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THE EFFECT OF CURRENT DENSITY PEMFC TO WATER LIQUID FORMATION IN CATHODE

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ABSTRACT

A Proton Exchange Membrane Fuel Cell (PEMFC) is developed as a potential solution in power supply applications. Performance of PEMFC was depicted by current density and voltage. The water liquid content in PEMFC depends on several factors. Current density is one of factors that affect water liquid formation in PEMFC. This study aimed to know the influence of current density of water liquid formation in Cathode. The result was shown that at temperature from 303 K to 333 K, the water liquid formation was small at higher current density. At current density above 1Acm^{-2}, it makes little difference of water liquid content. Increasing the temperature (about 343 K) will decrease the performance of PEMFC, which is Relative Humidity Cathode (RHC) 50% and the Relative Humidity Anode (RHA) 90 %.

Keywords: current density, water formation, cathode, PEM fuel cell.

1. INTRODUCTION

One of the important problems in the operating PEMFC is the water management in the stack fuel cell [1], and to achieve the performance of the optimal fuel cell, it is necessary to balance water in a stack fuel cell to ensure that the membrane remains in a hydrated state, not of flooding on the cathode side and prevent the occurrence of dehydration at the anode [2-5]. Water content in the membrane is determined by the balance between water produced and water transport processes such as: electro-osmotic drag than water (EOD) related to the transfer of protons through the membrane, back diffusion from the cathode, the diffusion of water to or from the flow of oxidant or gas fuel. The operating system on the PEMFC is very important to get the water balance of the membrane can be in PEMFCsystem so that optimum system performance can be achieved [1, 6-7]. PEMFCsystem must operate at conditions where the water produced in the stack cannot be on a faster evaporation. The purpose is to keep the membrane is not in dry conditions. This condition can be achieved if the temperature PEMFC systems generally cannot be more than 100 ^{0}C [8].

Mass balance of water in the system stack must be known precisely, this can be done with good control with the presence of water in the PEMFC. Management of water content which is not good in PEMFCsystem can cause low water content. Besides that, the presence of liquid water on the cathode side of the fuel cell resulted in a decrease in the amount of oxygen for the reaction in the catalyst layer [9-11]. High content of water in the membrane caused the flooding in fuel cells tack [12-13]. Water content in the PEMFC is a contradiction. One side is needed to ensure good proton conductivity of the membrane, and the other side may block proton access to the catalyst surface [14-17]. Water content in the membrane is determined by the balance between water produced with water transport on the system.

The condition for control membrane PEMFC system is in hydrated condition that can use a humidifier. Humidifier function is to humidify the reactant gas before it flows into the PEMFC. Reactant gas humidification affect system performance increase produced PEMFC[18-19].

Flooding in the stack influence the decrease of the current density produced, and resulted in a decrease in the performance of PEMFC system [7, 20-21].Flooding phenomenon can occur on both sides of the electrodes (anode and cathode), but flooding on the cathode is important because it involves the oxygen reduction reaction produces water[22-23]. Liquid water flowing from the cathode to form in the RHC value from 40% to 92% and an operating temperature is from 343 to 363 K.In this condition the concentration of liquid water flowing out of the cathode decreases with an increase in the RHC[8]. Focus this study is the effect of the current density of performance and water liquid formation that out from the cathode side. This situation is conducted in a variety of different operating conditions of temperature and relative humidity value difference PEMFC stack system. Design process PEM fuel cell system is continued study by Mulyazmi [8].

2. MATERIALS AND METHODS

a) Desain concept

PEMFC system performance described by the current density and voltage, and is influenced by many factors. One factor is the water content in the membrane PEMFC. Water flowed into the cells to get enough water content using a variety of methods such as injection liquid, gaseous reactants flowing through the humidifier before flowing into the PEMFC. In this study, the method used is to add an external humidifier to humidity reactant gas before it flows into the cell as shown in Figure1. External humidifier used in this system is a membrane humidifier type.This type requires heat to generate steam to reach an appropriate humidity. membrane humidity in this study performs two functions.

ARPN Journal of Engineering and Applied Sciences

The first function is to moisten hydrogen before flowing into the anode side of the membrane humidifier I (MH1). The second function is to moisten the oxygen before flowing into the cathode side of the membrane humidifier II (MH2). The component out of side of the anode is a hydrogen and air (vapor phase and liquid). These components can be reused as a reactant and is fed into the anode side.

Before hydrogen flow to the PEMFC, must be humidified in MH1. Water vapor is used to control the humidity of hydrogen comes from water vapor that flows out from the cathode side.Water vapor is is useful to humidify the hydrogen coming from the cathode output. Component flowing out of the cathode consists of water (vapor phase and liquid), oxygen and nitrogen.Waste water vapor that flows out of MH1 is used to humidify the oxygen before the oxygen flow to the cathode side of the MH2.The water content of the membrane depends on several factors, such as relative humidity of the reactants on the anode side and cathode side, the temperature and pressure, and the stoichiometric ratio of hydrogen and oxygen. This study is also to determine the relationship of the operating conditions of PEMFC performance and its impact on the formation of liquid water flowing out cathode.The basis for determining the concentration of reactants on the PEMFC system has been described by mulyazmi [8], and used later to determine the concentration of related design PEMFC system. The amount of liquid water that comes out of both sides of the PEMFC includes all incoming and water produced by the PEMFC. The concentration of the water coming out of the side of the anode and the cathode including the concentration of water to go with the hydrogen gas that flows into the anode, the concentration of water vapor which moves on EOD event and concentration in water back diffusion from the cathode side to the anode side.

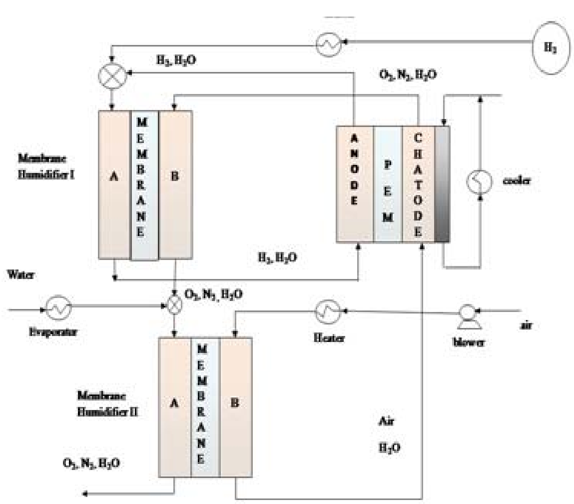

Figure-1. Process PEMFC system with direct hydrogen.

b) Mass balance of PEMFC system

The amount of liquid water that comes out of both sides of the PEMFC includes all incoming and water produced by the PEMFC. The concentration of water out of the anode side($\mathcal{N}_{H_2O\,out\,anode}$) and the cathode side($\mathcal{N}_{H_2O\,out\,chatode}$) including the concentration of water that come with the hydrogen gas that flows into the anode side, the concentration of water vapor which moves in the EOD and the concentration of water in the back diffusion from the cathode side to the anode side. The amount of water vapor in the hydrogen $\mathcal{N}_{H_2OinH_2}$ supplied flows into the anode side is defined as follows:

$$\mathcal{N}_{H_2OinH_2} = \mathcal{S}_{H_2} \cdot \mathcal{N}_{H_2} \cdot \eta_{cell} \cdot \frac{\varphi . P_{V_S}}{P_a - \varphi . P_{V_S}} \quad (1)$$

The amount of water vapor in the oxygen supplied into the cathode side is defined as follows:

$$\mathcal{N}_{H_2O in\, O_2} = \frac{s_{O_2}}{4F} i . \eta_{cell} \frac{\varphi . P_{V_S}}{P_a - \varphi . P_{V_S}} \quad (2)$$

The maximum amount of water vapor that flows out of the anode and cathode are assumed to have a relative humidity of 100% with no significant pressure drop. The concentration of water vapor at a relative humidity of 100%, which flows out of the anode and cathode are defined as follows:

$$\mathcal{N}_{H_2O in\, H_2,out} = \mathcal{N}_{H_2 unreac} \cdot \eta_{cell} \cdot \frac{P_{sat}}{P - . P_{sat}} \quad (3)$$

The concentration of water vapor in oxygen at 100% relative the humidity are as follows

$$\mathcal{N}_{H_2O\ in\ air,out} = \mathcal{N}_{air,out} \eta_{cell} \frac{P_{sat}}{P - . P_{sat}} \quad (4)$$

Where:$\mathcal{N}_{H_2OinH_2,out}$ is the concentration of water vapor that flows out of the anode side (mol). $\mathcal{N}_{H_2Oinair,out}$is the concentration of water vapor flowing out of the cathode side (mol). The number of protons that move from the anode side to the cathode side of the EOD$\mathcal{N}_{drag}$can be calculated using the following equation[24-26]:

$$\mathcal{N}_{drag} = \frac{n_d}{F} i \quad (5)$$

$n_d$can be defined using the following equation:

$$n_d = \frac{2.5\ \lambda pem}{22} \quad (6)$$

λpem is the water content of the membrane. The water content of the membrane can be calculated using the following equation:

$$\lambda = 0.0043 + 17.81 a_{H2O} - 39.85\ a_{H2O}^2 + 36 . a_{H2O}^3$$
$$0 < a_{H2O} \leq 1 \quad (7)$$

By Hassan [1]the water diffuse from the cathode side to the anode side are as follows

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ARPN Journal of Engineering and Applied Sciences

$$J_w = k_g(y_a - y_c) \tag{8}$$

The concentration of water vapor that flows out of the anode is as follows:

$$\mathcal{N}_{H_2Ooutanode} = \left(\mathcal{S}_{H_2} \cdot \mathcal{N}_{H_2} \cdot \eta_{cell} \cdot \frac{\varphi . P v_s}{P_a - \varphi . P v_s} - \frac{n_d(x) I(x)}{F}\right) + k_g(y_a - y_c) \tag{9}$$

The concentration of water vapor that flows out of the chatode is as follows:

$$\mathcal{N}_{H_2Ooutchatode} = \left(\mathcal{S}_{O_2} \cdot n_{cell} \frac{\mathcal{N}_{O_2}}{XO_2} \frac{\varphi . P v_s}{P_c - \varphi . P v_s} + \frac{\mathcal{N}_{H_2supply}}{\mathcal{S}_{H_2}} + \frac{n_d(x) I(x)}{F}\right) - k_g(y_a - y_c) \tag{10}$$

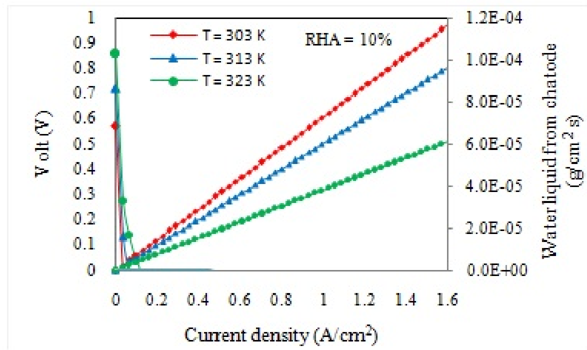
3. RESULTS AND DISCUSSION

a) Water liquid out of chatode

The amount of liquid water flowing out of the anode and cathode side in relation to the performance of PEMFC generated. The conditions of operation used in PEMFC involving the RHA and RHK from 0 to 100%, the current density of 0.1 Acm^2 to 0.9 Acm^2, the stoichiometric ratio of hydrogen 1.2 and oxygen is 2, and the pressure on the anode side the cathode is 1atm. The following are some of the effects of operating conditions on the formation of liquid water flowing out of PEMFC.

Figure-2 shows that the performance of the PEMFC increased at higher operating temperatures. This is shown by the increasing voltage at a constant current density.Increased temperature PEMFC affect decrease the amount of liquid water flowing out of the cathode side.This occurs because the the increase in cell temperature causes an increase in the amount of water in the vapor phase to achieve 100% relative humidity.As a result, the water in the liquid phase flowing out of the cathode decreases at higher operating temperatures.Increasing the RHA to increase the amount of liquid water flowing out of the cathode side.This occurs because the the RHA and resulted in improved performance of PEMFC insignificant. This situation can occur when the RHA increased from 10% to 90% at 323 K, which causes maximum current density increased from 0.13 A cm^2 to 0.19 A cm^2.

Increase the performance of the PEMFC is shown by the increase in the amount of water vapor moved along with the proton on EOD phenomenon. Increase performance resulted in an increase in the amount of water produced by the reaction.At the RHA 10%, liquid water formed and flow out of the cathode side at a temperature in the range of 303 K to 323 K. Water flowing out of the cathode is in the vapor phase when the temperature is above 323 K. Increase the RHA resulted in an increase in liquid water.This behavior can be observed in the RHA 50% and 90%. In this case, the liquid water occurs at a temperature of 303 K to 333 K. If temperatures above 333 K, the water flowing out of the cathode is in the vapor phase.Current density for all operating conditions indicate that liquid water produced values tend to be the same even if there are differences in the RHC. although the RHA varies, the current density at each temperature operation is likely to be the same.Liquid water on the RHC 90% and a temperature of 333 K lower than at temperatures below 333 K. liquid water flowing out of the cathode side is higher when the voltage is 0 V and the current density is at a great value.



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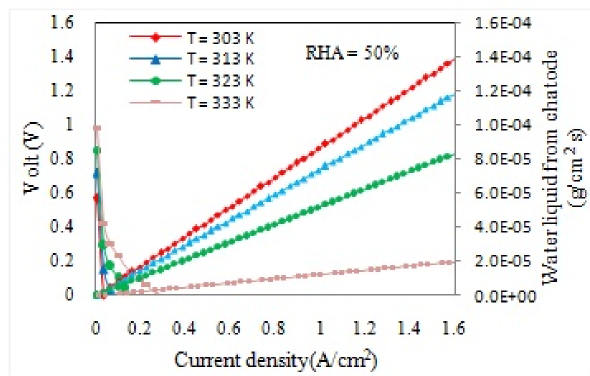

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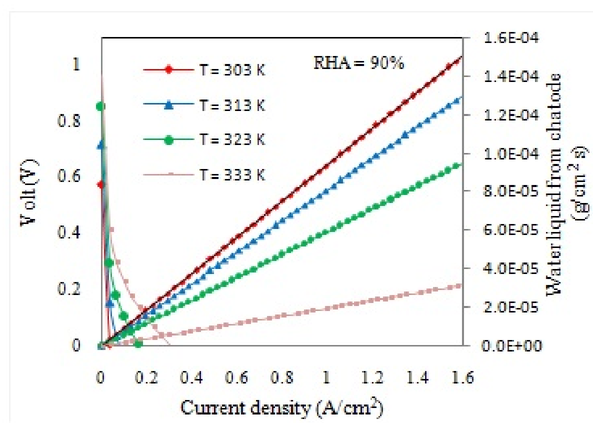

(c)

Figure-2. The relationship between the performance and liquid water from the cathode at RHC=10%: (a) RHA =10%, (b) RHA=50% and RHA= 90%.

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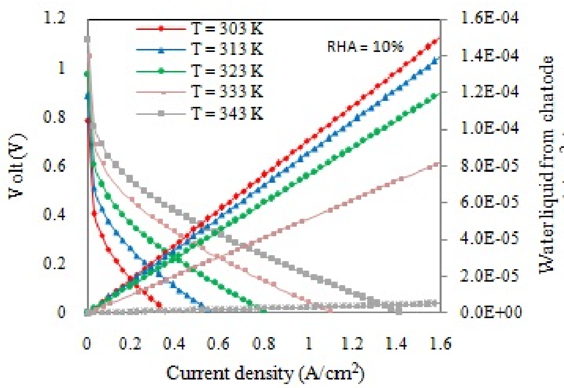
Figure-3 shows the performance of the PEMFC to the formation of liquid water at RHK 50%. At the RHA in the range of 10% to 90% and the temperature PEMFC from 303 K to 343 K, so the formation of liquid water. Increasing the RHA will cause an increase in liquid water flowing out of the cathode side significantly. Increasing the amount of water also resulted in a decrease in performance PEMFC.



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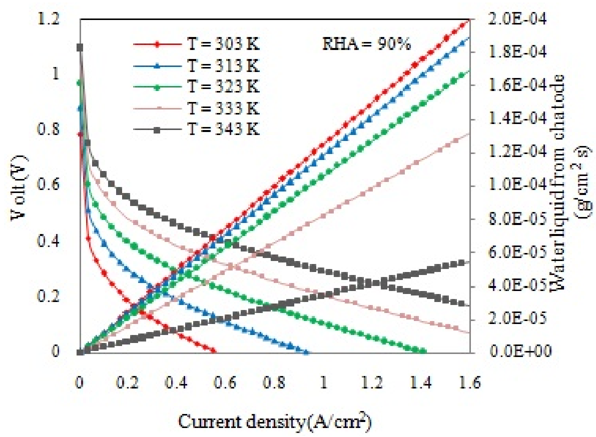
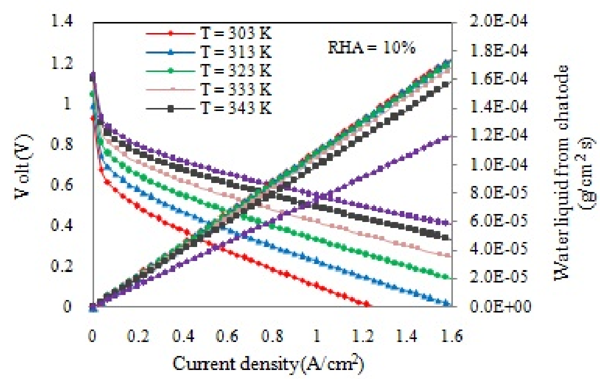


(b)

Figure-3. The relationship between the performance and liquid water from the cathode at RHC=50%:(a) RHA =10%, (b) RHA= 90%.

Increase the operating temperature PEMFC resulted in a decrease in the amount of liquid water flowing out of the cathode side.At a temperature of 303 K to 333 K, an increase in operating temperature increases the performance of the PEMFC.The increase in operating temperature below the current density of 0.6 A cm-2 causes a slight increase in the amount of liquid water formed.Whereas at a temperature of 333 K and 343 K show an increase in the amount of liquid water formation. this is shown by the increase in the voltage and current density.

Figure-4 shows that the formation of liquid water occurs at RHK 90% and temperature PEMFC from 303 to 363 K.PEMFC performance improvement especially at temperatures of 303 K to 333 K. to a temperature of 333 K, PEMFC performance improvements occur insignificant. At the RHA 10% performance PEMFC little different at 343 K and 353 K, and the RHA 50% more likely to have the same value, while at the RHA 90% have the same value at 353 K and 363 K and the similar pattern at 343 K.This condition indicates that the increase in value of RHA, RHK and is not effective in improving PEMFC.When the RHA is 10%, 70% and 90% and temperature PEMFC is 303 K, 313 K and 323 K, then the amount of liquid water flowing out of the cathode is the same.PEMFC at temperatures of 343 K and 353 K with RHA 90%, the amount of water on the cathode side is equal to the current density below 1 Acm^2.if the current density above 1 Acm^2, there was little difference in the amount of liquid water.The amount of liquid water flowing out of the cathode side that has the same value and showed that there were no increase in the amount of water on the cathode side.This is because there is no further increase in the reaction of hydrogen with oxygen as a result of water formed being fixed in PEMFC stack.



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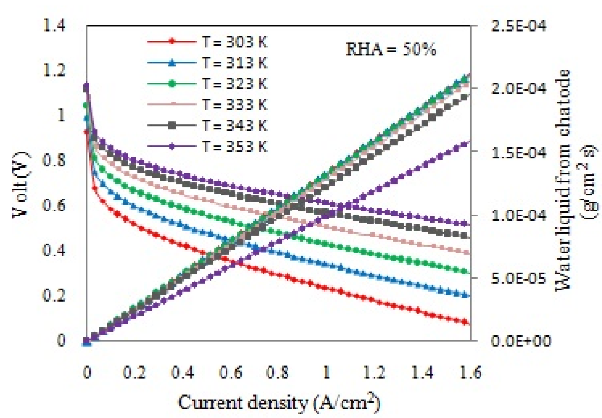

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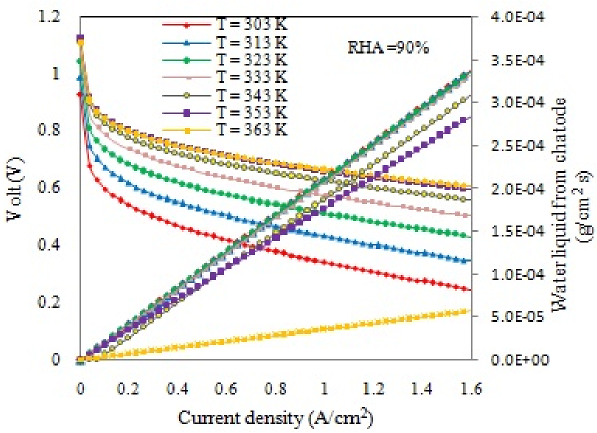


(c)

Figure-4. The relationship between the performance and liquid water from the cathode at RHC=90% :(a) RHA =10%, (b) RHA= 90%.

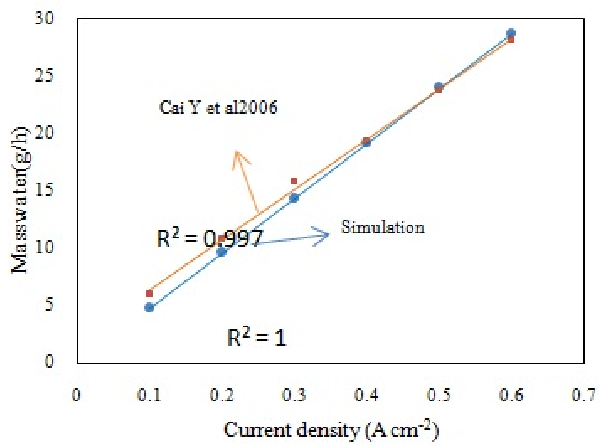
b) Validation

Results of this research compared with experiments conducted by Cai *et al*. (2006) and Karmik (2006). Figure-5 shows the results obtained are likely to be similar. Figure-5a shows the relationship of the current density of the mass of water flowing out of the cathode side.The system operating conditions shown in Table-6.1.The increase in current density PEMFC cause an increase in the mass of water flowing out of the cathode side. The results of the simulation compared with experimental Cai has seen a similar trend and in Figure-5 (a).Under the current density of 0.4 A cm-2 showed that a slight difference in mass of water flowing out of the cathode side, while above 0.4 the mass of water flowing out of the cathode is likely the same. One factor is the performance difference is generated. The higher the performance of the produced water is increasing.

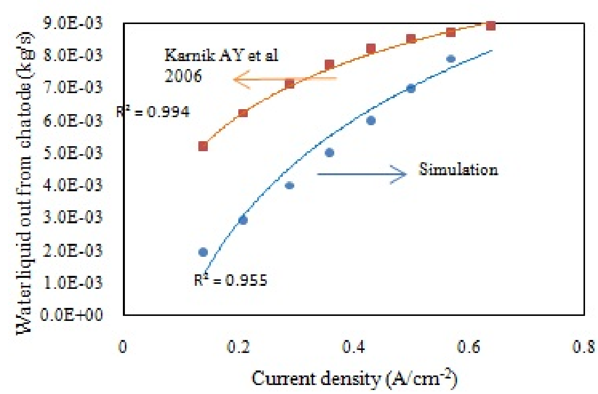
Table-1. Parameters experiment by Cai Y and Karnik A.Y.

Parameter	Cai Y	Karmik A.Y
Relative humidity at the chatode (RHC)	75%	0
Relative humidity at the anode (RHA)	56%	100%
Anode side presure (PA)	2 atm	1.3 atm
Chatode side presure (PK)	2 atm	1.3atm
Current density (i)	0.1-0.6 A cm^2	0.1-0.6 A cm^{-2}
Cell temperature (T)	333 K	353 K
Stoikhiometri ratio for hidrogen	1.1	2
Stoikhiometri ratio for oksigen	2.5	2
Active area MEA	128 cm^2	280 cm^2

Figure-5 (b) is the result of research studies conducted by Karmik.This figure shows the relationship between the current density and the amount of liquid water produced at the cathode.Data used for system operation conditions shown in Table-6.1.Increasing the current density led to rising water liquid water produced at the cathode side.The results of this study showed similar trends between the increase in the current density of the liquid water produced at the cathode side.The increase in current density causes the amount of liquid water produced similar trends.This is reflected in a high density, which increases the mass of liquid waterthe increase is not too high in fact almost the same.Besides, the results of this study show that the simulation results are lower amount of liquid water produced compared to research conducted by Karnik.



(a)



(b)

Figure-5. Compare water liquid from chatode used simulation with (a) Karnik A.Y *et al.* 2006 (b) Cai Y *et al.* 2006.

4. CONCLUSIONS

- Increase the RHC,a causes a decrease the liquid water flowing from the anode side and increase liquid water from of the cathode side.
- Increase the RHC resulted in an increase in the voltage. While the appreciation of the RHA does not

lead to a significant improvement of the performance of PEMFC.

- The liquid water occurs at a lower RHC value, if the operating temperature PEMFC decreased from 363 K to 323 K,

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