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The Effect of Increasing Catalyst Concentration of Fabricated Hydrogen Generator on Proton Exchange Membrane Fuel Cell Performance.

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Abstract. Hydrogen can be utilised through a Proton Exchange Membrane Fuel Cell (PEMFC) which has many advantages, namely more energy yield, higher energy density, no emissions, and no need for recharging compared to using batteries. The highest electrolyzer efficiency results were found on the 0.05M KOH catalyst with a value of 1.70% and it can be concluded that the higher the catalyst concentration, the higher the electrolyzer efficiency. The highest power density and fuel cell efficiency quality is found in the 0.05M NaCl catalyst but with the lowest Specific Fuel Consumption (SFC) of 0.62 kg/kWh, this indicates that the relationship between concentration and power density and fuel cell efficiency is directly proportional while it is inversely proportional to Specific Fuel Consumption (SFC). The best Break Even Ratio value is found in the NaCl catalyst type 0.05 with a value of 0.082. The use of a seawater catalyst has the highest efficient value at a percentage of 100% with electrolyzer efficiency reaching 13.36% and the lowest SFC, namely 0.24 kg/kWh. Based on these results, the use of hydrogen generators for Proton Exchange Membrane Fuel Cells (PEMFC) needs to be developed.

Keywords: catalyst, efficiency, hydrogen, SFC, PEMFC

1. Introduction

Batteries as energy storage are still not able to store large amounts of electricity in a small mass or volume (low energy density), can cause emissions in the form of Carbon, Cobalt, and Lithium which can pollute the soil and disturb health, and need to be recharged. Therefore, it is necessary to utilize other superior energy storage, one of which is Hydrogen. The use of Hydrogen in storage is widely used for stationary fuel cells including electricity, internal combustion engines, and fuel cell vehicles. Hydrogen produces more energy with a much higher energy density than other energy storage media. If a system has a high energy density, it can store a lot of energy in a small amount of mass. Hydrogen as an energy conversion has no emissions because it is processed through electrolysis with a by-product of water. Hydrogen also does not require refills and will not run out as long as it always has a supply. Hydrogen is the most abundant gas at around 75% of the total mass of the sun [1]. Under normal circumstances on Earth, Hydrogen is in the form of diatomic gas consisting of 2 atoms with the symbol H2. Most of the Hydrogen on Earth is in the form of compounds with other elements such as hydrocarbons and water. Therefore, Hydrogen gas needs to be separated from its compounds before being utilized. One method to produce Hydrogen gas using Green Hydrogen is by electrolysis of water.

Electrolysis of water is the decomposition of water compounds (H2O) into Hydrogen (H2) and Oxygen (O2) gases using electric current [2]. The production of Hydrogen gas from the electrolysis process occurs in the Hydrogen Generator and one of them depends on the use of the type and concentration of catalyst. Catalysts function as substances that can increase the rate of chemical reactions but do not react.

Several previous studies have been conducted related to the use of variations in KOH catalyst concentration and input current resulting in the highest amount of Hydrogen gas production at a concentration of 2M with a 20A current of 189.3 ml and the highest efficiency of 93.5% [3]. Other research using NaOH and NaCl catalysts where research shows that H2 gas production with the highest concentration is obtained in aqua DM + NaCl + NaOH catalyst with a voltage of 12 volts 4500 ppm [4].

Utilisation of Hydrogen produced from the electrolysis process is then flowed to the fuel cell to be converted into electrical energy. Fuel cell is a converter of energy obtained from the electrochemical process converted into electrical energy. Fuel cell is one of the best technologies applied because it comes from an environmentally friendly fuel source, Green Hydrogen, does not produce emissions because of the by-products in the form of water, and higher energy density than other energy conversions such as batteries or batteries [5]. The use of fuel cells in this era must be done considering the world is facing two crises, namely dwindling fossil fuel sources and global climate change [6]. One type of fuel cell, namely Proton Exchange Membrane Fuel Cell (PEMFC), can be an option because of its low operating temperature in the range of 40℃ to 100℃, does not produce emissions that affect the number of pollutants, and has a long stack life [7]. Proton exchange membrane fuel cells (PEMFC) produce water and heat energy as by-products while the resulting electrons (e-) are used as electrical energy [8]. Proton Exchange Membrane Fuel Cell (PEMFC) only requires Hydrogen and Oxygen from air and water so that it is not corrosive. In addition, it can operate at low temperatures, operate quickly, the heating time is low, so it has high durability [9].

Hydrogen fuel cell applications have been stated to be tested in several books, Csala Danes [10], utilising fuel cells as a crossing motorboat design where fuel cells are used as one of the drivers of hybrid ships. [11] also wrote that fuel cells can be used as lighting on fishing boats to reduce the work of generators then obtained the results of fuel cell power using 250gram electrolytes producing 122.24 wh. A very recent application of fuel cell technology is the fuel cell trial on a Yanmar ship in Oita, Japan on 25 March 2021 [12]. Based on the description above, it is necessary to conduct research to design and fabricate Hydrogen Generators for Proton Exchange Membrane Fuel Cell (PEMFC) and test variations in catalyst type and concentration. In this study using KOH, NaCl, and NaOH catalyst types with catalyst concentrations of 0.01M; 0.02M; 0.03M; 0.04M; and 0.05M to see the results of Hydrogen production quantity and quality of electrical energy produced.

2. Methods

The research was conducted at the Fluid Laboratory of Surabaya State Shipbuilding Polytechnic with experimental research methods and carried out on a laboratory scale. The implementation starts from preparing control data including electrolysis time for 6 minutes, electrolyte in the form of 1 litre distilled water, electrodes on the Hydrogen Generator using stainless steel on the anode and Copper (Cu) on the cathode with the shape of a rectangular plate (15cm×4cm×2mm), the number of anode and cathode arrays of 6 plates each, the incoming power of the Hydrogen Generator 30 Watt, the lamp loading is set. Materials for making Hydrogen Generator for Proton Exchange Membrane Fuel Cell (PEMFC) were also prepared including electrodes, long dart, reactor tube, storage tube, filtration tube, and other supporting materials. The experimental test phase is carried out by conducting tests on each variation of the Hydrogen Generator. The fabricated circuit of Hydrogen Generator for Proton Exchange Membrane Fuel Cell (PEMFC) is described in Figures 1 and 2.

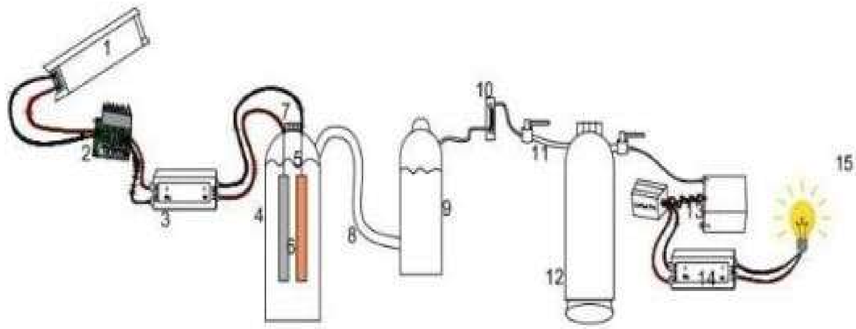


Fig. 1. Schematic of Prototype Hydrogen Generator for PEMFC.

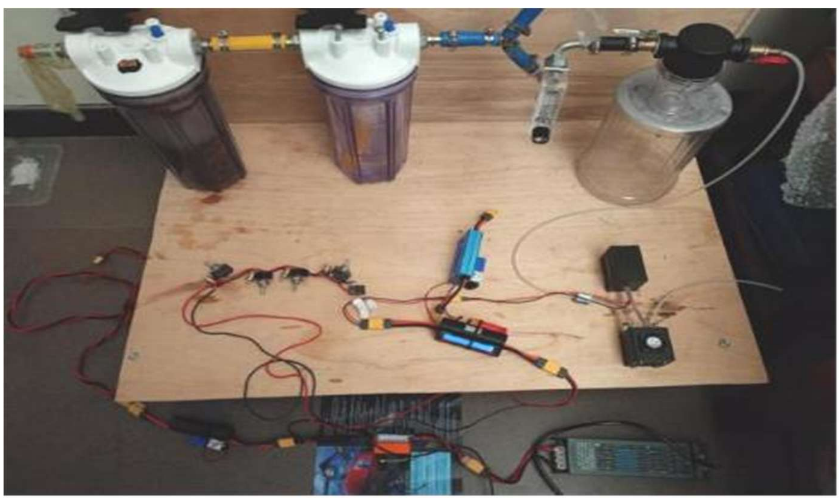


Fig. 2. Prototype Generator Hydrogen for PEMFC

In this study, variations were made in the use of catalyst types, namely KOH, NaCl, and NaOH and variations in catalyst concentrations, namely 0.01M; 0.02M; 0.03M; 0.04M; and 0.05M. The combination of variations becomes 15 types. The variations were then experimented and obtained data on the quantity of Hydrogen gas production rate produced in the Hydrogen Generator and then flowed to the fuel cell to be converted into electrical energy and identified the resulting power density. The calculations carried out include the Hydrogen gas production rate, power density, SFC, and electrolyser efficiency and fuel cell efficiency in the Hydrogen Generator for Proton Exchange Membrane Fuel Cell (PEMFC).

3. Result and Discussion

The Hydrogen Generator system is designed by combining several components such as reactor tubes, filter tubes, and temporary storage tubes. The Proton Exchange Membrane Fuel Cell (PEMFC) used is a device that has been assembled with the specifications of the H2 Gatech brand with a maximum output of 10 Watts. Furthermore, the Hydrogen Generator system is connected to the Proton Exchange Membrane Fuel Cell (PEMFC) tool so that it can become a unitary system to convert water into electrical energy through lamp loading. Hydrogen Generator uses the working principle of water electrolysis and is used to produce Hydrogen gas. The Hydrogen Generator is equipped with a cathode and anode plate which is electrified in electrolysis. On the positive plate (anode) oxygen gas bubbles are formed and on the negative plate (cathode) hydrogen gas bubbles are formed [13]. In this study, the Hydrogen Generator uses stainless steel on the anode and Copper (Cu) on the cathode. The selection of stainless steel on the anode because based on Suardamana's research [13] that the best type of stainless steel on the anode is 304 stainless steels while the selection of Copper (Cu) material on the cathode because it is included in a strong oxidizer and is expected to be more effective in producing Hydrogen gas production formed at the cathode. Furthermore, oxygen and hydrogen enter the filtering tube/bubbler where oxygen will be bound by water in the tube because the solubility of oxygen gas is more soluble in water with a solubility of 0.0034 while hydrogen is only 0.00016. The hydrogen gas then goes through the Rotameter and is stored in a temporary storage tube. Furthermore, it is flowed to the Proton Exchange Membrane Fuel Cell (PEMFC) so that it can be converted into electrical energy to turn on the lights as loading. The specifications of the anode and cathode electrodes are rectangular (15cm×4cm×2mm), the number of plates on the anode 6 and on the cathode 6 so that the number of electrodes is 12 plates. The use of input electricity using a Power Supply Unit. Readings of voltage, current, and power in and out using water within 6 minutes.

The result is the input data of KOH, NaCl, and NaOH catalyst types with concentrations of 0.01M; 0.02M; 0.03M; 0.04M; and 0.05M in Figure 3 as follows.

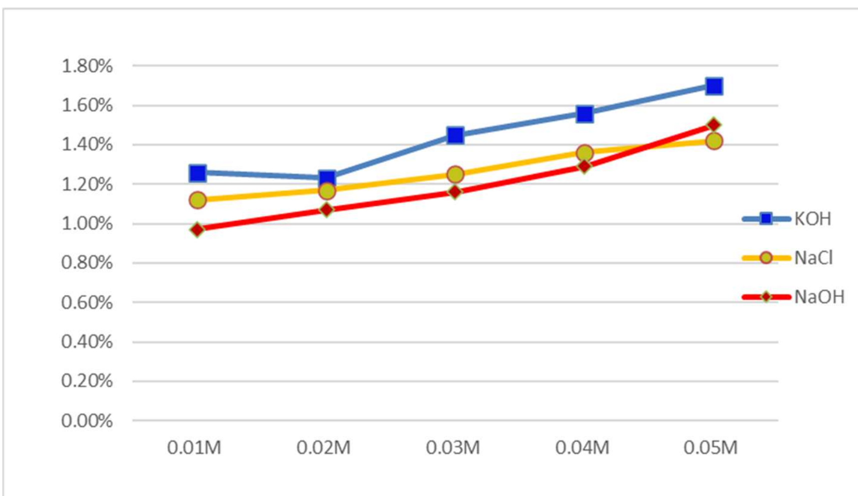
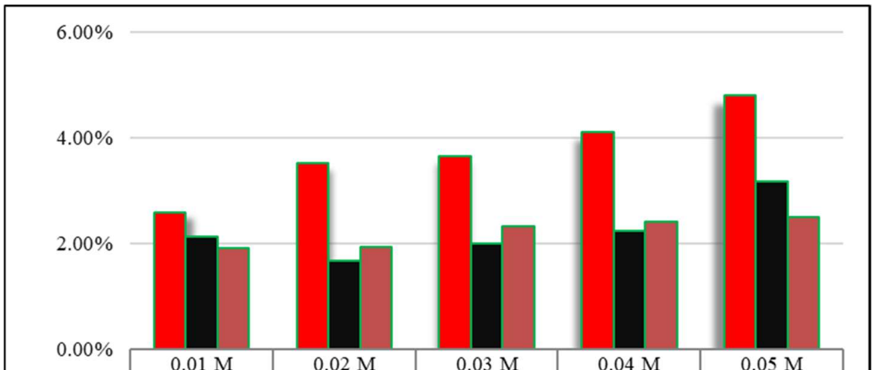


Fig. 3. Graph of Relationship between Type and Concentration of KOH, NaCl, and NaOH Catalyst with Electrolyser Efficiency

Based on the overall data results, the three catalysts namely KOH, NaCl, and NaOH have the ability as a catalyst which can help break down water into hydrogen and oxygen. This is because the catalyst has strong catalyst ions that can affect the stability of water molecules into H+ and OH- ions which are easier to electrolysis due to a decrease in activation energy [15]. In addition, the pH level of the catalyst affects where from neutral the more alkaline the pH the better for the catalyst. The pH of KOH is 13, the pH of NaCl is 7-8, and the pH of NaOH is 11 (Hamidah, 2021). Apart from the type of catalyst, the catalyst concentration also affects the hydrogen discharge and electrolyser efficiency where the higher the catalyst concentration, the higher the hydrogen discharge and electrolyser efficiency. This is related to the concentration and salinity in the samples used ranging from 0.4%-2.90% where the higher the salinity, the better it is used as a catalyst. This is in line with the research of Dewantoro [16] and Wahyono that the higher the concentration, the faster the electrolysis process. Based on the data, it is found that among the three types of catalysts that have the best performance in helping to produce Hydrogen is 0.05M KOH catalyst with a Hydrogen discharge value of 6.33 m3/s. This is because KOH as a homogeneous alkaline pH catalyst has an advantage in its high catalysing ability compared to acidic or neutral pH catalysts. So, it is concluded that the type of catalyst can affect the process of electrolysis of water to produce fuel in the form of Hydrogen.

This data also shows that the higher the Hydrogen discharge produced, the higher the electrolyzes efficiency. The highest electrolyser efficiency is found in the 0.05M KOH catalyst with an efficiency value of 1.70%. This is due to the use of the same input electrical energy of 40 Watts on the type and concentration of catalyst but can produce higher hydrogen power which reaches 6.33 m3 / s at KOH 0.05M. Based on the data obtained, it is found that the smallest hydrogen discharge value and the smallest electrolyser efficiency are found in 0.01M NaOH catalyst with consecutive values of 3.62 m3/s and 0.97%. This is because at the same concentration of 0.01M in KOH, NaCl, and NaOH catalysts have different gram periods, and the smallest is NaOH 0.01M which is only 0.4 grams. So, it is concluded that the catalyst concentration affects the electrolysis process of water to produce fuel in the form of Hydrogen.

In addition to the type and concentration of catalyst, electrodes consisting of stainless steel were used on the anode and Copper (Cu). The cathode also affects the electrolysis process where the process becomes smooth and conducts input electricity to help the water electrolysis process. In line with Suardamana's research [13] that the best type of stainless steel on the anode is stainless steel 304. The output data of the results of the catalyst types of KOH, NaCl, and NaOH with each concentration of 0.01M; 0.02M; 0.03M; 0.04M; and 0.05M in Figure 4.



	0.01 M	0.02 M	0.03 M	0.04 M	0.05 M
NaCl	2.59%	3.52%	3.64%	4.10%	4.81%
KOH	2.12%	1.68%	1.99%	2.24%	3.17%
NaOH	1.92%	1.94%	2.32%	2.41%	2.49%

Fig. 4. Overall Graph of Effect of Catalyst Type and Concentration on fuel cell efficiency

Based on the data described above, the input power in the form of Hydrogen as fuel in the fuel cell which is getting more will not necessarily produce output energy in the form of large electrical power as well. This is because this study did not measure the purity level of hydrogen flowing through the rotameter so that the possibility of gas discharge that enters through and is read by the rotameter does not only contain hydrogen but other gases such as oxygen. So that when converted into electrical energy has an electrical output power that changes the level of ups and downs in each concentration. The highest hydrogen power results through the electrolyser process are found in the type of KOH catalyst concentration of 0.05M with a value of 0.685 Watt but the highest electrical energy output power produced by the fuel cell is obtained in the type of NaCl catalyst concentration of 0.05M with an output of 3.3 Watt. This is related to power density, fuel cell efficiency, and SFC (Specific Fuel Consumption). Power density is the amount of power (energy spent per unit time) per unit volume, fuel cell efficiency is the best power comparison between electrical power (load output power) and input power (Hydrogen gas), and SFC (Specific Fuel Consumption) is a measure of the efficiency of a machine that describes the ratio between the amount of fuel used and the electrical energy produced. The relationship between electrical output power is directly proportional to power density and fuel cell efficiency while inversely proportional to SFC (Specific Fuel Consumption). The higher the power density and fuel cell efficiency, the more efficient the use of fuel cell equipment as an energy converter. The lower the SFC (Specific Fuel Consumption), the better in terms of the usage ratio between input and output energy so that no losses occur. In general, the energy produced must be greater than the use of input fuel. In this study, the highest SFC (Specific Fuel Consumption) was 1.78 kg/kWh with the lowest fuel cell efficiency of 1.68% on 0.02M KOH catalyst while the lowest SFC (Specific Fuel Consumption) was 0.62 kg/kWh with the highest fuel cell efficiency of 4.81% on 0.05M NaCl catalyst. In addition, the electrical energy output of the fuel cell is also associated with the loading of 4 lamps each 2.5 Volt 0.3A (7.5 Watt) in parallel. In all experiments totalling 15 variations can turn on the lights with dim to bright light intensity.

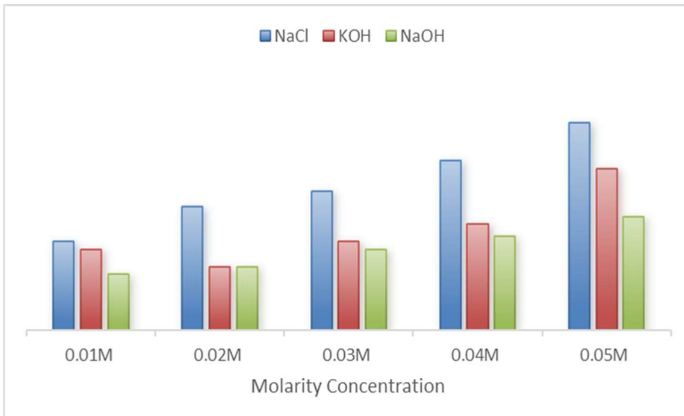


Fig. 5. Graph of BER on Catalyst Type and Concentration

The Break-Even Ratio (BER) results of the KOH, NaCl, and NaOH catalyst types with each concentration of 0.01M; 0.02M; 0.03M; 0.04M; and 0.05M are shown in Figure 5. BER is the balance of power when processing Hydrogen in the Hydrogen Generator with the fuel cell output power in the form of electricity to turn on the load in the form of lights. The BER is generally worth a maximum of 1: 1 where the input and output power are equal. The highest BER value is found in 0.05M NaCl catalyst while the smallest BER value is found in 0.01M NaOH catalyst. The BER is related to the output power in the form of electrical energy which should be greater than the input power requirements in the form of Hydrogen. The higher the BER value, the better the type and concentration of catalyst used and the more efficient the electrolyser and fuel cell.

4. Conclusion

The highest Electrolyser Efficiency is found in 0.05M KOH catalyst with a value of 1.70% and it can be concluded that the higher the catalyst concentration, the higher the Electrolyser Efficiency. The highest quality of power density and fuel cell efficiency is found in 0.05M NaCl catalyst with consecutive values of 173.64 Watt/litre and 4.81% and the lowest Specific Fuel Consumption (SFC) of 0.62 kg/kWh so that the use of this catalyst has highly efficient performance with little fuel consumption. The best BER value is found in the type of NaCl catalyst variation 0.05M with a value of 0.082.

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