Journal of Renewable Energies
Revue des Energies Renouvelables
journal home page : https://revue.cder.dz/index.php/rer

Investigation, Analysis and Optimization of PEMFC Channel Cross-Section Shape

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Abstract

In this study, a three-dimensional (CFD) model is employed to simulate and optimize the CCS (Channel Cross-Section) shape of the single straight channel PEMFC. Four CCS shapes, namely trapeze, inverted trapeze, half of ellipse and inverted half of ellipse, are investigated using ANSYS-FLUENT software and compared to the rectangular and triangular CCS shapes. The results obtained from the simulation are compared to the experimental results of the literature. A good agreement is observed between the numerical and experimental results. From the obtained results, it appears that the best delivered power density is reported by the trapeze CCS configuration, whereas, the worst delivered power density is obtained by the inverted half of ellipse CCS configuration. The highest pressure-drop and pumping power are obtained with the triangular CCS configuration and the smallest are resulted by the rectangular CCS configuration. Finally, the highest net power output is reported by the trapeze channel cross-section configuration, while, the lowest one is yielded by the inverted half of ellipse CCS configuration.

Keywords: Fuel cell, PEMFC, CFD, CCS, Presser drop, Net power density

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1. Introduction

For many years, researchers around the world had been focusing on finding new energy sources taking into consideration the world's concern about the depletion of fossil fuels and green energy effects growing [1-3]. Owing to their sustainable hydrogen energy utilization, high-energy conversion efficiency and nearly zero emission, fuel cells, especially the Proton Exchange Membrane Fuel Cell (PEMFC) is becoming the most promising energy source [4].

A standard PEMFC consists of a membrane sandwiched between anode and cathode catalyst layers (CLs) and gas diffusion layers (GDLs) making the entire set a membrane electrode assembly (MEA). This last one is placed between the two sides' bipolar plates (BPPs) [5]. The flow channels inside the bipolar plates and their configurations play an important role as they influence the PEMFC performance [6-7].

Recently, numerous researches dealing with the effects of PEMFC's flow channel designs on the cell performance have been presented in the literature, and which are globally related to the shape of flow fields such as serpentine and parallel flow channels as the most common designs in a PEMFC stuck [5-8]. A new tubular shaped design and modified cross-sectional channels PEMFCs are studied by [9,10], respectively. In addition, inversed designs have been employed to optimize the shape of the PEMFC's gas channel [11]. The inserted obstacles inside the flow channel have been added to improve the PEMFC performance [12]. To date, numerical methods, especially computational techniques are strongly used to investigate the influence of unconventionally shaped flow channels without building a physical structure, eliminating the manufacture and machining costs [13]. Several commercial software packages are available for PEMFCs modelling including ANSYS fluent software with the PEMFC add-on module, which can allow examining different designs [14].

In this work, a 3-D CFD multi-phase model is used to simulate and optimize the channel cross-section shape of the single straight channel PEMFC. Four CCS shapes, namely trapeze (Trap), inverted trapeze (Inv-Trap), half of ellipse (Elip) and inverted half of ellipse (Inv-Elip), are investigated using ANSYS-FLUENT software and compared to the rectangular (Rect) and triangular (Triang) channel cross-section shapes.

2. Physical and mathematical Model

The considered PEMFC in this contribution is a single cell with straight channels and planar configuration. ANSYS-Design Modular Tool is employed to make the geometries of the selected configurations of PEMFC cells; Fig. 1. The studied cell is composed of a current collector, a gas flow channel, a gas diffusion layer (GDL), and a catalyst layer (CL) in both anodic and cathodic sides as well as a membrane in the middle of the sandwich. The dimensions of the components are given in Table 1.

The simulation is carried out using the following assumptions:

-The system operates under isothermal and steady-state conditions.

- The reactants seeped in the anode and cathode channels are considered ideal and incompressible fluids.
- The flow regime is laminar and incompressible because the velocity and pressure gradients are very low.
- The membrane, catalyst (CL) and gas diffusion layer (GDL) are considered to be homogeneous and isotropic porous areas.
- The membrane is considered as an impermeable medium to the diffusion of reactant gases and it is assumed to be fully hydrated.
- Butler-Volmer equation was taken into account for the electrochemical reactions and the species diffusion modelling.
- The elimination of the water liquid-phase produced from the electrochemical reactions and the phase change are not taken in consideration.

Table 1. Relevant geometrical parameters

Parameters	Unit	Values
Cell length	mm	100
Land width	mm	1
CCS area	mm^2	1
Current collector thickness	mm	2
GDL thickness	mm	0.25
CL thickness	mm	0.028

In this work, six channel cross-section shapes, which are : Trap, Inv-Trap, Elip, Inv-Elip, Rect and Triang, are considered and investigated using ANSYS-FLUENT software. Fig. 1.

To accomplish the investigation of the studied CCS shapes and their impact on the PEMFC performance, pressure drop as well as other transport characteristics, Using the commercial CFD ANSYS-Fluent, numerical simulations are carried out. The governing equations as well as the electrical charges and Butler–Volmer equations are involved in the PEMFC model. The add-on Module manual for ANSYS PEMFC describes and discusses in detail the model equations and the methods of implementation [15-16]. Dirichlet boundary conditions are applied at the inlet of the anodic and cathodic channels' sides for the species concentrations, temperature and mass flow. The mass flow rates are considered constant at the inlet of each channel in all cases of the realized simulations. On the other hand, Neumann boundary conditions are applied to the other parameters. At the interfaces fluid/solid, the non-slip boundary condition and zero species flux are considered.

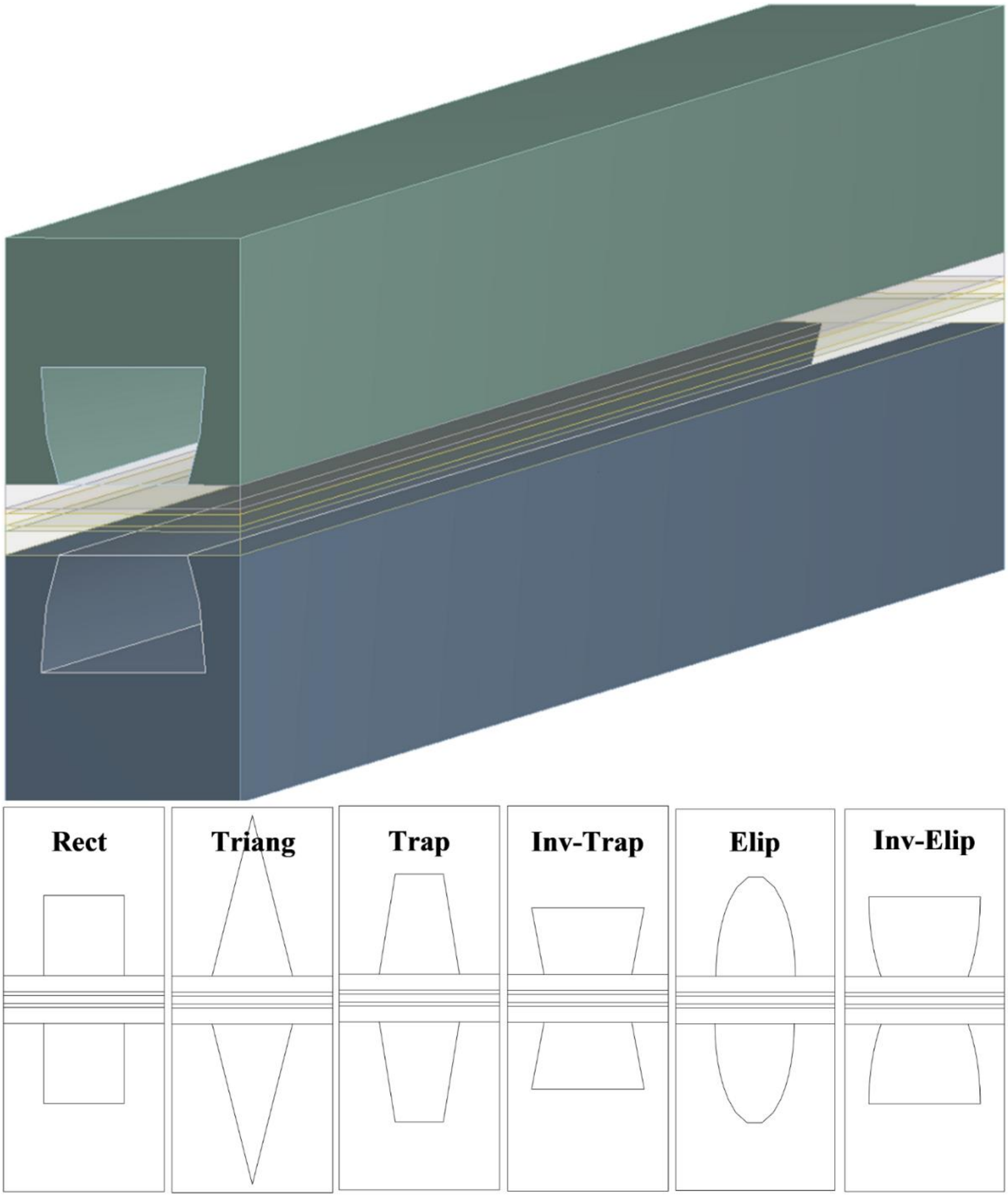

Fig 1. Elementary cell and studied channel cross-section shapes

3. Results and discussion

After the simulation of the PEMFC single cell with straight channels, using the commercial CFD ANSYS-Fluent code, the mesh independence and validation of the obtained results are performed. Further, it should be noticed that the mesh independence and the comparison of simulation results versus experimental results are presented in our previous works [15-16].

Figures 2, 3, 4, 5 and 6 show, respectively, the pressure hydrogen mass fraction, water concentration, oxygen concentration and velocity distributions of the studied CCS shapes obtained by the carried out simulations using ANSYS-FLUENT.

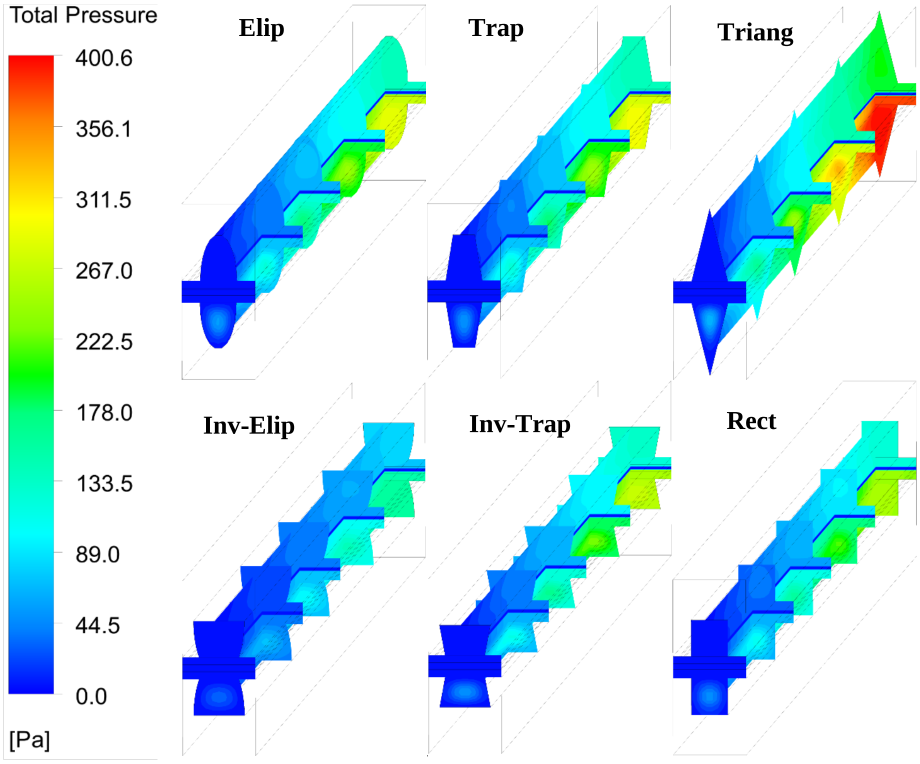

Fig 2. Total pressure profiles of the studied CCS shapes

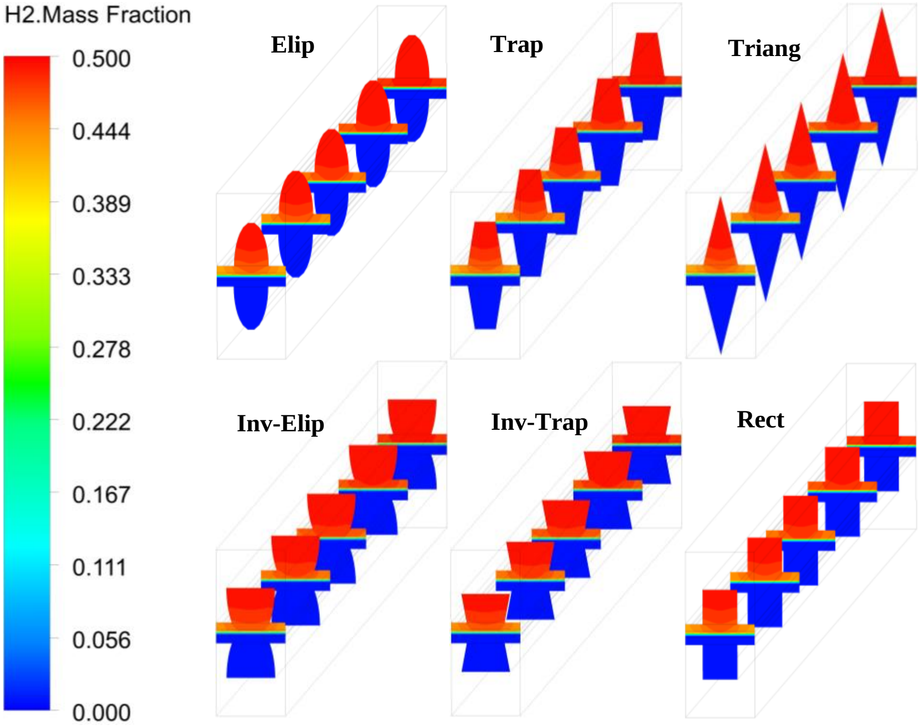

Fig 3. H_2 mass fraction profiles of the studied CCS shapes

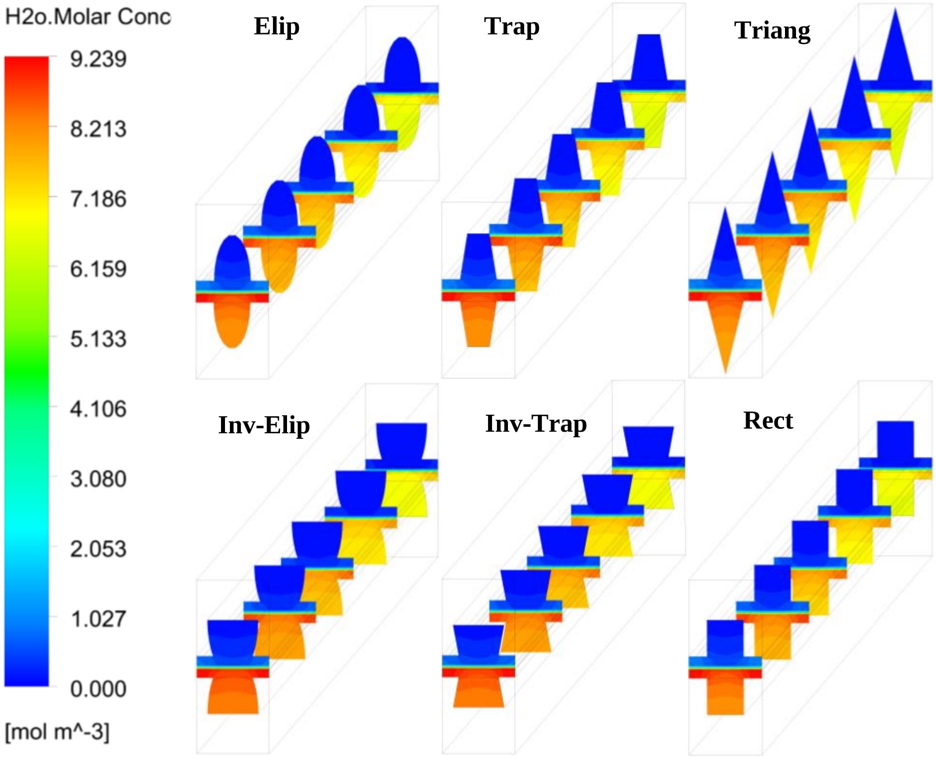

Fig 4. H_2O molar concentration profiles of the studied CCS shapes

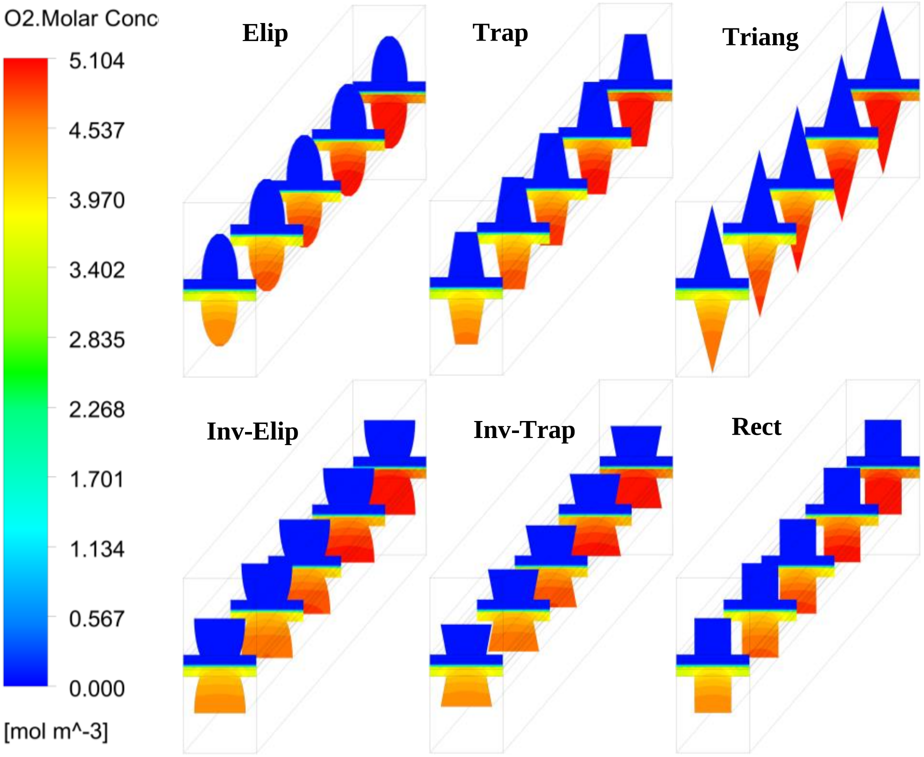

Fig 5. O_2 molar concentration profiles of the studied CCS shapes

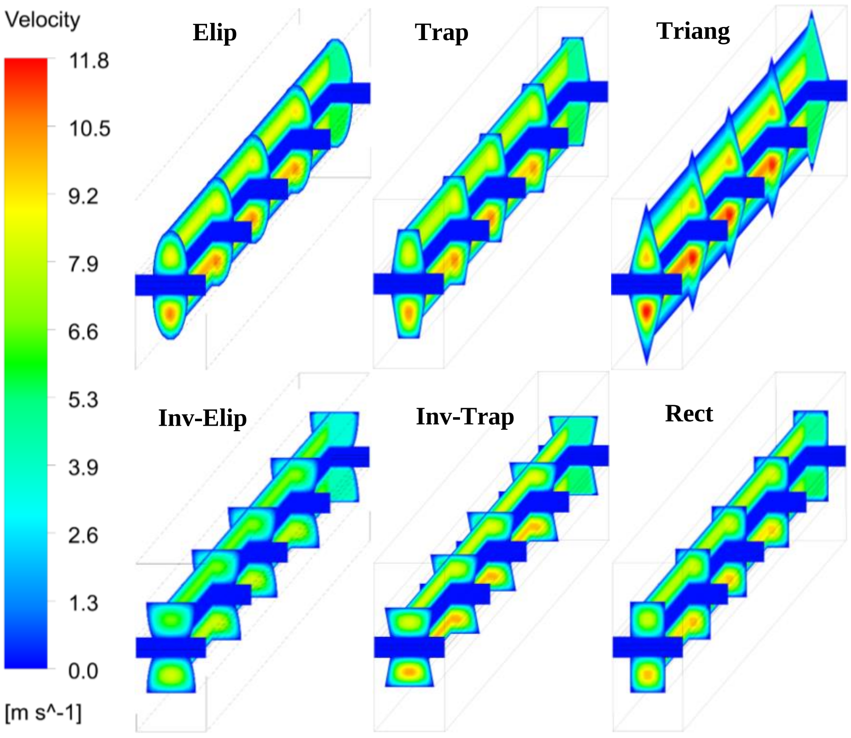

Fig 6. Velocity profiles of the studied CCS shapes

Fig 7 shows and reports the produced, pumping and net power densities of all studied CCS shapes of the PEMFC channels.

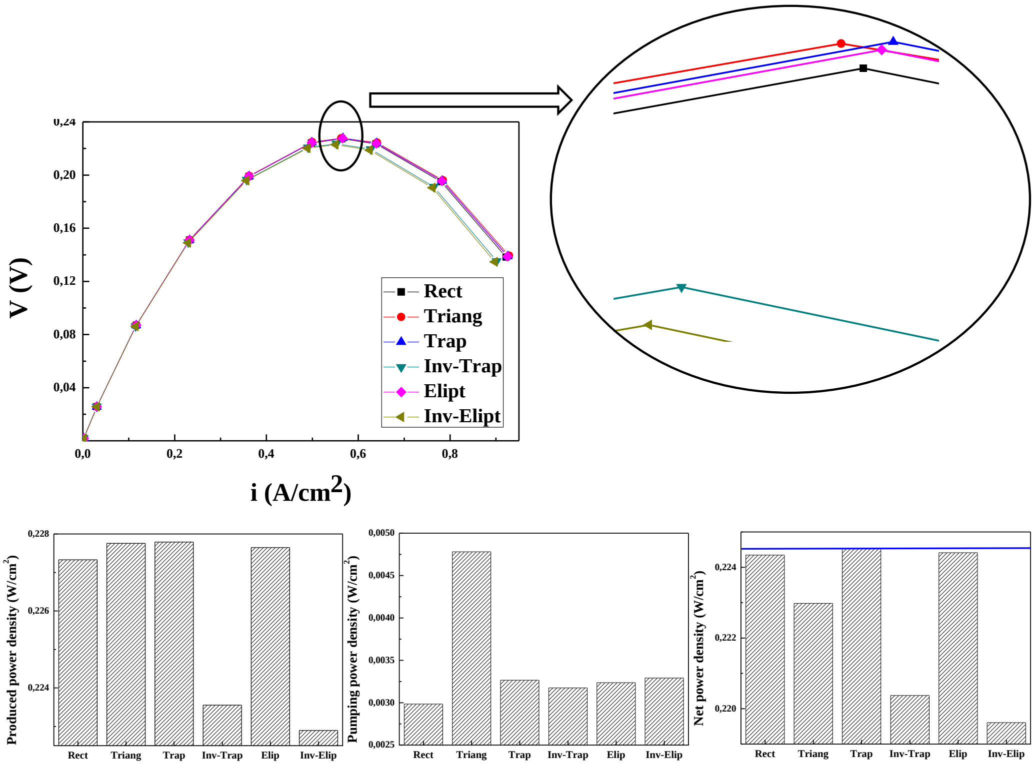

Fig 7. Produced, pumping and net power densities of studied PEMFCs

From Fig. 7, it appears that the best-delivered power density is reported by the trapeze CCS configuration, whereas, the worst delivered power density is obtained by the Inv-Elip CCS configuration. The highest pressure-drop and pumping power obtained are reported by the Triang CCS configuration and the smallest are resulted by the Rect CCS configuration. Finally, the best net power output is reported by the Trap CCS configuration, whereas, the worst net power output is obtained by the Inv-Elip CCS configuration.

4. Conclusion

In this work, which presents a continuation of our ones on the fuel cells, a three-dimensional CFD model is considered to investigate, analyse and optimize PEMFC CCS shape. The current density, power density, pressure and hydrogen, oxygen and water mass fractions' distributions of the single straight channel PEMFC according to six CCS shapes, which are: Trap, Inv-Trap, Elip, Inv-Elip, Rect and Triang, are investigated, presented and analysed. The considered three-dimensional model is supposed non-isothermal, single-phase steady state and the domain of study is limited by a single PEMFC cell with straight channels according to co-flow arrangements. Fluent-ANSYS is used to solve the governing equations and to plot the results of the six studied CCS shapes. From the analysed results, it can be inferred that the best delivered power density is provided by the Trap CCS configuration, whereas, the worst delivered power density is obtained in the case of the Inv-Elip CCS configuration. The highest pressure-drop and pumping power are reported for the Triang CCS configuration and the smallest are referred to the Rect CCS configuration. Finally, the best net power output is supplied by the Trap CCS configuration, however the worst net power output is found to be yielded by the Inv-Elipse CCS configuration.

5. References

[1] Sahli Y., Zitouni B., Ben Moussa H., Abdenebi H. In: Progress in Clean Energy, Volume 1, editors. Dincer I., Colpan C., Kizilkan O., Ezan M., Switzerland: Springer, Cham; 2015, p. 449-461. https://doi.org/10.1007/978-3-319-16709-1_32.

[2] Sahli Y, Zitouni B, Ben Moussa H. THERMODYNAMIC OPTIMIZATION OF THE SOLID OXYDE FUEL CELL ELECTRIC POWER. University Politehnica of Bucharest Scientific Bulletin Series B-Chemistry and Materials Science 2018;80:159-170.

[3] Abdenebi H., Zitouni B., Ben Moussa H., Haddad D., Zitouni H., Sahli Y. In: Progress in Clean Energy, Volume 2, editors. Dincer I. et al., Switzerland: Springer, Cham; 2015, p. 567-581. https://doi.org/10.1007/978-3-319-17031-2_41.

[4] Laribi S., Mammar K., Sahli Y., et al. Energy Reports. 2021;7: 4214-21. https://doi.org/10.1016/j.egyr.2021.07.010.

[5] Yin Y., Wang X., Shangguan X., et al. International Journal of Hydrogen Energy. 2018;43:8048-62. https://doi.org/10.1016/j.ijhydene.2018.03.037.

[6] Mohammedi A., Ben-moussa H., Tamerabet M., Sahli Y. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences. 2020;66:84-103.

[7] Monsaf T., Hocine BM., Youcef S., Abdallah M. International Journal of Hydrogen Energy. 2017;42:1237-51. http://dx.doi.org/10.1016/j.ijhydene.2016.12.084.

[8] Scholta J., Escher G., Zhang W., et al. Journal of Power Sources 2006;155:66-71. doi:10.1016/j.jpowsour.2005.05.099.

[9] Mohammadi-Ahmar A., Osanloo B., Solati A., Ghasemi J. Energy Conversion and Management. 2016;128:238-49. doi.org/10.1016/j.enconman.2016.09.074.

[10] Zeng X., Ge Y., Shen J., et al. International Journal of Heat and Mass Transfer. 2017;105:81-89. http://dx.doi.org/10.1016/j.ijheatmasstransfer.2016.09.068.

[11] Wang XD., Huang YX., Cheng CH., et al. International Journal of Hydrogen Energy. 2010;35:4247-4257.

[12] Barati S., Khoshandam B., Ghazi MM. International Journal of Hydrogen Energy. 2018;43:21928-39. https://doi.org/10.1016/j.ijhydene.2018.10.032.

[13] Yang WJ., Wang HY., Lee DH., Kim YB. Applied Energy 2015;146:1–10. http://dx.doi.org/10.1016/j.apenergy.2015.01.130.

[14] Mahmoudimehr J., Daryadel A. International Journal of Hydrogen Energy. 2017;42:23141-23159. http://dx.doi.org/10.1016/j.ijhydene.2017.07.196.

[15] Mohammedi A., Sahli Y., Ben Moussa H. Renewable Energy Focus. 2020;35:72-83. https://doi.org/10.1016/j.ref.2020.09.003.

[16] Mohammedi A., Sahli Y., Ben Moussa H. Fuel 2020;263:116713. https://doi.org/10.1016/j.fuel.2019.116713.