



Analysis of the Effect of Electrode Material and NaCl Solution Concentration on Hydrogen Gas Production in a WET Cell Generator

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ABSTRACT

Rising energy demands and dwindling fossil fuel reserves are driving the development of more environmentally friendly alternative energy sources. Hydrogen is a promising alternative energy source, characterized by high calorific value and water vapor as its sole byproduct. Water electrolysis using a WET Cell generator is a widely used method for hydrogen production. Hydrogen gas yield during electrolysis is influenced by several factors, including electrode material and electrolyte solution concentration. This study aims to analyze the effects of electrode materials, aluminum (Al), copper (Cu), and stainless steel (SS), and NaCl solution concentrations on hydrogen gas yield in a WET Cell generator. An experimental laboratory approach was employed using a 3x3 factorial design, incorporating three electrode materials and three NaCl solution concentrations (0%, 5%, 10%). Hydrogen gas concentration was measured in ppm using an Arduino Uno based MQ-8 sensor and subsequently analyzed with IBM SPSS Statistics 27 software using descriptive statistics, normality tests, homogeneity tests, and two-way ANOVA. The results indicate that average hydrogen yields for the respective electrodes were 46.05 ppm, 51.32 ppm, and 49.81 ppm at 0% NaCl; 124.05 ppm, 252.50 ppm, and 60.38 ppm at 5% NaCl; and 238.80 ppm, 94.89 ppm, and 131.61 ppm at 10% NaCl. The combination of stainless steel electrodes and 10% NaCl solution yielded the highest hydrogen output (238.80 ppm), while the combination of stainless steel electrodes and 0% NaCl solution yielded the lowest (46.05 ppm). The two-way ANOVA results indicate that the electrode type, NaCl solution concentration, and the interaction between the two have a significant effect on hydrogen gas productivity (Sig. < 0.05).

Keywords: Hydrogen, Water Electrolysis, WET Cell, Electrode Material, NaCl, MQ-8

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1. Introduction

Energy demand continues to increase with population growth, industrial development, and expanding transportation activities. Meanwhile, dependence on fossil fuels remains high, while fossil fuel reserves continue to decline. These conditions have driven the development of alternative energy sources that are more environmentally friendly and sustainable. One promising alternative

energy source is hydrogen, owing to its high heating value, favorable energy conversion efficiency, and water vapor as its only by-product when used in fuel cells. These characteristics make hydrogen a potential substitute for fossil fuels in the future (Muhammad, 2021; Natasha et al., 2024).

One widely used method for hydrogen production is water electrolysis using a *WET Cell* generator. In this

process, electrical energy is used to split water molecules (H_2O) into hydrogen gas (H_2) and oxygen gas (O_2). However, water has relatively low electrical conductivity, which limits the rate of hydrogen production. Therefore, adding an electrolyte solution can increase the concentration of mobile ions in the solution, thereby reducing electrical resistance and accelerating the electrolysis reaction (Jasmine and Rustana, 2020; Manurung et al., 2022). The principle of water electrolysis in a *WET Cell* generator is illustrated in Fig. 1

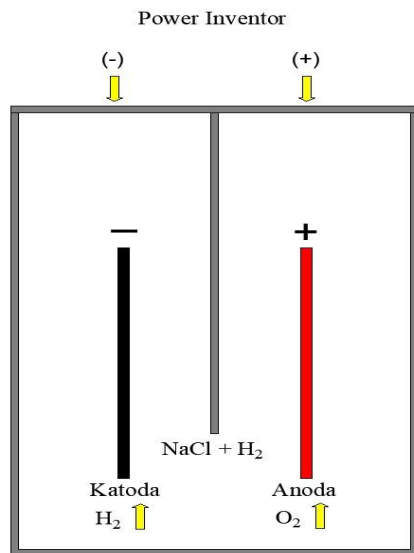


Figure 1. Schematic of the Water Electrolysis Process in a WET Cell Generator

The success of the electrolysis process is influenced not only by the electrical voltage source but also by the electrolyte solution and electrode materials used. Sodium chloride (NaCl) is commonly used as an electrolyte because it is readily available, economical, and capable of increasing the electrical conductivity of the solution, thereby improving the efficiency of gas production during electrolysis (Kassem et al., 2024; Mustaghfirin et al., 2024). However, the presence of chloride ions (Cl^-) can also accelerate corrosion in certain electrode materials. Therefore, electrode material selection is an important factor affecting the stability of the electrolysis process and the productivity of hydrogen gas.

Previous studies have investigated the effects of electrolyte type, electrode material, electrode surface area, and electric current on hydrogen gas productivity (Gani, Adawiah, and Nur, 2021; Simanullang, Studi, and Mesin, 2024). Other studies have also employed an MQ-8 sensor integrated with an Arduino Uno to detect hydrogen gas concentrations in real time (Pratama, Nasution, and Nasution, 2026). However, studies combining three electrode materials—aluminum, copper, and stainless steel—with three NaCl solution concentrations in a *WET Cell* generator, while analyzing the interaction between these two factors in relation to hydrogen gas productivity,

remain limited. Therefore, this study was conducted to address this research gap.

This study differs from previous research by experimentally investigating combinations of three electrode materials, namely aluminum, copper, and stainless steel, and three NaCl solution concentrations in a *WET Cell* generator, using an MQ-8 sensor integrated with an Arduino Uno as the data acquisition system. This approach enables the evaluation of the individual effects of each factor and their interaction on hydrogen gas productivity. Accordingly, this study aims to analyze the effects of electrode material and NaCl solution concentration on hydrogen gas productivity in a *WET Cell* generator and to determine the treatment combination that produces the highest hydrogen gas productivity.

2. Methodology of Research

This study employed a laboratory experimental method to analyze the effects of electrode material and NaCl solution concentration on hydrogen gas productivity in a *WET Cell* generator. The experiments were conducted at the Internal Combustion Engine Laboratory, Department of Mechanical Engineering, Faculty of Engineering, Universitas Widya Gama Malang, Indonesia.

A 3×3 factorial experimental design was used, comprising two independent variables: electrode material and NaCl solution concentration. The first factor consisted of three electrode materials: aluminum (Al), copper (Cu), and stainless steel (SS). The second factor consisted of three NaCl concentrations: 0% (without NaCl), 5%, and 10%. Each treatment combination was tested in triplicate, resulting in a total of 27 experimental runs.

Based on this experimental design, the research procedures, from equipment and material preparation to experimental testing and data analysis, were carried out systematically, as illustrated in Fig. 2.

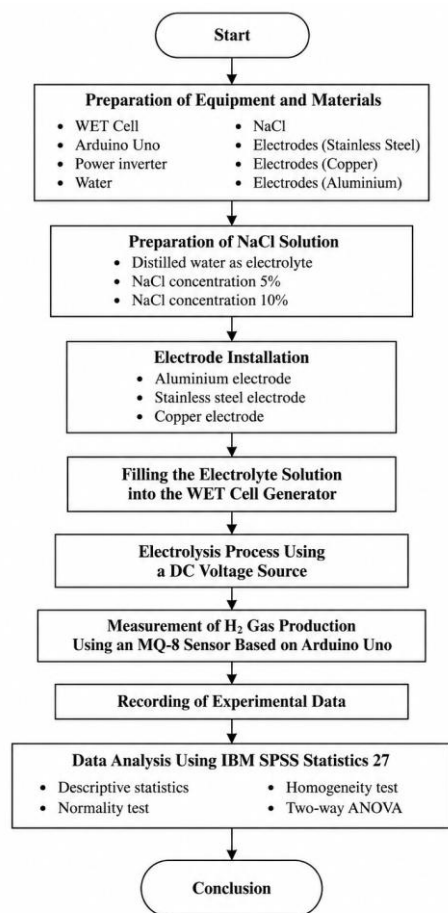


Figure 1. Flowchart

Generator *WET Cell* yang digunakan The WET Cell generator employed a parallel-plate electrode configuration, in which the electrodes were directly immersed in the electrolyte solution. This configuration was selected because it can provide a more uniform electric field distribution, thereby promoting more efficient electrolysis (Afisna et al., 2024; Rajora and Haverkort, 2022). During testing, the applied voltage was maintained at 12 V, the interelectrode distance was set to 2 cm, the electrode surface dimension was 4 cm, the electrolyte volume was 6 L, and the testing duration was 180 min. These parameters were maintained as controlled variables throughout the experiments.

The main equipment included a WET Cell generator, aluminum, copper, and stainless steel electrodes, an MQ-8 sensor, an Arduino Uno as the data acquisition system, a DC power supply, and a computer for data processing. The materials consisted of water and sodium chloride (NaCl) as the electrolyte. The MQ-8 sensor was used to monitor hydrogen gas concentration during electrolysis (Pratama, Nasution, and Nasution, 2026).

The electrolysis setup was prepared according to the specified NaCl concentration levels of 0%, 5%, and 10%. The electrodes were installed in the WET Cell generator, and the electrolyte solution was added until the electrode surfaces were fully immersed. The DC power supply was then connected to initiate the electrolysis process. During testing, the MQ-8 sensor connected to the Arduino Uno

recorded gas concentration in parts per million (ppm). All recorded measurements were stored as experimental data for subsequent analysis.

The experimental data were analyzed using IBM SPSS Statistics version 27. The statistical analyses included descriptive statistics, normality testing, homogeneity testing, and two-way analysis of variance (ANOVA) at a significance level of 0.05. The analysis was used to evaluate the effects of electrode material and NaCl concentration, as well as the interaction between these two factors, on hydrogen gas productivity

3. Result and Discussion

3.1. Hydrogen Gas Productivity Based on Electrode Material and NaCl Solution Concentration

The experiments were conducted to investigate the effects of electrode material and NaCl solution concentration on hydrogen gas productivity in a WET Cell generator. Hydrogen gas concentration was detected using an MQ-8 sensor integrated with an Arduino Uno and expressed in parts per million (ppm). Across all treatment combinations, differences in the measured hydrogen gas concentrations were observed among the electrode materials and NaCl solution concentrations. To provide a clearer understanding of the experimental results, the mean hydrogen gas concentration for each treatment combination is presented in Table 1.

Table 1. Mean Hydrogen Gas Concentration Based on Electrode Material and NaCl Solution Concentration

No	Material Elektroda	NaCl 0%	NaCl 5%	NaCl 10%
		(PPM)	(PPM)	(PPM)
1	Stainless			
	Steel (SS)	46.05	124.05	238.80
2	Tembaga			
	(Cu)	51.34	252.53	94.89
3	Aluminium			
	(Al)	49.81	60.38	131.61

Based on Table 1, the mean hydrogen gas concentration in water without the addition of NaCl (0%) ranged from 46.05 to 51.34 ppm. After the addition of 5% NaCl, the measured hydrogen gas concentration increased for all electrode materials, with the highest value obtained using the copper electrode at 252.50 ppm. At an NaCl concentration of 10%, the stainless steel electrode produced the highest value of 238.80 ppm, whereas the value obtained using the copper electrode decreased to 94.89 ppm.

The mean values were subsequently visualized in a graph to illustrate the differences in hydrogen gas concentration more clearly across the electrode materials and NaCl solution concentrations, as shown in Fig. 3.

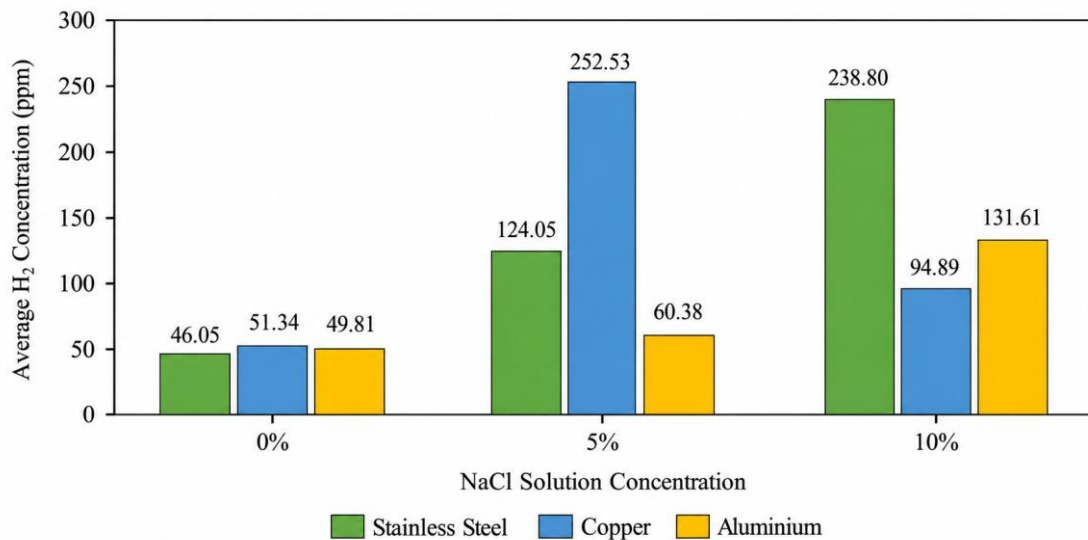


Figure 3. Mean Hydrogen Gas Concentration Based on Electrode Material and NaCl Solution Concentration)

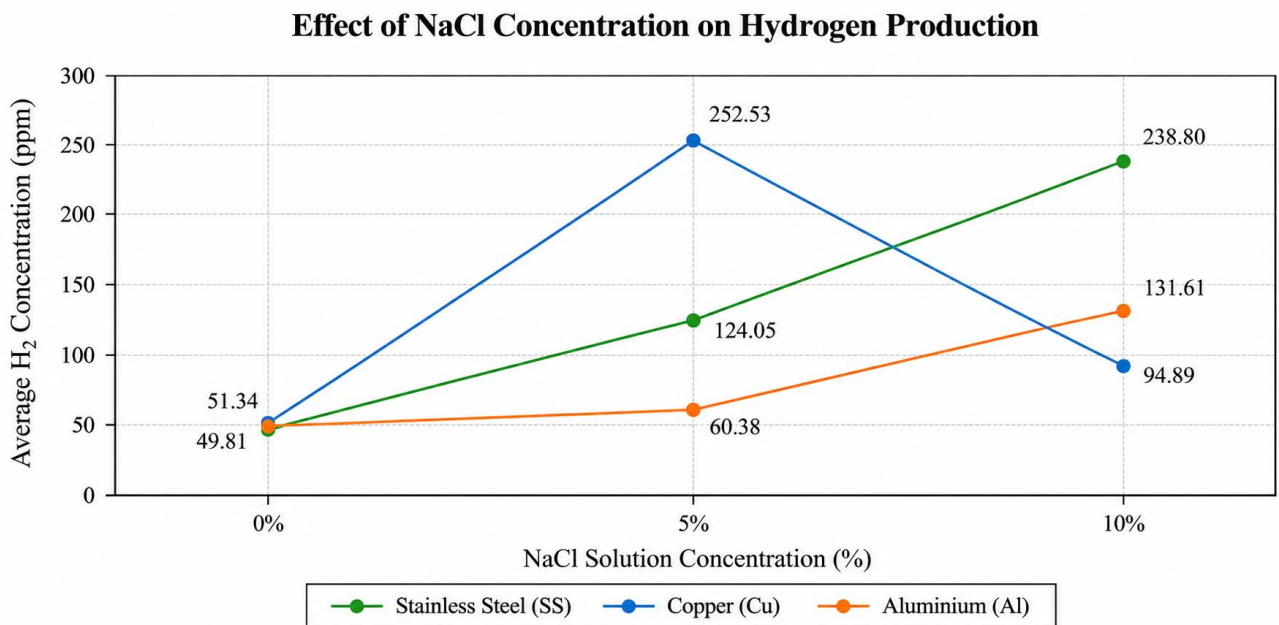


Figure 4. Interaction Plot of Electrode Material and NaCl Solution Concentration on Hydrogen Gas Concentration

As shown in Fig. 3, increasing the NaCl solution concentration produced different results depending on the electrode material. At an NaCl concentration of 5%, the copper electrode yielded the highest mean hydrogen gas concentration, at 252.50 ppm. In contrast, at an NaCl concentration of 10%, the highest value was obtained using the stainless steel electrode, at 238.80 ppm. The aluminum electrode also exhibited an increase in the measured hydrogen gas concentration, from 49.81 ppm at 0% NaCl to 60.40 ppm at 5% NaCl and 131.61 ppm at 10% NaCl.

These results indicate that increasing the NaCl solution concentration did not produce a consistent trend across all electrode materials. Therefore, in addition to examining the mean values for each treatment, the

relationship between electrode material and NaCl solution concentration must be investigated to identify the pattern of changes in hydrogen gas concentration for each electrode material. The relationship between these two variables is presented as an interaction plot in Fig. 4.

As shown in Fig. 4, increasing the NaCl solution concentration resulted in different patterns of change in hydrogen gas concentration for each electrode material. The hydrogen gas concentration measured using the stainless steel electrode increased gradually as the NaCl concentration increased from 0% to 10%. In contrast, the copper electrode exhibited a substantial increase at an NaCl concentration of 5%, followed by a decrease at 10%. Meanwhile, the aluminum electrode showed a gradual increase, although its measured concentration remained lower than those obtained with stainless steel and copper under most test conditions. These patterns

indicate that the electrode materials responded differently to changes in NaCl concentration.

These differences can be further discussed in terms of electrolyte conditions and the characteristics of each electrode material. When water was used without NaCl addition (0%), the measured hydrogen gas concentration was relatively low for all electrode materials. This may be associated with the limited electrical conductivity of water, which can restrict current flow and reduce charge transfer during electrolysis.

When the NaCl concentration was increased to 5%, the measured hydrogen gas concentration increased for all electrode materials. The addition of NaCl increases the concentration of ions in the solution, thereby improving its electrical conductivity. This condition can facilitate current flow during electrolysis and potentially enhance hydrogen gas generation.

At an NaCl concentration of 10%, the stainless steel electrode produced the highest measured hydrogen gas concentration, at 238.80 ppm. However, this trend was not observed for the copper electrode, for which the measured concentration decreased from 252.50 ppm at 5% NaCl to 94.89 ppm at 10% NaCl. This difference indicates that increasing the electrolyte concentration does not necessarily result in a consistent increase in hydrogen gas concentration across all electrode materials.

The differences in the measured concentrations may be related to the characteristics of each electrode material. Stainless steel generally exhibits good corrosion resistance, although its stability depends on the specific grade and electrochemical conditions. Copper has high electrical conductivity but may undergo surface changes when exposed to chloride-containing solutions. Meanwhile, aluminum can form an oxide layer on its surface that may impede electron transfer and affect its electrochemical behavior. These differences may contribute to the varying responses of the electrode materials to changes in NaCl concentration.

3.2. Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics 27 to determine the effects of electrode material, NaCl solution concentration, and the interaction between these two factors on hydrogen gas concentration. The results indicated that electrode material had a statistically significant effect on hydrogen gas concentration ($p < 0.05$). This finding suggests that differences among stainless steel, copper, and aluminum electrodes influenced the measured hydrogen gas concentration.

NaCl solution concentration also had a statistically significant effect on hydrogen gas concentration ($p < 0.05$). This result indicates that changes in NaCl concentration from 0% to 5% and 10% resulted in differences in the measured hydrogen gas concentration. Furthermore, the interaction between electrode material

and NaCl solution concentration was statistically significant ($p < 0.05$). This finding indicates that the effect of NaCl solution concentration on hydrogen gas concentration depended on the electrode material used.

Based on these results, both electrode material and NaCl solution concentration, as well as their interaction, played important roles in determining the measured hydrogen gas concentration in the WET Cell generator. The statistical analysis also supports the observations presented in Table 1 and Figs. 3 and 4, which show differences in hydrogen gas concentration among the treatment combinations.

3.3 Discussion

The results indicate that electrode material and NaCl solution concentration affected the hydrogen gas concentration measured in the WET Cell generator. Based on the mean values, the absence of NaCl (0%) resulted in relatively low hydrogen gas concentrations of 46.05 ppm for stainless steel, 51.34 ppm for copper, and 49.81 ppm for aluminum. When the NaCl concentration was increased to 5%, the measured concentrations increased to 124.05 ppm for stainless steel, 252.50 ppm for copper, and 60.40 ppm for aluminum. At an NaCl concentration of 10%, the measured concentrations were 238.80 ppm for stainless steel, 94.89 ppm for copper, and 131.61 ppm for aluminum. These results indicate that NaCl addition was generally associated with higher measured hydrogen gas concentrations, although the magnitude and direction of the response varied depending on the electrode material.

When water was used without NaCl addition, the measured hydrogen gas concentrations were relatively low for all electrode materials. This condition may be associated with the low electrical conductivity of water, which limits current flow during electrolysis. The addition of NaCl introduces Na^+ and Cl^- ions into the solution, increasing its electrical conductivity. Improved conductivity can facilitate charge transport during electrolysis and may enhance hydrogen generation. These findings are consistent with Basunjaya et al. (2025), who reported that increasing NaCl concentration can improve electrolyte conductivity and hydrogen gas production in a WET Cell-type HHO generator. However, their study also indicated that higher NaCl concentrations may accelerate electrode corrosion, highlighting the importance of selecting electrode materials with suitable corrosion resistance.

Nevertheless, each electrode material exhibited a different response to increasing NaCl concentration. The stainless steel electrode showed a consistent increase in measured hydrogen gas concentration, from 46.05 ppm at 0% NaCl to 124.05 ppm at 5% NaCl and 238.80 ppm at 10% NaCl. This trend suggests that stainless steel maintained an increasing response as the electrolyte concentration increased. This behavior may be associated

with the corrosion resistance of stainless steel, which can help maintain electrode surface stability under electrochemical conditions. These findings are consistent with Afisna et al. (2024), who reported that electrode material influences gas production characteristics during

electrolysis. Therefore, electrode selection depends not only on electrical conductivity but also on the material's ability

4. Conclusions

1. Based on the research findings and analysis, it can be concluded that electrode material and NaCl solution concentration had statistically significant effects on the measured hydrogen gas concentration in the *WET Cell* generator. The results of the two-way analysis of variance (two-way ANOVA) indicated that electrode material, NaCl solution concentration, and the interaction between these two factors had statistically significant effects, with $p < 0.05$.
2. Based on the mean values for all treatment combinations, the measured hydrogen gas concentrations for the stainless steel electrode were 46.05 ppm at 0% NaCl, 124.05 ppm at 5% NaCl, and 238.80 ppm at 10% NaCl. The copper electrode yielded concentrations of 51.34 ppm at 0% NaCl, 252.50 ppm at 5% NaCl, and 94.89 ppm at 10% NaCl, whereas the aluminum electrode yielded concentrations of 49.81 ppm at 0% NaCl, 60.40 ppm at 5% NaCl, and 131.61 ppm at 10% NaCl.
3. The highest measured hydrogen gas concentration among all treatment combinations was obtained using the copper electrode at an NaCl concentration of 5%, reaching 252.50 ppm. Meanwhile, at an NaCl concentration of 10%, the highest value was obtained using the stainless steel electrode, at 238.80 ppm. These results indicate that changes in electrolyte concentration did not produce a uniform response across the different electrode materials. Therefore, the measured hydrogen gas concentration in the *WET Cell* generator was influenced by the combination of electrode material and NaCl solution concentration.
4. Overall, electrode material and electrolyte concentration should be considered simultaneously when developing *WET Cell* generators. The findings of this study may serve as a reference for further development of water electrolysis processes aimed at improving hydrogen generation, while accounting for the characteristics of the electrode materials and the electrolyte conditions used

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