Numerical Analysis of Cathode Water Concentration in High Temperature PEM Fuel Cell with Single Flow Channel

R.Girimurugan[1] K.A.RameshKumar[2]
[1]Assistant Professor [2]Associate Professor
[1,2]Department of Mechanical Engineering
[1,2]Nandha College of Technology, Erode, Tamilnadu, India-638052

Abstract— Operating and design parameters are the key factors which are mostly affected the performance of Proton Exchange Membrane Fuel Cell (PEMFC). Generation of water on cathode side of PEMFC reduces its performance. So reduction of water generation on cathode side is the most important analysis to improve the performance of PEMFC. In this study high temperature Proton Exchange Membrane Fuel Cell with single flow channel configuration is selected to evaluate the effect of cathode water generation under the four different operating temperatures (463K, 473K, 483K, and 493K) by using COMSOL Multiphysics software. Result shows that the Proton Exchange Membrane Fuel Cell at an operating temperature of 493K gives the least cathode water concentration among the other three operating temperatures.

***Key words*:** High temperature PEMFC, single flow channel, cathode water concentration, COMSOL

I. INTRODUCTION

Due to the increasing world concern about the environmental pollution and the depletion of fossil fuel reserves, the solutions for the generation of clean energy are an urgent demand. In the last decade, fuel cells appear to be one of the most suitable alternatives for generation of clean energy and, among then, PEM fuel cells seem to be one of the most reliable ones. Some of the PEMFC advantages with regard to other types of fuel cells are their easy implementation and their longer lifetime. Furthermore, their low operation temperature, high power density, fast start-ups, soundness of the system and low emission have encouraged the interest of various industry sectors to open up new fields of application for these fuel cells, including the motor industry, the stationary power generation, portable applications, etc. [1]. Many factors have effects on the PEM fuel cell performance with water management being one of the most important factors [2-3]. The water management must be carefully considered. If the cell membrane electrolyte is too dry, the ionic conductivity will decrease. When the cell is too wet, flooding of the porous agglomerate and gas diffusion layer adversely affects the performance of PEM fuel cell, leading to concentration over potential [4]. Since flooding has been identified as one of the main current-limiting processes, understanding and improving liquid water transport throughout the cell is critical in improving PEMFC performance. The 'flooding' of a gas diffusion layer is a phenomenon often observed when cell performance decreases at higher current densities [5-7]. Mainly, the cathode gas diffusion layer causes a decrease in performance of fuel cell when the process is mass transport limited. The liquid water formation from the electrochemical reaction results in water flooding of the porous media, especially the cathode gas diffusion layer, which obstructs the reactant gas that is flowing to the catalytic electrodes [8-10]. Developed a novel gas diffusion layer used for maintaining the membrane-electrode assembly (MEA) with a satisfactory water content and distribution. A novel gas diffusion layer (GDL) was designed by inserting a water management layer (WML) between the traditional GDL and the catalyst layer of PEM. The WML was a non-uniform layer designed with gradients in the structures between the inlet and outlet wells of flow channel. It provides some additional interesting possibilities for water management within a PEMFC [13]. The micro porous layer on the GDL with PTFE loading or hydrophobic treatment was developed to improve water management in the cathode gas diffusion layer [12-14] leading to improved performance. Demonstrated an anode water removal technique which was achieved by creating higher water concentration gradient between cathode and anode gas diffusion layer interfaces by applying the pressure drop between the inlet and outlet of the anode flow channels in order to increase the abilities of the water removal by the fuel stream due to the pressure gradient. However, this technique is limited because the pressure drop between the anode and cathode gas diffusion layers interfaces leads to degradation and failure of the electrolytic membrane [15]. Developed a flow channel design based on the appropriate pressure drop along the flow channel so that the liquid water is evaporated and removed by the gas stream and the gas stream in the flow channel is maintained fully saturated to prevent membrane dehydration. Sample flow channels have been designed, manufactured and tested for five different cell sizes of 50, 100, 200, 300 and 441 cm^2. Improvement of water removal was found. Scaling up of the cell active area provides similar cell performance. So in this paper numerical performance analysis has been carried in high temperature PEM fuel cell with single flow channel configuration with respect to the four different operating temperatures [16].

II. PROBLEM FORMULATION

Generation and accumulation of water content on cathode side is affected the PEM fuel cell's performance. Effective concentration of water on cathode side gives the better performance improvement of PEM fuel cell. So in this study numerical analysis has been chosen in high temperature PEMFC to evaluate the effect of Cathode water concentration for different operating temperatures.

III. MODELING

Entire three dimensional model of the high temperature PEMFC with single flow channel is done by using SOLID WORKD modeling package with the different design parameters which are given Table.1

Sl.No.	Description	Notation	Value	Units
1.	Cell length	L	0.02	meters
2.	Channel height	H_{ch}	1×10^{-3}	
3.	Channel width	W_{ch}	1×10^{-3}	
4.	Rib width	W_{rib}	1×10^{-3}	
5.	GDL width	H_{gdl}	380×10^{-6}	
6.	Porous electrode	$H_{electrode}$	50×10^{-6}	
7.	Membrane	$H_{membrane}$	100×10^{-6}	

Table 1: Design parameters for single flow channel PEMFC

Three dimensional model of PEM fuel cell is shown if the Fig.1. By using SOLID WORKS software package and the above mentioned design parameters three dimensional model of high temperature PEM fuel cell with single flow channel configuration is successfully designed.

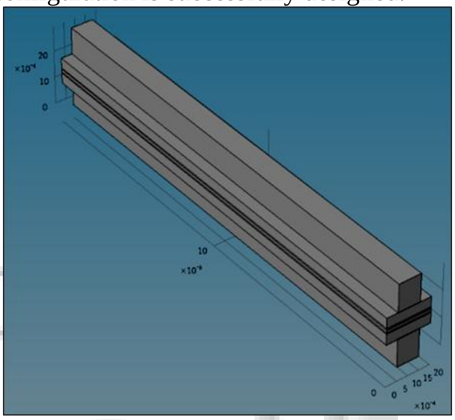

Fig. 1: 3D model of Single flow channel PEMFC

IV. MESHING

Meshing of the entire three dimensional model of the single flow channel PEMFC is done by using COMSOL Multiphysics software in mesh domain with fine mesh element to get the most accurate results. Complete mesh model is shown in Fig.2.

V. ANALYSIS

Numerical analysis of high temperature PEM fuel cell with single flow channel configuration is done by using COMSOL Multiphysics software with the following different operating parameters like as gas diffusion layer porosity, gas diffusion layer permeability, gad diffusion layer electrical conductivity, inlet H_2 mass fraction, inlet H_2O mass fraction and inlet oxygen mass fraction etc., are taken into account to carry out the analysis.

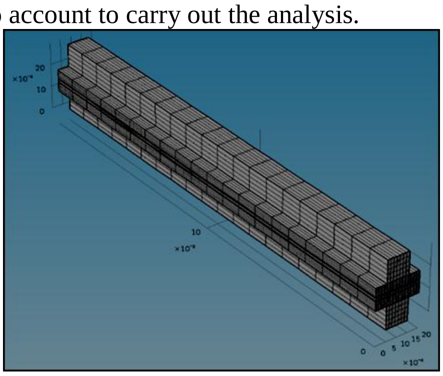

Fig. 2: Mesh model of single flow channel PEMFC

VI. RESULTS AND DISCUSSIONS

A. Results:

Numerical analysis of high temperature PEM fuel cell with single flow channel configuration under the four different operating temperatures are done by using COMSOL Multiphysics software to investigate the effect of cathode water concentration with respect to the four different operating temperatures. Following are the numerical results which were obtained from COMSOL Multiphysics software.

1) Effect of cathode water concentrations at 463K:

Concentration of water in cathode side at an operating temperature of 463K is shown in Fig.3. It shows that the water concentration is minimum at the beginning of the inlet flow channel then it is gradually increased towards the outlet of the flow channel due to the effective reaction of H_2 and O_2 gases. Maximum and minimum water concentration in cathode side obtained in this case is 4.5969 mol/m^3 & 0.472 mol/m^3 respectively.

2) Effect of cathode water concentrations at 473K:

Cathode water concentration at an operating temperature of 473K is shown in Fig.4. It shows that the water concentration is minimum at the beginning of the inlet flow channel then it is gradually increased towards the outlet of the flow channel due to the effective reaction of H_2 and O_2 gases. Maximum and minimum water concentration in cathode side obtained in this case is 4.4991 mol/m^3 & 0.4621 mol/m^3 respectively.

3) Effect of cathode water concentrations at 483K:

Effect of cathode water concentration at an operating temperature of 483K is shown in Fig.5. It shows that the water concentration is minimum at the beginning of the inlet flow channel then it is gradually increased towards the outlet of the flow channel due to the effective reaction of H_2 and O_2 gases. Maximum and minimum water concentration in cathode side obtained in this case is 4.4055 mol/m^3 & 0.4525 mol/m^3 respectively.

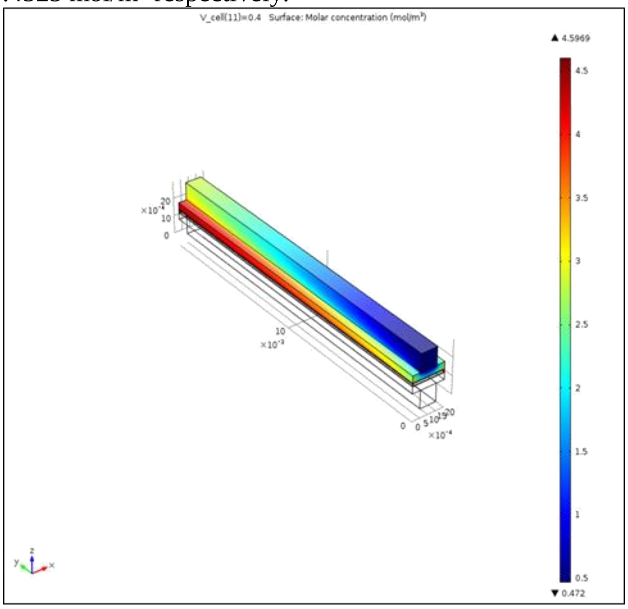

Fig. 3: Effect of cathode water concentrations at 463K

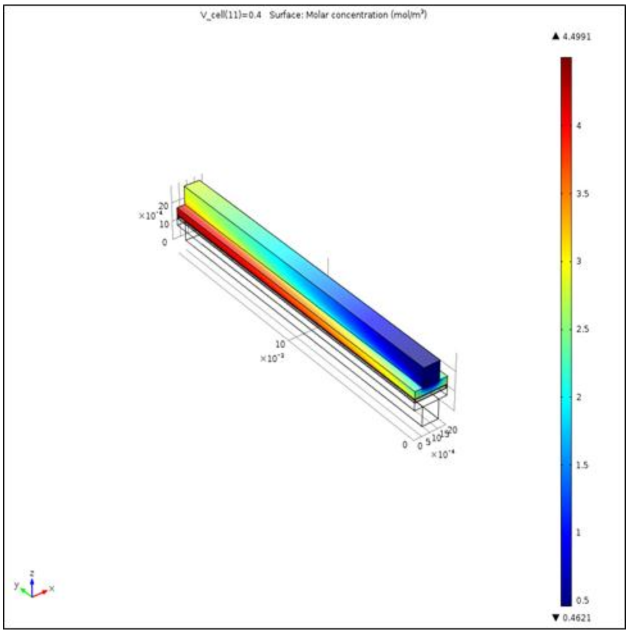

Fig. 4: Effect of cathode water concentrations at 473K

4) Effect of cathode water concentrations at 493K:

Effect of concentration of water in cathode side at an operating temperature of 493K is shown in Fig.6. It shows that the water concentration is minimum at the beginning of the inlet flow channel then it is gradually increased towards the outlet of the flow channel due to the effective reaction of H_2 and O_2 gases. Maximum and minimum water concentration in cathode side obtained in this case is 4.3153 mol/m^3 & 0.4433 mol/m^3 respectively.

B. Discussions:

Effect of cathode water concentrations for four different operating temperatures is shown in the Fig.7. It clearly shows that the concentration of water in cathode side is maximum at an operating temperature of 463 K and minimum at an operating temperature of 493 K then it is gradually decreased with respect to the other two operating temperatures.

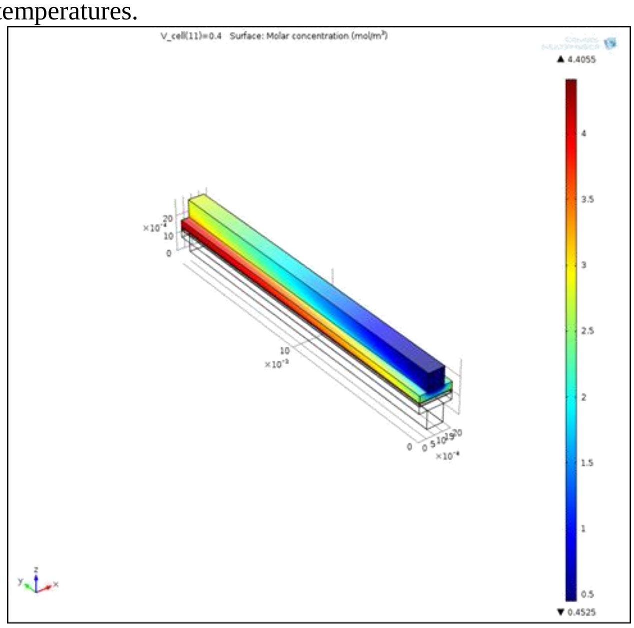

Fig. 5: Effect of cathode water concentrations at 483K

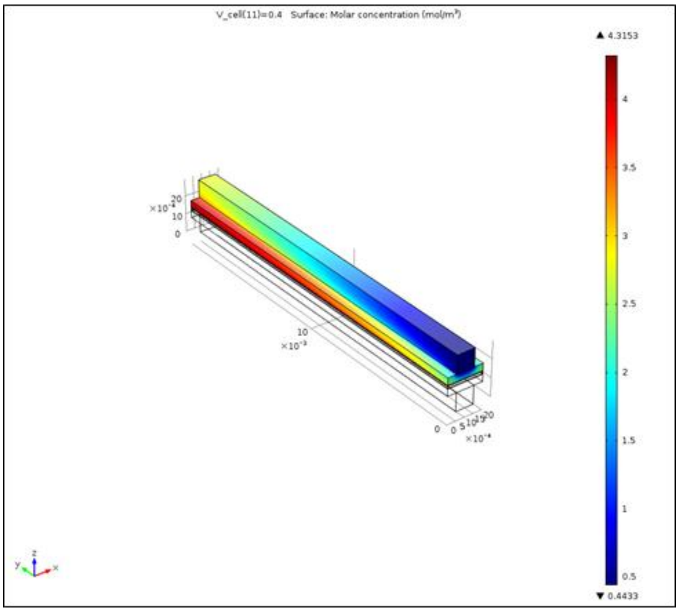

Fig. 6**:** Effect of cathode water concentrations at 493K

VII. SUMMARY

Numerical analysis of high temperature PEM fuel cell with single flow channel configuration is successfully carried out to investigate the effect of cathode water concentrations by using COMSOL Multiphysics software under the different operating temperatures. The following conclusions have been made based on the numerical results which were obtained from the COMSOL Multiphysics software. High temperature PEM fuel cell with an operating temperature of 493K gives the lower cathode water concentrations (4.3153 mol/m^3) compared with other three operating temperatures. Thus the results clearly show that the better water concentration on cathode side is obtained at higher operating temperatures.

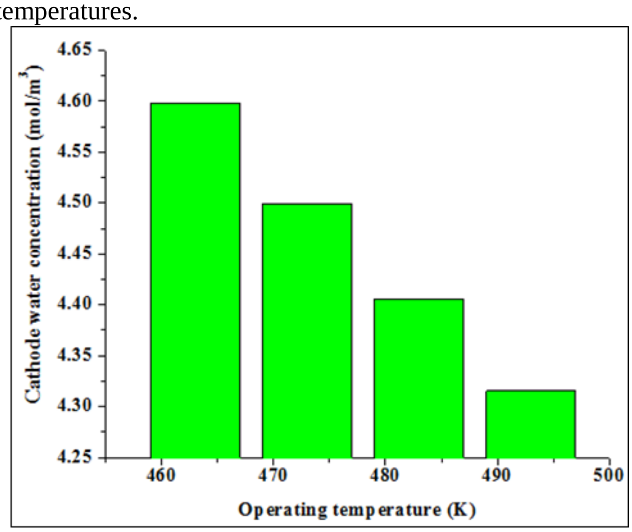

Fig. 7: Cathode water concentrations at different operating temperatures

RFERENCES

[1] A.R.Maher and Al-Baghdadi Sadiq, CFD models for analysis and design of PEM fuel cells, *Nova Science Publisher, Inc.;* 2008.

[2] M.L.Perry and S.Kotso, A back-up power solution with no batteries, *In: INTELEC 2004 Proceedings;* 2004, 210-217.
[3] B. Thoben, A. Siebke, Influence of different gas diffusion layers on the water management of the PEFC cathode, *Journal of New Materials for Electrochemical Systems*, 7, 2004, 13-20.
[4] W.K. Lee, S. Shimpalee, J.W.Van and H. ZeeNaseri-Neshat, Experimental technique for PEM fuel cells. *In: Proceedings of the 36th Intersociety Energy Conversion Engineering Conference, Savannah, Georgia, IECEC2001-ET-11*; 2001
[5] W. Yan, H. Chu J. Chen, C. Soong and F. Chen, Transient analysis of water transport in PEM fuel cells, *Journal of Power Sources, 162,* 2006, 1147-56.
[6] Theodorakakos, T. Ous, M. Gavaises, J.M. Nouri, N. Nikolopoulos and H. Yanagihara, Dynamics of water droplets detached from porous surfaces of relevance to PEM fuel cells, Journal of Colloid and Interface Science, 300, 2006, 673-687.
[7] Lee and H. Chu, Effects of cathode humidification on the gas liquid interface location in a PEM fuel cell, *Journal of Power Sources, 161,* 2006, 949-956.
[8] W. He, T.V. Nguyen, A new diagnostic tool for liquid water management in PEM fuel cells using interdigitated flow fields, *Chemical & Petroleum Engineering Department, the University of Kansas Lawrence*, 2002, KS 66045.
[9] Su A, F.B. Weng, C.Y. Hsu and Y.M. Chen, Studies on flooding in PEM fuel cell cathode channels, *International Journal of Hydrogen Energy*, 31, 2006, 1031-1039.
[10] Cheng , O. Minggao and Y. Baolian, Analysis of water management in proton exchange membrane fuel cells, *Tsinghua Science and Technology*, *11 (1),* 2006, 1007-1014.
[11] J. Chen, T. Matsuura and M. Hori, Novel gas diffusion layer with water management function for PEMFC, *Journal of Power Sources 131,* 2004, 155-161.
[12] Z. Qi and A. Kaufman, Improvement of water management by a micro porous sub layer for PEM fuel cells, *Journal of Power Sources, 109,* 2002, 38-46.
[13] L. Carrette , K.A. Friedrich and U. Stimming, *Fuel cells - fundamentals and application, Fuel Cell, 1,* 2001, 5-39.
[14] Hakenjos A, H. Muenter, U. Wittstadt and C. Hebling, A PEM fuel cell for combined measurement of current and temperature distribution, and flow field flooding, *Journal of Power Sources, 131,* 2004, 213-216.
[15] H.H. Voss, D.P. Wilkinson, P.G. Pickup, M.C Johnson and V.Basura, Anode waters removal; a water management and diagnostic technique for solid polymer fuel cells, *Electrochemical Acta, 40,* 1995, 321-328.
[16] X. Li and I. Sabir, A flow channel designs procedure for PEM fuel cells with effective water removal, Journal of Power Sources, 163, 2007, 933-942.