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DESIGN AND MANUFACTURE OF REFORMER IN POLYMER ELECTROLYTE MEMBRANE FUEL CELL

DIZAJN I PROIZVODNJA REFORMERA ZA GORIVNE ĆELIJE SA POLIMERSKOM ELEKTROLITNOM MEMBRANOM

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Ključne reči
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Abstract

The paper describes the development and manufacturing aspects of the reformer in polymer electrolyte membrane (PEM) fuel cell, from the first step of realization that includes modelling the main parts of the reformer; analysing the reforming initial geometry, adopting changes in shape and dimensions caused by inaccessibility of tools during machining; and the manufacture of the reformer. Development and manufacturing are performed based on a model developed in SolidWorks®. Based on this model, numerical analysis is performed in order to show the influence of geometry and its changes that affect reformer performance, and is not shown here. Adopted changes in the reformer design are presented, along with detailed explanation. Reformer processing is carried out on a milling machine and Wire EDM machine. The transversal hole diameter on the reformer is increased from 1 to 2 mm to reduce economic cost. Before processing, the tool path simulation is also performed. Beside the main subject, general data on proton exchange membrane fuel cell are introduced with a short description and explanations of the PEM function, method and purpose.

Izvod

U ovom radu su prikazani razvoj i aspekti proizvodnje reformera za gorivne ćelije sa polimerskim elektrolitnim membranama (PEM), od početnog koraka realizacije koji obuhvata modeliranje glavnih delova reformera, preko analiziranja početne geometrije, usvajanja promena oblika i dimenzija prouzrokovanog nedostupnošću alata za mašinsku obradu, do proizvdnje reformera. Razvoj i proizvodnja su izvedeni na osnovu modela napravljenog u SolidWorks softverskom paketu. Na osnovu tog modela su urađene numeričke analize kako bi se utvrdio uticaj geometrije i njene promene na performanse reformera, ali ova tema nije obrađena u ovom radu. Prikazane su usvojene promene u dizajnu reformera, uz detaljna objašnjenja. Obrada reformera je izvršena na glodalici i Wire erozimatu. Prečnik trasnverzalnog otvora na reformeru je promenjen sa 1 na 2 mm kako bi se povećala eknomičnost. Pre obrade je izvršena simulacija putanje alata. Pored glavne teme ovog rada, prikazani su i opšti podaci o razmeni protona u membrani gorivne ćelije u okviru uvoda, uz kratak opis i objašnjenje funkcije PEM, kao i njihove metode i funkcije.

INTRODUCTION

Proton exchange membrane fuel cells or PEMFC are also known as polymer electrolyte membrane (PEM), /1/. These two terms have the same acronyms. PEM are based on a proton conducting polymer electrolyte. Conventional PEMs usually employ water containing polymers as the electrolyte responsible for proton conduction. These types of fuel cells that contain 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 cause faster chemical reactions, higher efficiencies, and most important - better tolerance to fuel impurities. The performance of high-temperature polymer electrolyte membrane fuel cells (HT-PEMFC) is critically dependent on the selection of materials and optimization of individual components. Due to their light weight, PEMFCs are most suited for transportation applications. PEMFCs for buses, which use compressed hydrogen for fuel, can operate at up to 40% efficiency. Generally, PEMFCs are implemented on buses over smaller cars because of the available volume to house the system and store fuel. PEMFCs are best for small scale systems until economically scalable pure hydrogen is available. Furthermore, PEMFCs have the possibility of replacing batteries for portable electronics, though integration of the hydrogen supply is a technical challenge, particularly without a convenient location to store it within the device.

Much of the current research on catalysts for PEM fuel cells can be classified as having one of following main objectives:

- to obtain higher catalytic activity than standard carbon-supported platinum particle catalysts used in current PEM fuel cells,
- to reduce the poisoning of PEM fuel cell catalysts by impurity gases,
- to reduce the cost of fuel due to the use of platinum-based catalysts.

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. The highest efficiency is achieved by using pure hydrogen as a fuel, since then the amount of pollutant by-products is minimal (it would be ideal if there weren't any). As a substitution, hydrocarbons, especially methanol and methane are recognized as more practical choices as a fuel for PEMFCs, /2-5/.

Presented in the following text are aspects of design, development and manufacture of reformers for high temperature PEMs. One model of reformer with its dimension and parts is developed in SolidWorks software and presented in the further text. Manufacturing is performed based on this model as well as studies related to dimension influences on the reforming process with a reformer size proposal and CFD analysis, /6/. Processing of the developed model turned up to be very non-economical and impossible from a technical aspect, so some dimensions have been changed.

In addition to these tests, scientists around the world have carried out numerous other test in order to achieve an efficiency increase of the reformer, /7/. CFD analyses are a more easier way for performing simulations and have a great role in fuel cell examinations, /6, 8/.

PEM FUEL CELL SYSTEM

One system of a polymer electrolyte membrane fuel cell contains three main reactors. The first 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. The whole system is built from components that can be seen in Fig. 1. From top to bottom the following components are:

- incoming and outcoming 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.

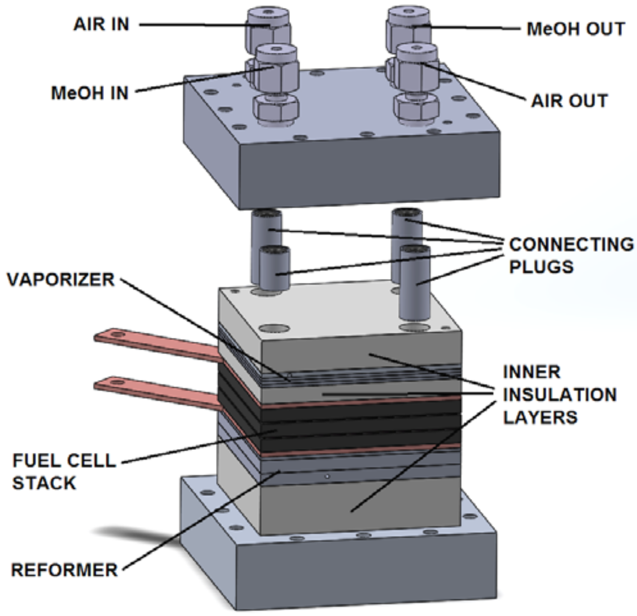


Figure 1. Design of the system with HTPEM fuel cell stack and integrated vaporizer and reformer.

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 of 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 (∅3 mm) and the main flow field distributing channel.

METHANOL STEAM REFORMING MODEL OR REFORMER

In Fig. 2a shown is a SolidWorks assembly of parts that form the MSR or reformer. The middle part represents the reaction volume with incoming and outgoing channels. The reaction volume is separated by two stainless steel mashes (after widening of the incoming channel and narrowing of the outgoing channel) which are inserted into 0.5 mm 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 Fig. 2b, it is composed of three plates – upper and lower cover plates, with thickness of 3.8 mm and 1 mm, in respect, and a middle plate, 4 mm thick. The middle plate contains the reaction volume, and inlet and outlet channel.

a)

b)

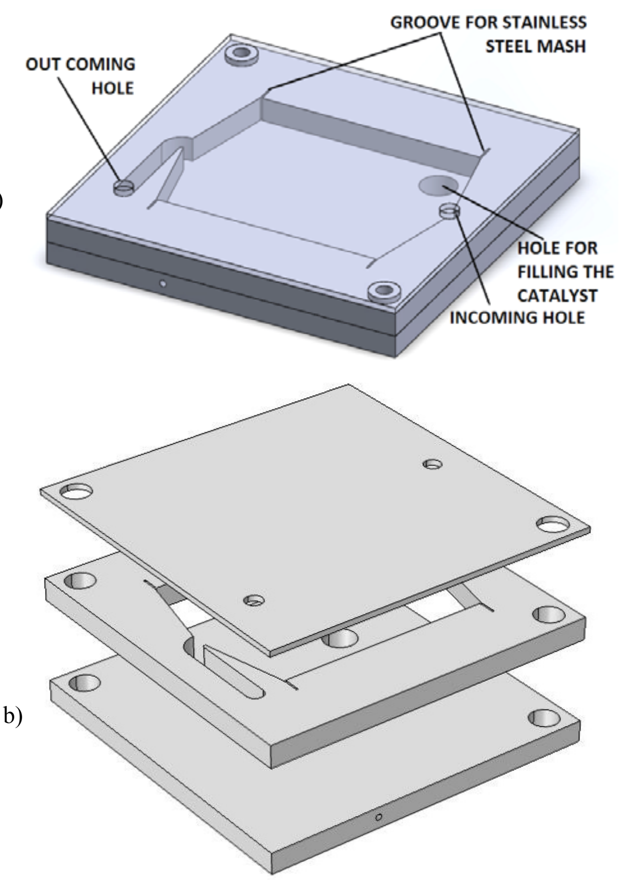


Figure 2. a) Methanol steam reformer with top plate in transparent mode, b) three plates of the methanol steam reformer stack.

a)

b)

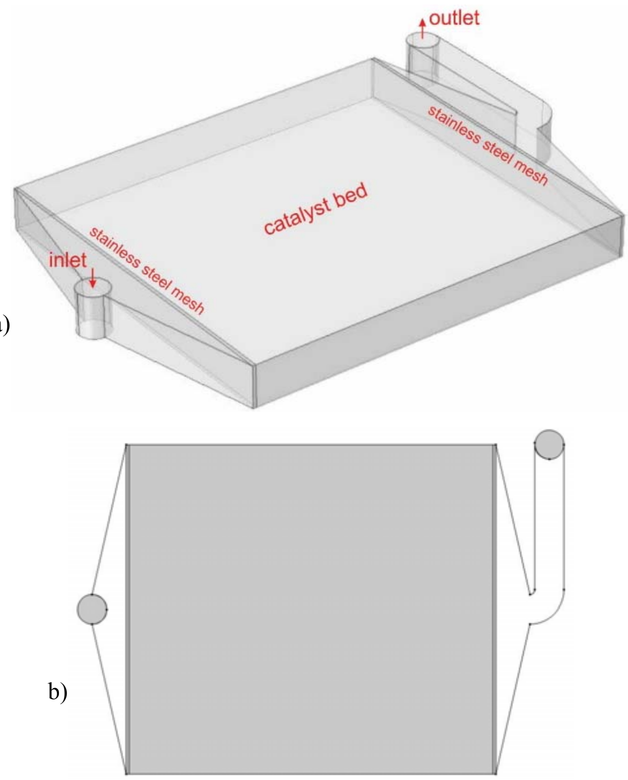


Figure 3. a) Initial geometry of the reaction volume with inlet and outlet channels, b) cross section of reaction volume with channels.

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

Before the 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

DEVELOPMENT AND MANUFACTURE

For the purpose of developing the shown reformer, operations involve processing on a milling machine and the Wire EDM machine. Before designing the manufacturing process, an analysis of assembly parts is performed. Since use of non-conventional machining methods increases manufacturing costs, the shape and dimensions optimization of the reformer is performed. Since EDM machining requires the use of a wire with a diameter of 0.3 mm, the shape and dimensions of the middle plate opening is changed. The transversal hole on the reformer is meant for placing the thermocouple, thus the hole diameter is changed from 1 to 2 mm, whereas the depth remained the same as shown in Fig. 4. This was done for lowering machining costs. The designed groove width (detail A, Fig. 4) in this case is not a functional measure, since a mesh is meant to be welded to the plate at that location. Because of this, the design dimension has been changed to 0.5 mm in order to use a wire with maximum diameter, which provides sharper cutting modes during EDM processing with a wire. At the same time, manufacturing of a plate with a radius equal to one half of the groove width is planned, whereas all of the changes that are made are shown in Fig. 4, detail B. For CAD models changed in this way, the processing technology design is performed by using software package Creo/PARAMETRIC, and thus control codes for CNC machines are obtained.

Processing of three reformer plates is first performed on a mill where overall dimensions are obtained and adequate holes are made. A technological opening is made in the middle of the central reformer plate, in order for the EDM wire to pass through it. Basing and tightening of the workpiece is performed using specially designed auxiliary equipment (Fig. 5a). Before processing, the tool path simulation is performed on the machine itself (‘Ewis’ EV.00.000M4, made by Ukrainian company P.O. Novator), for the purpose of verifying the previously generated control code. After the control code is verified, the processing is performed with auxiliary movement rate of 4.8 mm/min (Fig. 5b).

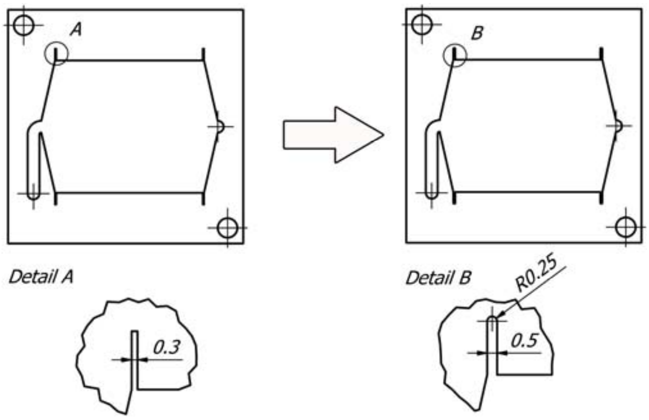
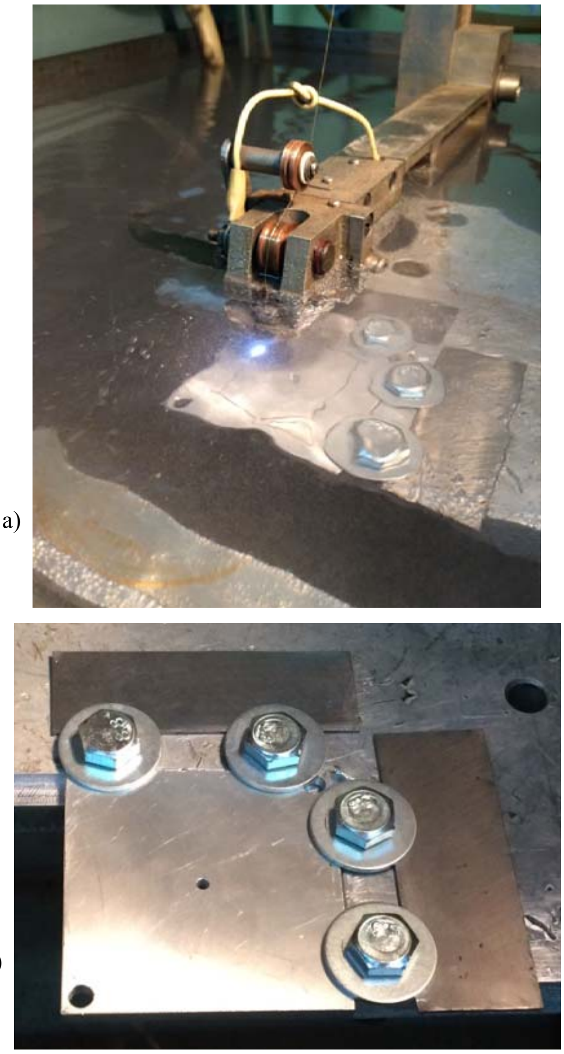


Figure 4. Display of changed dimensions in the model.



a)

b)

Figure 5. a) Basing and tightening of the workpiece in auxiliary equipment, b) processing of the EDM with a wire.

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 influence 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 the optimization of reformer shape and dimensions is performed in order to decrease the time needed for its production. One of the adopted changes in reformer manufacture is the change of the middle plate opening diameter (due to the fact that the EDM processing wire has a diameter of 0.3 mm) from 1 to 2 mm.

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