Design of polymeric electrolyte membrane reformer

M. Milosevic [a*], G. Mladenovic [b], A. Sedmak [b], A. Plohar [c], B. Likozar [c] J. Lozanovic Sajic [a]

[a] Innovation Center of Faculty of Mechanical Engineering, Belgrade, Serbia,
* mmilosevic@mas.bg.ac.rs

[b] Faculty of Mechanical Engineering, Univesrity of Belgrade, Serbia

[c] Department of Catalysis and Chemical Reaction Engineering, National Institute of Chemistry, Ljubljana, Slovenia

Abstract

This paper describes the design and manufacturing aspects of polymeric electrolyte membrane (PEM) reformer from the beginning step of realization that includes modelling of main parts of the reformer, adopting changes in shape and dimensions, and manufacturing and development of the reformer. For these purposes, one model in SolidWorks software was developed, and based on that model manufacturing was performed. Adopted changes in the reformer are presented, along with detailed explanations. Beside the main subject of this paper, general data about proton exchange membrane fuel cell are shown in the introduction of this paper with short description and explanations of PEM function, method and purpose.

Keywords: PEM, reformer, design, manufacturing

1. INTRODUCTION

Proton exchange membrane fuel cells or PEMFC are also known as polymeric electrolyte membrane (PEM) [1]. These two terms have the same acronyms. PEM are based on a polymeric electrolyte which is proton conducting. Conventional PEMs usually employ water containing polymers as electrolyte that is responsible for proton conduction. These type of fuel cell that contains water have a high power density at low operating temperature, and due to the physical properties of water cannot be used above a temperature of 80 °C.

High temperature PEMs or HTPEM are based on polymers doped with phosphoric acid. High temperature PEMs, unlike conventional PEMs, can operate at temperatures up to 200° C. Higher temperatures causes faster chemical reactions, higher efficiencies and most important better tolerance to fuel impurities. HTPEMs can be started and shutdown relatively quickly and also have good fuel tolerance. Because of aforementioned characteristics they are most suitable for mobile applications (electric cars, boats). The material challenges encountered in HTPEMs are mainly related to the phosphoric acid which migrates under operation.

The best fuel for PEMFC is pure hydrogen and for all other type of fuel cells, but the storage of hydrogen and portability of hydrogen storage systems are problematic for small-size mobile applications. Highest efficiency is achieved by using pure hydrogen as fuel, since then the amount of pollutant byproducts is minimal (it would be ideal if there weren't any). As a substitution, hydrocarbons, especially methanol and methane is recognized as more practical choices as a fuel for PEMFCs [2, 3, 4, 5].

Presented in the following text are spects of design and production of reformers for high temperature PEMs. One model of reformer with its dimension and parts is presented in further text. Manufacturing is performed based on this model as well as studies related to dimension influences to reforming process with reformer dimension proposal and CFD analysis [6].

Addition to these tests, scientists all around the world have carried out numerous other test in order to achieve efficiency increasing of reformer [7]. CFD analysis are more easiest way for performing simulation based on the further test will be or not be performed thus have a great role in fuel cell examinations [6].

2. PEM FUEL CELL SYSTEM

One system of polymeric electrolyte membrane fuel cell contain three main reactors. One is the reformer for methanol steam reforming (MSR). The second is the high temperature proton exchange membrane fuel cell stack (HT PEMFC). The third is the vaporizer.

Whole system is built from components that can be seen in Figure 1. From top to bottom the following components are:

- incoming and out coming connectors for fluids
- top metal plate with holes for compression bolts
- 10 mm inner insulation layer
- Vaporizer with metal cover plate
- 5 mm inner insulation layer
- HT PEMFC stack consisting of:
    - 2 membrane electrode assemblies (MEA)
    - 4 MEA gaskets
    - 3 graphite-composite bipolar plates
    - 2 copper current collectors
- methanol steam reformer (MSR)
- 15 mm inner insulation layer
- bottom metal plate with holes for compression bolts

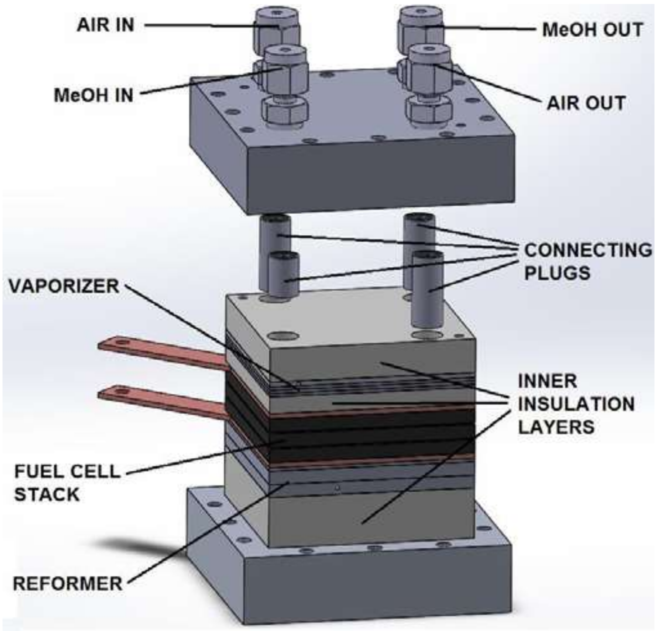

Figure 1. Design of the system with HTPEM fuel cell stack and integrated vaporizer and reformer

The inner insulation layers are used to obtain the desired temperature distribution within the system. The reactors are stacked in a planar way to enhance heat transfer from exothermal HT PEMFC stack to endothermal reformer and vaporizer. The fuel processing reactors are positioned in the system according to their operating temperature and they are connected via series of connecting plugs. The sealing of flowing fluids is achieved by using O-ring gaskets. Dimensions of all the parts constructing the system match the dimensions of actual model components with the exception of MEA and gaskets which are already drawn in a compressed state.

The bipolar plate flow fields also match the ones of an actual component. The only thing missing is the connection between the main entry channel (φ3 mm) and the main flow field distributing channel.

3. METHANOL STEAM REFORMING MODEL OR REFORMER

In Figure 2 left can be seen a SolidWorks assembly of parts that form the MSR or reformer. The middle part represents the reaction volume with incoming and out coming channels. The reaction volume is separated by two stainless steel mashes (after widening of the incoming channel and narrowing of the out coming channel) which are inserted into 0.5 wide grooves perpendicular to three-direction of flow. The external dimensions of the reformer, 60×60 mm are complementary with fuel stack dimensions. As can be seen in Figure 2 - right, it is composed of three plates,– upper and lower cover plates, with thickness of 3.8mm and 1mm respectively, and a middle plate, 4mm thick. The middle plate contains the reaction volume and inlet and outlet channel.

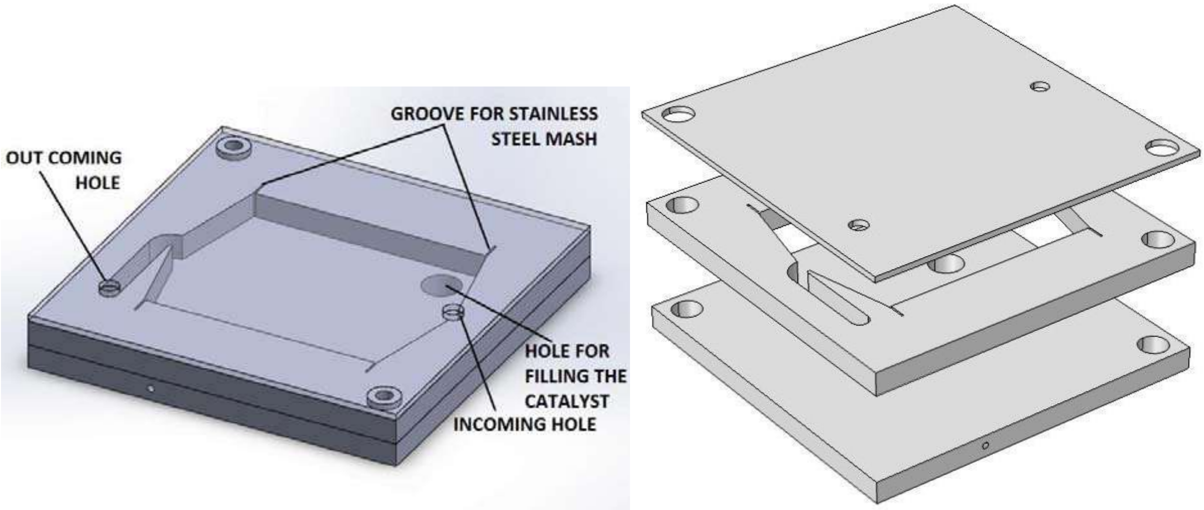

Figure 2. Left: Trigonometric view of the MSR with top plate in transparent mode, Right: Three plates of the methanol steam reformer stack

The initial geometry of the reaction volume with channels is shown in Figure 3 left. The reaction volume dimensions are 34 x 37.4 x 4 mm. The catalyst bed in the reaction volume should be separated from the channels with a stainless steel mesh, with the space of 3mmin front and behind of the reaction volume. Inlet and the outlet both have a diameter of 3 mm. The non-variable parts of the reformer geometry are designated by gray in Figure 3 right. In the variable part, there is a length of 3.5mm between the center of the inlet circle and the steel mesh, and a 5.5mm gap between the steel mesh and the center of the outlet circle.

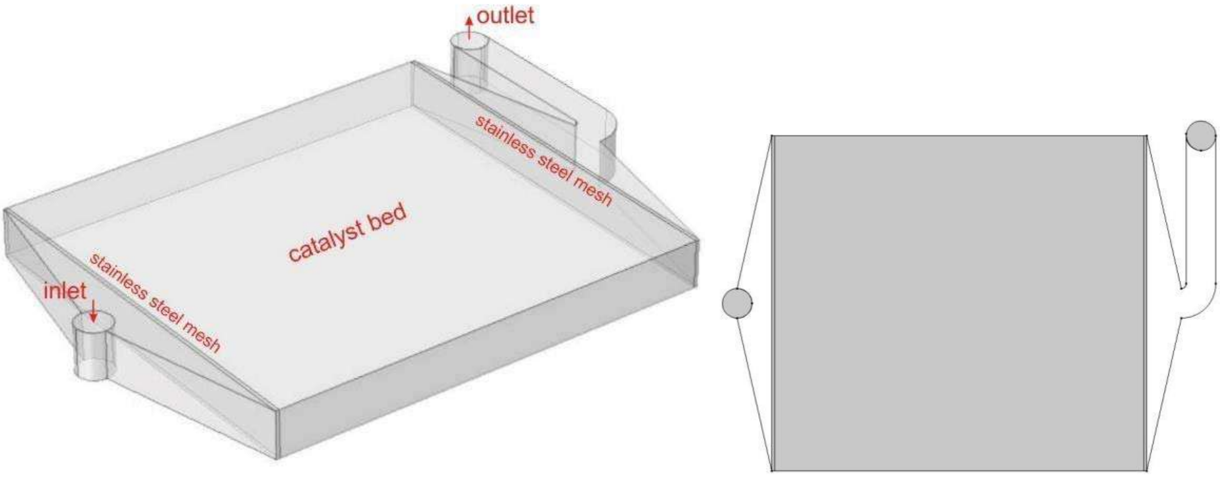

Figure 3. Left: The initial geometry of the reaction volume with inlet and outlet channels, Right: Cross section of the reaction volume with channels

Before examination test or reforming the following data are defined:

- ratio methanol-water mixture
- temperature in the reformer
- flow rate at the inlet channel
- catalist particle dimater
- bulk density
- catalyst density

4. MANUFACTURING AND DEVELOPMENT

For the purpose of development of the shown reformer, operations involving processing on a milling machine and EDM with a wire. Before designing the processing, an analysis of assembly parts was performed. Since the application of non-conventional processing methods increases manufacturing costs, shape and dimensions optimization of the reformer was performed. Since EDM processing requires the use of a wire with a diameter of 0.3 mm, the shape and dimensions of the middle plate opening was changed. Transversal hole on the reformer is meant for the placing of the thermocouple, thus the hole diameter was changed from 1 to 2 mm, whereas the depth remained the same.

5. CONCLUSION

The reformer is an integral part of the existing indirect internal reforming high temperature PEMFC and most of its geometry is already defined. Experiments based on the above mentioned reformer model prove that the changes in geometry have an influences in flow irregularities but do not have a large influence on the value of pressure at the entrance of the porous media or on the pressure drop in the porous media [6].

As mentioned before, application of non-convectional processing methods increases general costs, thus optimization of reformer shape and dimensions was performed in order to decrease the time needed for its production. One of the adopted change in reformer manufacturing is the change of the middle plate opening diameter (due to the fact that EDM processing wire has a diameter of 0.3 mm) from 1 to 2 mm.

6. ACKNOWLEDGEMENTS

This research was carried out under the NATO SPS Project EAP.SFPP 984738, and the Ministry of Education and Science of the Republic of Serbia projects TR35040 and III 43007. Slovenian Research Agency is gratefully acknowledged for supporting the Programme P2-0152, Chemical Reaction Engineering.

7. REFERENCES

[1] Fuel Cell Handbook, 7th edition, U.S. Dept. of Energy, Nov. 2004.

[2] J.R. Rostrup-Nielsen, Conversion of hydrocarbons and alcohols for fuel cells. Phys.Chem. Chem. Phys., 3 (2001) 283-288.

[3] J.O. Jensen, Q. Li, C. Pan, et al, High temperature PEMFC and the possible utilization of the excess heat for fuel processing. 32 (2007) 1567-1571.

[4] D. Palo, R.Dagle and J. Holladay, "Methanol steam reforming for hydrogen production," Chemical Reviews, vol. 107, p. 3992–4021, 2007.

[5] J. Agrell, H. Birgersson and M. Boutonnet, "Steam reforming of methanol over a Cu/ZnO/Al2O3 catalyst: a kinetic analysis and strategies for suppression of CO formation," Journal of Power Sources, vol. 106, p. 249–257, 2002.

[6] I. Ivanović, A. Sedmak and M. Milošević, "The Influence of Inlet Geometry on the Performance of a Micro Methanol Steam Reformer," in t*he 6th International Conference and Workshop, REMOO-2016*, Budva, Montenegro, 2016. Jing Su: Development of a Novel Compact Reformer for PEMFC, Doctoral Dissertation, University Of Florida, 2009.

[7] H. An, A. Angli, B. Agus, B. Sasmito, C. Jundika and A. Kurnia, "Computational fluid dynamics (CFD) analysis of microreactor performance: effect of various configurations," Chemical Engineering Science, vol. 75, p. 85–95, 2012.