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Improvising Performance of Fuel Cells in Hybrid Fuel Cell Electric Vehicles (FCEV)

R. Bakiya Lakshmia* N.P. Harikrishnanb and A.Vimala Julietc*****

Abstract : Fuel cells are electrochemically reactive devices which are used extensively in transport, portable and stationary energy storage applications. The Proposed system is 2-D model of a stack of PEM fuel cells used in hybrid vehicles replacing batteries. Design of fuel cell channel and stationary studies were done in COMSOL. The analytical model of the system is compared with the simulated results by including relevant physics in a PEMFC fuel cell operation. Performance of fuel cells was found to improve with the choice of material chosen for simulation and the effective humidity within the cell. Simulation results were observed for variations in current density and electrolyte potential due to changes in operating conditions like humidity and temperature.

Keywords : PEMFC, Hybrid Electric Vehicles, humidity, COMSOL.

1. INTRODUCTION

Different approaches for generating clean form of electrical energy is one of the key areas of research in several countries. One such method that has been proved to be pollution free is Fuel cell technology. Fuel cell technology helps in conversion of chemical energy of fuels into usable electrical energy. Efficiency of fuel cell was found to be 60-75% and was found to reduce in the long run [2]. However the efficiency can be improved by selecting suitable materials that can withstand the high operating conditions and also by effective control of humidity within the fuel cell. The byproducts of fuel cell being heat and water vapor have been recycled and utilized in many automobile industries, power stations and other portable electronics. Hence these fuel cells are clean energy fuels which help to overcome the reliance on oil imports and help to improve the environmental air quality.

Hybrid Fuel Cell Electric Vehicles

Fuel cells mainly used in Hybrid Electric Vehicles (HEV) runs with an electric motor with both a battery as well as a combustion engine with a fuel tank for propulsion. HEV employs two or more sources of power to enhance the overall efficiency of the vehicle. Combined effect of an internal combustion engine with an electric battery-motor system will help to achieve a better solution to the fuel portability. However, the propulsion provided by the battery is only for short distances and will also drain the entire charge of the battery. The use of fuel cells will ensure the continuous supply of power as long as air and hydrogen are available. The operating conditions of the fuel cells interactively affect the water balance in the fuel cell and ultimately the cell performance [1]. During PEM fuel cells operation, its temperature, pressure, stoichiometric flow ratio and humidification condition are the most common parameters that can affect performance and thus need to be carefully considered when applying specific MEA (membrane electrode assembly) and flow field design.

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* Assistant Professor, Department of ICE, SRM University, SRM Nagar, Chennai, India

** M.Tech, Department of ICE, SRM University, SRM Nagar, Chennai, India

*** Professor, Department of ICE, SRM University, SRM Nagar, Chennai, India *E-mail- bakiyalakshmi.r@ktr.srmuniv.ac.in*

2. METHODS AND MATERIALS

2.1. Modeling

The fuel cell model is as shown in figure1 consists of top view of the anode and cathode Gas diffusion layers and the proton exchange membrane sandwiched in between. The model was designed and simulated in 2D model using COMSOL Multiphysics™. Materials for fuel cell and their properties were chosen from the Material library; the electrodes were chosen to be carbon nanotubes, GDL were chosen to be graphite and Polyimide as the membrane material. Figure 1 represent the overall designed fuel cell obtained by giving different geometrical parameters such as GDL width, GDL height, membrane thickness, membrane height. The values of these modeling structural parameters have been tabulated below in Table.1.

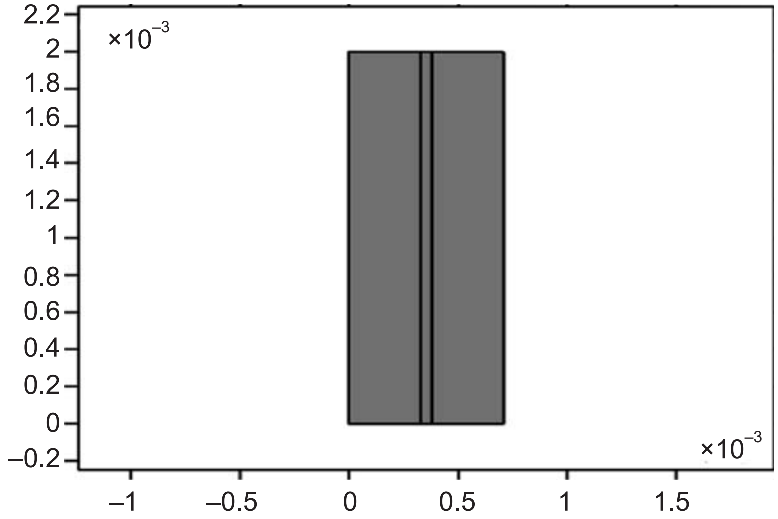

Figure 1: 2D Model of PEMFC

Table 1
Model Parameters

Model parameters	*Values*
GDL permeability	1*e*–13 m²
Fluid viscosity	2.1*e*–5 Pa·s
Reference pressure	1.0133*e*5 Pa
Anode inlet pressure	3*e*5 Pa
Cathode inlet pressure	3*e*5 Pa
Equilibrium potential, anode	0 V
Equilibrium potential, cathode	1 V
Exchange current density, anode	1*e*8 A/m²
Exchange current density, cathode	650 A/m²
Cell voltage	0.7 V
Temperature	328 K

2.2. Meshing

The meshing for the 2D model was done by mapped meshing. In total there were about 902 mesh elements comprising the triangular elements, the edge elements and the vertex elements which were studied. The numbers of edge elements were 128 while the triangular elements were 766 and the vertex elements were 8. The minimum element quality value was found to be 0.7832 while the average element quality value was 0.9177. Figure 2 represents the meshed image of the designed model.

2.3. Applied Physics and Stationary studies

Following 3 physics were included in the model and stationary study was performed on the model – secondary current distribution (electric current), Darcy's Law and Transport of Concentrated species. The cell operating condition was maintained at 328 K. The values of the other different parameters are tabulated in table-1.

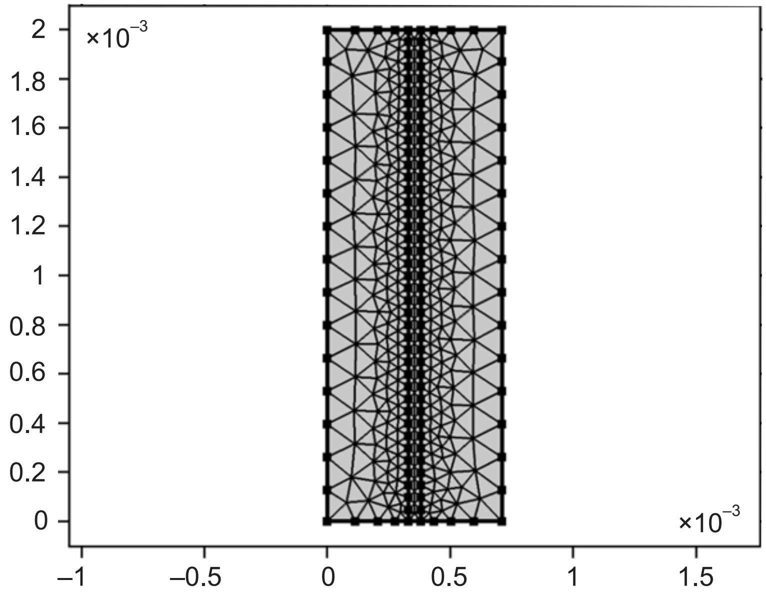

Figure 2: Meshed structure

2.3.1. Secondary Current Distribution

This study comes under Electrochemistry module which contains generic physics interfaces for modeling potential and current distributions in electrochemical cells. The Secondary Current Distribution interface is used for studying the transport of charged ions in an electrolyte of uniform composition as well as current conduction in electrodes using Ohm's law in combination with a charge balance. This physics interface also accounts for the activation over potentials due to charge transfer reactions. The domains 1,2,3 are the domains which are selected to be studied using the secondary current distribution The electrolyte potential and the electric potential were set to be linear.

2.3.2. Darcy's Law

This study is a part of the Fluid flow physics which is used to simulate flow and pressure fields of liquids and gases. This physics interfaces cover single-phase flow, multiphase flow, thin-film flow, porous media flow and flow in pipes. The Darcy's Law interface is used for studying the fluid flow through interstices in a porous medium. It can be employed to model other low-velocity flows or media having very small permeability and porosity where the major driving force is considered to be pressure gradient and the flow is mostly influenced by the frictional resistance within the pores. The domains 1 and 3 are selected for analyzing through the Darcy's law. The Pressure is considered to quadratic and the acceleration of gravity is considered to be constant.

2.3.3. Transport of Concentrated Species

This study is a part of the Chemical Species Transport interfaces that are employed for computing the concentration fields of chemical species in solutions. The chemical reactions and transport through diffusion, convection, and migration in dilute and concentrated solutions are also defined. The Transport of concentrated species interface helps to study gaseous and liquid mixtures where the species concentrations are of the same order of magnitude and cannot be identified as a solvent. In this case, properties of the mixture depend on the composition, and the molecular and ionic interaction between all species needs to be considered. This is done separately for the anode GDL and cathode GDL domains. Here the mass fraction is considered to be linear for the both layers. Maxwell-Stefan has been applied as the diffusion model for this study.

3. RESULTS AND DISCUSSION

In this section, the results obtained through simulation were compared and analyzed for improved efficiency of fuel cell.

3.1. Surface Pressure

The figure 3 gives the profile of surface pressure exerted on the anode and cathode channel. This has been obtained by the applied physics of Darcy's Law. There seems to be a maximum of 3 bar to minimum of 1.2 bar pressure on the surface.

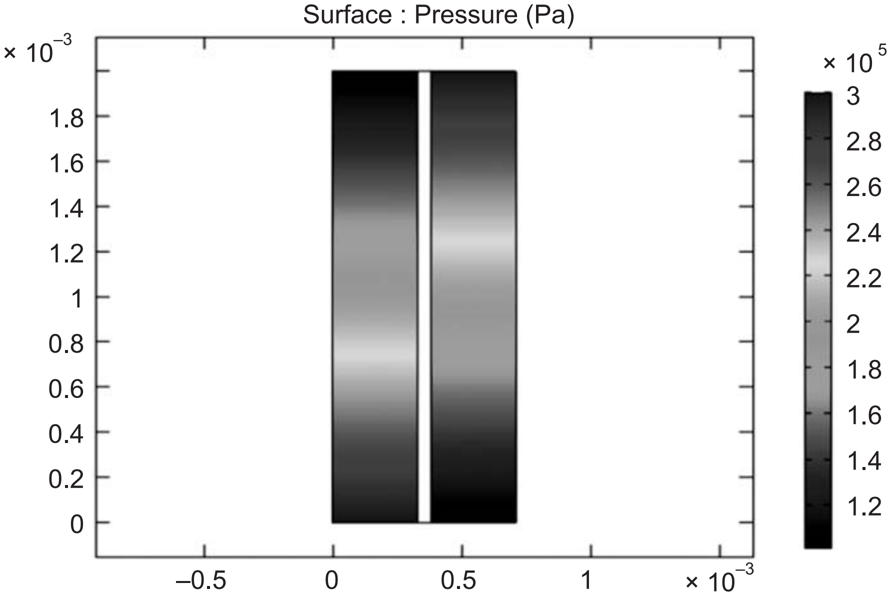

Figure 3: Surface pressure

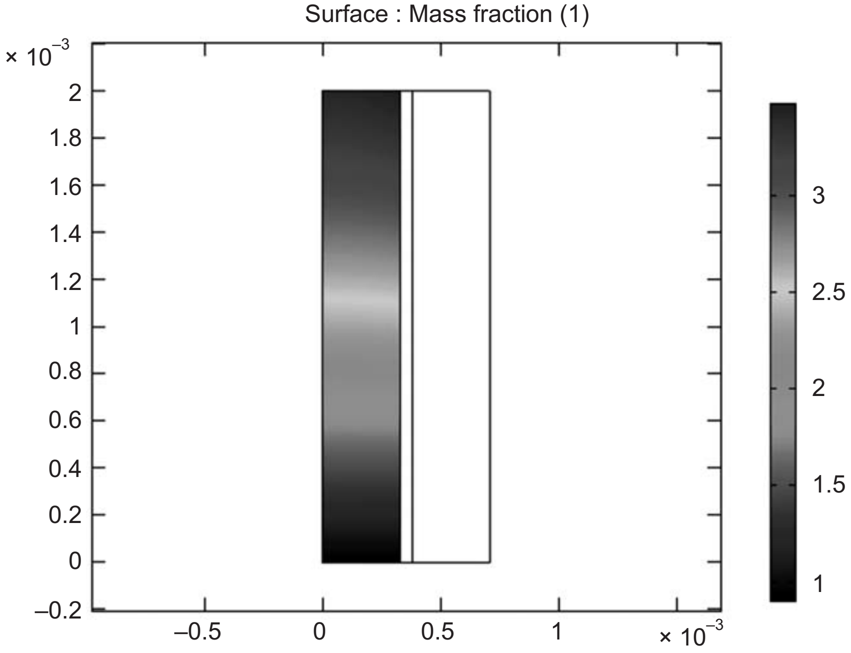

Figure 4: Mass fraction anode side

3.2. Mass Fraction

The figures 4 and 5 show the mass fraction of the surface on anode and cathode side respectively. There is a flow of hydrogen with molar mass of 2g/mol on the anode side and flow of oxygen with molar mass of 32g/mol mainly on the cathode side.

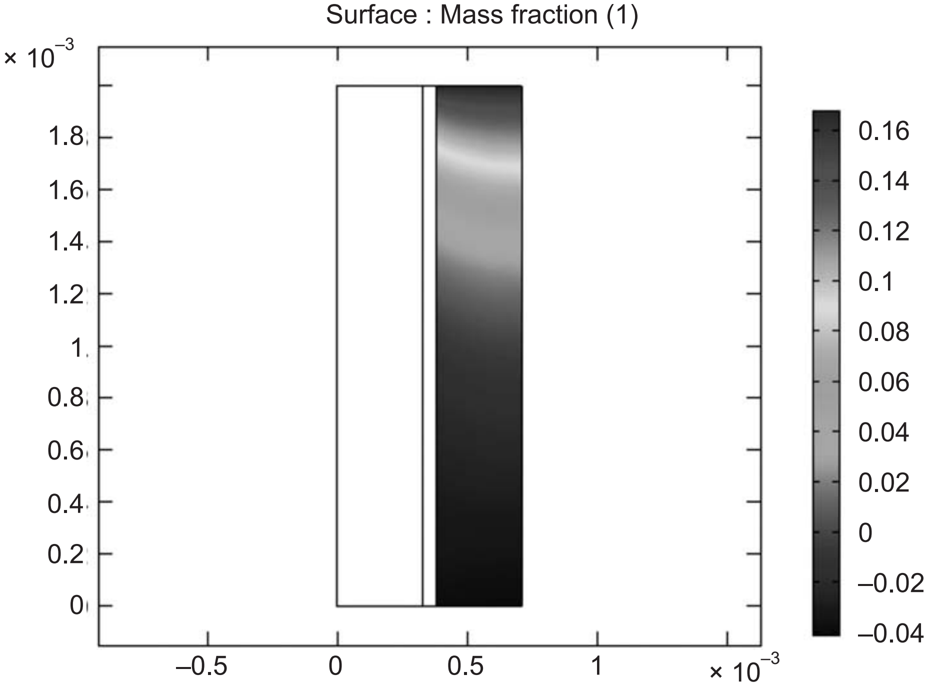

Figure 5: Mass fraction on cathode side

3.3. GDL Current Density Distribution

The figure 6 gives us an insight in to the distribution of current density over the GDL layer. There seems to be a maximum of 1e3 A/m^2. We could observe that there is mainly 0.65e3A/m^2 on the surface. There is also electrode current density vector depicted in the figure 6.

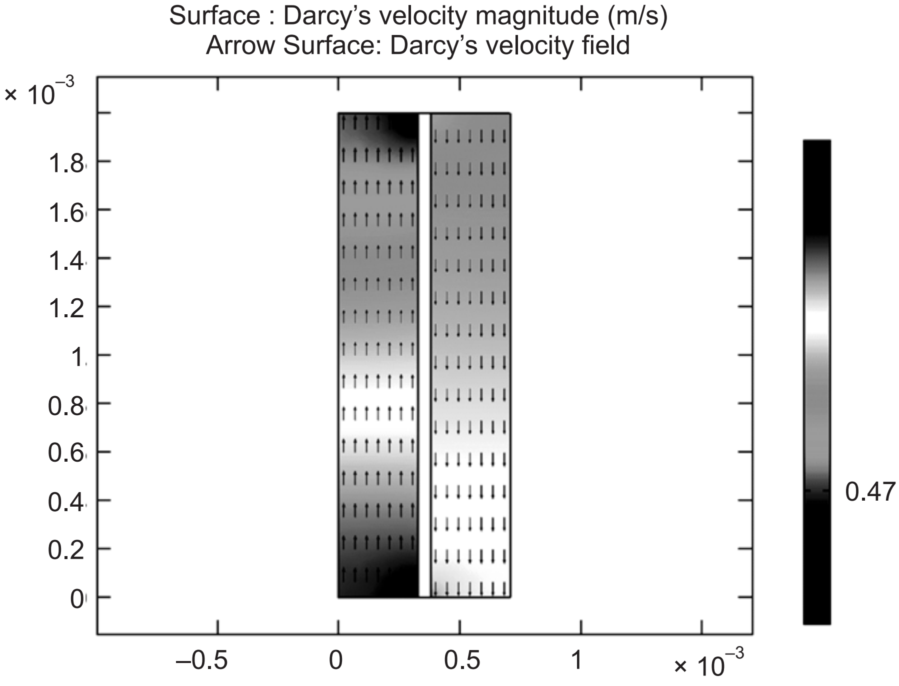

Figure 6: Electrode current density magnitude

3.4. Velocity Field

The figure 7 presents the velocity field in the anode as well as the cathode side. This was obtained with the aid of Darcy's Law which gives us velocity magnitude as well as velocity field. The average velocity on both sides is around 0.47 m/s.

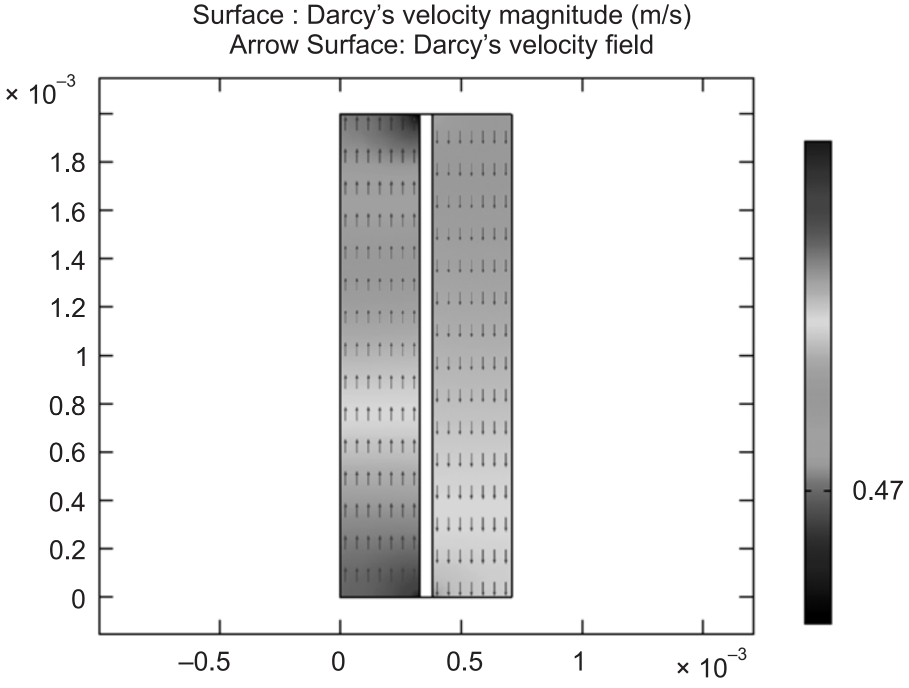

Figure 7: Velocity magnitude

3.5. Electrolyte potential and current density

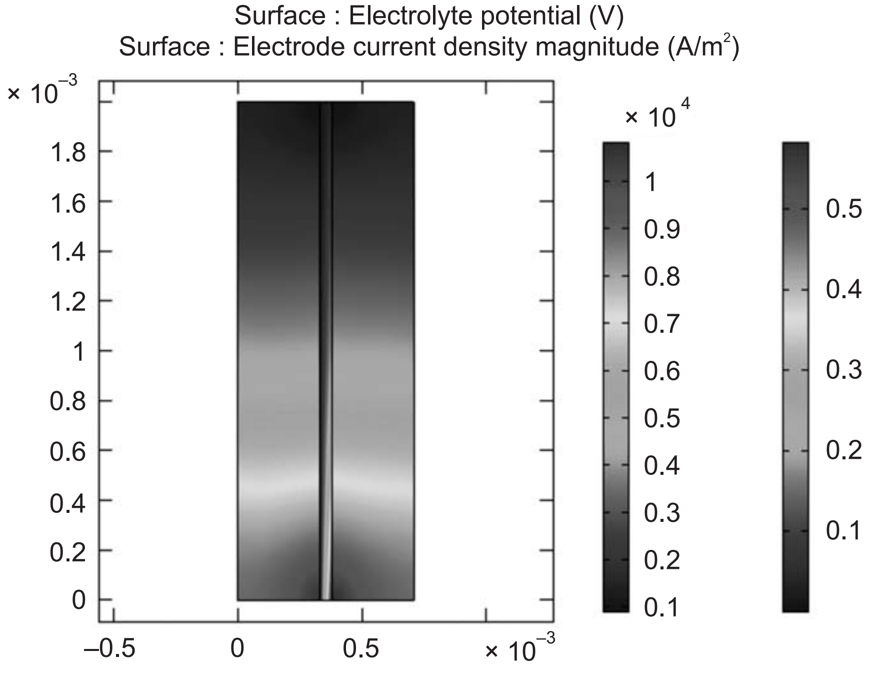

Figure 8: (*a*) For H_20 weight fraction = 0.2 wt%

The following results were obtained for different values of the cathode inlet H_20 weight fraction which shows prominent variation in the electrolyte potential and the current density. The cathode inlet H_2O weight fraction with value 0.2 wt% gives 1 V of electrolyte potential while the value 0.6 wt% give a value of 1.3 V of electrolyte potential and further more increasing of the inlet cathode H_2O to value of

0.9 wt% leads to a decreased electrolyte potential of 1.3 V. Figure 8a, 8b, 8c displays the results for the inlet. Cathode weight fractions of the values 0.2 wt%, 0.6 wt% and 0.9 wt% respectively. As the weight fraction is an indication of the water vapor present within the fuel cell, one can conclude that there is a direct relation between fuel cell humidity and its electrolyte potential. Thus an optimum humidification of 0.6 wt% can be maintained to achieve high electrical output.

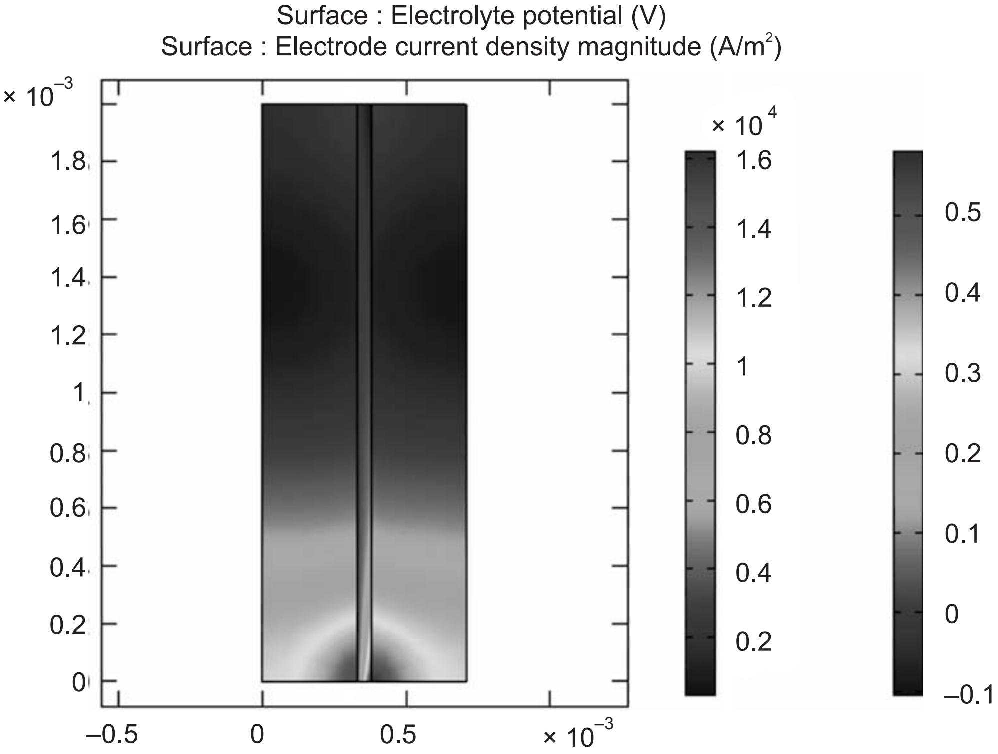

Figure 8: (*b*) For H_20 weight fraction = 0.6 wt%

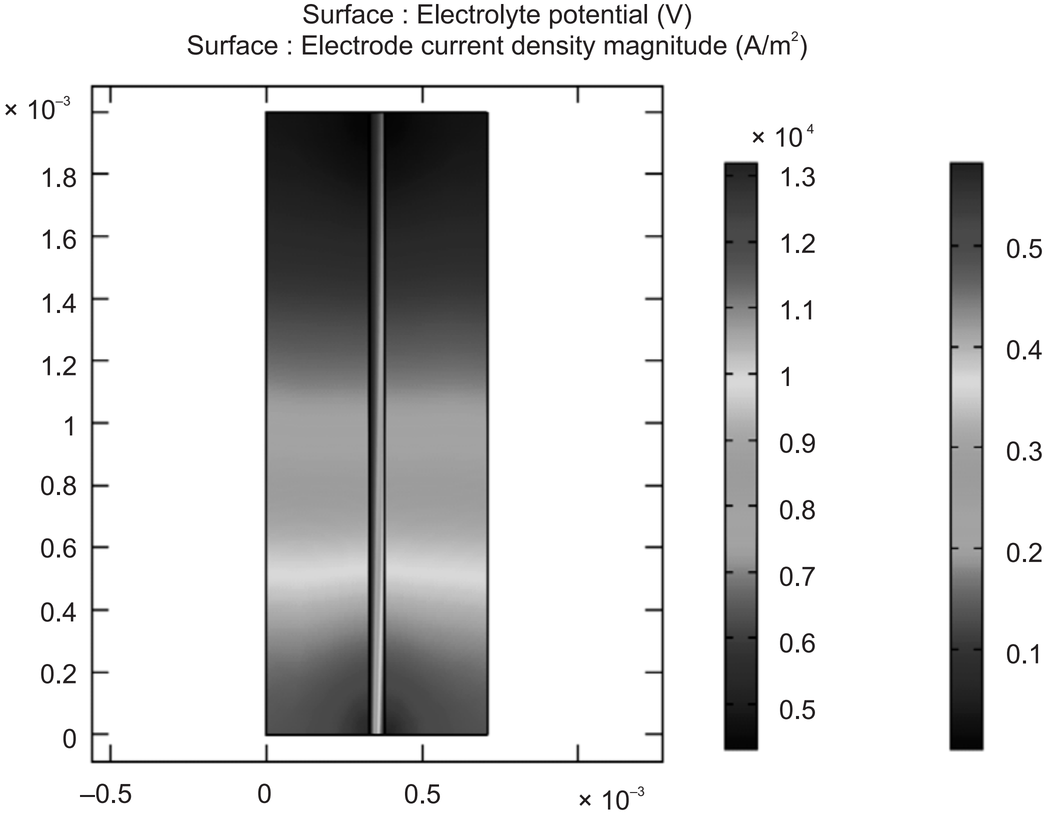

Figure 8: (*c*) For H_20 weight fraction = 0.9 wt%

4. CONCLUSION

2D model of a PEMFC has been simulated in COMSOL and stationary studies were done. Novel materials were chosen for obtaining increased electrical output. In addition the humidity content in the fuel cell was varied to measure the electrical output. The results indicated an improvement in the fuel cell electrical output of 0.3V for a change in 0.3wt%. Thus the fuel cell performance greatly dependent on the humidity content present within the fuel cell.

5. ACKNOWLDGEMENTS

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