Studies on Hydrogen Evolution Using PEM Electrolyzer

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***Abstract* - Water electrolysis is one of numerous ways for producing environmentally friendly and pure hydrogen. However, in terms of sustainability and environmental effect, PEM water electrolysis was identified as one of the most promising systems for high purity efficient hydrogen synthesis from renewable energy sources, emitting just oxygen as a byproduct and emitting no carbon. Furthermore, the hydrogen (H_2) and oxygen (O_2) generated are directly employed in fuel cells and industrial applications. However, due to cost constraints, overall water splitting results in just 4% of worldwide industrial hydrogen being generated by electrolysis of water. Nowadays, there is a greater desire to produce green hydrogen, which has raised attention. The rising need to produce green hydrogen has boosted interest in PEM water electrolysis. As a result, significant research has recently been performed in the creation of cost effective electrocatalysts for PEM water electrolysis. In this study, we covered current breakthroughs in PEM water electrolys, new and old difficulties connected to electrocatalysts and PEM cell components. This evaluation will bring more research improvements and a road plan to aid in the development of the PEM water electrolyzer as a commercially viable hydrogen production purpose.**

***Index Terms*—Photon exchange membrane, Electrolyser, electrocatalyst, Green hydrogen.**

I. INTRODUCTION

Today's energy sources are either renewable or non-renewable. Energy that can be used repeatedly and replenished is known as renewable energy. These energies come from things like sunlight, wind, water movement, heat from geothermal sources, and so on. Developed nations have made significant progress in renewable energy systems, which are more effective, less expensive, and contributing more to total energy consumption. Compared to non-renewable energy like fossil fuels, which are used much more quickly, don't regenerate as quickly, and pollute the environment, renewable energy has a significant advantage.[1] Fossil fuels are used to generate stationary and vehicular energy in the current global energy system. Industries use a lot of energy, and the main sources of energy are: natural gas, coal, and oil. The fact that these inputs are used as energy sources has resulted in higher consumption rates. From the 18th century to the present day, society has relied on fossil fuels to meet its energy needs. Over 80% of the world's energy comes from fossil fuels. Oil accounted for 31.1%of the total in 2014, followed by coal (29%) and natural gas (21.5%). Hydrogen has emerged as a promising energy carrier. There are significant opportunities for renewable energy resources to be used in many areas, in comparison to other energy sources, which are concentrated in a limited number of countries. However, renewable energy sources have been studied as alternatives to ensure the sustainability of modern societies. There would be significant benefits to energy security and economics from the rapid deployment of renewable energy, energy efficiency, and technological diversification of energy sources[2][9][10]. Hydrogen is one of the renewable energies under discussion[6]7[7][8].

1.1 Types of electrolysers.

Water is divided during electrolysis by an electrical potential dissociation of the water molecule in an electrical field. The cathode (-) produces hydrogen, whereas the anode (+) produces oxygen. An electrolyte serves as both an electrical insulator and an ionic conductor. H+, OH-, or O_2 ions are exchanged between the electrodes. Polymer electrolyte membranes, acidic (PEM), alkaline, or solid oxide electrolytes are the many types of electrolyzers.[11-14]. Water electrolysis is one of the most competent methods for producing hydrogen since it employs renewable H_2O and produces solely pure oxygen as a by-product[3][15]. The four kinds of electrolysis methods are 1. Alkaline water electrolysis (AWE) 2.

Solid oxide electrolysis (SOE) 3. Microbial electrolysis cells (MEC) 4. Proton exchange membrane water electrolysis (PEM)

1.2 Proton exchange membrane water electrolysis

Grubb invented the first PEM water electrolysis in the early 1950s, and General Electric Co. developed it in 1966 to overcome the disadvantages of alkaline water electrolysis. Similar to PEM fuel cell technology, PEM water electrolysis makes use of solid polysulfonated membranes (Nafion,fumapem) as an electrolyte (proton conductor). These proton exchange membranes offer a number of advantages, including lower gas permeability, high proton conductivity (0.1 0.02 Scm^{-1}), and lower thickness for high-pressure operations (R20–300 mm). PEM water electrolysis is one of the best ways to convert renewable energy into high-purity hydrogen in terms of sustainability and impact on the environment. Another promising method of PEM water electrolysis has many advantages, including a compact design, a high current density (above 2 A/cm^2), high efficiency, quick response, small footprint, operation at lower temperatures, production of ultrapure hydrogen and oxygen as a byproduct, and ease of balancing, making it more appealing for use in industrial settings. High activity of noble metals like Pt/Pd as the hydrogen evolution reaction (HER) at the cathode and IrO2/RuO2 are the most advanced electrocatalysts for PEM electrolysis [4].

As the oxygen evolution reaction (OER) at the anode, which makes alkaline water electrolysis more expensive. As a result, one of the most difficult tasks in PEM water electrolysis is balancing high efficiency with low production costs. Since then, a lot of research has been done to improve the parts of PEM water electrolysis, and this technology is getting closer to commercial markets [2][3].

The objective of this study is to procure a PEM stack and measure the change in voltage and Hydrogen flow rate with varying current densities and to fabricate an electrolyzer that should be operating at a flow rate of 200 ml/min.

1.3 PEM Electrolyzer Components.

The main components of a PEM water electrolysis cell are membrane electrode assemblies (MEAs), current collectors (gas diffusion layers), and separator plates as shown in figure 1.1 The electrolysis cell's heart is MEA, which divides the cell into two halves (anode and cathode).as shown in figure 1.

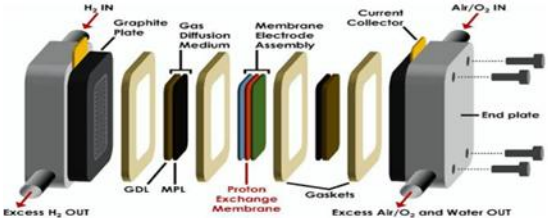
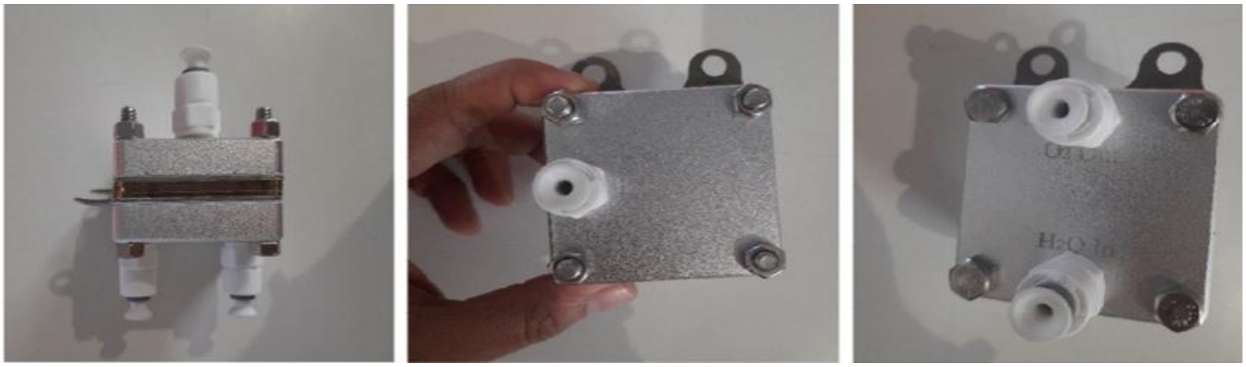


Figure 1. Schematic illustration of PEM water electrolyser components [1]

II. METHODOLOGY

The components of the electrolyser where procured.The supporting structure of an electrolytic cell is made up of two stainless steel plates, which were chosen for their strength, corrosion resistance, durability, and simplicity of eining. The square plates had a thickness of 35 mm, and they measured 100 mm on each side. An entrance for the water and a gas exit were provided on these plates as shown in figure 2. The water reservoir was constructed using a sheet of 1.7 mm thick commercial neoprene to avoid having to machine the stainless-steel plate. The cathode and anode electrodes each have an active area of 9.62 cm^2. The stainless-steel current distribution meshes were constructed with holes that were 0.5 mm in diameter and 1 mm thick. They serve the dual purposes of supporting the electrodes and dispersing electrons across the whole surface of the catalyst. The anode and cathode plates are isolated from one another by a silicon gasket that is 0.25 mm thick and prevents leakage. A 9.62 cm^2 centre depression is present in both seals. The Teflon-coated carbon fabric gas diffusers are used to increase contact between the meshes used to distribute current and the catalytic surface. Both were 9.6 cm^2 circles that were sliced. A 50mm square membrane composed of Nafion that was between 115 and 127 μ m thick served as the electrolyte. The membrane permits the hydrogen ions to go from the anode to the cathode and produce molecular hydrogen as a result. Several chemical baths at 60°C were employed to activate the membrane. The electrolyzer's 9.62 cm^2 reactive area served as the standard for the catalytic inks' preparation. With 7.81 gr of IrO_2, 23.44 mg of RuO_2, 120 μ ml of liquid Nafion, 900 μ ml of ethylic alcohol, and 200 μml of water, catalytic ink for the anode was created. Using 5 mg of Pt-Etek at 20% of its weight, 100 ml of liquid Nafion, 700μ ml of ethylic alcohol, and 200 μml of water, the catalytic ink for the cathode was created. A sprayer approach using an aerograph was employed to saturate the inks over the Nafion membrane. The previously marked 9.62 cm^2 circle was the spray area marked. The MEA assembly was created in hydraulic press utilizing the heat pressing technique. The sprayed Nafion membrane with a gas diffuser was placed in the centre, and a pressure of 5 Ton/cm^2 was applied at 120°C for 5 s. The pressure was then lowered to 0.25 Ton/cm^2, which was maintained for 2 min to ensure a proper integration. Four quick coupling stainless steel connections were placed on the outside surfaces of the arrangement to allow for the entry and outflow of water and gases during the machining of the stainless-steel plates in a vertical milling machine.



(a) (b) (c)

Figure 2. Photographs of the PEM Electrolytic cell (a) sideview (b) front view (c) rear view

2.1 Experimental Setup

A flexible tube was connected from a distilled water reservoir to the port labelled “H_2O in” and another tube was connected from the port labeled “O_2 out” of the electrolyzer back to the distilled water reservoir as shown in figure 3. Very small flow of distilled water was maintained during the measurements. Water flowing out of the cell from the “O_2 out” port contained oxygen gas. The other port was connected to a graduated inverted burette filled with water for collecting and measuring the evolved H_2 gas. Electrical connections were made from the SMPS to the two electrodes.

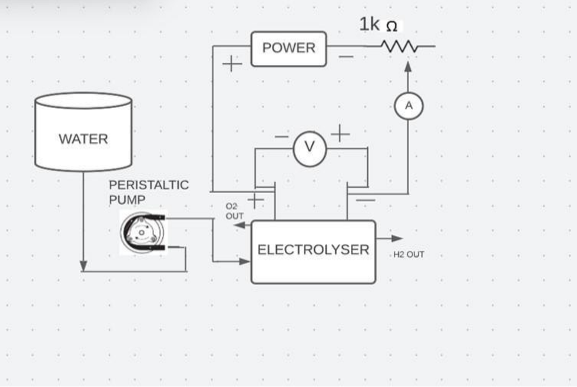


Figure 3. Layout of Experimental Procedure

2.1.1 Working model

The Working model was built as shown in figure 3. Poly carbonate sheet is used for box making with Iron bars acting as support frame. A Switched Mode Power Supply (SMPS) was used to provide power to the PEM mebrane. An overturned Water bottle is used to provide water via gravitational force which was filled from outside by a bottle.

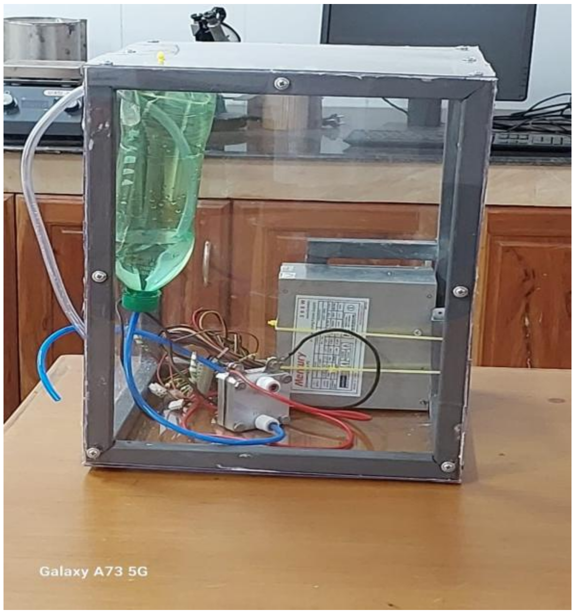


Figure 3. working model of PEM Electrolyzer

III. RESULTS AND DISCUSSION

For the initial set of experiments the voltage was varied from 0.5 to 2.2 V. For the next set of experiments variation of current 10 A to 18 A were taken with a step size of 1 A.

3.1 Variation of current density with Voltage.

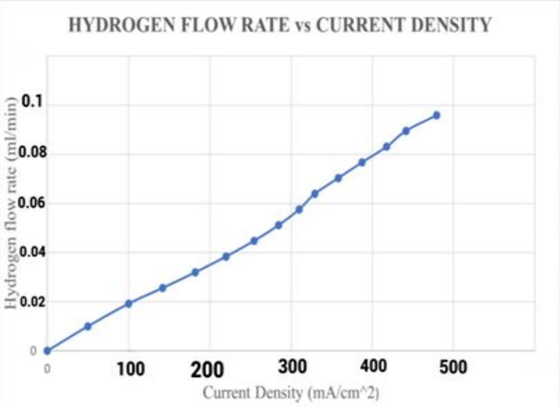


Figure 4. Variation current density with voltage

The effect of the water feed flow rate was determined to identify the most optimal water feed flowrate for operating the PEM electrolyzer. The power supply was varied within the 50 mA/cm^2 to 500 mA/cm^2 range. The feed water flowrates used in this study ranged from 0.5 mL/min to 2 mL/min. Figure 4 shows the relationship between cell voltage and current density.

The cell voltages for the 0.5 1mL/min flow rates are almost identical for low current densities of 50 mA/cm2 to 200 mA/cm^2. However, when the current density rises, a distinct difference becomes apparent. When the current density was larger, it resulted in lower cell voltages, which improved cell performance for the 2 mL/min water flowrate compared to other flow rates. This outcome makes sense given that larger current densities might improve the reaction kinetics at both electrodes and therefore result in reduced charge-transfer resistance, enhancing the cells' performance. The flowrate of water fed into the water electrolysis unit can affect the rate of hydrogen production.

3.2 Effect of Hydrogen production on varying current densities.

The performance of the PEM electrolyzer was also evaluated in terms of Hydrogen production rate. The hydrogen flow rate increased as the current supplied to the PEM electrolyzer increased. An increase in the current density results in the availability of the overpotential for the subsequent process, leading to a faster breakdown of water molecules in hydrogen and oxygen compared to those in lower current densities. the hydrogen flowrate increased with increasing operating temperature. An increase in cell temperature results in an increase in cell performance as a result of a decrease in cell polarization at a certain current. In turn, these phenomena result in less power consumption for certain hydrogen production rates. Energy consumption can be calculated from the voltage and hydrogen flowrates of the PEM electrolyzer. The optimal energy consumption was observed when the current density was 200 mA/cm^2 for all operating temperatures and the energy consumption decreased with increasing stack temperature.

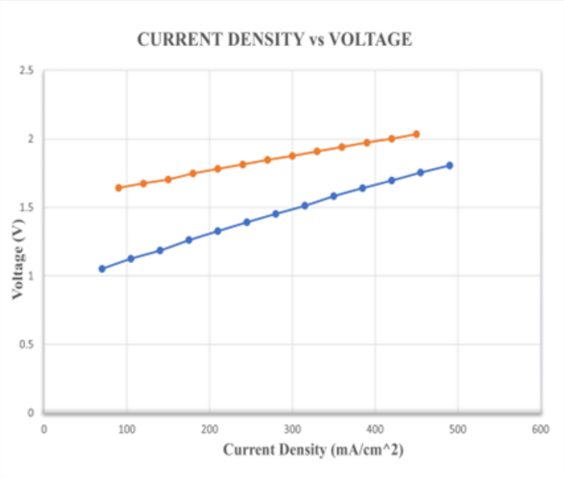


Figure 5. Variation of current density with Hydrogen flowrate

IV. CONCLUSION

The effects of operating conditions on PEM electrolyzer performance was studied. The effects of powersupply 50-500 mA/cm2, Water flowrate (0.5ml/min-5ml/min), operating temperature 30 ^{0}C. were analysed. When the current density was larger around 500 mA/cm^2, the cell performance were found to be improved for the 2 mL/min water flowrate compared to other flow rates. The optimal energy consumption was observed for this range of current density. For the increase in cell operating temperature an increase in the cell performance were observed at the specific current density.

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