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STUDY OF THE ETHANOL FUEL CONSUMPTION RATE EFFECTS ON THE MICRO DIRECT ETHANOL FUEL CELL (MICRO-DEFC) PERFORMANCE FOR APPLYING WITH THE PORTABLE ELECTRONIC DEVICES

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ABSTRACT

This research is focused on a micro fuel cell for using ethanol as a fuel for applying with portable electronic devices. The direct ethanol fuel cell (DEFC) is selected for this research. DEFC uses ethanol in the fuel cell instead of the more toxic methanol. Ethanol is a hydrogen-rich liquid and it has a higher specific energy (8.0 kWh kg^{-1}) compared to methanol (6.1 kWh kg^{-1}). The objective of this research is to study the micro direct ethanol fuel cell performance especially on the ethanol fuel consumption rate for applying with the portable electronic devices. The cell performance is specified in the terms of cell voltage, cell current and power of the cell for room operating conditions. The cell operating conditions are around 31–32 °C for the temperature, 1 atm for the pressure. The steady state time for collecting each data value is about 5–10 minutes. In this work that the power is limited not more than 10 watts for suitable with application to the portable electronic devices.

KEYWORDS: *Cell performance; Ethanol; Fuel cell; Fuel consumption; Portable electronic device*

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INTRODUCTION

Nowadays an increasing number of the population is going fast and the demand of energy is very much increased. Energy from fossil fuel is the one of the main energy to use today, which this energy causing the environmental pollutants and tend to cost more. It has a chance to expire in the near future. We can't deny that we will not use energy because energy is essential for the lives of human beings the present and future. Presently, human realized about the importance of using renewable energy as clean and conserve the environment. For the renewable energy from the fossil fuels that it is guarantee that in the future also an alternative energy that we can be utilized. The man has invented an alternative energy many out suchenergy from the sun, water power from dams and not long ago we have anew alternative energy is called fuel cell. 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 are different from batteries in requiring a continuous source of fuel and oxygen or air to sustain the chemical reaction, whereas in a battery the chemicals present in the battery react with each other to generate an electromotive force (emf) [1]. Fuel cells can produce electricity continuously for as long as these inputs are supplied. The first fuel cells were invented in 1838. Since then, fuel cells have been used in many other applications. Fuel cells are used for primary and backup power for commercial, industrial and residential buildings and in remote or inaccessible areas. They are also used to power for small electric appliances, and also for vehicles. There are many types of fuel cells, but they all consist of an anode, a cathode, and an electrolyte that allows positively charged hydrogen ions (or protons) to move between the two sides of the fuel cell. 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]. 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 startup time ranging from 1 second for proton exchange membrane fuel cells (PEM fuel cells, or PEMFC) to 10 minutes for solid oxide fuel cells (SOFC). In the present that the fuel cells are divided into 9 types [2] also 1. Alkaline Fuel Cell (AFC) 2. Phosphoric Acid Fuel Cell (PAFC) 3. Molten Carbonate Fuel Cell (MCFC) 4. Solid Oxide Fuel Cell (SOFC) 5. Proton Exchange Membrane Fuel Cell (PEMFC) 6. Regenerative Fuel Cell (RFC) 7. Direct Alcohol Fuel Cells (DAFCs) that divided into 2 typesinclude 8. Direct Methanol Fuel Cell (DMFC) and 9. Ethanol Fuel Cell (DEFC).

As a fuel cell is used hydrogen gas as fuel so it is relatively high price equipment to store hydrogen. The fuel cell that using hydrogen as fuel which including a Proton Exchange Membrane Fuel Cell or PEMFC 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 2 types of alcohol fuel cell that are: 1. Direct Methanol Fuel Cell (DMFC) and 2. Ethanol Fuel Cell (DEFC). Previously a lot of research focuses on the study and development of Direct Methanol Fuel Cell (DMFC). 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 DMFCs or Direct Methanol Fuel Cell 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 energyqualified by the volatile and highly flammableuse 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. Ethanol is less toxic and has higher energy density. Also can produced from biological processes in agriculture which is great energy [6]. Ethanol can be obtained in great quantity from biomass through a fermentation process from renewable resources like from sugar cane, wheat, corn, or even straw. Bio-generated ethanol (or bio-ethanol) is thus attractive since growing crops for biofuels absorbs much of the carbon dioxide emitted into the atmosphere from fuel used to produce the biofuels, and from burning the biofuels themselves. This is in sharp contrast to the use of fossil fuels. 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 quicklyso 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 × 115 mm × 102 mm that can produce the electric power about 102 W for operations more than 3600 hours [8].

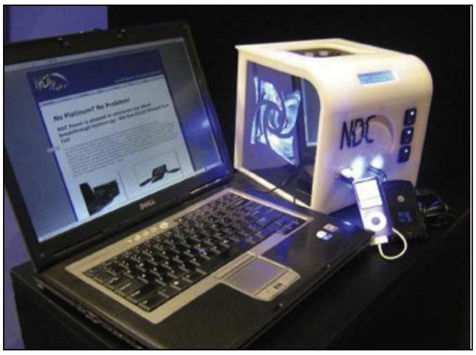


Fig. 1 Direct ethanol fuel cell, DEFC [9].

Ethanol also remains the easier fuel to work with for widespread use by consumers. Ethanol is a hydrogen-rich liquid and it has a higher specific energy (8.0 kWh kg^{-1}) compared to methanol (6.1 kWh kg^{-1}). The objective of this research is to study the micro direct ethanol fuel cell performance especially on the ethanol fuel consumption rate for applying with the portable electronic devices. The cell performance is specified in the terms of cell voltage and power density at any specific current density for several operating conditions. In this work that the power is limited not more than 10 watts for suitable with application to the portable electronic devices. The accuracy of the experimental results will be compared with the theoretical calculations.

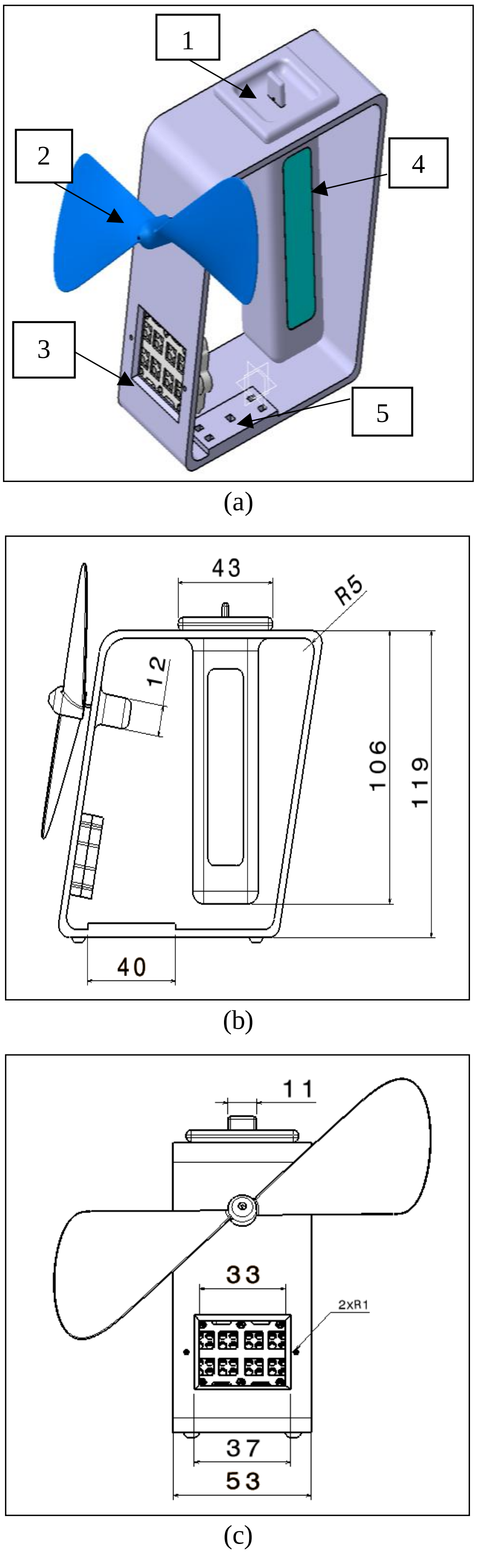
MATERIALS AND METHODS

Apparatus and method for testing the performance of Micro-DEFC

This research is to study the micro direct ethanol fuel cell performance especially on the ethanol fuel consumption rate for applying with the portable electronic devices as power less than 10 watts. The experimental apparatus was setting to study the effect of ethanol consumption rate on the fuel cell performance at different ethanol concentrations. There are the ratios of ethanol equal to 3, 5, 7, 9, 11, 13 and 15 milliliters in 60 milliliters of water, respectively.

Experimental apparatus

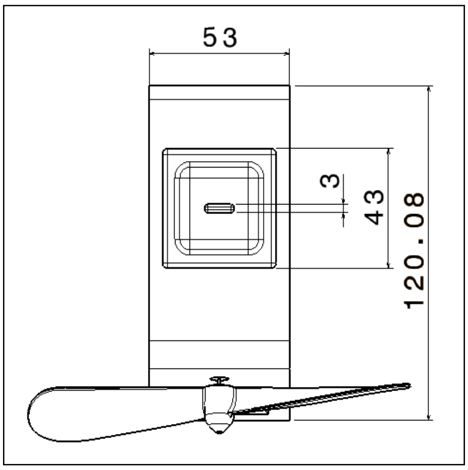
The experimental apparatus are (Micro-DEFC), ethanol fuel 95 % by volume, pure water, cylinder size equal to 100 ml, syringe solution size equal to 10 ml and paper measure acid-alkaline or PH paper.



(a)

(b)

(c)



(d)

Fig. 2 (a) Direct ethanol fuel cell, DEFC (b) Drawing front view (c) Drawing side view (d) Drawing top view.

The details on the Figure 2 are : 1. Lid set (Micro-DEFC), 2. Vane set (Micro-DEFC), 3. Membrane (MEA), 4. Set structure (Micro-DEFC) ,5. Cylinder Solution. Bio-energy feed ethanol set 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.

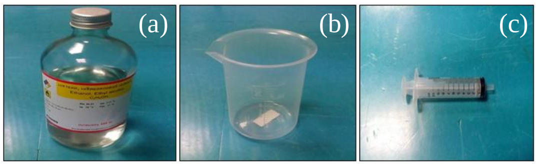


Fig. 3 (a) Ethanol 95 % by volume, (b) Cylinder solution100 ml., (c) Syringe solution size 10 ml.

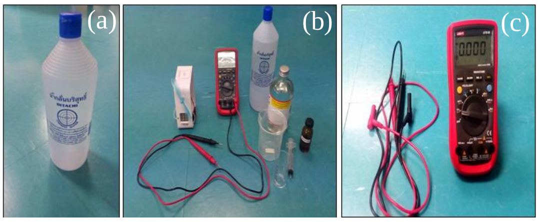


Fig. 4 (a) Pure water, (b) Direct ethanol fuel cell set, DEFC, (c) Digital multi-meters.

Theoretical calculations

Calculate density of electricalcurrent

The rules of ideal gas from equation of state that is the relation between number of moles (N) and volume (V). [10]

$$PV = NRT \qquad (1)$$

P =Pressure (Pa), V =Fuel feed rates (mm^3/min), N =Number of moles (mol s^{-1}) R = Universal gas constant = 0.082 (m^{3}atm kg mol k^{-1}), $T = 0$ (C^0) or 273 (K)

When lateral move (N) to get number of moles to represent the following equation to determine density of electrical current (i),

$$N = \frac{PV}{RT} \qquad \text{(mol s}^{-1}\text{)} \quad (2)$$

The density of electrical current (i) from recipe hydrogen 1 mole can transfer 2 electrons so flow rate of hydrogen gas can calculate from (3) [3].

$$N_{H_2} = \frac{i}{2F} \qquad \text{(mol s}^{-1}\text{)} \quad (3)$$

i = Density of electric current (A m^{-2}), F = Faraday constant = 9.64853 × 10^4 (C mol^{-1}) Oxygen 1 mole can transfer 4 electrons 4 so flow rate of oxygen is

$$N_{O_2} = \frac{i}{4F} \qquad \text{(mol s}^{-1}\text{)} \quad (4)$$

When using air instead oxygen that the air flow rate can be calculated

$$N_{air} = \frac{i}{4F} x \frac{1}{0.21} \qquad \text{(mol s}^{-1}\text{)} \quad (5)$$

When moving forward look for (i) that density of electrical current is following equation (6)

$$i = N \cdot 2F \qquad \text{(A)} \quad (6)$$

Calculation the voltage

The voltage of single cell DEFC theory at feeding ethanol at 25 °C and 1 (atm) by the chemical reaction show the following. [11]

Anode: $C_2H_5OH + 3H_2O \quad 12e^+ + 12H^+ + 2CO_2$ (E^0_{anode} = 0.084 V) (7)

Cathode: $12e^+ + 12H^+ + 3O_2 \quad 6H_2O$ ($E^0_{cathode}$ = 1.229 V) (8)

Overall: $C_2H_5OH + 3O_2 \quad 3H_2O + 2CO_2$ (E^0_{cell} = 1.145 V) (9)

From fig. 5 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.

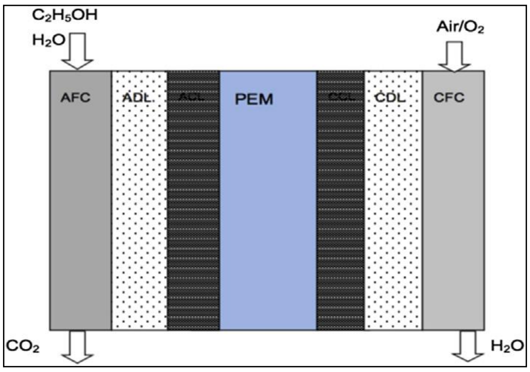


Fig. 5 The system of direct ethanol fuel cell (DEFC).

Calculate the voltage (V) in single cell DEFC for portable electronic devices [11] that show in equation (10) below,

$$E_{cell} = E^0_{cell} - n_{conc} - n_{ohmic} - n_{act} \qquad (10)$$

E_{cell} = Voltage of fuel cell (V)

E^0_{cell} = Voltage of fuel cell follow theory (V)

n_{conc} = Concentration of voltage loss related to kinetics of reaction

n_{ohmic} = Resistance loss (Ω)

n_{act} = Reaction of voltage loss involved to kinetics

Calculation concentration losses of voltagerelated kinetics of reaction

The move of substrate on anode catalyst layer and cathode catalyst layer resulting loss concentration inside the cell loss concentration calculation from equation at (11)[12],

$$n_{conc} = \frac{RT}{zF} In\left(\frac{I_{\lim}}{I_{\lim} - i}\right) \qquad (11)$$

$R =$ Universal gas constant = 8.314 (J g mol k^{-1}), $z =$ Number electrons in system.

While limitation of flow electric current show following equation [13],

$$I_{\lim} = Z_a F D_b^{eff} \frac{C_b}{L_b} \qquad (12)$$

$D_b^{eff} =$ Spread efficiency coefficient ethanol at anode, $C_b =$ Concentration of ethanol at anode (molar, M), $L_b =$ The width of flow channel anode (mm).

Calculation resistance loss (Ω)

$$\eta = iR_{total} \qquad (13)$$

$$R_{total} = \eta_{membr} + \eta_{contact} \qquad (14)$$

$$\eta_{membr} = \frac{l_m}{K_m^o} i \qquad (15)$$

$$\eta_{contat} = \frac{l_m + 2l_c}{K_s} \qquad (16)$$

Calculation reaction of voltage loss involved to kinetics

Calculation reaction of voltage loss involved to kinetics show following equation (17) [14],

$$\eta_{act,anode} = \frac{RT}{\alpha_a z_a F} \ln(\frac{i}{i_o}) \qquad (17)$$

$$\eta_{act,cathone} = \frac{RT}{\alpha_c z_c} \ln(\frac{i}{i_o}) \qquad (18)$$

From equation 10, so we can calculate the voltage (V) in DEFC single cell following,

$$E_{cell} = E_{cell}^0 - n_{conc} - n_{ohmic} - n_{act} \qquad (19)$$

$$E_{cell} = E_{cell}^0 - (\frac{RT}{z_a F} \ln(\frac{i \lim}{i \lim - i})) - (i(\frac{l_m}{K_m} + \frac{l_m + 2l_c}{K_s})_0) - (\frac{RT}{\alpha_a z_a F} \ln(\frac{i}{i_o}) + \frac{RT}{\alpha_c z_c F} \ln(\frac{i}{i_o}) \qquad (20)$$

Calculation flow rate of ethanol unite (molar, M) for electrochemical reaction

The ethanol fuel flow rate can calculate by equation 21,

$$n_i = \frac{i}{nF} \qquad (21)$$

$n_i =$ Flow rate of ethanol unite (molar, M), $i =$ Density of current (A), $n =$ Number electrons in system, $F =$ Faraday constant = 9.64853 × 10^4 (C mol^{-1}).

When flow rate of ethanol or n_i represent in equation at (22) that it will be flow rate of volume v_i following equation,

$$v_i = \frac{n_i M_i}{p_i} \qquad (22)$$

$v_i =$ Flow rate of volume (cm^3 h^{-1}), $n_i =$ Flow rate of ethanol unite (molar, M), $M_i =$ Molecular (g mol^{-1}), $\rho_i =$ Density of ethanol (g cm^{-3}).

Calculation total power

Electric power (P) can be calculate from following equation

$$P = VxI \qquad (23)$$

$P =$ Electric power (W), $V =$ Voltage (V), $I =$ Electric current (A).

After we know the cell voltage then we can calculate the efficiency of fuel cell from the ratio between actual electrical potential (E_{cell}) and electrical potential from the reaction between the ethanol and oxygen that show below.

Calculation performance of fuel cell

$$\eta_{actual,E} = \frac{E_{cell}}{E_{cell}^o} x100\% \qquad (24)$$

$\eta_{actual,E} =$ Performance actually of fuel cell (%), $E_{cell} =$ Voltage (V), E_{cell}^0 = 1.445 (V) [11].

Table 1 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	$J\ molK^{-1}$	
Effective diffusion coefficient of ethanol in diffusion layer D_{EtOH}^{d}	3.916 x 10^{-2}	cm^2s^{-1}	[15]
Void volume fraction of anode diffusion layer, ε^d	0.4		[16]
Electronic conductivity of solid phase (PtRu/C), K_s	8.13 x 10^{-6}	Scm^{-1}	[15]
Protonic Conductivity of ionomer, K_m	0.1416	Scm^{-1}	[15]
Anode transfer coefficient , α_a	0.089	cm^2	[15]
Cathode transfer coefficient , α_c	1.0	$A\ cm^{-2}$	[15]
Component parameters			
Oxygen density	1.141	$g\ cm^{-3}$	Fixed
CO_2 density	0.77	$g\ cm^{-3}$	Fixed
Ethanol density	0.785	$g\ cm^{-3}$	Fixed
Water density	1	$g\ cm^{-3}$	Fixed

RESULTS AND DISCUSSION

The experimental results on the micro direct ethanol fuel cell performance especially on the ethanol fuel consumption rate for applying with the portable electronic devices are shown below.The cell operating conditions are around 31–32 °C for the temperature (at room temperature), 1 atm for the pressure. The steady state time for collecting each data value is about 5–10 minutes. The experimental results are shown below in Table 2 and 3 and in figures 6, 7 and 8, respectively.

Table 2 The experimental data collection

Ethanol concentration (95 %) by volume(ml.)	Experimental results no.1			Experimental results no.2			Experimental results no.3		
	I (mA)	V (mV)	Power (mW)	I (mA)	V (mV)	Power (mW)	I (mA)	V (mV)	Power (mW)
3	11.33	0.6822	7.7268	11.257	0.6788	7.6406	10.029	0.647	6.495
5	10.256	0.6676	6.8508	11.8920	0.6484	7.7025	12.999	0.6716	8.7156
7	17.616	0.7926	13.9652	15.784	0.7234	11.4227	18.186	0.7564	13.754
9	17.243	0.7396	12.7706	14.504	0.7204	10.4485	15.358	0.7824	12.0419
11	17.428	0.731	12.7418	16.063	0.7252	11.6412	13.615	0.7134	9.7276
13	15.537	0.7706	11.9783	14.959	0.7304	10.9525	15.95	0.6996	11.1606
15	16.953	0.7414	12.5705	15.836	0.7012	11.1119	16.109	0.6748	10.8966

Note : Concentration is molar (molar, M). Molar shows number mole of solution 1 dm^3

Table 3 The average experimental data collection

Ethanol concentration(95%) by volume (ml.)	The average experimental results		
	I (mA)	V (mV)	Power (mW)
3	10.872	0.6693	7.2874
5	11.7157	0.6625	7.7563
7	17.1953	0.7574	13.0473
9	15.7017	0.7474	11.7573
11	15.702	0.7232	11.3702
13	15.482	0.7335	11.3638
15	16.2993	0.7058	11.5263

From the experimental results noted that increasing the concentrations of ethanol by volume, at the ratios of ethanol equal to 3, 5, 7, 9, 11, 13, 15 milliliters in 60 milliliters of water that the performance specified by current production, voltage production and the power of the fuel cell are continually rapid increasing from the ratio of ethanol equal to 3, 5, 7 milliliters in 60 milliliters of water. After that the performances are gradually drop. If the concentration of ethanol are less than 3 milliliters or more then 15 millilitersin 60 milliliters of water that the fuel cell set cannot produce the cell voltage and cell current (produce little value that cannot measure).

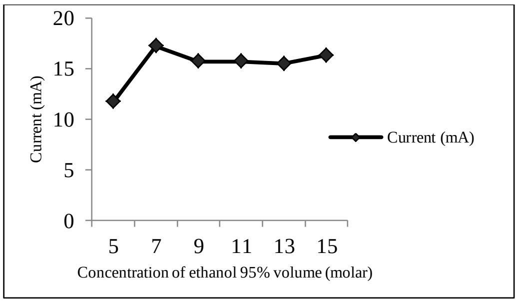


Fig. 6 Effect of ethanol fuel concentration on the fuel cell current.

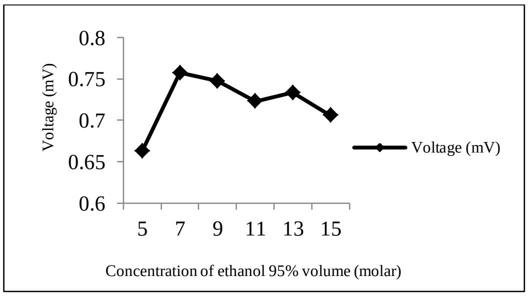


Fig. 7 Effect of ethanol fuel concentration on the fuel cell voltage.

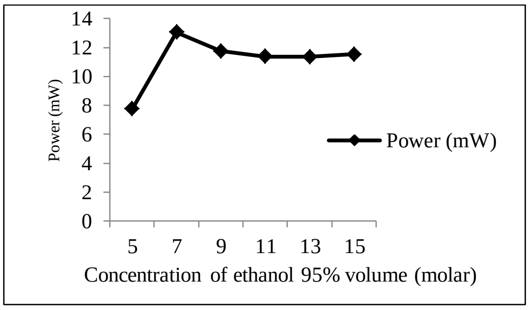


Fig. 8 Effect of ethanol fuel concentration on the fuel cell power.

With the increasing of concentrations of ethanol by volume, the reactant concentration at the reaction sites increases so the electrochemical rate also increasing but when it reaches the saturated point the performances are gradually drop. From table 3 or the average experimental data collections from table 2 that the maximum current production, maximum cell voltage and maximum power of fuel cell are 17.1953 mA, 0.7574 mV and 13.0473 mW, respectively. The maximum cell performance values are occurred at the ratio of ethanol equal to 7 milliners in 60 milliliters of water.

CONCLUSION

The experimental apparatus on the micro direct ethanol fuel cell for predicting the cell performance has been set. The objective of this research is to study the micro direct ethanol fuel cell performance especially on the ethanol fuel consumption rate for applying with the portable electronic devices. The cell performance is specified in the terms of cell voltage, cell current and power of the cell for room operating conditions. The cell operating conditions are around 31–32 °C for the temperature, 1 atm for the pressure. The steady state time for collecting each data value is about 5–10 minutes. With the increase of concentrations of ethanol by volume, the reactant concentration at the reaction sites increases so the electrochemical rate also increase but when it reaches the saturated point the performances are gradually drop. From the average experimental data collections that the maximum current production, maximum cell voltage and maximum power of fuel cell are 17.1953 mA, 0.7574 mV and 13.0473 mW, respectively. The maximum cell performance values are occurred at the ratio of ethanol equal to 7 milliners in 60 milliliters of water. At the concentration of ethanol are less than 3 milliliters or more then 15 milliliters in 60 milliliters of water that the fuel cell set cannot produce the cell voltage and cell current (produce little value that cannot measure).

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