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ENERGY TRANSFER SYSTEMS IN CHEMICAL ENERGY CONVERSION DEVICES INTO ELECTRICITY: PEM FUEL CELLS

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1. PEM fuel cells importance

Increasing energy consumption due to a continuous development of many goods consuming producer industries for population which is steadily increasing leads to a global mobilization to identify affordable and sustainable solutions to achieve every year the energy surplus. One of these directions is to produce energy from renewable energy sources eco-friendly, namely Proton exchange fuel cells (PEMFCs). PEMFCs are electrochemical devices that convert chemical energy directly into electrical energy fuel, without being subjected to the limitations of the Carnot cycle. Compared with conventional internal combustion engines, this process allows to achieve considerably higher efficiencies. PEM fuel cells success ultimately depends on the performance, durability and competitive costs [1, 2, 3, 4, 5]. To improve durability and reduce costs of fuel cell devices, tools and diagnostic procedures are required [6, 7].

The approached thematic in this paper is part of recent achievements in large scale production of PEMFCs: by these topics are developed (design, manufacture and testing) two component parts bipolar plates and gas diffusion layer, using low cost materials and manufacturing techniques, components which can considerably improve the structure and functionality of this fuel cell type. The manufacturing techniques used for the bipolar plates and gas diffusion layer production and the main results will be discussed further, in Section two.

2. Bipolar plates and gas diffusion layer manufacturing

We used aluminium alloy 2007 T4511 as main material to produce the PEMFC's flowing plates. Unlike stainless steel, aluminium offers a substantially mass reduction for the entire fuel cell, while is maintaining the same excellent

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mechanical properties that metals give them. The size of a single flowing plate has 60×60×10 mm.

For the flow field design, we choose a serpentine-parallel geometry projection due to the advantages they present (uniform distribution of reactive species and forced removal of potential water droplets which may accumulate in channels), thus reducing pressure drops and excessive loss of the reactants concentration. The flow field is divided in three sections (each section has as flow channels grouped in parallel linear serpentine) having separate inputs and outputs. The flow field active surface was 32×29 mm.

We used CNC milling technique to obtain the plate's flow field projection formed by fifteen channels 1mm wide and 0.5mm deep, fourteen ribs 1mm wide and two main channels 2mm wide and 0.5mm deep. After milling the flow field of the process was continued with the hole of the fastening holes and with that of the supply / exhaust, respectively. The final plate includes four mounting holes with a 7mm diameter and two holes for supply / discharge of a 3 mm diameter.

To prevent corrosion of aluminium plates and to assure them a longer life was deposited a thin layer of gold (20 nm) on the surface of channels using magnetron sputtering technique.

Electrical conductivity, porosity and morphology of the components were examined through ex-situ methods as: X-rays, Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM), Cone-Beam Computed Tomography (CBCT), Brunauer- Emmet-Teller (BET) surface analyse, four-point method.

Following investigations carried out by Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) analysis was founded that during CNC milling technique a small amount of carbon was deposited on the surface due to processing and the gold coating was unevenly distributed on the surface plate and on the channels and their walls, the largest amount of gold deposited in the channel depth being ~ 20%.

The electrical conductivity obtained by four points measuring procedure at 2 bars, respectively 4 bars was ~ 22 S /m, respectively ~ 6.6 S /m.

The copper plates have been designed in order to replace the carbon support treated with Teflon material intended to serve as a gas diffusion layer for PEM fuel cells.

To obtain a gas diffusion layer a mixture of copper filings and naphthalene (to generate pores in the structure) was used.

The size of the copper filling grains was under 450 microns.

The copper - naphthalene mixture was compacted at 150 kN pressure using a stainless-steel die 304 and a hydraulic press.

We obtained by pressing eight samples of copper – naphthalene having a 3mm to 5mm thickness range. Porous layers were obtained by sintering in a controlled atmosphere of Ar-H2 (95: 5%) of different quantities of copper filings (18 g and 23 g) in additions with different amounts of naphthalene (4% - 11%) at 900°C using a tube furnace, with a 70 liters/hour flow rate. To prevent bending during the thermal treating process, samples were sandwiched between two porous alumina plates of 20 cm length. The porous copper samples were analysed using: X-rays, SEM, CBCT, BET and boiling after the immersion in paraffin oil investigation techniques. X-ray investigation was applied to the samples both before sintering and after sintering to follow eventual disposal of the naphthalene introduced into the mixture. Registered spectra showed that sintered samples no longer contain naphthalene, copper being the only identified element. Diameter and pore size distribution were determined by analysing SEM and CBCT images and by BET surface analysis. The images were investigated using ImageJ software and data fitting was made in OrginPro 2016 program. The results showed that macroporous structures have a preponderant pore size distribution between 1.4 μm to 30 μm on the surface and 8.56 μm to 50 μm in section. The pore size (~164 nm) determined by the average adsorption pore width (4V/A via BET) indicates that the sample is dominated by the presence of a mesoporous structure. To determine the porosity of the copper layers we used the oil impregnation and water boiling method according to the ISO 2738/1999 standard. The samples were dried for 90 minutes at 105ºC, cooled down at room temperature (23°C), in order to achieve a constant mass and then weighted. Results showed that the samples with a higher copper content (23 g) absorbed a larger oil quantity (> 15%) and had a greater open porosity (the maximum being 73.4% - sample with 7% naphthalene) and that the water absorption values were between 1.66 - 7.9 %, this being important to maintain wet the proton exchange membrane. It was made a comparative study between a copper plate of 7% - 23 g and carbon paper Toray060 (5% Teflon) using a "U" tube manometer filled with liquid. Toray paper which was used in the study had 0.19 mm thickness and 78% porosity, and the copper plate had 4 mm thickness and 73.4% porosity. Results revealed that for equalizing approximately two liters of the liquid column are required 45.83 seconds when air is passing through the porous copper material and 35.48 seconds through the Toray060 carbon paper material at relative low partial pressures – 0.0619 atmospheres.

3. Conclusions

In the present paper was presented the development of two component parts of a PEM fuel cell, bipolar plates and gas diffusion layer, using low cost materials and manufacturing techniques.

The new flow field divided into three sections of channels grouped in parallel linear serpentine with separate inputs and outputs, that was designed for the bipolar can solve the problem of droplets accumulation and mass concentration losses. According to the acquired characteristics (porosity, pore size and pore size distribution, water absorption) in the porous copper layers manufacturing process, these components could be used as gas diffusion layer for the PEMFC, being able to make the in different sizes, depending on the application.

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