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# Effects of Gas Flow Field with Wave-like Form Obstacles on PEM Fuel Cell Performance

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***Abstract –*** Fuel cells can be considered as clean, efficient and economic devices for the next power generation. Flow configuration and operating conditions such as temperature, relative humidity and stoichiometric number are key factors for improving cell performance. The objective of this study is to analyze the effects of the wave-like form obstacles located in the anode gas flow channel on the cell performance. To investigate the performance characteristics of proton exchange membrane fuel cells(PEMFCs), numerical simulations are performed at different operating conditions by using a three dimensional PEM fuel cell with wave-like form obstacles based on FLUENT model. Our simulations indicate that higher current densities can be obtained for gas flow channels with wave-like form obstacles compared to the conventional straight flow channel in proton exchange membrane fuel cell in certain cell voltages. It was recorded that the wave-like form obstacles have a positive effect on the convective heat transfer performance.

*Keywords – Computational Fluid Dynamics, PEM Fuel Cell, Wave-like Form Obstacles, Cell Performance*

## I. INTRODUCTION

Our dependence on fossil fuels will decrease thanks to fuel cells with each passing day due to its high efficiency, negligible harmful environmental effects, wide range of application. Using pure hydrogen, fuel cells only produce water, electricity and heat generation thus eliminating harmful emissions [1].

Fuel cells can be classified according to its electrolyte material such as phosphoric acid fuel cell (PAFC) molten carbonate fuel cell (MCFC), solid oxide fuel cell (SOFC), alkaline fuel cell (AFC), and polymer electrolyte membrane fuel cell (PEMFC) [2].

At present, PEMFCs are the most promising and attractive candidate for stationary, portable transportation applications and so on [3].

Bilgili et al. have investigated the effects of the operating parameters such as temperature, relative humidity and anode stoichiometry on the performance of PEMFCs containing obstacles in the anode and cathode gas flow channels. Numerical simulations are performed by using a three dimensional computational model at different operating conditions. Higher current densities are obtained for the geometry with rectangular obstacles in comparison with straight geometry. Consequently, the electrochemical reaction is improved and higher cell voltage is achieved at high current densities [4].

Shen et al. have added rectangular blockages in the gas flow channels to improve the performance of three dimension PEMFC model. The installation of the rectangular blockages in the gas flow channels have showed an improvement of the mass transport and output voltage rise up. The field synergy principle is suitable for the PEMFC geometry with rectangular blockages with respect to the results. Mass transfer of reactants is improved by adding of the rectangular blockages in the flow channel. It could be drawn from this study, the angle between the velocity vector and the concentration gradient has reduced for the generated geometry by adding rectangular blockages [5].

Heidary et al. have investigated the effects of partial or full block placement along the gas flow channels on the cell performance of a 3D numerical PEMFC model. As a result, full block placement along the flow channels enhances the electrical power despite the high pressure drop with respect to partial placement. Partial block placement enhances the cell performance in concentration loss region of the polarization curve. Full block placement along the cathode-side flow channel with a number of 5 blocks contributes the net power up to 30% [6].

Kuo et al. have studied how to improve the performance of the PEM fuel cell. The gas flow in the channels is interrupted by different type of obstacles such as wave like, trapezoid like and ladder like enhances the gas flow velocity compared to straight gas flow channel. Hence, the convective heat transfer performance also increases. The laminar flow is assumed depending on the Reynolds number of approximately 200 [7].

Biyikoglu and Oztoprak have studied the effects of baffle blocks in the gas flow channels on the cell performance characteristics. The objective of this study is to determine the optimum gap distance that means between the tip of the block and the gas flow channel [8].

The main goal of this paper is to analyze the effects of the wave-like form obstacles located in the anode gas flow channel on the cell performance of the single channel PEM fuel cell model.

## II. Materials and Method

In this study, a single-channel, single phase polymer electrolyte membrane PEM fuel cell is modeled and analyzed by using a commercial CFD package, ANSYS FLUENT 18.1 PEM fuel cell add-on module. The SIMPLE algorithm was used as the solution algorithm for discretized equations.

In the model development, the following assumptions were used; Only steady state case is considered. The gas flow is laminar based on the Reynolds number calculation.

The gas flow is assumed as incompressible due to the small flow pressure and velocity gradients. The gas diffusion layer(GDL), catalyst layer(CL) and membrane are assumed to be homogeneous and isotropic. The gas mixture is considered as ideal gases. Membrane is not permeable to gases. Viscous dissipation, buoyancy effects are negligible. The inlets should all be assigned the boundary zone type mass flow inlet and outlets should be assigned the pressure outlet type. PEMFC comprises of polymer electrolyte membrane(PEM), two current collectors, two gas diffusion layers(GDLs), two catalyst layers(CLs) and two flow channels on the one for the anode side and one for the cathode side. The operation temperature of the PEM fuel cell is 343 K. Proton exchange membrane fuel cells(PEMFCs) operate on pure hydrogen and air. The following sequence was followed in PEM fuel cell modeling and analysis:

The geometry of the single-channel PEM fuel cell is generated by using ANSYS Design-Modeler. Mesh structure is created by using ANSYS Meshing for generated geometry.

Zone names and types are specified because it is required in the ANSYS FLUENT PEM fuel cell add-on module. Mesh file is uploaded on ANSYS FLUENT, set up the case, set the operating and boundary conditions and run the calculations. Postprocess the results. The model is validated compared to an experimental data is provided in this paper. The model is constructed to replicate the cell employed by Wang et al.**[9]** 327600 elements, 345309 nodes are used for generated geometry and most of the elements are hexahedral. Mesh structure of PEM fuel cell is shown in Fig. 1. The model is analyzed under the different operating conditions according to the Table 1. The solution converges at the end of 300 iterations. F-Cycle of Multigrid cycle setting and BCGSTAB (Bi-Conjugate Gradient Stabilization Method) are used to converge the solution for species, potential and saturation equations. Under relaxation factor is used to control the solution. Low under relaxation factors may stop the solution or high under relaxation factors may cause the fluctuations on the solution. In this study, under relaxation factors are given in the Table 2. The current density values are recorded by taking individual solution for the cell potential values that are 0.50V, 0.55V, 0.60V, 0.65V, 0.70V, 0.75V, 0.80V, 0.85V and 0.90V. Fig. 2 shows a good agreement between the simulation and experimental data.

Table 1. Operating conditions

| Parameters | Value | Unit |
|---|---|---|
| Operation Pressure | 3 | atm |
| Cell Temperature | 343 | K |
| Anode Stoichiometric Ratio | 2 | - |
| Cathode Stoichiometric Ratio | 2 | - |
| Mass Flow Rate on the Anode Side | Calculated | kg/s |
| Mass Flow Rate on the Cathode Side | Calculated | kg/s |
| Relative Humidity on the Anode Side | 50%, 80%, 100% | - |
| Relative Humidity on the Cathode Side | 100% | - |

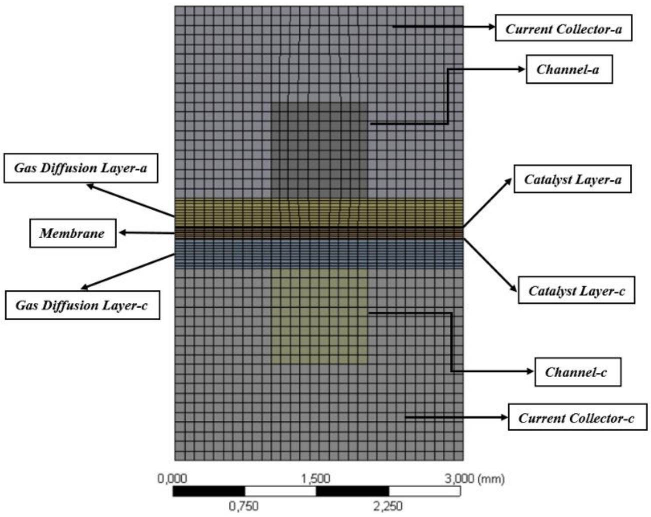


Fig. 1 Mesh structure of PEM fuel cell

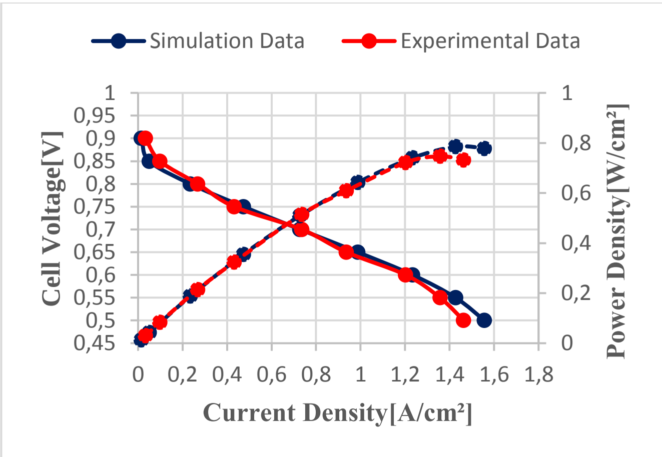


Fig. 2 Validation of the simulation data with experimental data

Table 2. Under relaxation factors

| Parameter | Under Relaxation Factor |
|---|---|
| Pressure | 0.7 |
| Momentum | 0.3 |
| $H_2$ | 1 |
| $O_2$ | 1 |
| $H_2O$ | 1 |
| Electric Potential | 1 |
| Protonic Potential | 0.95 |
| Water Saturation | 1 |
| Water Content | 0.95 |

## III. RESULTS

The analyses were performed at operating pressure of 303.975 kPA and temperature of 343 K. The program was run with 300 iterations after the electrochemical properties and boundary conditions were defined. Current densities are measured by changing the electrical potentials. Electrical potentials are changed from 0.50V to 0.90V. The graphs of cell potential and power density were generated with respect to current density. Figure 3, 4 and 5 show that the I-V polarization curves and I-W power density curves for the comparison of straight flow channel and flow channel with wave-like form obstacles PEM fuel cell model at the different operating conditions. Contours of Figure 3,4 and 5 show that adding a wave-like form obstacle is to increase the mass transport. Figure 6,7 and 8 show that adding a obstacle to the flow channel on the anode side give rise to decrease of the magnitude of velocity.

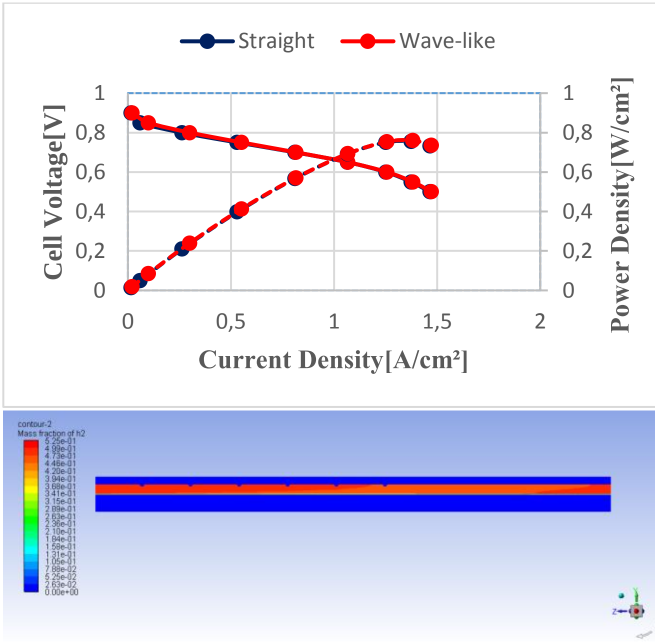


Fig. 3 I-V and I-P curves $Rh_a = 100\%$ $Rh_c = 100\%$ and T=343 K

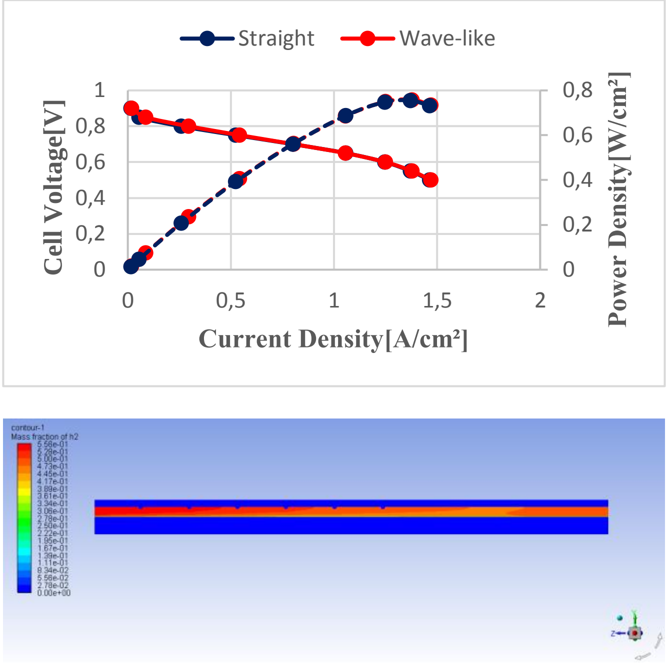


Fig. 4 I-V and I-P curves $Rh_a = 80\%$ $Rh_c = 100\%$ and T=343 K

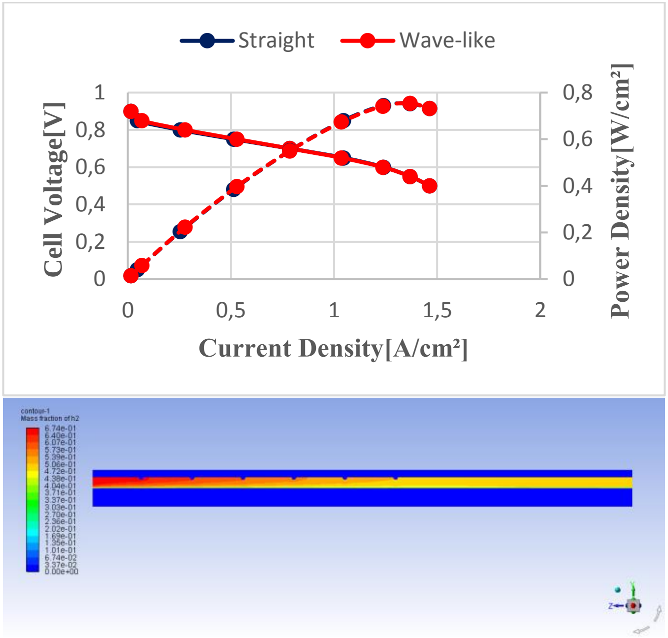


Fig. 5 I-V and I-P curves $Rh_a = 50\%$ $Rh_c = 100\%$ and T=343 K

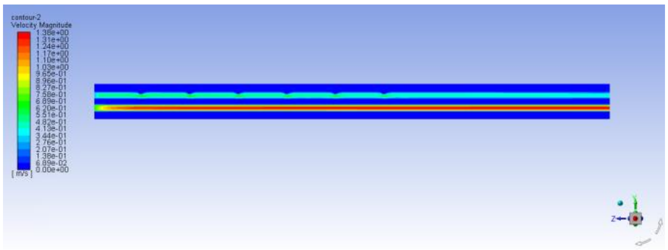

Fig. 6 Contour of velocity magnitude in the middle of model at $Rh_a = 100\%$ $Rh_c = 100\%$ and T=343 K

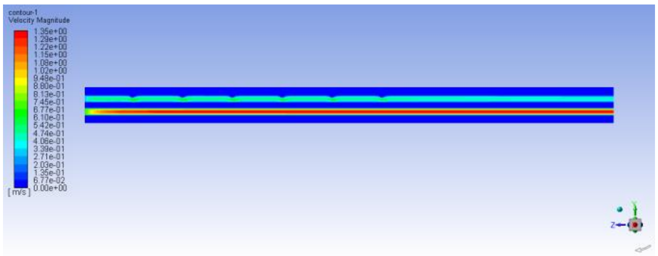

Fig. 7 Contour of velocity magnitude in the middle of model at $Rh_a = 80\%$ $Rh_c = 100\%$ and T=343 K

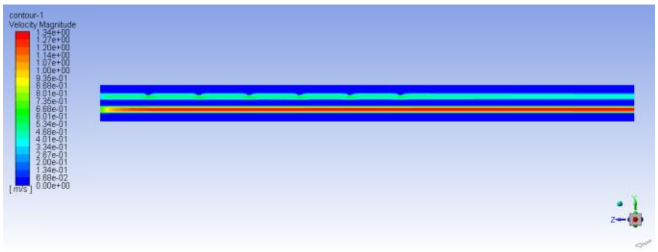

Fig. 8 Contour of velocity magnitude in the middle of model at $Rh_a = 50\%$ $Rh_c = 100\%$ and T=343 K

## IV. DISCUSSION

In this study, a PEM fuel cell model is developed by using a commercial CFD package, ANSYS FLUENT 18.1 PEM fuel cell add-on module. The numerical analyses are performed for three cases that are occurred varying relative humidity on the anode side of the flow channel. The cathode side of the PEM fuel cell is completely moisturized. Higher current densities are obtained for flow channel with wave-like form obstacles compared to straight flow channel at $Rh_a = 100\%$, $Rh_c = 100\%$ according to Table 3. Higher current densities are obtained for flow channel with wave-like form obstacles compared to straight flow channel at $Rh_a = 80\%$, $Rh_c = 100\%$ and higher voltages according to Table 4. Higher current densities are obtained for flow channel with wave-like form obstacles compared to straight flow channel at $Rh_a = 50\%$, $Rh_c = 100\%$ and higher voltages according to Table 5.

Table 3. Comparison of the current densities between straight flow channel and flow channel with wave-like form obstacles at $Rh_a = 100\%$, $Rh_c = 100\%$, 3 atm

| **Cell Potential(V) , Current Density(A/cm²), $Rh_a = 100\%$, $Rh_c = 100\%$** | | | |
|---|---|---|---|
| **Cell Potential** | **Current Densities of Straight Flow Channel** | **Current Densities of Flow Channel with Wave-like Form Obstacles** | **Difference between Current Densities** |
| 0,90V | 0,01525 | 0,02041 | 0,00516 |
| 0,85V | 0,05861 | 0,10030 | 0,04169 |
| 0,80V | 0,26198 | 0,30007 | 0,03809 |
| 0,75V | 0,53041 | 0,55114 | 0,02073 |
| 0,70V | 0,81022 | 0,81573 | 0,00551 |
| 0,65V | 1,06515 | 1,06641 | 0,00126 |
| 0,60V | 1,25096 | 1,25651 | 0,00555 |
| 0,55V | 1,37398 | 1,38235 | 0,00837 |
| 0,50V | 1,46556 | 1,47244 | 0,00688 |

Table 4. Comparison of the current densities between straight flow channel and flow channel with wave-like form obstacles at $Rh_a = 80\%$, $Rh_c = 100\%$, 3 atm

| **Cell Potential(V) , Current Density(A/cm²), $Rh_a = 80\%$, $Rh_c = 100\%$** | | | |
|---|---|---|---|
| **Cell Potential** | **Current Densities of Straight Flow Channel** | **Current Densities of Flow Channel with Wave-like Form Obstacles** | **Difference between Current Densities** |
| 0,90V | 0,01525 | 0,01837 | 0,00312 |
| 0,85V | 0,05526 | 0,08790 | 0,03264 |
| 0,80V | 0,25952 | 0,29522 | 0,0357 |
| 0,75V | 0,52416 | 0,54280 | 0,01864 |
| 0,70V | 0,80167 | 0,80451 | 0,00284 |
| 0,65V | 1,05835 | 1,05552 | 0,00283 |
| 0,60V | 1,24703 | 1,24986 | 0,00283 |
| 0,55V | 1,37199 | 1,37829 | 0,0063 |
| 0,50V | 1,46431 | 1,46995 | 0,00564 |

Table 5. Comparison of the current densities between straight flow channel and flow channel with wave-like form obstacles at $Rh_a = 50\%$, $Rh_c = 100\%$, 3 atm

| **Cell Potential(V) , Current Density(A/cm²), $Rh_a = 50\%$, $Rh_c = 100\%$** | | | |
|---|---|---|---|
| **Cell Potential** | **Current Densities of Straight Flow Channel** | **Current Densities of Flow Channel with Wave-like Form Obstacles** | **Difference between Current Densities** |
| 0,90V | 0,01525 | 0,01579 | 0,00055 |
| 0,85V | 0,04731 | 0,06849 | 0,02117 |
| 0,80V | 0,25448 | 0,27813 | 0,02364 |
| 0,75V | 0,51395 | 0,52923 | 0,01528 |
| 0,70V | 0,78650 | 0,78584 | 0,00066 |
| 0,65V | 1,04697 | 1,03657 | 0,01040 |
| 0,60V | 1,24118 | 1,23720 | 0,00398 |
| 0,55V | 1,36956 | 1,37030 | 0,00074 |
| 0,50V | 1,46400 | 1,46477 | 0,00077 |

## V. CONCLUSION

In this paper, straight/partial wave-like form obstacles along the parallel flow field channels of a PEM fuel cell are numerically investigated the effect on the cell performance. Relative humidity is changed on the anode side to better understand the effect of wave-like form obstacles on the cell performance. The maximum current density 0,55114 A/cm² is obtained at 0.75V cell potential and $R_{ha}$=100% in flow channel with wave-like form obstacles. The maximum current density 0,53041 A/cm² is obtained at 0.75V and $R_{ha}$=100% in straight flow channel. It was recorded that the current density values for the flow channel geometry with wave-like form obstacles are higher on high voltage region of the polarization curves. It can be drawn from the simulation results adding a obstacle is to enhance the mass transport and convective heat transfer.

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