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Water-to-Fuel Conversion Device via Electrolysis Using Stainless-steel Electrodes

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ABSTRACT

Every year, the increase in essential human needs results in an increase in energy use due to population growth and the increasingly rapid development of the technology industry, which has caused almost all sectors to depend on energy and technology. So, the latest and most recent energy is one of the highlights that is very important in the development of science. The water electrolysis method can convert water (H2O) into HHO gas. In the electrolysis of water, various kinds of catalysts are often used, one of which is NaOH, which will be used in this study. The purpose of adding a catalyst is to speed up the reaction rate. So, in this study, the researchers designed an HHO generator to convert H2O into engine fuel using the water electrolysis method, which can produce hydrogen gas. The variables used in this study were variations in the concentration of the NaOH catalyst, namely 5%, 10%, 15%, 20%, and 25%. The electrodes used are stainless steel electrodes with a volume of electrolyte solution equal to 1.5 liters. The number of electrodes is 18 pieces, and the electric current used is 10 Amperes, with the electric voltage being 12 volts. The most optimal tool efficiency is found at the concentration of 25% NaOH solution, which achieves an efficiency of 87.3%.

1. Introduction

The rapid growth of industrialization and the transportation sector has significantly increased global energy consumption, predominantly reliant on fossil fuels. This reliance has raised concerns regarding the finite nature of these resources and their detrimental environmental impacts, such as greenhouse gas emissions and air pollution, which have prompted the exploration of alternative energy sources (Ashraf et al., 2020; Raganati & Liao, 2023; Rao et al., 2018). Hydrogen has emerged as a promising candidate due to its high energy density and clean combustion properties, making it an attractive fuel for the future (Konrad, 2014). Water electrolysis is recognized as a viable method for hydrogen production, offering several advantages over

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other techniques. This process involves the decomposition of water molecules into hydrogen and oxygen gases by applying an electric current through an electrolyte solution (Chang & Du, 2013). The use of water as the primary feedstock renders this method environmentally benign and sustainable, aligning with the global shift towards renewable energy sources (Bereczky, 2017). Previous studies have extensively investigated various aspects of water electrolysis for hydrogen production, including the optimization of electrode materials, electrolyte compositions, and operating conditions. Stainless steel has been identified as a suitable electrode material due to its corrosion resistance, durability, and cost-effectiveness (Abdollahi et al., 2019). The incorporation of catalysts, such as sodium hydroxide (NaOH), has been shown to enhance the reaction kinetics and improve the overall efficiency of the electrolysis process. Research indicates that the concentration of NaOH plays a crucial role in optimizing the electrolysis reaction, as it influences the production rate of hydrogen (Meng et al., 2019). Furthermore, the development of advanced materials and catalysts continues to be a focal point in enhancing the efficiency and viability of hydrogen production through electrolysis (Zhi et al., 2023).

This study aims to design an advanced water-to-fuel conversion device using stainless steel electrodes and the electrolysis method, with a focus on optimizing hydrogen generation. The incorporation of a NaOH catalyst and systematic investigation of key parameters, such as electrode configuration and electrolyte concentration are expected to yield enhanced hydrogen production rates and system performance.

2. Research Method

2.1. Materials

This study was conducted at the processing laboratory in Universitas Jambi, and the research utilizes simple, readily available materials. The equipment used in this study includes a hot glue gun, cutting tools, plastic jars of 1950 ml and 3500 ml sizes, scissors, aquarium tubing, a ¼-inch valve, an aerator valve, a 12V 10A power supply, an aquarium aerator, electrical insulator, wires, clips, graduated cylinders, glass-beakers, and stir rods. The materials used were aquades, carbon electrodes, and NaOH as catalysts.

The experimental setup involved preparing the plastic jars, placing the carbon electrodes inside, and connecting them to the power supply. Distilled water and NaOH catalyst were added to the jars, and the tubing, valves, and aerator were connected to control gas flow and provide aeration. Safety precautions were taken, including proper insulation of electrical components and conducting experiments in a well-ventilated area.

2.2. Work Experimental

The design of the equipment was followed by the preparation of electrolytic solutions with varying concentrations: 5%, 10%, 15%, 20%, and 25%. The next step involves testing the equipment's performance through production tests. During the testing phase, three primary parameters are measured: (a) the power consumption of the equipment, (b) the efficiency of the equipment, and (c) the volume of gas produced. The production test results were analyzed to evaluate the performance and efficiency of the equipment in the different concentrations of electrolytic solutions.

This methodology ensures a structured approach to evaluating the designed equipment and its functionality across different solution concentration.

2.2.1. Electrode Preparation and Assembly

Electrode preparation refers to the necessary steps in research to adjust the shape and size of the electrodes to match the predefined design specifications. The electrodes used in this study are made of stainless steel, measuring 15 × 7 cm, with a total of 18 plates. These plates are divided into two series circuits, consisting of 9 anodes and 9 cathodes, each with a thickness of 1.5 mm. Holes are drilled into each plate using a 10 mm drill bit to facilitate the installation of bolts, which connect the plates as conductors for electrical flow between them.

After drilling and cutting the 18 stainless steel plates, the plates are assembled using 10 mm bolts. Each plate is separated by a spacer, which is made from inner tubes of a motorcycle tire. This spacer serves to maintain a gap between the plates, thus reducing the power load on the power supply.

The stainless-steel plates are then arranged in a series configuration, with two separate circuits, one consisting of 9 plates as anodes and the other 9 plates as cathodes. The bolts at both ends of the assembly are connected to wires, which are then wrapped in electrical insulation. This insulation is crucial to minimize heat generation and to prevent direct contact between the wires and the electrolysis solution, thus avoiding electrical leakage and the potential for wire damage or combustion.

2.2.2. Power Supply and Electrolyte Solution Container Preparation

The power supply is an electronic device designed to provide electrical current and voltage to an electronic circuit, ensuring the system operates as intended. In this study, the power supply serves as the voltage source for the electrolysis process of the electrolyte solution. During electrolysis, a chemical reaction occurs when an electric current is passed through the electrolyte, converting electrical energy into chemical energy.

The power supply used in this experiment has an input specification of 220 V AC and an output of 12 V DC, with a current rating of 10 A. Since the power supply is new, it is first connected by linking the input and output terminals with appropriate cables. Crocodile clips are attached to the output cables to facilitate the easy connection of the electrode wires. The power consumption (P) of the HHO generator in watts (W) was determined by multiplying the measured potential difference (V) in volts and the electric current (I) in amperes, as given in Equation 2 (Thowil Afif et al., 2017):

$$P = VI$$

where P represents the power consumption (W), V is the potential difference (V), and I denotes the electric current (A). This equation allows for the calculation of the HHO generator's power consumption based on the experimental voltage and current measurements.

For the electrolysis reaction and the subsequent gas bubbling that still contains water vapor, plastic containers with capacities of 2000 ml and 3500 ml are used. The electrolysis reaction vessel has dimensions of 12 cm x 11.5 cm x 17 cm. A ¼-inch valve is installed on the lid of the reaction vessel to allow for the output of the produced gas, while an aquarium aerator valve regulates the flow of air entering the electrolyzer. Additionally, the connection cables for the graphite electrodes are mounted on the lid of the container.

The second vessel, known as the bubbler, contains water and serves as a gas separator, trapping any water vapor mixed with the gas. An aquarium tubing system is connected to the bubbler, which transports the generated gas from the electrolyzer to the bubbler unit for separation.

2.2.3. Preparation of NaOH Electrolyte

Before conducting the experiment, it is essential to prepare the electrolyte solution by dissolving NaOH catalyst in water. A total volume of 1500 ml of solution was prepared, with five different concentrations of NaOH: 5%, 10%, 15%, 20%, and 25%.

2.2.4. Apparatus Setup

After completing the preparations, the entire apparatus was assembled, and a trial run was conducted by adding the prepared electrolyte solution into the electrolysis tank containing the stainless-steel electrodes. The electrolysis vessel is connected to the power supply, which functions as the electrical current source. On the top lid of the electrolysis vessel, two valves are installed: one for gas output and the other for an aquarium aerator. The gas output valve was connected to tubing, allowing the gas generated in the electrolysis cell to flow into the output container.

Before the experiment, the vessel is filled with water, and inside the container, a 100 ml graduated cylinder is positioned upside down with a stand and clamp for support. The tubing from the electrolysis vessel is directly connected to the graduated cylinder to monitor the flow rate of the generated HHO gas, which appears as bubbles. The aquarium aerator valve was added to regulate the flow of air into the electrolysis cell, ensuring the generated gas was directed into the output container. The volume flow rate of the gas is then measured using a stopwatch. After determining the gas flow volume, the productivity of the HHO gas is calculated. The efficiency (η) of the designed apparatus was determined using Equation 3:

$$\eta = \frac{Q_{HHO} \times \rho_{HHO}}{P} \times LHV_{HHO} \quad \dots(1)$$

where η is the efficiency, Q represents the HHO gas productivity (l/s), ρ is the density of HHO gas (g/l), LHV denotes the lower heating value (J/g), and P is the power consumption of the generator (W). This equation calculates the efficiency by considering the HHO gas production rate, gas density, energy content, and power input.

2.2.6. HHO Gas Productivity

The method for data collection to calculate air productivity was conducted in the same manner as the data collection for HHO gas productivity. Data was collected five times for each electrolyte concentration, during which the flow rate was observed and measured using a stopwatch. The key distinction during the observation of air productivity was that the power supply was not used. This is to ensure that no electrolysis reaction occurs within the electrolyzer, and only air is allowed to exit the electrolyzer and flow into the output container. The results are recorded, and the average time for each concentration is calculated using equation (2.4). The air productivity data obtained is then used as a reference to calculate the productivity of the generated HHO gas.

HHO gas productivity refers to the potential output from the gas production device, measured in terms of the volume of gas produced within a specific time frame. By observing the time required to achieve the generated volume, the efficiency of the designed system can be determined. To calculate HHO gas productivity, equation 1 was employed.

$$Q = \frac{\forall}{t} \quad \dots(2)$$

where Q represents the HHO gas productivity (l/s), V is the volume of HHO gas produced (l), and t denotes the generation time (s). This equation enables the quantification of HHO gas production rate based on the measured gas volume and corresponding time interval.

Since the study uses an aquarium aerator to assist in pressurizing the gas, ensuring its flow into the output container, the total gas productivity is adjusted by subtracting the air productivity contributed by the aerator. This adjustment allows for the determination of the pure productivity of the HHO gas.

Data collection for HHO gas productivity is conducted by recording the flow rate of the gas five times at each concentration of the electrolyte solution, with measurements taken using a stopwatch. The results are recorded, and the average time for each concentration is used in equation (2) to compute the gas productivity.

3. Result and Discussion

3.1. HHO Gas Production

The experimental results demonstrate a notable correlation between NaOH electrolyte concentration and the efficiency of hydrogen gas production in the water electrolysis system using stainless steel electrodes. The relationship between NaOH concentration and system performance exhibits distinct patterns across the tested range of 5% to 25% concentration.

At lower NaOH concentrations (5-10%), the system showed relatively lower efficiency, with gas productivity rates of 0.0016 L/s and 0.0006 L/s, respectively. The extended average reaction times of 14.372s and 16.696s at these concentrations indicate higher electrical resistance in the electrolyte solution, which may be attributed to insufficient ionic conductivity. Notably, the 10% concentration demonstrated the lowest HHO gas productivity (0.0006 L/s) and the longest reaction time (16.696s), suggesting this concentration may represent a critical point where the solution's ionic conductivity is suboptimal for efficient electrolysis.

As the NaOH concentration increased from 15% to 25%, a consistent improvement in system performance was observed. The reaction time decreased progressively from 13.526s at 15% concentration to 11.906s at 25% concentration, indicating enhanced electron transfer efficiency. This improvement is reflected in the corresponding increase in HHO gas productivity, which rose from 0.0020 L/s at 15% to 0.0030 L/s at 25% concentration. The total gas productivity (HHO + air compressor) followed a similar trend, reaching its peak at 0.0084 L/s with 25% NaOH concentration.

While theoretical calculations often assume stoichiometric production of hydrogen and oxygen in a 2:1 ratio, the practical composition of the generated gas mixture is more complex. The HHO gas produced contains not only hydrogen and oxygen but also their dimers, molecular forms, water vapor, and Santilli Magnecules. Based on experimental analysis, the maximum HHO gas production rate of 0.0030 L/s (equivalent to 0.18 LPM) at 25% NaOH concentration would correspond to approximately 0.12 LPM of hydrogen and 0.06 LPM of oxygen, accounting for the stoichiometric ratio and practical composition factors.

The data reveals an optimal performance zone at higher NaOH concentrations (20-25%), where the system achieves maximum efficiency. At 25% concentration, the combination of the shortest reaction time (11.906s) and highest gas productivity (0.0030 L/s for HHO) suggests that this concentration provides the most favorable conditions for electrolysis. However, it's important to note that while higher current flow rates could potentially increase HHO production, this approach carries significant risks. These include system damage from excessive heat generation, increased water vapor content in the produced gas, and potentially dangerous reaction kinetics that could lead to explosion. Additionally, high-current electrolysis would require substantial modifications to the electrode design, including considerations for electrode size and coating specifications.

The contribution of the air compressor to total gas productivity remains relatively consistent across all concentrations, with the difference between total gas productivity and HHO productivity ranging from 0.0054 L/s to 0.0054 L/s. This consistency suggests that the air compressor's performance is independent of electrolyte concentration, as expected, and serves primarily to enhance the overall gas output of the system through mechanical means rather than electrochemical processes.

These findings provide valuable insights for efficient water-to-fuel conversion devices utilizing electrolysis with stainless steel electrodes. The results suggest that operating the system at NaOH concentrations between 20-25% would yield the most efficient conversion of water to hydrogen fuel, balancing reaction kinetics with gas productivity while maintaining safe operating conditions. However, further investigation into the long-term effects of high NaOH concentrations on electrode durability and system maintenance requirements would be beneficial for practical applications.

3.2. System efficiency

The experimental investigation of the water-to-fuel conversion device reveals complex relationships between NaOH electrolyte concentration, system efficiency, and HHO gas production rates. The comprehensive equation (2) accounts for both the system's gas production capabilities and energy conversion efficiency, providing a robust metric for evaluating system performance across varying electrolyte concentrations.

The system's performance at lower NaOH concentrations revealed intriguing patterns in electrochemical behavior and energy conversion efficiency. At 5% NaOH concentration, the system demonstrated moderate efficiency of 45.9609% with a corresponding HHO gas productivity of 0.0016 L/s, suggesting reasonable but suboptimal ionic conductivity conditions. However, a remarkable phenomenon was observed at 10% concentration, where system efficiency experienced a dramatic decline to 18.1808% accompanied by reduced gas productivity of 0.0006 L/s. This significant performance deterioration indicates a critical threshold where the electrolyte concentration becomes insufficient to maintain effective ionic transport mechanisms, resulting in increased electrical resistance and reduced energy conversion efficiency. The pronounced efficiency drop at this concentration point provides valuable insights into the minimum electrolyte concentration requirements for maintaining stable electrochemical reactions in stainless steel electrode systems.

A remarkable recovery and enhancement in system performance were observed as NaOH concentration increased beyond the critical 10% threshold. At 15% concentration, the system exhibited a substantial improvement in efficiency, reaching 58.4437% with HHO gas productivity increasing to 0.0020 L/s. This recovery demonstrates the system's ability to overcome the low-concentration performance barrier through enhanced ionic conductivity and improved electron transfer kinetics. The upward trend in efficiency continued consistently through higher concentrations, achieving 81.9557% at 20% NaOH and ultimately peaking at 87.2979% with 25% NaOH concentration. This steady improvement in performance metrics corresponds with the highest observed gas productivity of 0.0030 L/s at 25% concentration, indicating optimal conditions for electrochemical conversion processes and maximum energy utilization efficiency.

The efficiency curve exhibits distinctive characteristics that provide profound insights into the system's electrochemical behavior. The most notable feature is the pronounced V-shaped pattern observed between 5% and 15% concentrations, followed by a steady logarithmic increase from 15% to 25%. This unique efficiency profile suggests a complex interplay between electrolyte concentration, ionic conductivity, and electrochemical reaction kinetics. The sharp efficiency increase observed between 10% and 20% concentrations (from 18.1808% to 81.9557%) represents the most critical operational range for system optimization, where relatively small adjustments in electrolyte concentration yield substantial improvements in energy conversion efficiency. This dramatic improvement can be attributed to enhanced ionic mobility, reduced solution resistance, and optimized electron transfer processes at the electrode-electrolyte interface.

These comprehensive findings indicate that 25% NaOH concentration provides the most favorable conditions for water electrolysis using stainless steel electrodes, achieving near-optimal efficiency levels in terms of both energy conversion and gas production rates. The experimental data suggests that at this concentration, the system achieves an optimal balance between ionic conductivity, electrode kinetics, and energy utilization. However, the relatively modest efficiency improvement between 20% and 25% concentrations (an increase of only 5.3422%) suggests the system may be approaching its theoretical performance limits. This observation raises important questions about the practical feasibility of further efficiency improvements through increased electrolyte concentration alone. The diminishing returns in efficiency gains also highlight the importance of considering other system parameters, such as electrode design, surface area optimization, and temperature control, for achieving further performance enhancements in water-to-fuel conversion devices.

4. Conclusion

The water-to-fuel conversion device using stainless steel electrodes demonstrates optimal performance at 25% NaOH concentration, achieving maximum efficiency of 87.2979% and HHO gas productivity of 0.0030 L/s. The system exhibits a characteristic V-shaped efficiency pattern between 5-15% NaOH concentrations, followed by logarithmic improvement up to 25%. The critical range for operational optimization lies between 10-20% NaOH concentration, where efficiency increases dramatically from 18.1808% to 81.9557%. However, the diminishing efficiency gains above 20% concentration suggest approaching theoretical performance limits. These findings establish 20-25% NaOH as the optimal concentration range for practical applications, balancing maximum efficiency with stable system operation

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