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HHO Gas Productivity Analysis Using a Dry Cell Type HHO Generator with Variations of Copper and Stainless Steel Electrodes , Electric Current, and NaOH Concentration

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ABSTRACT

With the increasing global energy demand, particularly in the transportation sector, the need for alternative energy sources is growing. HHO (Hydrogen–Hydrogen–Oxygen) gas, produced via electrolysis, presents a promising alternative due to its clean-burning properties and rapid combustion. However, optimizing the performance of dry cell HHO generators remains a significant challenge. This study investigates the effect of varying electrode materials (copper and stainless steel), electric current, and NaOH concentration on HHO gas production. The key performance indicator used is the flow rate of HHO gas produced. Results show that increasing electric current significantly enhances HHO production, though this relationship is non-linear due to the rise in electrolyte temperature and internal resistance. A higher NaOH concentration increases electrolyte conductivity, improving HHO production, but excessive concentrations can lead to higher temperatures and electrode degradation. Copper electrodes outperformed stainless steel in gas production due to better electrical conductivity, while stainless steel exhibited superior corrosion resistance over time. Optimizing the combination of electrode material, current, and NaOH concentration is crucial for enhancing the performance of dry cell HHO generators, offering valuable insights for hydrogen-based energy systems.

Keywords: *HHO generator, electrolysis, NaOH concentration, copper electrode, stainless steel electrode, hydrogen energy*

1. INTRODUCTION

Global energy demand, particularly in the transportation sector, continues to increase in line with the growth in the number of motor vehicles. In Indonesia, fossil fuels remain the primary energy source, especially petroleum, whose availability is declining year by year. The decline in fossil fuel reserves and high dependence on conventional fuels pose significant energy sustainability and environmental impact issues [1], [2]. Therefore, the development of environmentally friendly and sustainable alternative energy sources is an urgent need.

One of the alternative energies that has been widely developed is hydrogen, particularly HHO (Hydrogen–Hydrogen–Oxygen) gas, which is produced through the process of water electrolysis. HHO gas is highly flammable, burns rapidly, and produces relatively clean emissions, as it only produces water vapor as a result of combustion [3], [4]. Previous studies have examined the use of HHO generators as an additional energy source, through variations in electrode type, electric current, electric frequency, and catalyst type to increase HHO gas production [5], [6].

Previous studies have shown that electrode and catalyst material parameters have a significant effect on the rate of HHO gas production. The use of stainless steel, aluminum, or copper electrodes with catalysts such as NaOH, KOH, and $NaHCO_3$ produces different performances [7], [8], [9]. However, the results obtained still show considerable variation and have not provided an optimal HHO generator configuration, particularly for dry cell HHO generators with varying electrical currents and NaOH catalyst concentrations [10], [11].

Recent advancements in HHO gas production have primarily focused on optimizing the electrolysis process by varying parameters such as electrode material, electric current, and electrolyte type. Previous studies have demonstrated that electrode material significantly influences gas production rates, with copper and stainless steel commonly used due to their availability and electrical properties.

Copper is favored for its high electrical conductivity, which accelerates the electrolysis reaction. However, stainless steel is preferred in some cases for its corrosion resistance, especially in long-term use under varying operational conditions. Catalyst concentration also plays a pivotal role;

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NaOH, for example, is widely used as it enhances the electrolyte's conductivity, thus facilitating more efficient electrolysis.

Despite these insights, there is still a lack of studies addressing the interaction between these factors, particularly in the context of dry cell HHO generators, which present unique challenges. This study addresses this gap by investigating the combined effect of these variables on HHO gas production.

Based on these research gaps, this study aims to analyze the effect of variations in copper and stainless steel electrode materials, electrical current, and NaOH catalyst concentration on HHO gas production in dry cell HHO generators. The results of this study are expected to contribute to determining the optimal combination of parameters to increase the flow rate of HHO gas, as well as to serve as a reference in the development of more efficient and applicable hydrogen-based alternative energy technology [12], [13].

2. RESEARCH SIGNIFICANCE

This research has scientific significance in the development of hydrogen-based alternative energy studies, particularly in the utilization of HHO gas produced through the electrolysis of water. By examining the effect of electrode material variations and electrical parameters on HHO gas production, this research contributes to the understanding of the mechanism of HHO gas formation in dry cell generators, which are currently still being developed to improve their efficiency and productivity.

From a technical perspective, this study is significant in determining the optimal combination of HHO generator operating parameters. Variations in copper and stainless steel electrode materials, electric current, and NaOH catalyst concentration were analyzed to determine their effect on the HHO gas flow rate. The results of this study are expected to serve as a reference in the design of a more efficient, stable, and safe dry cell type HHO generator for application as an energy support system in internal combustion engines and other energy applications.

In addition, this research has practical and environmental significance. The use of HHO gas as an alternative energy source has the potential to reduce dependence on fossil fuels and lower motor vehicle emissions. With increased efficiency in HHO gas production through the selection of appropriate electrode materials and operating parameters, this technology has the potential to be further developed as an environmentally friendly and sustainable clean energy solution.

3. RESEARCH METHODS

This study uses an **experimental** method to analyze the effect of electrode material variation, electric current, and catalyst concentration on HHO gas production in a dry cell type HHO generator. The experimental method was chosen to obtain quantitative data directly from the results of testing the HHO generator under controlled operating conditions. The main parameter observed in this study was the HHO gas flow rate, which was used as an indicator of generator performance.

3.1 Research Object and Experimental Setup

The object of this study is a dry cell type HHO generator designed and assembled for laboratory testing purposes. The HHO generator uses two types of electrode materials, namely copper (Cu) and stainless steel (SS), which are arranged in parallel inside the dry cell reactor. The electrolysis system is connected to a direct current (DC) source that allows the electrical current to be adjusted as needed for testing. The electrolyte solution used is water with the addition of sodium hydroxide (NaOH) catalyst at a certain concentration.

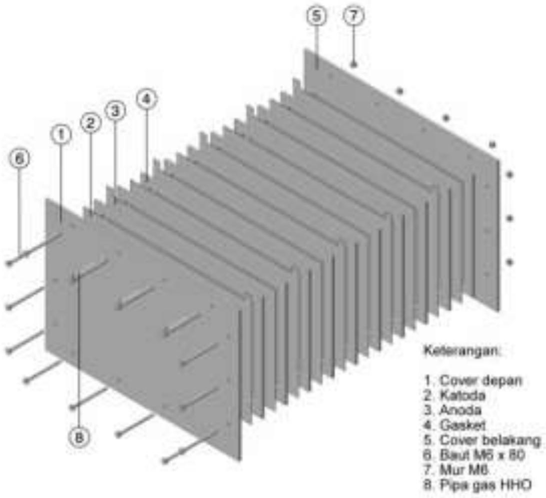

Figure1 . HHO Generator Device Design

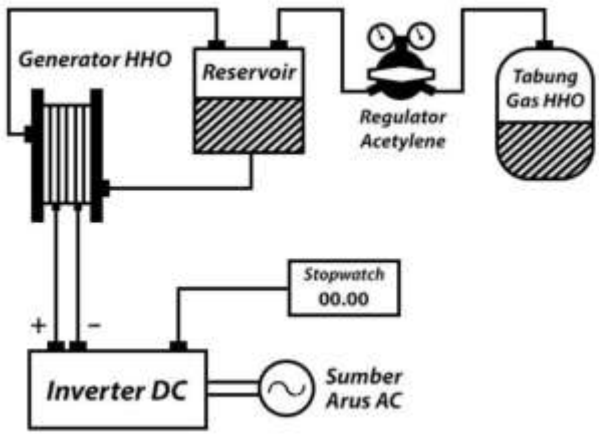

Figure2 . Research Schematic

3.2 Experimental Variables

Research variables are divided into independent variables, dependent variables, and control variables. Independent variables include electrode material type (Cu and SS), electrical current variation, and NaOH catalyst concentration. The dependent variable is the flow rate of HHO gas produced by the generator. Meanwhile, control variables include the volume of the electrolyte solution, the distance between electrodes, the ambient temperature, and

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the test time, which are kept constant throughout the experiment.

3.3 Experimental Procedure

The test was conducted by filling the HHO generator reactor with a NaOH electrolyte solution at a predetermined concentration. After the system was assembled and checked for leaks, a DC power source was connected to the HHO generator electrodes. The electrical current was then gradually varied according to the test scenario.

At each variation of current and catalyst concentration, the generator was run until it reached a stable condition before data collection. The HHO gas flow rate was measured at specific time intervals using an appropriate measuring device ( ). Each test was repeated to improve the accuracy and reliability of the data obtained.

3.4 Data Analysis Method

The test data was analyzed quantitatively by comparing the HHO gas flow rate for each variation in electrode material, electric current, and NaOH catalyst concentration. The analysis results were presented in graph form to show the tendency of each variable's effect on HHO gas production. This analysis was used to identify the parameters that provided the most optimal HHO gas production rate and to evaluate the effectiveness of using copper and stainless steel electrode materials in dry cell type HHO generators. The results of the analysis were then compared with the findings of previous studies to strengthen the discussion and validity of the research results.

4. RESULTS AND DISCUSSION

The results of this study were obtained from experimental testing of dry cell HHO generators with variations in electrode materials, electric current, and NaOH catalyst concentration. The main parameter analyzed was the HHO gas flow rate as an indicator of generator performance. The discussion focused on the effect of each variable on the rate of HHO gas production and its relationship to the characteristics of the water electrolysis process.

4.1 Effect of Electric Current Variations on HHO Gas Production

Test results show that an increase in electric current has a significant effect on increasing the flow rate of HHO gas produced. The greater the electric current supplied, the faster the electrolysis reaction rate, thereby increasing the amount of HHO gas formed. This is due to the increased number of electrons flowing through the electrodes, which accelerates the process of separating water molecules into hydrogen and oxygen gases [14], [15].

However, at higher electric current values, the increase in HHO gas flow rate is not always linearly proportional. This condition is influenced by the increasing temperature of the electrolyte solution and the internal resistance of the system, which can reduce the efficiency of the electrolysis process. These results are in line with previous studies which state that there is an optimal limit of electric current in the operation of HHO generators to maintain system efficiency and stability [16], [17].

Arus Listrik (Ampere)	Debit Gas (NaOH 10 %) [m^3/s]	
	Tembaga	SS304
10	0,00042962	0,00031375
20	0,00031375	0,000350783
30	0,000156875	0,000384264
40	0	0,00044371
50	0	0,000470625

Table1 . HHO Gas Flow Rate Produced with Variations in Electric Current at a 10% NaOH Concentration

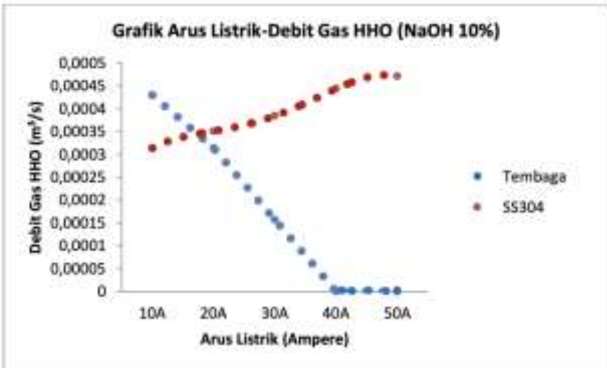

Figure3 . HHO Gas Flow Rate Graph at 10% NaOH Concentration

4.2 Effect of NaOH Catalyst Concentration on HHO Gas Production

Variations in NaOH catalyst concentration have a significant effect on HHO gas flow rate. An increase in NaOH concentration causes an increase in electrolyte solution conductivity, thereby reducing electrical resistance in the system and allowing electrical current to flow more effectively. This condition accelerates the rate of electrolysis and increases HHO gas production [18], [19].

However, an excessively high increase in catalyst concentration has the potential to cause negative effects, such as excessive solution temperature increase and the risk of electrode component degradation. Therefore, it is necessary to select the optimal NaOH concentration in order to achieve a balance between increased gas production and the stability of the HHO generator system [20], [21].

Konsentrasi NaOH (%)	Debit Gas (20 Ampere) [m^3/s]	
	Tembaga	SS304
10	0,00031375	0,000350783
20	0	0,000531989
30	0	0,000554637
40	0	0,000554637
50	0	0,000565621

Table2 . HHO Gas Flow Rate Produced with Variations in NaOH Concentration at an Electric Current of 20 A

4.3 Effect of Electrode Material Type on HHO Gas Flow Rate

The comparison between copper (Cu) and stainless steel (SS) electrodes shows a difference in the HHO gas flow rate produced. Copper electrodes tend to produce higher HHO gas flow rates compared to stainless steel electrodes under the same current and catalyst concentration conditions. This is related to the higher electrical conductivity of copper, which makes the flow of electric current in the electrolysis system more effective [22].
However, stainless steel electrodes have advantages in terms of corrosion resistance and material stability during the electrolysis process. Although the gas flow rate produced is relatively lower, the use of stainless steel provides more stable performance over a longer test period. These findings indicate a trade-off between gas productivity and electrode material resistance in the selection of HHO generator electrode materials [23].

Konsentrasi NaOH (%)	Debit Gas (40 Ampere) [m^3/s]	
	Tembaga	SS304
10	0	0,00044371
20	0	0,000637229
30	0	0,000692741
40	0	0,000718892
50	0	0,000744124

Table3 . HHO Gas Flow Rate Produced with Variations in NaOH Concentration at an Electric Current of 40 A

4.4 General Discussion on HHO Generator Performance

Overall, the results of this study indicate that the performance of dry cell HHO generators is greatly influenced by the combination of electric current, NaOH catalyst concentration, and electrode material type. Increasing the electric current and catalyst concentration tends to increase HHO gas flow, but this must be controlled so as not to reduce system efficiency and reliability.
These research results are consistent with previous studies which state that optimization of operating parameters is a key factor in the development of efficient and applicable HHO generators. With the selection of the right electrode material and operating parameters, HHO generators have the potential to be further developed as an environmentally friendly hydrogen-based alternative energy support system [24].

5. CONCLUSIONS

The study reveals that optimizing the combination of electrode material, electric current, and NaOH concentration is crucial for enhancing HHO gas production in dry cell generators. While copper electrodes produce higher gas yields, stainless steel offers better durability, making it more suitable for long-term use. Future research should focus on refining the parameters to balance gas productivity with electrode longevity.
The results of this study can inform the design of future hydrogen generators and contribute to reducing energy consumption in industrial applications, further advancing HHO technology as a sustainable alternative energy source.

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7. AUTHOR CONTRIBUTIONS

Conception and design: Sugeng Hadi Susilo,
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Data acquisition: Fica Aida Nadhifatul Aini
Analysis and interpretation of data: Sugeng Hadi Susilo,
Writing publication: Fica Aida Nadhifatul Aini.
Approval of final publication: Sugeng Hadi Susilo
Resources, technical and material supports: Fica Aida Nadhifatul Aini
Supervision: Sugeng Hadi Susilo

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