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# Effect of Back Pressure and Flow Geometry on PEM Fuel Cell Performance - An Experimental Study

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**Abstract:** The purpose of this study is to examine the performance of a PEM fuel cell at different back pressures and channel geometries. Experiments are conducted in BHEL (R&D), Hyderabad with a single cell to study the effect of back pressure created in the hydrogen flow channel on fuel cell performance. The outlet tube from the hydrogen flow channel is immersed in water to a specified depth in a graduated cylindrical container. The back pressure created in the channel depends on the depth to which the outlet tube is immersed in water in the cylinder. The hydrogen bubbles through water to the exit. The excess pressure induced on the fluid helps in forcing the gas through the GDL to the catalyst surface. The voltage and power are measured as functions of current density at different back pressures in the hydrogen flow channel and with different flow fields. The rate of power generation depends on the rate of diffusion of hydrogen through the gas diffusion layer (GDL). After diffusing through GDL hydrogen splits into hydrogen ion and electron on the surface of the catalyst layer. Hence an increase in voltage or power is obtained at a specified current density. Experiments are conducted with three different flow field plates, viz., for 4-Serpentine flow, interdigitated flow and dual inlet single outlet flow. Experimental data have been obtained at three different back pressures with each flow field plate. The three different back pressures are created by immersing the tube in the cylinder at three different depths. An increase in power production is obtained clearly with an increase in back pressure. Further the augmentation in voltage is the highest in the case of serpentine flow.

**Keywords:** 4-Serpentine flow channels; back pressure; dual inlet single outlet; fuel cell; PEM.

## 1. Introduction

Fuel cells have been used extensively over the last few years in various defense and space applications because of their portability. Fuel cells convert chemical energy directly into electricity. However, their use as alternate energy sources to fossil fuels is limited due to their high cost of manufacture and maintenance. Hence efforts are made continuously by researchers all over the world to reduce their cost and to improve their performance.

The MEA (membrane electrode assembly) is an important component in the fuel cell consisting of GDL (porous carbon paper), catalyst layer and proton exchange membrane. Hydrogen gas is passed on one side of the MEA, while oxygen is passed on the other side. The

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extent of production of electric current depends on the rate of diffusion of hydrogen gas across the GDL. The hydrogen gas is forced to diffuse across the porous carbon paper (GDL) while it flows in the channel in the flow field plate. Bends and dead ends are present in the flow path for this purpose. In addition, back pressure can be maintained in the channel to increase the rate of diffusion of hydrogen. Research has been carried out on performance of the fuel cell with back pressure and with different flow field plates.

Hawang et al. [1] conducted a parametric study of a double-cell stack of a proton exchange membrane fuel cell (PEMFC) using Grafoil$^{TM}$ flow-field plate by maintaining different back pressures across the flow channel. They observed that a high flow back-pressure increases the cell performance through enhancing the reaction on both electrodes of the fuel cell at a specified cell operating temperature. The cell performance for the pressurized cathode side is better than that for the pressurized anode side due to the favorable back-diffusion of water in the membrane.

Wang et al. [2] studied the effect of different fuel cell operating temperatures, cathode and anode humidification temperatures, pressures and various combinations of these parameters experimentally.

Systematic experimental data are obtained by Wang et al. [3] on the performance of a proton exchange membrane fuel cell with interdigitated flow fields. The experiments concentrate on the effects of cell temperature, gas humidification, back pressure and reactant gas flow rate. The results are presented in the form of polarization curves. In addition, a three-dimensional fuel cell mathematical model is used to simulate the cell performance with the interdigitated flow fields.

Bipolar plates (BPs) are a key component of proton exchange membrane (PEM) fuel cells with multifunctional character studied by Hermann et.al [4]. The effects of interdigitated flow channel design on the cell performance of Proton Exchange Membrane (PEM) fuel cells are investigated experimentally by Yan et al. [5]. Maher et al. [6] developed a full three-dimensional, non-isothermal computational fluid dynamics model of a PEM fuel cell with straight flow field channels. Wang et al. [7] developed a three-dimensional model to analyze the effect of the design parameters in the bipolar plates. Jeon et al. [8] studied the effect of serpentine flow-field designs on PEM fuel cell performance. Kuo et al. [9] studied the effect of different types of flow channels on the performance improvement in fuel cells.

Polarization and electrochemical impedance spectroscopy experiments are performed on a direct methanol fuel cell (DMFC) incorporating the heteropoly acids (HPAs) phosphomolybdic acid, H3PMo12O40, (HPMo) or phosphotungstic acid, H3PW12O40, (HPW) in the anode Pt/C catalyst layer by Jack et al.[10]. Both HPW-Pt and HPMo-Pt showed higher performance than the Pt control at 30 psig of backpressure and at ambient pressure. Anodic polarizations were also performed, and Tafel slopes were extracted from the data between 0.25V and 0.5V. At 30 psig, Tafel slopes of 133 mV/dec, 146 mV/dec, and 161 mV/dec were found for HPW-Pt, HPMo-Pt and the Pt control, respectively. Jason et al. [11] investigated the bio-inspired flow channel designs for bipolar plates in proton exchange membrane fuel cells. Hamilton and Pollet [12] described some recent developments in the area of flow field plates (FFPs) for proton exchange membrane fuel cells. The function, parameters and design of FFPs in PEM fuel cells are outlined and considered in light of their performance. Kumar and Kolar [13] are studied the effect of cathode channel dimensions on the performance of an air-breathing PEM fuel cell.

In view of the importance of the problem experiments are conducted on single PEM fuel cell with three different flow field plates, namely 4-serpentine, interdigitated and dual inlet single outlet plates. With each flow field plate, experiments are conducted without back pressure, and with three different back pressures. The back pressure is created by the method described as follows. The gas at its exit from the flow field plate is passed through a tube which is immersed

in water contained in a cylinder. The mouth of the tube is immersed to a certain depth in water in the cylinder. The static head of water acts at the mouth of the tube from which the gas exits. The performance of the fuel cell is examined with the three flow field plates and three different back pressures.

## 2. Experimental setup

The experimental set up consists of a single PEM fuel cell with active surface area 9.8 × 9.6 cm of a membrane electrode assembly (MEA) sandwiched between flow field plates, current collector plates and end plates is shown in Figure 1. The experimental set up also consists of three storage cylinders containing hydrogen, oxygen and nitrogen respectively, which are to be used in the fuel cell. Fuel cell test station is used to measure voltage, current and power. Humidification chambers (bottles or tanks) are provided to humidify the hydrogen and oxygen before they enter the fuel cell.

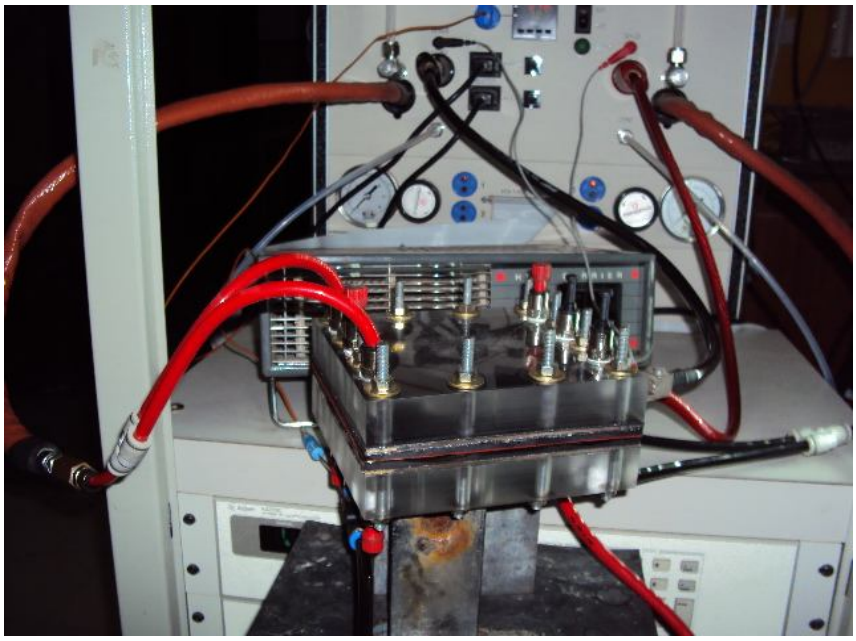

**Figure 1.** Photograph of single PEM fuel cell Experimental set up

The membrane electrode assembly (MEA) consists of the polymer electrolyte membrane (Nafion 1135, 88 μm), the anode and cathode catalyst layers, and the anode and cathode gas diffusion layer (GDL). The electrocatalyst used is carbon-supported Pt. The catalyst ink is prepared from platinum-carbon powder with ethyl alcohol. The catalyst ink is applied as a layer on the gas diffusion layer (which is a carbon paper). The catalyst loading on the anode-side is 0.15 mg/cm$^2$ with a thickness of catalyst layer of 20 μm. A catalyst loading of 0.3mg/cm$^2$ is used on the cathode-side with a thickness of catalyst layer of 40 μm. Carbon papers having thickness of 400 μm are used as gas diffusion layers on both sides. The membrane electrode assembly (viz., membrane, GDLs and catalyst layers) is placed between two graphite plates and is pressed between gold-coated copper plates.

MEA's are prepared in-house with the existing lab facility. The thickness mentioned such as 20 & 40 microns are not exact values, they are average thickness values measured at different locations, arithmetic average of those individual values. The electro-catalyst layer deposited over

the gas diffusion layer using screen printing technique which is being used in many applications to obtain uniform thickness over the substrate material. Catalyst layer thickness is controlled using different screen mesh sizes for a given catalyst ink specific gravity. The catalyst loading mentioned by the authors is an average catalyst loading which is measured based on the mass of catalyst coated GDL before and after process of coating. The torque applied over the plate varies based on the plate dimensions and tightening rod diameter, each time we calculate the torque corresponding to applied pressure of 15 $Kg/cm^2$.

Different flow arrangements have been tested by researchers with the aim of achieving good diffusion of hydrogen through GDL. Experimental studies are conducted with three types of flow field plates for different back pressures. A photograph of the 4-serpentine and interdigitated flow fields are shown in Figure 2.

**Figure 2.** (a) Photograph of 4-Serpentine channel

**Figure 2.** (b) Photograph of Interdigitated channel

A fuel cell test station is used to set and control the fuel cell temperature, humidification temperatures and backpressures on both the anode and cathode sides with the aid of a computer. The test station is supplied by Fuel Cell Technologies Inc., Chennai. The reactant gases (hydrogen and oxygen) drawn from the respective storage tanks are humidified by bubbling through water tanks or bottles. A provision exists to control the extent of humidification of the reactant gases by regulating the temperature of water in the tanks. Fuel cell temperatures and humidification temperatures are controlled by a microprocessor-based temperature/process controller, named CN76122 T/C. Back pressures are controlled by backpressure regulators. The test station also includes a computer-based control and data acquisition system based on Labview$^{TM}$ -based application software. The computer system is connected to flow rate controllers, which are located before the humidifiers. The mass flow rates are set and read through the software. A control panel is provided in the PEM fuel cell test station. The values of all the parameters, which are controlled and monitored, are shown in the control panel.

The fuel cell polarization curves are obtained from this program as well by controlling the HP6050 Electronic Load, which measures the voltage versus current response of the fuel cell.

## 3. Experimental procedure

The three different back pressures are created by immersing the tube in the cylinder to three different depths 4, 8 and 12 in.$H_2O$ head for a single fuel cell as shown in Figure 3. The effect of backpressure in hydrogen flow channel is studied experimentally on the power generated with all the three flow channels. The sequence of steps for each experimental run is as follows:

(1) Power on the Fuel Cell Test Station and open the valves of the gas cylinders of hydrogen, nitrogen and oxygen.
(2) Before starting experiment, purge the anode side with nitrogen to ensure no oxygen is present.
(3) Set the experimental parameters of mass flow rate, fuel cell temperature, humidification temperature and backpressure.
(4) All these parameter readings are noted down from digital meters. Accuracy of these parameters on anode and cathode humidification temperatures are up to one decimal; flow rate up to two decimal, voltage and current values with an accuracy up to 3 decimals.
(5) Set the minimum value of voltage or current and give an increment in voltage or in current. These are selected in the control panel in the fuel cell polarization data panel in the test software interface.
(6) Set the time delay between two successive input voltages (or currents).
(7) Press the 'Start' button to initiate the experiment and collect data.

Time delay: A time delay is allowed between successive data points to ensure steady state at each voltage. A delay of upto 200 s was required for this purpose during the experiments conducted with currents in the range of 0.5-40A.

## 4. Results and discussion

The experimental data obtained on the single PEM with three different flow field plates and with three different back pressures are presented in Figure 4 through 11.

An increase in power production is obtained with an increase in back pressure. The augmentation in voltage is the highest in the case of serpentine flow. Some of the figures are presented below to show some model results.

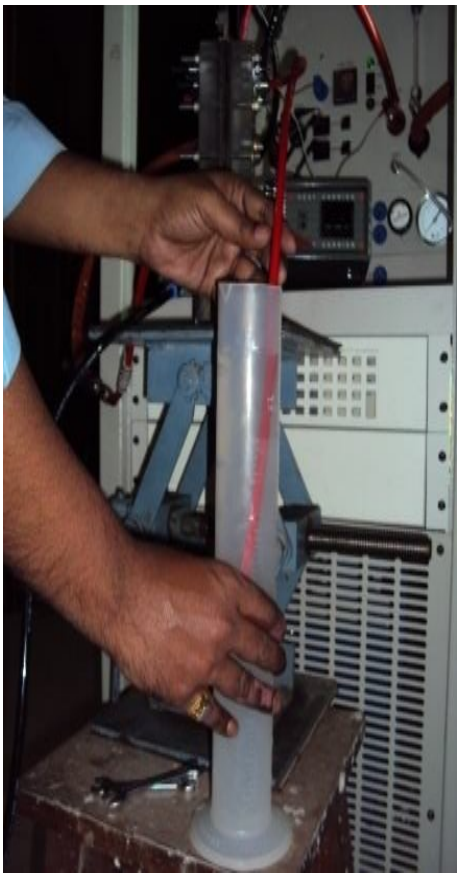

**Figure 3.** Photograph of experimental set up of single cell to create backpressure

The performance of 4-Serpentine (4-S), Interdigitated (ID) and Dual inlet single outlet (DISO) flow channels are compared at the same operating conditions: backpressure, 0.00982 atm, 0.0196 atm, 0.0295 atm, temperature of 60$^{o}$C, and a relative humidity of 100%.

The polarization curves and power curves for 4-S flow channel are shown in Figure 4 and 5 respectively. Figure 6 and 7 respectively are the V-I and P-I curves for DISO flow channel. The 4-S and DISO flow channels show improvement in overall performance and power with different back pressures. The polarization curves and power curves for new-type interdigitated flow channel are shown in Figure 8 and 9 respectively. It can be observed from Figure 8 and 9 the performance of the cell decreases with backpressures. The reason may be the formation of water is more; with this the availability of the gases at the catalyst surfaces decreases. Hence the performance decreases with back pressures. The results of all these channels are also compared for different back pressures. The 4-serpentine design has the best performance followed by the interdigitated and dual inlet and single outlet design.

A comparison of the three different flow field plates would be of interest in a fuel cell while studying its performance. Hence the experimental data presented above are presented below in Figure 10 to give the performance characteristics of fuel cell with the three flow fields with no back pressure. Figure 10 shows that the highest power output is obtained with the 4-Serpentine flow channel in the fuel cell. The interdigitated and DISO flow channels stand in the second and third order respectively in performance. The results at a back pressure of 8 in H2O are presented in Figure 11 with the three flow channels indicates a slightly different behavior. While the 4-Serpentine yields the peak value of power the DISO flow channel becomes the second best.

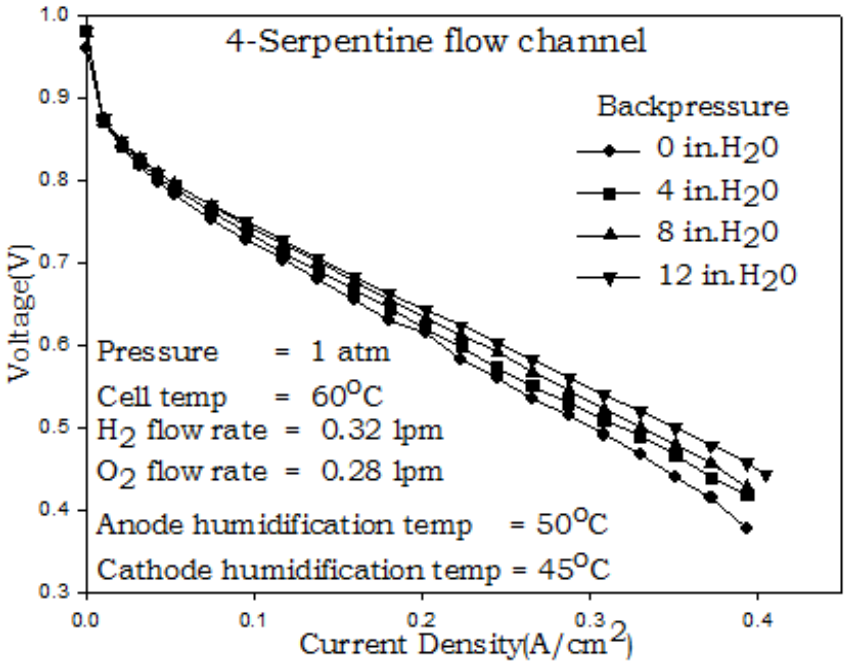


**Figure 4.** Effect of back pressure in 4-Serpentine channel (V-I curves)

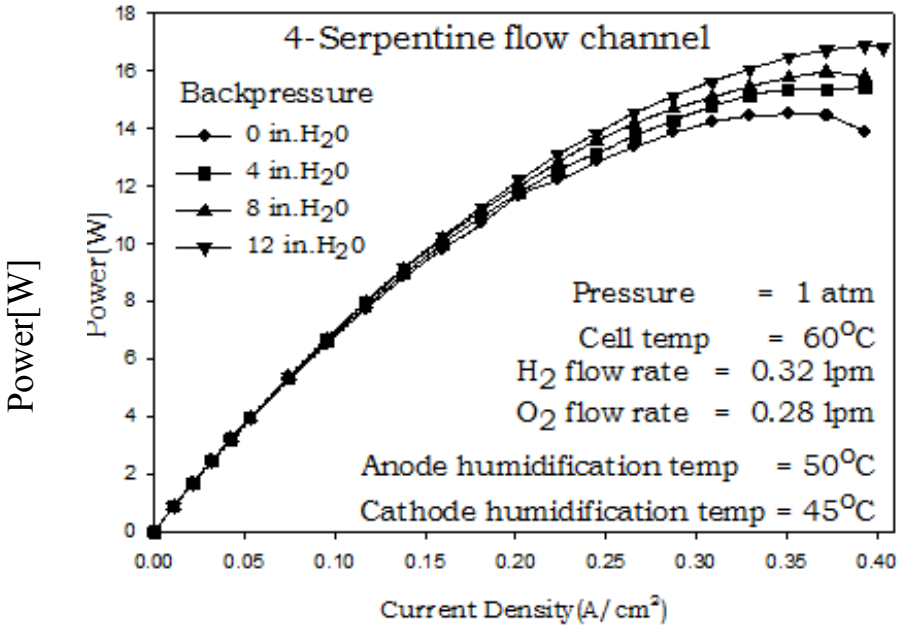


**Figure 5.** Effect of back pressure in 4-Serpentine channel (P-I curves)

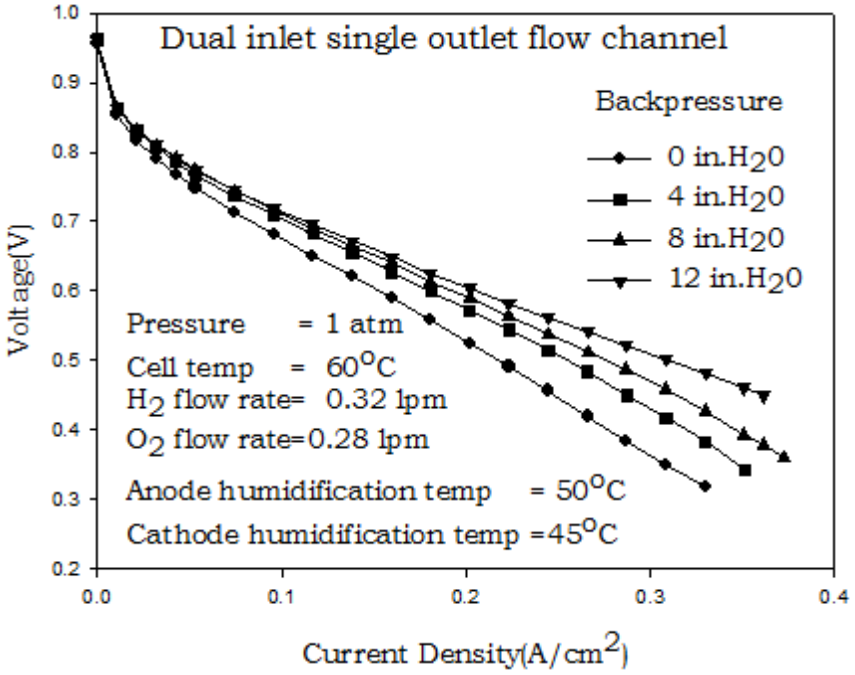


**Figure 6.** Effect of back pressure in dual inlet single outlet channel (V-I curves)

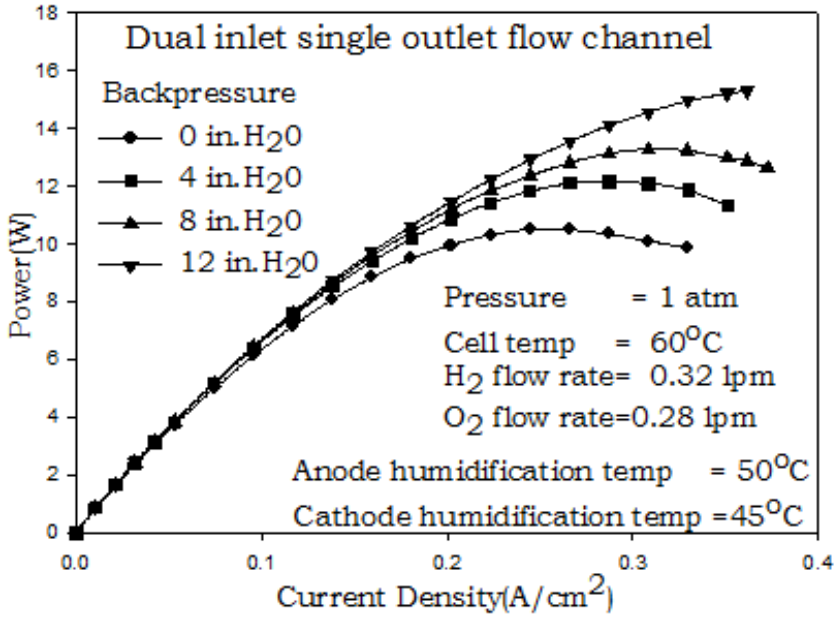


**Figure 7.** Effect of back pressure in dual inlet single outlet channel (P-I curves)

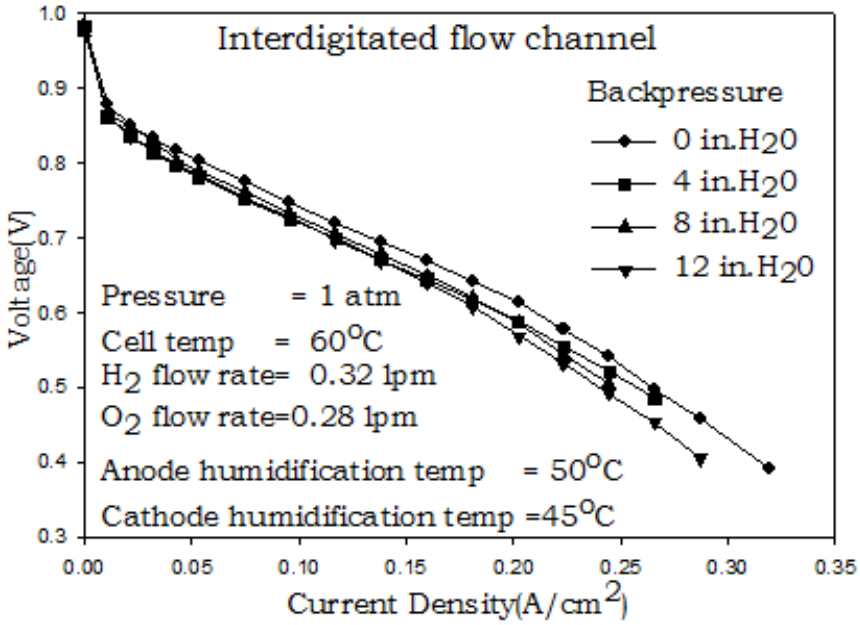


**Figure 8.** Effect of back pressure in Interdigitated channel (V-I curves)

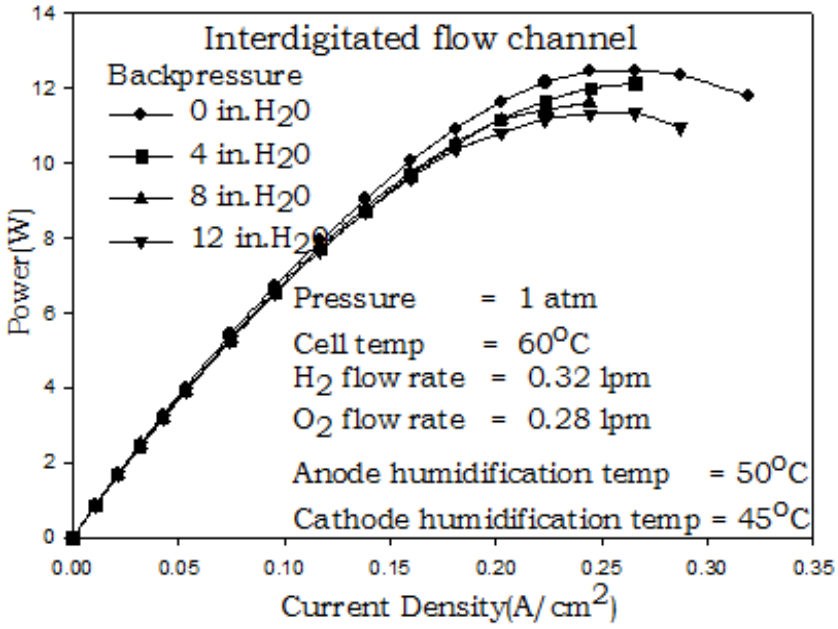


**Figure 9.** Effect of back pressure in interdigitated channel (P-I curves)

The experimental data are cast in the form of explicit equations for voltage (V) as a function of current (I) and back pressure ($P_B$) for the three different flow channels making use of non-linear regression analysis. The equations obtained and their standard deviations with experimental data are given below. These equations are valid over the current range of 0 to 40 A and back pressure of 0 to 12 in water.

4-Serpentine: $V = (0.9046 - 0.01613\ I + 1.015 \times 10^{-4}\ I^2) \exp(-0.004\ P_B)$ Std. Devn. = ±4.8%

Interdigitated: $V = (0.9098 - 0.0170\ I + 1.131 \times 10^{-5}\ I^2) \exp(-0.004\ P_B)$ Std. Devn. = ±2.9%

DISO: $V = (0.8988 - 0.02004\ I + 1.617 \times 10^{-4}\ I^2) \exp(-0.004\ P_B)$ Std. Devn. = ±8.9%

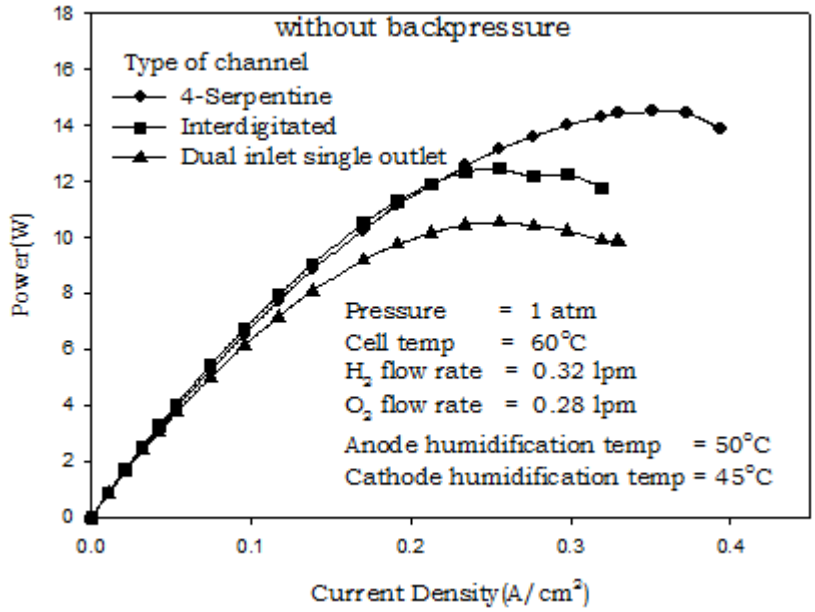


**Figure 10.** Effect of back pressure (0 in.$H_2O$) on different channels (P-I curves)

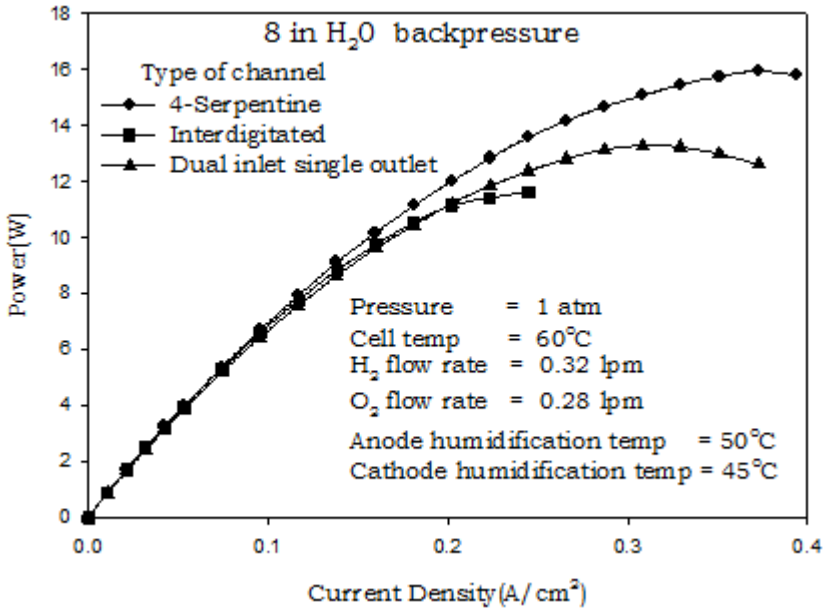


**Figure 11.** Effect of back pressure (8 in.$H_2O$) on different channels (P-I curves)

## 5. Conclusions

(1) The performance of the fuel cell increases with an increase in back pressure in the flow channels due to an increase in residence time of hydrogen in the channel. As a result there is an increase in the diffusion rate of hydrogen across the GDL.
(2) The 4-Serpentine flow channel helps in obtaining the highest power output both without and with back pressure. At higher back pressures the dual inlet and single outlet flow channel performs better than the interdigitated channel.
(3) The regression equations obtained in this study would be useful to compute readily the

voltage as a function of current and back pressure for the three different flow channels.

(4) Two new flow channels have been used in this study. They are the interdigitated and DISO channels. Even the 4-serpentine channel was developed and made indigenously. The experiments conducted to examine the effect of back pressure offer a new method to increase the power output particularly at low catalyst loadings. The intension of using low catalyst loading was to decrease the cost.

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