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Study of PEM Fuel Cell for Different Cell Temperature

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***Abstract:** Polymer electrolyte membrane fuel cells (PEMFCs) are considered an eco-friendly, highly efficient, and pollution-free alternative energy source. Due to their outstanding properties, these are used in stationary and transport applications like wild areas, military, space missions, the auto sector, and a few others. Therefore outstanding properties refer to the PEM fuel cells as a future alternative energy source. In this work, the serpentine membrane has been analyzed under different temperatures, and compared with experimental data and previous works. The results show that cell temperature is affected by cell voltage and power density. The cell voltage and power density are decreased with increased temperature and are much clear from the polarization curve. The overall investigations have suggested that the study of the thermal effect on PEM fuel cells provided good results, and the study made it more promising and could enhance its performance.*

***Keywords:** PEM Fuel Cells; Alternative Energy Source; Electrolyte; Membrane; Catalyst layer.*

I. INTRODUCTION

The Proton exchange membrane fuel cells are highly efficient, eco-friendly, and an alternative energy source [1] that could be fulfilling all energetic requirements from a single energy source. The PEM fuel cells are used in stationary and transport applications like military, wild areas, space operations, and automobile industries and can be in retail life after some retrieval improvements such as decreasing its high cost and relievable modification as a need for general use [2]. There are many other advantages like low weight, easy to transport, portable and some others. The incredible properties refer to it as a future alternative energy source [3-5]. In fuel cells, chemical fuels (Also depending on the nature of the fuel cells) directly convert into electrical energy by using an electrochemical reaction. In PEM fuel cells, atmospheric air is used as fuel which makes it eco-friendly. Therefore the PEM fuel cells can be a better energy source because these have several incredible properties. The study of PEM fuel cell is much important as a future energy source because its present approach is not sufficient. So it is necessary the modification in its present state [6]. Also, it can be used in the retail sector nearly future after making sufficient modifications to PEM fuel cells such as decrease their high cost and make reliable for general use. It could be possible when the PEM fuel cells tested and manufactured in bulk quantity [7].

K. Benmouiza and A. Cheknane investigated the dynamic behavior of PEM fuel cells and optimizes their performance. Analysis of the voltage drop in terms of activation, ohmic and mass transport under different operating parameters such as current density, mass transfer coefficient, electrolyte thickness, active cell area, and temperature affected the polarization curve [8]. The cell performance is reduced with low operating temperature. Sun L, Jin Y and You F studied open-cathode PEMFC which is a promising energy source in small-scale power generation due to its compact channel which integrates air supply and coolant flow. The operating temperature is significant for efficiency, but temperature control is a challenging task due to the various uncertainties and disturbances that are lumped as a unified item. The proposed models demonstrate the uncertainty compensation ability of ADRC and experimental tests on a 300W PEMFC show that the proposed ADRC method has various advantages over the conventional PI controller in both tracking and regulation performances [9]. Singh S K, Agarwal A, & Kanumuri T improve the power quality of a fuel cell-powered filter less distributed generation system using sinusoidal pulse width modulation [10].

II. METHOD OF ANALYSIS

The PEMFCs investigate under a three-dimensional steady-state model and the equations are used to find the solution under several configurations of the membrane.

2.1 The assumptions for model

The mathematical studies of PEM fuel cells have produced the following assumptions:

- The serpentine flow field of thickness 0.0036 mm is used in this work.
- In this investigation, the PEM fuel cell operates under 303K, 323K, and 353K operating temperatures.
- The value of the water transport coefficient is taken into account at 1.15 cm^2/sec.

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2.2 Computational model

Three-dimensional computational models have been used for the theoretical investigation of PEM fuel cells and to enhance their performance from the simulation of the operating parameter. The PEM fuel cell can be analyzed by subcategories of three-dimensional computational models and the description of the sub-model is given below in detail [11]:

2.2.1Membrane sub-model

The water transport of a membrane also depends on the electro-osmotic drug and back diffusion, and for more information must see ref [12, 13]. The net water transport across the flow field is given as:

$$\alpha = n_d - F.D_w.\frac{(C_{w,c}-C_{w,a})}{l.t_{cat}.t_{mem}} \quad (1)$$

2.2.1.1 Water content

The electro-osmotic drag and diffusion coefficients are proposed from the activities of the gas. The net transport from the anode to the cathode side can be written as [14]:

$$a = \frac{P_{H_2O}}{P_{sat}} \quad (2)$$

The conductivity of the membrane is given as:

$$\lambda = \begin{cases} 0.043 + 17.81a - 39.85a^2 + 36a^3, 0 < a \le 1 \\ 14 + 1.4(a-1), \quad 1 < a \le 3 \end{cases} \quad (3)$$

2.2.1.2 Proton conductivity

The proton conductivity of the membrane is the function of water content and cell temperature and is given as [15]:

$$\sigma_{mem} = [0.5139\lambda - 0.326]\exp\left[1268\left(\frac{1}{303} - \frac{1}{T}\right)\right] \quad (4)$$

2.2.2 Electrochemical sub-model

The identical voltage of the fuel cells is described from the Nernst equation as follows [16]:

$$E = E_0 + \frac{RT}{2F}\ln\left(\frac{P_{H_2}P_{O_2}^{0.5}}{P_{H_2O}}\right) \quad (5)$$

The output voltage of a single cell-based fuel cell is equal to the individual voltage itself. But for the n^{th} cell-based fuel cell the output voltage is calculated from the multiplicity of the number of cells with a voltage of the single cell but here some voltage drops in different categories such as activation, ohmic, and concentration losses due to inherent voltage losses (internal currents and cross-over losses). Therefore open circuit voltage is also less than the ideal voltage and the voltage of a fuel cell can be described as follows [17]:

Cell voltage

$$V_{cell} = V_{oc} - V_{act} - V_{ohm} - V_{conc} \quad (6)$$

Activation voltage drop

$$V_{act} = \frac{RT}{\alpha_c F}\ln\left(\frac{i}{i_{o,c}}\right) \quad (7)$$

***Ohmic* voltage drop**

$$V_{ohm} = \left(R_{cell} + \frac{t_{mem}}{\sigma_{mem}}\right) \quad (8)$$

Concentration voltage drop

$$V_{conc} = \frac{RT}{nF}\ln\left(1 - \frac{i}{i_{lim}}\right) \quad (9)$$

Table 1 shows the utilized parameters of fuel cells.

Description	Symbol	Value
Cell/electrode length (mm)	L	70
Cell/electrode width (mm)	W	70
Gas channel length (mm)	l	2500
Gas channel width (mm)	w	5
Gas channel depth (mm)	d	2.5
Rib width (mm)	s	2.5
GDL porosity	ε_{GDL}	0.5
Catalyst porosity	ε_{CL}	0.5
Membrane thickness (mm)	δ_{MEM}	0.0036
Open-circuit voltage (V)	V_{oc}	1.05
Operating temperature (°C)	T_{cell}	30 – 80
End plate (mm)	Aluminum	10
Gasket (mm)	Silicon rubber	1

III. RESULTS AND DISCUSSION

The serpentine membrane with a thickness of 0.0036mm is used to investigate the PEM fuel cell and much information about membrane geometry and operational data are given in Table 1.

On the behalf of Table 1, some predictions are found with the help of a three-dimensional computational model. The polarization curve shows the changes in voltage and power density with temperature and current density. The ideal voltage of the PEM fuel cell is calculated from the Nernst equation which is given in Eq. 5 and the peak voltage for an ideal cell is received at 1.24V. But experimentally it is not possible because, in the experiment, few voltages are dropped in inherent voltage losses such as activation, ohmic, and concentration voltage drop. Therefore the actual voltages are less than the ideal voltage and depend on the geometrical and physical conditions of the cell. In this study, the open circuit voltage finds to be 1.05V and the cell operates at 300K to 373K thermal temperatures.

The three-dimensional model is used to calculate the theoretical data for serpentine membranes with a thickness of 0.0036mm and water transport coefficient of 0.5. Fig. 1 illustrates the polarization curve with power density at 303K and 353K thermal temperatures and compared with experimental data [18]. In this configuration, the peak power density for cell temperatures 303K and 353K is found to be 0.9063W/cm² and 0.8818 W/cm² at a current density of 1.35 A/cm² and compared with experimental data. It is clear from Fig. 1 the calculated data show good agreement with experimental data. Fig. 2 shows the curve between activation voltage drop and relative changes in current density compared with cell temperature at 303K, 323K, and 353K.

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Similarly, Fig. 3 shows the comparison of cell temperatures same as Fig. 2 but in which the concentration voltage drops have been used the place of activation voltage drop. In this situation, the concentration voltage drops are saturated at current density 1.35A, and the concentration voltage is increased very rapidly near to limiting current and to be approached infinity on 1.4A.

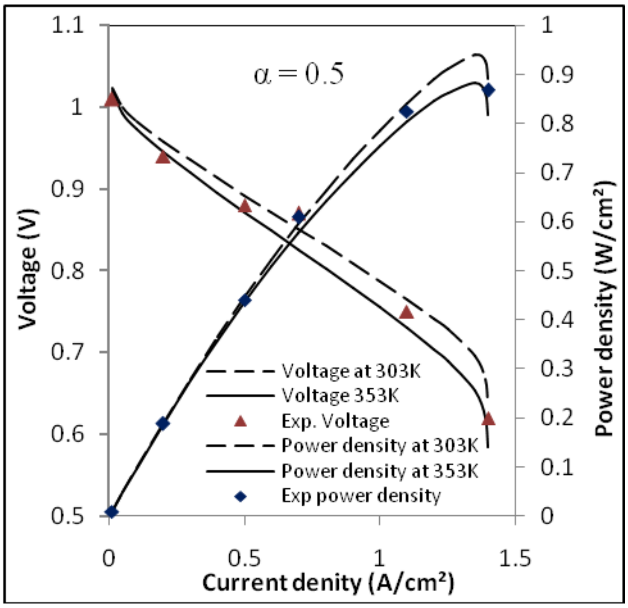


Figure 1 shows the polarization curve of power density and voltage drop with relative change of current density under cell temperatures 303K, and 353K using the water transport coefficient α = 0.5 and compared with Experimental data [18].

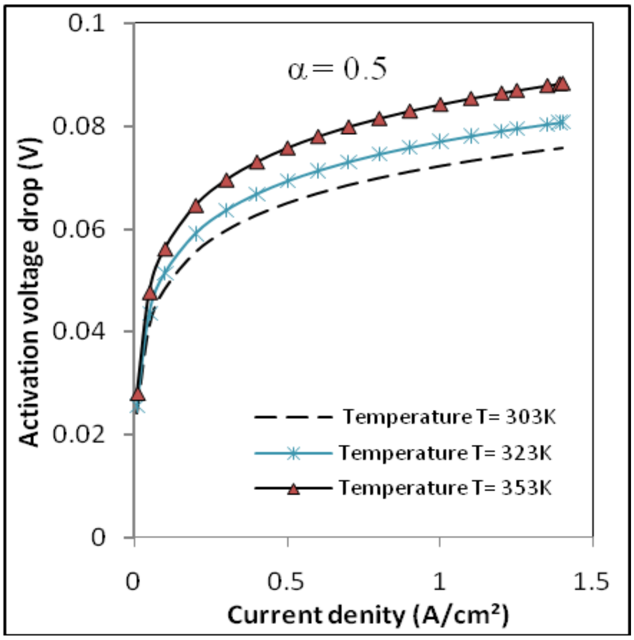


Figure 2 shows the polarization curve of activation voltage drop under cell temperatures 303K, 323K and 353K using water transport coefficient α = 0.5.

Fig. 4 illustrates the activation voltage drop between cell temperature at 270K to 370K using water transport coefficients 1.5, 0.3, 4.5, and 0.6, and the peak activation voltage is found to be 0.1520V, 0.0760V, 0.0506V and 0.0380V. Finally, Fig. 5 shows the curve between **(a)** power densities and **(b)** voltage with cell temperatures at different water transport coefficients α is used to be 1.5 to 6 at current density 1.2A. It is clear from Fig. 5(a) the power density is decreased with increasing temperature, same as from Fig. 5(b) the voltage decreased with increasing temperature. Also, the ohmic voltage is not a function of temperate. So ohmic voltage has not participated in this study or not shows any effect on temperature. The overall study suggested that the performance of PEM fuel cells is affected by cell temperature.

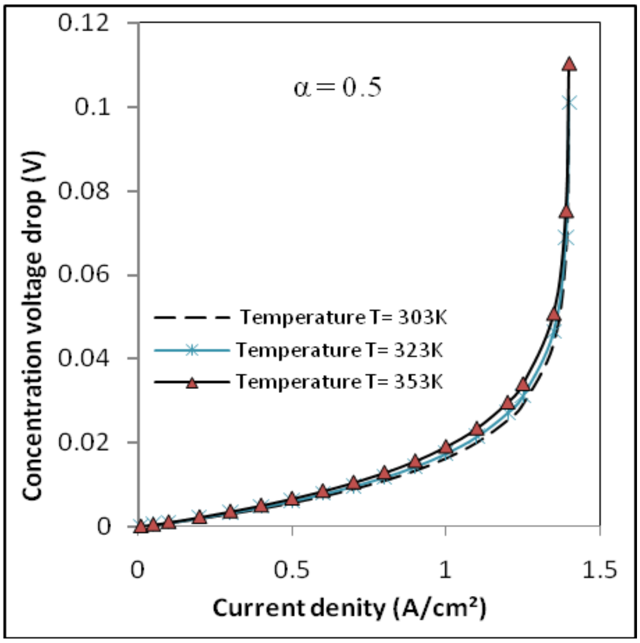


Figure 3 shows the polarization curve of concentration voltage drop under cell temperatures 303K, 323K and 353K using water transport coefficient α = 0.5.

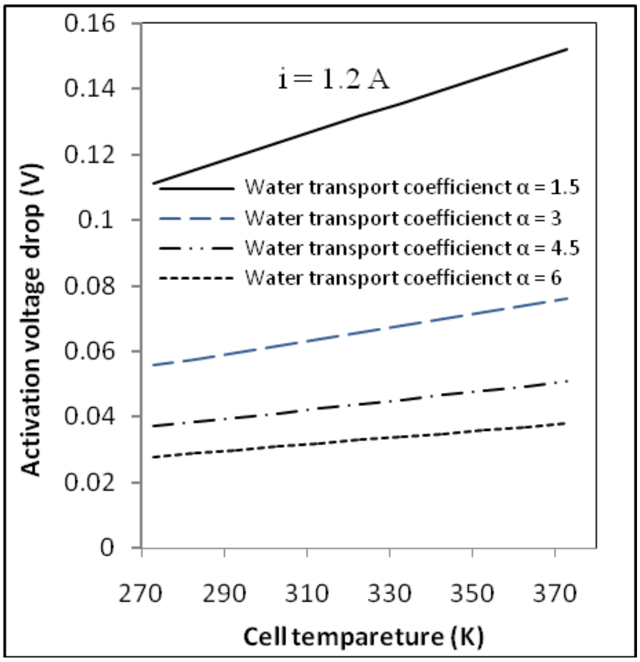
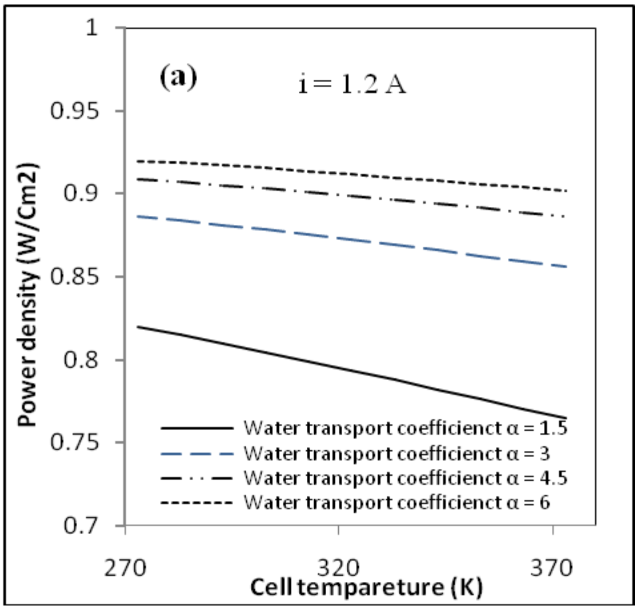


Figure 4 shows the curve between activation voltages with temperature under different water transport coefficients α using 1.5 to 6.

IV. CONCLUSION

The main objectives of this work are to try to control environmental pollution and better understand the environment affected due to the production of energy. Electrical energy plays a big role to fulfil all kinds of energy-related desires. All these things suggest the use of an environment-friendly energy source and the PEM fuel cell can be one of those that can complete our energy-related desires because the PEM fuel cell is eco-friendly and well efficient. But its high cost is a big drawback that does not affordable generally. Therefore we want to make retrieval modifications in PEM fuel cells, could understand the working conditions from different aspects and improve the cause that affected the cell performance, and can make the PEM fuel cells more relievable for retail use. After modification, it can be a good future energy source.



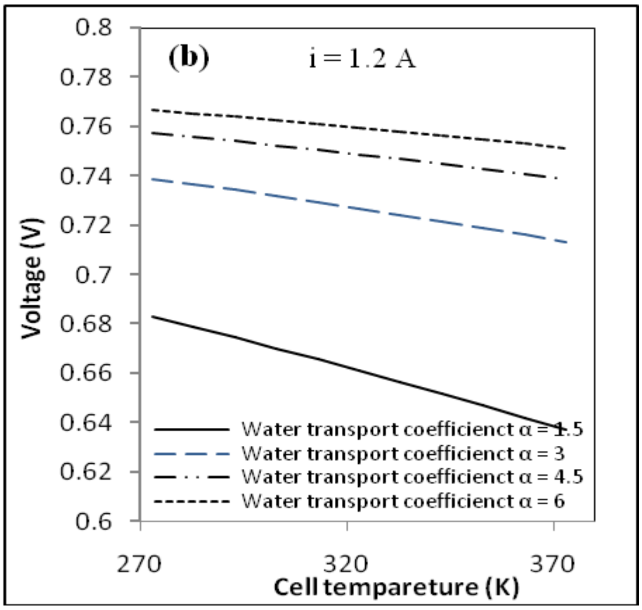


Figure 5 shows the curve **(a)** power densities and **(b)** voltage between temperatures under different water transport coefficient α using 1.5 to 6 at current density 1.2A.

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Authors Contributions	First author prepared overall paper such as choosing topic, collecting data and calculating results. Second author drafting the article, suggested proposed parameters and help to calculating results. Third author reviewed this article and provide sufficient comments.

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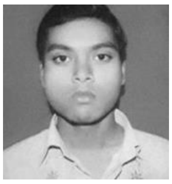

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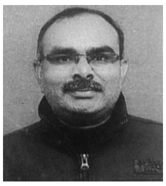

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