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INVESTIGATION OF HYDROGEN GAS PRODUCTION USING COPPER AND STAINLESS-STEEL ELECTRODES WITH VARIED ELECTRICAL CURRENT AND NaOH CATALYST CONCENTRATION

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In recent years, the global energy demand, particularly the usage of fossil fuels as motor vehicle propellants such as gasoline and diesel, had steadily increased. This surge in consumption, alongside the burgeoning vehicle count, resulted in a depletion of petroleum reserves. Consequently, exploring alternative fuel sources became imperative. Hydrogen gas, derived from water through water electrolysis using an HHO generator, emerged as a promising alternative. This research investigated the impact of diverse copper and stainless-steel electrodes in varied electrolyte solutions and electrical currents for generating HHO gas. Employing an experimental methodology, the study modified an existing HHO generator, reassembling it with different materials based on the experimental design. Subsequent testing and data collection revealed that the highest flow rate of HHO gas, at 0.000807564 m^3/s, occurred using stainless-steel electrodes with an electrical current of 50 A and a 50% NaOH concentration. The study concluded that the size of the electric current and the amount of NaOH significantly influenced the speed of HHO gas flow, indicating a direct relationship between these factors and gas production.

Keywords: hydrogen gas, electrical current, NaOH catalyst concentration

1 INTRODUCTION

In recent years, the global demand for energy, particularly fossil fuels utilized as motor vehicle fuels (e.g., gasoline and diesel), has been steadily increasing [1], [2]. The escalating consumption of motor vehicle fuels, coupled with the ever-growing number of motor vehicles on the road, has resulted in a depletion of petroleum reserves. Consequently, there is a pressing need to explore alternative fuel sources to replace conventional petroleum-based fuels. One promising alternative is hydrogen gas, which can be obtained from the most abundant resource on Earth, water, through a process known as water electrolysis, yielding a mixture of HHO gas (Oxy-Hydrogen) using an HHO generator [3].

Electrodes, electrical currents, and NaOH catalyst concentrations have been studied in HHO generators to produce HHO gas [4], [5]. The effect of electrode thickness on HHO gas production in a wet-type HHO generator with NaHCO3 as the catalyst was examined [6]. A neutral stainless-steel 316 and aluminium electrode HHO generator was tested [7]. [8] studied how electrical frequency affects HHO generator and motorbike engine performance. [9] explored the impact of electrolyte solution molarity and electrical current on HHO gas production in a dry cell-type HHO generator. [10] analyzed the use of various NaOH, NaCl, and KOH catalyst variations on HHO gas Flowrate and efficiency. [11] investigated the influence of different percentages of NaOH as a catalyst in the electrolysis process using a dry cell-type electrolyzer.

The study examines the effects on the production of hydrogen peroxide gas caused by using a variety of copper and stainless-steel electrodes immersed in a range of electrolyte solutions and subjected to a range of electrical currents. This research holds great promise for advancing the development of alternative fuels that are more efficient and environmentally friendly. The increasing global demand for motor vehicle fuels, especially fossil-based ones, has led to the depletion of petroleum reserves, making it necessary to explore alternative fuel sources. Hydrogen gas, derived from water through electrolysis, is one such attractive alternative.

2 THEORY

2.1 Brown's Gas (HHO Gas)

Brown's gas comes from the electrolysis of pure water (H_2O). The gas made by electrolyzing water is made up of two Hydrogen atoms and one Oxygen atom (HHO). So, Brown's gas is usually called HHO gas or oxy-hydrogen [12].

An HHO generator is a device that generates fuel from water and serves as an alternative fuel-saving method to conventional petroleum-based fuels. HHO or Oxy-Hydrogen is formed when water (H_2O) decomposes into hydrogen and oxygen atoms. Wet-cell and dry-cell HHO generators exist. The wet cell's anode (+) and cathode (-) plates are totally submerged in water. As a result, when the cell's capacity is one litre, all the water is electrolyzed, leading to permanent HHO cell accumulation and progressively increasing heat. However, the dry cell variant of electrolysis involves the conversion of a minimal quantity of water confined within the cell plates, resulting in the production of limited heat as a consequence of the circulation of hot and cold water within the reservoir [13].

2.2 HHO Gas Production Rate (Mass Flowrate)

The primary product of the water electrolysis process using an HHO generator is HHO gas. In order to accurately evaluate the efficacy of an HHO generator, it is important to ascertain the quantity of HHO gas generated by this generator.

The determination of the mass Flowrate of HHO gas can be achieved by the utilization of Equation (1)[14].

$$\dot{m} = Q \times \rho \tag{1}$$

Where $\dot{m}$ is the HHO gas production rate (flow rate) (kg/s), Q is the HHO gas production rate (m^3/s), and ρ is the Density of HHO gas (kg/m^3).

The Flowrate of HHO gas production ($\dot{m}$) is given by Equation (2).

$$Q = V/t \tag{2}$$

Where Q is the gas production rate (m^3/s), V is the measured gas volume (m^3), and t is the time of HHO gas production (s).

2.3 Water Electrolysis

Hydrogen gas, being the most prevalent element on Earth, is sourced abundantly from water, which is readily available in nature. HHO gas can be generated by the utilization of an HHO generator by subjecting water to a specific process. The HHO generator is a fuel synthesis device that facilitates the production of HHO gas through the decomposition of water molecules into hydrogen and oxygen [15] – [17].

The process of water electrolysis involves the utilization of electrical energy to generate clean hydrogen (H_2) and oxygen (O_2). During this particular process, the cathode, which is the negative electrode, generates hydrogen gas, while the anode, which is the positive electrode, generates oxygen gas. To facilitate a rapid electrolysis process, an electrolyte solution, such as NaOH, is added as a catalyst.

Electrolysis is a process that separates chemical compounds into their constituent elements or produces new molecules by applying an electric current. Electrolysis of water is the process of breaking down water molecules (H_2O) into Hydrogen (H_2) and Oxygen (O_2). The electrolysis of water involves passing an electric current through water using two electrodes (cathode and anode). For efficient electrolysis, the water is mixed with an electrolyte acting as a catalyst [18], [19].

In this study, the electrolyte used is a basic solution, NaOH, which is a strong base, leading to a base reaction. At the cathode, a chemical reaction occurs where two water molecules undergo reduction by acquiring two electrons. This reduction process leads to the production of hydrogen gas (H_2) and hydroxide ions (OH^-). The OH^- ions from the cathode reaction move towards the anode, where electrons are released onto the anode's surface and then move back to the battery or power supply. Due to the release of these electrons, two OH^- ions decompose to form water and oxygen bubbles. Hydrogen gas (H_2) is produced at the cathode, whereas oxygen gas (O_2) is generated at the anode, and these electrolysis products appear as small gas bubbles on the surface of each electrode [20].

The electrodes used in this study are copper and stainless-steel electrodes. Copper is chosen as it is one of the best conductors of electricity after silver, which has the highest conductivity level. The anticipated outcome is that it will exert a substantial impact on the quantity of HHO gas generated. Conversely, stainless-steel is an alloy with relatively better conductivity and resistance to corrosion compared to other alloys or pure metals, and it is also more affordable. Thus, stainless-steel is a suitable choice for the electrodes in the electrolysis process. In this study, type 304 stainless-steel is chosen, which contains adequate chromium content to form a chromium oxide film layer that can hinder iron (F_e) oxidation, making it resistant to corrosion.

3 MATERIAL AND METHODS

This research was conducted using an experimental method with the aim of investigating the influence of copper and stainless-steel electrode materials, electrical current, and NaOH catalyst concentration on the gas production rate in the HHO generator.

This research was conducted using a dry-cell type HHO generator and an acetylene regulator as the data collection tool. This study's independent variables were electrode materials, current, and catalyst concentration. The gas Flowrate from HHO generator pressure conversion was the dependent variable in the research. To get gas pressure data, an acetylene regulator was utilized. The regulator was installed after the reservoir tank and before the HHO gas storage tank to maintain a stable gas flow rate.

Gas pressure testing for HHO gas was conducted with a duration of one minute for each treatment (pressure per minute). The research scheme is illustrated in Fig. 1.

The electrodes used in this study were copper electrodes and type 304 stainless-steel electrodes, both with the same cross-sectional area of 400 mm x 250 mm and a plate thickness of 1,0 mm. The applied electrical currents varied at 10A, 20A, 30A, 40A, and 50A, while the catalyst used was Sodium Hydroxide (NaOH) with concentrations ranging from 10%, 20%, 30%, 40%, to 50%.

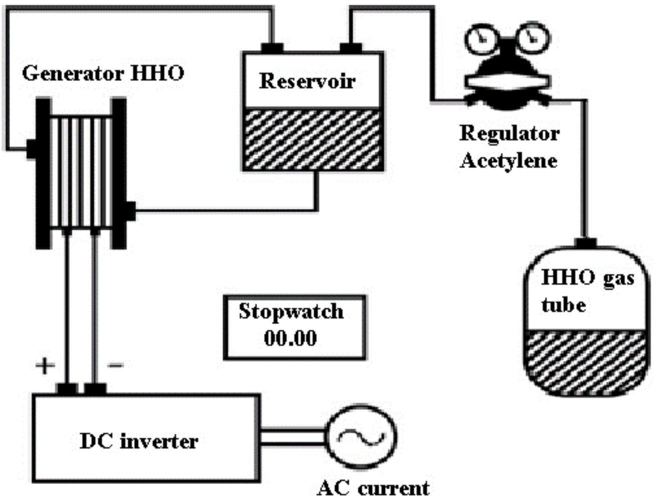

Fig. 1. Experimental set up

4 RESULTS

4.1 HHO Gas Flowrate with Electrical Current Variation

The research undertaken has yielded data regarding the Flowrate of HHO gas coming from the conversion of gas pressure by the HHO generator. The provided dataset comprises measurements of HHO gas flow rates obtained under different electrical current conditions.

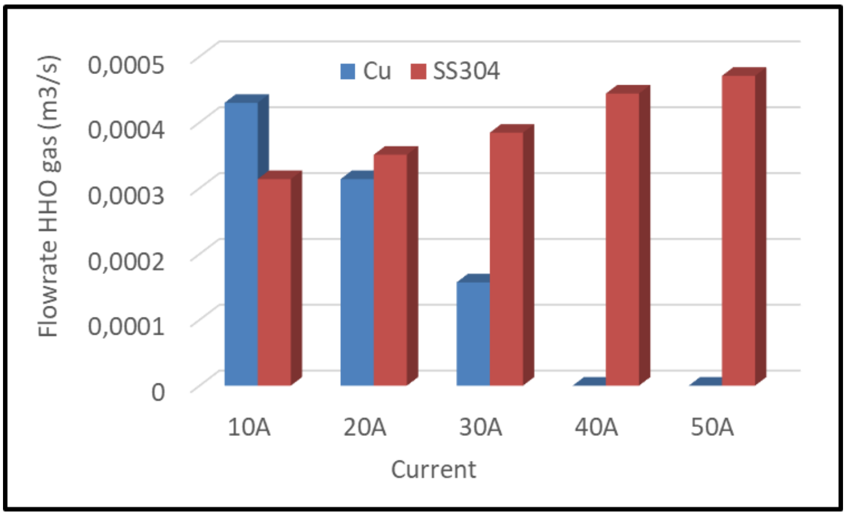

Fig. 2. HHO Gas Flowrate Graph with 10% NaOH Concentration

Fig. 2 shows the gas flow rates generated by the HHO generator with copper and stainless-steel electrodes in the electrolyte solution with a 10% NaOH concentration exhibit different or contrasting trends. In the case of stainless-steel electrodes, it can be observed that the Flowrate of HHO gas exhibits an upward trend, characterized by an average increase of 0.000039219 m^3/s or approximately 20-30% for every incremental rise in the applied electrical current. At the lowest electrical current level (10 A), the generated HHO gas Flowrate is 0.00031375 m^3/s, while at the highest electrical current level (50 A), the HHO gas Flowrate reaches 0.000470625 m^3/s. This indicates that increasing the electrical current can enhance the HHO gas Flowrate produced.

The copper electrode exhibits a significant decrease in the velocity of HHO gas flow. The rate of HHO gas generation is rather low, and as time progresses, this production rate gradually diminishes until the electrolysis process ultimately becomes non-functional, resulting in a flowrate value of 0. The maximum Flowrate of HHO gas was observed at the starting electrical current of 10 A, resulting in a value of 0.00042962 m^3/s.

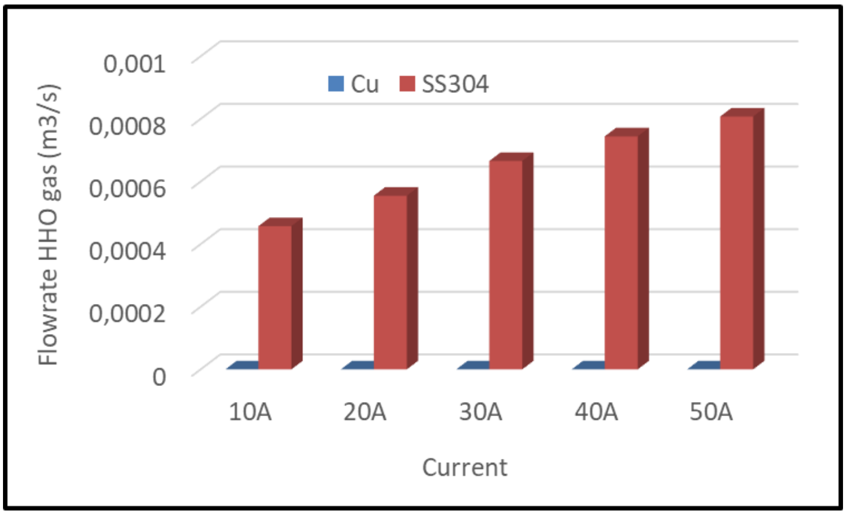

Fig. 3 HHO Gas Flowrate Graph with 50% NaOH Concentration

Fig. 3 shows that the HHO gas Flowrate produced by the stainless-steel electrode in the HHO generator of the dry-cell type increases with a 50% NaOH electrolyte concentration. On average, it increases by 0.00008755 m^3/s or 20-30% with each increase in the applied electrical current. At the lowest electrical current level (10 A), the generated HHO gas Flowrate is 0.000457365 m^3/s, while at the highest electrical current level (50 A), it reaches 0.000807564 m^3/s. An increase in electrical current can boost the HHO gas Flowrate in the generator. The copper electrode prevents water electrolysis, resulting in a 0% HHO gas Flowrate at all electrical current levels.

4.2 HHO Gas Flowrate with Various NaOH Concentrations

Based on the conducted research, the data for HHO gas flowrate resulting from gas pressure conversion in the HHO generator were obtained. The following data represents the HHO gas flowrate produced with various NaOH concentrations.

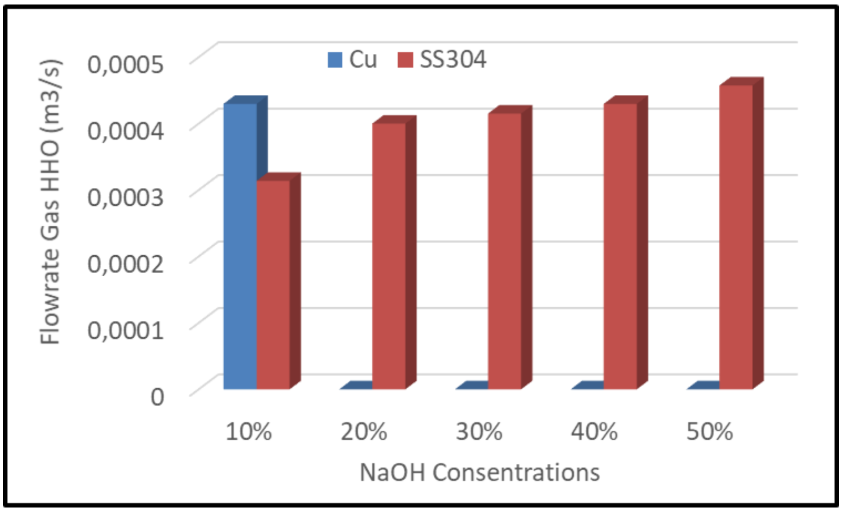

Fig. 4. HHO Gas Flowrate Graph with 10A Electrical Current

Fig. 4 shows that the HHO gas Flowrate generated by the stainless-steel and copper electrodes in the electrolyte with 10 Amperes of electrical current shows inverse or contrasting graphs. For the stainless-steel electrode, the HHO gas Flowrate increases with an average increase of 0.000035904 m^3/s or 20-30% with each increase in NaOH concentration in the electrolyte solution. The most significant increase occurs at a NaOH concentration of 20%, resulting in a Flowrate of 0.000086204 m^3/s. At the lowest NaOH concentration (10%), the produced HHO gas Flowrate is 0.00031375 m^3/s, while at the highest NaOH concentration (50%), it reaches 0.000457365 m^3/s. This demonstrates that apart from increasing the electrical current, the HHO gas Flowrate also increases with higher NaOH catalyst concentrations in the electrolyte solution used in the HHO generator. The greater the NaOH concentration provided, the higher the HHO gas Flowrate produced. However, for the copper electrode, the HHO gas Flowrate experiences a significant decrease, and over time, it diminishes to the point where the electrolysis process stops working entirely. At the lowest NaOH concentration (10%), the HHO gas Flowrate is 0.00042962 m^3/s, and for the subsequent NaOH concentrations, the generated HHO gas Flowrate is zero.

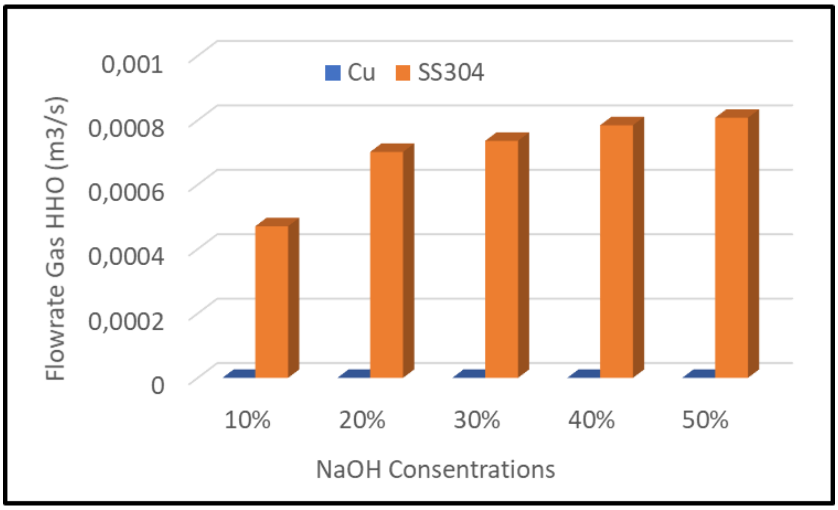

Fig. 5. HHO Gas Flowrate Graph with 50A Electrical Current

Fig. 5 shows that the HHO gas Flowrate produced by the stainless-steel electrode in the electrolyte with 50 Amperes of electrical current increases. The average increase is 0.000084235 m^3/s or 20-30% with each rise in NaOH concentration in the electrolyte solution. The most significant increase occurs at a NaOH concentration of 20%, resulting in a Flowrate of 0.000230941 m^3/s. At the lowest NaOH concentration (10%), the produced HHO gas Flowrate is 0.000470625 m^3/s, while at the highest NaOH concentration (50%), it reaches 0.000807564 m^3/s. This demonstrates that, similar to the previous scenario, increasing the electrical current and NaOH catalyst concentration in the electrolyte solution enhances the HHO gas Flowrate when using the stainless-steel electrode. However, when using the copper electrode, the water electrolysis process does not work, resulting in zero HHO gas Flowrate at all NaOH concentration levels.

The scope of this research encompasses several intricate aspects. The study primarily focuses on experiments involving the use of a Dry Cell HHO Generator, specifically powered by a 900-Watt DC Inverter as the primary voltage source. The electrodes employed in this research are made of copper and stainless-steel type 304, each with a thickness of 0.5 mm. Each HHO generator utilized in each experiment consists of 10 layers of electrode plates. Additionally, for each experiment, a total of 4 liters of water is required to facilitate the process. All testing procedures are conducted within a 1-minute timeframe at each testing level.

5 DISCUSSION

The electrode material used in this study was stainless-steel type 304. Stainless-steel 304 is an austenitic stainless-steel that is corrosion-resistant and consists of 0.042% carbon, 1.19% manganese, 0.034% phosphorus, 0.006% sulfur, 0.049% silicon, 18.24% chromium, 8.15% nickel, and the remaining iron (F_e) [21]. Iron (F_e) and chromium (Cr) are the primary components of stainless-steel, with the highest percentage. In the HHO generator with stainless-steel electrodes, the reactions between stainless-steel and sodium hydroxide (NaOH) solution for hydrogen production can be represented by Equation (3) – (6):

Reaction on iron (Fe):

$$2F_e + 6H_2O + 2NaOH \rightarrow 2NaF_e(OH)_4 + 3H_2 \quad (3)$$

$$NaF_e(OH)_4 \rightarrow NaOH + F_e(OH)_3 \quad (4)$$

Reaction on chromium (Cr):

$$2Cr + 6H_2O + 2NaOH \rightarrow 2NaCr(OH)_4 + 3H_2 \quad (5)$$

$$NaCr(OH)_4 \rightarrow NaOH + Cr(OH)_3 \quad (6)$$

Sodium hydroxide (NaOH) is consumed for hydrogen production through the exothermic reaction (first reaction) and is regenerated through the decomposition reactions of $NaF_e(OH)_4$ and $NaCr(OH)_4$ (second reaction). The combination of these two reactions indicates that only water is consumed for hydrogen production when looking at the reactions.

However, a significant finding in this study is that, in principle, the electrode material performs better with higher electrical conductivity. In this case, the copper electrode should generate more HHO gas due to its higher electrical conductivity compared to stainless-steel electrodes. However, the electrolysis process in the HHO generator with copper electrodes did not work properly. This issue is attributed to the copper electrode's susceptibility to corrosion and the corrosive nature of the NaOH catalyst, which is a strong base that can cause corrosion on the cathode. Consequently, the surface of the electrode plate that comes into contact with the electrolyte corrodes rapidly, obstructing the contact between the electrolyte solution and the electrode. As a result, the electrolysis process inside the HHO generator does not function well, leading to a low HHO gas production rate, which further decreases over time until the electrolysis process stops entirely.

In general, corrosion mechanisms occurring in NaOH solutions begin with the oxidation of copper metal in the solution, releasing electrons to form positively charged metal ions. The solution acts as the cathode with typical reactions involving H_2 release and O_2 reduction due to H^+ and H_2O being reduced. This reaction occurs on the metal surface, leading to repeated dissolution of the metal into the solution.

At low and humid temperatures, corrosion occurs through electrochemical reactions involving oxidation and reduction reactions. Electrochemical reactions can be characterized as chemical reactions that entail the transport of electrons from the anode (-) to the cathode (+) inside the electrolyte solution is given by Equation (7) – (9).

$$\text{Cathode: } Cu^{2+}(aq) + 2e \rightarrow Cu(s) \tag{7}$$

$$\text{Anode: } Cu(s) \rightarrow Cu^{2+}(aq) + 2e \tag{8}$$

The reaction between copper and sodium hydroxide attacks the copper metal, freeing sodium, and can be seen in the following reaction:

$$Cu + 2NaOH \rightarrow CuOH_2 + 2Na \tag{9}$$

The production of HHO gas in water electrolysis depends on electrode material and surface area. Hence, the choice of electrode material should be made considering its favourable attributes of electrical conductivity and resistance to corrosion [22]. The electrolysis process can be influenced by the choice of electrode, as the qualities of each electrode play a significant role. The HHO gas Flowrate produced is directly proportional to the quality of the electrode material employed.

5.1 Effect of Electric Current

Water electrolysis is a chemical reaction that involves the decomposition of water (H_2O) into oxygen (O2) and hydrogen (H_2) gases through the application of an electric current to the water. It is given by Equation (10).

$$\text{Electric energy} + 2H_2O \rightarrow 2H_2 + O_2 \tag{10}$$

At the cathode, two water molecules are reduced through the acceptance of two electrons, leading to the production of hydrogen gas (H_2) and hydroxide ions (OH^-), It is given by Equation (11).

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \tag{11}$$

At the anode, the process of electrolysis causes the dissociation of two water molecules, resulting in the production of oxygen gas (O_2) and the release of four hydrogen ions (H^+) and electrons (e^-) that are then transferred to the cathode. The process of neutralization occurs when H+ and OH^- ions combine, resulting in the regeneration of water molecules is given by Equation (12) [23].

$$2OH^- \rightarrow 1/2\ O_2 + H_2O + 2e^- \tag{12}$$

The analogous water electrolysis reaction is given by Equation (13).

$$2H_2O \rightarrow 2H_2 + O_2 \tag{13}$$

Bubbles composed of hydrogen and oxygen will be generated as a result of this reaction and can be accumulated on the electrode. The aforementioned concept is then employed to generate hydrogen peroxide (H_2O_2), which can serve as a fuel source for cars driven by hydrogen.

Electrolysis occurs when an electric current flows through an ionic compound and undergoes chemical reactions. An electrolyte solution can conduct electricity because it contains ions that can move freely. These ions are responsible for conducting the electric current through the solution. The number of ions conducting current directly affects electric current magnitude. The escalation in the quantity of ions engaged in the process of current conduction results in an elevated rate of reaction [24]. Consequently, when the magnitude of the electric current increases, there is a proportional increase in the rate of HHO gas flow.

5.2 Effect of NaOH Concentration

To speed up the process, this study uses NaOH as a catalyst. Sodium hydroxide dissociates into sodium cations and hydroxide anions in water. Water dissolves sodium hydroxide, which generates heat. In the alkaline solution, OH^- ions enhance copper or stainless-steel interaction with water [25].

Reaction on stainless-steel electrode with NaOH solution

The main components of stainless steel are iron (Fe) and chromium (Cr), and the reactions that occur with both elements are given by Equation (14) – (19).

Reaction on iron (F_e):

$$2Fe + 6H_2O + 2NaOH \rightarrow 2NaFe(OH)_4 + 3H_2 \quad (14)$$

$$NaFe(OH)_4 \rightarrow NaOH + Fe(OH)_3 \quad (15)$$

Reaction on chromium (Cr):

$$2Cr + 6H_2O + 2NaOH \rightarrow 2NaCr(OH)_4 + 3H_2 \quad (16)$$

$$NaCr(OH)_4 \rightarrow NaOH + Cr(OH)_3 \quad (17)$$

Reaction on copper electrode with NaOH solution

$$2Cu + 6H_2O + 2NaOH \rightarrow 2NaCu(OH)_4 + 3H_2 \quad (18)$$

$$NaCu(OH)_4 \rightarrow NaOH + Cu(OH)_3 \quad (19)$$

Sodium hydroxide (NaOH) is consumed in the exothermic reaction (first reaction) to produce hydrogen and is regenerated through the decomposition reactions of $NaFe(OH)_4$, $NaCr(OH)_4$, and $NaCu(OH)_4$ (second reaction). The combination of these two reactions indicates that only water is consumed for hydrogen production when considering these reactions.

The research limitations use a HHO generator-type dry Cell. The voltage source uses a 900-watt DC Inverter. The electrodes used are made of copper and SUS 304 with a thickness of 1,0 mm, with the electrode plate size being 250 mm x 400 mm. where each HHO generator consists of 10 layers of electrode plates with four litres of water.

The research makes a significant contribution to scientific knowledge in the use of HHO generators, considering electrodes, electrical current, and the concentration of NaOH catalyst. The results indicate that stainless steel electrodes yield the highest rate of HHO gas production, and increasing electrical current and NaOH concentration enhances HHO gas production. These findings have the potential to advance the development of more efficient and environmentally friendly alternative fuels.

6 CONCLUSION

The Flowrate of gas generated by the HHO generator is subject to notable influence from variations in electrode materials, electric current, and catalyst concentration (NaOH). The choice of electrode material plays a crucial role, with stainless-steel electrodes yielding the highest Flowrate of HHO gas among the tested materials. Additionally, increasing the electric current leads to a proportional increase in the Flowrate of HHO gas, with a trend of approximately 20–30% higher Flowrate for each 10 A increment on the stainless-steel electrode. Moreover, the concentration of the catalyst (NaOH) also plays a vital role, as higher concentrations lead to increased electrical conductivity of the solution, resulting in higher flow rates of HHO gas during the water electrolysis process. The optimal conditions for maximizing HHO gas production in the generator involve utilizing stainless-steel electrodes, higher electric currents, and higher NaOH concentrations. These findings hold significant implications for further research and development of HHO generators as a promising alternative fuel source.

7 ACKNOWLEDGEMENTS

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