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Generating Hydrogen Gas with a Polyvinyl Alcohol Membrane Dry Cell Electrolyzer Using KOH Electrolyte

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Abstract: Global environmental concerns requiring excellent air quality have prompted the development of a variety of eco-friendly energy sources. Hydrogen gas is an environmentally friendly option that may be created using an electrolysis device that converts water into hydrogen (H_2) and oxygen (O_2). In this study, a dry cell electrolyzer with a polyvinyl alcohol (PVA) membrane was used as a separator between two stainless steel 316 electrodes to generate a high hydrogen yield. The hydrogen gas production from the dry cell electrolyzer was determined using gas chromatography. The results showed that using a KOH electrolyte and a PVA membrane considerably enhanced the hydrogen gas composition. Hydrogen gas compositions after electrolysis using a dry cell electrolyzer without a PVA membrane and KOH electrolyte concentrations of 0 M, 0.04 M, 0.07 M, and 0.11 M being 13.70%, 25.10%, 32.50%, and 15.60%, respectively. With a PVA membrane, the hydrogen compositions were 71.50%, 89.10%, 80.50%, and 84.60%, respectively. The results of these experiments show that the most hydrogen gas was produced utilizing a dry cell electrolyzer with a PVA membrane and a 0.04 M KOH electrolyte concentration. When a PVA membrane and a KOH electrolyte are utilized in electrolysis, the hydrogen gas composition improves significantly compared to when either is utilized.

Keywords: Dry cell electrolyzer, hydrogen, KOH, Polyvinyl Alcohol Membrane

1. Introduction

The limitations posed by fossil fuels and the growing need for eco-friendly energy require diversifying energy sources to ensure availability. This shift has led to an increased adoption of renewable energy [1]. Moving towards sustainable energy solutions, leveraging hydrogen derived from renewable sources becomes crucial in efforts to lower carbon emissions and establish a sustainable energy landscape [2]. Hydrogen, recognized for its substantial energy density, stands out as a promising environmentally friendly energy carrier. The demand for electrolytic hydrogen generation stems from the depletion and environmental effect of fossil fuels, which are primary contributors to the worldwide environmental issues we encounter [3].

Electrolysis is a process that produces hydrogen and oxygen gases by breaking down water molecules (H_2O) with an electric current. At the cathode, water molecules acquire electrons to generate hydrogen gas (H_2) and hydroxide ions (OH-). Conversely, at the anode, water molecules decompose into oxygen gas (O_2), releasing hydrogen ions (H+) and electrons [4]. The hydrogen and oxygen gases produced form bubbles around the electrodes and can be collected. This technique finds application in the production of hydrogen and hydrogen peroxide (H_2O_2) for diverse uses, including as fuel for hydrogen-powered vehicles [5].

There exist two primary types of electrolyzer: wet cell and dry cell variants. Dry cell electrolyzer are widely preferred in both small and large-scale hydrogen production systems over their wet cell counterparts. Their advantages encompass enhanced gas purity, cost-effective electrode materials, and greater ease of access [6,7].

The Polyvinyl Alcohol (PVA) membrane provides advantages in Dry cell electrolyzer by serving as an effective separator. It not only enhances dimensional stability and electrochemical performance but also significantly boosts hydrogen production efficiency. For instance, it achieves a current density of 0.38 A/cm² at 2V with a 5% KOH solution at 30°C. Moreover, this membrane is cost-effective, demonstrates robust performance in standard operating conditions, and surpasses numerous commercially available separator membranes. These attributes offer valuable insights for the development of future membrane designs [8].

Potassium hydroxide (KOH) in the electrolyte solution is pivotal for improving hydrogen production during electrolysis. Studies demonstrate that the concentration of KOH has a profound impact on productivity rates, energy usage, and overall process efficiency. Higher KOH concentrations result in higher rates of hydrogen production. Furthermore, KOH significantly boosts hydrogen productivity compared to conventional Faraday electrolysis techniques. Consequently, KOH plays a critical role in optimizing process efficiency [9].

Increasing the concentration of the catalyst leads to higher observed electric currents, facilitating more electron transfers and consequently accelerating the rate of oxyhydrogen gas formation [10].

In this research, hydrogen gas is generated through a PVA membrane dry cell electrolyzer employing KOH as the electrolyte. The presence of the membrane leads to gas with a higher hydrogen content compared to using a membrane-less dry cell electrolyzer. KOH acts as a catalyst that can generate higher electrical currents compared to NaOH, KCl, and seawater, consequently yielding greater quantities of gas [11].

2. Material and Method

2.1. Material

The components utilized include a 15 mm thick PVA membrane for gas separation, with KOH electrolyte varying in concentrations of 0.00 M, 0.04 M, 0.07 M, and 0.11 M. Stainless steel 316 electrodes sized at 16 x 16 cm are employed for this setup.

2.2. Method

The process of water electrolysis results in a combination of hydrogen and oxygen gases [12]. The reactions taking place at the electrodes are detailed below:

Cathode : $2H_2O + 2e^- \rightarrow H2 + 2OH^-$ (1)

Anode : $4OH^- \rightarrow O_2 + 2H_2O + 4e$ (2)

Overall reaction : $2H_2O \rightarrow 2H_2 + O_2$ (3)

The dry cell electrolyzer is equipped with a KOH electrolyte solution, which is then energized with an electric voltage to generate hydrogen and oxygen gases. Serving as a separator, the PVA membrane facilitates the flow of ions while effectively isolating the hydrogen and oxygen gases produced. Figure 1 illustrates the components of the hydrogen gas production apparatus.

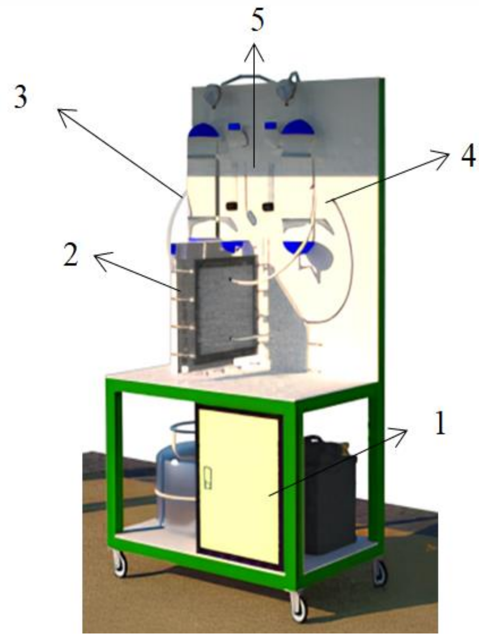

Figure 1. *Prototype of the Hydrogen Gas Generation Device*

Description of the image: 1. Power supply, 2. PVA membrane Dry Cell Electrolyzer, 3. Oxygen storage tank, 4. Hydrogen storage tank, 5. Flowmeter. The high cost and energy requirements of the water electrolysis process pose challenges to its implementation. Optimization is necessary for hydrogen production using water electrolysis methods to meet sustainable hydrogen production needs [13]. The electrolyzer developed in this study is a dry-cell electrolyzer consisting of one anode electrode and one cathode electrode [14]. The electrode material used in this electrolyzer is stainless steel 316, which offers high conductivity at a lower cost compared to other electrode materials [15]. A larger electrode cross-sectional area facilitates easier electron transfer during the electrolysis process, resulting in more electrons reacting and generating a larger electric current [16].

3. Result and Discussion

3.1. The Impact of Implementing a PVA Membrane in a Dry

Cell Electrolyzer

A dry cell electrolyzer is a device where only part of the electrodes are immersed in the electrolyte, which occupies the space between the electrodes. This type of electrolyzer primarily benefits from minimal water usage, as the electrolyte water is confined between the cell plates. Circulating hot and cold water in the storage tanks helps minimize heat generation. Consequently, less energy is lost as heat, leading to a relatively reduced consumption of electric current. However, the system's downside is that the hydrogen composition is often low due to a high percentage of oxygen gas (O_2). For hydrogen to be a viable alternative energy source, achieving a high hydrogen composition is essential.

Hence, incorporating a PVA membrane can improve the efficiency of a dry cell electrolyzer by yielding a higher hydrogen content. The inclusion of a PVA membrane influences the gas composition produced, as demonstrated in Table 1 and depicted in Figures 2 and 3.

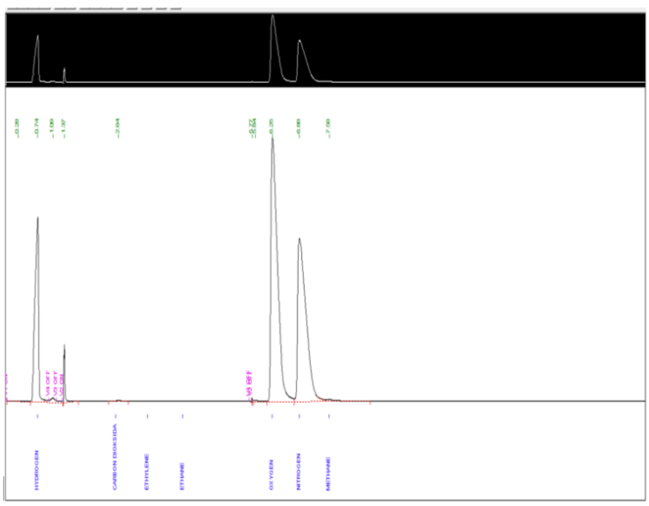

Figure 2. *Gas Composition Measurement Curve from Electrolysis Using a Dry Cell Electrolyzer Without KOH Electrolyte and PVA Membrane (S1)*

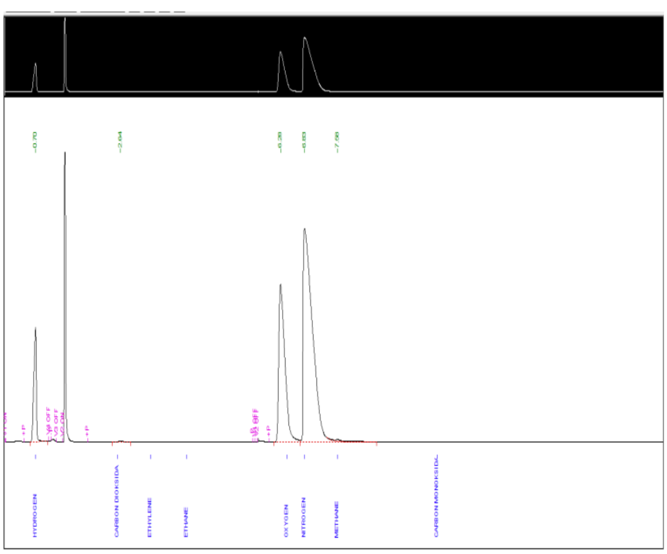

Figure 3. *Measurement curve of gas composition resulting from electrolysis using a dry cell electrolyzer with 0.04 M KOH electrolyte and a PVA membrane (S6)*

Table 1. *Composition of Gases*

Gas (% mol)	*S1	*S2	*S3	*S4	*S5	*S6	*S7	*S8
H_2	13,7	25,1	32,5	15,6	71,5	89,1	80,5	84,6
N_2	57,6	32,8	34,1	50,2	18,6	6,8	11,9	9,8
O_2	28,7	42,2	33,4	34,2	9,9	4,1	7,6	5,6

*S1 does not have a KOH electrolyte or a PVA membrane.
*S2 has 0.04 M KOH electrolyte but does not have a PVA membrane.
*S3 has 0.07 M KOH electrolyte but does not have a PVA membrane.
*S4 has 0.11 M KOH electrolyte but does not have a PVA membrane.
*S5 lacks KOH electrolyte but includes a PVA membrane.
*S6 has 0.04 M KOH electrolyte and includes a PVA membrane.
*S7 has 0.07 M KOH electrolyte and includes a PVA membrane.
*S8 has 0.11 M KOH electrolyte and includes a PVA membrane.

The PVA membrane efficiently separates the produced hydrogen gas [17], in line with research that shows a notable rise in hydrogen concentration. Figure 2 illustrates that S6, employing a 1.5 mm thick PVA membrane with 0.04 M KOH electrolyte, attained the highest hydrogen composition at 89.1%, whereas S2, using 0.04 M KOH electrolyte without a PVA membrane, achieved only 25.1%.

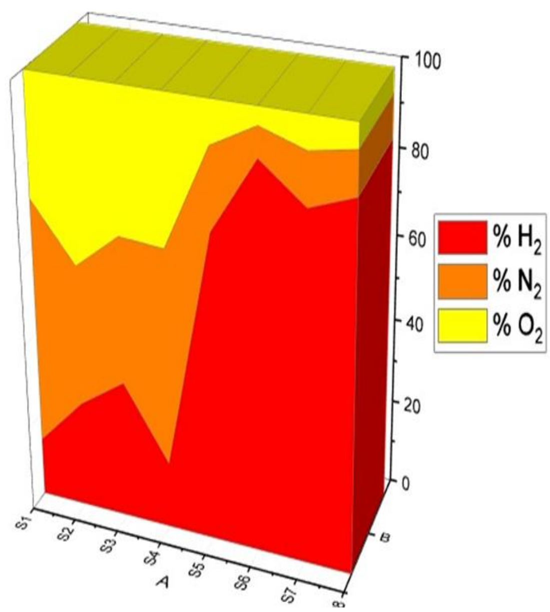

***Figure 4**. Composition of Gases*

During the electrolysis of water with KOH as the electrolyte, redox reactions occur, resulting in the production of gases. When the electrodes are activated, they break down compounds within the electrolyte, generating ions.

While this method of electrolysis is effective and efficient, it demands a substantial electric current. As the current flows, the electrodes (cathode and anode) become interconnected.

Electrolyzing water with an electrolyte using an electric current splits water (H_2O) into hydrogen (H_2) and oxygen (O_2). This process also yields hydroxide ions (OH-) and hydrogen gas (H_2).

Hydrogen possesses superior characteristics such as a high calorific value, faster laminar flame speed, and lower gasoline ignition energy, making it a potential alternative fuel for engines. Hence, ensuring high-purity hydrogen is essential.

The use of a PVA membrane significantly enhances the composition of hydrogen gas, underscoring its importance in this research.

3.2. The impact of varying KOH electrolyte concentrations on the dry cell electrolyzer

Electrolytes can modify water properties, directly impacting the voltage needed for electrolysis at specific current levels. The concentration of the electrolyte affects the quantity of gas produced and determines the optimal catalyst concentration for efficiently generating hydrogen gas to achieve sustainable energy production [18,19].

When conducting water electrolysis using KOH as the electrolyte, energized electrodes initiate the breakdown of compounds within the electrolyte, resulting in ion generation. While this electrolysis method is effective and efficient, it demands a significant electric current. As the current flows, the electrodes (cathode and anode) establish connectivity.

Elevated concentrations of electrolyte enhance surface reactions within the electrolyte, thereby increasing ionic conductivity, ion mobility, and current intensity. Consequently, this leads to heightened gas flow rates and volumes from the electrolysis process [20,21].

The hydrogen gas content is lowest and varies significantly when using KOH electrolyte, with an increase in hydrogen gas content at each concentration. The KOH concentration also impacts the amount and volume of hydrogen gas produced [22].

The electrical resistance is influenced by the KOH electrolyte concentration; higher KOH molarity results in higher current flow, as seen in Figure 5.

Based on hydrogen production with a dry cell electrolyzer using a PVA membrane and KOH electrolyte, the highest hydrogen gas composition achieved was 89.10% using a PVA membrane and 0.04 M KOH, whereas the lowest hydrogen gas composition was 13.70% without using a PVA membrane or KOH.

Gas production increased gradually with higher KOH concentrations due to increased uniform charge density. The discrepancy between the theoretical and experimental gas flow rates also increased with higher currents. Previous research has shown that using KOH significantly enhances hydrogen production composition. KOH has high ionic conductivity, although its highly corrosive nature limits the choice of materials that can be used with it [23].

Electrolytes speed up reactions by reducing activation energy while keeping reaction equilibrium unchanged. During water electrolysis, highly alkaline electrolyte solutions are employed to improve electrical conductivity among cells. Just like strong acids, strong alkaline electrolytes can potentially induce metal corrosion when utilized [24].

The conductivity of a solution is influenced by the concentration of electrolytes dissolved in water. Higher molarity levels of electrolytes correspond to increased electric current flow, suggesting that electrolyte solutions possess higher electrical conductivity capabilities, thereby facilitating easier passage of electricity through them.

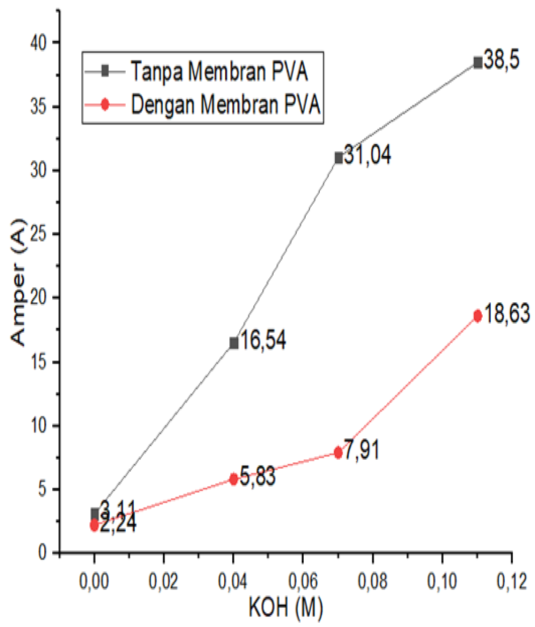

***Figure 5.** The Impact of KOH Concentration and PVA Membrane on Electrical Current*

4. Conclusion

The results of the study on hydrogen gas generation with a PVA membrane electrolyzer and a KOH electrolyte showed a comparison of hydrogen composition. The greatest hydrogen composition of 89.10% was obtained with a 0.04 M KOH electrolyte and a PVA membrane, whereas the lowest hydrogen composition of 13.70% was obtained without either a PVA membrane or KOH. According to the research findings, using a PVA membrane and KOH electrolyte during electrolysis can greatly increase the composition of hydrogen gas compared to not utilizing a PVA membrane and KOH electrolyte.

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