathode electrocatalysts for oxygen reduction reactions (ORR). Electrocatalyst with small size and high dispersion results in high electrocatalytic activity. The catalyst support (i.e., carbon support) used in a fuel cell operating environment should possess higher surface area, higher corrosion resistance, higher electrical conductivity[9].The effect of flow field orientation on the performance of PEM Fuel cell using nano catalyst support have been studied[10].

## II. EXPERIMENTAL SETUP

The experimental setup contains a single PEM fuel cell with an active surface area of  $25\text{cm}^2$ .MEA-1 is fabricated with a loading of  $0.6 \text{ mg of Pt/cm}^2$  for anode and  $0.4 \text{ mg of Pt/cm}^2$  for cathode. MEA-2 is fabricated with a loading of  $0.6 \text{ mg of Pt/cm}^2$  for anode and  $0.5 \text{ mg of Pt/cm}^2$  for cathode. MEA-3 is fabricated with a loading of  $0.6 \text{ mg of Pt/cm}^2$  for anode and  $0.6 \text{ mg of Pt/cm}^2$  for cathode. The fuel cell contains a membrane electrode assembly (MEA) sandwiched between flow field plates, current collector plates and end plates. The

experimental setup also consists of two storage cylinders containing high-purity (99.99%)  $\text{H}_2$  and  $\text{O}_2$  and respectively, which are used as the fuel and the oxidant gases in our experiment. A schematic diagram of the fuel cell testing set up is shown in figure 2. The experimental setup consists of gas control facility where  $\text{H}_2$  and  $\text{O}_2$  gases are controlled. This pressure controlling output were connected to the Alicat mass flow controllers to control the mass flow rate of  $\text{H}_2$  and  $\text{O}_2$  gases. The output of mass flow controllers is connected to the water bath to humidify the dry gases. From this humidifier the gases coming out are connected to fuel cell, so that it will ensure that the membrane used in the MEA does not dehydrate and crack under stress. Experimental studies were conducted with three types of MEAs prepared using variable catalyst loading of Pt-Ru/C for anode and Pt/C for cathode designated as MEA-1, MEA-2, and MEA-3 respectively using 17 and 13 path parallel serpentine flow field plates.



Fig 1: 17 and 13 path parallel serpentine flow field plate



Fig.2: Experimental setup for testing a Fuel cell

## III. EXPERIMENTATION

The fabricated MEAs were tested manually as shown in the Fig.2 under variable operating parameters. The cell temperature is controlled by using a PID controller, which is equipped with cartridge heaters to maintain the cell

temperature, and with a temperature sensor to measure the cell temperature. The anode (H<sub>2</sub>) and cathode (O<sub>2</sub>) gas flow rates are controlled through Alicat mass flow controllers which the outlet pressure maintained at 1 bar, which will be the operating pressure of the fuel cell. The dry gas is sent into the water bath of de-ionized water to disperse it as a humidified gas and was equipped with a temperature controller. The end copper plates of the assembled fuel cell are connected to the K-PAS load bank through the insulated copper wire setup. The flow of electrons through this copper wire set up completes the electrical circuit and thus the load bank measures the current produced at specified load conditions. Voltage is selected from the mode, and by varying the voltage manually the corresponding direct current readings are noted.



Fig.3: Open circuit voltage (OCV) for MEA-1 using 17 path



Fig.4: Open circuit voltage (OCV) for MEA-2 using 17 path



Fig.5: Open circuit voltage (OCV) for MEA-3 using 17 path

Similarly, the Open circuit voltage (OCV) obtained for MEA-1,2 and 3 using 13 path flow field are 1.005, 1.036 and 1.054 V respectively.

#### IV. OPERATING PARAMETERS

The studies were conducted to analyse the performance of the cell by varying the operating conditions such as Cell temperature (CT), Anode humidification temperature (AHT), Cathode humidification temperature (CHT), Anode Gas flow rate (AFR) & Cathode Gas flow rate (CFR). Relative humidity becomes very low as we approach 0.9 V (close to open circuit, OCV) and is comparatively better at 0.7 V. This behaviour is quite clear because at low cell voltages (less than 0.3 V), the chemical reaction rate becomes higher where liquid water plays a key role in membrane hydration, but it also blocks the transport of oxygen top the cathode catalyst layer. This factor has a significant impact on overall cell performance. Hence, all current densities were logged in the cell operating voltage range from 0.3 V to 0.7 V. A range of operating parameters considered in the present experiment is as shown in the table below.

Table 1: Range of operating parameters

S.no	Parameter	Range	Units
1	Cell temperature (CT)	30-60	°C
2	Anode humidification temperature (AHT)	30-60	°C
3	Cathode humidification temperature (CHT)	30-60	°C
4	H <sub>2</sub> flow rate at anode side	0.15-0.45	Lpm
5	O <sub>2</sub> flow rate at cathode side	0.25-0.85	Lpm

#### V. RESULTS AND DISCUSSIONS

##### Effect of cell temperature

Cell temperature (CT) has a strong influence on PEM fuel cell performance. Increasing the cell temperature is helpful to enhance gas diffusivity, electrochemical reaction rate, ionic transport in membrane and accordingly the cell performance. The experimental results were obtained for MEA-1, MEA-2 & MEA-3 using 17 path and 13 path parallel serpentine flow field plate in a PEM fuel cell set up and varying the cell temperature from 30°C to 60°C.

During the course of experiments, H<sub>2</sub> and O<sub>2</sub> gas humidification temperatures are held constant at 30°C, flow rates of H<sub>2</sub> and O<sub>2</sub> were maintained at 0.15 lpm and 0.25 lpm respectively. Polarization and Power curves demonstrating the effect of cell temperature on PEM fuel cell performance for

MEA-1, MEA-2 and MEA-3 using standard 17 path parallel serpentine flow field design geometry is as shown in Fig.6,7 and 8 respectively. It was observed that the current density increased as the cell temperature was increased incrementally from 30°C to 50°C due to the reduction in activation losses. At 60°C there was a step decline in the cell performance due to the dehydration of Nafion 117 membrane at elevated temperatures. At this temperature, the rate of membrane dehydration at the anode exceeds the rate at which water is produced at the cathode since water balance in the cell is maintained by back-diffusion of water. Hence, the conductivity of Nafion declines resulting in a drop in performance. Polarization curves demonstrate fuel cell performance improvement in the lower as well as higher current density regions. At a reference voltage of 0.6 V, a current density 0.162 A/cm<sup>2</sup>, 0.168 A/cm<sup>2</sup> and 0.173 A/cm<sup>2</sup> for 17 path and a current density of 0.153 A/cm<sup>2</sup>, 0.162 A/cm<sup>2</sup> and 0.164 A/cm<sup>2</sup> for 13 path is obtained for MEA-1,2 & 3 respectively.

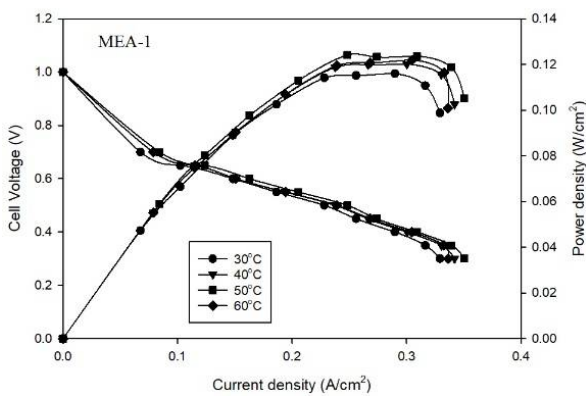


Fig.6: Effect of cell temperature for MEA-1 using 17 Path

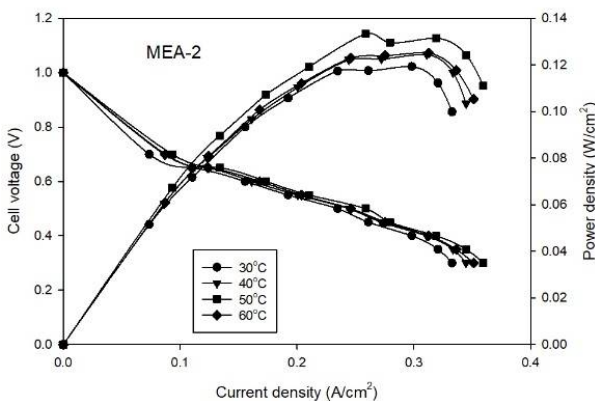


Fig.7: Effect of cell temperature for MEA-2 using 17 Path

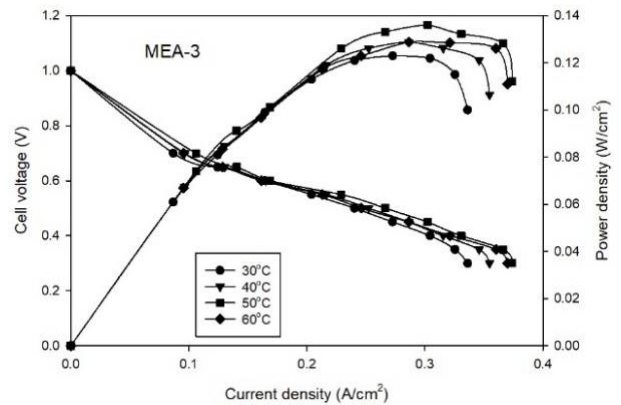
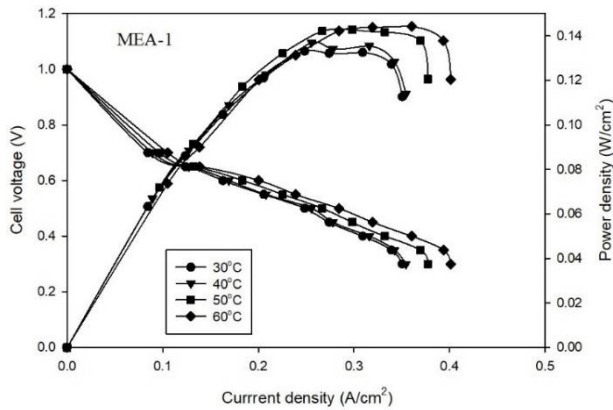


Fig.8: Effect of cell temperature for MEA-3 using 17 Path

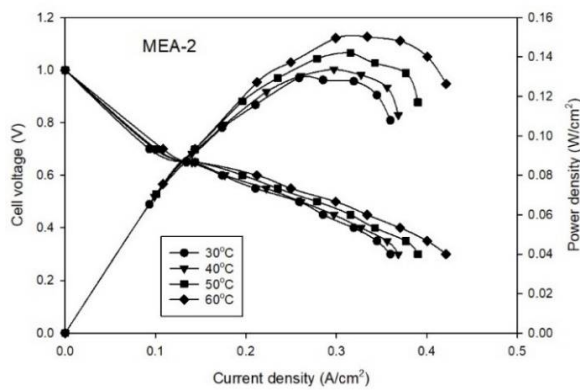
**Effect of Anode gas humidification temperature (AHT)**

Anode gas humidification temperature (AHT) has a potential effect on PEM fuel cell performance. Experiments were conducted to determine the PEM fuel cell performance by varying H<sub>2</sub> gas humidification temperature from 30°C to 60°C. During the experiments, cell and O<sub>2</sub> gas humidification temperatures were held constant at 50°C and 30°C respectively, while gas flow rates of H<sub>2</sub> and O<sub>2</sub> were maintained at 0.15 lpm and 0.25 lpm respectively. Polarization and power curves demonstrating the effect of anode gas humidification temperature on PEM fuel cell performance for MEA-1, MEA-2 and MEA-3 for 17 path parallel serpentine flow field plate is as shown in the Fig.9,10 and 11 respectively.

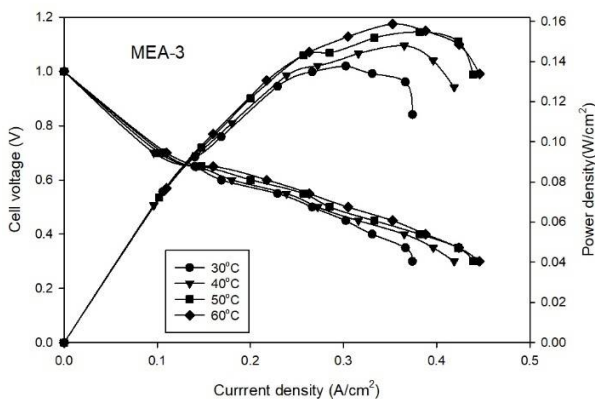
It was observed that the current density increased as H<sub>2</sub> humidification temperature was increased incrementally from 30°C to 60°C. At low humidification temperature of 30°C, cell performance is low due to low reacting gas saturation causing the membrane to dry out which in turn affects in ionic conductivity. As H<sub>2</sub> Humidification temperature increases incrementally to 60°C, performance improves due to higher gas saturation, membrane hydration leading to improved ionic conductivity. At H<sub>2</sub> gas humidification temperatures above 60°C, a decline in performance was observed due to condensation of water droplets in the gas flow channels due to the temperature gradient between humidified H<sub>2</sub> gas and the inside of cell, which effects the PEM fuel cell performance. It was observed that the PEM fuel cell performs better at a slighter higher H<sub>2</sub> humidification, i.e., 60°C, than at a value equal to the cell operating temperature of 50°C. A PEM fuel cell performance of 0.2 A/cm<sup>2</sup>, 0.212 A/cm<sup>2</sup> and 0.217 A/cm<sup>2</sup> for 17 path and 0.194 A/cm<sup>2</sup>, 0.2 A/cm<sup>2</sup> and 0.209 A/cm<sup>2</sup> was obtained for MEA-1,2 and 3 respectively at a reference voltage of 0.6 V.



**Fig.9: Effect of Anode humidification temperature for MEA-1 using 17 Path**



**Fig.10: Effect of Anode humidification temperature for MEA-2 using 17 Path**

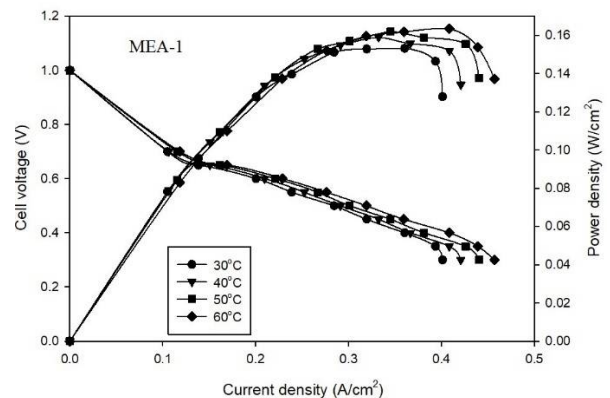


**Fig.11: Effect of Anode humidification temperature (AHT) for MEA-3 using 17 Path**

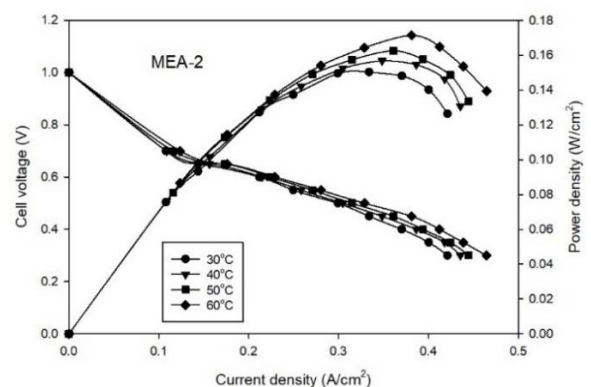
**Effect of cathode gas humidification temperature (CHT)**

Experiments were conducted by varying O<sub>2</sub> gas humidification temperature from 30°C to 60°C. During the experiments, cell and H<sub>2</sub> gas humidification temperatures were held constant at 50°C and 60°C respectively, while gas flow rates of H<sub>2</sub> and O<sub>2</sub> were maintained at 0.15 lpm and 0.25 lpm

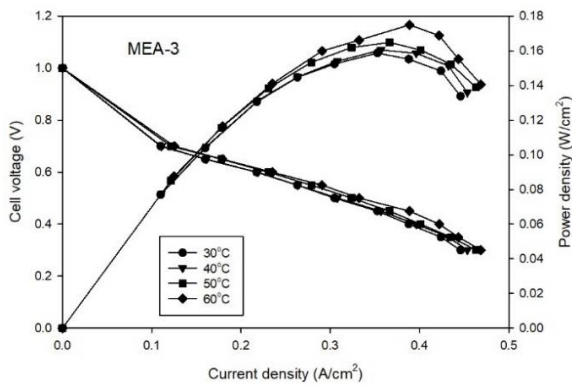
respectively. Polarization and power curves demonstrating the effect of cathode gas humidification temperature on PEM fuel cell performance for MEA-1, MEA-2 and MEA-3 using 17 path is as shown in the Fig.12,13 and 14 respectively. It was seen that when CHT was increased from 30°C to 60°C, a marginal improvement in PEM fuel cell performance was observed. At low values of CHT (30°C), there was little variation in cell performance due to low O<sub>2</sub> saturation. As CHT was increased to 60°C, water production at cathode was complemented by the high O<sub>2</sub> gas saturation. This concentration gradient propelled back-diffusion of water from the cathode to the anode enabling water balance within the cell. We can only observe a decreasing trend of the limiting current density with an increase in CHT, which is because of a decrease in effective porosity of the gas diffusion layers and reactant concentration on the surface of the catalyst layer. At a voltage of 0.6 V, a current density of 0.228 A/cm<sup>2</sup>, 0.229 A/cm<sup>2</sup> and 0.235 A/cm<sup>2</sup> for 17 path and a current density of 0.222 A/cm<sup>2</sup>, 0.223 A/cm<sup>2</sup> and 0.224 A/cm<sup>2</sup> for 13 path was obtained for MEA-1, MEA-2 and MEA-3 respectively.



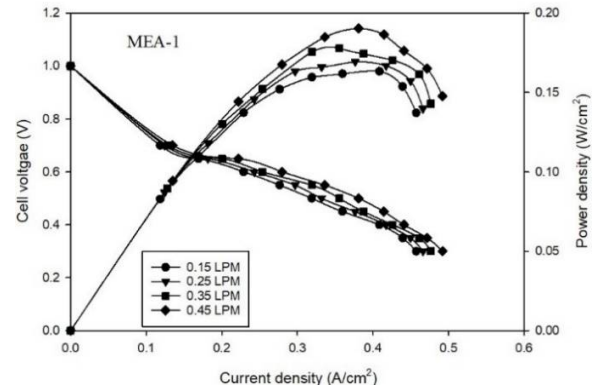
**Fig.12: Effect of Cathode gas humidification temperature (CHT) for MEA-1 using 17 path**



**Fig.13: Effect of Cathode gas humidification temperature (CHT) for MEA-2 using 17 path**



**Fig .14: Effect of Cathode gas humidification temperature (CHT) for MEA-3 using 17 Path**

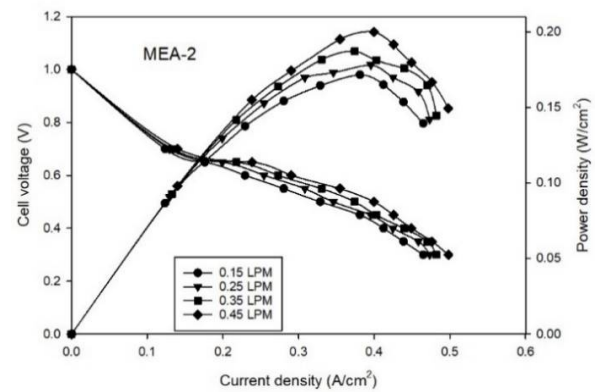


**Fig .15: Effect of Anode gas flow rate for MEA-1 using 17 Path**

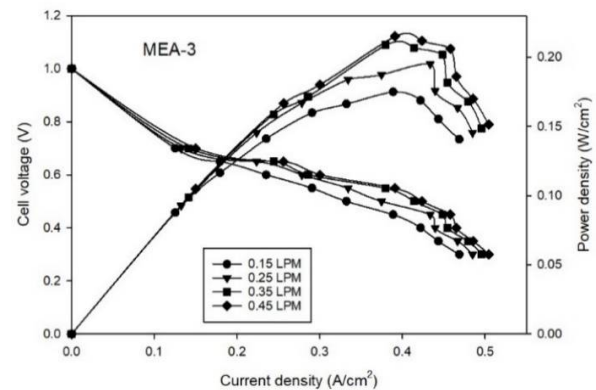
**Effect of Anode gas flow rate (AFR)**

H<sub>2</sub> gas flow rate is another operating parameter that could impact the PEM fuel cell performance. The rate at which reactants are supplied to the fuel cell system must be greater or equal to the rate at which they are assumed in the system. To investigate the impact of anode gas flow rate (AFR) on PEM fuel cell performance, experiments were conducted by varying H<sub>2</sub> gas flow rate from 0.15 lpm to 0.45 lpm. During the experiments, the cell and H<sub>2</sub>/O<sub>2</sub> gas humidification temperatures were held constant at 50°C and 60°C respectively, while O<sub>2</sub> gas flow rate was maintained at 0.25 lpm.

Polarization and power curves demonstrating the effect of anode gas flow rate for MEA-1, MEA-2 and MEA-3 using 17 path as shown in the Fig.15,16 and 17 respectively. From the graphs, it was observed that at a high current density there was a sudden voltage drop. This corresponds to a drop in reactant concentration at the surface of the catalyst layer to the point of zero concentration. The current density produced at this dead point is known as limiting current density which signifies the point of zero concentration of reactants on the surface of the electrode. This limiting current density is directly proportional to AFR. A current density of 0.279 A/cm<sup>2</sup>, 0.29 A/cm<sup>2</sup> and 0.3 A/cm<sup>2</sup> is obtained for 17 path and 0.265 A/cm<sup>2</sup>, 0.279 A/cm<sup>2</sup> and 0.292 A/cm<sup>2</sup> for 13 Path for MEA-1, MEA-2 and MEA-3 respectively at a reference voltage of 0.6 V.



**Fig.16: Effect of Anode gas flow rate for MEA-2 using 17 path**



**Fig.17: Effect of Anode gas flow rate for MEA-3 using 17 path**

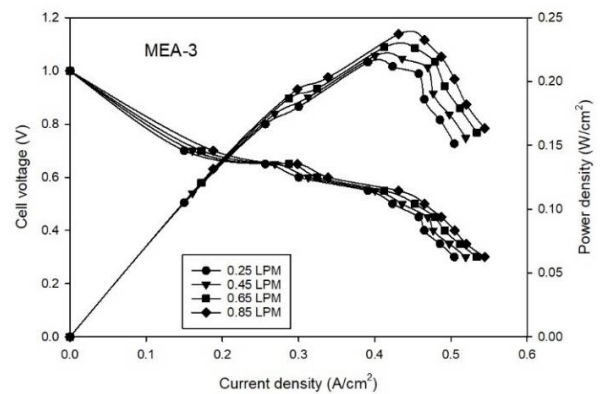
**Effect of cathode gas flow rate (CFR)**

Cathode gas (O<sub>2</sub>) flow rate is another operating parameter that significantly impacts PEM fuel cell performance. In a PEM fuel cell, the stoichiometric ratio of O<sub>2</sub> should always be greater than 1, i.e., supplying O<sub>2</sub> to avoid starvation condition at the cathode. The impact of cathode gas flow rate (CFR) on PEM fuel cell performance was

investigated by varying O<sub>2</sub> gas flow rate from 0.25 lpm to 0.85 lpm. During the experiments, cell and H<sub>2</sub>/O<sub>2</sub> gas humidification temperatures were held at 50°C and 60°C respectively, while H<sub>2</sub> flow rate was maintained at 0.45 lpm. Polarization and power curves demonstrating the effect of CFR on PEM fuel cell performance for MEA-1, MEA-2 and MEA-3 using 17 path are shown in the Fig.18,19 and 20 respectively.

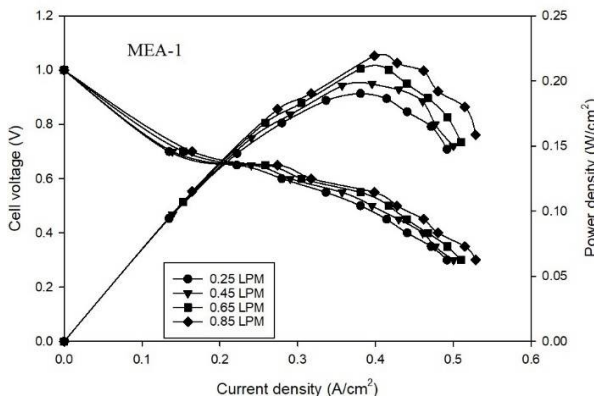
It was observed that the current density increased as CFR was increased from 0.25 lpm to 0.85 lpm. As CFR was increased, more O<sub>2</sub> was transported to the surface of the cathode catalyst layer via the gas diffusion layer. This enhanced the electrochemical reaction between H<sup>+</sup> protons and O<sub>2</sub> to form product water. Also, an increase in cathode flow rate results in high carryover of the product water by unreacted O<sub>2</sub> which prevents flooding conditions at the cathode outlet channel, thereby enabling smooth fuel cell operation and enhancing output. At a reference voltage of 0.6 V, a current density of 0.317 A/cm<sup>2</sup>, 0.326 A/cm<sup>2</sup> and 0.328 A/cm<sup>2</sup> for 17 path and 0.292 A/cm<sup>2</sup>, 0.316 A/cm<sup>2</sup>, 0.318 A/cm<sup>2</sup> for 13 path was obtained for MEA-1, MEA-2 and MEA-3 respectively.

**Fig.19: Effect of Cathode gas flow rate (CFR) for MEA-2 using 17 Path**

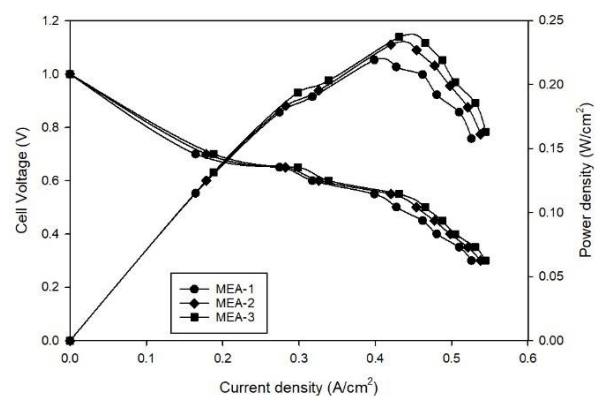


**Fig.20: Effect of Cathode flow rate for MEA-3 using 17 Path.**

The polarization and power curve showing the comparison of MEA-1,2 and 3 using 17 path flow field at peak operating conditions (Cell temperature of 50°C, gas humidification temperatures of 60°C, H<sub>2</sub> gas flow rate of 0.450 lpm and O<sub>2</sub> gas flow rate of 0.850 lpm) was shown in the below Fig.21.



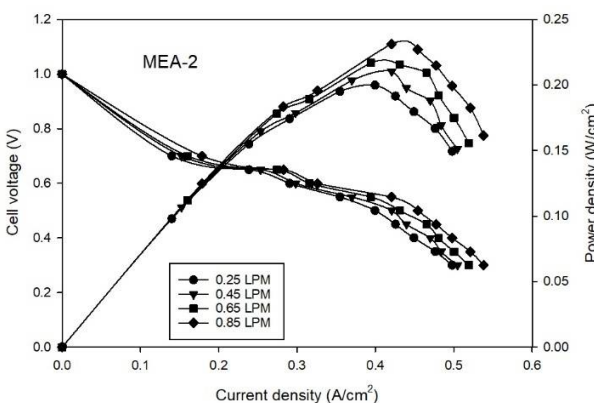
**Fig.18: Effect of Cathode gas flow rate (CFR) for MEA-1 using 17 Path**

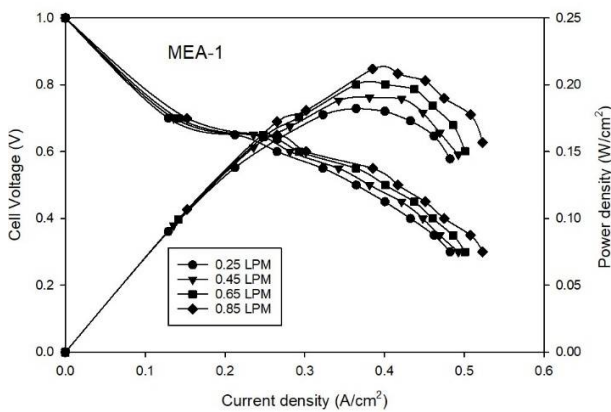


**Fig.21: Comparison of MEA-1,2 and 3 using 17 path flow field**

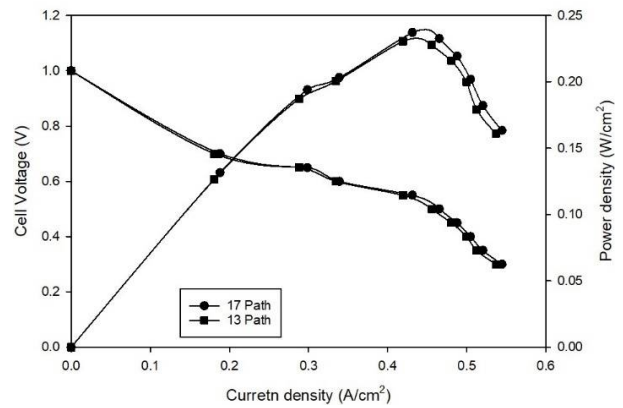
The present experimental work was done with 17 and 13 path parallel serpentine flow field plate.

The maximum performance of MEA-1,2 and 3 using 13 path parallel serpentine flow field plate was obtained at cell temperature of 50°C, gas humidification temperatures of 60°C, Anode (H<sub>2</sub>) flow rate of 0.45 lpm and a Cathode (O<sub>2</sub>) flow rate of 0.85 lpm. The below Fig.22,23 and 24 shows the effect of cathode flow rate for MEA-1,2 and 3 respectively using 13 path.

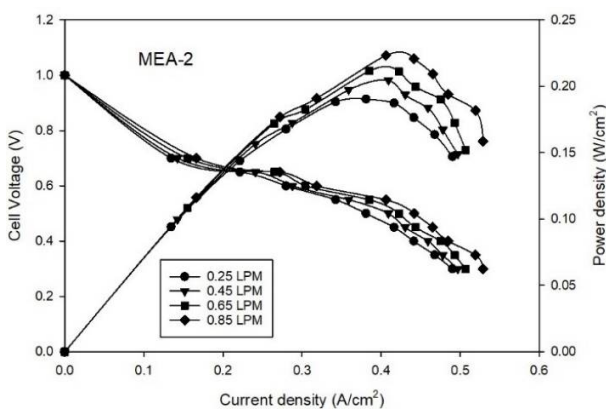




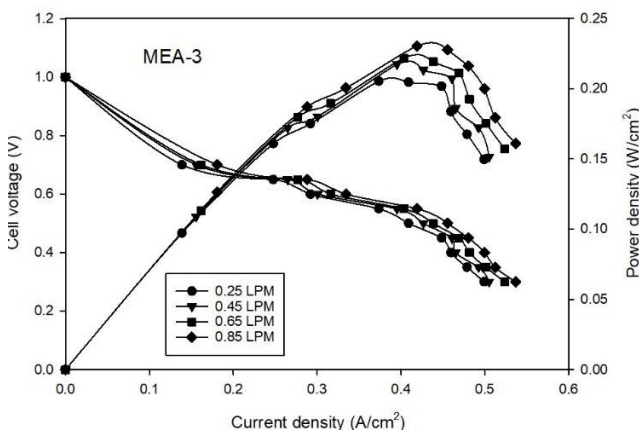
**Fig.22: Effect of CFR for MEA-1 using 13 path**



**Fig.25:Comparative graph between 17 & 13 path for MEA-3**



**Fig.23: Effect of CFR for MEA-2 using 13 path**



**Fig.24: Effect of CFR for MEA-3 using 13 Path**

The comparative study reveals that 17 path flow field yields a better output performance than that of 13 path due to the better gas diffusivity.

## VI. CONCLUSIONS

Experimental studies were carried on a single proton exchange membrane (PEM) fuel cell with an active area of 25 cm<sup>2</sup>. The performance of the three MEAs composed of 30% Pt-Ru/C and 20% Pt/C for anode and cathode respectively with various catalyst loadings was studied using 17 path and 13 path parallel serpentine flow field plate.

1. The output current density of MEA-1, MEA-2 and MEA-3 at peak operating conditions (Cell temperature of 50°C, gas humidification temperatures of 60°C, H<sub>2</sub> gas flow rate of 0.450 lpm and O<sub>2</sub> gas flow rate of 0.850 lpm) are 0.317 A/cm<sup>2</sup>, 0.326 A/cm<sup>2</sup> and 0.328 A/cm<sup>2</sup> for 17 path flow field and 0.292 A/cm<sup>2</sup>, 0.316 A/cm<sup>2</sup> and 0.318 A/cm<sup>2</sup> was obtained for 13 path parallel serpentine flow field at a reference voltage of 0.6 V.
2. Among the three MEAs fabricated and tested, the MEA-3 (Anode 30% Pt-Ru/C with a loading of 0.6 mg of Pt/cm<sup>2</sup>, Cathode 20% Pt/C with a loading of 0.6 mg of Pt/cm<sup>2</sup>) delivered better output performance irrespective of the flow field.
3. From the comparative graph shown in the Fig.25, it is evident that a 17 Path parallel serpentine flow field delivered better output performance than a 13 Path parallel serpentine flow field.

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