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Numerical Investigation of Effects of Porous Layer Properties and Thickness on Performance of PEMFC

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In this study, fluid flow and concentration distribution on the cathode side of a Proton Exchange Membrane Fuel Cell were numerically analyzed. The problem domain consists of a cathode gas flow channel, cathode gas diffusion layer and cathode catalyst layer. The governing equations, continuity, momentum and concentration equations were discritized by the control volume method and solved using a computer program based on SIMPLE algorithm. Simulations were made for different values of gas diffusion layer porosity, catalyst layer porosity and the ratio of the cathode gas diffusion layer thickness to the gas flow channel height. Using the results of these simulations, the effects of these parameters on flow, oxygen concentration and current density distribution were analyzed. It is observed that increasing the porosities of the gas diffusion layer and catalyst layer increases the current and power densities. The increase in the porosity of the gas diffusion layer also increases the oxygen concentration in both gas diffusion and catalyst layers but decreases the oxygen concentration in gas flow channel. Simulations also showed that increasing porosity of the catalyst layer increases the oxygen concentration in a catalyst layer but decreases the oxygen concentration in a gas flow channel and gas diffusion layer. It is also seen that the effect of the gas diffusion layer porosity is more dominant on cell performance compared to the catalyst layer porosity. The analysis of the effect of the ratio of the cathode gas diffusion layer thickness to the gas flow channel height on the cell performance showed that the increasing ratio of the cathode gas diffusion layer thickness to the gas flow channel height decreases the current and power densities. An analysis of the data obtained from simulations also shows that increasing the ratio of the cathode gas diffusion layer thickness to the gas flow channel height increases the oxygen concentration in the gas flow channel but decreases the oxygen concentration in both gas diffusion and catalyst layers.

Numeričko istraživanje efekata poroznih svojstava i debljine sloja na performance protonske izmjenjivačke membrane gorive ćelije

Izvornoznanstveni članak

U ovom radu je numerički analizirano strujanje fluida i raspodjela koncentracije protonske izmjenjivačke membrane na katodnoj strani gorive ćelije. Problemska domena se sastoji od kanala katode kroz koji struji plin, difuznog sloja plina na strani katode kao i katodnog katalitičkog sloja. Generalne jednadžbe, jednadžbe kontinuiteta, jednadžbe količine gibanja i jednadžbe koncentracije su diskretizirane metodom kontrolnog volumena i riješene koristeći računarski program koji je baziran na algoritmu SIMPLE. Simulacije su napravljene za različite vrijednosti poroznosti difuzijskog sloja na strani plina, poroznosti katalitičkog sloja i omjera debljine difuzijskog sloja na strani plina i visine kanala kroz koji struji plin. Koristeći rezultate ovih simulacija, analizirani su efekti ovih parametara na strujanje, koncentraciju kisika i raspodjelu gustoće struje. Uočeno je da se s povećavanjem poroznosti difuzijskog sloja na strani plina i katalitičkog sloja, povećava se jakost struje i snage. Povećavanjem poroznosti difuzijskog sloja na strani plina, povećava se i koncentracija kisika i u difuzijskom sloju na strani plina i u katalitičkom sloju, ali se smanjuje koncentracija kisika u kanalu kroz koji struji plin. Simulacije su također pokazale da povećavanjem poroznosti u katalitičkom sloju povećavaju u njemu koncentraciju kisika, ali smanjuje se koncentracija kisika u kanalu strujanja plina kao i u difuzijskom sloju na strani plina. Također je uočeno da je efekt poroznosti u difuzijskom sloju na straniplina bitno utjecajniji na performanse gorive ćelije od poronosti kataltičkog sloja. Analiza efekta omjera debljine difuzijskog sloja na strani plina na katodi i visine kanala kroz koji struji plin na performance gorive ćelije je pokazala da se povećavanjem debljine difuzijskog sloja plina na katodi u odnosu na visinu kanala, smanjuje jakost struje i gustoću snage. Analiza podataka dobivena simulacijom također pokazuje da se povećavanjem omjera debljine difuzijskog sloja plina na strani katode prema visini kanala, povećava koncentraciju kisika u kanalu strujanja plina ali smanjuje koncentraciju kisiku i u dufuzijskom sloju plina i katalitičkom sloju.

Keywords
Computational Fluid Dynamics
Porous Medium
Proton Exchange Membrane Fuel Cells

Ključne riječi
Porozni medij
Protonska izmjenjivačka membrana gorivih ćelija
Računarska dinamika fluida

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Symbols/Oznake

a	- total catalyst surface area per unit volume of cathode, m^{-1} ukupna katalitička površina po jedinici volumena katode
c	- molar concentration, mol/m^3 - molarna koncentracija
c_{tot}	- total molar concentration, mol/m^3 - ukupna molarna koncentracija
C	- dimensionless concentration - bezdimenzijska koncentracija
C_0	- inlet molar concentration, mol/m^3 - ulazna molarna koncentracija
Da	- Darcy number - Darcyjev broj
D_{f}	- diffusion coefficient of the fluid - difuzijski koeficijent fluida
D_{g}	- diffusion coefficient of the porous medium - difuzijski koeficijent poroznog medija
D_{h}	- hydraulic diameter of the channel, mm - hidraulički promjer kanala
H	- channel height, mm - visina kanala
H_{c}	- catalyst layer height, mm - visina katalitičkog sloja
H_{g}	- gas diffusion layer height, mm - visina plinsko difuzijskog sloja
g	- gravitational acceleration, m/ s^2 - gravitacijsko ubrzanje
i	- current density, A/m^2 - gustoća struje
j	- transfer current, A/m^2 - strujni prijenos
F_{o}	- Forcheimer constant - Forcheimerova konstanta
F	- Faraday constant, C/mol - Faradayeva konstanta
K	- permeability of the porous medium, m^2 - propustnost poroznog medija
l_{e}	- exit channel length, mm - dužina izlaznog kanala
l_{i}	- inlet channel length, mm - dužina ulaznog kanala
l_{t}	- total channel length, mm - ukupna dužina kanala
L	- dimensionless length of the porous medium - bezdimenzijska dužina poroznog medija
L_{e}	- dimensionless exit channel length - bezdimenzijska dužina izlaznog kanala
L_{i}	- dimensionless inlet channel length - bezdimenzijska dužina ulaznog kanala
L_{t}	- dimensionless total channel length - bezdimenzijska ukupna dužina kanala
M	- molar mass, kg/mol - molarna masa
P	- pressure, Pa - tlak
p	- dimensionless pressure - bezdimenzijski tlak
Pr	- Prandtl number - Prandtlov broj
R	- universal gas constant, J /(mol ·K) - univerzalna plinska konstanta
Re	- Reynolds number - Reynoldsov broj
S	- sink term - ponorski član
Sc	- Schmidt number - Schmidtov broj
T	- temperature, K - termodinamička temperatura
U_0	- inlet velocity of the fluid, m/s - ulazna brzina fluida
U	- dimensionless velocity in x-direction - bezdimenzijska brzina u x smjeru
u	- velocity in x-direction, m/s - brzina u x smjeru
v	- velocity in y-direction, m/s - brzina u y smjeru
V	- dimensionless velocity in y-direction - bezdimenzijska brzina u y smjeru
V	- cell voltage, V - napon ćelije
V_{oc}	- open circuit voltage, V - napon otvorenog kruga
x	- length in x-direction, m - duljina u x smjeru
X	- dimensionless length in x-direction - bezdimenzijska duljina u x smjeru
y	- length in y-direction, m - duljina u y smjeru
Y	- dimensionless length in y-direction - bezdimenzijska duljina u y smjeru
α	- transfer coefficient - koeficijent prijenosa
ε	- porosity - poroznost
$\varepsilon_{\mathrm{dl}}$	- gas diffusion layer porosity - poroznost plinskog difuzijskog sloja
$\varepsilon_{\mathrm{cl}}$	- catalyst layer porosity - poroznost katalitičkog sloja

ρ	- density of air, kg/m^3 - gustoća zraka
μ	- dynamical viscosity, kg/(m·s) - dinamički viskozitet
ν	- kinematic viscosity, m^2/s - kinematički viskozitet
η	- activation loss, V - gubitak aktivacije
Φ_s	- phase voltage, V - fazni napon

1. Introduction

As the amount of fossil fuels has been decreasing, alternative energy sources have become very popular. The negative effects of use of fossil energy sources on the environment have made alternative energy sources important research subjects. In recent years, many scientists have been working on fuel cell applications to make this technology ready for practical applications.

The fuel cells are devices that convert the electro-chemical energy to electrical energy. Improving the availability of the fuel cells will be a solution for global warming and energy needs.

The processes taking place in fuel cells involve fluid flow, heat and mass transfers and electro chemical reactions. The current density vs. voltage relation is one of the key parameters affecting cell performance. On the other hand, parameters such as geometry of the cell and characteristics of the materials used as a component of the fuel cell also play significant roles on cell performance. Due to these complexities, numerical simulation is commonly preferred for analysis of fuel cells.

In literature there are many studies on Proton Exchange Membrane Fuel Cells. [6] developed an isothermal, one dimensional, steady state PEMFC model. The effect of water management on cell performance was analyzed. It was determined that the net water per H+ flux ratio is about one tenth of the electro-osmotic drag coefficient measured for a fully hydrated membrane. [7] developed a two dimensional mathematical model to simulate a PEMFC. The aim of this study was to obtain the effects of hydrogen passing from anode to cathode on the cell performance by analyzing the electro-chemical kinetics, current distribution and mass transports. [1] developed a two dimensional mathematical model of a PEMFC. The simulations provided oxygen and water concentration distributions. The velocity distribution of the water and the effect of this distribution on the cell performance were also investigated. [3] developed a two dimensional mathematical model of a PEMFC to analyze the effects of different parameters on cell performance. The effects of porosity of the cathode layer, inlet oxygen concentration, operation temperature and pressure on the cell performance were analyzed. It was observed that the porosity of the cathode layer has important effects on the cell performance.

In the present study, a two-dimensional model was developed to analyze the processes at the cathode side of a PEMFC in detail. The domain considered for the investigations consists of the cathode gas channel, cathode gas diffusion layer and cathode catalyst layer. The equations governing the flow of air and distribution of oxygen concentration in all layers are derived taking into consideration the effects of porosity of layers together with all other parameters. The effects of electro-chemical reaction are accounted for in the oxygen concentration equation by including a sink term which depends on local current density. The model allows the oxygen concentration distribution, velocity distribution, current density distribution and power density distribution to be obtained. To solve the equations, a computer code was developed. From the results of simulations, the effects of gas diffusion layer porosity and the ratio of the GDL thickness to the gas flow channel height on the cell performance were investigated.

2. Mathematical Modelling

The geometry of the solution domain and the coordinate system are shown in Figure 1. The problem domain consists of the cathode gas flow channel, cathode diffusion layer and cathode catalyst layer. To minimize the difficulties of specifying the boundary conditions at the entrance and exit, the problem domain is extended as a parallel plate channel both at the inlet and the exit.

In the formulation of the problem, the following assumptions are made to simplify the problem:

- The flow is 2-D and steady.
- The flow is laminar in entire domain.
- The flow is incompressible.
- The cathode gas diffusion layer and catalyst layer are considered isotropic porous medium.
- The gas (air) flowing along the problem domain is perfect gas.
- The PEMFC is isothermal.
- The volume occupied by water formed as a result of the electro-chemical reaction at the catalyst layer is negligible.
- Air enters the domain with a uniform velocity distribution.

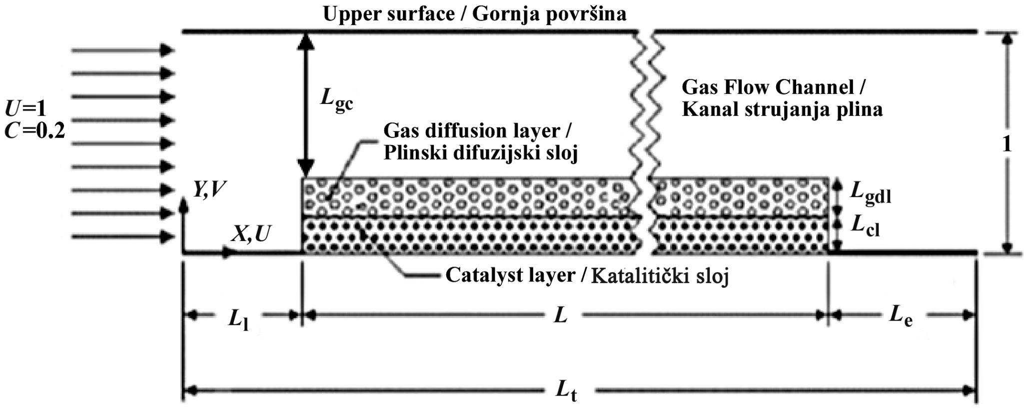

Figure 1. The problem geometry and the coordinate system

Slika 1. Geometrija problema i koordinatni sustav

2.1. Governing Equations

The problem domain consists of three different regions: The gas flow channel, gas diffusion layer and the catalyst layer. Both the gas diffusion layer and the catalyst layer are porous layers. The governing equations should take into account all these different regions in the problem domain. The flow in a gas flow channel is governed by Navier-Stokes equations. In the gas diffusion layer and catalyst layer, the effects of porosity should be represented in the equations. In this study, the flow in the gas diffusion layer and catalyst layer are formulated by Darcy-Brinkman-Forcheimer equations. The governing equations were derived in a general form so that by assigning proper values to different variables, equations of different regions including gas flow channel, gas diffusion layer, and catalyst layer are obtained. The non-dimensional forms of these general equations are given below [2]. In these equations; ε represents porosity, and term S_{O2} represents oxygen consumption as a result of the electro-chemical reaction.

Continuity Equation

$$\frac{\partial(\varepsilon U)}{\partial X}+\frac{\partial(\varepsilon V)}{\partial Y}=0. \tag{1}$$

In this equation, U and V are dimensionless velocities in x and y directions, respectively. Porosity ε=1 in gas flow channel and ε=0.4 in catalyst layer. In gas diffusion layer, porosity is assigned different values to investigate the effects of the porosity on the cell performance.

Momentum Equation

x-direction

$$\frac{1}{\varepsilon^2}\left[\frac{\partial(UU)}{\partial X}+\frac{\partial(VU)}{\partial Y}\right]=-\frac{\partial P}{\partial X}+R+ \\ +\frac{1}{\varepsilon Re}\left[\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right]. \tag{2}$$

In this equation, the term R represents the effect of porosity on the flow motion. In gas flow channel R=0. Using Darcy-Brinkman- Forcheimer formulation R in the porous regions is expressed as,

$$R=-\frac{1}{ReDa}U-\frac{Fo}{Da^{1/2}}\left(U^2+V^2\right)^{1/2}U. \tag{3}$$

This expression is known as Darcy-Brinkman-Forcheimer equation. In this expression Da is Darcy number and Fo is Forcheimer number.

y-direction

$$\frac{1}{\varepsilon^2}\left[\frac{\partial(UV)}{\partial X}+\frac{\partial(VV)}{\partial Y}\right]=-\frac{\partial P}{\partial Y}+R+ \\ +\frac{1}{\varepsilon Re}\left[\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right]. \tag{4}$$

Like x-direction momentum equation, in gas flow channel R=0 and in the porous regions,

$$R=-\frac{1}{ReDa}U-\frac{Fo}{Da^{1/2}}\left(U^2+V^2\right)^{1/2}U. \tag{5}$$

Oxygen Concentration Equation

The distribution of oxygen in the flow domain is governed by the following equation:

$$\frac{1}{\varepsilon^{1.5}}\left[\frac{\partial(UC)}{\partial X}+\frac{\partial(VC)}{\partial Y}\right]=\frac{1}{ScRe}\left[\frac{\partial^2 C}{\partial X^2}+\frac{\partial^2 C}{\partial Y^2}\right]+S_{O_2}. \tag{6}$$

In this equation, C represents the oxygen concentration. Sc is Schmidt number ($Sc=D/\nu$). S_{O2} represents the oxygen consumption as a result of the electro-chemical reaction. In the gas flow channel and in gas diffusion layer there is no electro-chemical reaction, hence in these regions source term S_{O_2} is zero. In the catalyst layer, this term is related to current density, Faraday constant, local concentration, channel height and inlet velocity as given in the following expression [5];

$$S_{\mathrm{O}_2} = -\frac{1}{4F} j_\mathrm{c} \frac{H}{U_0 c}. \tag{7}$$

In this expression, F is Faraday constant, j_c is current density at the cathode, H is channel height and U_0 is inlet velocity. The local current density at the cathode can be expressed by Butler-Volmer equation.

$$j_\mathrm{c} = a j_0^{ref} \left(\frac{C_{\mathrm{O}_2}}{C_{\mathrm{O}_2\mathrm{ref}}} \right) \left[e^{\frac{\alpha_\mathrm{c} F}{RT} \eta} - \frac{1}{e^{\frac{\alpha_\mathrm{c} F}{RT} \eta}} \right]. \tag{8}$$

The activation overpotential term can be expressed as [4];

$$\eta(x,y) = \phi_\mathrm{s} - V_\mathrm{oc}. \tag{9}$$

In Eq. 9, Φ_s is cell voltage and V_oc is the open circuit potential which can be expressed as [5];

$$V_\mathrm{oc} = 0.0025T + 0.2329. \tag{10}$$

2.2. Boundary Conditions

At the entrance (X=0)

Since the flow domain is extended at the inlet, it can be assumed that the fluid enters the channel with a uniform velocity. The mole fraction of oxygen is equal to a prescribed mole fraction. Hence, the dimensionless velocity components and oxygen mole fractions can be expressed as;

$U(0, Y) = 1$, $V(0, Y) = 0$, $C = C_0$.

At the exit (X=L_t)

As the computational domain is also extended at exit, the variation of all the variables in the flow direction at the exit can be considered negligible. Hence, at the exit,

$$\frac{\partial U(L,Y)}{\partial X} = 0,\ V(L,Y) = 0,\ \frac{\partial C(L,Y)}{\partial X} = 0.$$

On the upper surface (Y=1)

The upper surface is a non-porous wall. Hence, the no-slip condition and no mass penetration through the upper surface should be satisfied.

$$U(X,1) = 0,\ V(X,1) = 0,\ \frac{\partial C(X,1)}{\partial Y} = 0.$$

At the bottom surface (Y=0)

At the bottom surface of the catalyst layer, there are no oxygen molecules passing through the bottom surface. As a result of this variation of oxygen concentration is negligible at this surface. In addition to this, slip condition is applied at this surface.

$$U(X,0) = 0,\ V(X,0) = 0,\ \frac{\partial C(X,0)}{\partial Y} = 0.$$

3. Numerical Solution

The governing equations, together with the boundary conditions were discritized by the finite volume method. The convection terms are discritized by using hybrid scheme. The SIMPLE algorithm was used to solve the coupled velocity and pressure equations. Gauss-Seidel point-by-point solution technique was used for the solution of algebraic equations. To run the program developed, the inlet velocity of air, the cell voltage, operation temperature, the porosities of gas diffusion layer and catalyst layer were specified. Then, at every grid point in each layer, the velocity components and pressure were calculated. The local current densities were solved by using Butler-Volmer equation. Once the local current densities were obtained, the local current overpotentials were calculated. Then the source term in oxygen concentration equation was calculated and finally, the oxygen concentration equation was solved for the mole fraction distribution of oxygen. This solution scheme was repeatedly applied until the convergence criterion was satisfied. After a mesh optimization study, a non-uniform mesh of 290 × 40 was chosen. In the solutions, convergence criterion of 10^{-5} was used for all the variables. To validate the numerical model developed, the results of the simulations were compared with the results in literature. The computed results showed satisfactory agreement with the experimental data [2].

4. Results and Discussions

Using the model and the computer program developed the effects of the gas diffusion layer and catalyst layer porosities and the ratio of the GDL thickness to the gas flow channel height on the cell performance were analyzed. The values of the parameters considered in the study are given in Table 1.

To analyze the effects of the porosity of the gas diffusion layer on the flow and the cell performance, the simulations were performed for GDL porosities of 0.3, 0.4 and 0.5 while other parameters were kept constant. The cell voltage V= 0.7 V, operation temperature T=353 K, Reynolds number Re=25 and catalyst layer porosity ε_cl=0.4 and the ratio of the GDL thickness to gas channel height 0.43 were kept constant.

In Figure 2, the x-direction velocity profiles at the vertical mid-plane are shown for different gas diffusion layer porosities. As seen in this figure, in the gas channel, velocity has a parabolic profile. In the gas diffusion and catalyst layers, velocity of air is quite small due to the resistance exerted by the porous material of these layers.

Table 1. The values of the parameters considered in the study

Tablica 1. Vrijednosti parematnih razmatranih studiji

Parameters / Parametar	Unit / Jedinica	Value / Vrijednost
Dimensionless length of the inlet extended plate / Dimenzijska dužina ulazne ploče, L_i	-	5
Dimensionless length of the porous medium / Dimenzijska dužina prozne stvari, L	-	50
Dimensionless length of the outlet extended plate / Dimenzijska dužina izdužne ploče, L_e	-	5
Forcheimer constant / Forcheimerova konstanta, F_o	-	0.35
Schmidt number / Schmidtov broj, *Sc*	-	0.8
Prandtl number / Prandtlov broj, *Pr*	-	0.74
Faraday constant / Faradayova konstanta, *F*	C/mol	96485
Darcy number / Durcyov broj, *Da*	-	10^{-5}
Molar mass of air / Molarna masa zraka, M_{air}	kg/mol	0.029
Molar mass of oxygen / Molarna masa kisika, M_{O2}	kg/mol	0.032
Cathode transfer coefficient / Koeficijent katodnog prijenosa, α_c	-	1.0
Reference transfer current density *x* Effective surface per volume / Referentna prenesena gustoća struja *x* efektivna površina po volumenu, aj_0^{ref}	A/m^3	5×10^2
Ratio of oxygen mole fraction to nitrogen mole fraction / Molni omjer kisika i dušika, C_{o2}/C_{N2}	-	0.2 / 0.8

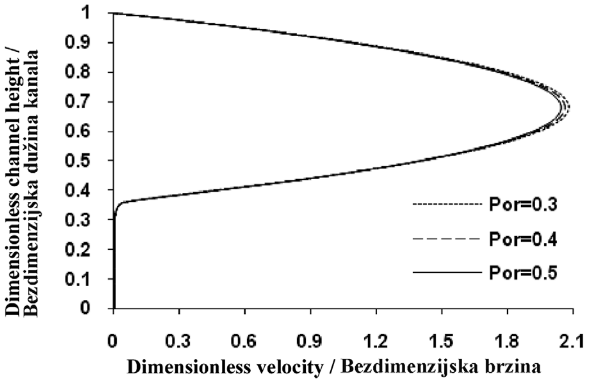

Figure 2. Air velocity profile at the mid-vertical plane for different GDL porosities (*T*=353K, *Re*=28)

Slika 2. Profil brizine u središnjoj vertikalnoj ravnini za različite GDL poroznosti (*T* = 353 K, *Re* = 28)

The oxygen concentration profiles at vertical mid-plane for different values of gas diffusion layer porosities are shown in Figure 3. In this figure, it is seen that the oxygen concentration decreases considerably from the gas flow channel to the catalyst layer. This is the result of the electro-chemical reaction taking place in the catalyst layer. It is also seen that oxygen concentration in the gas flow channel decreases with increasing gas diffusion layer porosity. On the other hand, it is observed that in the porous layers, the oxygen concentration expands with increasing gas diffusion layer porosity. The main reason for this is that the electro-chemical reaction occurring in the catalyst layer is a slow reaction. Since the reaction rate is low, all oxygen molecules passing through the catalyst layer could not be reacted. Hence, at high gas diffusion layer porosities, the number of the oxygen molecules does not decrease in GDL and catalyst layer because higher GDL porosities lead to higher diffusion rate. As the ratio of oxygen molecules consumed as a result of the electro-chemical reaction to the total oxygen molecules diffusing in the catalyst layer is less than that of at lower gas diffusion layer case, at higher GDL porosity cases, higher oxygen concentration is obtained in porous layers.

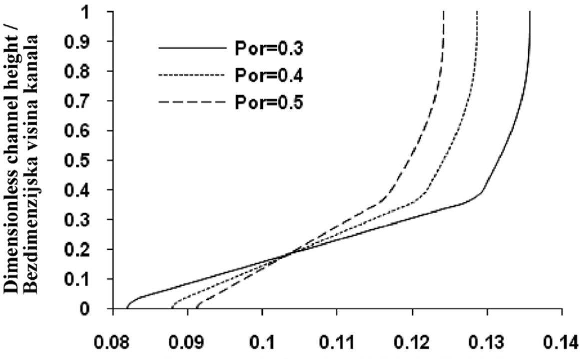

Figure 3. Oxygen mole fraction at the mid-vertical plane of the cell for different GDL porosities

Slika 3. Molni udio kisika u sred.- vertikalnoj ravnini ćelije za različite GDL poroznosti

The power density vs. current density curves for different gas diffusion layer porosities are shown in Figure 4. In Figure 5, the current densities vs. voltage curves for different GDL porosities are given. In these figures, it is seen that the power density at all current densities expands slightly with increasing GDL porosity. In addition to this, it is also seen that higher GDL porosities lead to higher current densities. This change is expected because GDL porosity has an effect on the limiting current density. As the limiting current density directly affects the maximum mass transfer rate, increasing GDL porosity increases the amount of the oxygen molecules at the porous layers because the transport mechanism is diffusive in these layers. For this reason, increasing GDL porosity results in a high limiting current density and also leads to a higher performance.

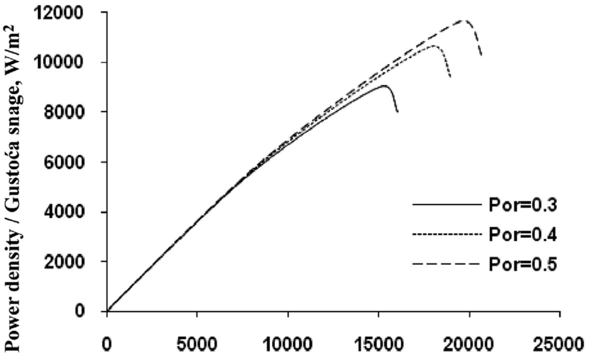

Figure 4. Power density-current density curve for different GDL porosities

Slika 4. Krivulje gustoća snage - gustoća struje za različite GDL poroznosti

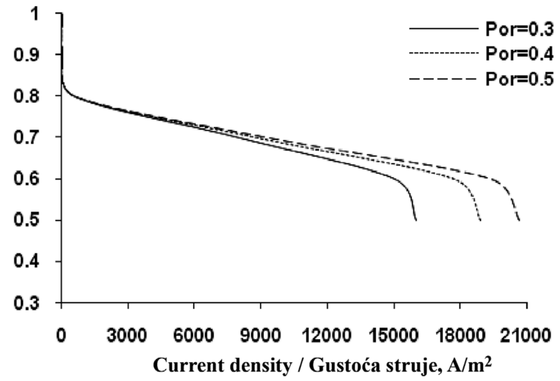

Figure 5. Voltage-current density curve for different GDL porosities

Slika 5. Krivulje napon – gustoća struje za različite GDL poroznosti

To analyze the effects of the porosity of the catalyst layer on the flow and the cell performance, the simulations were performed for catalyst layer porosities of 0.16, 0.28 and 0.4 while other parameters were kept constant. The cell voltage V= 0.7 V, operation temperature T=353 K, Reynolds number Re=25 and gas diffusion layer porosity ε_{gdl}=0.4 and the ratio of the GDL thickness to gas channel height ratio=0.43 were kept constant.

In Figure 6, the x-direction velocity profiles at the vertical mid-plane are shown for different catalyst layer porosities. As seen in this figure, in the gas channel, velocity has a parabolic profile. In the diffusion and catalyst layers, velocity of air is quite small due to the resistance exerted by the porous material of these layers. The velocity profiles for different catalyst layer porosities are qualitatively equal. Since the thickness of the catalyst layer is less than the other layers, the effect of the porosity of this layer on velocity is negligible.

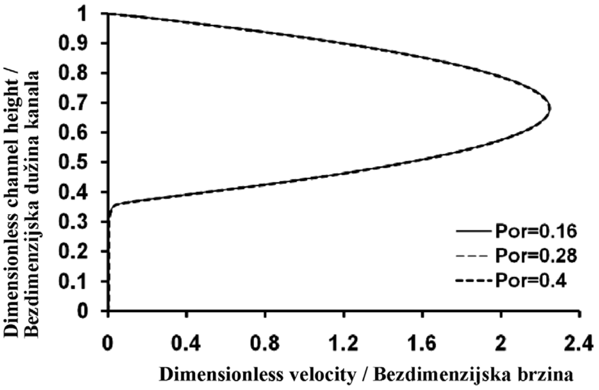

Figure 6. Air velocity profile at the mid-vertical plane for different catalyst layer porosities (T=353K, Re=28)

Slika 6. Profil brizine zraka u središnjoj vertikalnoj ravnini za različite poroznosti katalitičkog sloja (T = 353 K, Re = 28)

The oxygen concentration profiles at vertical mid-plane for different values of catalyst layer porosities are shown in Figure 7. In this figure, it is seen that the oxygen concentration decreases considerable from the gas flow channel to the catalyst layer. This is the result of the electro-chemical reaction taking place in the catalyst layer. It is also seen that oxygen concentration in the gas flow channel drods with increasing catalyst layer porosity. It is also observed that the oxygen concentration increases in the catalyst layer with increasing catalyst layer porosity. This increase in catalyst layer can be explained as that the high oxygen concentration occurs in catalyst layer with increasing porosity of this layer. Increasing the catalyst layer porosity increases the amount of the oxygen molecules passing through the catalyst layer. As it is mentioned in the effects of the gas diffusion layer porosity, the reaction rate of the electro-chemical reaction occurring in catalyst layer is slow. As a result of this all oxygen molecules passing through the catalyst layer could not be consumed. On the other hand, the thickness of the catalyst layer is less than the gas diffusion layer. For this reason, it is clearly seen that there is not a significant effect of the catalyst layer porosity on oxygen concentration distribution compared to the gas diffusion layer porosity effect.

The power density vs. current density curves for different catalyst layer porosities are shown in Figure 8. In Figure 9, the current densities vs. voltage curves for different catalyst layer porosities are given. In these figures, it is seen that the power density at all current densities expands slightly with increasing catalyst layer porosity. As stated above, the variation of the oxygen concentration in the catalyst layer is very small. As a result of this, the variations of the power and current densities for different catalyst layer porosities are also small. Increasing the amount of the oxygen molecules in the electro-chemical reaction adds to the power density and current density.

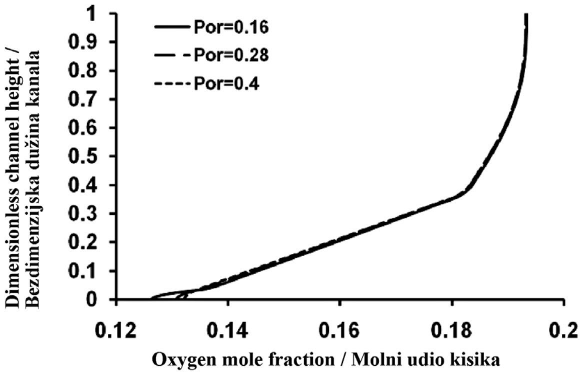

Figure 7. Oxygen mole fraction at the mid-vertical plane of the cell for different catalyst layer porosities

Slika 7. Molni udio kisika u sred.- vertikalnoj ravnini ćelije za različite poroznosti katalitičkog sloja

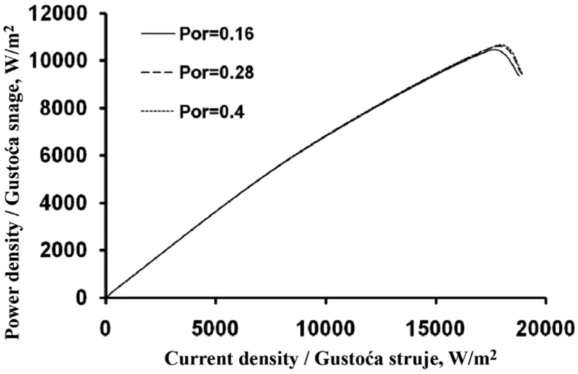

Figure 8. Power density-current density curve for different catalyst layer porosities

Slika 8. Krivulje gustoća snage . gustoća struje za različite poroznosti katalitičkog sloja

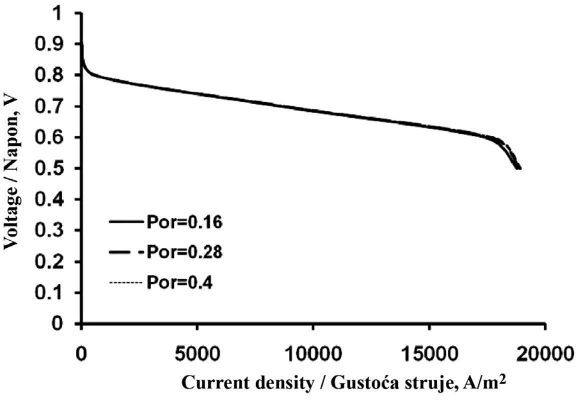

Figure 9. Voltage-current density curve for different catalyst layer porosities

Slika 9. Krivulje napon – gustoća struje a različite poroznosti katalitičkog sloja

To analyze the effects of the ratio of the cathode gas diffusion layer thickness, L_{gdl}, to the gas flow channel height, L_{gc}, on the flow and the cell performance, simulations were performed for ratios of 0.33, 0.43 and 0.53 while other parameters were kept as constant. The cell voltage V= 0.7 V, operation temperature T=353 K, Reynolds number Re=25, gas diffusion layer porosity ε_{GDL}=0.4 and catalyst layer porosity ε_{cat}=0.4 were kept constant. In Figure 10, profiles of x-direction velocity components at the vertical mid-plane are shown for different values of ratio of the cathode gas diffusion layer thickness to the gas flow channel height. As seen in this figure, in the gas channel, velocity has a parabolic profile. In the diffusion and catalyst layers, velocity of air is quite small due to the resistance exerted by the porous material of these layers. It can also be seen that the case with the highest ratio has the highest velocity in the gas flow channel. This behavior can be explained as the flow channel height drops with increasing ratio and an rise in velocity in the gas channel takes place.

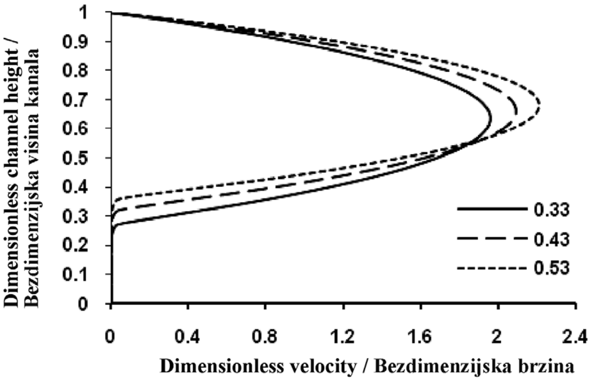

Figure 10. Air velocity profile at the mid-plane for different ratios of GDL thickness to gas channel height (T=353 K, Re=28, ε_{cat}=0.4)

Slika 10. Profil brizine zraka u središnjoj vertikalnoj ravnini za različite omjere GDL debljine i visine kanala kroz koji struji plin (T = 353 K, Re = 28, ε_{cat} = 0.4)

The oxygen concentration profiles at vertical mid-plane for different values of ratio of gas diffusion layer thickness to gas flow channel height are shown in Figure 11. In this figure, it is seen that the oxygen concentration decreases in the direction normal to the flow. The oxygen concentration decreases considerably from the gas flow channel to the catalyst layer. This is the result of the electro-chemical reaction taking place in the catalyst layer. It is also seen that oxygen concentration in the porous layers drops when increasing the ratio. The main reason for this is that with increasing GDL thickness, the number of the oxygen molecules diffusing through the GDL drops as expected. Since the transport of molecules is principally diffusive, the number of the oxygen molecules drops when increasing the ratio of gas diffusion layer thickness to gas flow channel height.

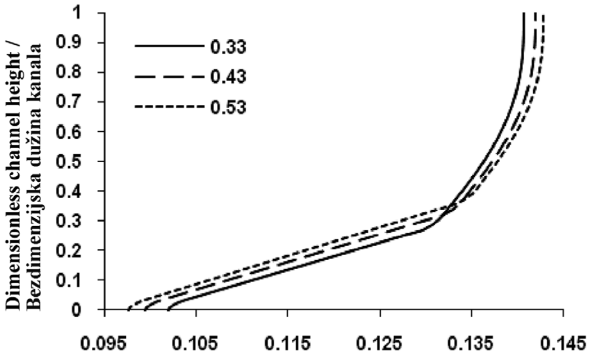

Figure 11. Oxygen mole fraction at the mid-plane for different ratios of GDL thickness to gas channel height

Slika 11. Molni udio kisika u sred.- vertikalnoj ravnini ćelije za različite omjere GDL debljine i visine kanala kroz koji struji plin

The power density vs. current density curves for different values of the ratio of gas diffusion layer thickness to gas flow channel height are shown in Figure 12. In Figure 13, the current densities vs. voltage curves for different ratios are given. In these figures, it is seen that the power density falls slightly with an increasing ratio. This decrease is expected because the number of the oxygen concentration passing through the porous layers drops when increasing the ratio. Due to the lower oxygen concentration, the electro-chemical reaction rate decreases and hence the power density falls slightly when increasing the ratio of the cathode gas diffusion layer thickness to the gas flow channel height.

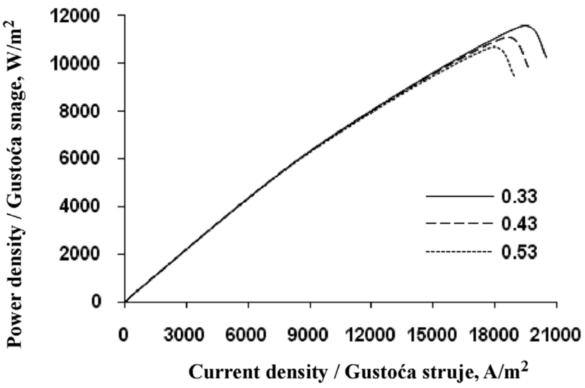

Figure 12. Power density-current density curve for different ratios of GDL thickness to gas channel height

Slika 12. Krivulje gustoća snage - gustoća struje za različite omjere GDL debljine i visine kanala kroz koji struji plin

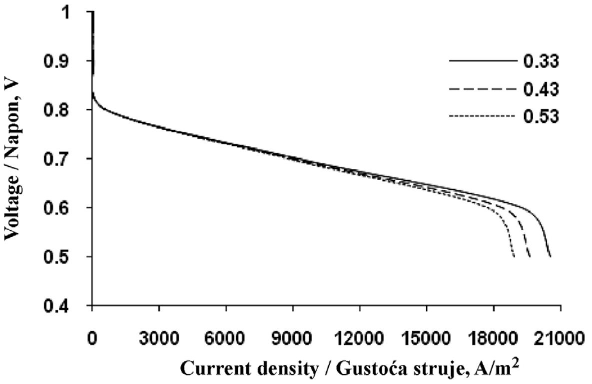

Figure 13. Voltage-current density curve for different ratios of GDL thickness to gas channel height

Slika 13. Krivulje napon – gustoća struje a različite omjere GDL debljine i visine kanala kroz koji struji plin

5. Conclusions

In this study, a 2-D model was developed for the numerical analysis of the cathode side of a PEM Fuel Cell. The velocity distribution, oxygen concentration distribution, current density and power density distributions were obtained in the cathode side of the PEM fuel cell for different gas diffusion and catalyst layer porosities and the ratios of the cathode gas diffusion layer thickness to the gas flow channel height. It is observed that increasing the gas diffusion layer porosity adds to the oxygen concentration in gas diffusion layer and catalyst layer but decreases the oxygen concentration in the gas flow channel. It is also observed that expanding the gas diffusion layer porosity increases power density and current density of the cell. By analyzing the simulation data, it is observed that increasing the porosity of the catalyst layer has same effects on velocity distribution, power density and current density variation as the effects of the gas diffusion layer porosity. Analyzing the effect of the catalyst layer porosity also showed that the oxygen concentration falls in a gas flow channel and gas diffusion layer but oxygen concentration is expanded with increasing porosity of catalyst layer. It is also observed that increasing the ratios of the cathode gas diffusion layer thickness to the gas flow channel height results in a decrease in oxygen concentration in porous layers but an increase in oxygen concentration in gas flow channel of the cell. Finally it is also seen that the effect of the porosity of the gas diffusion layer is more dominant than the effect of the porosity of the catalyst layer on the cell performance. From the mass transfer point of view, gas diffusion layer porosity should be higher and the ratio of gas diffusion layer thickness to gas flow channel height should be lower to improve the PEM fuel cell performance.

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