



Analysis of the Effects of Wet-Cell Electrolysis Variations Using Aluminum and Iron Electrodes on Hydrogen and Oxygen Gas Concentrations

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ABSTRACT

This research is motivated by the global energy crisis due to declining fossil fuel reserves, necessitating the development of renewable energy sources (EBT) such as hydrogen gas through water electrolysis. This study aims to analyze the effect of KOH solution concentration variations (1%–5%) combined with natural coconut water electrolyte, and to compare the use of aluminum (Al) and iron (Fe) electrode materials on hydrogen gas production rate in a wet cell system. The method used is quantitative laboratory experimentation with a 15 V DC power supply, 500 mL electrolyte volume, and 60-minute testing duration. Hydrogen and oxygen gas measurement used MQ-8 and MQ-135 sensors based on Arduino Uno in PPM units. Results show that 5% KOH concentration provides the highest gas production rate for both electrode types. The combination of aluminum electrodes with coconut water and 5% KOH achieves a maximum hydrogen gas production of 787.48 ppm, while 1% concentration yields minimum values. Iron electrodes outperform in pure water media (hydrogen 730.82 ppm at 5% KOH), while aluminum electrodes dominate in coconut water media.

Keywords: Electrolysis, hydrogen gas, wet cell, aluminum electrode, iron electrode

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1. Introduction

The world is currently facing increasingly complex challenges associated with the depletion of fossil fuel reserves, particularly natural gas and petroleum. Several alternative renewable energy sources include solar energy, wind energy, bioethanol, biodiesel, and biohydrogen [1]. The abundance of water resources offers considerable potential for renewable energy development through water electrolysis [2]. Hydrogen contained in water can be produced as a clean and environmentally friendly fuel [3].

HHO gas (oxyhydrogen), a mixture of hydrogen (H₂) and oxygen (O₂) produced by the decomposition of water

molecules through electrolysis, can be used as a supplementary fuel to improve combustion efficiency and reduce exhaust gas emissions [3,4]. Water electrolysis using an electrode cell consisting of a cathode and an anode supplied with direct current (DC) generates hydrogen and oxygen gases. Two commonly used electrolyzer configurations are wet-cell and dry-cell systems [5].

The type of electrolyte used significantly influences the efficiency of the electrolysis process [6]. Coconut water is a natural electrolyte containing minerals such as K⁺, Na⁺, Mg²⁺, and Ca²⁺, which enable it to conduct electricity, although its conductivity is generally lower

than that of strong electrolytes [7]. In contrast, potassium hydroxide (KOH) is a strong alkaline electrolyte that dissociates extensively in water, thereby increasing solution conductivity and facilitating the electrolysis process [8].

Aluminum (Al) and iron (Fe) were selected as electrode materials because they are readily available, relatively inexpensive, and exhibit good electrical conductivity [9]. This study aims to: (1) analyze the effects of electrolyte media and KOH concentration variations (1%–5%) on the hydrogen production rate; and (2) compare the performance of aluminum and iron electrodes in a wet-cell electrolysis system.

2. Methodology of Research

This study employed an experimental research design with a quantitative approach. The experiments were conducted at the Fluid Mechanics Laboratory, Campus 3, Universitas Widya Gama Malang, from May to July 2026.

2.1 Wet-Cell Apparatus Design

The wet-cell apparatus was designed as a simple electrolysis system consisting of a 500 mL non-conductive acrylic container, aluminum and iron electrodes arranged in parallel with a spacing of 5 cm, an electrolyte solution, and a 15 V direct-current (DC) power supply. The generated hydrogen gas was conveyed through a tube to a measuring apparatus using the water-displacement method.

2.2 Research Variables

The independent variables comprised: (1) the type of electrolyte solution and (2) the electrode material (aluminum and iron). The dependent variables were hydrogen and oxygen gas production, expressed in parts per million (ppm). The controlled variables included a voltage of 15 V, an electrolyte volume of 500 mL, an experimental duration of 60 minutes, and an interelectrode spacing of 5 cm.

2.3 Experimental Procedure

The experimental procedure consisted of the following steps: (1) preparing the acrylic wet-cell container and installing the electrodes; (2) preparing KOH solutions at concentrations ranging from 1% to 5% using purified water and coconut water as the electrolyte media, with a total volume of 500 mL for each solution; (3) operating the DC power supply at a constant voltage of 15 V; and (4) performing each experimental condition in triplicate to ensure measurement repeatability.

3. Result and Discussion

The results of this study present data on hydrogen and oxygen gas production obtained from various combinations of KOH concentrations, electrolyte media, and electrode materials.

3.1 Average Gas Production in Purified Water

Table 1 presents the average hydrogen and oxygen gas production using iron (Fe) and aluminum (Al) electrodes in purified water with KOH concentrations ranging from 1% to 5%.

Table 1. Average H₂ and O₂ Gas Production in Purified Water at Different KOH Concentrations

NO	KOH (%)	H ₂ Besi Air Murni (ppm)	O ₂ Besi Air Murni (ppm)	H ₂ Al Air Murni (ppm)	O ₂ Al Air Murni (ppm)
1	1%	381,12	135,90	271,56	97,07
2	2%	399,56	136,54	390,65	108,49
3	3%	594,78	156,13	396,02	126,93
4	4%	603,21	172,86	417,92	169,86
5	5%	730,82	179,63	581,49	192,44

Based on Table 1, hydrogen gas production increased progressively with increasing KOH concentration for both electrode materials. For the iron electrode, the highest hydrogen concentration was obtained at a KOH concentration of 5%, reaching 730.82 ppm, whereas the aluminum electrode reached 581.49 ppm. This increase can be attributed to the higher concentration of K⁺ and OH⁻ ions in the solution, which enhances ionic conductivity and facilitates electrochemical reactions at the electrode surfaces. The 1% KOH concentration produced the lowest values for both electrodes, namely 381.12 ppm for iron and 271.56 ppm for aluminum. This behavior may be associated with the lower concentration of available ions, which reduces the ionic conductivity of the electrolyte and increases the internal resistance of the electrolysis system.

3.2 Average Gas Production in Coconut Water

Table 2 presents the average gas production obtained using coconut water as the electrolyte medium with KOH concentrations ranging from 1% to 5%, employing iron and aluminum electrodes.

Table 2. Average H₂ and O₂ Gas Production in Coconut Water at Different KOH Concentrations

NO	KOH (%)	H ₂ Besi Air Kelapa (ppm)	O ₂ Besi Air Kelapa (ppm)	H ₂ Al Air Kelapa (ppm)	O ₂ Al Air Kelapa (ppm)
1	1%	269,70	112,05	326,84	107,78
2	2%	312,25	126,74	333,37	117,95
3	3%	371,72	139,57	341,04	125,07
4	4%	398,15	146,92	411,65	128,24
5	5%	556,28	154,52	787,48	188,09

Based on Table 2, the combination of coconut water, 5% KOH, and aluminum electrodes yielded the highest overall hydrogen gas concentration, reaching 787.48 ppm. The presence of naturally occurring minerals in coconut water, including K⁺, Na⁺, Mg²⁺, and Ca²⁺, combined with KOH, may increase the concentration of mobile ions in the solution, thereby enhancing ionic conductivity,

reducing ohmic resistance, and facilitating electrochemical reactions at the aluminum electrode surface. In comparison, the iron electrode in the coconut water medium achieved its highest hydrogen gas concentration of 556.28 ppm at a KOH concentration of 3.3 Effect of KOH Concentration on Gas Production

5%, which was lower than that obtained using the aluminum electrode under the same electrolyte conditions.

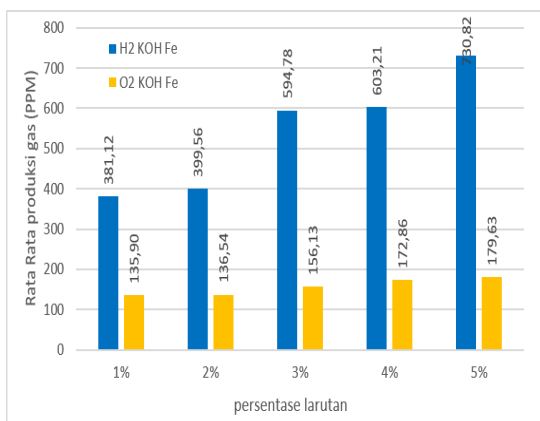


Figure 1. Effect of KOH Concentration in Purified Water on Hydrogen and Oxygen Gas Concentrations Using Iron Electrodes.

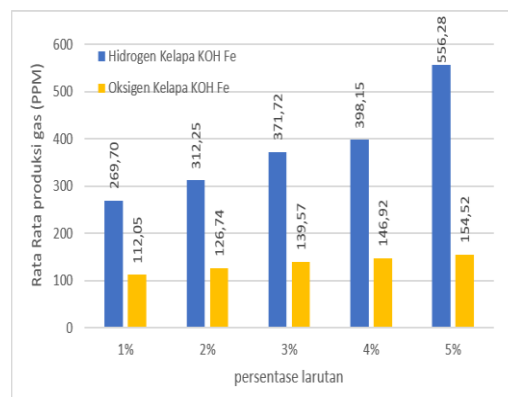


Figure 2. Effect of KOH Concentration in Purified Water on Hydrogen and Oxygen Gas Concentrations Using Iron Electrodes.

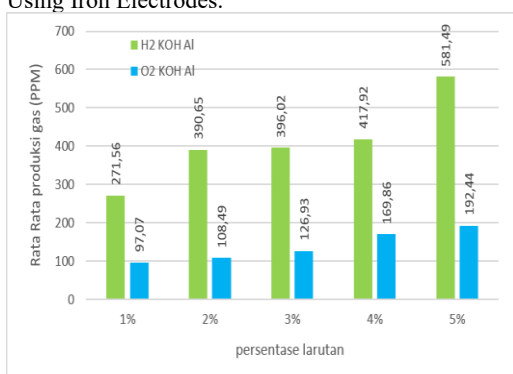


Figure 3. Effect of KOH Concentration in Purified Water on Hydrogen and Oxygen Gas Concentrations Using Aluminum Electrodes.

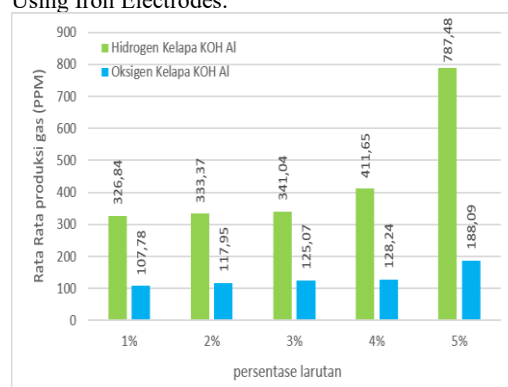


Figure 4. Effect of KOH Concentration in Purified Water on Hydrogen and Oxygen Gas Concentrations Using Aluminum Electrodes.

Across all electrode and electrolyte combinations, hydrogen and oxygen gas concentrations increased monotonically as the KOH concentration increased from 1% to 5%. This trend is consistent with the electrochemical principle that increasing electrolyte concentration enhances the ionic conductivity of the solution, reduces the internal resistance of the cell, and facilitates ion transport and redox reactions at the electrodes [7,8].

At a KOH concentration of 5%, the iron electrode in purified water produced a hydrogen gas concentration of 730.82 ppm, the highest value among all experimental conditions involving purified water. Meanwhile, in the coconut water medium, the aluminum electrode with 5% KOH achieved the highest hydrogen gas concentration across all experimental conditions, reaching 787.48 ppm. The steepest increase occurred between KOH concentrations of 4% and 5%, suggesting that the improvement in ionic conductivity within this concentration range may have contributed substantially to the increase in gas concentration.

3.4 Comparison of the Performance of Aluminum and Iron Electrodes

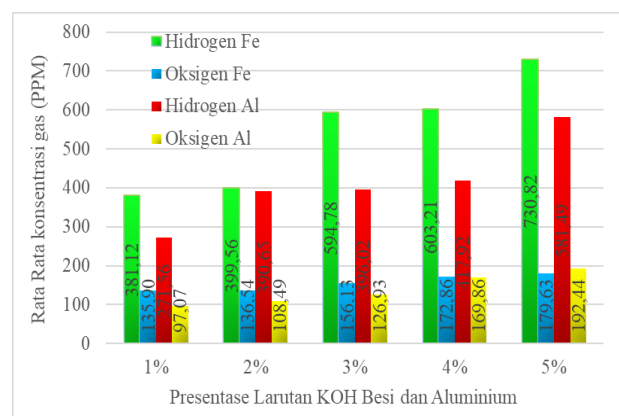


Figure 5. Comparison of Hydrogen and Oxygen Gas Production Using Aluminum (Al) and Iron (Fe) Electrodes in Purified Water.

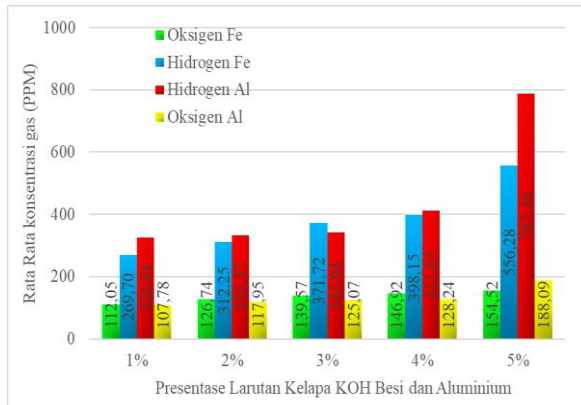


Figure 6. Comparison of Hydrogen and Oxygen Gas Production Using Aluminum (Al) and Iron (Fe) Electrodes in Purified Water.

In the purified water medium, the iron electrode consistently produced higher hydrogen gas concentrations than the aluminum electrode at all KOH concentrations. At a KOH concentration of 5%, the iron electrode in purified water achieved a hydrogen concentration of 730.82 ppm, compared with 581.49 ppm for the aluminum electrode. This difference may be associated with differences in the electrochemical behavior of iron and aluminum in the electrolyte, including their surface characteristics, corrosion behavior, and current distribution during electrolysis.

In contrast, the aluminum electrode exhibited superior performance in the coconut water medium. At a KOH concentration of 5%, the aluminum electrode produced a hydrogen gas concentration of 787.48 ppm, compared with 556.28 ppm for the iron electrode. The electrochemical activity of the aluminum surface in the presence of naturally occurring minerals in coconut water may contribute to this difference. However, at lower KOH concentrations (1%–3%) in the coconut water medium, the performance differences between the two electrodes were smaller, suggesting that the influence of electrode material may become more pronounced at higher electrolyte concentrations.

Regarding oxygen gas concentration, the aluminum electrode in purified water containing 5% KOH produced the highest value, reaching 192.44 ppm, compared with 179.63 ppm for the iron electrode. This result may indicate differences in anodic electrochemical behavior between aluminum and iron under these experimental conditions. However, further investigation is required to establish the underlying reaction mechanisms.

3.5 Discussion of the Electrochemical Mechanisms

The experimental results are consistent with electrochemical theory, which indicates that the addition of the strong alkaline electrolyte KOH provides OH^- ions that facilitate the cathodic reduction reaction ($2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$) and the anodic oxidation reaction ($4\text{OH}^- \rightarrow \text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^-$) [7,10]. As the KOH concentration increases, the ionic concentration of the solution also

increases, thereby reducing ohmic resistance and enabling more efficient electrical current flow.

The combination of coconut water and KOH may produce a synergistic effect. Naturally occurring minerals in coconut water, including K^+ , Na^+ , Mg^{2+} , and Ca^{2+} , contribute to the baseline ionic conductivity of the solution, while KOH supplies OH^- ions at a higher concentration to support electrochemical reactions. Under the experimental conditions investigated, the combination of coconut water, 5% KOH, and aluminum electrodes yielded the highest hydrogen gas concentration, reaching 787.48 ppm.

The fluctuations observed in several experimental trials may be associated with the accumulation of gas bubbles on the electrode surfaces, a phenomenon known as the *bubble coverage effect*. These bubbles can temporarily block active reaction sites and increase polarization resistance, thereby affecting the efficiency of the electrochemical process. This phenomenon may be particularly relevant to aluminum electrodes because of their surface characteristics and electrochemical behavior. However, further measurements are required to confirm the contribution of bubble coverage to the observed fluctuations.

3.6 Comparison with Previous Studies

Table 3 summarizes previous studies that provide the theoretical foundation for the present research and highlights their relevance to the investigation.

Table 3. Summary of Relevant Previous Studies

No.	Researcher	Research Focus	Key Findings	Relevance
1	Chatenet et al. (2022)	Alkaline water electrolysis using KOH	KOH has high ionic conductivity, improving hydrogen-production efficiency.	Supports the use of KOH as the main electrolyte.
2	Musthofa et al. (2025)	Coconut water in electrolysis	Coconut water contains K^+ , Na^+ , Mg^{2+} , and Ca^{2+} ions that may act as natural electrolytes.	Supports coconut water as an alternative natural electrolyte.
3	Siregar et al. (2020)	Aluminium as an electrolysis electrode	Aluminium is conductive, lightweight, and easy to shape.	Supports selecting aluminium as an electrode material.
4	Firfansyah (2022)	Iron as an electrolysis electrode	Iron has good mechanical strength; corrosion resistance depends on the electrolyte.	Supports selecting iron as a comparison electrode.

The findings of this study are consistent with those reported by Chatenet et al. [8], who highlighted the role of KOH as an effective electrolyte in alkaline water electrolysis systems. The use of coconut water as a natural electrolyte is also in agreement with the findings of Musthofa et al. [6], which indicate that the mineral content of coconut water can support the electrolysis

process. Furthermore, the superior performance of aluminum electrodes in the coconut water medium observed in this study provides additional insight into the potential application of natural electrolyte media in combination with KOH. This finding may contribute to the existing body of knowledge, although further comparative studies are required to establish its novelty and clarify the underlying electrochemical mechanisms

4. Conclusion

Based on the experimental results and discussion, the following conclusions can be drawn:

1. KOH concentration had a positive effect on hydrogen gas concentration across all electrode and electrolyte combinations. A KOH concentration of 5% consistently yielded the highest hydrogen gas concentrations, whereas a concentration of 1% produced the lowest values. This trend may be attributed to the increased concentration of mobile ions, which enhances electrolyte conductivity and reduces the internal resistance of the electrolysis system.
2. The optimal configuration for achieving the highest hydrogen gas concentration was the aluminum (Al) electrode combined with coconut water and 5% KOH, yielding peak concentrations of 787.48 ppm H₂ and 188.09 ppm O₂. In contrast, the iron electrode performed better in purified water, achieving a maximum hydrogen concentration of 730.82 ppm at a KOH concentration of 5%. These findings indicate differences in the electrochemical behavior of the two electrode materials under different electrolyte conditions.
3. The performance of the wet-cell electrolysis system was strongly influenced by the combination of electrolyte type, electrolyte concentration, and electrode material. The combination of coconut water and KOH may provide complementary contributions to ionic conductivity, potentially enhancing hydrogen gas concentration. Further investigations are needed to verify the proposed synergistic effect and clarify the underlying electrochemical mechanisms.

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