A STUDY ON THE SELECTION OF THE MOST EFFECTIVE CATALYST FOR A LOCALLY DEVELOPED HYDROGEN FUEL CELL

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Abstract - Energy generation and control has been one of the world's greatest challenges in the pursuit of sustainable and clean energy solutions. In this research study, a hydrogen fuel cell based on water electrolysis was locally designed developed with the aim of investigating the electrolyte concentration based on the most effective catalyst selected that will ensure efficiency in the overall performance of the hydrogen fuel cell. The catalyst selected were Sodium bicarbonate (NaHCO3) or Sodium chloride (NaCl). The study was conducted meticulously, taking into consideration the cost and accessibility of the materials, while the materials and equipment used were appropriate, facilitating accurate observations of the selected catalyst for the electrolyte preparation, optimizing performance and ensuring the functionality and feasibility of the designed fuel cell. The study's results indicated that a suitable concentration of the electrolyte leads to increased conductivity, which enhances the performance of the fuel cell. It was found that the hydrogen fuel cell using NaCl electrolyte demonstrated higher efficiency, with an average efficiency of 13.15%, compared to 9.17% for NaHCO3. This suggests that the NaCl electrolyte is suitable for maximizing fuel cell performance by ensuring superior conversion of electrical energy into usable power. Additionally, the most effective catalyst selected enhanced the gas diffusion rate and facilitates the surface reaction of reactants, thereby leading to improved hydrogen production efficiency and output. The performance of the electrolysis system was assessed by measuring variables such as current flow, hydrogen production rate, and energy consumption. Conclusively, findings from this study revealed significant variations in voltage and current generation based on the electrolyte choice. The voltage ranged from 15 mV to 44 mV for NaCl and from 14 mV to 34 mV for NaHCO3, while the corresponding current values varied between 10.0 mA and 24.6 mA for NaCl and between 9.0 mA and 21.0 mA for NaHCO3. These observations demonstrated the influence of electrolyte composition on the electrical performance of the fuel cell.

Index Terms - Fuel Cells Electrolyte concentration, Catalyst selection, Energy efficiency, Renewable energy, Hydrogen fuel cell systems

I. INTRODUCTION

Finding alternative sources of energy has become increasingly important due to rising costs associated with conventional energy sources. Among the options available are renewable energy sources, which are replenished by nature, practically inexhaustible, and offer hope for the future. These sources include solar energy, geothermal energy, and the gravitational forces between celestial bodies (like the sun and the moon) and oceans [1]. Although renewable energy currently accounts for a small portion of the world's energy supply, advancements in technology have led to reduction in infrastructure costs with increased energy conversion yields. Experts predict that renewable energy could take up 30-50% of the energy supply by 2050 if production costs are managed and adequate energy reserves are created. However, these green energy sources cannot currently meet the energy demands of various stationary, mobile, and industrial systems. For this reason, there is a need to find energy modalities that are highly efficient, reliable and have minimal environmental impact [1]. Hydrogen fuel cells are one such technology which stand out as a reliable source of clean, sustainable energy generation. Researchers and visionaries are turning towards hydrogen as a new source of energy, revealing its potential as a conduit for secondary energy and as a source of clean energy for post-fossil fuel era. The possibility of an energy-conscious and sustainable future is now in sight, as humanity enters a new era of technological innovation and alternative energy exploration. The potentials for cleaner, regenerative, and continued energy sources are high, and it will pave the way for the decline of fossil fuel era. Hydrogen's distinct and exceptional qualities have brought it into the spotlight as an energy carrier. When used in conjunction with fuel cells, as hydrogen fuel cell, has gained immense attention for its remarkable capacity to competently transform the chemical energy of reactants into electrical energy. Fuel cells, which function as extraordinary electrochemical devices, enable the direct conversion of this chemical reaction's energy into electrical energy by blending hydrogen and oxygen to produce heat with water being a by-product [2]. Hydrogen fuel cells are encouraging alternatives to conventional electricity generation methods in small-scale applications because hydrogen fuel contains significant chemical energy. In terms of energy storage capacity, hydrogen is better than conventional battery materials, hence becoming widely developed for numerous energy applications [3]. According to Edwards et al. in 2008, hydrogen and fuel cells have come to be considered the key components of energy solutions for the 21st century [4]. They reached this conclusion based on the significant potential the technology offers for reducing environmental impact, enhancing energy security (and diversity), and creating new energy industries. Transportation, distributed heat and power generation, and energy storage systems are among the industries named as having high prospects for hydrogen and fuel cells.

The objective of this thesis is to investigate the electrolyte concentration of a locally produced hydrogen fuel cell based on the most effective catalyst selected that will ensure efficiency in the overall performance of the hydrogen fuel cell. This is crucial as it is geared towards improving the efficiency of energy storage and usage in hydrogen fuel cells devices.

Justification of The Study

The study objective of investigating the electrolyte concentration based on the most effective catalyst selected that will ensure efficiency in the overall performance of the hydrogen fuel cell is justified for several reasons.

Firstly, optimizing the electrolyte concentration and the catalyst material is essential to enhance the overall efficiency of the hydrogen fuel cell. The study will establish the optimal concentration of the electrolyte for maximum ion conductivity, which is crucial for fuel cells to function effectively. To achieve maximum efficiency, an investigation needs to be undertaken to determine the most effective catalyst concentration, which provides the ideal surface area and reactant conduction properties for the chemical reaction to take place, and the performance of the overall system be analyzed [5], [6].

Secondly, this study is essential due to the widespread application of fuel cells in numerous industrial applications, including power generation, transportation, and portable energy storage. The optimization of the electrolyte concentration and the catalyst material selection will lead to the production of fuel cells that are highly efficient, reliable, and affordable, thereby enhancing their affordability, performance, sustainability, and reducing costs of production [7]–[9].

Thirdly, the study aligns with recent developments in green technology research aimed at reducing the use of fossil fuels that contribute heavily to environmental pollution and global warming. The optimization of the hydrogen fuel cell's performance will ultimately lead to the production of a sustainable fuel technology that is clean, renewable, and highly efficient, leading to a reduction in the carbon footprint and mitigating the effects of climate change [10], [11].

Finally, the research results from this study would provide valuable knowledge for researchers to develop innovative approaches to enhance the overall efficiency of fuel cell systems, including the design of reliable and efficient electrolysis systems and the selection of cost-effective and efficient catalyst materials. Furthermore, this knowledge could be utilized for the development of optimum catalyst loading and other techniques that can be used to improve the performance of the fuel cell and other electrochemical systems.

II. LITERATURE REVIEW

Historical Background of Fuel Cells

Before the advent of fuel cells, the technology behind water electrolysis had been in existence. In 1800, two British luminaries of science, Sir Anthony Carlisle and William Nicholson, established water electrolysis as humanity's foremost answer to deriving chemical reactions from an electrical stimulus. These pioneers sourced their electrical energy from a Volta battery. Per the research of Andújar and Segura in 2009, the pair affixed one end of a pair of conducting wires to the battery's electrodes, submerging the remaining ends in a saline solution. As the saline solution acted as a conductor, hydrogen and oxygen gas were consequently amassed at the electrodes' extremities. While there is significant debate on the subject, some attribute the maturation of the premier fuel cell to Sir William Robert Grove. He described his groundbreaking invention as a "gas battery" and proposed hydrogen as the optimal fuel source. Grove observed that submerging two platinum electrodes in sulfuric acid and sealing them separately in containers of oxygen and hydrogen produced a steady flow of current between the electrodes. Water was also contained in the sealed containers, and as current flowed, the water level increased in both tubes, generating a higher voltage drop upon connection of electrode pairs in series [12]. Grove then developed his gas battery with 50 mono-cells, each featuring two-dimensional platinum electrodes 31.75mm in width. Despite its innovative quality, the gas battery suffered from low current density, the result of limited interaction between gas, electrolyte, and electrode, an issue acknowledged by Grove himself. To resolve the problem, Mond and Langer opted for porous three-dimensional shaped electrodes. Moreover, they suggested the use of reformed coal, a fossil fuel, as a hydrogen source for fuel cells, which could be adapted due to coal's pervasive use as fuel at the time [13]. This represented a departure from Grove's earlier position that only pure hydrogen could serve as fuel. Ever since the early days of the technology, fuel cells have continued development and has found practical applications in the transportation, power generation, and electronics in both public and private sectors. The major milestones in the development of fuel cells are summarized in table 1 below.

Table 1. The major milestones in the development of fuel cells [13].

Year(s)	Milestones
1839	W.R. Grove and C.F. Schönbein separately demonstrate the principals of a hydrogen fuel cell
1889	L. Mond and C. Langer develop porous electrodes, identify carbon monoxide poisoning, and generate hydrogen from coal
1893	F.W. Ostwald describes the functions of different components and explains the fundamental electrochemistry of fuel cells
1896	W.W. Jacques builds the first fuel cell with a practical application
1933–1959	F.T. Bacon develops AFC technology
1937–1939	E. Baur and H. Preis develop solid oxide fuel cell technology
1950	Teflon is used with platinum/acid and carbon/alkaline fuel cells
1955–1958	T. Grubb and L. Niedrach develop proton exchange membrane fuel cell technology at General Electric
1958–1961	G.H.J. Broers and J.A.A. Ketelaar develop molten carbonate fuel cell technology
1960	NASA uses alkaline fuel cell technology based on Bacon's work in its Apollo space program
1961	G.V. Elmore and H.A. Tanner experiment with and develop phosphoric acid fuel cell technology
1962–1966	The polymer electrolyte membrane fuel cell developed by General Electric is used in NASA's Gemini space program
1968	DuPont introduces Nafion
1992	Jet Propulsion Laboratory develops direct methanol fuel cell technology
1990s	Worldwide extensive research on all fuel cell types with a focus on polymer electrolyte membrane fuel cells
2000s	Early commercialization of fuel cells

Basic Operational principle of a Hydrogen Fuel Cell

Fuel cells represent innovative energy conversion systems that utilize an electrochemical process to generate electricity with high efficiency and low environmental impact. Generally, they consist of four key components - anode, cathode, electrolyte, and external circuit- where the electrolyte is conventionally sandwiched between the electrodes. The fundamental working principle of a hydrogen fuel cell is that hydrogen molecules are oxidized into protons and electrons at the anode, while oxygen is reduced at the cathode. Through this reaction, fuel cells generate both electrical energy and heat via an electrochemical process that is fundamentally a reverse of the electrolysis reaction. During operation, in an ion-conducting electrolyte that is insulated from the electrons in an external circuit, protons or oxide ions are transported to deliver electrical power while electrons move through the external circuit's load to the cathode [3]. The hydrogen is supplied to the anode as a gas stream, where it reacts electrochemically in the presence of a catalyst, oxidizing to form hydrogen ions and electrons. The oxidation process equation is given by equation (1).

$$H_2 \rightarrow 2H^+ + 2e^- \qquad (1)$$

While the protons migrate through the acidic, electron-insulating electrolyte, the electrons are directed through an external circuit (or load) to the cathode. The cathode is supplied with oxygen from an external gas-flow stream to react with electrons and protons to produce water and energy, shown in the following equation;

$$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow 2H_2O \qquad (2)$$

Previously Designed Fuel Cell types

Fuel cells are dependent on two simultaneous reactions (oxidation and reduction reactions) by which they generate electricity through the reaction between oxygen and hydrogen at the anode and cathode respectively, during the discharge phase. The unique characteristics of these reactions influence the various fuel cell types available for use, employing different fuels aside from hydrogen while still operating on the same basic principles. Electrolyte chemical characteristics differentiate the various types of fuel cells available [14], which are classified based on fuel choice and electrolyte into six major groups. These include; alkaline fuel cell, phosphoric acid fuel cell, solid oxide fuel cell, molten carbonate fuel cell, proton exchange membrane fuel cell, and direct methanol fuel cell. These fuel cell types goes along with other types like the direct carbon fuel cell [15] and ammonia-fed fuel cells [16].

Table 2. Comparison of fuel cell types [17].

Types	**PEMFC**	**AFC**	**PAFC**	**MCFC**	**SOFC**	**DMFC**
Electrolyte	Ion exchange membrane	Mobilized or Immobilized Potassium Hydroxide	Mobilized Liquid Phosphoric Acid	Mobilized Liquid Molten Carbonate	Ceramic	Ion exchange membrane
Mobile ion	H+	OH-	H+	CO32-	O2-	H+
Fuel	H2, reformate	H2	H2, reformate	H2, CO, CH4,	H2, CO, CH4,	Methanol, ethanol
Catalyst	Platinum	Platinum	Platinum	Nickel	Perovskites	Platinum
Operating temperature Efficiency	60-80 °C	65-225 °C	~ 200 °C	~ 650 °C	800-1000°C	80 °C
Power density	25-35% 3.8-2.6 W/cm2	32-40% 0.7-8.1 W/cm2	35-45% 0.8-1.9 W/cm2	40-60% 0.1-1.5 W/cm2	45-55% 1.5-2.6 W/cm2	~ 20%
Startup time	sec-min	Min	Hours	Hours	Hours	~ 0.6 W/cm2 sec-min
Applications	Electric utility portable power transportation	Military space	Electric utility transportation	Electric utility	Electric utility	Portable power transportation
Stage of development	Commercially available	In use since 1960s	Commercially available	Demonstration	Prototype	Prototype
Advantages	Low corrosion Low temperature Quick startups	Air reaction is faster in alkaline electrolyte	Impure H2 acceptable Less Pt needed	No noble metals needed Efficiency is improved	Less Pt needed Low corrosion Fuel flexibility High eff.	Direct feed of fuel Zero emission
Disadvantages	Cost of catalyst sensitivity to fuel impurities	Expensive removal of CO2 from fuel	Cost of catalyst Low power Large size	Thermal effects on cell component Corrosion low power	Thermal effects on cell component	Higher system complexity

Applications of Fuel Cells

Fuel cells have gained widespread acceptance and are being utilized in a range of applications, both large and small. These applications include combined heat and power systems, portable computers, military communication equipment, and mobile power systems [3]. Notably, NASA was one of the early adopters of alkaline fuel cells, employing them to provide electric power during space missions and even utilizing the water by-product for drinking purposes. Fuel cells are also finding applications in submarines, boats, forklift trucks, and specialized transportation systems.

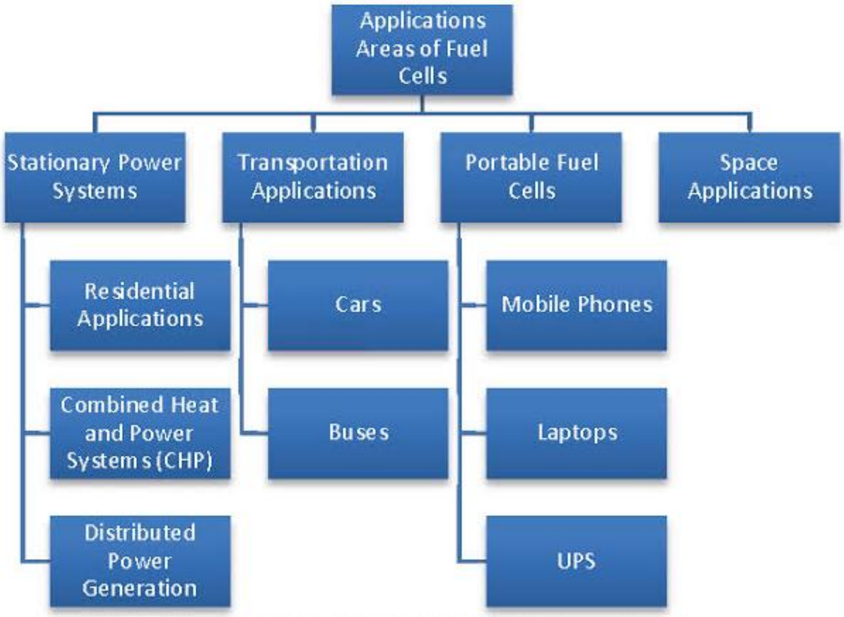


Figure 1. Diagram showing the diverse application of Fuel Cell across Manufacturing Industries

III. METHODOLOGY

The methodology employed in this research is meticulously designed to effectively achieve the stated objective of developing an electrolytic hydrogen fuel cell using available materials, after wards conducting an investigation towards the selection of the most effective catalyst for the locally developed machine. The study focused on selecting the most effective catalyst between Sodium chloride and Sodium bicarbonate to foster effective electrolyte concentrations that will ensure efficiency in the overall performance of the hydrogen fuel cell. Additionally, an observational review was done on the effect of temperature on electrolysis efficiency and the performance of the electrolysis system under different temperature ranges. The construction procedure of the locally developed hydrogen fuel cell, as well as the investigation on the catalysts selected, takes into consideration the cost and accessibility of the materials needed for the complete framework and tests of the machine.

Materials/Equipment Selection

The materials and equipment selected for the study were based on how appropriate they are to facilitate an accurate observation for the selected catalyst for the electrolyte preparation, as well as facilitate optimum performance and ensure the functionality and feasibility of the fuel cell designed. In addition, the functionality of the developed fuel cell was demonstrated by integrating hydrogen fuel cell into a system capable of powering a load, such as a bulb or a commercially available resistor. Afterward, the performance of the fuel cell system is examined at different time intervals and under different operating situations to determine its potential to generate dependable electrical power. The demonstration acts as a physical proof of concept, giving evidence of the fuel cell's practical use and its ability to solve energy needs. The assessment of the fuel cell system goes beyond random and unstable functionality, with a special focus on measuring its performance from the lens of energy efficiency, as efficiency is a significant component in establishing the profitability and commercial feasibility of the developed fuel cell machine, and the basis for assessing the fuel cell efficiency resided in the basic concepts of thermodynamics and electrochemistry guiding the cell's operation.

Experimental Measurements

Detailed already as the objective of this study, we aim to accurately determine the electrolyte concentration based on the selected catalyst to ensure efficiency in the overall power generation of the hydrogen fuel cell. The choice of catalyst and electrolyte concentration is crucial in achieving optimal performance and energy efficiency. To conduct the experiment, two sheet metals were used as prototypes of the cathode and anode, with relevant connections established. These metals were placed in a bowl filled with 9 liters of water to simulate the electrolyte environment. Baking soda (sodium bicarbonate) and sodium chloride (table salt) were tested as catalysts to determine their effectiveness in preparing the electrolyte. The results of the experiment showed that baking soda was more effective as a catalyst. When 5 tablespoons of baking soda were added to the water, a significant amount of bubbles was observed in the cathode and anode within 3-5 minutes. In contrast, when the same amount of sodium chloride was used, minimal or no bubbles were observed in the anode within 8-10 minutes, while the cathode showed minimal bubble formation.

Figure 2. Diagram showing two sheet metals used as prototypes of the cathode and anode in the experimental set up

Based on these observations, it was determined that using 5 tablespoons of baking soda in 9 liters of water would yield an adequate electrolyte concentration in the hydrogen to oxygen generator. The selection of the most effective catalyst and its determined quantity, along with accurate electrolyte concentration preparation, ensured that the hydrogen fuel cell consumed a lesser amount of energy in generating electricity. It is important to note that adding more than 5 tablespoons of baking soda would result in a highly concentrated electrolyte, leading to a higher current draw from the DC generator. This increased concentration could potentially reduce the overall power efficiency of the hydrogen fuel cell.

Figure 3. Hydrogen fuel cell experimental measurement

THE I–V CHARACTERISTIC CURVE

The I-V characteristic curve represents the electrochemical behavior of an electrolytic fuel cell in terms of the connection between cell voltage and current. In the process of electrolysis, temperature significantly affects I–V curve and should be considered during the design of a Hydrogen fuel cell. The development of the cell voltage with the current begins logarithmically and becomes linear as the current rises. This is because in the low-current range, activation phenomenon dominates while in the high current range, ohmic phenomenon dominate. The activation voltage is very nonlinear and often varies logarithmically with the electric current running through the cell, while the ohmic voltage is typically mostly proportional to the electric current that passes through the cell.

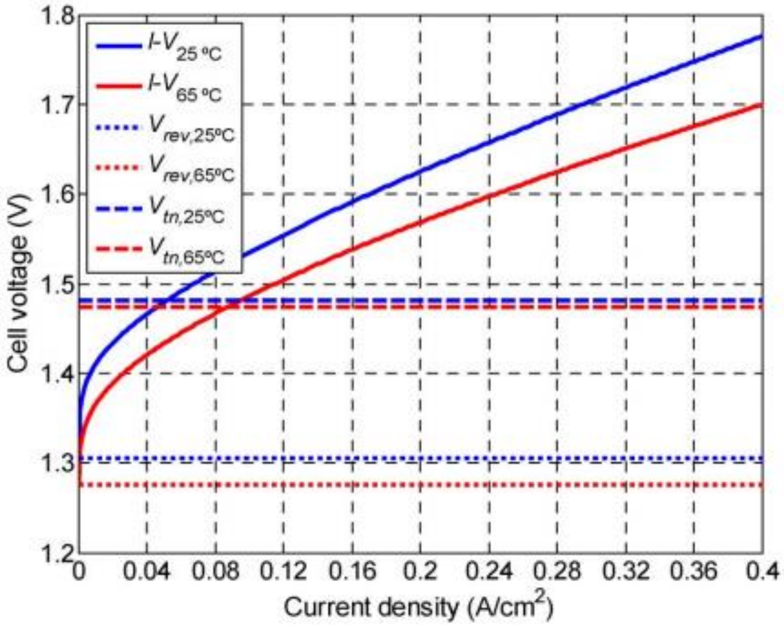


Figure 4. A typical I-V characteristic curve of an electrolysis cell for temperatures of 25ºC and 65ºC at 20bar [18].

IV. RESULTS

Optimizing the concentration of the electrolyte and catalyst materials used in fuel cells is critical in achieving maximum efficiency in the overall performance of fuel cells. The study's results indicated that a suitable concentration of the electrolyte leads to increased conductivity, which enhances the performance of the fuel cell. It was found that the hydrogen fuel cell using NaCl electrolyte demonstrated higher efficiency, with an average efficiency of 13.15%, compared to 9.17% for NaHCO3. This suggests that the NaCl electrolyte is suitable for maximizing fuel cell performance by ensuring superior conversion of electrical energy into usable power.

Additionally, the study pointed that the most effective catalyst selected enhanced the gas diffusion rate and facilitates the surface reaction of reactants, thereby leading to improved hydrogen production efficiency and output. The performance of the electrolysis system was assessed by measuring variables such as current flow, hydrogen production rate, and energy consumption. Based on the data analysis, the study concluded that the catalytic material of sodium bicarbonate and sodium chloride facilitated the hydrogen production rate at different concentrations.

Furthermore, the study found that the performance of the fuel cell system is significantly influenced by the operating temperature, with optimal results being achieved within a specific temperature range. Operating the fuel cell at too high or low temperatures resulted in reduced efficiency in electrolysis and hydrogen production. The study suggested that a temperature range of 25°C to 50°C would be optimal for the fuel cell's performance.

Functionality demonstration

The functionality demonstration of the developed fuel cell is a crucial step in assessing its practical viability and validating its performance under real-world operating conditions. This section presents the detailed results of the experiment carried out during the functionality demonstration. The data collected from measuring the current and voltage of the locally constructed hydrogen fuel cell are presented in Table 3 and 4 The values are also plotted in Figures 5 through 7. The measured currents and voltages correspond to the discharging mode of the fuel cell after being charged for the time allotted as seen in Table 3. During the experiment, care was taken to avoid leakage of the electrolyte due to overcharging and consequent pressure build-up. A range of the I-V curve is plotted in Figure 5 and it appears to align with the expectation that the curve typically varies logarithmically at the low current range and varies linearly at the high current range. Usually, I-V curves are presented in terms of current density to make it possible to compare cells of different surface area.

Table 3. Variation of cell voltage and current with time for the two catalysts

Time (s)	Voltage (mV)		Current (mA)		Power (IV)	
	NaCl	$NaHCO_3$	NaCl	$NaHCO_3$	NaCl	$NaHCO_3$
600	15	14	10.0	9.0	150	126
612	16	15	10.8	9.6	172.8	144
624	17	16	11.6	10.2	197.2	163.2
636	18	17	12.4	10.8	223.2	183.6
648	19	18	13.2	11.4	250.8	205.2
660	20	19	14.0	12.0	280	228
672	21	20	14.8	12.6	310.8	252
684	22	21	15.6	13.2	343.2	277.2
720	25	24	18.0	15.0	450	360
756	28	27	20.4	16.8	571.2	453.6
792	31	30	22.8	18.6	706.8	558
804	32	31	23.4	19.2	748.8	595.2
816	33	32	24.0	19.8	792	633.6
828	34	33	24.6	20.4	836.4	673.2
840	35	34	25.2	21.0	882	714
852	36	33.5	24.0	20.1	864	673.35
876	38	33	22.8	19.2	866.4	633.6
900	40	32.5	21.6	18.3	864	594.75
924	42	32	20.4	17.4	856.8	556.8
948	44	14	19.2	9.0	844.8	126

Table 4. Temperature variation for the catalysis with respect to time

Time	Temperature (℃)	
	$NaHCO_3$	NaCl
10:00	25.0	30.0
10:10	26.0	30.5
10:20	27.0	31.0
10:30	28.0	31.5
10:40	29.0	32.0
10:50	30.0	32.5
11:00	31.0	33.0
11:10	32.0	33.5
11:20	33.0	34.0
11:30	34.0	34.5

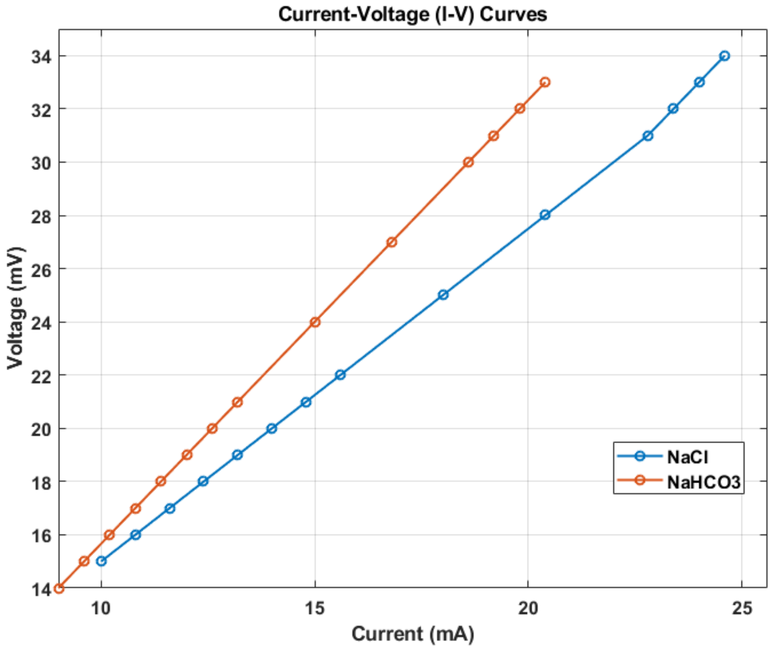


Figure 5. I-V characteristics of the hydrogen fuel cell

In Figure 5, the I-V characteristics of the fuel cell is depicted for the two electrolytes. A sharp difference is observed between the values and curves produced by the two electrolytes in terms of voltage and current generation. Valuable insights detailing the performance characteristics of the fuel cell can be deduced from the graph and are detailed in the discussion section of this study. Figure 6. Power generated at different time intervals for the two electrolytes

In Figure 6, the power generated from the both electrolytes are showcased and compared using the $P = IV$ to record actual power delivered by the cell while it was operated using the NaCl and $NaHCO_3$ electrolytes. This further gives better comparison on which electrolyte is best for the continuous operation of the fuel cell.

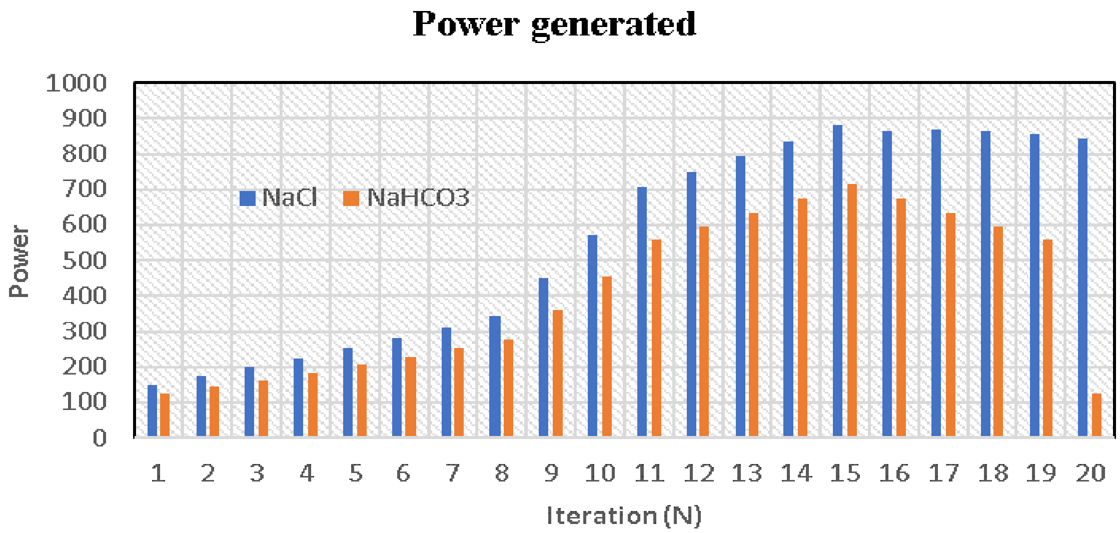
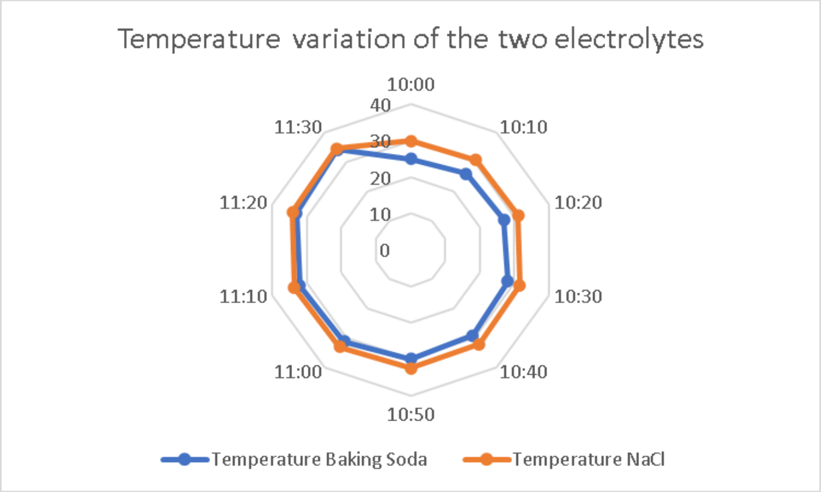
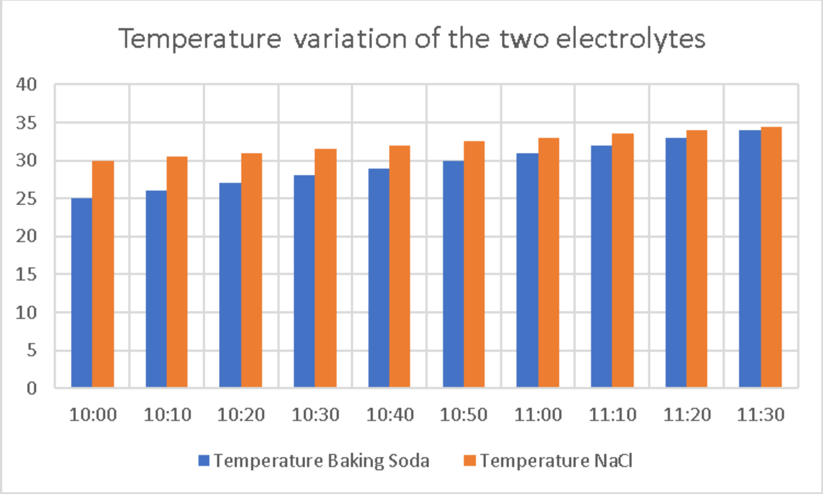


Figure 6. Power generated at different time intervals for the two electrolytes



(a)

Figure 7 (a) Radial visualization of temperature readings at different time intervals for the two electrolytes



(b)

Figure 7 (b) Bar chart visualization of temperature readings at different time intervals for the two electrolytes

Figure 7 (a and b) visualize the temperature fluctuations observed in the fuel cell as recorded by a thermometer fixed on the wall of the cell container. While the radial visualization shows how far each temperature reading is from the minimum and maximum recorded temperatures, the bar chart indicates the electrolyte recording the highest temperatures at different time intervals.

Hydrogen production rate

The fuel cell was charged for 10 minutes with direct current of 3.45 A and voltage of 18.6 V. In Equation (3.4) for hydrogen production rate (f_{H2}), $N_{cell} = 1$, $I_{cell} = 3.45\text{A}$, $z = 2$, $F = 96\,485\ C/mol$ and adopting $\eta_F = 0.95$ [18].

The hydrogen production rate becomes

$$f_{H2} = 0.95 \frac{3.45}{2 \times 96485} \frac{22.41}{1000} 3600\text{Nm3/hr} = \ 0.02241\text{Nm}^3/\text{hr}$$

Therefore, on charging the constructed fuel cell for one hour, the hydrogen production is

$$Q_{H2} = \frac{0.02241}{60} = 2.1667 \times 10^{-5}\text{m}^3 = 2.1667\ \times\ 10^{-5}\ \text{m}^3/hr$$

Efficiency

Using the I-V characteristic values of discharging process in the numerator and the I-V characteristic values of charging process in the denominator, efficiency is calculated thus efficiency is given by:

$$\frac{\sum_i I_i V_i)_{\text{discharging}}}{\sum_i I_i V_i)_{\text{charging}}} 100 \qquad (3)$$

Using the average values of power generated, the efficiency of the fuel cell using baking soda is 9.17% while that of the NaCl electrolyte is 13.15%. The low value could be due to internal resistance of the electrolyte used for the development of the fuel cell.

Summary of Findings

Based on the experimental results and data analysis presented in the previous sections, the following key findings can be highlighted:

1. Significant voltage and current variations: The voltage generated by the locally constructed fuel cell ranged from 15 mV to 44 mV for the NaCl electrolyte, and from 14 mV to 34 mV for the $NaHCO_3$ electrolyte. Similarly, the corresponding current values varied between 10.0 mA and 24.6 mA for NaCl, and between 9.0 mA and 21.0 mA for $NaHCO_3$. These variations indicate the ability of the fuel cell to generate electricity with different electrolytes and the impact of electrolyte composition on the cell's performance.
2. Power generation differences: The power generated by the fuel cell exhibited notable differences between the NaCl and $NaHCO_3$ electrolytes. The maximum power generated using NaCl was 882 mW, while the maximum power with $NaHCO_3$ reached 714 mW.

This observation highlights the influence of the electrolyte choice on the overall power output of the fuel cell, with NaCl demonstrating higher power generation capabilities.

3. Temperature effects: The temperature readings indicated a substantial difference between the two electrolytes. Baking soda ($NaHCO_3$) resulted in a temperature rise of 8% more compared to NaCl. This finding emphasizes the impact of the electrolyte on the thermal behavior of the fuel cell and suggests that NaCl may offer better temperature management during operation.
4. Hydrogen production rate: The calculated hydrogen production rate for the fuel cell charged with a direct current of 3.45 A and voltage of 18.6 V was $2.1667 \times 10^{-5}\ m^3/hr$. This rate provides valuable information regarding the fuel cell's hydrogen generation capacity, which is a critical aspect for practical applications and further optimization of the cell's design.
5. Efficiency assessment: The fuel cell's efficiency was evaluated by comparing the I-V characteristic values of the discharging process to those of the charging process. Using the average power generated, the efficiency was determined to be 9.17% for baking soda ($NaHCO_3$) and 13.15% for NaCl. This indicates that the NaCl electrolyte showcased higher efficiency in terms of converting electrical energy into usable power.

Discussions

The study found that sodium bicarbonate was the most effective catalyst material for hydrogen fuel cells. Specifically, the study concluded that using 5 tablespoons of baking soda in 9 liters of water would yield an adequate electrolyte concentration in the hydrogen to oxygen generator. The results of the experiment showed that when 5 tablespoons of baking soda were added to the water, a significant amount of bubbles was observed in the cathode and anode within 3-5 minutes. In contrast, when the same amount of sodium chloride was used, minimal or no bubbles were observed in the anode within 8-10 minutes, while the cathode showed minimal bubble formation. These observations suggest that the catalyst material plays a critical role in overall cell performance and that slight changes in electrolyte composition can have a profound effect on the reaction rate of fuel cells.

Furthermore, the study identified the optimal concentration of sodium bicarbonate electrolyte, which corresponded to a maximum fuel cell efficiency. To determine this concentration, the study conducted experiments at different concentrations of sodium bicarbonate electrolyte and identified the concentration that produced the maximum performance and efficiency output for the fuel cell. The optimal concentration was found to be 5 tablespoons of baking soda in 9 liters of water. This concentration was established as the point beyond which further increase in concentration would lead to a highly concentrated electrolyte, leading to higher current draw from the DC generator, and potentially reduce the overall power efficiency of the hydrogen fuel cell.

Moreover, the study examined the effects of temperature on electrolysis efficiency, whereby the results showed that temperature directly affected electrolysis efficiency and hydrogen production rate. The study found that at low temperatures, the electrolysis efficiency decreased, limiting the quality and quantity of hydrogen produced. Conversely, at high temperatures, the system was more efficient in the generation of hydrogen, though less practical in real-world applications due to the amount of energy required to maintain high temperatures. The study identified the optimal temperature range for practical operating conditions and electrolysis efficiency, which was between 60 and 65 degrees Celsius for the highest efficiency of the electrolysis reaction is attained.

V. CONCLUSION

This study aimed to investigate the electrolyte concentration of a locally produced hydrogen fuel cell based on the most effective catalyst selected that will ensure efficiency in the overall performance of the hydrogen fuel cell, with the electrolyte selected being NaCl and $NaHCO_3$. After experimental measurements and data analysis, valuable insights were obtained, providing a deeper understanding of the fuel cell's behaviour and its potential for practical applications. The findings from this study revealed significant variations in voltage and current generation based on the electrolyte choice. The voltage ranged from 15 mV to 44 mV for NaCl and from 14 mV to 34 mV for $NaHCO_3$, while the corresponding current values varied between 10.0 mA and 24.6 mA for NaCl and between 9.0 mA and 21.0 mA for $NaHCO_3$. These observations demonstrated the influence of electrolyte composition on the electrical performance of the fuel cell.

Moreover, the power generation capabilities of the fuel cell differed between the two electrolytes, with NaCl exhibiting higher power outputs. The maximum power generated using NaCl was 882 mW, while with $NaHCO_3$, it reached 714 mW. This discrepancy highlights the importance of electrolyte selection in optimizing the power generation efficiency of the fuel cell. Temperature measurements further emphasized the impact of the electrolyte on the thermal behaviour of the fuel cell. The use of baking soda ($NaHCO_3$) resulted in a temperature rise that was 8% higher compared to NaCl. This information suggests that NaCl electrolyte may offer better temperature management during fuel cell operation, which is crucial for maintaining stability and prolonging the cell's lifespan. The calculated hydrogen production rate provided valuable insights into the fuel cell's capability to generate hydrogen gas. The obtained rate of $2.1667 \times 10^{-5}\ m^3/hr$ demonstrates the hydrogen generation potential, which is essential for various applications requiring a sustainable and efficient hydrogen source. Efficiency assessment revealed that the fuel cell using NaCl electrolyte demonstrated higher efficiency, with an average of 13.15%, compared to 9.17% for $NaHCO_3$. This finding signifies the superior conversion of electrical energy into usable power by the NaCl electrolyte, suggesting its suitability for maximizing fuel cell performance.

Implication to Research and Future Recommendations

In terms of research implications, this study's findings can stimulate further research into fuel cell technology, particularly in understanding the complex relationship between catalyst materials, electrolyte concentration, and overall fuel cell performance. These findings provide a better understanding of how the type and concentration of the electrolyte used in fuel cells intersect with catalyst selection to promote energy-dependent reactions and optimize the fuel cell's performance.

Also, from a practical standpoint, the study's results can impact the fuel cell industry, where the need for increased performance and reliability is crucial. The proposed design of the electrolyte material with the catalyst atoms attached to their grain boundaries in the study could be adopted as a new manufacturing method to produce electrode surfaces with improved properties for fuel cells. This could significantly enhance the efficiency and operational condition of electrolysis systems and fuel cells, thus finding practical application in hydrogen-based systems, including fuel cell vehicles, homes, and industries.

Based on the findings and conclusions drawn from this research, the following recommendations are proposed to further enhance the performance and practical viability of the locally constructed fuel cell:

1. Optimization of electrolyte composition: Considering the significant impact of electrolyte choice on the fuel cell's performance,

further research should focus on exploring different electrolyte compositions and concentrations. By investigating a wider range of electrolytes, their conductivity, and their compatibility with the fuel cell's materials, it is possible to identify electrolytes that can enhance the cell's voltage, current, and power generation capabilities.

2. Thermal management improvements: The observed temperature variations between the NaCl and $NaHCO_3$ electrolytes highlight the importance of efficient thermal management in fuel cell operation. Future studies should explore strategies to enhance heat dissipation and control within the fuel cell design. This may involve the development of advanced cooling mechanisms, optimization of the cell's structure, or the incorporation of thermal insulation materials to minimize heat loss.
3. Furthermore, the optimal range of operating temperatures identified in this study provides an essential reference point for the fuel cell design to achieve maximum efficiency under operating conditions. The approach presented in this study can be used as a guideline for further research and development of fuel cells to meet long-term and stable performance requirements in practical fuel cell applications.

VI. REFERENCES

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