

The Passive Direct Ethanol Fuel Cell Performance Investigation For Applying With The Portable Electronic Devices

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Abstract: Ethanol is an attractive fuel since it is less toxic and has higher energy density than methanol and can be produced from biomass. Direct ethanol fuel cells (DEFCs) appear as a good choice for producing sustainable energy for portable applications. However, they are still far from attaining acceptable levels of power output, since their performance is affected by the slow electrochemical ethanol oxidation and water and ethanol crossover. In the present work, the experimental study on the performance of a passive DEFC is described. The experimental performance testing were studied about three kinds of the ethanol blended. There are the ethanol was blended with pure distilled water, the ethanol was blended with conventional drinking water and the ethanol was blended with normal tap water. The effect of fuel cell operating temperature change on the electrical production is also study too. By observing for all of three experiments, increasing the volume of ethanol and the fuel cell operating temperature effect on the electrical production of the cell. By increasing the volume of ethanol and the temperature, the fuel cell gradually produce the electrical value and gradually increase to the maximum value, and then gradually decrease until the fuel has been depleted. Increasing the volumetric of ethanol and cell operating temperature effect on the electrical current production and power of the fuel cell but do not much affect on the electrical potential. Compared to the three experiments, the third experiment that the ethanol was blended with normal tap water. Due to the impurity of the water, the crossing of the water from the electrode to the electrode within the electrochemical reaction zone of the fuel cell results in the abrasion of the electrochemical reaction of the fuel cell. So, it is given the low fuel cell production capacity.

Keywords: Drinking water, Ethanol, Fuel cell, Pure distilled water, Tap water, Temperature.

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I. INTRODUCTION

A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction of positively charged hydrogen ions with oxygen or another oxidizing agent. Fuel cells can produce electricity continuously for as long as these inputs are supplied. Fuel cells are used for primary and backup power for commercial, industrial and residential buildings and in remote or inaccessible areas. There are many types of fuel cells, but they all consist of an anode, a cathode and an electrolyte. The anode and cathode contain catalysts that cause the fuel to undergo oxidation reactions that generate positively charged hydrogen ions and electrons. The hydrogen ions are drawn through the electrolyte after the reaction. At the same time, electrons are drawn from the anode to the cathode through an external circuit, producing direct current electricity. At the cathode, hydrogen ions, electrons, and oxygen react to form water [1,2]. As the main difference among fuel cell types is the electrolyte, fuel cells are classified by the type of electrolyte they use and by the difference in start-up time ranging from one second for proton exchange membrane fuel cells (PEMFC) to 10 minutes for solid oxide fuel cells (SOFC). The fuel cell that using hydrogen as fuel that its performance is high but need to use the purity of hydrogen and the electrodes made from platinum. So, it is rather expensive. Fuel cells are divided into two types of alcohol fuel cell that are Direct Methanol Fuel Cell (DMFC) and Direct Ethanol Fuel Cell (DEFC). Previously a lot of research focuses on the study and development of Direct Methanol Fuel Cell. There is downside and many other problems in reaction kinetics for the slowly oxidation of methanol fuel and across the water from one electrode to the one electrode (crossover) [3, 4]. Matsuoka et al [5] reported that DMFC electrodes are slowly reaction kinetics because obstruct of carbon monoxide (CO) catalyst platinum (Pt) at low temperatures and high surface quality of the catalysts for membrane. In fact the methanol is nonrenewable energy qualified by the volatile and highly flammable use methanol may result main issue if applied to portable electronic devices disadvantage of the foregoing. Interested ethanol fuel which is good choice for fuel cell also address the issue of methanol fuel, also ethanol is less toxic and has higher energy density. Ethanol can produced from biological processes in agriculture which is great energy [6]. Ethanol is a hydrogen-rich liquid and it has a

higher specific energy (8.0 kWh/kg) compared to methanol (6.1 kWh/kg). The use of ethanol would also overcome both the storage and infrastructure challenge of hydrogen for fuel cell applications. In a fuel cell, the oxidation of any fuel requires the use of a catalyst in order to achieve the current densities required for commercially viable fuel cells, and platinum-based catalysts are some of the most efficient materials for the oxidation of small organic molecules [7]. Due to the development in science and technology is going quickly so the fuel cell is developed to small and compact size for using with the portable electronic devices such as Direct Ethanol Fuel Cells, DEFCs, which size is about 125 mm x 115 mm x 102 mm that can produce the electric power about 102 W for operations more than 3600 hours. Direct ethanol fuel cells have attracted much attention recently in the search for alternative energy resources. As an emerging technology, direct ethanol fuel cells have many challenges that need to be addressed. Many improvements have been made to increase the performance of direct ethanol fuel cells, and there are great expectations for their potential. However, many improvements need to be made in order to enhance the potential of direct ethanol fuel cells in the future.

Concerning the different concepts of fuel delivery and handling, the DEFCs can be categorized as passive and active. Active systems need moving parts to feed oxidant and fuel to the cell requiring power to operate. This type of system supply has greater costs and lower system energy density and thus is better suited for large fuel cells. Passive systems use natural capillary forces, diffusion, convection (air breathing) and evaporation to achieve all processes without any additional power consumption. Therefore a passive system is more suitable for portable power sources [8-12]. Like the active ones, the passive systems suffer from ethanol crossover, when the cell is operated with high ethanol concentrations. This leads to a fuel cell performance loss since ethanol diffuses through the membrane generating heat but no power [19-23]. The solution is to use low ethanol concentrations on the anode side. As already mentioned, in passive systems, ethanol is delivered to the catalyst layer by a passive diffusion mechanism, so if ethanol is not supplied adequately and timely, polarization of the cell voltage may occur due to a lack of ethanol. Also, the output of a passive DEFC operating with low ethanol concentrations is not acceptable for real applications. Therefore, low ethanol crossover is essential for using high ethanol concentrations in portable power applications. Different approaches including improving and changing the fuel cell structure have been proposed in the last years for an active feed DEFC [19-27]. However, as the author is aware, less work on passive DEFC systems was performed.

In DEFCs, water is produced at the cathode, and to avoid some ethanol crossover problems, more dilute solutions are fed to the anode side. This leads to a higher water concentration gradient between the anode and the cathode side, so more water crosses the membrane towards the cathode side due to electro-osmotic drag and diffusion. However, the presence of a large amount of water on the cathode due to the oxygen reduction reaction along with water that permeates from the anode, tends to flood the cathode leading to an increase in oxygen transport resistance and reducing the cell performance [28]. Thus, another important issue on DEFCs is how to remove water from the cathode to avoid several flooding and subsequently supply water to the anode to make up water loss due to crossover through the membrane. Although, some efforts have been made for studying water transport in DMFCs [16-18], a general understanding of water crossover in DEFCs, especially for passive feed systems, is far less understood. As explained before, the great challenge in passive DEFC systems is how to reduce both ethanol and water crossover without sacrifice of performance. Based on previous work performed with DMFCs, the solution is to use high concentrations of ethanol solutions and use different membrane, diffusion layers and catalyst layers materials with different thicknesses [13-18].

Based on that, in this study, the effect of ethanol concentration was investigated. The experimental performance testing were studied about the three kinds of the ethanol blended. There are the ethanol was blended with pure distilled water, the ethanol was blended with conventional drinking water and the ethanol was blended with normal tap water. The cell performance was evaluated and analyzed by measuring the cell voltage and cell current production characteristics at ambient conditions (atmospheric pressure and ambient temperature) and the effect of operating temperature change on the electrical production performance also study too.

II. EXPERIMENTS

The experimental apparatuses are composed of 1. DEFC set, 2. Ethanol 95 % by volume 3. Pure distilled water/ conventional drinking water/ normal tap water , 4. Cylinder size equal to 100 ml, 5. Syringe solution size equal to 10 ml and 6. Paper measure acid-alkaline.

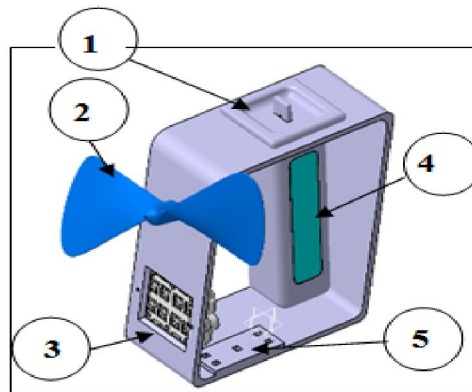


Figure 1 The passive direct ethanol fuel cell

Figure 1 shows the passive DEFC set applied in the present work. The details on Fig 1. are 1. Lid set (DEFC) , 2. Vane set, 3. Membrane (MEA), 4. Set structure (DEFC) and 5. Cylinder solution. Bio-energy feed ethanol is fuel direct demonstration for changing the ethanol fuel to electrical energy. The process does not combustion. It can work continuously many hours. The main experimental study is about the consumption of ethanol fuel for production electricity.

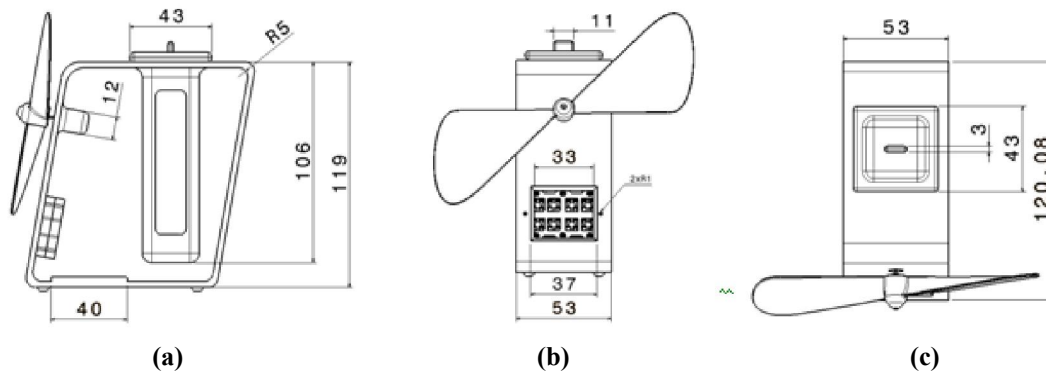


Figure 2 (a) The DEFC drawing front view; (b) The DEFC drawing side view; (c) The DEFC drawing top view (all dimensions are in millimeters)

III. THEORETICAL CALCULATIONS

3.1 Calculation of the cell voltage

The voltage of single cell DEFC theory at feeding ethanol at 25 (C^o) and 1 atm by the chemical reaction show as the following equation below. [29]

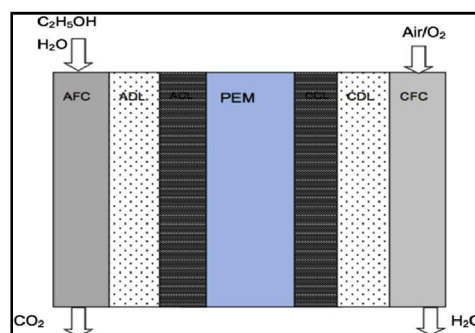
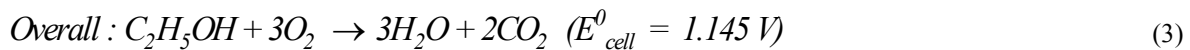
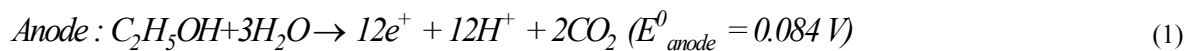


Figure 3 The system of direct ethanol fuel cell (DEFC)

From figure 3 that the letters are PEM : Membrane , CDL: Cathode gas diffusion layer , ADL : Anode gas diffusion layer , CCL : Cathode catalyst layer , ACL : Anode catalyst layer , CFC : Splice plate cathode , AFC : Splice plate anode. Calculate the voltage (V) in single cell DEFC for portable electronic devices [30] that show as equation (4) below.

$$E_{cell} = E_{cell}^0 - \eta_{conc} - \eta_{ohmic} - \eta_{act} \quad (4)$$

When E_{cell} = Voltage of fuel cell (V), E_{cell}^0 = Voltage of fuel cell follows the theory (V), η_{conc} = Concentration of voltage loss related to kinetics of reaction (V), η_{ohmic} = Voltage loss related to resistance (V) and η_{act} = Voltage loss related to reaction involved to kinetics (V).

The move of substrate on anode catalyst layer and cathode catalyst layer resulting the loss concentration inside the cell. The concentration of voltage loss can be calculated from equations (5) - (12) [22].

$$\eta_{conc} = \frac{RT}{zF} \ln\left(\frac{I_{lim}}{I_{lim} - i}\right) \quad (5)$$

While limitation of flow electric current show following equation (6)

$$I_{lim} = Z_a F D_b^{eff} \frac{C_b}{L_b} \quad (6)$$

When R = Universal gas constant = 8.314 (J/g mol K) , z = Number of electrons in system, D_b^{eff} = Spread efficiency coefficient of ethanol at anode , C_b = Concentration of ethanol at anode (molar) and L_b = The width of flow channel at anode (mm).

The cell voltage resistance loss can be calculated from equation (7) - (10).

$$\eta_{ohmic} = i R_{total} \quad (7)$$

$$R_{total} = \eta_{membr} + \eta_{contact} \quad (8)$$

$$\eta_{membr} = \frac{l_m}{K_m} i \quad (9)$$

$$\eta_{contat} = \frac{l_m + 2l_c}{K_s} \quad (10)$$

While the voltage loss related to reaction involved to kinetics can be calculated follow the equations below [30]

$$\eta_{act,anode} = \frac{RT}{\alpha_a z_a F} \ln\left(\frac{i}{i_o}\right) \quad (11)$$

$$\eta_{act,cathone} = \frac{RT}{\alpha_c z_c} \ln\left(\frac{i}{i_o}\right) \quad (12)$$

From equation 4, so we can calculate the voltage in DEFC single cell following

$$\begin{aligned} E_{cell} &= E_{cell}^0 - \eta_{conc} - \eta_{ohmic} - \eta_{act} \\ &= E_{cell}^0 - \left(\frac{RT}{z_a F} \ln\left(\frac{i_{lim}}{i_{lim} - i}\right)\right) - \left(i\left(\frac{l_m}{K_m} + \frac{l_m + 2l_c}{K_s}\right)_0\right) - \left(\frac{RT}{\alpha_a z_a F} \ln\left(\frac{i}{i_o}\right) + \frac{RT}{\alpha_c z_c F} \ln\left(\frac{i}{i_o}\right)\right) \end{aligned} \quad (13)$$

3.2 The flow rate of ethanol for electrochemical reaction

The ethanol fuel mole flow rate can be calculated by equation (14) and the ethanol volume flow rate can be calculated by equation (15) as shown below

$$n_i = \frac{i}{nF} \quad (14)$$

$$v_i = \frac{n_i M_i}{\rho_i} \quad (15)$$

When n_i = Ethanol fuel mole flow rate (mol/s), n = Number of electrons in system , v_i = Ethanol volume flow rate (cm³/h) , M_i = Molecular (g/mol) , ρ_i = Density of ethanol (g/cm³)

3.3 The total power and efficiency of fuel cell

Electrical power (P) can be calculated from the following equation

$$P = VxI \quad (16)$$

We have voltage (V) then we can calculate the efficiency of fuel cell ($\eta_{actual,E}$) from the ratio between actual electrical potential (E_{cell}) and electrical potential from the reaction between the ethanol and oxygen that show below (E_{cell}^o).

$$\eta_{actual,E} = \frac{E_{cell}}{E_{cell}^o} \times 100\% \quad (17)$$

The parameters use in the calculations are shown below in table 1.

Table1 The parameters use in the calculation

Parameters	Constants	Units	References
Design parameters			
Active area	4	cm ²	Fixed
Current density	0.175	A/cm ²	Fixed
Catalyst layer thickness, l_c	0.01	cm	
Diffusion layer thickness, l_d	0.14	cm	
Membrane thickness, l_m	0.01778	cm	
Operating parameters			
Pressure	1	atm	Fixed
Faraday constant, F	96,500	Cmol ⁻¹	
Gas constant, R	8.314	J/molK	
Effective diffusion coefficient of ethanol in diffusion layer D_{EtOH}^d	3.916×10^{-2}	cm ² s ⁻¹	[31]
Void volume fraction of anode diffusion layer, ϵ^d	0.4		[32]
Electronic conductivity of solid phase (PtRu/C), K_s	8.13×10^{-6}	Scm ⁻¹	[31]
Protonic Conductivity of ionomer, K_m	0.1416	Scm ⁻¹	[32]
Anode transfer coefficient, α_a	0.089	cm ²	[31]
Cathode transfer coefficient, α_c	1.0	A/cm ²	[31]
Component parameters			
Oxygen density	1.141	gcm ⁻³	Fixed
Co ₂ density	0.77	gcm ⁻³	Fixed
Ethanol density	0.785	gcm ⁻³	Fixed
Water density	1	gcm ⁻³	Fixed

IV. RESULTS AND DISCUSSION

In passive DEFC systems the temperature rises with time due to the electrochemical reactions. Based on that, in order to minimize this effect on the results presented in this section, all the experiments were conducted at a controlled temperature, ensuring a constant temperature value during each experimental testing. Therefore, it is very important to evaluate the performance effects on passive DEFCs, and the present work accomplish that. It is expected that the performances and power outputs presented in the present section are lower in a passive DMFC, mainly due to the slow ethanol oxidation reaction on the anode side. However, since ethanol is less toxic and can be produced from renewable sources is a more attractive fuel to produce energy for portable applications. The performance of the passive DEFC was determined by a set of tests, in order to obtain the cell power curves. The influence of ethanol concentration was carefully investigated.

Based on above mentioned, in this study, the effect of ethanol concentration was investigated. Study about the impact of ethanol concentration in this research expressed by blending the ethanol by volume with three kinds of water i.e., the ethanol was blended with pure distilled water, the ethanol was blended with conventional drinking water and the ethanol was blended with normal tap water. The cell performance was evaluated and analyzed by measuring the cell voltage and cell current production characteristics at ambient conditions (atmospheric pressure and ambient temperature). And also, the effect of operating temperature change on the electrical performance is study too. The experimental results are shown below.

The first experiment is studied about the ethanol was blended by volume with the pure distilled water. The experiments were done at the volume of ethanol equal to 5, 7, 9, 11, 13 and 15 milliliters, respectively, with 60 milliliters of pure distilled water solvent at ambient condition and at different cell operating temperature (at 1 atm of pressure). The results are shown in figure 4, 5 and 6, respectively. Figure 4 shows the volume of ethanol equal to 15 ml at 50 °C is given the electrical current equal to 19.3 mA and the lowest value is at the volume of ethanol equal to 5 ml. The maximum value is at 50 °C of each ethanol volume, when the temperature is above 50 °C, the output of the fuel cell decrease. The production of the fuel cell potential in figure 5 is little difference. The difference was slightly higher at the volume of ethanol 15 ml at 50 °C as 0.98 V. Figure 6 shows the fuel cell

power generation at each ethanol volume dissolved in 60 ml of pure distilled water. The maximum fuel cell power generation capacity is equal to 19.0 mW that occurred at 15 ml of ethanol volume and 50 °C of fuel cell operating temperature. The lowest is occurred at the volume of ethanol equal to 5 ml. Increasing the volume of ethanol that the higher the ethanol volume and the higher the fuel cell operating temperature that the fuel cell power production is also higher. The maximum value is at 50 °C of each ethanol volume, when the temperature is above 50 °C, the output of the fuel cell is reduced. From the experiment noticed that at the volume of ethanol more than 15 ml blended with 60 ml of pure distilled water cannot measure the cell current production, the cell voltage and the cell power. Because of the passive systems suffer from ethanol crossover, when the cell is operated with high ethanol concentrations. This leads to a fuel cell performance loss since ethanol diffuses through the membrane generating heat but no power [19-23]. The solution is to use lower ethanol concentrations on the anode side. And also, at the ethanol concentration volume lower than 5 ml blended with 60 ml of pure distilled water that the experiment cannot measured the cell performance too. As already mentioned, in passive systems, ethanol is delivered to the catalyst layer by a passive diffusion mechanism, so if ethanol is not supplied adequately and timely, polarization of the cell voltage may occur due to a lack of ethanol. Also, the output of a passive DEFC operating with low ethanol concentrations is not acceptable for real applications. Therefore, low ethanol crossover is essential for using high ethanol concentrations in portable power applications. Different approaches including improving and changing the fuel cell structure have been proposed in the last years for an active feed DEFC [19-27].

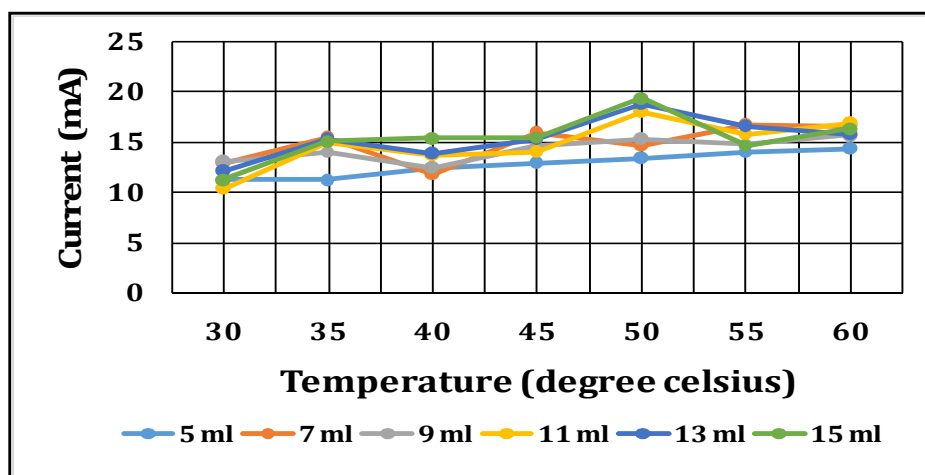


Figure 4 The electrical current (mA) at each ethanol volume dissolved in 60 ml of pure distilled water at the different cell operating temperature (°C)

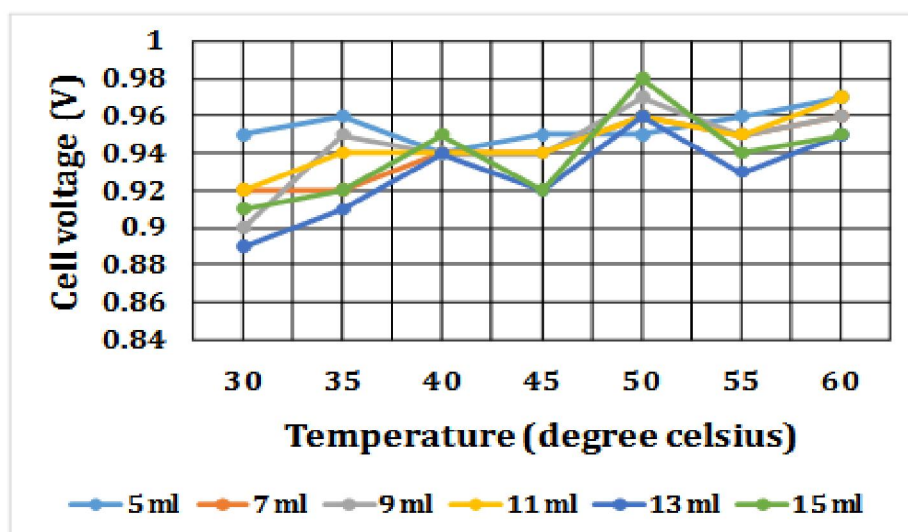


Figure 5 The cell voltage (V) at each ethanol volume dissolved in 60 ml of pure distilled water at the different cell operating temperature (°C)

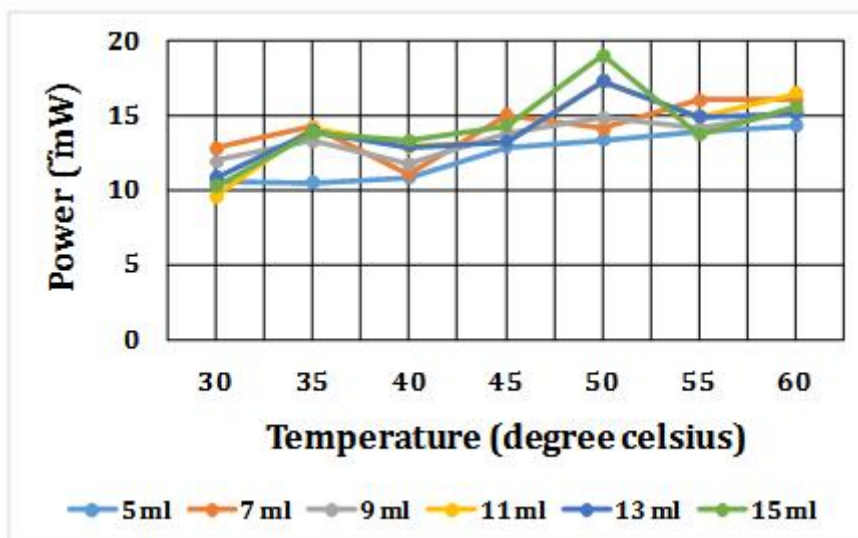


Figure 6 Show the electrical power (mw) at each ethanol volume dissolved in 60 ml of pure distilled water at the different cell operating temperature (°C)

Table 2 is the theoretical calculation of the fuel cell voltages and the last column is the fuel cell efficiency. Based on the calculation, at the ethanol concentration of 5 ml dissolved in 60 ml of pure distilled water and the working temperature of 30 °C is given the highest efficiency of 92.524% and the maximum voltage of 1.0594 volts. Observe on the theoretical calculations. The voltage difference is slightly different. At the higher cell operating temperature that the electrical potential and fuel cell efficiency is clearly reduced.

Table 2 The fuel cell efficiency calculation results when blended ethanol with pure distilled water.

Ethanol concentration (95 %) (ml. blended with 60 ml. of pure distilled water)	the theoretical calculation of the value of the fuel cell voltages (V, V)	Temperature (T, °C)	Fuel cell efficiency (%)
5	1.0594	30	92.524
7	1.0258	35	89.591
9	0.9917	40	86.618
11	0.9577	45	83.645
13	0.9236	50	80.671
15	0.8896	55	77.698

The second experiment was conducted as the first one, by replacing the solvent as a conventional drinking water. The experiments were done at the volume of ethanol equal to 5, 7, 9, 11, 13 and 15 milliliters, respectively, with 60 milliliters of conventional drinking water solvent at ambient condition and at different cell operating temperature (at 1 atm of pressure). The results were similar to those of the first experiment. The results are shown in figure 7, 8 and 9, respectively.

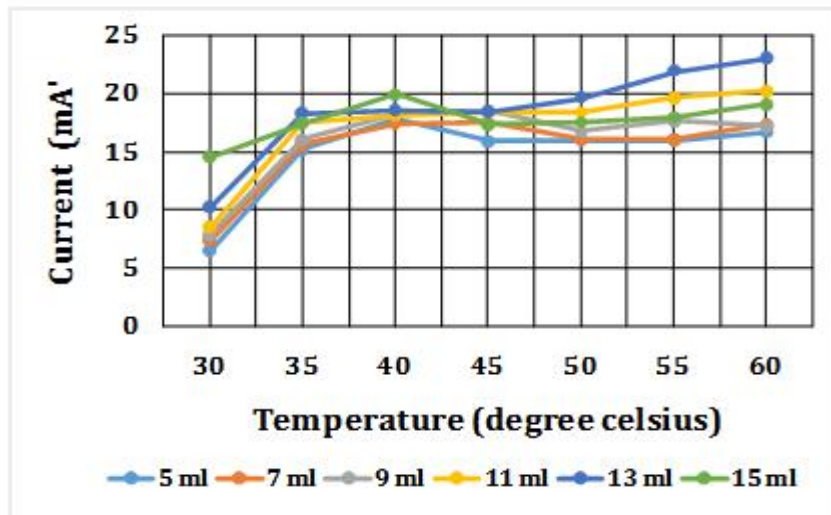


Figure 7 The electrical current (mA) at each ethanol volume dissolved in 60 ml of conventional drinking water at different cell operating temperature (°C)

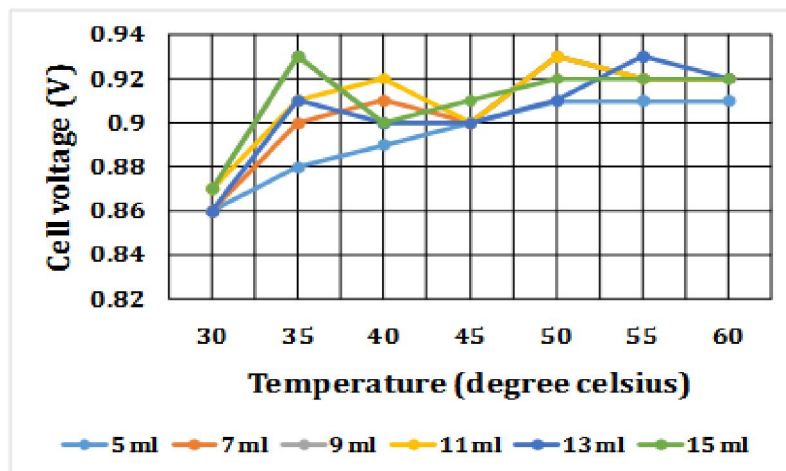


Figure 8 The cell voltage (V) at each ethanol volume dissolved in 60 ml of conventional drinking water at the different cell operating temperature (°C)

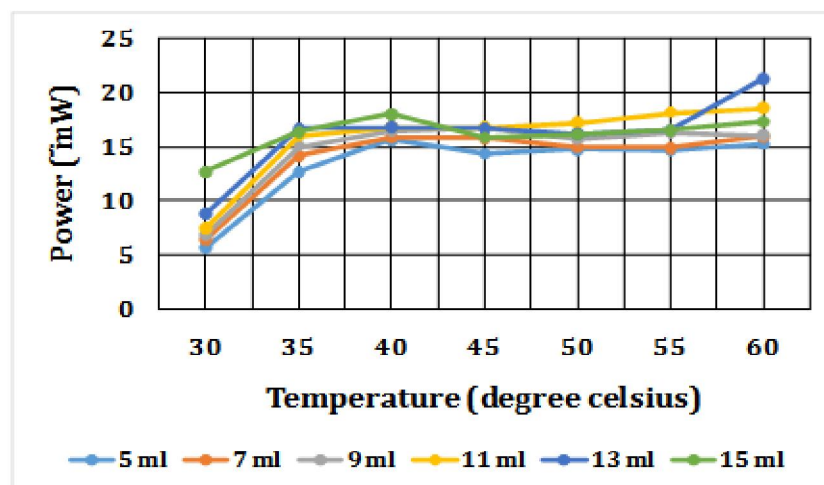


Figure 9 Show the electrical power (mw) at each ethanol volume dissolved in 60 ml of conventional drinking water at different cell operating temperature (°C)

The results are as following that the volume of ethanol 13 ml at 60 °C is given the electrical current equal to 23 mA and the lowest value is at the volume of ethanol equal to 5 ml. The power generation of the fuel cell at each ethanol volume dissolved in 60 ml of conventional drinking water. The maximum fuel cell power generation capacity is occurred at 13 ml of ethanol volume and at 60 °C of fuel cell operating temperature. The maximum value is equal to 21.2 mW. The lowest is occurred at the volume of ethanol equal to 5 ml.

The final experiment was conducted as in the first and the second experiment by changing solvent to tap water. The results are lower than the first two cases above.

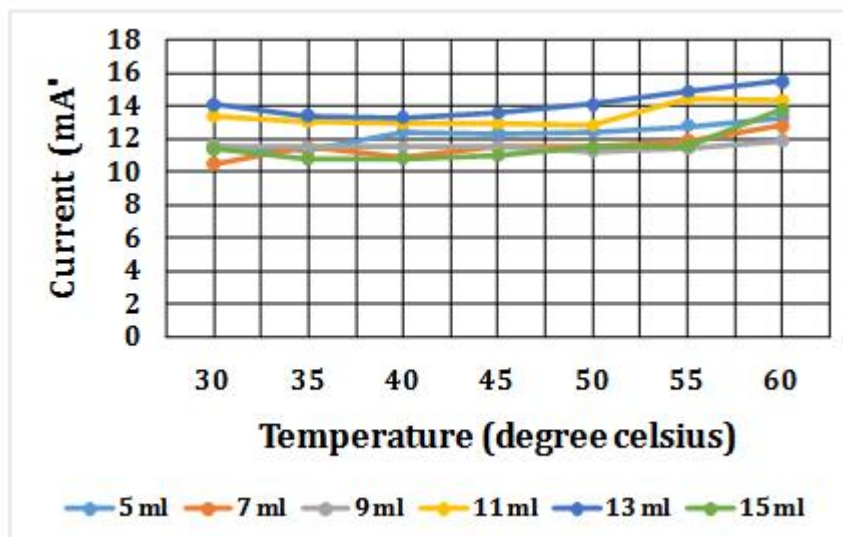


Figure 10 Shows the electrical current (mA) at each ethanol volume dissolved in 60 ml of tap water at the different cell operating temperature (°C)

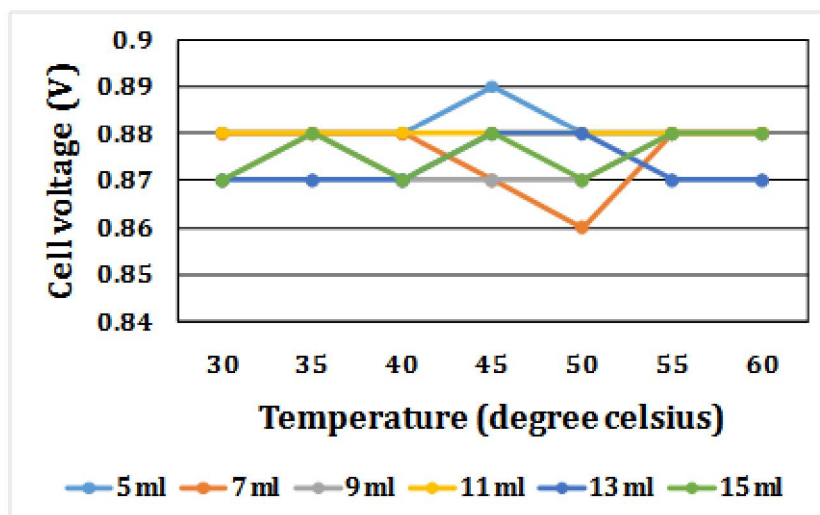


Figure 11 Shows the cell voltage (V) at each ethanol volume dissolved in 60 ml of tap water at the different cell operating temperature (°C)

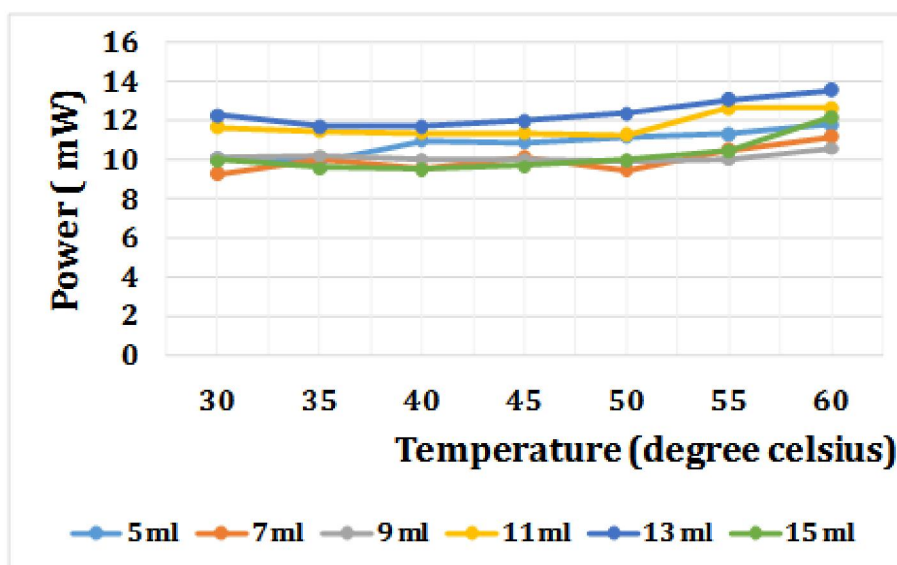


Figure 12 Show the electrical power (mw) at each ethanol volume dissolved in 60 ml of tap water at the different cell operating temperature (°C)

The maximum current is occurred at 13 ml of ethanol at 60 °C that is equal to 15.5 mA and the lowest value is at 7 ml of ethanol. Due to the third experiment, the water crossover between the electrode of the fuel cell is more than two cases above. Figure 12 shows the power generation of the fuel cell at each ethanol volume dissolved in 60 ml of tap water. The maximum fuel cell power generation capacity is occurred at 13 ml of ethanol volume and at 60 °C of fuel cell operating temperature. The maximum value is equal to 13.6 mW. The lowest is occurred at the volume of ethanol equal to 7 ml. The trial of all three cases above showed that the conventional drinking water soluble solvent yielded the best result and the tap water is the lowest

V. CONCLUSIONS

Direct Ethanol Fuel Cells or DEFCs are a subcategory of proton-exchange fuel cells in which ethanol is used as the fuel. Their main advantage is the ease of transport of ethanol, an energy-dense yet reasonably stable liquid at all environmental conditions. DEFC is a new fuel cell that is similar to the PEMFC fuel cells, where both are used as polymer-type membrane electrolytes. However, DEFCs are still far from attaining acceptable levels of power output, since their performance is affected by the slow electrochemical ethanol oxidation and water and ethanol crossover. Concerning the different concepts of fuel delivery and handling, the DEFCs can be categorized as passive and active. Active systems need moving parts to feed oxidant and fuel to the cell requiring power to operate. This type of system supply has greater costs and lower system energy density and thus is better suited for large fuel cells. Passive systems use natural capillary forces, diffusion, convection (air breathing) and evaporation to achieve all processes without any additional power consumption. Therefore a passive system is more suitable for portable power sources.

In the present work, an experimental study on the performance of a passive DEFC is described. The experimental performance testing were studied about three kinds of the ethanol blended. There are the ethanol was blended with pure distilled water, the ethanol was blended with conventional drinking water and the ethanol was blended with normal tap water. The effect of operating temperature change on the electrical production is also study too. By observing for all three experiments, increasing the volume of ethanol and the cell operating temperature effect on the electrical production of the cell. By increasing the volume of ethanol and the temperature, the fuel cell gradually produce the electrical value and gradually increase to the maximum value, and then gradually decrease until the fuel has been depleted. Increasing the volumetric of ethanol and cell operating temperature effect on the electrical current production and power of the fuel cell but do not much affect on the electrical potential. Compared to the three experiments, the third experiment that the ethanol was blended with normal tap water. Due to the impurity of the water, the crossing of the water from the electrode to the electrode within the electrochemical reaction zone of the fuel cell results in the abrasion of the electrochemical reaction of the fuel cell. So, it is given the low fuel cell production capacity. The passive systems suffer from ethanol crossover, when the cell is operated with high ethanol concentrations. This leads to a fuel cell performance loss since ethanol diffuses through the membrane generating heat but no power. The solution is to use low ethanol concentrations on the anode side. As already mentioned, in passive systems, ethanol is delivered to the catalyst layer by a passive diffusion mechanism, so if ethanol is not supplied

adequately and timely, polarization of the cell voltage may occur due to a lack of ethanol. Also, the output of a passive DEFC operating with low ethanol concentrations is not acceptable for real applications. Therefore, low ethanol crossover is essential for using high ethanol concentrations in portable power applications.

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