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PERFORMANCE ANALYSIS ON PROTON EXCHANGE MEMBRANE FUEL CELL BY USING TAGUCHI METHOD OF OPTIMIZATION

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ABSTRACT
The various operational parameters and geometrical characteristics have a significant impact on how well the Proton Exchange Membrane Fuel Cell (PEMFC) performs. Cell temperature, back pressure, anode and cathode inflow velocities, Gas Diffusion Layer (GDL) porosity and thickness, cathode water mass percentage, flow channel dimensions, rib width, and porous electrode thickness are among the operating and design parameters that are optimized in this article. Using the traditional orthogonal array Taguchi approach, the optimization of design and operating parameters in software was done in two steps. From the preliminary analysis, it was concluded that rib width had the least impact on fuel cell performance and that back pressure had the greatest impact.
Keywords—Optimization, Operating parameters; Geometric properties, Taguchi method;

1.Introduction

With an increasing awareness of environmental concerns and a desire for energy independence, the development of renewable and clean energy sources has become the focus of significant research activity. Hydrogen will play a major role in fulfilling the global energy demands in future. Fuel cell, acting as a transducer, absorbs energy from hydrogen reduction and evolves electrical energy emerged as an ideal choice for use in a wide range power supplies. The PEMFCs are currently under rapid development and promise to become an economically viable commercial power source in many areas, especially for transportation, stationary, portable and automobile applications, because of their high energy density at low operating temperatures and zero emissions [1]. In this effort, many critical issues of PEMFC technology need to be addressed. One of the key issues is the performance enhancement of fuel cell by studying the influence of various operating and design parameters. Dyi-Huey Chang et al. [2] studied the effect of flow channel depth and flow rates on performance of miniature PEMFC. They concluded that optimum flow rate was essential for shallow channel depth to maintain sufficient pressure to force reactant into channel and also to have proper water balance. Shimpalee et al. [3] investigated the effect of number of gas paths on a 200 cm2 serpentine flow field design. They concluded that the 13-channel flow field design gives the best performance for a single cell PEMFCAtul Kumar et al. [5] optimized the flow channel dimensions and shape in the flow field of end plates in a single pass serpentine flow field design. The triangular and hemispherical shaped cross section resulted in 9% excess hydrogen consumption in anode side, thus it can influence the enhanced performance of the PEM fuel cell. Wei-Mon Yan et al. [6] studied the effect of flow channel designs on performance of PEMFC and concluded that the interdigitated flow field having 1.4 times better power output than the conventional flow field design. Lin Wang et al. [7] concluded that effect of humidification temperatures is not significant at higher current densities.

Also when humidification temperatures are less than cell temperature, the PEMFC performance deteriorates. Apart from the effect of flow field design and operating parameters, the performance of the PEM fuel cells is greatly influenced by the water management issue. Adequate water-vapour must be available to maintain high electrolyte ionic-conductivity for ensuring suitable performance. However, if excessive water is present in the liquid phase, it can block pores in the catalyst and GDLs, which hinders the transport of reactants to the catalyst. Karthikeyan et al. investigated the water impact on performance of PEMFC with porous flow channels [8]. They concluded that the porous flow channels had 48% more power output than non porous flow channels due to water accumulation in non porous flow channels. Thus, proper water management is absolutely essential for enhanced fuel cell performance. Also, water and thermal management issues were severely affected by proper selection of design and operating parameters. Hence, it is clearly evident that there is an exigent need of analyzing the simultaneous influence of operating and design parameters using mathematical tool and to optimize the same for better performance of the PEMFC by using Taguchi method.

This is because many factors such as rib width of the flow channel and porosity are not easy to change for each trial, while running experiments. In order to study the combined effect of all such factors, due to the constraints posed with experimentation, the numerical modeling was chosen as a platform for analysis. The proposed work focusing on implementation of Taguchi method for optimizing operating and design parameters for performance enhanced studies on PEM fuel cell has been addressed. Also, the combined effect of those parameters has been addressed in this paper.

2. Modelling in software

Using commercial finite element software (COMSOL Multiphysics 4.2), a five-layered proton exchange membrane fuel cell was modeled. Electrolyte membrane, anode and cathode porous electrodes with embedded catalyst, anode and cathode gas diffusion layers, and anode and cathode electrodes were the five layers taken into consideration. When modeling the PEMFC, assumptions like steady, laminar, and incompressible flow are taken into account, but contact resistance and the gravitational field effect are ignored [10]. For this analysis, a single fuel cell with a flow channel length of 125 mm and an electrolyte with a thickness of 183 microns, Nafion 117, was selected. Although thinner electrolytes function better, Nafion 117 was used in order to sustain a back pressure of 1.5 bar. Every trial using the orthogonal array of the Taguchi approach involved a change in the other design and operating parameters that need to be optimized. The program was chosen to contain the corresponding modules required for the analysis. The analysis comprised modules for free and subsurface flow, current distribution, and species movement. The flow module deals with the movement of the species within the defined boundaries, such as pressure, velocity, etc. The chemical processes occurring for the specified diffusivity matrix are the focus of the species transport module. The quantity of current density created in relation to the reaction taking place is determined by the current distribution module. As a result, the software conducted a coupled analysis of all three modules, and the power density was calculated from the polarization curve.

2.1 Adoption of the Taguchi method

When creating the design of experiments, all those factors with taken into account levels in each have to be included in order to analyze the combined influence of many factors affecting the performance of fuel cell. However, by doing so, the number of experiments increases to a level that is virtually unattainable. Ten different parameters, each with three levels, were taken into account for the research being described. To determine the importance of these parameters while taking into account low, high, and intermediate range values, a three-level design was chosen. It was discovered that 59049 runs would need to be completed in a full factorial design in order to discover the cumulative significant effect of each element. L27 standard orthogonal array is employed in the analysis for a maximum of 13 factors in a 3-level design using the Taguchi technique. The relevance of factors and the ideal combination would be discovered in 27 runs when this orthogonal array is applied.

The analysis was carried out in two steps, namely the refining of components that had already been coarsely optimized. Levels were chosen in the first step of analysis so that each factor's whole operational range was covered in order to determine the significance of each factor. Operating cell temperature, back pressure, GDL porosity and thickness, flow channel dimensions and rib width, porous electrode thickness, anode and cathode input velocities, and cathode inlet water content were the elements taken into account for this investigation.

Table 1. Selection of factors and levels

Factors	Level 1	Level 2	Level 3
Back pressure (bar)	0.6	1.2	1.7
Cell temperature (K)	300	320	350
GDL porosity (%)	40	60	80
Flow channel depth and width (mm)	1x1	2x1	2x2

A steady state, 2D mathematical model was utilized by Biao Zhou et al. [13] to examine the impact of water content on a PEM fuel cell. They came to the conclusion that cathode inlet liquid water injection in the range of 50% to 100% did not enhance cell performance.

Table 2. Mean S/N ratios for each level of factors

Factors	Level 1	Level 2	Level 3
Back pressure	-15.7278	-14.9360	-14.3573
Cell temperature	-14.9056	-15.0009	-15.1147
GDL porosity	-15.0931	-14.9440	-14.9842
Flow channel dimensions	-14.7160 -	-15.2265 -	-15.0788 -

Since the power output of the PEMFC must be maximized, the analysis was done for the "Larger The Better" kind. Signal/Noise (S/N) ratios, which represent the proportion of controlled to random components, were used to underpin the analysis results. Table 2 displayed the mean S/N ratios corresponding to their levels. By approximating the mean of the S/N ratios over all trials that corresponded to that level of the factor, it was calculated

3.Optimization of operating and design parameters:

Table 2 provided the best operating and design parameters. The variables that have the least impact on the response are typically lumped together and disregarded for further investigation. However, in order to obtain accurate results with superior performance on PEMFC, all the elements in this analysis were taken into account, regardless of their significance.

4. Conclusion

- Improvements to the optimized settings resulted in better fuel cell performance. More phases of optimization with refining produce results with high precision.

- More factors (>7) with higher level designs (>3) can be examined utilizing the Taguchi method's multi-stage parameter optimization.
- When compared to each parameter's independent effects, the combined effect of all the parameters produced a distinct reaction.
- Taguchi technique suitability for fuel cell application was shown by the maximum power density corresponding to Taguchi calculations being in good agreement with those software results [14].
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5.Future scope

With the help of this effort, more factors can be accurately analyzed for factor optimization. One of the best tools for optimization also turned out to be the Taguchi method. As a result, fine-tuned optimization using the Taguchi method is a novel strategy that improves fuel cell performance over traditional optimization. This work also demonstrated the Taguchi method's suitability for fuel cell applications, demonstrating that sophisticated optimization may be used in tests. When the Taguchi method is used in experiments with precise optimization, greater outcomes are anticipated. To achieve improved performance in real-world applications, fuel cells must be operated with these ideal design and operating conditions.

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