Electric Power Supply of Mobile Phone Charging Station from Electrolyzed Hydrogen Using Hydrogen Fuel Cell

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Abstract. The demand for improved air quality due to global environmental issues promotes the development of various sustainable energy sources. Hydrogen gas, a clean-burning fuel, can be produced through the electrolysis process. This approach utilizes a dry cell electrolyzer equipped with a polyvinyl alcohol (PVA) membrane, which acts as a separator for the two electrodes, preventing hydrogen and oxygen from mixing. It is also to increase the composition of hydrogen gas significantly. The application of KOH electrolyte can increase the electric current, which contributes to the increased power requirement and more significant hydrogen gas production. The hydrogen produced is converted into electrical energy utilized to supply charging stations and mobile phones as loads using hydrogen fuel cells with the results of charging successful (CS) and charging failed (CF) status. KOH electrolyte variation are 0 M, 0.04 M, 0.07 M and 0.11 M sequentially in each hydrogen production experiment without using PVA membrane and by using PVA membrane thickness of 1.5 mm and 3 mm. For electrolysis using PVA membrane thickness of 1.5 mm requires power of 26.81 VA, 67.51 VA, 92.63 VA, 211.82 VA resulting in hydrogen composition of 71.50%, 89.10%, 80.50%, 84.60% and hydrogen fuel cell produces power of 0 VA, 2.71 VA, 2.06 VA, 2.98 VA with CF, CS, CS, CS status. The highest hydrogen composition of 89.10% was obtained from the electrolysis of PVA membrane thickness of 1.5 mm using KOH electrolyte concentration of 0.04 M. But no less important electrical power efficiency (comparison of electrical power requirements in dry cell electrolyzer and electrical power generated in hydrogen fuel cell) highest of 17.79% obtained in dry cell electrolyzer with PVA membrane thickness of 3 mm using KOH electrolyte concentration of 0.04 M.
Keywords: Electrical power, Hydrogen fuel cell, KOH, PVA membrane

1 Introduction

The need for good air quality during global environmental problems encourages the development of various environmentally friendly energy sources, thus encouraging the increased use of renewable energy [1]-[3]. On the road to green energy, the use of hydrogen from renewable energy sources is essential to reduce carbon emissions and ensure a sustainable energy future [4]. The demand for hydrogen production via electrolysis arises from the exhaustion and contamination caused by fossil fuels, which play a significant role in the global environmental crisis [5].

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Electrolysis generates hydrogen and oxygen gases by breaking down water molecules (H_2O) into oxygen (O_2) and hydrogen (H_2) with the application of an electric current. In this process, water molecules at the cathode gain electrons to produce hydrogen gas (H_2) and hydroxide ions (OH^-). Meanwhile, at the anode, water molecules split to release oxygen (O_2) along with H^+ ions and electrons [9]-[12].

Stainless steel 316 (SS 316) electrodes are well-regarded in electrolysis for their excellent conductivity and their suitability as cost-effective, bifunctional electrocatalysts for water splitting. This makes SS 316 electrodes an optimal choice, as they show promising performance in facilitating sustainable hydrogen production via water electrolysis [13].

The Polyvinyl Alcohol (PVA) membrane has a pore size ranging from 1-2 μm, which is smaller than the size of oxygen (O_2) molecules, measured at 2-3 μm [14]. This smaller pore size, along with the membrane's thicker solid layer, reduces O_2 permeation, making it effective as a separator in dry cell electrolyzers.

The production rates of hydrogen and oxygen gases in KOH solution electrolysis are influenced by both solution concentration and electric current. Results indicate that hydrogen gas production rises with increased electric current and higher KOH concentration, and oxygen gas production follows a similar trend. Thus, optimizing the KOH concentration and electric current can enhance the efficiency of hydrogen and oxygen gas generation through electrolysis [15]-[17].

In this study, electrolysis is conducted using SS 316 electrodes arranged in parallel and a polyvinyl alcohol (PVA) membrane to prevent hydrogen and oxygen from mixing, aiming to achieve an optimal hydrogen gas composition. The researcher also adjusts the concentration of the KOH solution and varies the thickness of the PVA membrane to maximize hydrogen volume output from the dry cell electrolyzer and optimize the electrical power produced by the hydrogen fuel cell.

The hydrogen fuel cell efficiently transforms oxidants and the chemical energy stored in fuel directly into DC electricity, producing heat and water as by-products. As an effective electrochemical converter and power generation technology, the hydrogen fuel cell is drawing significant interest for its clean energy output, independence from fossil fuels, and its capability to generate electricity without the need for mechanical movement [18]-[20].

2 Materials and Methods

2.1 Materials

In this study, PVA membranes of thicknesses 0 mm, 1.5 mm, and 3 mm are used, along with KOH electrolyte solutions at different molar concentrations of 0.00 M, 0.04 M, 0.07 M, and 0.11 M. The electrodes employed are made of stainless steel 316, each measuring 16 x 16 cm.

Electrolytes aid reactions by lowering the activation energy, without altering the reaction equilibrium. In water electrolysis, a strong base electrolyte solution is used to enhance electrical conductivity between cells. Like strong acids, strong base electrolyte solutions may also lead to metal corrosion when applied.

The concentration of the electrolyte solution in water affects its conductivity. With an increase in the molarity of the electrolyte, the electric current that can flow through the solution also increases. This suggests that the electrolyte solution possesses a greater ability to conduct electricity, facilitating a more efficient flow of electric current.

The setup consists of four hydrogen fuel cells, each with a voltage rating of 0.9 volts, connected in series to generate the necessary voltage for the charging station, which requires a minimum input voltage of 3.8 volts. This configuration is designed to power a cellphone equipped with a 5000 mAh battery as the load.

2.2 Electrolysis Process

At the cathode, the reaction occurs as follows: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$. At the anode, the process is represented by the equation: $4OH^- \rightarrow O_2 + 2H_2O + 4e$. The overall reaction can be summarized as: $2H_2O \rightarrow 2H_2 + O_2$.

The dry cell electrolyzer is filled with an electrolyte solution based on KOH and subjected to an electric voltage, resulting in the production of hydrogen and oxygen gases. The PVA membrane serves as a separator, facilitating ion movement while keeping the hydrogen and oxygen gases separated. Figure 1 illustrates the components of the hydrogen production system, which include: 1. Power supply, 2. Dry cell electrolyzer with PVA membrane, 3. Oxygen collection tube, 4. Hydrogen collection tube, and 5. Flowmeter.

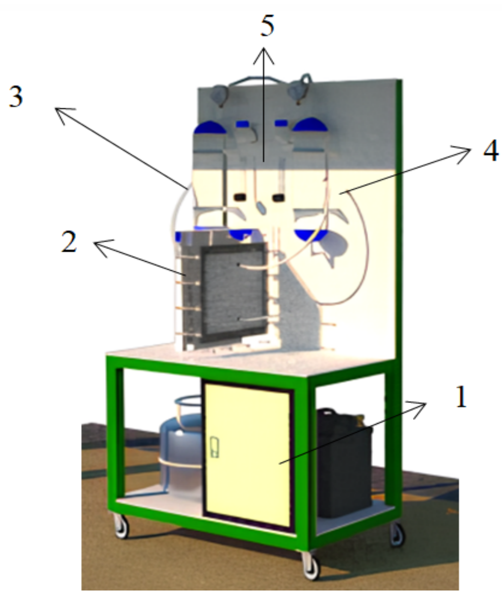

Fig. 1. Prototype of the Hydrogen Gas Production System

The significant expenses and energy demands associated with the water electrolysis process present challenges to its practical application. To achieve sustainable hydrogen production, it is essential to optimize the hydrogen generation process through water electrolysis. This research presents a dry cell electrolyzer design containing a single anode and cathode. The electrodes are constructed from 316 stainless steel, a material chosen for its high conductivity and cost-effectiveness compared to other electrode materials.

The high costs and energy requirements of the water electrolysis process present barriers to its practical use. To enable sustainable hydrogen production, optimization of hydrogen generation via electrolysis is necessary. This research introduces a dry cell electrolyzer, comprising a single anode and cathode. The electrodes are made of 316 stainless steel, a material selected for its excellent conductivity and comparatively lower cost than alternative electrode materials.

2.3 Hydrogen Fuel Cell Process

Hydrogen fuel cells convert the chemical energy stored in fuel and oxidants directly into DC electricity, generating heat and water as by-products, with no moving mechanical components. One of the most promising fuel cell technologies for commercialization is the polymer electrolyte membrane fuel cell (PEMFC). Unlike traditional power engines, such as gas turbines, steam turbines, or internal combustion engines, which rely on thermal cycles, fuel cells are not limited by the Carnot cycle and can achieve higher efficiency. However, the high costs of fuel cell technology have hindered its broader adoption. Researchers are working on developing new materials and manufacturing processes to improve fuel cell performance and reduce component costs. Current efforts focus on enhancing efficiency, durability, and reliability to make fuel cells competitive with conventional combustion engines. This review examines the use of PEMFCs in a series configuration, consisting of four units, each with a voltage output of 0.9 V, to meet the required 3.8 VDC for charging stations.

3 Result and Discussion

3.1 Impact of PVA Membrane on the Gas Composition of Electrolysis Results from a Dry Cell Electrolyzer

The dry cell electrolyzer generates hydrogen using different concentrations of KOH electrolyte and varying thicknesses of the PVA membrane. The KOH concentrations tested were 0.00 M, 0.04 M, 0.07 M, and 0.11 M, while the PVA membrane thicknesses were set at 0 mm, 1.5 mm, and 3 mm, with each solution volume being 0.5 liters. A power supply with a constant voltage of 12 VDC was utilized, and two electrode plates were employed. The composition of the produced gas was analyzed using an Agilent 7890B gas chromatograph, as detailed in Table 1.

Table 1. Gas Composition

Gas (% mol)	*S1	*S2	*S3	*S4	*S5	*S6	*S7	*S8	*S9	*S10	*S11	*S12
H_2	13.7	25.1	32.5	15.6	71.5	89.1	80.5	84.6	84.2	80.6	84.7	88.5
N_2	57.6	32.8	34.1	50.2	18.6	6.8	11.9	9.8	8.7	13.1	10.0	7.3
O_2	28.7	42.2	33.4	34.2	9.9	4.1	7.6	5.6	7.1	6.3	5.3	4.2

*S1 refers to the setup without KOH electrolyte and PVA membrane.
*S2 includes 0.04 M KOH electrolyte but lacks a PVA membrane.
*S3 utilizes 0.07 M KOH electrolyte without a PVA membrane.
*S4 incorporates 0.11 M KOH electrolyte without a PVA membrane.
*S5 represents the configuration without KOH electrolyte and with a PVA membrane of 1.5 mm thickness.
*S6 features 0.04 M KOH electrolyte along with a 1.5 mm thick PVA membrane.
*S7 contains 0.07 M KOH electrolyte combined with a 1.5 mm thick PVA membrane.
*S8 consists of 0.11 M KOH electrolyte with a 1.5 mm thick PVA membrane.
*S9 is without KOH electrolyte with PVA membrane of 3 mm thickness
*S10 is with 0.04 M KOH electrolyte with 3 mm thickness PVA membrane
*S11 is with 0.07 M KOH electrolyte with PVA membrane of 3 mm thickness
*S12 is with 0.11 M KOH electrolyte with 3 mm thickness PVA membrane
*S1 to S8 are obtained from previous research data [9].

Research that has been carried out on dry cell electrolyzer with variations in KOH electrolyte concentration and PVA membrane thickness produces some gas measurement data using Agilent 7890B gas chromatography and gets the results of measuring the presence of hydrogen, oxygen and nitrogen gas, this is a reference for researchers that the equipment that has been made has functioned properly to produce hydrogen gas from each variation of KOH electrolyte concentration and PVA membrane thickness in order to get optimal results.

This proves that the PVA membrane can prevent the mixing of oxygen and hydrogen produced, resulting in a higher hydrogen composition compared to electrolysis without the use of a PVA membrane. Polyvinyl alcohol (PVA) membrane increases the hydrogen gas composition significantly, it is very important to use PVA membrane in this study.

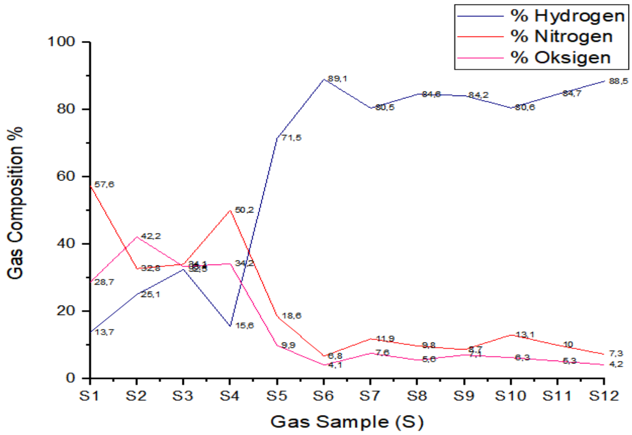

Fig. 2. Gas Samples

3.2 Effect of KOH Electrolyte Solution on Electrical Power of Dry Cell Electrolyzer

Electrolytes have the ability to alter water's characteristics, which in turn impacts the necessary voltage for electrolysis at a specified current. The concentration of the electrolyte plays a key role in determining the gas production rate [10,11]. A higher concentration of electrolytes boosts surface interactions, improving ionic conductivity, increasing ion mobility, and enhancing current intensity. As a result, this leads to a higher rate of gas generation during electrolysis [8,12]. The change in electrical resistance is influenced by the KOH electrolyte concentration; as the molarity of KOH rises, the current increases, which results in a greater electrical power, as shown in Fig. 3.

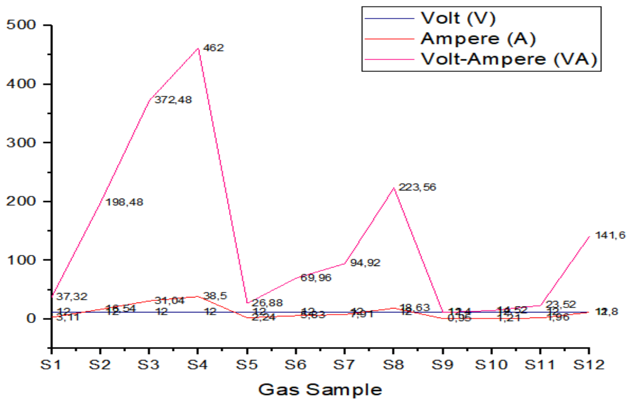

Fig. 3. Effect of Different KOH Electrolyte Solution Levels on the Electrical Power of the Dry Cell Electrolyzer

Fig. 3 shows that the concentration of KOH electrolyte can affect the amount of current required in the electrolysis process to produce hydrogen gas. This happens because the concentration of KOH electrolyte affects the conductivity of the solution, which is the ability of the solution to conduct electric current. Previous research has shown that the rise in KOH concentration is directly related to an increase in hydrogen gas production, as it enhances the conductivity of the water. Higher conductivity results in a greater electric current, which accelerates the electrolysis process, breaking water down into hydrogen and oxygen more efficiently. With a higher electrolyte concentration, more ions are available to move and carry the electric charge, which further boosts the solution's conductivity. As a result, a higher concentration leads to increased hydrogen gas production. Besides conductivity, the concentration of the electrolyte also influences the number of ions in the solution. As the concentration increases, more ions are present to take part in the electrolysis process. If the electrolyte concentration is high, the number of ions involved in the electrolysis reaction will be greater, and this causes the amount of electric current flowing to also be higher.

3.3 Effect of Electrolyte Concentration and PVA Membrane on Gas Production

After understanding how varying KOH levels impact the electric current needed for the electrolysis process and noting the differences between each KOH electrolyte variation, the next step is to compare the resulting production flow.

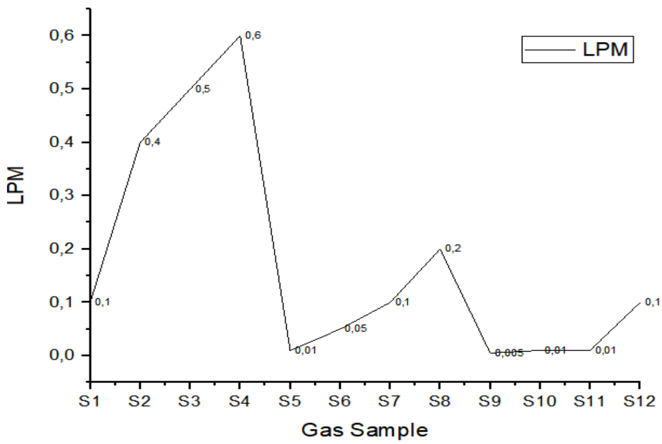

Fig. 4. Effect of KOH Electrolyte Concentration and PVA Membrane on Gas Production in Dry Cell Electrolyzer

These results are consistent with the experimental data, which show that KOH produces the highest gas output of 0.6 LPM at a concentration of 0.11 M, compared to lower concentrations of 0.07 M, 0.04 M, and 0.00 M, regardless of the presence of a PVA membrane in the dry cell electrolyzer. This trend is reflected in Figures 4.6 to 4.8, which illustrate that the electric current also rises as the KOH concentration increases.

However, the opposite trend is observed when the dry cell electrolyzer utilizes a PVA membrane; the electric current decreases as the thickness of the PVA membrane increases. This indicates that the introduction of a PVA membrane increases the distance between the electrodes, resulting in higher electrical resistance and hindering the flow of electric current.

In a dry cell electrolyzer without a PVA membrane, gas output rates of 0.10 LPM, 0.40 LPM, 0.50 LPM, and 0.60 LPM correspond to KOH electrolyte concentrations of 0.00 M, 0.04 M, 0.07 M, and 0.11 M, respectively. When a 1.5 mm thick PVA membrane is used, gas production rates measure 0.00 LPM (not measurable), 0.05 LPM, 0.10 LPM, and 0.20 LPM, in that order. With a 3 mm thick PVA membrane, the measurements are 0.00 LPM (not measurable), 0.00 LPM, 0.00 LPM, and 0.10 LPM, respectively. Generally, an increase in electric current corresponds to a higher gas production rate.

3.4 The Effect of KOH Electrolyte Concentration and Polyvinyl Alcohol (PVA) Membrane on the Comparison of Electric Power Required in Dry Cell Electrolyzer and Electric Power Generated in Hydrogen Fuel Cells

Hydrogen Fuel Cell is a tool to convert hydrogen gas produced into DC electricity. The specifications of the hydrogen fuel cell used in the study are 0.9 volts as many as 4 units arranged in series in order to get the required voltage and supply electricity to the charging station and get the results of the status of successful charging (SC) or charging failed (CF) on a 5000 mAh mobile phone battery as a load with a minimum voltage of 3.8 Volt. The measurement results of voltage, current and power (VA) can be seen in Fig. 5.

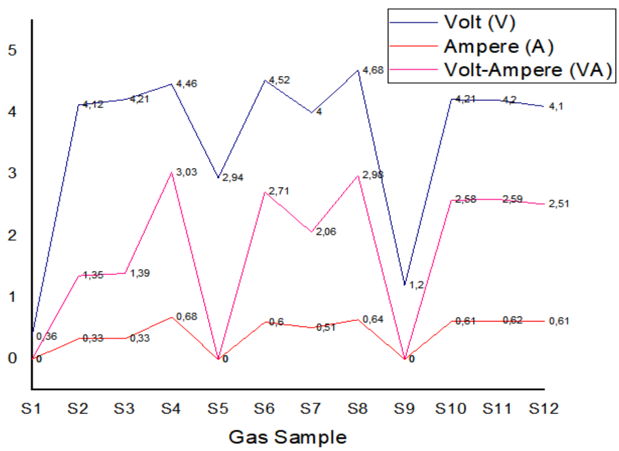

Fig. 5. Electrical power (VA) generated in hydrogen fuel cell

From Fig. 5. It can be seen which gas sample is the best seen from the comparison of electrical power in the process of producing hydrogen with dry cell electrolyzer until it produces electrical power (VA) again using hydrogen fuel cell to be utilized for charging cell phone batteries as loads. Comparison of the best electrical power obtained in sample S10 (with 0.04 M KOH electrolyte with 3 mm thickness PVA membrane) where the electrical power required dry cell electrolyzer amounted to 14.52 VA and the electrical power generated in the hydrogen fuel cell amounted to 2.58 VA, then the percentage of comparison results obtained by 17.74%. Cell phone charging status from samples S1 to S12 successively obtained results CF, SC, SC, SC, CF, SC, SC, SC, CF, SC, SC and SC.

4 Conclusion

Dry cell electrolyzer successfully produces hydrogen gas as evidenced by the results of gas measurements with gas chromatography, hydrogen can be an environmentally friendly energy carrier and produce electrical energy using hydrogen fuel cells as evidenced by the status of successful charging on the charging display on the cellphone. A short time is needed between the hydrogen production time and measurement using gas chromatography so that the gas produced from the dry cell electrolyzer is not contaminated with ambient air, namely oxygen and nitrogen. Hydrogen from electrolysis is also important to do storage first before flowing into the hydrogen fuel cell so that the speed of hydrogen flow flowing into the hydrogen fuel cell can be adjusted and can be measured constantly and the hydrogen fuel cell can produce stable electrical power in order to obtain optimal electrical power comparison results.

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