Experimental Study Of The Operating Temperature Effect On The Performance of PEM Fuel Cell

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ABSTRACT

The fuel cell is one of the most important renewable energy sources and increased attention in recent years to replace conventional energy sources, particularly internal combustion engines. The performance of fuel cells depends on a number of physical and chemical parameters .This paper included an experimental study of the operating temperature effect on the performance of the fuel cell type (PEM) when the fuel cell work at variable flow rate of hydrogen and under variable electrical loads.The experimental tests were conducted using fuel cell stack with capacity of 100 watts at three operating temperatures (50, 58,65)ºC , and the flow rate of hydrogen (0- 1100) ml / min. The results showed that the fuel cell efficiency decreases with increasing operating temperature due to the activation loss increasing, in addition to the increase of ohmic losses while the effect of operating temperature on the concentration polarization loss were limited

Keywords*:Fuel cell, hydrogen fuel, renewable energy, temperature*

INTRODUCTION

This template provides Hydrogen fuel cells are one of the most important renewable energy sources , which is defined "it's cells produce electricity through a electrochemical reaction using hydrogen and oxygen" [1]. In general, the hydrogen is oxidized to protons moving within the central electrolyte to the anode, as well as to electrons moving from outside circuit to the anode where they will meet with oxygen to form water[2,3]. There is an urgent need to increase the use of this type of energy sources, especially after the legalization of the use of internal combustion engines to produce energy ,which is one of the most important sources of environmental pollution, also it is possible to use fuel cells as power sources in automobiles, portable power and power generation [4].

There are many types of fuel cells developed and used over the last years and can be classified either as fuels, oxidized , type of electrolyte , the working temperature of the cell and the mechanism of entry of the reactants to the cell, but the most common type of classification is the classification of the fuel cell depending on the type of electrolyte used, in accordance with this classification can be classified as follows [5]: proton exchange membrane fuel cells (PEMFCs)

1. alkaline fuel cells (AFCs)
2. phosphoric acid fuel cells (PAFCs)
3. molten carbonate fuel cells (MCFCs)
4. solid oxide fuel cells (SOFCs)

The PEM fuel cells have several advantages for other types of fuel cells, due to the high energy density, light weight, low operating temperature [6]. The low operating temperature allows the use of low cost materials. The operating temperature has a significant impact on the water management in the cell, which is the main limiting factor for the performance of PEM fuel cells, due to the membrane hydration. Where the ionic resistance increase with the membrane moisture decrease, and that lead to a decline in performance of the cell and may be lead to cell failure. In addition, the membrane moisture decrease lead to proton conductivity decrease. On the other hand, the excess water in the fuel cell may be lead to flooding the cell [7].

Pérez-Page and Pérez-Herranz [8] have been studied the influence of operation temperature on PEM fuel cell performance , the result showed that the performance of fuel cell was improved with temperature increase from 20 C to 40 C. The performance of the fuel cell decreases at higher temperatures as the membranes can be dried.

This causes a decrease on the mean fuel cell voltage. Belkhiri et al [9] theoretically studied the effect of temperature on PEM fuel cell performance, they present a steady-state, two-dimensional mathematical model with operating temperature effect , on the performance PEM fuel cell. The result showed that the fuel cell operating temperature has a significant influence on the PEMFC performance .Many transport properties such as proton conductivity of membrane and the diffusivities of gases were depend on temperature.

The influence of operating parameters on the performance of PEM fuel cell have been studied experimentally by Singh and Pawar [10], they fund that the anode humidification temperature has effects on the performances. The fuel cell performances were lower at the low current density range, due to the lower the degree of humidification.

Sasan Yousefi et al [11] studied the performance of a passive direct methanol fuel cell at different cell temperature. The results showed that the increasing in the surrounding temperature leads to the increased natural convection inside the fuel cell. This increased natural convection increases Methanol crossover. Strahl et al [12] presented an experimental and theoretical analysis of temperature effects on the performance of an open-cathode, self-humidified PEM fuel cell system. The result shows that the improving in the fuel cell performance by thermal management. The exchange current density was the most significant temperature dependent parameter. Riascos et al. [13] showed an approach for control temperature of PEM fuel cells. Li et al. [14] studied a dynamic thermal affine model for the temperature control problem in fuel cell systems.

This work presents an experimental analysis of temperature effects PEM fuel cell system when the fuel cell work at variable flow rate of hydrogen and under variable electrical loads. The experimental tests were conducted using fuel cell stack with capacity of 100 watts at three operating temperatures (50, 58,65) ºC , and the flow rate of hydrogen (0- 1100) ml / min.

MATERIALS AND METHODS

The experimental setup used in this work is the same used by the authors in [5].The fuel cell unit is supplied with a stack of proton exchange membrane fuel cell (PEMFC) with a rated power of 100 W. The stack is composed of 24 cells with the shape of channeled plate that allows the air flow through the membrane. The membrane facilitates the hydrogen flow, generating the electrons release. There are separating plates which conduct electricity, allowing thus such electrons flow, between each pair of cell. The schematic of the experimental setup is shown in figure (1).

Cells are self- humidifying and do not require any type of external humidification. The stack has an integrated fan able to provide the required air for the good operation and maintenance of the operation temperature.

Hydrogen storage represents one of the essential points regarding the hydrogen economy. For that purpose, a canister of metal hydride (300L) is included.

Internal pressure of the device is 8 bar at a room temperature of 20-25oC. It has discharge pressure of 15-20 bar, for that reason the fuel cell unite also includes two pressure regulators. One of them is for it's the installation in the H_2 cylinder in order to regulator the outlet pressure at 30 bar. The other is placed at the outlet of the metal hydride canister in order to regulate the inlet pressure to the stack in a range of 0.4 – 0.5 bar

In additional, the unit includes two solenoid valves. One of them is located before the stack. It controls the hydrogen inlet and when the unit is switched off, the valve is closed to avoid any possible hydrogen leakage. This valve is automatically closed when the temperature of the stack exceeds 65 o C. The other valve is placed at the stack outlet. It purges outside the excess of water and hydrogen for a correct operation .

The unit also has load regulation system. It enables the study of the generated electrical energy, the representation of the characteristic operation curves and their comparison with theoretical curve. It included a variable power, which enables to vary the generated current.

The whole electrical circuit of the stack is protected by a short circuit unit in case over current (12A) and low voltage shut down (12V). In the event of one of these problems, the hydrogen inlet solenoid valve is automatically closed.

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Lastly, and as a result of the danger in the use of hydrogen, include a hydrogen leak detector with a detection range from 0 to 2% Vol. Table 1 presents the properties of the fuel cell unit that used in this work.

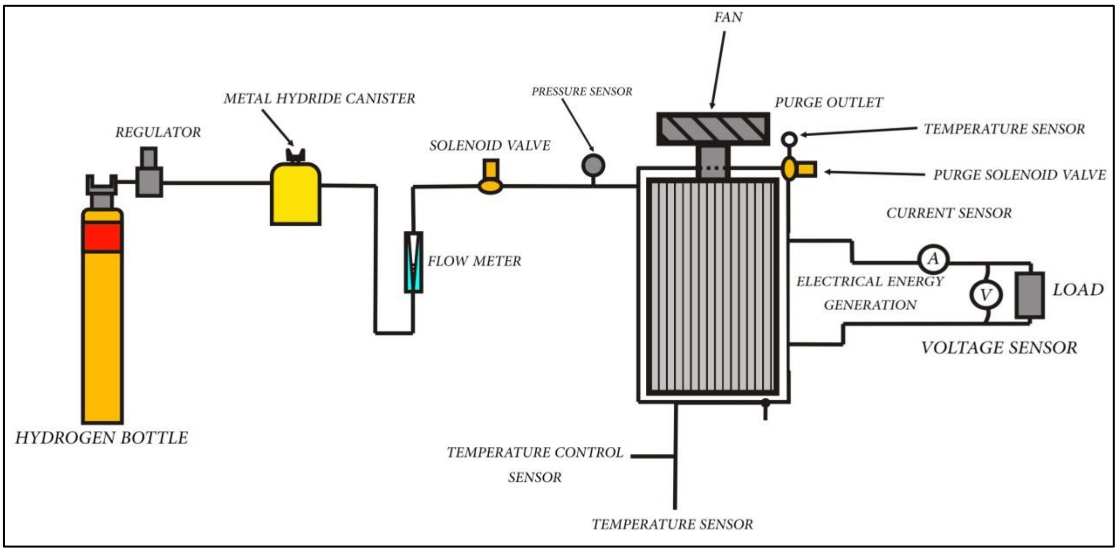

Figure (1) Schematic diagram of fuel cell experimental setup

TABLE1. FUEL CELL UNIT PROPERTIES

Type of fuel cell	PEM
No. of cells	24
Rated power	100 W
Efficiency	14.4 V 2.7 A
Reactants	HYDROGEN AND AIR
External operating temperatures	5-30 ºC
Maximum temperature of the stack	65 ºC
H2 operating pressure	0.45-0.55 bar
Hydrogen purity	≥ 99.995 % dry hydrogen
Humidification	Self-humidifying
Cooling	Air (with integrated fan)
Dimensions of the membrane	90mm x 45mm
Start time	30 s. at room temperature
Flow at maximum efficiency	1.4 l/min
Efficiency of the stack	40 % (14.4V)
Over-temperature shutdown	65 ºC
Over-current shutdown	12 A
Low voltage shutdown	12 V

RESULTS AND DISCUSSIONS

The fuel cell performance can be evaluated from the polarization curves at operation temperatures (50, 58, 65) ºC , figure 2 shows the polarization curves of the fuel cell at these temperatures. The polarization curves indicate that the fuel cell stack performance was decreased with temperature increase. When the fuel cell operate at high temperature, the membrane conductivity decreases because of the reduction in the relative humidity of the reactant gases and the water content in the membrane. Therefore, the fuel cell performance was worse when the fuel cell temperature was increased to 65 ºC. As the temperature increases, there will be a greater rate of water evaporation. When the temperature reaches a critical temperature where the amount of evaporated water exceeds the amount of produced water, the membrane will start to dry out [15-18]. The increase of the resistance when the membranes dry out causes the decrease in the fuel cell voltage observed in Figure 2 at the higher operation temperature of 65C [19]. The current density-voltage relationship for a given fuel cell and operating conditions (concentration, flow rate, pressure, temperature, and relative humidity) is a function of kinetic (activation), ohmic, and mass transfer resistances. Deviations between the ideal equilibrium potential and the polarization curve provide a measure of fuel cell efficiency. Electrical energy is obtained from a fuel cell when a current is drawn, but the actual cell potential is lowered from its equilibrium potential because of irreversible losses due to various reasons. Several factors contribute to the irreversible losses in a practical fuel cell. The losses, which are generally called polarization or over potential, originate primarily from activation polarization, ohmic polarization, and gas concentration polarization.

The activation loss is the first of these three major polarizations, Performance loss resulting from slow reaction kinetics at either/both the cathode and anode surfaces is called activation polarization. Activation polarization is related to the activation energy barrier between reacting species and is primarily a function of temperature, pressure, concentration, and electrode properties. Competing reactions can also play a role in activation polarization. Kinetic resistance dominates the low current density portion of the polarization curve, where deviations from equilibrium are small. At these conditions, reactants are plentiful (no mass transfer limitations) and the current is so small that ohmic (iR) losses are negligible.

Performance loss due to resistance to the flow of current in the electrolyte and through the electrodes is called ohmic polarization, the ohmic polarization change with the current increase. Ohmic polarization is depicted using Ohm's Law (V=iR), where i is current density (mA/cm2) and R is resistance (W-cm2), and command in the linear part of the current density-voltage curve as shown in figure 2 .

The concentration losses occur significantly at all range of current density . Concentration polarization occurs when a reactant is interacting on the surface of the electrode cause a concentration gradient between the gas and the surface. Concentration polarization is Mainly affected by concentration and flow rate of the reactants, the temperature of fuel cell temperature, and the structure of the gas diffusion layer and catalyst properties.

Numbers of processes are cause the formation of the concentration polarization. These are (1) diffusion difficulties of the gas phase in the electrode pores, (2) solution formation of reactants into the electrolyte, (3) dissolution formation of products out of the system

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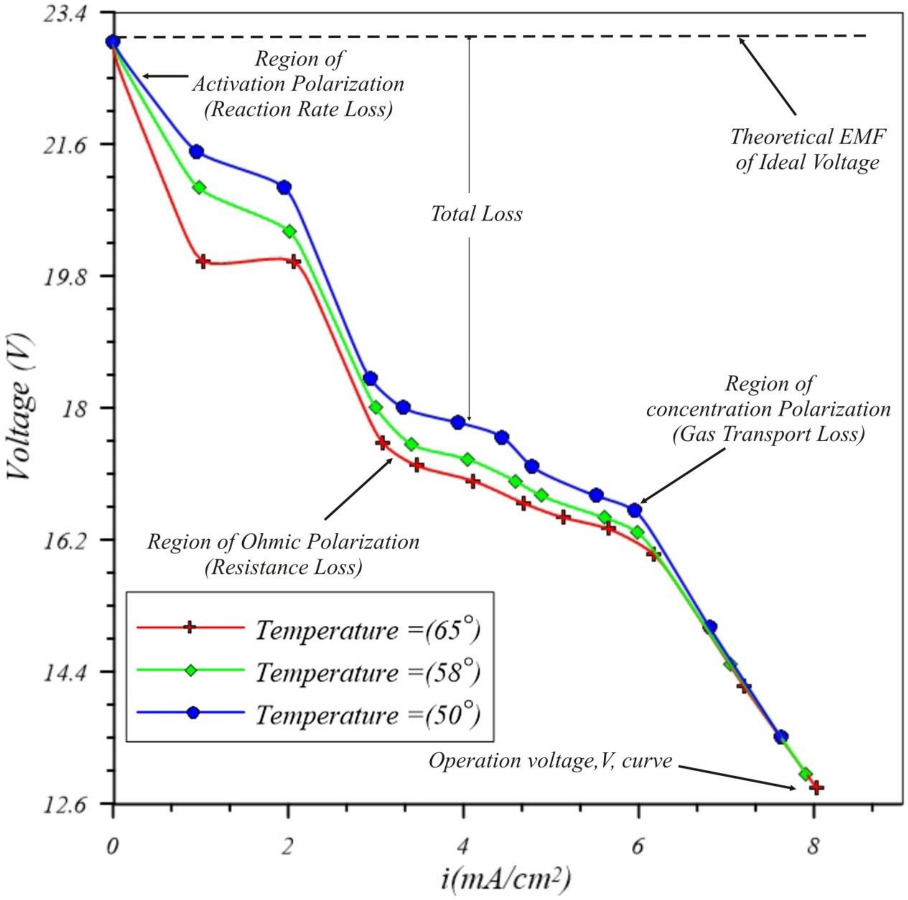

Figure 2. Experimental results of the polarization curve at different operation temperatures

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This is evident from figure (3), where can be observed decrease cell efficiency with the increase in operating temperature. As can be observed decrease in efficiency with increasing hydrogen flow rate so that the maximum efficiency of the cell was at low current densities and high voltage due to increased losses with increasing current density as described in figure (2). In fact, as the current density is decreased, the active cell area must be increased to obtain the desired amount of power.

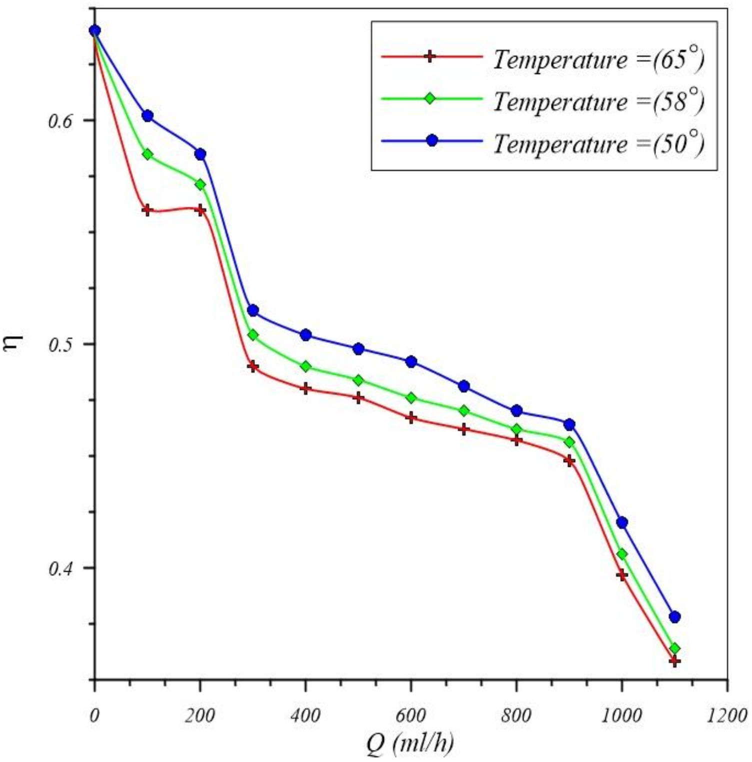

Figure 3. Variation of fuel cell efficiency with hydrogen flow rate at different operation temperatures

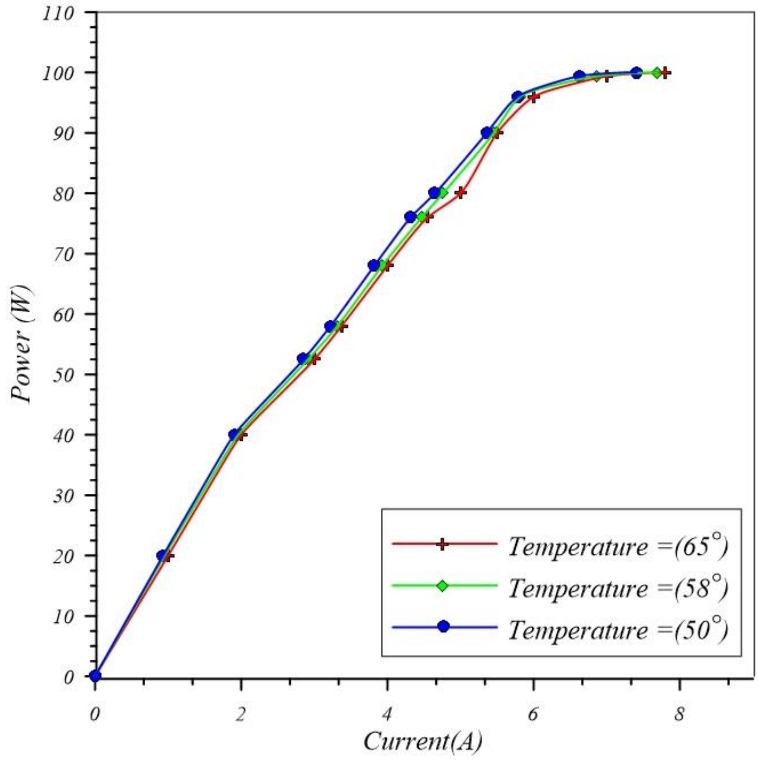

Figure 4. Output power relation with produced current at different operation temperatures

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Figures (4) and (5) show the variation of power with produced current and the relation between produced current and hydrogen flow rate at different operation temperatures. Where power increased with current density increase, it is normal and seems logical to design the cell to operate at the maximum power that peaks at a higher current density. However, operation at the higher power will mean operation at lower cell voltages or lower cell efficiency. Setting the operating point at the peak power density may cause instability in power control because the system will have a tendency to oscillate between higher and lower current densities around the peak. It is normal practice to operate the cell at a point towards the left side of the power peak and at a point that yields a compromise between low operating cost (low current density) and low capital cost (high current density).

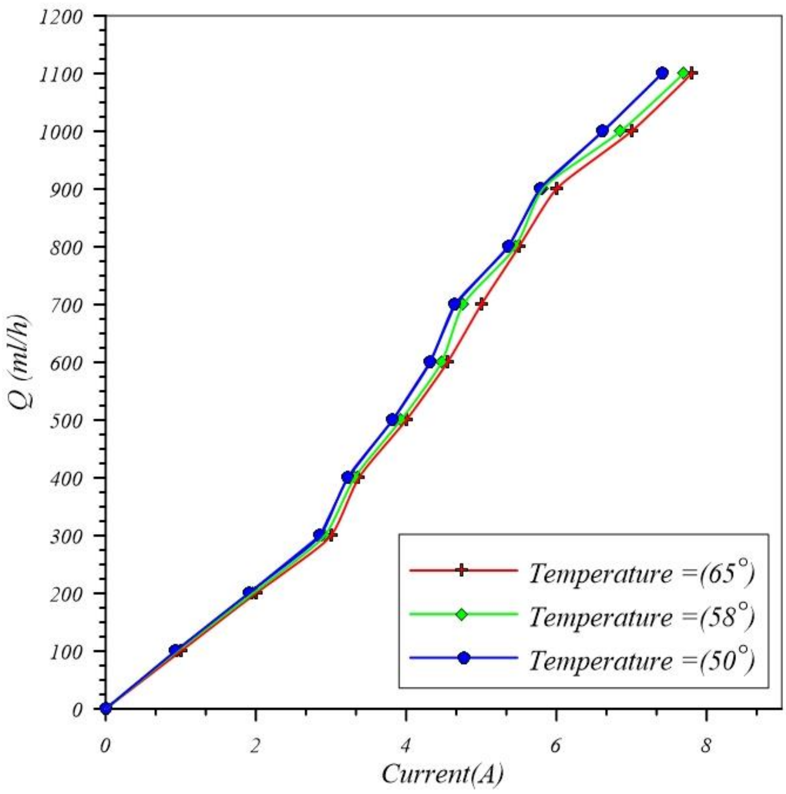

Figure 5 .Rrelation between produced current and hydrogen flow rate at different operation temperatures

CONCLUSIONS

In this work, the effect of the operation temperature on the performance of a 100 W PEM fuel cell has been studied the polarization curves of the fuel cell showed that the performance of the fuel cell decreases as the membranes can be dried at higher temperature. This causes a decrease on the mean fuel cell voltage.

The experimental results appear that the polarization curve is identical with the theoretical polarization curve of fuel cell where the three types of losses are clear and showed the same behavior known of the cell. The fuel cell efficiency decrease with the increase the operating temperature within range (50-65) ºC and hydrogen flow rate. The maximum efficiency of the cell was at low current densities and high voltage. The operating point the fuel cell must be selected so that the power output greater as possible, taking into consideration both of the cell voltage and efficiency were their being inversely proportionate with the power output.

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