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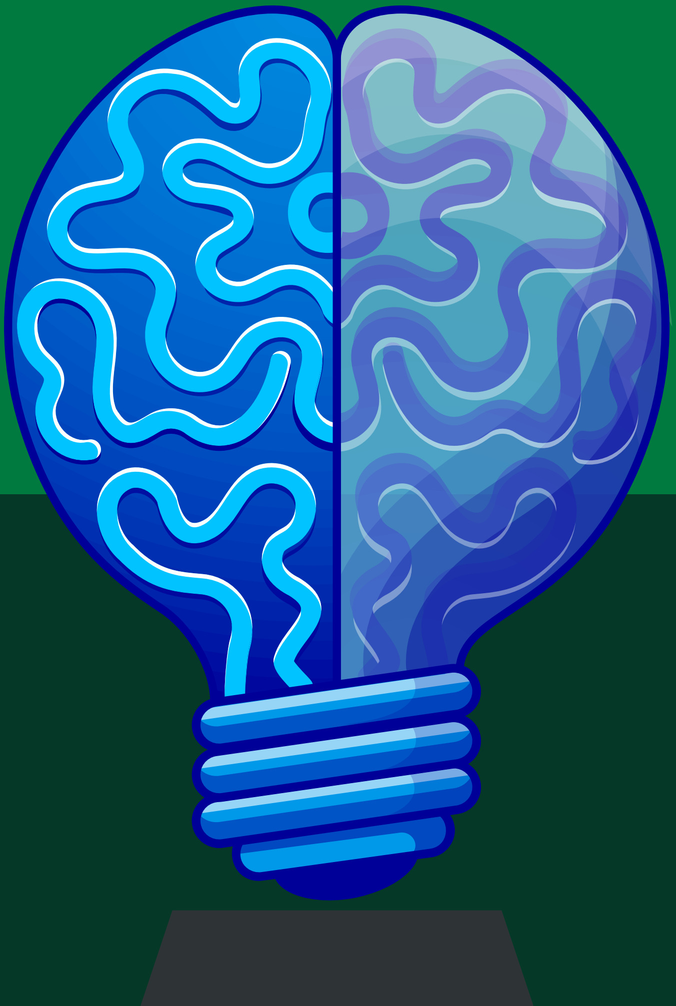

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Preface

The Scientific Project Colloquium offers a platform for publishing Diploma Science final year projects (FYP). The objective is to effectively distribute research findings throughout all scientific disciplines. The primary objective of including final year projects into the course curriculum is to encourage students to put their theoretical knowledge into practical applications.

We would like to express our gratitude to our primary establishment, the Faculty of Applied Sciences and Universiti Teknologi MARA, Perak Branch, for their invaluable assistance.

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INVESTIGATION OF FUEL CELL OUTPUT UNDER DIFFERENT ELECTROLYTE CONDITIONS AND RENEWABLE HYDROGEN GENERATION SOURCE FROM TELUK BATIK, MALAYSIA

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Abstract: Proton exchange membrane fuel cells (PEMFCs) represent a promising clean energy technology, providing an efficient and environmentally sustainable method of electricity generation through electrochemical reactions. The performance and efficiency of PEMFCs are strongly influenced by several parameters, including electrolyte type and concentration, operating temperature, input voltage, and the source of water used for electrolysis. Optimising PEMFC systems requires a comprehensive understanding of how these factors interact, particularly in relation to the application of non-conventional electrolytes and renewable water sources for hydrogen production. This study investigates the performance of PEMFCs under different electrolyte conditions (HCl and NaOH), renewable water sources such as seawater, and applied input voltages (5 V, 10 V, 15 V). The experimental design further examined the effects of different electrolytes with 0.5 M concentration and operating temperatures (room temperature, 70 °C, 80 °C, and 90 °C) on output voltage. Results demonstrate that electrolyte concentration, temperature, water source, and input voltage exert a significant influence on PEMFC efficiency and power output. Specifically, higher NaOH concentrations [0.5 M], elevated temperatures (90 °C), and greater applied voltages (15 V) enhanced hydrogen generation and overall cell performance. In contrast, the use of non-distilled water sources such as seawater was associated with reduced efficiency. These findings provide valuable insights into optimising PEMFC systems for sustainable energy production, particularly when integrating renewable water resources and non-traditional electrolytes.

Keywords: *Proton exchange membrane fuel cells (PEMFC), Clean energy, Hydrogen production, Sea water, Electrolyte concentrations*

INTRODUCTION

The escalating cost of fossil fuels, combined with the imperative to mitigate greenhouse gas emissions, has intensified efforts to develop more efficient and environmentally sustainable energy generation technologies (Wang & Azam, 2024). Malaysia, endowed with extensive water resources and an average annual rainfall of approximately 2000 mm, offers considerable potential for renewable energy exploitation (Mekhilef, 2010). Rivers, lakes, and groundwater represent major freshwater reserves that can be strategically utilized for energy applications. A proton exchange membrane electrolyser (PEME), which generates clean hydrogen gas, operates in a complementary manner to a Proton Exchange Membrane Fuel Cell (PEMFC) for electricity production (Bodkhe, Shrivastava, Soni, & Chadge, 2023). This study employs Proton Exchange Membrane Fuel Cells (PEMFCs) and hydrogen fuel cells to generate energy from locally available water resources, including seawater, with research focused on the Teluk Batik shore in Perak, Malaysia. The main objective is to systematically evaluate the influence of four critical parameters—electrolyte type, electrolyte temperature, power input, and renewable water source such as seawater—on the performance, efficiency, and durability of hydrogen fuel cells. Electrolysis is an electrochemical process that utilizes electrical energy to dissociate water molecules into hydrogen (H_2) and oxygen (O_2) (Cavaliere, 2023). The efficiency of electrolysis is strongly dependent on several key parameters, including the type of electrolyte, operating temperature, applied power input, and the quality of the water source (Mazloomi & Sulaiman, 2012). Temperature exerts a significant influence on ion mobility and electrochemical reaction kinetics during the electrolysis process (Elder, Cumming, & Mogensen, 2015). The experimental scope includes the assessment of multiple electrolytes such as seawater, hydrochloric acid (HCl), and sodium hydroxide (NaOH) to understand their effects on output voltage, ionic conductivity, electrochemical reaction kinetics, and overall system efficiency. Investigations will be conducted with electrolyte concentrations [0.5 M], operating temperatures (ambient, 70 °C, 80 °C, 90 °C), and applied voltages (5 V, 10 V, 15 V).

The study will further examine the impact of power input on energy conversion efficiency, long-term stability, and operational durability. Additionally, the feasibility of employing unconventional water sources, such as seawater, will be explored with respect to their contribution to system performance. By analysing the interplay of these operating variables, this research seeks to establish synergistic conditions that maximize hydrogen fuel cell output and reliability. The outcomes are expected to validate the technical feasibility of optimized hydrogen fuel cells for deployment in diverse environmental settings, thereby advancing the development of sustainable, cost-effective, and scalable hydrogen production technologies.

METHODOLOGY

The experiment was designed to evaluate the effects of electrolyte concentration, temperature, and water source type on fuel cell performance. Hydrochloric acid (HCl), and sodium hydroxide (NaOH) were employed as electrolytes at concentration of 0.5 M. The PEMFC performance was assessed by measuring the voltage output at three voltage levels (5 V, 10 V, and 15 V) during a 1-minute test period using DC voltage. The 1-minute testing duration was selected because the output voltage continued to increase over time; thus, this time frame allowed any fluctuations or initial transient effects in the system to stabilize before measurement. The experiments were conducted at four distinct temperature settings: room temperature (23–24 °C), 70 °C, 80 °C and 90 °C, to examine the influence of temperature on the electrochemical reactions within the fuel cell. The study also included three seawater sources for electrolysis. The PEMFC system was connected to a power supply, and hydrogen production was recorded over a 1-minute interval for each combination of temperature and water source. For data collection, a digital millivoltmeter was used to measure the voltage output of the fuel cell, and the output was recorded at 1-minute intervals. Temperature control was maintained using thermal insulation, achieved by wrapping the electrolysis kit with a towel to minimize heat loss to the environment, thereby ensuring that the experimental conditions remained stable throughout the testing process. The data from each experimental run were subsequently analysed to determine the relationships among electrolyte type, concentration, temperature, and fuel cell performance, as well as the impact of renewable water sources on hydrogen generation.

Electrolyte Preparation

Preparation of HCl solutions

To prepare 500 mL of 0.5 M HCl from a 12 M HCl stock solution, 20.83 mL of concentrated HCl was carefully measured using a pipette and transferred into a 500 mL volumetric flask containing approximately 200 mL of distilled water. The solution was mixed gently, allowed to cool, and then diluted to the calibration mark with distilled water to obtain the final 0.5 M HCl solution. The volumetric flasks were then labelled and set aside for experimental use.

Preparation of NaOH solutions

To prepare 500 mL of 0.5 M NaOH solution, 10 g of solid NaOH pellets was accurately weighed and dissolved in approximately 200 mL of distilled water in a beaker. The solution was stirred until fully dissolved and allowed to cool. It was then transferred into a 500 mL volumetric flask and diluted to the calibration mark with distilled water to obtain the final 0.5 M NaOH solution. The solutions were stirred until the NaOH pellets were completely dissolved, after which volumetric flasks were then labelled and set aside for experimental use.

Filtration process for seawater

The seawater water sample was filtered using filter paper to remove suspended particles and impurities. Each sample was poured through filter paper placed in a funnel until the water appeared clear and free of debris. A total of 1000 mL of each sample was collected and stored for subsequent experiments.

Experiment setup

The experiment was setup by the used of power supply with two wires connected to the PEM, two tubes connected to the hydrogen fuel cell for gas flow, and two additional wires connected to an ammeter for measuring the output voltage. To demonstrate the working principle of a hydrogen fuel cell, a small fuel cell kit was assembled, which included an anode, a cathode, and a proton exchange membrane that allowed only protons to pass through. A hydrogen source was generated by splitting water into hydrogen and oxygen through electrolysis, achieved by adding different electrolytes to enhance the conductivity of the water.

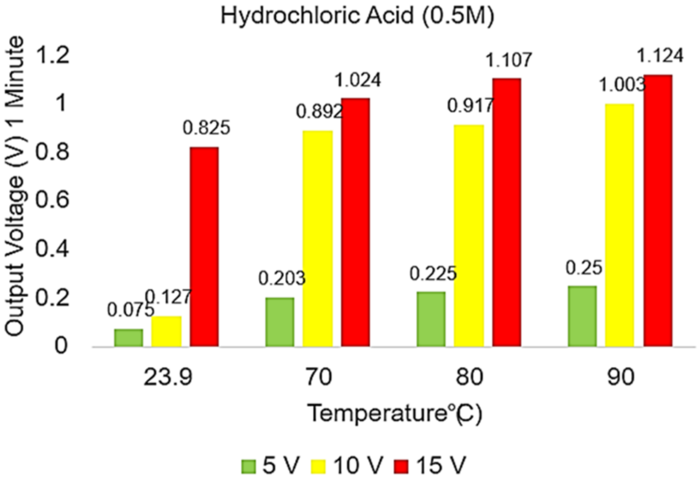
Study Area and Site Selection

Seawater sampling was performed at a shore site in Teluk Batik, Perak, Malaysia (4°11′19.4″N, 100°36′18.9″E).

FINDINGS

The performance evaluation of hydrochloric acid (HCl) and sodium hydroxide (NaOH) as electrolytes revealed that higher concentrations and elevated temperatures markedly enhance electrolysis efficiency. Among the tested electrolytes, HCl and NaOH produced the highest output voltages, with NaOH at 0.5 M demonstrating the most consistent performance under all experimental conditions. In terms of alternative water sources, seawater shows potential as a renewable electrolyte for energy applications. The highest concentration, 0.5 M HCl, further improved electrolysis performance, yielding a maximum voltage of 1.124 V at 90 °C with 15 V applied, representing the optimum performance for HCl within the studied parameters. Comparable findings have been reported that increasing analyte flow rate, concentration, oxygen flow rate, and temperature resulted in decreased cell voltage but increased current columbic efficiency (CCE) (Joudaki, Mohammadi, Yousefi, Eivazkhani, & Yousefi, 2009).

a)



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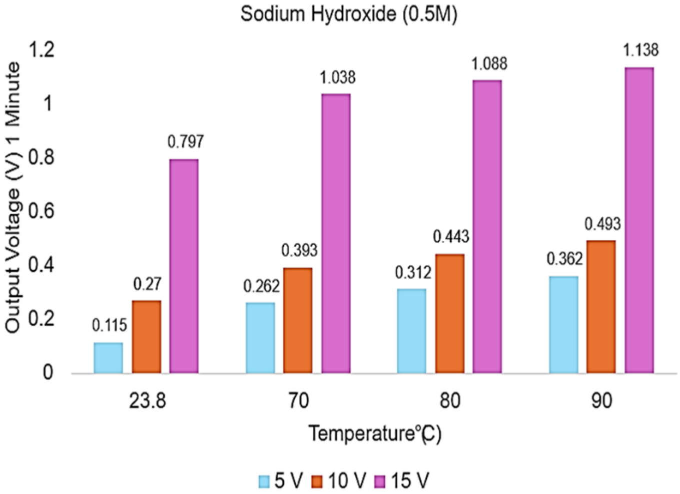

Figure 1 (a) Temperature-dependent voltage output for HCl [0.5 M] at applied voltages of 5 V (green), 10 V (yellow), and 15 V (red). (b) Voltage–temperature relationship for NaOH [0.5 M] at applied voltages of 5 V (blue), 10 V (orange), and 15 V (purple).

The electrolysis performance of 0.5 M HCl shows a strong relationship between temperature, applied voltage, and output voltage in figure 1 (a). At room temperature (23.9 °C), the output voltages were relatively low, measuring 0.075 V, 0.127 V, and 0.825 V for applied inputs of 5 V, 10 V, and 15 V, respectively. As the operating temperature increased, output voltages improved markedly. At 70 °C, the recorded values rose to 0.203 V (5 V), 0.892 V (10 V), and 1.024 V (15 V). Further enhancement was observed at 80 °C, with outputs of 0.225 V, 0.917 V, and 1.107 V for 5 V, 10 V, and 15 V, respectively. The highest performance occurred at 90 °C, yielding maximum voltages of 0.250 V (5 V), 1.003 V (10 V), and 1.124 V (15 V). These results confirm that higher electrolyte concentration, in combination with elevated temperature and applied voltage, substantially enhances electrolysis efficiency (Zhang et al., 2023).

The electrolysis performance of 0.5 M NaOH exhibits a consistent increase in output voltage with rising temperature and applied voltage as shown in figure 1 (b). At room temperature (23.8 °C), the recorded values were 0.115 V, 0.270 V, and 0.797 V for inputs of 5 V, 10 V, and 15 V, respectively. At 70 °C, the output increased to 0.262 V (5 V), 0.393 V (10 V), and 1.038 V (15 V). Further improvements were observed at 80 °C, yielding 0.312 V, 0.443 V, and 1.088 V, while the highest performance was achieved at 90 °C, with maximum voltages of 0.362 V (5 V), 0.493 V (10 V), and 1.138 V (15 V). The electrolysis performance of NaOH demonstrates a pronounced enhancement in output voltage with increasing concentration and temperature. The highest concentration tested, 0.5 M NaOH yielded the best performance, achieving 1.138 V at 90 °C and 15 V, representing the peak electrolysis efficiency across all NaOH concentrations. These results confirm that higher

NaOH concentration, coupled with elevated temperature and applied voltage, delivers the strongest electrolysis efficiency among the tested conditions (Zhang et al., 2023).

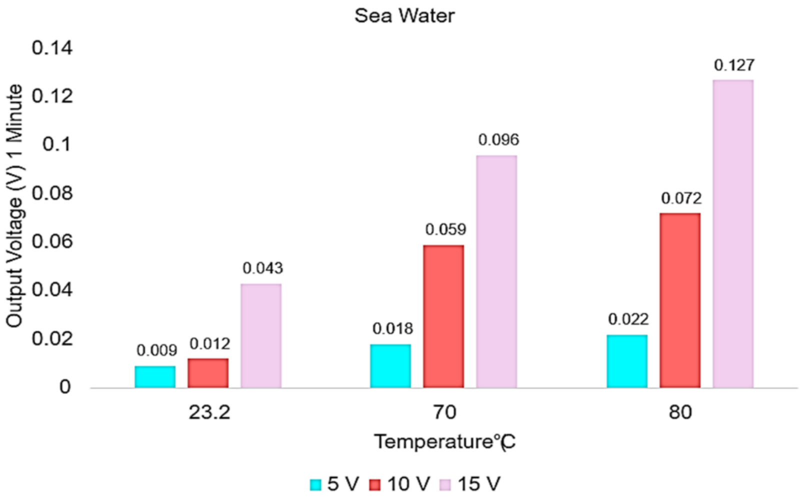

Figure 2 Temperature-dependent voltage output of seawater (boiling point: 97.4 °C) at applied voltages of 5 V (blue), 10 V (red), and 15 V (light purple).

The influence of renewable energy sources, such as solar and wind, on electrolysis systems can be assessed through the performance of alternative electrolytes and natural water samples. The electrolysis behaviour of natural waters demonstrates considerable variability. Hydrogen production via the electrolytic decomposition of water is scientifically straightforward, reliable, and clean, with fundamental principles established in the early 19th century (Fickett & Kalhammer, 2018). However, large-scale adoption has been limited by the high cost of electricity relative to fossil-based feedstocks such as natural gas or naphtha (Zanon-Zotin et al., 2024).

Since electrolysis plant design is minimally affected by oxygen utilization—and on-site oxygen applications remain rare—hydrogen is the primary focus of water electrolysis studies. Advances in electrolysis technologies aim to reduce these limitations, bringing practical hydrogen production closer to its theoretical efficiency limits. Moreover, figure 2 for seawater (boiling point 97.4 °C) at Teluk Batik shore, Perak indicates a progressive increase in output voltage with both temperature and input voltage. At room temperature (23.2 °C), the output voltage is recorded as 0.009 V at 5 V, 0.012 V at 10 V, and 0.043 V at 15 V. When the temperature is raised to 70 °C, the output voltage increases to 0.018 V (5 V), 0.059 V (10 V), and 0.096 V (15 V). At 80 °C, the output improves further, reaching 0.022 V (5 V), 0.072 V (10 V), and 0.127 V (15 V). Seawater (boiling point 97.4 °C) exhibits encouraging performance, with output voltage gradually increasing alongside temperature and applied voltage, reaching a maximum of 0.127 V at 80 °C with a 15 V input as shown in figure 2. Compared to a pure electrolyte, the dissolved salts in seawater decrease the electrolytic efficiency; therefore, pretreatment is necessary to enhance the output voltage (Shetty et al., 2025).

CONCLUSION

The findings of this study provided valuable insights into the performance of Proton Exchange Membrane Fuel Cells (PEMFCs) under varying electrolyte types, concentrations, temperatures, and water source conditions. The results demonstrated that both temperature and electrolyte concentration exerted a significant influence on output voltage and electrolysis efficiency. Among the tested electrolytes, NaOH at 0.5 M consistently produced the highest output voltages, with optimal performance achieved at elevated temperatures (90 °C) and higher applied voltages (15 V). For alternative water sources, seawater collected at a nearshore site Teluk Batik, Perak displayed notable improvements in output voltage with increasing temperature and applied voltage, suggesting its potential as a practical electrolyte for renewable energy applications. Despite experimental limitations, such as challenges in temperature control and equipment precision, the results underscore the importance of water quality, electrolyte concentration, and temperature in enhancing hydrogen production for PEMFC applications. These findings indicate that seawater electrolysis offers a viable pathway to support the advancement of a sustainable hydrogen economy, with potential implications for clean transportation, energy storage, and emission reduction across multiple sectors. Future research should focus on improving seawater-based electrolysis efficiency and addressing current experimental constraints. Key directions include investigating the influence of seawater composition from different geographical locations other than shore at Teluk Batik, Perak on output voltage, exploring alternative electrode materials to enhance reaction kinetics, and examining the role of catalysts in increasing electrolysis efficiency. Additionally, microbial activity within seawater may impact the electrolysis process; thus, identifying native microorganisms and developing strategies to mitigate their effects could further optimize system performance. Addressing these areas of research will be critical for advancing seawater-based hydrogen production and accelerating the transition toward a sustainable hydrogen economy.

COMPLIANCE OF ETHICAL STANDARDS

Not applicable.

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