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EXPERIMENTAL INVESTIGATION ON SERPENTINE AND PARALLEL FLOW CHANNEL IN PEMFC FOR EFFECTIVE WATER REMOVAL

A. P. Senthil Kumar*[1], S. Janaki[2], K. Sadesh[1]

[1*]Department of Mechanical Engineering, PSG College of Technology, Coimbatore, Tamilnadu, India.
[2]Department of Mechatronics Engineering, SNS College of Technology, Coimbatore, Tamilnadu, India.

ABSTRACT

Polymer electrolyte membrane (PEM) fuel cells are most suited for daily use applications. Advancements in PEM fuel cells are being carried out by many research and development activities over the years. But water management is the major problem in PEM fuel cells which leads to reduced performance and durability. Hence this work deals with effective water management. To examine water removed in PEM fuel cells of 25cm2 active area, experiment was conducted with various combinations of serpentine and parallel flow channels at anode and cathode, of rib to channel ratio of 2:2. Additionally the effect of slope on cathode side flow channel with an arbitrary slope of 1/25 was studied. The different combinations of flow channels which were used at anode and cathode are parallel without slope and parallel with slope, serpentine and serpentine, serpentine and parallel with slope respectively. By activation conditioning and experimentation, it is evident that inducing slope at the side of cathode increases the water removal rate and thereby paving way for performance enhancement. Therefore, by effective water removal from the fuel cell subtle equilibrium is maintained between dehydration and flooding and so the performance of PEM fuel cell is increased.

KEYWORDS

PEM fuel cell, Water management, Flooding and Activation conditioning.

Author for Correspondence:
Senthil Kumar A P,
Department of Mechanical Engineering,
PSG College of Technology,
Coimbatore, Tamilnadu, India.

Email: apspsgct@yahoo.com

INTRODUCTION

PEM fuel cells are widely used because of its robustness, low operating temperature, high power density, quick start up, excellent dynamic response. PEM fuel cells consist of, endplates, sealing gaskets, flow channel plates, MEA (Membrane electrode assembly), fastening structures; provision for inlet and outlet etc., an exploded view of the same is shown in Figure No.1. At anode H_2 splits into H^+ and

e^- ions, at cathode H^+ and e^- ions combines with $O_2$to form water and heat as by products are described below:

At anode: $2H2 \rightarrow 4H^+ + 4e^-$

At cathode: $O2 + 4H^+ + 4e^- \rightarrow 2H2O$

Net reaction: $2H2 + O2 \rightarrow 2H2O + Heat$

The MEA plays a vital role in PEM fuel cell, when fed with hydrogen and oxygen it generates electrical power[1]. The electrolyte forms an electronic insulator and barrier for gases between electrodes for high proton conductivity and high current density. Electro catalyst materials are necessary to increase the rate of chemical reaction. Conventional catalyst layers include nanometre- sized particles of platinum dispersed on a high- surface-area carbon support[2]. Platinum is an excellent catalyst for the hydrogen oxidation reaction and has a very high exchange current density but is susceptible for CO poisoning. This supported platinum catalyst is mixedwith an ion- conducting polymer and sandwiched between the membrane and the GDLs[1]. The GDL (Gas diffusion layer) sit outside the catalyst layers and facilitate transport of reactants into the catalyst layer, as well as removal of product water[3]. Each GDL is typically composed of a sheet of carbon paper in which the carbon fibres are partially coated with polytetrafluoroethylene (PTFE).

The MEA used for all trials consists of platinum coated GDL hot pressed on Nafion 212 membrane. The Pt coating on GDL at anode and cathode side of about 0.3mg/cm2 and 0.6mg/cm2. The sealing gaskets are used to avoid leakage of gas. Flow channel plates are used for reactant gas flow to the membrane. In this way, the gases can react with a lower energy of activation, allowing the reaction to take place at a lower temperature. However, high cost of electro catalysts, hydrogen production and storage, high market entry cost are the major drawbacks of this technology. Water management in PEM fuel cell plays a major role in increasing the protonic conductivity and performance[1]. To maintain these, relative humidity of reactive gases is held at higher value to ensure that the membrane remains fully hydrated[4]. Due to excessive liquid water, resulting in high mass transport resistance the pores of catalyst layer (CL), gas diffusion layer (GDL) as well as flow channels may be flooded[5,1]. Channel level flooding is observed under low stoichiometry or low current conditions, when the stack temperature is relatively cool. Diffusion media flooding can occur as a result of excess water accumulation by condensation[6]. Catalyst layer flooding can occur as a result of liquid condensation and pore filling or localized film formation[4]. Thus an optimum equilibrium has to be maintained between membrane drying and water flooding to prevent fuel cell degradation and guarantee a high performance level.

The performance of PEMFC can be studied with the help of the polarisation curve (V-i curve) shown in Figure No.2 which details the losses in PEMFC:

Activation loss

These are losses associated with the initial dramatic voltage losses in low temperature fuel cells. These losses are basically representative of a loss of overall voltage at the expense of forcing the reaction to completion.

Ohmicloss

These losses simply occur due to the resistance to electron flow in the bipolar plates[3-4]. The final way to reduce resistance associated with Ohmic losses is to create a thin electrode, thus giving the protons a shorter distance to travel before they can combine with the oxygen and electrons.

Concentration loss

These losses occur due to insufficient reactant gas flow to the membrane as it slow down the reaction rate. It can be rectified by supplying excess fuel and oxidant to the cell.

Due to the formation and stagnation of water at the side of cathode the ohmic losses increases thereby decreasing the performance of PEMFC[3]. By modifying the design of flow channel at the cathode the formed ware can be removed effectively leading to lower ohmic loss.

Design considerations

This work considers PEMFC with 25cm2 active area with a rib to channel ratio of 2:2. Experiment was conducted with following combinations as flow channel design at anode and cathode respectively.

Serpentine and serpentine

Parallel without slope and parallel with slope

Serpentine and parallel without slope
Serpentine and parallel with slope
In PEMFC as the gas is consumed at both anode and cathode there will be a pressure drop as the reaction progresses (i.e., along the flow at the active area of membrane) if the pressure at the cathode side is reduced by increasing the volume ofthe flow channel at the cathode side by inducing a slope of 1/25, the pressure at the cathode side drops further and thus enhances the flow of protons from anode to cathode this enhances the performance of cell[3,2].

Experimental work

The fuel cell test station used is of capacity 250 W. when interfaced with a PC it is capable of recording the voltage, current, cell temperature, time etc., and applying loads precisely. The station is capable of delivering humidified reactants at specified temperatures. FC view is an easy to learn package for graphing and analysis of fuel cell data. Individual data files can be analysed using a variety of techniques including built-in functions for analysis of activation, sources of polarisation based on a simple empirical model, as well as linear regression on any available axis. Then the line gas tube, current collector tube to draw current from the cell is also connected as shown in Figure No.3.

After interfacing the Fuel Cell test station to the FC (Fuel cell) view software the following conditions are specified for all trials:

Cell temperature = 40^{o}C Cell size = 25cm2
Purge flow rate = 100ml/min

For anode gas

Flow rate = 500ml/min
Stoichiometric ratio = 1.10
Humidifier temperature = 40^{o}C
Line temperature = 40^{o}C

For Cathode gas

Flow rate = 250ml/min
Stoichiometric ratio =2
Humidifier temperature = 40^{o}C
Line temperature = 40^{o}C

Activation conditioning of membrane

Many sites in the Pt coated GDL remains inactive and lead to poor performance of fuel cell. Thus conditioning is to be done to activate all the sites in Pt coated GDL and increases the performance and protonic conductivity of fuel cell. There are two steps for conditioning as:

Voltage Pulse
Current Pulse

Voltage Pulse

It applies constant voltage for a specified amount of time. In this work voltage pulsing is done by maintaining 0.6V for 20 minutes, 0.5 V for 10 minutes followed by 0.7 V for 10 minutes this set was repeated five times[3].

Current pulse: It applies constant current for a specified amount of time. In this work voltage pulsing is done by maintaining 5 A for 20 minutes[3].

Performance Analysis

There are two techniques used for performance analysis:

Voltage Scan
Current Scan

Voltage Scan

It sweeps the applied voltage between specified set points. By starting from 1 V (open circuit voltage) then go to 0.2 (limiting voltage) for scan rate of 0.3mV/s.

Current scan

It sweeps the applied current between specified set points. By starting from 0 then go to 25 A (approx.) for scan rate of 10mA/s. These are used to plot polarization curves. It is a current response as a function of the applied potential.

Water removal from the fuel cell

To determine the quantity of water leaving the fuel cell Calcium chloride ($CaCl_2$) is considered. It is soluble, deliquescent and hygroscopic in nature thus it considered best for water absorption. The salt is preheated in hot-air oven of about 110^{o}C for 1 hour to remove the moisture already present. The tube is connected at the outlet of cathode side in fuel cell as shown in Figure No.6. The weight of tube with $CaCl_2$ is 44.363g.

Theoretically, for maximum current flow of 25A, water formed in the fuel cell is 3.185 but practically for 15.2A as maximum current flow, water formed due to electrochemical reaction in the fuel cell is 1.937g.

The results are obtained scanning from 1 V (OCV) to 0.2 (limit voltage) for 0.3mV/s scan rate. The water

removal of various flow channels discussed are tabulated below in Table No.1.

When the voltage is too low means after obtaining maximum power the curve begins to drop as shown in Figure No.5.

For serpentine flow channel, the maximum power is 4.761 W for 0.45 V (approx.) and 0.55A/cm2.

For parallel flow channel, the maximum power is 4.754 W for 0.4 V (approx.) and 0.5A/cm2.

For Serpentine and parallel flow channel without slope, the maximum power is 4.812W for 0.44 V (approx.) and 0.52A/cm2.

For Serpentine and parallel flow channel with slope, the maximum power is 4.853 W for 0.43 V (approx.) and 0.54A/cm2.

Table No.1: Maximum power and water removed from various flow channel designs considered

S.No	Flow channel		Maximum power(W)	Weight of tube before water absorption (g)	Weight of tube after water absorption (g)	Water absorbed in salt (g)
	At anode	*At cathode*				
1	Serpentine	Serpentine	4.761	44.161	44.722	0.561
2	Parallel without slope	Parallel with slope	4.754	44.972	46.167	1.195
3	Serpentine	Parallel without slope	4.812	44.564	45.986	1.422
4	Serpentine	Parallel with slope	4.853	44.456	45.967	1.511

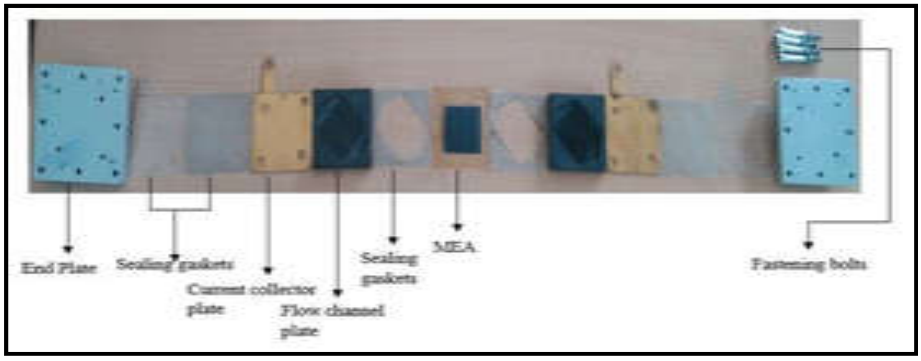

Figure No.1: Exploded view of structure of Fuel cell

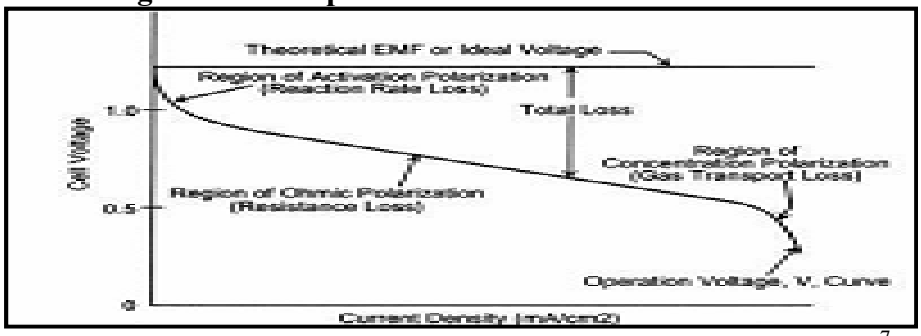

Figure No.2: Polarisation curve of Current density Vs Voltage[7]

Figure No.3: Interfaced fuel cell test station and the system

Figure No.4: Assembled fuel cell with CaCl2 connected at the outlet

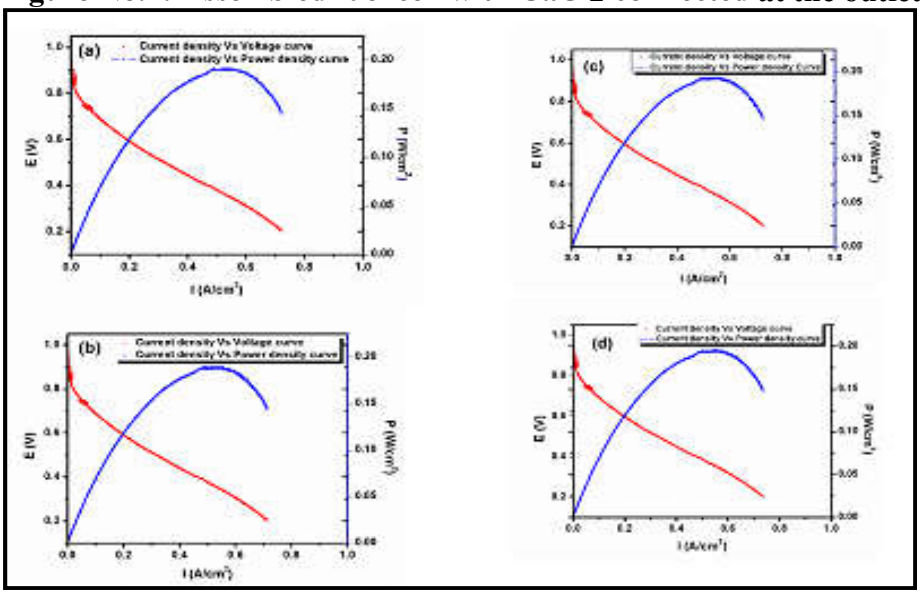

Figure No.5: Graph of Current density Vs Voltage curve (Polarisation curve) and Current density Vs Power density curve for all combinations (a) Serpentine and Serpentine (b) Parallel without slope and Parallel with slope (c) Serpentine and Parallel without slope (d) Serpentine and Parallel with slope

CONCLUSION

Thus it is inferred that combination of Serpentine and parallel flow channel with slope of 1/25 has maximum power and effective water removal. Due to low interfacing area between anode, electrolyte and cathode protonic conductivity increases. Therefore, water is removed effectively and enhances the performance of fuel cell.

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CONFLICT OF INTEREST

We declare that we have no conflict of interest.

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