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# NUMERICAL ANALYSIS ON 36cm$^2$ PEM FUEL CELL FOR PERFORMANCE ENHANCEMENT

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## ABSTRACT

The effect of the various parameters affects the performance of the Proton exchange Membrane (PEM) fuel cell. In this work the various landing to channel width of (L: C) 1:1, 1:2 and 2:2 Multipass serpentine flow channel PEM fuel cell with 36 cm$^2$ (6cm x 6cm) effective area was analyzed numerically. The model was developed and simulated under the pressures ranges from 1 bar to 2.5 bar, stepping by 0.5 bar and temperature ranges from 323 K to 353K increasing by 10 K using Creo 2.0 the fluent CFD 14 software respectively. The maximum power densities of 0.658, 0.642 and 0596 W/cm$^2$ were obtained in the L: C of 1:1, 1:2 and 2:2, respectively.

**Keywords:** CFD, simulated, creo, multi pass serpentine, PEM fuel cell.

## INTRODUCTION

The research work is increasing day by day on PEM fuel cell due to their high energy density, lower operating temperature and high efficiency. The PEMFC can compete in both stationary and automobile power generation applications because of high efficiency and showing less environmental impact than other thermal engines [1]. To increase the polarization of fuel cell, the flow channel design of the fuel cell was properly designed that the uniform distribution of reactant was achieved to reach the membrane through the gas diffusion layer so that the improving current and proper temperature dissipation was achieved. So the performance was affected by the design parameters like flow field and channel design of PEMFC analyzed by Oosthuizen *et al* [2]. It was an important task in identifying the flow field design and flow channel which affects the performance of fuel cell significantly while designing [3].Water and thermal management also very important to improve the performance of fuel cell. It was discussed with two dimensional model by Nguyen and Yi [4, 5]. Most of the two dimensional models were developed to study the operating parameters without considering the ribs between the gas channels. The three dimensional model was developed to study the distribution of velocity, pressure, reactant mixture density and current contours under the ribs by Dutta *et al* [6]. The water management study is important to maintain the power density, high efficiency and for the stable operation of the PEMFC in the long run. Humidification of membrane is important for high proton conductivity, because it is directly impacting on its water content [7, 8]. The accumulation of more water in the anode and cathode side is affecting the performance of fuel cell significantly. The excess water (flooding) blocks the pores of the GDL and flow channel causes the reduction in reactant mass transport to the catalyst site particularly at the cathode side [9, 10]. On the other hand, dehydration is drying the membrane due to shortage of water on the anode side which leads to higher ohmic and ionic losses in the PEM fuel cell so the result in significant drop on potential and power [11-13]. The trend is going to study the influence of various flow field designs by computational fluid dynamics [14]. In this study, we designed multi pass flow channel of 36 cm$^2$ active area landing to channel ratio (L: C) -1:1,1:2 and 2:2 were created and with the help of this, the performance of PEM fuel cell has also been calculated by varying operating temperatures of 323,333,343 and 353 K and operating pressures at1, 1.5, 2 and 2.5 bar respectively.

## METHODOLOGY

The modelling of multi pass PEM fuel cell involved three major steps. The first step was creating individual parts of the multi pass single channelled serpentine PEM fuel cell which was done in Creo Parametric 2.0. Creating the mesh from the geometry using ICEM CFD 14 was the second step. In order to solve the myriad of equations associated with a fuel cell simulation, the entire cell was divided into computational cells. In our study, we got a maximum of 0.7 million nodes and 0.83 million elements for various landing to channel ratios. The simulation has been solved all the simultaneous equations to obtain reaction kinetics of PEM fuel cell, namely mass fraction of $H_2$, $O_2$, and $H_2O$, temperature, static pressure and current flux density distribution. Creating a good mesh has been one of the most difficult steps involved in modeling. It requires a careful balance of creating enough computational cells to capture the geometry without creating much of its care should be taken such that it would not exceed the available memory of the meshing computer. Many other factors must also be considered into account in order to generate a computational mesh which provides representative results when simulated. The last step was the adoption of boundary condition with physical and operating parameters of PEMFC for solving the reaction kinetics.

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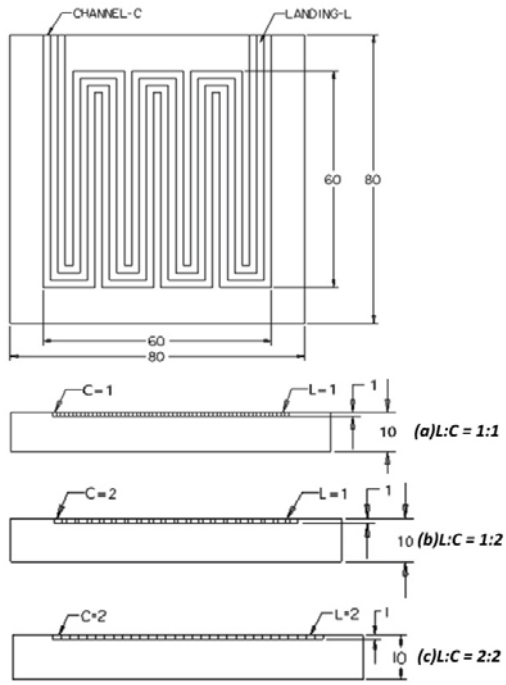
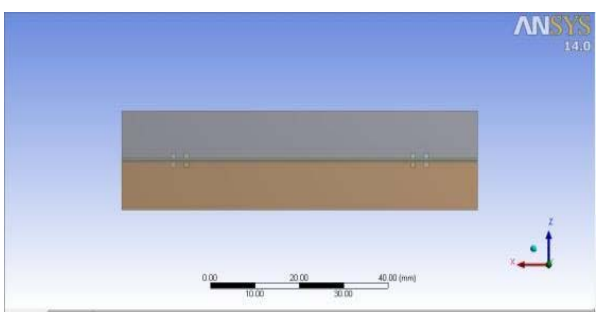
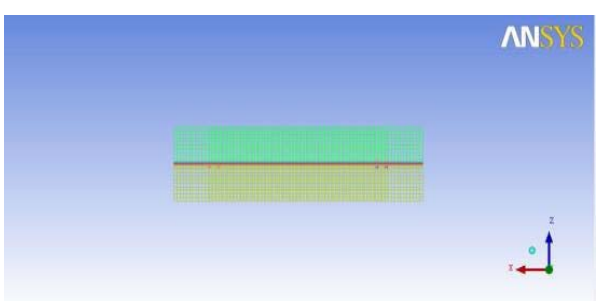



**Figure-1.** 2D model of double pass serpentine flow channel of 36cm$^2$ active area with Landing to Channel ratio (L: C) - (a) 1:1 (b) 1:2 (c) 2:2.




(a)




(b)

**Figure-2.** (a) Modelling of PEMFC (b) Meshing of PEMFC.

**Dimensions of Fuel Cell**

MEA assembly 8 cm x 8 cm x 0.012 cm
Gas diffusion layer 8 cm x 8 cm x 0.03 cm
Flow channel 6 cm x 6 cm x 1 cm
Anode and Cathode catalyst 8 cm x 8 cm x 0.008 cm

**Boundary Conditions**

- Inlet and outlet zones for the anode gas channel
- Inlet and outlet zones for the cathode gas channel
- Surfaces representing anode and cathode terminals
- Optional boundary zones that could be defined include any voltage jump surfaces, interior flow surfaces or non-conformal interfaces that are required.

**Continuum Zone**

- Flow Channels for anode and cathode-sides
- Anode and cathode current collectors
- Anode and cathode gas diffusion layers
- Anode and cathode catalyst layers
- Electrolyte membrane

All the inlets should be assigned the boundary zone type as 'mass flow inlet' and outlets should be assigned as 'pressure outlet' type. The anode is grounded (V = 0) and the cathode terminal is at a fixed potential which is less than the open circuit potential. Both the terminals should be assigned the 'wall' boundary type. Voltage jump zones can optionally be placed between the various components (such as between the gas diffusion layer and the current collector). Faces which represent solid interfaces must be of the type 'wall'.

**RESULTS AND DISCUSSIONS**

The influence of various flow channel design of PEM fuel cell has been carried out by using Fluent software by varying the operating range of pressure from 1 bar -2.5 bar and operating range of temperature from 333K -353K. The performance of the PEM fuel cell with the above mentioned flow channel and operating parameters has been shown by polarization curve (V-I curve) and the performance curve (P-I curve). The Polarization curve is the curve against the voltage (V) and current density (W/cm$^2$) and the performance curve is the curve against the current density (A/cm$^2$) and the power density (W/cm$^2$) which gives information about the performance of fuel cell (Figure-3).

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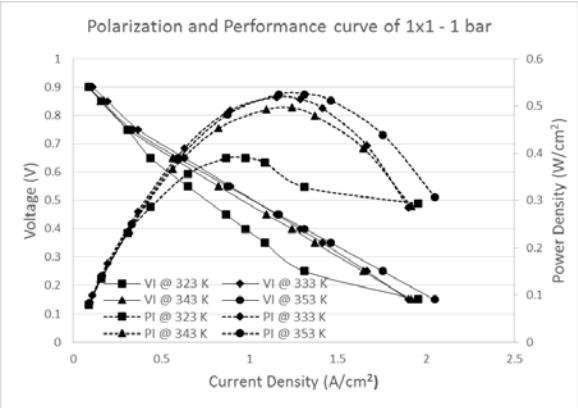


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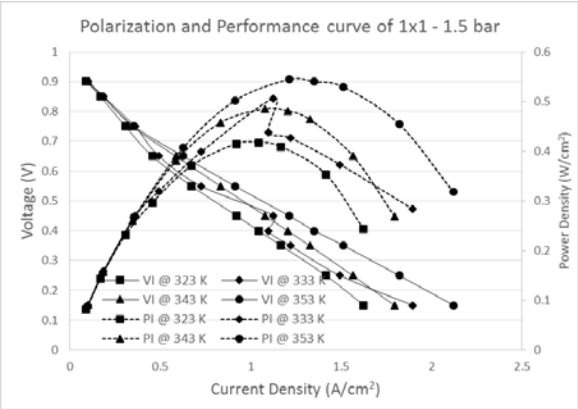


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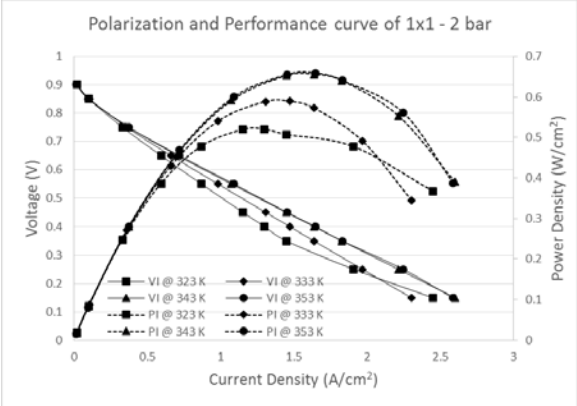


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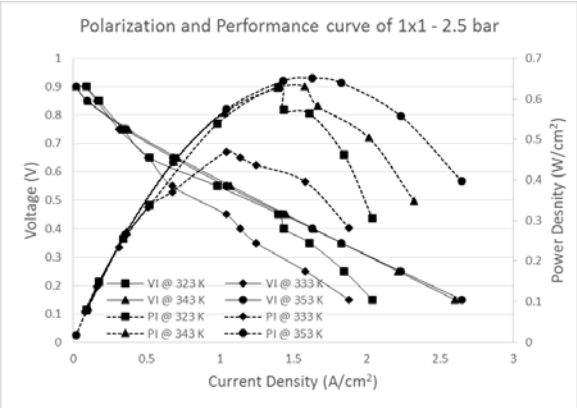


(d)

**Figure-3.** Polarization and performance curve of 1x1 at (a) 1 bar (b) 1.5 bar (c) 2 bar and (d) 2.5 bar.

The Figure-3(b) displays the performance and a polarization curve of PEMFC with Landing to Channel ratio 1:1 of effective area 36 $cm^2$ has produced 1.043 $A/cm^2$ current density and a power density of 0.417 $W/cm^2$ at 1.5 bar and 323 K operating temperature at the cell potential of 0.4 V. For the operating temperature of 333K at 0.45 V potential the current density was 1.095 $A/cm^2$ and the power density was 0.506 W/cm. For 0.45 V potential and at the operating temperatures of 343 K, 353 K the current densities were 1.078 $A/cm^2$ and 1.210 $A/cm^2$ respectively, and the power densities were found to be 0.485 $W/cm^2$ and 0.544 $W/cm^2$ respectively. The figure.3 (c) projects the polarization and the performance curve of the L: C ratios 1:1 at 2 bar pressure. The current density was found to be 1.30 $A/cm^2$ and the power density was found to be 0.520 $W/cm^2$ at 323 K operating pressure and 0.4 V cell potential. At 333 K operating temperature and at a cell potential of 0.4 V the current and the power densities were 1.472 $A/cm^2$ and 0.589 $W/cm^2$ respectively. At 343 K operating temperature and at the cell potential of 0.4 V the current and the power densities of 1.637 $A/cm^2$ and 0.655 $W/cm^2$ were obtained. Since the temperature of 353 K and the cell potential of 0.4 V the current density obtained was 1.646 $A/cm^2$ and the power density obtained was 0.658 $W/cm^2$. Figure-3(d) displays the polarization and the performance curve for the operating pressure of 2.5 bar with a temperature of 323 K and at the cell potential of 0.45 V the current and the power densities obtained were 1.398 $A/cm^2$ and 0.629 $W/cm^2$ respectively. At the operating temperature of 333 K, a pressure of 2.5 bar and the cell potential of 0.45 V the current density was 1.041 $A/cm^2$ and the power density was 0.468 A/cm. For the operating temperature of 343 K and the cell potential of 0.4 V the current density obtained was 1.575 $W/cm^2$ and the power density of 0.630 $W/cm^2$ was obtained. At the cell potential of 0.4 V and the temperature of 353 K, the current and the power densities obtained were 1.628 $A/cm^2$ and 0.651 $W/cm^2$, respectively.

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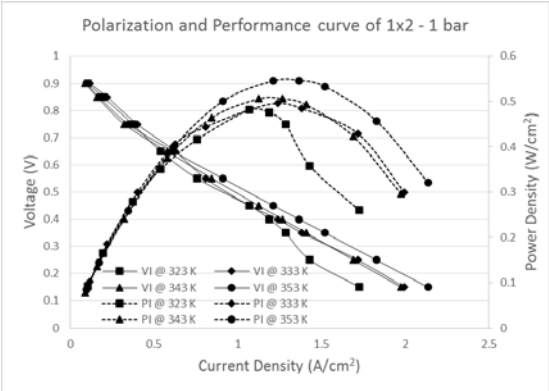


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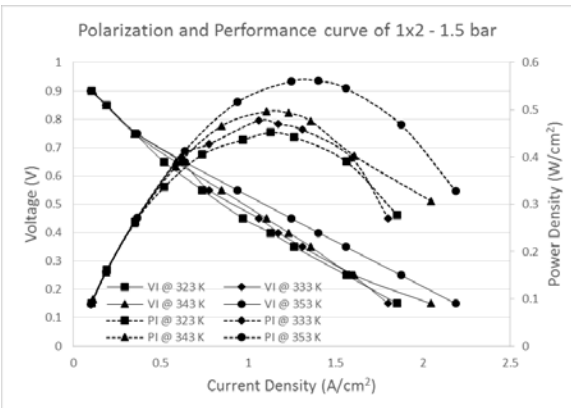


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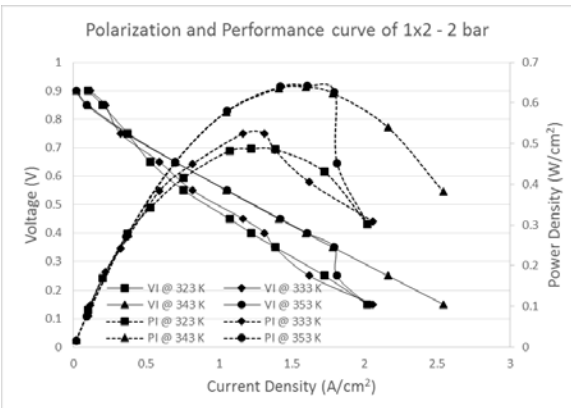


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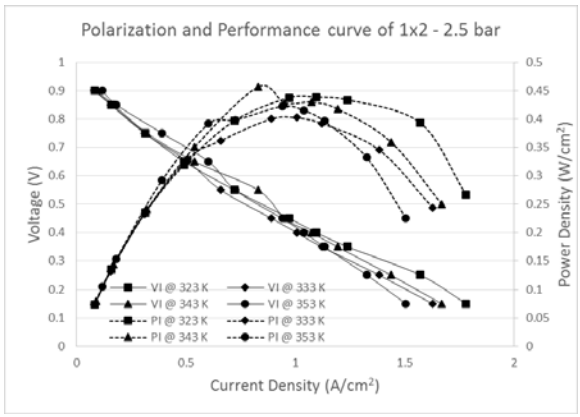


**(d)**

**Figure-4.** Polarization and performance curve of 1x2 at (a) 1 bar
(b) 1.5 bar (c) 2 bar and (d) 2.5 bar

Figure-4(a). Shows the graph between the current density, power density and the voltage for L: C ratio of 1:2 at 1 bar pressure. The PEM fuel cell with Landing to Channel ratio 1:2 and effective area of 36cm$^2$ produced a current density of 1.069 A/cm$^2$ and a power density of 0.481 W/cm$^2$ at 1 bar, 323K operating temperature and at the cell potential of 0.45 V. At the operating temperature of 333K and 0.4 V voltage, the current density of the fuel cell was 1.239 A/cm$^2$ and the power density was found out to be 0.495 W/cm$^2$. The polarization and the performance curve for 0.4 V potential at 343 K and 353 K, the current densities were found to be 1.265 A/cm$^2$ and 1.365 A/cm$^2$ respectively, and the power densities were found to be 0.506 W/cm$^2$ and 0.546 W/cm$^2$ respectively. The Figure-4 (b). displays the performance and a polarization curve of PEMFC with Landing to Channel ratio 1:2 of effective area 36 cm$^2$ has produced 1.129 A/cm$^2$ current density and a power density of 0.451 W/cm$^2$ at 1.5 bar and 323 K operating temperature at the cell potential of 0.4 V. For the operating temperature of 333 K at 0.45 V potential the current density was 1.0606 A/cm$^2$ and the power density was 0.477 W/cm$^2$. For 0.45 V potential and at the operating temperatures of 343 K the current density was 1.102 A/cm$^2$ and the power density was found to be 0.496 W/cm$^2$. At the cell potential of 0.4V and at the temperature of 353 K the current and the power densities were found to be 1.403 A/cm$^2$ and 0.561 W/cm$^2$ respectively. The figure.4 (c) projects the polarization and the performance curve of the L: C ratios 1:2 at 2 bar pressure. The current density was found to be 1.219 A/cm$^2$ and the power density was found to be 0.487 W/cm$^2$ at 323 K operating pressure and 0.4 V cell potential. At 333 K operating temperature and at a cell potential of 0.4 V the current and the power densities were 1.312 A/cm$^2$ and 0.525 W/cm$^2$ respectively. At 343 K operating temperature and at the cell potential of 0.4 V the current and the power densities of 1.596 A/cm$^2$ and 0.638 W/cm$^2$ were obtained. For the temperature of 353 K and the cell potential of 0.4 V the

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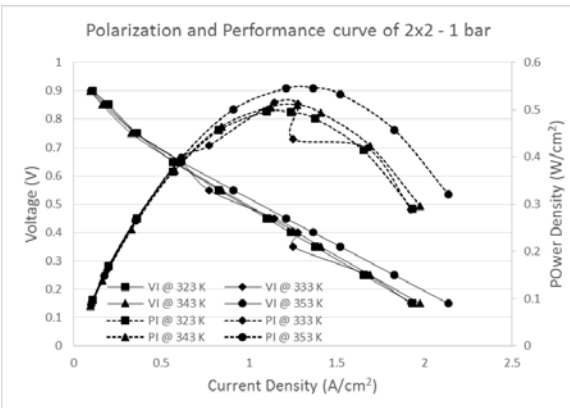
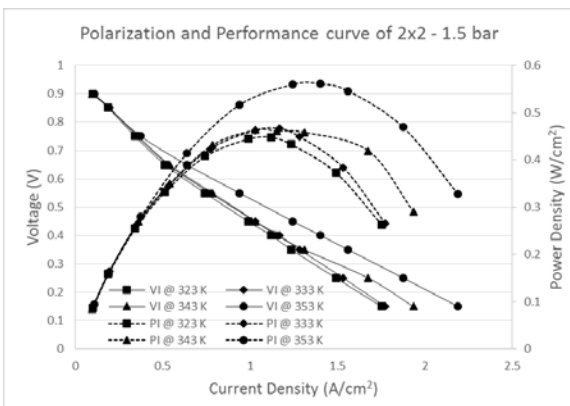
current density obtained was 1.605 A/cm$^2$ and the power density obtained was 0.642 W/cm$^2$. Figure-4(d) displays the polarization and the performance curve for the operating pressure of 2.5 bar with a temperature of 323 K and at the cell potential of 0.4 V the current and the power densities obtained were 1.095 A/cm$^2$ and 0.438 W/cm$^2$ respectively. At the operating temperature of 333 K, pressure of 2.5 bar and the cell potential of 0.4 V the current density was 1.005 A/cm$^2$ and the power density was 0.402 A/cm$^2$. For the operating temperature of 343 K and the cell potential of 0.4 V the current density obtained was 1.072 W/cm$^2$ and the power density of 0.429 W/cm$^2$ was obtained. At the cell potential of 0.4 V and the temperature of 353 K, the current and the power densities obtained were 0.939 A/cm$^2$ and 0.422 W/cm$^2$ respectively.

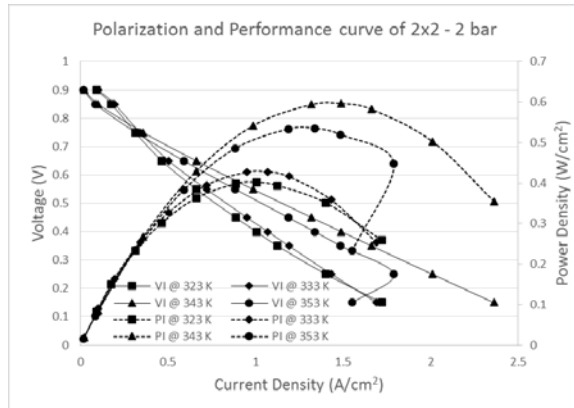



**(a)**

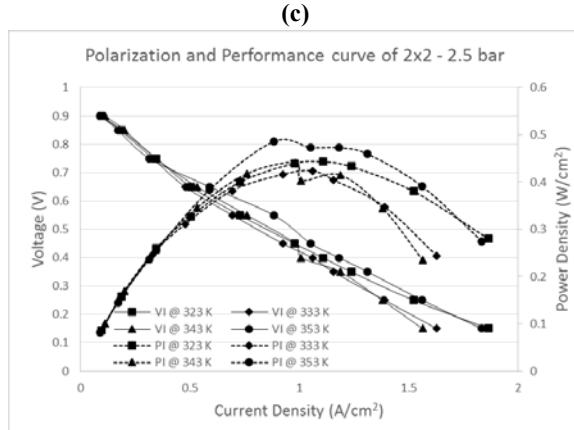



**(b)**

Figure-5(a). Shows the graph between the current density, power density and the voltage for L: C ratio of 2:2 at 1 bar pressure. The PEM fuel cell with Landing to Channel ratio 2:2 and effective area of 36cm$^2$ produced a current density of 1.101 A/cm and a power density of 0.495 W/cm$^2$ at 1 bar, 323K operating temperature and at the cell potential of 0.45 V. At the operating temperature of 333K and 0.45 V voltage, the current density of the fuel cell was 1.143A/cm$^2$ and the power density was found out to be 0.514 W/cm$^2$.




**(c)**




(d)

**Figure-5.** Polarization and performance curve of 2x2 at (a) 1 bar (b) 1.5 bar (c) 2 bar and (d) 2.5 bar.

The polarization and the performance curve for 0.4 V potential at 343 K and 353 K, the current densities were found to be 1.274 A/cm$^2$ and 1.365 A/cm$^2$ respectively, and the power densities were found to be 0.509 W/cm$^2$ and 0.546 W/cm$^2$ respectively. The figure. 5 (b).displays the performance and a polarization curve of PEMFC with Landing to Channel ratio 2:2 of effective area 36 cm$^2$ has produced 1.1207 A/cm$^2$ current density and a power density of 0.448 W/cm$^2$ at 1.5 bar and 323 K operating temperature at the cell potential of 0.4 V. For the operating temperature of 333K at 0.4 V potential the current density was 1.166 A/cm$^2$ and the power density was 0.466 W/cm$^2$. For 0.45 V potential and at the operating temperatures of 343 K the current density was 1.029 A/cm$^2$ and the power density was found to be 0.463 W/cm$^2$. As a cell potential of 0.4 V and the operating temperature of 353 K the current and the power densities obtained were 1.402 A/cm$^2$ and 0.561 W/cm$^2$ respectively. The figure.5 (c) projects the polarization and the performance curve of the L: C ratios 2:2 at 2 bar pressure.

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The current density was found to be 1.004 A/cm$^2$ and the power density was found to be 0.401 W/cm$^2$ at 323 K operating temperature and 0.4 V cell potential. At 333 K operating temperature and at a cell potential of 0.4 V the current and the power densities were 1.069 A/cm$^2$ and 0.427 W/cm$^2$ respectively. At 343 K operating temperature and at the cell potential of 0.4 V the current and the power densities of 1.4903 A/cm$^2$ and 0.596 W/cm$^2$ were obtained. Since the temperature of 353 K and the cell potential of 0.4 V the current density obtained was 1.338 A/cm$^2$ and the power density obtained was 0.535 W/cm$^2$. Figure. 5(d) displays the polarization and the performance curve for the operating pressure of 2.5 bar with a temperature of 323 K and at the cell potential of 0.4 V the current and the power densities obtained were 1.107 A/cm$^2$ and 0.443 W/cm$^2$ respectively. At the operating temperature of 333 K, a pressure of 2.5 bar and the cell potential of 0.4 V the current density was 1.059 A/cm$^2$ and the power density was 0.423 A/cm$^2$. For the operating temperature of 343 K and the cell potential of 0.45 V the current density obtained was 0.981 W/cm$^2$ and the power density of 0.441 W/cm$^2$ was obtained. At the cell potential of 0.45 V and the temperature of 353 K, the current and the power densities obtained were 1.051 A/cm$^2$ and 0.473 W/cm$^2$ respectively.

## CONCLUSIONS

**Table-1.** Maximum values for various landing to channel widths (L:C) - 1:1, 1:2 and 2:2.

| Model | Pressure (bar) | Temperature (K) | Voltage(V) | Current Density (A/cm$^2$) | Power Density (W/cm$^2$) |
|---|---|---|---|---|---|
| 1x1 | 1 | 353 | 0.4 | 1.311 | 0.524 |
| | 1.5 | 333 | 0.45 | 1.095 | 0.506 |
| | 2 | 353 | 0.4 | 1.646 | 0.658 |
| | 2.5 | 353 | 0.4 | 1.628 | 0.651 |
| 1x2 | 1 | 353 | 0.4 | 1.365 | 0.546 |
| | 1.5 | 353 | 0.4 | 1.403 | 0.561 |
| | 2 | 353 | 0.4 | 1.605 | 0.642 |
| | 2.5 | 323 | 0.4 | 1.095 | 0.438 |
| 2x2 | 1 | 353 | 0.4 | 1.365 | 0.546 |
| | 1.5 | 353 | 0.4 | 1.402 | 0.561 |
| | 2 | 343 | 0.4 | 1.490 | 0.596 |
| | 2.5 | 353 | 0.45 | 1.051 | 0.473 |

The maximum power density for a fuel cell is achieved between 0.4 - 0.45 cell potential for 36 cm$^2$ effective area flow channel designs and various operating temperatures and pressures. We achieved maximum power density of 0.658 W/cm$^2$ in landing to channel ratio of 1:1at 2 bar 353 K temperature. The power density of PEMFC with 1:2 of is produced the 0.642 W/cm$^2$ power density at 2 bar 353 K and the power density for L: C- 2:2 was 0.596 W/cm$^2$ at 2 bar 343K operating temperature.

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