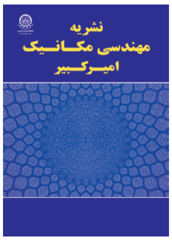

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Experimental Investigation of the Influence of Polymer Electrolyte Membrane Fuel Cells Operating Conditions on Its Performance and Water Management

M. R. Hasheminasab, M. J. Kermani*, S. S. Nourazar, M. H. Khodsiani

Fuel Cell Research Laboratory, Department of Mechanical Engineering, Amirkabir University of Technology, Tehran, Iran

ABSTRACT: In this research, the effect of anode stoichiometry, cathode stoichiometry and temperature of inlet gases on water management and performance of a polymer electrolyte membrane fuel cell is studied by means of design of experiments and direct visualization. In order to visualize the liquid water accumulation in cathode flow channels, a transparent polymer electrolyte membrane fuel cell is manufactured in the fuel cell research laboratory of Amirkabir University of Technology. The design of experiments is based on response surface method. Cell's performance is recorded over the test time and a video is simultaneously captured from its transparent cathode flow channels. Then, a digital image processing technique is used to quantify channel areas that are occupied by liquid water. The area of regions containing liquid water is divided by the total area of flow channels to calculate a parameter called water coverage ratio which is then used to study flooding phenomenon. Results show that increase in cathode stoichiometry, anode stoichiometry and gas inlet temperature leads to a decrease in water coverage ratio. Also, water coverage ratio lies between 1.8 and 4.3 when an optimized produced power is reached. As proved, anode and cathode stoichiometry has to be minimized to reach the maximum produced power at a high inlet gas temperature.

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1- Introduction

Many works have been done on fuel cells, as they are seen as a promising alternative to the internal combustion engines. Behind the growing interest in Polymer Electrolyte Membrane (PEM) fuel cells are their high power density and efficiency, and also zero in-place emission [1-3]. Flooding phenomenon is known to be one of the most significant issues to be considered in PEM fuel cells. Reactant starvation and its non-uniform distribution are damaging results of the flooding phenomenon. Consequently, non-uniformity of reactant distribution induces a non-uniform current density which deteriorates cell's durability and performance [4-5]. Selection and control of the operating conditions in a way that keeps the cell far from two damaging phenomena, namely, flooding and dehydration are termed as water management. Both flooding and dehydration lead to a considerable and even irreversible loss of performance. Rate of power generation and water management in a PEM fuel cell is under influence of its numerous operating factors. Design of Experiment (DOE) serves as a powerful statistical method to keep number of performed experiments in an economical range which saves many resources and efforts. This method reveals the most decisive factors and interactions between them. Material and component development, study and enhancement of single cell or stack performance, and development of fuel cell systems are all areas in which DOE are applied [6].

2- Methodology

In the present study, the performance and water management of a PEM fuel cell with multi-serpentine flow field is investigated through the Central Composite Design (CCD) of Response Surface Method (RSM). Studied operating parameters include Anode Stoichiometry (AST), Cathode Stoichiometry (CST) and inlet gas temperature (T^*). In order to carry out the investigation, a PEM fuel cell with transparent endplates is designed and manufactured at Fuel Cell Research Laboratory of the Amirkabir University of Technology. Transparent endplates provide optical access to the flow channels whose liquid water content is to be determined. Reactants flow in a multi-serpentine flow field of 2 mm thickness and 25 cm^2 active area. The flow field is made up of gold-coated stainless steel. To visualize the cathode flow channels, a Canon EOS 750D SLR camera is employed. Afterward, liquid water content of the flow channels is determined by developing an image processing algorithm. Water Coverage Ratio (WCR) which is used to study flooding phenomenon, defines as the ratio of the channel areas occupied by the liquid water to the total area of the flow channels.

*Corresponding author's email: mkermani@aut.ac.ir

3- Results and Discussion

A second-order regression model is fitted on responses of the PEM fuel cell to the operating parameters. Linear, square and interaction terms of the model are listed in Table 1.

Table 1. Estimated regression coefficients for models of Power (W) and WCR

Source	Estimated Regression Coefficients	
Parameter	Power (W)	WCR
Constant	11.2761	18.1574
	Linear	
T*	0.4354	-7.2411
AST	-5.4689	-2.0372
CST	1.0576	-0.9739
	Square	
T*×T*	0.1469	1.0197
AST×AST	0.2526	-2.7337
CST×CST	-0.0644	-0.4129
	Interaction	
T*×AST	0.8005	1.1875
T*×CST	-0.5610	-0.0282
AST×CST	0.5862	1.9671

The main effect plots of Fig. 1 illustrate the average response values observed for the change of CST. Therefore, main effect plots do not consider interactions between the considered factors. A horizontal line in main effect plot of a parameter reveals that it does not significantly affect the response, while an inclined line corresponds to the significance of the considered parameter. Fig. 1(a) depicts the enhancement of generated power when CST is increased. As observed in Fig. 1(b), increase of CST from 2.5 to 3.5 has no tangible effect on WCR, whereas an increase from 3.5 to 4.5 reduces WCR.

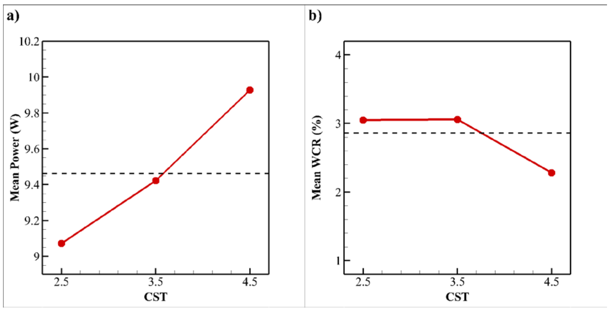

Fig. 1. Main effects plot for a) *Power* (W) b) *WCR*

Contour plots of Fig. 2 illustrate the values of generated power in planes of T* and CST at three levels of CST. Liquid water accumulation and cell power decrease with increasing AST when CST value is low, as observed in Fig. 2(a) and (b). Also, Power rises with increasing T*, while WCR falls; this is due to the dominant effect of improved reaction kinetics as a result of high temperature.

For the middle values of CST (3.5), changes in AST and T* are seen to have the same effect as in case of low CST values. For the upper bound of CST (4.5), the effect of dehydration as a result of the increase in AST is dominant for T* values of less than 2.3. On the other hand, an increase in AST values when T* is more than 2.3, results in performance improvement, as the effect of enhanced reaction kinetics dominates. Accordingly, the best performance is obtained either when both AST and T* are set to their highest level or their lowest level.

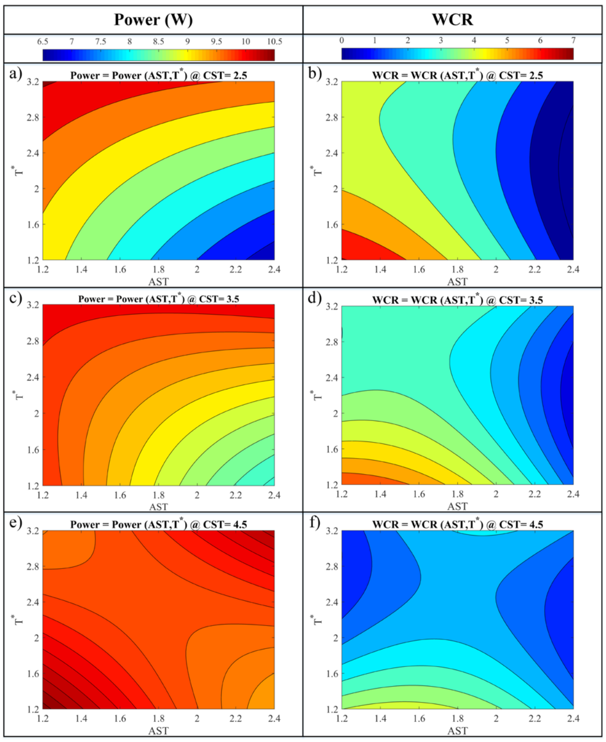

Fig. 2. Contour plots of Power and WCR in plane of AST and T^* at (a)(b) CST=2.5, (c)(d) CST=3.5 and (e)(f) CST=4.5.

In this research, the same contours for different levels of *T** and *AST* are presented in planes of *CST-AST* and *T*-CST*, respectively. The results are then thoroughly discussed.

4- Conclusions

The outcome of this research can be summarized as follows:

- Operating conditions directly affect the liquid water content observed in flow channels.
- The performance of PEM fuel cell is considerably influenced by liquid water content of flow channels. A water coverage ratio of 1.8 to 4.3% is observed for generated powers of over 10 W.
- An increase in CST and T* stabilizes the cell performance and reduces the sensitivity of the cell performance to other operating parameters. On the contrary, an increase in AST does exactly the opposite.
- An increase in AST reduces WCR and generated power. At high CST values, the values of AST and T* are recommended to be set in their lower limit.
- An increase in T* leads to a decrease in WCR and an increase in generated power. At high T* values, the values of AST and CST are recommended to be set in their lower limit.
- An increase in AST leads to a decrease in WCR and generated power. At low AST values, the values of CST and T* are recommended to be set in their upper limit.

5- References

[1] I.S. Hussaini, C.-Y. Wang, Visualization and quantification of cathode channel flooding in PEM fuel cells, Journal of Power Sources, 187(2) (2009) 444-451.

[2] L. Zhang, S.-R. Chae, Z. Hendren, J.-S. Park, M.R. Wiesner, Recent advances in proton exchange membranes for fuel cell applications, Chemical Engineering Journal, 204–206(0) (2012) 87-97.

[3] K.-H. Hou, C.-H. Lin, M.-D. Ger, S.-W. Shiah, H.-M. Chou, Analysis of the characterization of water produced from proton exchange membrane fuel cell (PEMFC) under different operating thermal conditions, International Journal of Hydrogen Energy, 37(4) (2012) 3890-3896.

[4] R. Anderson, L. Zhang, Y. Ding, M. Blanco, X. Bi, D.P. Wilkinson, A critical review of two-phase flow in gas flow channels of proton exchange membrane fuel cells, Journal of Power Sources, 195(15) (2010) 4531-4553.

[5] R. Anderson, M. Blanco, X. Bi, D.P. Wilkinson, Anode water removal and cathode gas diffusion layer flooding in a proton exchange membrane fuel cell, International Journal of Hydrogen Energy, 37(21) (2012) 16093-16103.

[6] B. Wahdame, D. Candusso, X. François, F. Harel, J.-M. Kauffmann, G. Coquery, Design of experiment techniques for fuel cell characterisation and development, International Journal of Hydrogen Energy, 34(2) (2009) 967-980.