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PERFORMANCE ENHANCEMENT ON 36CM^2 SINGLE PASS INTERDIGITATED FLOW CHANNEL OF PEMFC

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ABSTRACT

In this paper the performance of various rib to channel width of (R: C) 1:1,1:2 and 2:2 Single pass interdigitated flow channel of Proton Exchange Membrane Fuel Cell (PEMFC) with 36 cm^2 (6cm x 6cm) effective area with constant mass flow rate of species was analyzed numerically. The effect of the various parameters affects the performance of the PEMFC. The model was developed and simulated using Creo 2.0 the Fluent CFD 14 software respectively. The pressure ranges from 1 bar to 2.5 bar, with an interval of 0.5 bar and temperature ranges from 323 K to 353K increasing by 10 K. The maximum power of 18.1476, 18.774 and 18.0828 W was obtained in the R: C of 1:1, 1:2 and 2:2 respectively.

Keywords: CFD, simulated, creo, single pass interdigitated, flow channel design.

INTRODUCTION

The PEMFC is an efficient energy converting device which converts chemical energy of the air fuel mixture into electrical energy. The environment friendly fuel cell produces electrical energy along with heat and water as byproducts as long as the reactants are feeding. The PEM Fuel Cell is promising one for automobile application due to its lower operating temperature, quick startup and its quick response to changes in power demand addressed by [1]. The PEM Fuel Cell consists of an anode and a cathode in between these a proton exchange membrane is sandwiched. Pure hydrogen as fuel is supplied at the anode and is converted into charged protons and electrons. The protons move towards the cathode side through the membrane, whereas the current passes through the outer circuit. Positively charged protons and negatively charged electrons combine at the cathode side and combine with oxygen to produce water and heat. The electrochemical reactions are:

At the Anode: $\mathrm{H_2 \rightarrow 2H^+ + 2e^-}$

At the cathode: $\frac{1}{2}\mathrm{O_2} + 2H^+ + 2e^- \rightarrow \mathrm{H_2O}$

Overall reaction: $\mathrm{H_2} + \frac{1}{2}\mathrm{O_2} \rightarrow \mathrm{H_2O}$

Nguyen and White [2] and Yi and Nguyen [3] published two-dimensional models explaining the importance of thermal and water management to maintain the PEMFC performance. Though, the first model was quasi two-dimensional, and the other two models neglected the gas diffusion layers. However the effect of the ribs between the gas channels was omitted in one and two dimensional models. Dutta *et al* [4] developed a three-dimensional model to present distributions like pressure, velocity, local current contours and mixture density under the ribs. A recent study has shown that water management is important to ensure stable operation, high efficiency and to maintain the power density of PEM fuel cells in the long run. On one hand it is important to keep the membrane humidified for high proton conductivity, because the membrane conductivity is directly related to its water content [5-7]. On the other hand, PEMFC performance and lifetime were affected by stagnation of water. The pores of the Gas Diffusion Layer (GDL) and flow channel were blocked by the water accumulation which results in a shortage of reactant. Flooding is the accumulation of more water and can happen on both sides of the membrane. Fuel cell flooding occurs particularly on the cathode side [8]. Flooding leads to an instant increase in mass transport losses, particularly at the cathode, that is the transport rate of the reactants to the electro-catalyst sites is significantly reduced [8, 9]. The anode side leads more possibilities for dehydration of the membrane due to the poor water management, leading to a shortage of water, which leads to instant and long-term degradation. As a result of dehydration the proton-conducting membrane dries. The higher ionic resistance and ohmic losses are due to the decreasing of conductivity which in turn results decreasing of water content. [9, 6, 11]. That results in a significant drop in cell potential and consequently a temporary power loss [5, 11, 12].

The objectives of flow-field design are surging constant current and temperature supplies at the operating conditions of interest while maintaining or improving polarization analyzed by Oosthuizen *et al* [13]. So identifying the proper channel and flow field design is a very important task while designing the fuel cell which also affects the performance of fuel cell significantly [14]. Generally the trend is going to do the analysis of PEM fuel cell with various flow field designs and their influence using Computational Fluid Dynamics (CFD) [15]. Interdigitated single pass flow channel has not been considered with various operating and design parameters in the above analysis. Hence, in this paper immediate attention has been given to single pass interdigitated PEM

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fuel cell of 36 cm^2 effective area with constant mass flow rate of species for various operation conditions like pressure(1,1.5,2 and 2.5 bar), temperature(323, 333, 343 and 353K) and design parameter like rib to channel width ratio(R:C)- 1:1, 1:2 and 2:2.

METHODOLOGY

The modeling of single pass PEMFC involved three major steps. Creating individual parts of the single pass single channelled interdigitated PEMFC was the first step which was done in Creo Parametric 2.0. Creating the mesh from the geometry with the help of 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. The simulation has been solved all the simultaneous equations to obtain reaction kinetics of PEMFC, 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. The Figure-1 shows the consolidated model of single pass interdigitated 36 cm^2 effective area with Rib to Channel ratio (R:C) of 1:1,1:2 and 2:2.

Dimensions of Fuel Cell

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

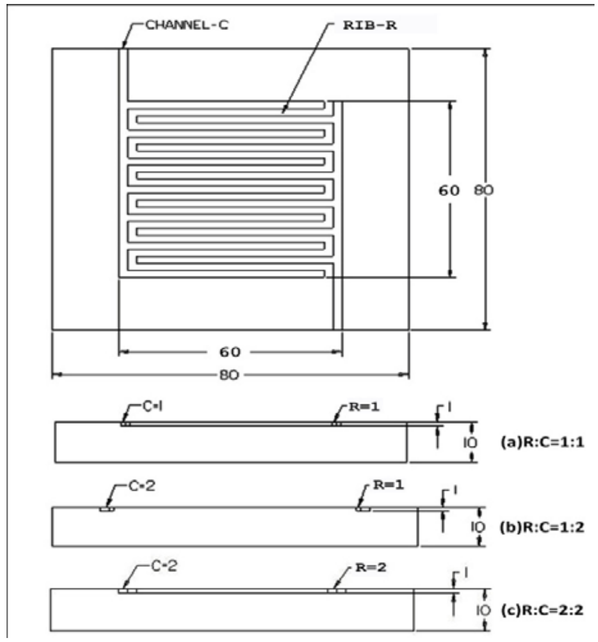

Figure-1. Model of single pass interdigitated flow channel of 36cm^2 active area with rib to channel ratio (R:C) - (a) 1:1 (b) 1:2 (c) 2:2.

Boundary Conditions

The basic boundary conditions are the inlet and outlet zones for the anode and cathode gas channel, surfaces representing anode and cathode terminals and also the optional boundary zones that could be defined, including non-conformal interfaces or interior flow and voltage jump surfaces that are required.

Continuum Zone

Continuum zone consists of flow channels for anode and cathode-sides, anode and cathode current collectors, gas diffusion layers, catalyst layers and the electrolyte membrane.

All the inlets should be assigned the boundary zone type as ‘mass flow inlet’ and outlets must be allotted like ‘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. The positive and negative terminals should be assigned the ‘wall’ type boundary. Voltage jump zones can be placed between the several components like between the gas diffusion layer and the current collector. Faces which represent solid interfaces must be of the type ‘wall’.

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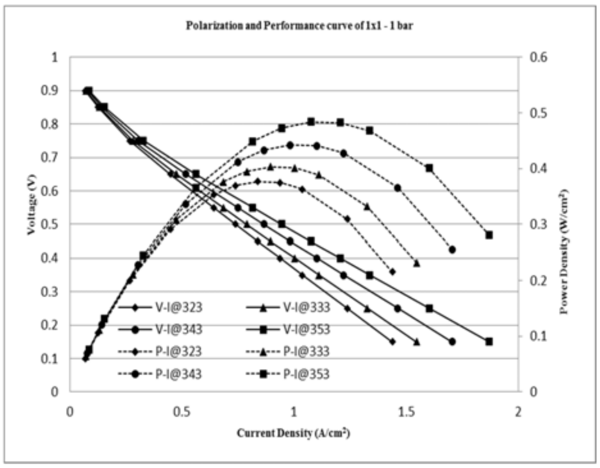
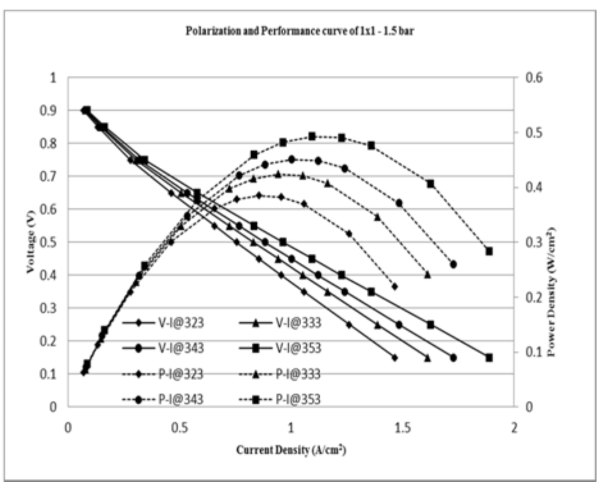
RESULT AND DISCUSSIONS

The performance curve (P-I curve) and the polarization curve (V-I curve) of PEMFC obtained from various operating pressure, temperature by varying the cell voltage from 0.05 V to 0.9 V and various rib to channel ratio using Fluent CFD 14.0. The Polarization curve is the graphical representation curve between the current density (A/cm^2) and voltage (V) and the performance curve is the curve against the power density (W/cm^2) to the current density (A/cm^2).

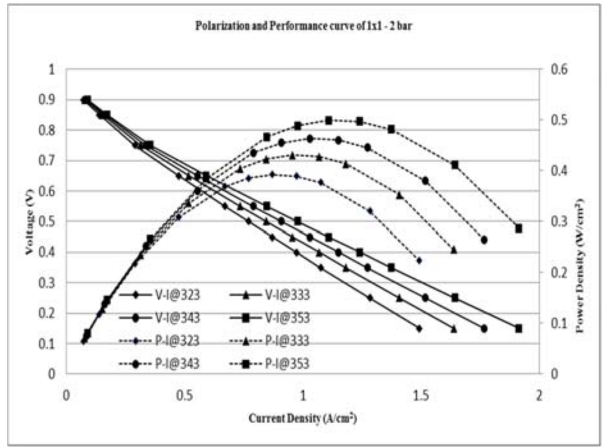


(a)



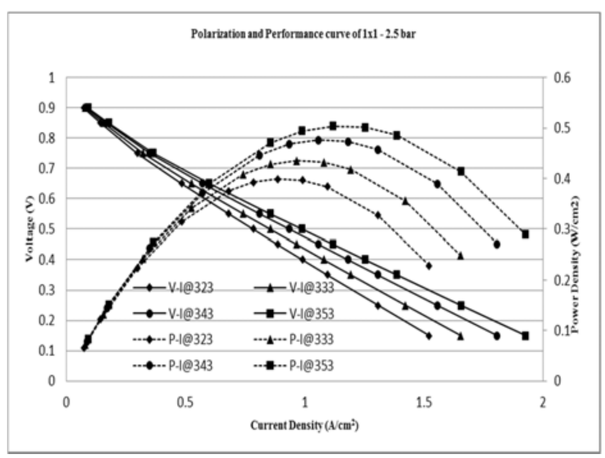
(b)

Figure-2(a) shows the graphical representation between the power density (W/cm^2), current density (A/cm^2) and the voltage (V) for R: C ratio of 1:1 for various temperatures at 1 bar pressure. The PEMFC with effective area of 36cm^2 produced a current density of 0.838 A/cm^2 and a power density of 0.3771 W/cm^2 at 323K operating temperature at the cell potential of 0.45 V. Since the operating temperature of 333K and 0.45 V voltages, the power density was found out to be 0.4029 W/cm^2 and the current density of the fuel cell was 0.895 A/cm^2. The polarization and the performance curve for 0.45 V potential at 343 K and 353 K, the power densities were found to be 0.4424 W/cm^2 and 0.4836 W/cm^2 and the current densities were found to be 0.983 A/cm^2 and 1.074 A/cm^2 respectively.



(c)

The Figure-2 (b) displays the polarization and performance curve of PEMFC with Rib to Channel ratio 1:1 of effective area 36 cm^2 for various temperatures at 1.5 bar. It produced a power density of 0.3849 W/cm^2 and 0.855 A/cm^2 current density at 323 K operating temperature at the cell potential of 0.45 V. For the operating temperature of 333K at 0.45 V potential the current density was 0.941 A/cm^2 and the power density was 0.4237 W/cm^2.For 0.45 V potential and at the operating temperatures of 343 K, 353 K the power densities were found to be 0.4509 W/cm^2 and 0.4925 W/cm^2 respectively and the current densities were 1.002 A/cm^2 and 1.094 A/cm^2 respectively.



(d)

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

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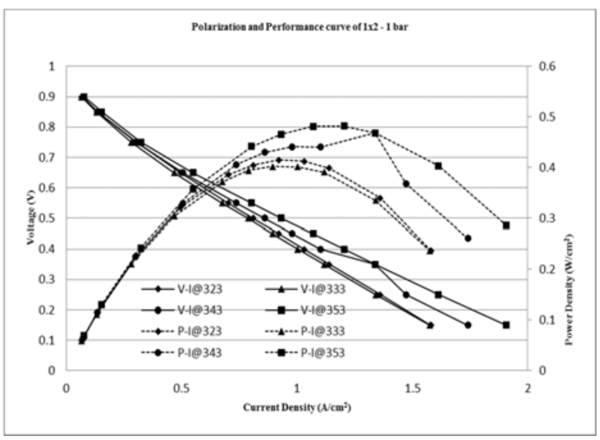
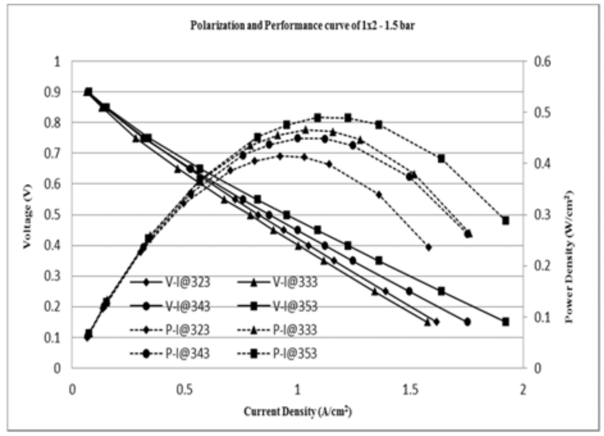
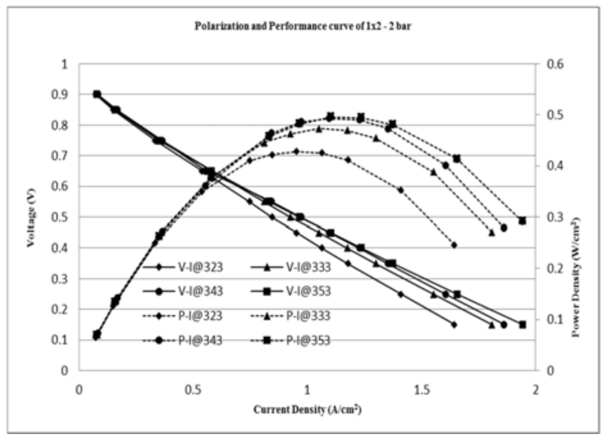
The Figure-2 (c) projects the polarization and the performance curve of the R: C ratio 1:1 at 2 bars pressure with various temperatures. The power density was found to be 0.3921 W/cm^2 and the current density was found to be 0.871 A/cm^2 at 323 K operating pressure and 0.45 V cell potential. At 333 K operating temperature and at a cell potential of 0.45 V the current and the power densities were 0.956 A/cm^2 and 0.4303 W/cm^2 respectively. At 343 K operating temperature and at the cell potential of 0.45 V the current and the power densities of 1.029 A/cm^2 and 0.4634 W/cm^2 were obtained. For the temperature of 353 K and the cell potential of 0.45 V the current density obtained was 1.108 A/cm^2 and the power density obtained was 0.4989 W/cm^2. Figure-2(d) displays the polarization and the performance curve for the various temperatures and operating pressure of 2.5 bar. At a temperature of 323 K and at the cell potential of 0.45 V the current and the power densities obtained were 0.886 A/cm^2 and 0.3990 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 0.967 A/cm^2 and the power density was 0.4352 A/cm^2. For the operating temperature of 343 K and the cell potential of 0.45 V the current density obtained was 1.058 A/cm^2 and the power density of 0.4764 W/cm^2 was obtained. At the temperature of 353 K, the cell potential of 0.45 V the current density and power density obtained were 1.120 A/cm^2 and 0.5041 W/cm^2 respectively.



(a)



(b)



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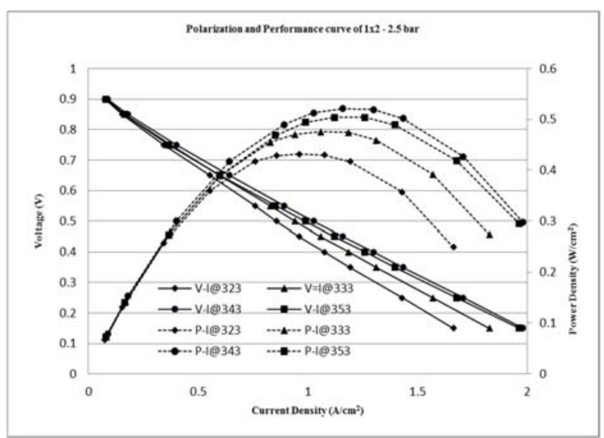

(d)

Figure-3. Polarization and performance curve of 1x2 at (a) 1 bar (b) 1.5 bar (c) 2 bar and (d) 2.5 bar.

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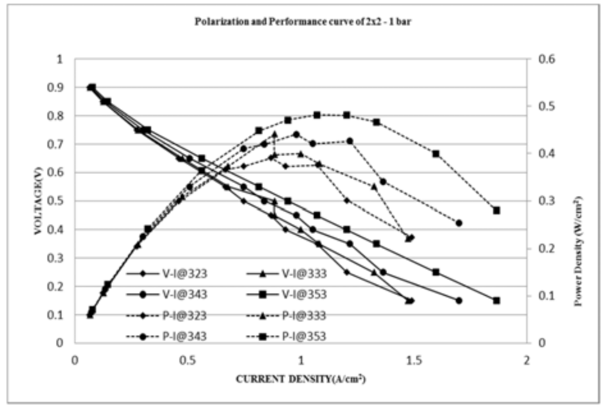
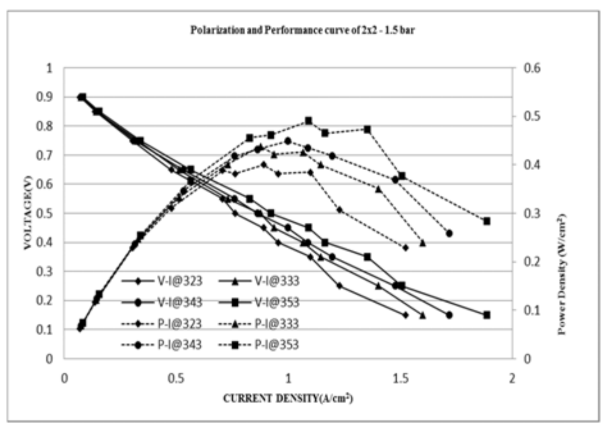
Figure-3 (a) shows the graphical representation between the current density, power density and the voltage for R: C ratio of 1:2 for 1 bar pressure at various operating temperatures. The PEMFC produced a current density of 0.921 A/cm^2 and a power density of 0.4148 W/cm^2 at 323K operating temperature and at the cell potential of 0.45 V. At the operating temperature of 333K and 0.45 V voltage, the power density was found out to be 0.4019 W/cm^2 and current density of the fuel cell was 0.893 A/cm^2.The performance and polarization the curve for 0.45 and 0.4 V potentials at 343 K and 353 K, the current densities were found to be 0.979 A/cm^2 and 1.204 A/cm^2 respectively, and the power densities were found to be 0.4407 W/cm^2 and 0.4186 W/cm^2 respectively. The figure. 3 (b).displays the performance and a polarization curve of PEMFC with Rib to Channel ratio 1:2 of effective area 36 cm^2 at 1.5 bar and various operating temperatures. It produced a power density of 0.4226 W/cm^2 and 0.939 A/cm^2 current density at 323 K operating temperature at the cell potential of 0.45 V. For the operating temperature of 333K at 0.45 V potential the power density was 0.4660 W/cm^2 and current density was 1.035 A/cm^2.For 0.45 V cell potential and 343 K temperature the current density was 0.999 A/cm^2 and the power density was found to be 0.4496 W/cm^2. At the cell potential of 0.45V and the temperature of 353 K the current and the power densities were found to be 1.088 A/cm^2 and 0.4899 W/cm^2 respectively. The Figure-3 (c) projects the performance and the polarization curve of the R: C ratio 1:2 for various operating temperatures at 2 bar pressure. The current density was found to be 0.951 A/cm^2 and the power density was found to be 0.4283 W/cm^2 at 323 K operating pressure and 0.45 V cell potential. At 333 K operating temperature and at a cell potential of 0.45 V the current and the power densities were 1.051 A/cm^2 and 0.4730 W/cm^2 respectively. At 343 K operating temperature and at the cell potential of 0.45 V the current and the power densities of 1.096 A/cm^2 and 0.4933 W/cm^2 were obtained. Since the temperature of 353 K and the cell potential of 0.45 V the current density obtained was 1.102 A/cm^2 and the power density obtained was 0.4960 W/cm^2. Figure 3(d) displays the performance and the polarization curve for the operating pressure of 2.5 bar and various operating temperatures. At a 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 0.959 A/cm^2 and 0.4318 W/cm^2 respectively. At the operating temperature of 333 K, the cell potential of 0.45 V the power density was 0.4759 A/cm^2 and the current density was 1.057 A/cm^2. For the cell potential of 0.45 V and the operating temperature of 343 K the current density obtained was 1.159 W/cm^2 and the power density of 0.5215 W/cm^2 was obtained. At the temperature of 353 K and the cell potential of 0.4 V, the current and the power densities obtained were 1.260 A/cm^2 and 0.5041 W/cm^2 respectively.



(a)

Figure-4(a) shows the graphical representation dealing with various operating temperatures (323,333,343 and 353 K) between the current density (A/cm^2), power density (W/cm^2) and the voltage (V) for R: C ratio of 2:2 at 1 bar pressure. The PEMFC with effective area of 36cm^2 and Rib to Channel ratio 2:2 produced a current density of 1.073 A/cm^2 and a power density of 0.3758 W/cm^2, at the cell potential of 0.35 V and 323K operating temperature. At the operating temperature of 333K and 0.5 V cell potential, the power density was found out to be 0.4414 W/cm^2 and the current density of the fuel cell was 0.882 A/cm^2.



(b)

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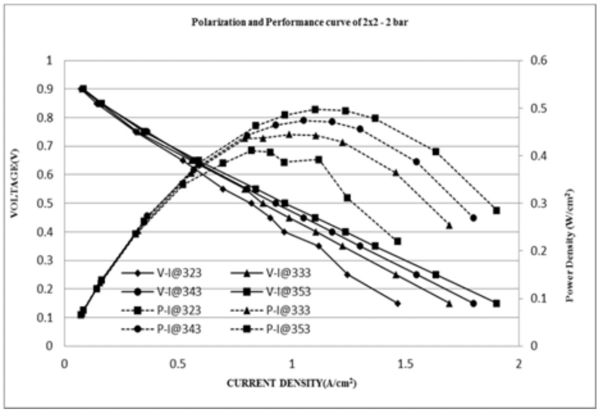
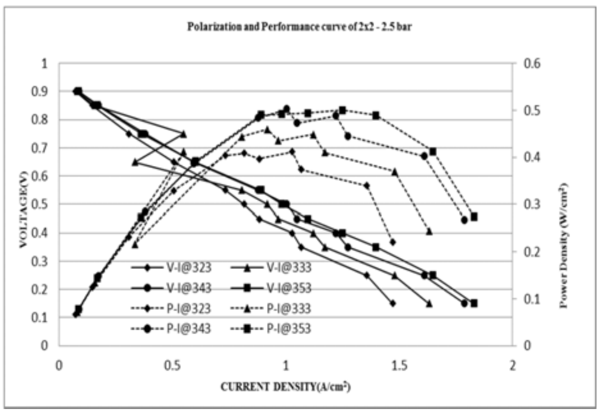


(c)



(d)

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

The performance and the polarization curve for 0.45 V potential at 343 K and 353 K, the current densities were found to be 0.979 A/cm^2 and 1.071 A/cm^2 respectively, and the power densities were found to be 0.4408 W/cm^2 and 0.4819 W/cm^2 respectively. The figure. 4 (b).displays the performance and a polarization curve of PEMFC with effective area 36 cm^2 of Rib to Channel ratio 2:2 has produced 0.889 A/cm^2 current density and a power density of 0.4003 W/cm^2 at 1.5 bar and 323 K operating temperature at the cell potential of 0.45 V. For the operating temperature of 333K at 0.45 V potential the power density was 0.4258 W/cm^2 and the current density was 1.064 A/cm^2. For 0.45 V potential and at the operating temperatures of 343 K the current density was 0.988 A/cm^2 and the power density was found to be 0.4491 W/cm^2. As a cell potential of 0.45 V and the operating temperature of 353 K the current and the power densities obtained were 1.090 A/cm^2 and 0.4906 W/cm^2 respectively. The Figure-4 (c) projects the performance and the polarization curve of the R: C ratio 2:2 at 2 bar pressure. The current density was found to be 0.822 A/cm^2 and the power density was found to be 0.4111 W/cm^2 at 0.5 V cell potential and 323 K operating pressure. At a 333 K operating temperature and at the cell potential of 0.45V the current and the power densities were 0.987 A/cm^2 and 0.4445 W/cm^2 respectively. At 343 K operating temperature and at the cell potential of 0.45 V the current and the power densities of 1.053 A/cm^2 and 0.4741 W/cm^2 were obtained. Since the temperature of 353 K and the cell potential of 0.45 V the current density obtained was 1.104 A/cm^2 and the power density obtained was 0.4970 W/cm^2. Figure-4(d) displays the performance and the polarization curve for the operating pressure of 2.5 bar and the R:C ratio 2:2, with a temperature of 323 K and at the cell potential of 0.4 V the current and the power densities obtained were 1.028 A/cm^2 and 0.4115 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 power density was 0.4481 A/cm^2 and the current density was 1.120 A/cm^2. For the cell potential of 0.5 V and the operating temperature of 343 K the current density obtained was 1.004 W/cm^2 and the power density of 0.5023 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 1.249 A/cm^2 and 0.4998 W/cm^2 respectively.

Table-1. Maximum values of various rib to channel widths.

Model	**Pressure** (bar)	**Temperature** (K)	**Voltage (V)**	**Current Density** (A/cm^2)	**Power Density** (W/cm^2)	**Power** (W)
1x1	1	353	0.45	1.074	0.484	17.409
	1.5	353	0.45	1.094	0.493	17.73
	2	353	0.45	1.108	0.499	17.960
	2.5	353	0.45	1.120	0.504	18.148
1x2	1	353	0.4	1.204	0.482	17.338
	1.5	353	0.45	1.088	0.490	17.636
	2	353	0.45	1.102	0.496	17.856

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	2.5	343	0.45	1.159	0.522	18.774
2x2	1	353	0.45	1.071	0.482	17.348
	1.5	353	0.45	1.090	0.491	17.662
	2	353	0.45	1.104	0.497	17.892
	2.5	343	0.5	1.004	0.502	18.083

CONCLUSIONS

Table-1 shows the power obtained between 0.45 - 0.5 cell potential for 36 cm^2 effective area of single pass interdigitated flow channel with constant mass flow rate of the species for various R: C-1: 1, 1:2 and 2:2 at various operating temperatures and pressures of PEMFC. We achieved a maximum power of 18.1476 W in Rib to Channel ratio of 1:1 at 2.5 bar 353 K temperature, 18.774 W power in R:C-1:2 for 2.5 bar at 343 K and the power for R:C- 2:2 was 18.0828 W for 2.5 bar at 353K operating temperature.

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