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Experimental analysis of the performance characteristics of PEM Fuel Cells

Hussein A Kazem, Miqdam T Chaichan

Abstract— A fuel cell is a device that uses the fuel chemical energy to produce electricity through a chemical reaction with oxygen or any other oxidizing agent. This paper studied the correlations between current, voltage, power, and efficiency for a PEM fuel cell derived by hydrogen that is produced from water electrolyzing.

The results show that the fuel cell provides the power until the power source voltage drops below the regulation voltage. The current and voltage relationship in electrolysis was determined and the minimum voltage of the electrolysis of water was found to be -0.001 V. The difference between a single fuel cell and a double fuel cell was studied. It requires more current for electrolysis to take place for double cells to break water into hydrogen and oxygen while the resulted efficiency from double cells is higher than that produced by the single cell.

Index Terms— PEM fuel cell, hydrogen, electrolyze, power, efficiency, performance

1 Introduction

The public considered fuel cells as science fiction two decades ago. However, the insistence of researchers and developers to update these cells and made it possible to be commercial and are used in several applications [1]. Fuel cells divided into several types; the Proton Exchange Membrane fuel cell (PEM FC) is considered the most important one of them. PEM cells characterize by its high power densities, simple construction, and the possibility of working at low temperatures. That cell operation at low temperatures enables the use of less expensive materials and reduces the effect of thermal cycles [2], [3].

The PEM cells are an electrochemical device that converts chemical reactions into electrical energy. The fast operation startup of these cells makes them suitable for locomotives and household applications [4]. PEM fuel cell consists of two sheets of graphite represent the poles with micro-flow channels separated by a membrane made of two bipolar channels with a dispersant of the platinum catalyst. The gas diffusion layer (GDL) is a porous layer where the reactants process through to the electrodes in specific areas of the micro-channels [5]. Hydrogen gas is used in these cells as it passes on one side of the MEA (membrane electrode assembly) while oxygen is passing on the other side.

An electric current production depends on hydrogen gas spread rate across GDL as it is forced to spread over the carbon paper and porous (GDL) and flows through the channel in the field of flow. There are curves and blocked roads in this channel to expand the gas diffusion area [6]. Hawang studied the effect of back pressure on the performance of PEM fuel cell. He noted that the increase in back pressure increased cell performance through enhanced interaction between the electrodes of the fuel cells at the cell specified operating temperature. The performance of the pressurized cathode cell is better than when the back pressure exists on the anode side due to better water diffusion in the membrane [7].

Wang studied experimentally the effect of different operating temperature on fuel cells, the humidification temperatures of the anode and cathode, the pressure, and the interference of these various effects on the performance of the cell. The experiments focused on the effect of temperature on the cell, gas moisturizing, back pressure and reactive gas flow rate. The results presented in the form of polarization curves and a mathematical model has been used to simulate three-dimensional fuel cell and finding the cell performance [8].

Benziger declared that the non-uniformities in the large area of the fuel cell to create a potential internal variation that forces the internal current to dissipate the energy. The non-uniformities in the fuel cell stack can drive low-power cells to failure at the end. The cell performance curves simplify the analysis of the control and operation of fuel cell systems [9].

Lee focused on the numerical simulation of the effect of some operating conditions especially humidity of the cathode on small parallel flow channels. The humidity increasing in the cathode flow channel reduces enhance ion conductivity of the polymer membrane. The researchers changed humidity from 0-100 % in the cathode flow channel. The results showed that the maximum energy density can be obtained in the case of humidity of 60% at the cathode where the oxygen concentration is moderate while maintaining a high rate of ion conductivity of the membrane [10].

Christou analyzed experimentally the impact of the dynamic low-pressure response in a PEM fuel cell performance. The study showed the characteristics of the electric efficiency, and the operation performance of the cell under variable load conditions [11].

Yan chose to use methanol to run PEM fuel cell with the addition of membrane allows the passage of protons very quickly, and the methanol permeability cross is small. The designed cell showed improvement in its performance and decreased the high-resistance interfaces between membranes

- Hussein A Kazem is currently Associated Professor in electric power engineering in Faculty of Engineering, Sohar University, Oman. E-mail: hussein_alwally@yahoo.com
- Miqdan T Chaichan is currently Assistant Proffesor in Mechnical Engineering in Energy and Sustainable Energies Technology Center, University of Technology, Iraq. E-mail: 20185@uotechnology.edu.iq

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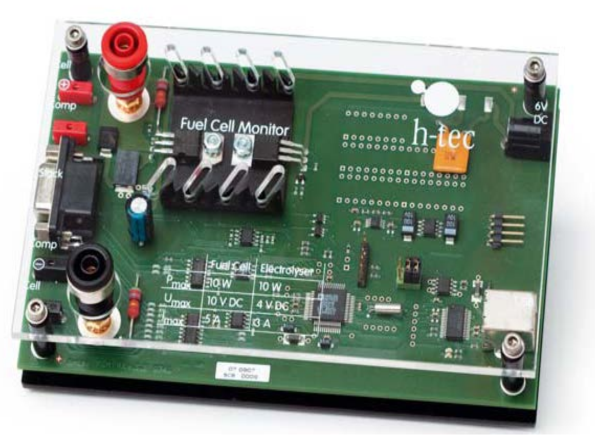
and electrodes. The maximum energy density was of 50-75 W of the cell at a cell temperature less than 60º C [12].

From the literature survey mentioned above, the fuel cells advantages as it stores more power in the same volume, aging for a longer time while being able to refuel the product quickly instead of recharging will be hopefully seen by most consumers as another area for freedom and lead to replacing the battery by fuel cells. Furthermore, the recent standard batteries that are used today like lithium-ion batteries are quite expensive, so, the cost barrier for the introduction to fuel cells to the portable market is lower than any other applications [13].

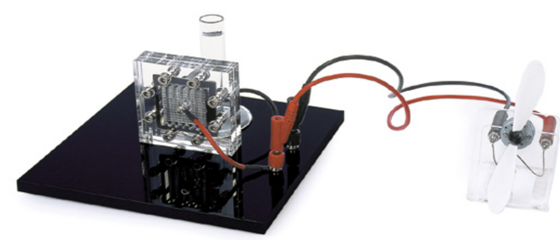
2 Experimental Setup

The hydrogen fuel cells are one of new attractive energy carrier source. Different type fuel cells are used for energy generation as the renewable energy sources are the most valuable energy resources in the future. The Proton Exchange Membrane (PEM) fuel cells are one of the leaders in the field of fuel cells in the last few years. In this paper, the analysis of performance characteristics of the Junior Basic model fuel cell (U104) is investigated. The U104 fuel cells are efficient in transport systems, communication and power supply. This fuel cell is running with water that is analyzed for hydrogen and oxygen with the aid of electricity generated by a solar cell. It simply has no moving parts and can be used in stack installation to increase power load of the fuel cells systems. The U104 fuel cell characteristics have been tested in this article were: the electrolyte nature; the current, voltage, power, and efficiency characteristics of a fuel cell; and the electrolyzer efficiency. Fig 1 represents the used system parts.



(a) Measuring transformer card
Fig 1: The tested fuel cell parts

For this purpose, the Fuel Cell Monitor Pro 3.0 software was used to calculate the efficiencies and electrical characteristics of fuel cells and electrolyzers. This software was used because it allows real-time monitoring of every cell in the fuel cell stack. This software allows plotting the fuel cell stack's voltage-current, power-voltage, power-current, and power-time characteristics. The recording can be done automatically, at a certain voltage or current points or manually, as well as, the data can be recorded in txt or csv format.



(b) Direct Methanol Fuel Cell
Fig 1: The tested fuel cell parts

2.1 Tests procedure

In the experiments, the decomposition of water (electrolyte) by the fuel cell from the electrical energy supplied from the solar cell to produces hydrogen. It is obvious after a certain time from running this experiment the water will be raised to the top of the tank, and the hydrogen will be formed at the bottom. The hydrogen formed in the tanks will be used to produce electrical energy. So, the solar radiation will attach the solar cell that allows current to flow through the fuel cell. Subsequently, hydrogen will be formed. Moreover, the hydrogen flow through the tubes will be attached to the fuel cell that connects the Ventilator fan. As a result, the fan will rotate. The electrical energy from the solar panel will convert into chemical then into electrical to turn the fan that is finally presenting a mechanical work.

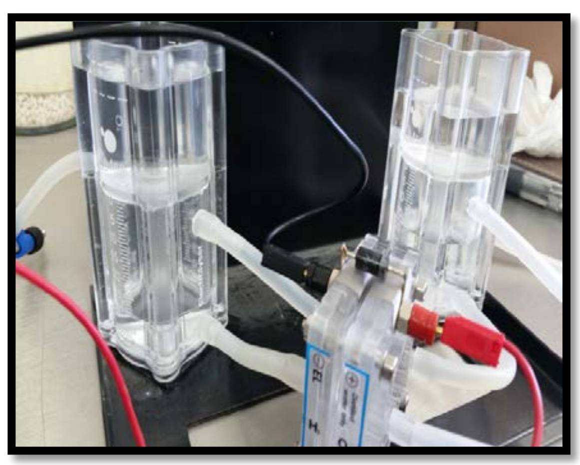


Fig 2: the storage tanks and the fuel cell

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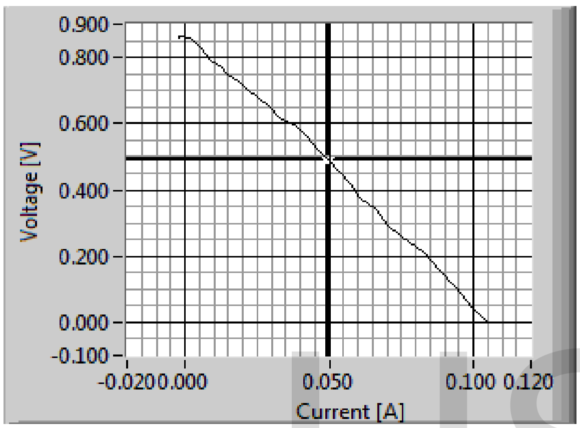
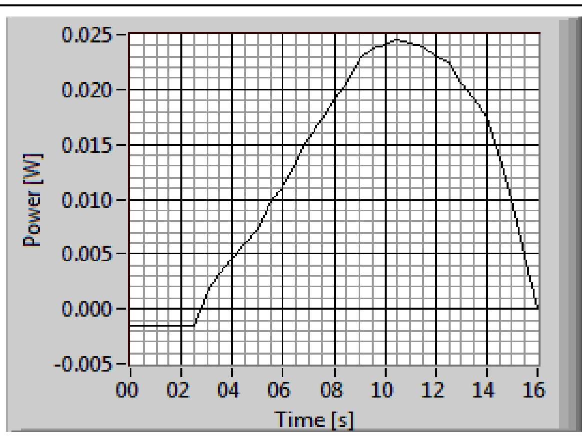
3 Results and Discussions

The external load impedance of a fuel cell with the aid of the electro-chemical reaction defines the resulted current and voltage. The polarization curve that represents the IV relation obtained from subjecting variable loads on the fuel cell. The polarization curve defines the cell performance and its chemical and physical characteristics.

Fig. 3a shows the typical polarization curve (current-voltage) for a hydrogen–oxygen polymer electrolyte membrane fuel cell characteristic behavior using automatically recorded. The voltage decreased when the current increased. Fig. 3b displays the characteristic of power and time behavior. The power increased with time to a certain limit then it dropped to zero.

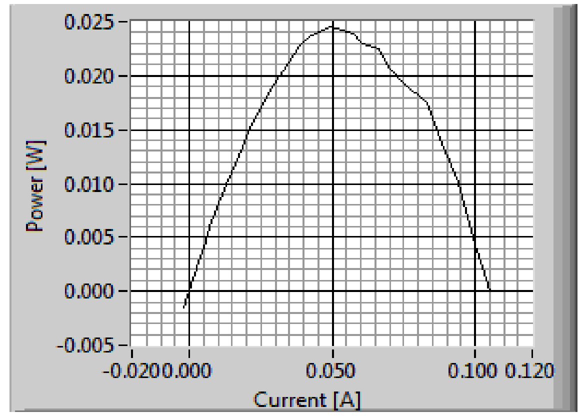


(a)
Fig 3: the fuel cell current, voltage, and power relationships

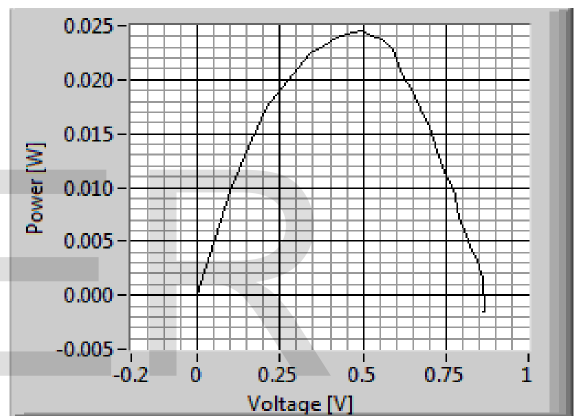


(a)
Fig 3: the fuel cell current, voltage, and power relationships

Also, Fig. 3c demonstrates the current and power behavior while Fig. 3d represents the characteristic response of the voltage and power. Both figures at the same selecting point by Cursor position produced the automatic performance. The Cursor position (MPP) was at 0.492 V; 0.050 A. The optimal operation conditions for the tested cell that produce the maximum power density occur at voltage of 0.5 V.



(c)
Fig 3: the fuel cell current, voltage, and power relationships



(d)
Fig 3: the fuel cell current, voltage, and power relationships

Fig. 4 declares the characteristic of current and voltage behavior in the fuel cell using the Electrolyzer FCM automatically records. Electrolysis uses the electricity to separate water into hydrogen and oxygen. As the figure illustrates, in the first period as the voltage increase the current increase as well until the current started to remain constant while the voltage was increased. After this stage, the curve is fluctuated going up and down representing the water separation into hydrogen and oxygen.

Fig. 5 shows all the characteristics of voltage behavior in the fuel cell with the current, time, and power when voltage-regulating was used. The voltage controlled at 1.00 V and the scan rate was 0.50 s. The results demonstrated fluctuations in voltage when the current was increased. When the change in the voltage, the cursor position voltage change were controlled while the cursor position current stay at the same situation the resulted change rate illustrated in Table 1.

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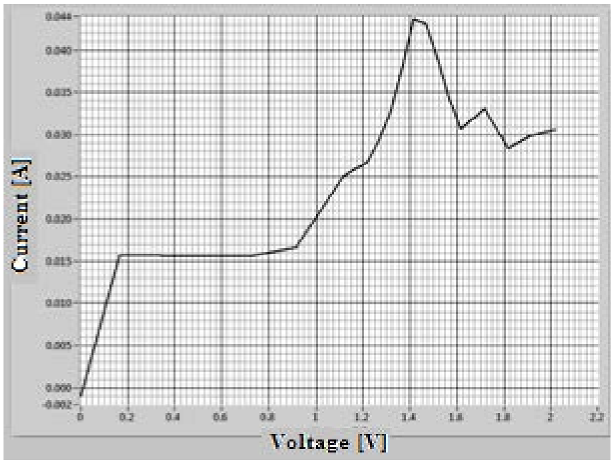
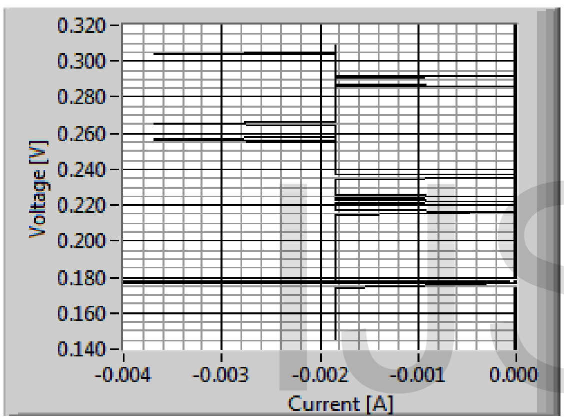
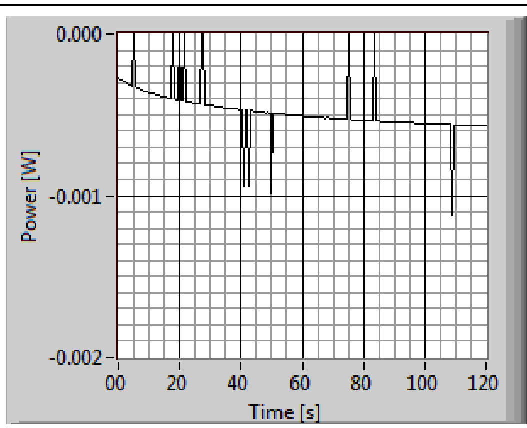


Fig. 4: the electrolyzer current-voltage relationship



(a)
Fig 5: the effect of voltage regulating on the current and power characteristics



(b)
Fig 5: the effect of voltage regulating on the current and power characteristics

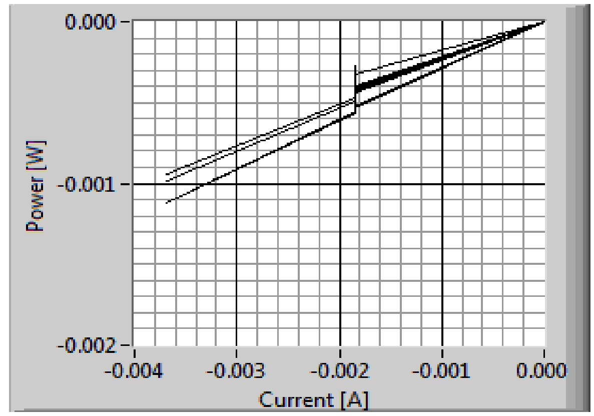


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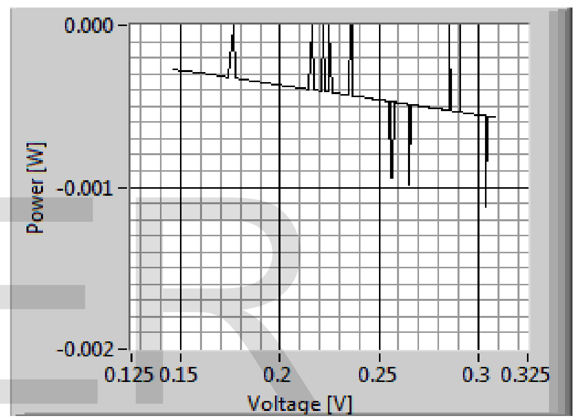
Fig 5: the effect of voltage regulating on the current and power characteristics



(d)
Fig 5: the effect of voltage regulating on the current and power characteristics

TABLE 1
THE VOLTAGE CONTROL EFFECT ON THE RESULTED CURRENT

Test No.	Scan rate	Voltage controlled	Cursor position voltage	Cursor position current
1.	0.50 s	1.00 V	0.177 V	0.000 A
2.	0.50 s	3.00 V	0.036 V	0.000 A
3.	0.50 s	6.00 V	0.011 V	0.002 A

Fig. 6 represents the current characteristics behavior of the fuel cell voltage, times, and power. The regulated current and the current controlled were 1.00 and 5.00A, and the scan rate was 0.50 s. There are fluctuations in the voltage curve when the current increased; also, the power was increasing with time and current. Table 2 shows the impact of controlling current on voltage cursor position at both 1.00 and 5.00A, and with different cursor positions.

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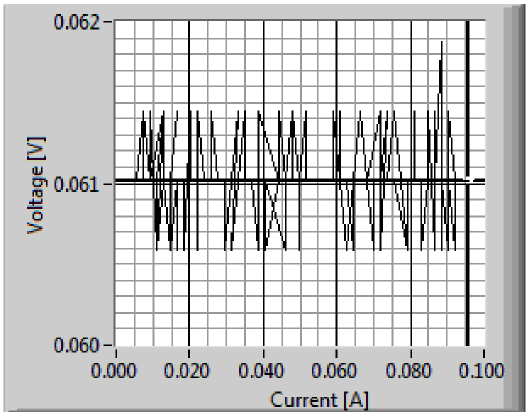

(a)
Fig 6: the effect of voltage regulating on the current and power characteristics

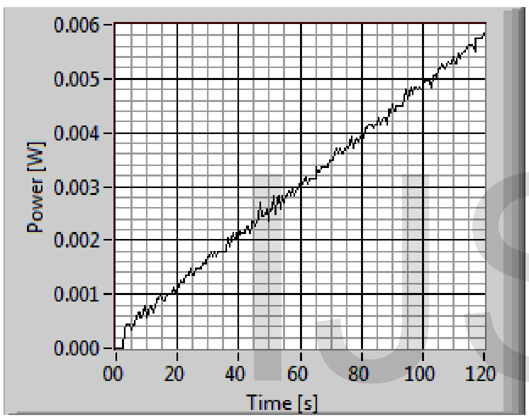

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Fig 6: the effect of voltage regulating on the current and power characteristics

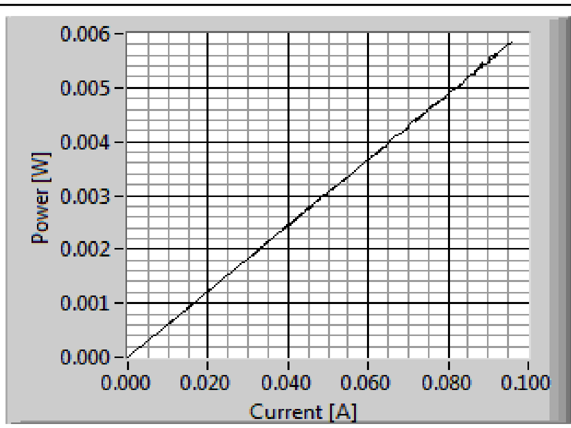

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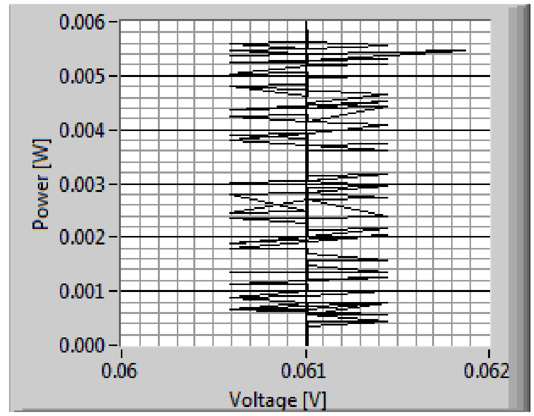
Fig 6: the effect of voltage regulating on the current and power characteristics



(c)
Fig 6: the effect of voltage regulating on the current and power characteristics

TABLE 2
THE CURRENT CONTROL EFFECT ON THE RESULTED VOLTAGE

Test No.	Scan rate	Current controlled A	Cursor position voltage V	Cursor position current A	Power W
1.	0.50 s	1.00	0.061	0.096	0.002684
2.	0.50 s	1.00	0.061	0.081	0.002684
3.	0.50 s	1.00	0.061	0.026	0.002684
4.	0.50 s	5.00	0.061	0.096	0.002684
5.	0.50 s	5.00	0.061	0.044	0.002684

Fig. 7 represents the relation between current and voltage for electrolyzer (Automatic) in a single fuel cell. The electrolyzer current and voltage values for a single fuel cell increased until it reached 0.018A. After that, it rose gradually and climbed until it reached the maximum value that is 0.136A and around 1.55V. Finally, it was decreased and then leveled off with a value of 0.046A and almost 2.08V.

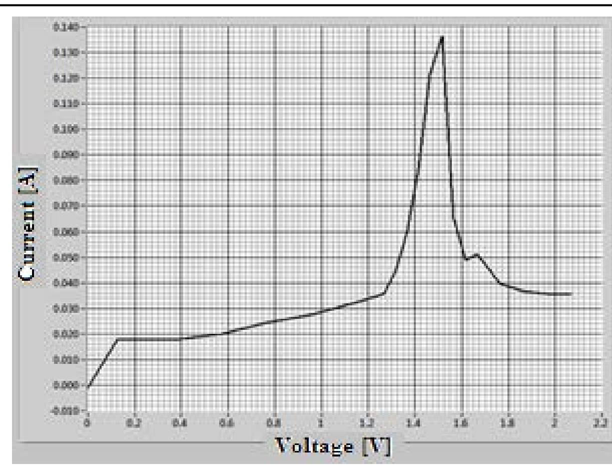


Fig. 7: the electrolyzer current-voltage relationship for single fuel cell

Fig. 8 reveals the relationship between current and voltage for electrolyzer (Automatic) in the double fuel cells. The

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value of the current and voltage for the electrolyzer in double fuel cells rose gradually and then climbed until it reached around 2.78A and 3.75V. In comparison between single and double fuel cells, the current-voltage relation for electrolysis, in a double fuel cell the current was higher compared to the single fuel cell. Furthermore, the voltage is also higher compared to the single one. This result proves that fuel cell performance enhances when it is in a stock instead of being singular.

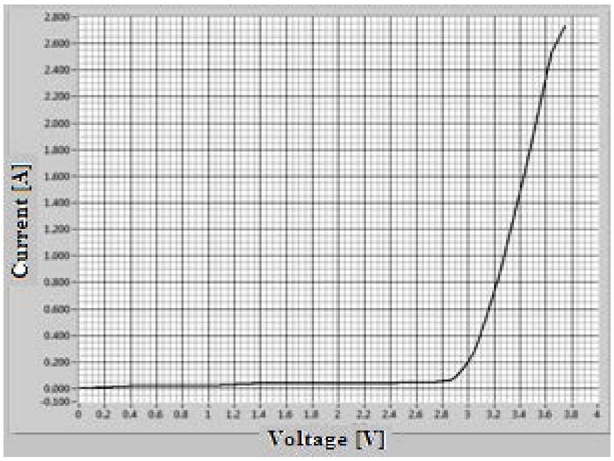
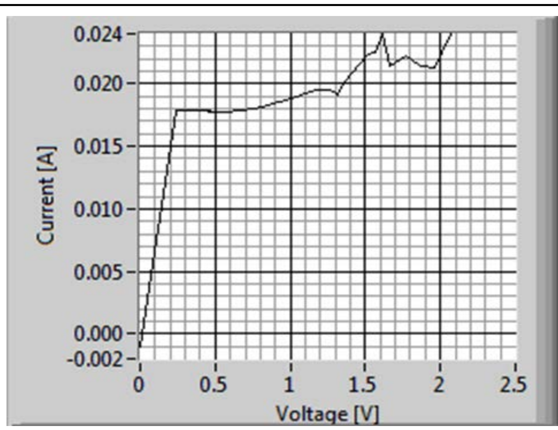


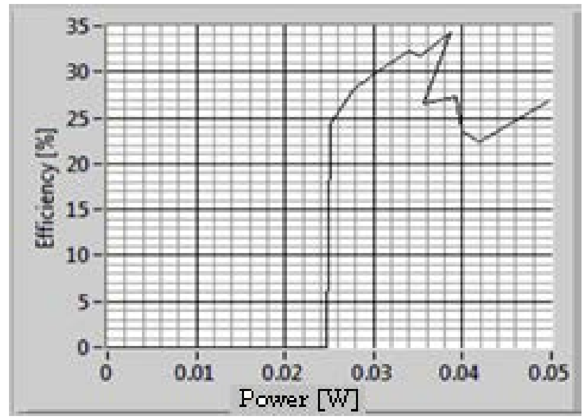
Fig. 8: the electrolyzer current-voltage relationship for double fuel cell

Fig. 9 clarifies the relation between current, voltage, and efficiency at power, current, and voltage for electrolyzer in double fuel cells. The measurement options: electrolyzer efficiency was selected carefully.

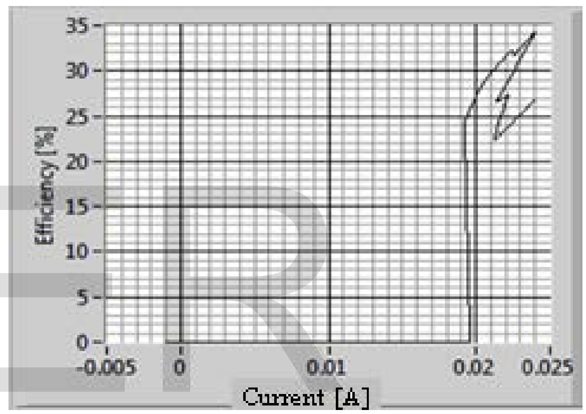


(a)
Fig 9: the effect of voltage and current on electrolyzes efficiency for single cell

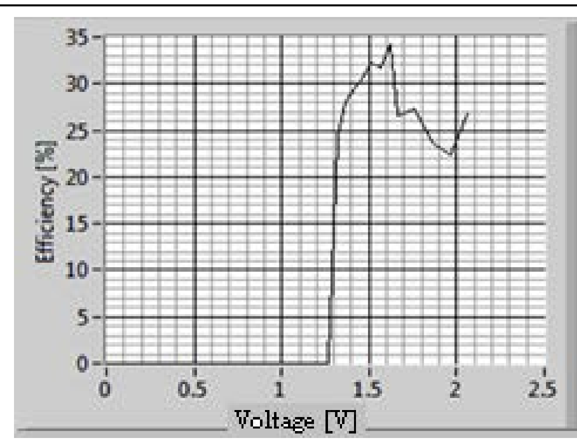
A single fuel cell was connected to the measuring transformer card using the measurement cables and the supplied power was connected to the measuring transformer card. The value of the electrolyzer efficiency increased sharply with the current and voltage in a single cell till it reached 0.018A and almost 0.22V.



(b)
Fig 9: the effect of voltage and current on electrolyzes efficiency for single cell



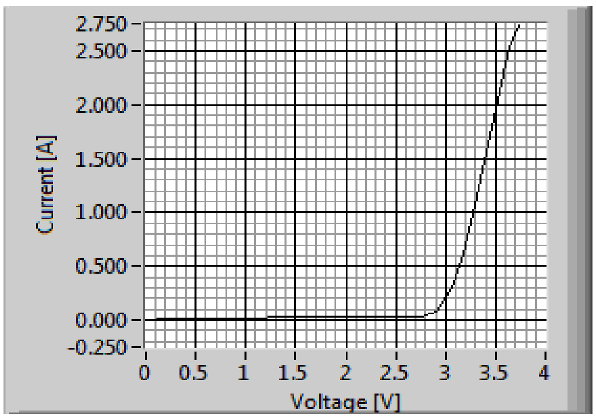
(c)
Fig 9: the effect of voltage and current on electrolyzes efficiency for single cell



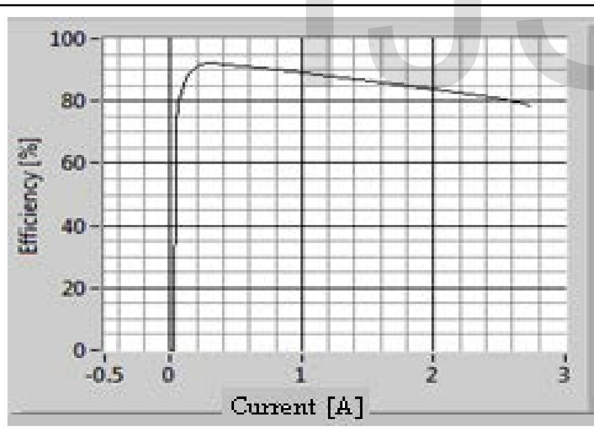
(d)
Fig 9: the effect of voltage and current on electrolyzes efficiency for single cell

After this value, it fluctuated wildly and the trend was upward. The cell efficiency relations with power, current and voltage started with a substantial value, and then it increased dramatically and fluctuated wildly. The maximum efficiency achieved was about 34%.

Fig. 10 clarifies the relation between current, voltage, and efficiency for electrolyzer in double fuel cells. Fig. 10a shows the value of current and voltage in the double cells electrolyzer for which the current was raised gradually then it climbed sharply. The figures 10b, c, and d represent the relation between the efficiency and the power, current, and voltage; in all the figures the efficiency increased till it reached around 93% and then fell slowly.



(a)
Fig 10: the effect of voltage and current on electrolyzes efficiency for double cells



(b)
Fig 10: the effect of voltage and current on electrolyzes efficiency for double cells

4 Conclusions

Fuel cells are electrochemical power supplies. A chemical potential difference provides a driving force to push an ionic current through an electrolyte and an electronic current through an external load.

The voltage-regulated original curve recording of a fuel cell, the fuel cell provides energy until the source voltage drops below the regulated voltage. Beyond this point, the fuel cell ability to supply power begins to descend, as long as, it is below the required voltage to produce the maximum power for the fuel cell.

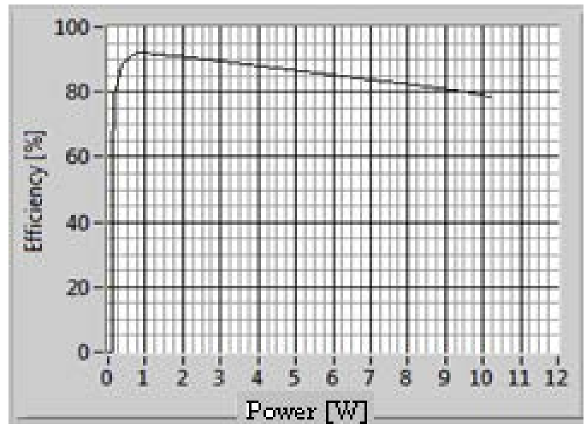


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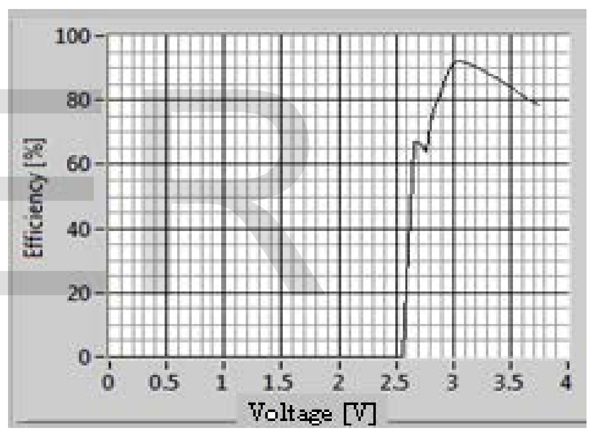
Fig 10: the effect of voltage and current on electrolyzes efficiency for double cells



(d)
Fig 10: the effect of voltage and current on electrolyzes efficiency for double cells

This study aimed to investigate the characteristic curves of a fuel cell. The current and voltage relationship in electrolysis was determined and the minimum voltage of the electrolysis of water is -0.001 V. The fuel cell must be supplied by hydrogen and oxygen from the electrolyzer as a power source. The processes in the fuel cell are the reverse of those that take place in electrolysis.

The difference between a single fuel cell and a double fuel cell was studied. It requires more current for electrolysis to take place for double cells to break water into hydrogen and oxygen while the resulted efficiency from double cells is higher than that produced from a single cell.

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