DEVELOPMENT OF SALTWATER LAMP USING DIFFERENT TYPE OF FUEL CELL TO INCREASE ITS EFFICIENCY

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ABSTRAK

Percubaan ini direka untuk mengkaji cara pelbagai jenis sel bahan api berfungsi dengan lampu air masin. Percubaan sel bahan api Al-air bermula dengan mengisi persediaan dengan empat plat aluminium dan empat katod udara yang ditenggelami dalam 350 ml air dengan 20 gram garam untuk menghasilkan elektrolit garam. Kemudian, ia disambungkan kepada multimeter untuk mengukur voltan dan arus. Eksperimen diulang dengan sel bahan api Al-Cu yang menggunakan empat plat aluminium dan empat plat kuprum. Kedua-dua sel bahan api telah diuji untuk masa yang singkat. Sel bahan api Al-air mempunyai cahaya yang lebih terang daripada sel bahan api Al-Cu. Bacaan ketumpatan kuasa sel bahan api Al-Cu adalah lebih rendah daripada sel bahan api Al-air. Kajian mendapati bahawa Al-air adalah pilihan yang baik untuk mengoptimumkan lampu garam, tetapi bahan aloi al lebih baik untuk mencegah masalah yang dicipta sendiri dan menghasilkan produk sampingan.

ABSTRACT

The objective of the experiment is to study the performance of saltwater lamps with a different type of fuel cell. The experiment for Al- air fuel cell started by using a complete setup of Al-air fuel cell with four aluminum plates and four air cathodes submerged in 350 ml water with 20gram of salt to form salt electrolyte into the case then it was connected to multimeter for voltage and current reading. The experiment was repeated using Al-Cu fuel cell which used four aluminum and four copper plates. Both fuel cells were tested for 30 minutes. According to the result obtained, Al-air has better brightness compared to Al-Cu fuel cell. Al-Cu fuel cell's power density reading is lower than Al-air fuel cell. In conclusion, Al-air is recommended for the optimization of the saltwater lamp but al alloy material was proposed for the self-prevention and by-product formation.

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LIST OF SYMBOLS

%	Percent
H^2	Hydrogen
3D	3 Dimension
G	Gram
µs	Micro siemens
W	Watts
Al	Aluminium
Cu	Copper
M	Molarity
CO^2	Carbon Dioxide
Mg	Magnesium
Ni	Nickel
Co	Cobalt
E°_{CELL}	Cell Potential
Si	Silicon
Mn	Manganese
Nacl	Sodium Chloride
$Al(OH)_3$	Aluminium Hydroxide
K^+	Potassium Ion
Cl^-	Chloride Ion
Na^+	Sodium Ion
Zn^{2+}	Zinc Ion
$CuSO_4$	Copper sulphate
SO_4^{2-}	Sulphate Ion
NO_3^-	Nitrate Ion

LIST OF ABBREVIATIONS

EES	Electrical Energy Store
LED	Light Emitting Diode
MAFC	Metal- air Fuel Cell
AAB	Aluminium Air Battery
EV	Electrical Vehicle
TEC	Thermal Expansion Coefficient
BSCF	Barium Strontium Cobalt Iron Oxide
LSCF	Lanthanum Strontium Cobalt Ferrite

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Energy is essential for technological applications that increase productivity and is the driving factor behind socioeconomic progress. Over the past two centuries, fossil fuels (coal, oil, and gas) have been the primary sources used to supply humankind's energy needs. At the moment, fossil fuels provide 80 percent of the world's energy needs (and, 2019). In wealthy economies, using electricity for illumination is a basic necessity, but in underdeveloped nations, particularly in rural regions, using electricity for daily tasks indicates privilege. According to a country remark presented by Malaysian representative during the First Annual Sustainable Energy for All Forum and Launch of the United Nations Decade of Sustainable Energy for All (2014 – 2024), the electricity access rate in Malaysia, as of 2013, had achieved 96.86 %. The percentage was above regional average. However, it was contributed by high electricity access rate in Peninsular Malaysia (99.72 %), whereas two East Malaysia (also known as Malaysian Borneo) states: Sabah and Sarawak had only achieved 92.92 % and 88.01 % respectively. The percentage revealed that approximately 0.8 million Malaysians are living without electricity access (Liang, n.d). The majority of them reside in East Malaysia's rural districts. Kerosene oil lamps are frequently used for lighting in many rural areas of East and Peninsular Malaysia, particularly when there is no power or access to electricity is too expensive. Households without access to electricity must rely on kerosene and dry-cell batteries to provide for their basic lighting needs, which has negative effects on both human health and the environment. According to this study, the best option to improve lighting access in Malaysia's rural areas is to create fuel cells that use salt water as an electrolyte. Saltwater battery is another type of batteries that is suitable for household energy storage. Unlike lead acid and lithium-ion batteries, saltwater batteries don't contain heavy metals that need to be properly disposed of when their useful lives are through. In saltwater batteries, the electrolytes process is secure and simple to recycle. Furthermore, the nature of saltwater batteries allows them to be completely discharged

(100 percent) without hurting the devices, unlike lead acid and lithium-ion batteries. Fuel cells can close the energy supply-demand gap in Malaysia's rural areas by supplying clean electricity (Fuel Cells, 2022). Salt is simple to obtain because it is seen as a necessary ingredient in cooking. Rapid progress in fuel cell technology, its impact for future economic, environmental and social issues and the increasing involvement of various actors and countries in its development (OECD, 2006) are clear signals for its possible impact in worldwide technological development and industrial transformation (Zeeda Fatimah Mohamad, 2011)

1.2 Problem Statement

About one-fourth of Malaysia's population is rural. The basic administrative unit in both East and Peninsular Malaysia is the kampung (village, or community of houses). ("Malaysia - Settlement Patterns | Britannica," 2022). For a country to flourish socially and economically, access to energy is essential. Rural locations frequently have less access to electricity than urban ones do. While most of the homes have no electricity, some of them do. As a result, local residents were unable to access lighting for purposes of education and daily activities. To get beyond the necessity for particular conditions and infrastructure for the development of rural areas, a sustainable renewable energy source is necessary. There is a lot of saltwater, and it is simple to directly harness energy. Malaysia also has a total area of 330,000 km2 and a coastline of around 4,800 km, half of which is made up of beaches and the rest of which is made up of mangrove-fringed and rocky shores (Sofia Ehsan et al ,2019).

In the development of saltwater lamps, fuel cell durability is crucial. From Felda and throughout Malaysia, energy cutoffs are a problem, particularly during the flood seasons. Having a sufficient lighting system to resources is a regular issue this time of year for victims and rescue teams. Electricity is typically turned off during floods to protect people, but eventually distant areas lose power and are left without even the most basic means of illumination at night. The evacuation centres also often encounter a lack of light or lamps in the canters to look after the victims. The performance of a fuel cell or stack is affected by many internal and external factors, such as fuel cell design and assembly, degradation of materials, operational conditions, and impurities or contaminants (Wu et al., 2008). More studies need to be done in making saltwater battery a safe rechargeable battery and concurrently help to reduce energy cost when using as electrical energy storage (EES) systems (Park et al., 2016) with increasing the durability of the saltwater lamp in fuel cell

1.3 Objective of The Study

This project has objective as below:

i. To develop the saltwater lamp using recyclable material

ii. To study the performances of saltwater lamp with different types of fuel cell

1.4 Scope of Study

The aim of study is to harness the energy potential of saltwater as electrolyte in fuel cell and develop it to become saltwater lamp for the rural area that have limitation access of electricity and illumination access for daily activities. With the appropriate type of fuel cell, the salt water will be able to assist the generation of electricity that can produces radiation in the form of light and long lasting to use. For local use in rural areas, the combination of an LED lamp with a saltwater battery is anticipated to prove efficient and effective. Heavy metals that must be appropriately disposed of at the end of a battery's lifespan are not present in saltwater batteries. The electrolytes procedure used by saltwater batteries is secure and simple to recycle. In contrast to lead acid and lithium-ion batteries, the nature of saltwater batteries allows them to be totally emptied (100%) without endangering the devices. The performance of saltwater lamps with ideal type of fuel cell was also the subject of this investigation. The experiment was conducted in two types of fuel cell, Al-air Fuel cell and simple fuel cell.

1.5 Important of Study

By developing a saltwater lamp that easy to utilize and carry can give a positive impact for the local in rural area in East and Peninsular Malaysia which can be used for education and daily activities purposes. Therefore, it is crucial to create a saltwater lamp that makes use of inexpensive electrodes that are simple to find in any hardware store. In order to create an appealing saltwater lamp, a cell's lifetime is also a key factor. The low cost of energy production may contribute to a higher standard of living for people. While adults can continue crafting under improved lighting to increase their household income, children can continue learning at night to raise educational standards.

CHAPTER 2

LITERATURE REVIEW

2.1 Galvanic Cell

The galvanic cell may have an anode or cathode of dissimilar metals in an electrolyte or the same metal in dissimilar conditions in a common electrolyte. For example, steel and copper electrodes immersed in an electrolyte represents a galvanic cell. The more noble metal copper acts as the cathode and the more active iron acts as an anode. Current flows from iron anode to copper cathode in the electrolyte. (Ahmad, 2006) A galvanic made up of 2 metals (electrodes), which are linked throughout an electrical conducting solution (an electrolyte) and linked externally to complete the circuit. In such a case, one of the metallic materials (more reactive) begins to solubilize in an electrolyte, whereas the other tends to contain new metal deposited on it. As the metal is dissolved, the more reactive electrons that are used in the metal deposition on the other electrode flow through the external contact (as an electrical current). The dissolution and deposition reactions, which made by the anode and the cathode reactions in the order, are called half-cell reactions, and without the separation of these two half-reactions spatially, this energy would be liberated as heat (Salah, 2020)

A basic example of a galvanic cell containing 2 cell diagram metal / metal ion systems ;$Zn_{(s)} + Cu^{2+}_{(l)}(aq) \rightarrow Zn^{2+} + (aq) + Cu_{(s)}$The galvanic cell can be used to perform this reaction; a copper strip is inserted into a beaker that contains a 1 M solution of Cu^{2+} ions, and a zinc strip is inserted into a different beaker that contains a 1 M solution of Zn^{2+} ions. The two metal bands, which function as electrodes, are attached by a wire, and the compartments are linked with a salt bridge, a U-shaped tube that is inserted into the two solutions that involve a concentrated liquid or gelled electrolyte. The ions in the salt bridge are chosen to prevent interfering with the electrochemical reaction through oxidation , reduction or precipitation or by forming a complex;

commonly used cations and anions are Na^+ or $K^+$and NO_3^- or SO_4^{2-} , (The ions in the salt bridge do not have to be the same as those in the redox couple in either compartment) .When the circuit is closed, a spontaneous reaction occurs: zinc metal is oxidized to Zn^{2+} ions at the zinc electrode (the anode), and Cu^{2+} ions are reduced to Cu metal at the copper electrode (the cathode). As the reaction progresses, the zinc strip dissolves, and the concentration of Zn^{2+} ions in the Zn^{2+} solution increases; simultaneously, the copper strip gains mass, and the concentration of Cu^{2+} ions in the Cu^{2+} solution decreases.The electrons that are released at the anode flow through the wire, producing an electric current . Galvanic cells therefore transform chemical energy into electrical energy that can then be used to do work (Grantham, 2003)

2.2 Metal Air Fuel Cell

Metal-air fuel cells (MAFCs) are a kind of electrochemical devices that can directly convert the chemical energy stored in metals fuels (e.g., Mg, Al or Zn) or their alloys into electricity(Wang et al., 2018) The anode may be made of metals and these metals may include alkali metals like lithium, potassium or sodium, alkaline earth metals like calcium and magnesium, some metalloid like Si, and Al or transition elements like iron and zinc. The electrolyte may vary from hydrous or non-hydrous depending on the type of the anode used. The other reduction electrode is made up of air, anode and cathode are separated by separators. The metal air batteries are the distinct energy storage system as the cathodic oxygen is unlimited source from environment and it need not be stored(Ahuja et al., 2021).

MAFC also be known as Metal- Air Battery (MABs). These batteries are inexpensive since the cathode source (natural oxygen) is abundant and the anode can be made from low-cost metals (Rahman et al., 2013). MABs therefore seems to be one of the useful and advanced contenders for the upcoming requirements because of their higher heat capacity and power density as compared to other parallel batteries specially for EVs. Metal air batteries are amongst the advanced class of primary and secondary cells. As the air is circulating throughout the cell in these batteries between the electrodes, they are at times classified as fuel cells

Compared with hydrogen and alcohol fuel cells, MAFCs possess many advantages, including facile solid fuel storage and transport, simple system structure, low cost, and more safety. Due to these intrinsic merits, MAFCs have gained many attentions and been regarded as promising power sources for application in emergency (Linden et al., n.d.).

2.2.1 Type of metal air fuel cell

Metal-air batteries such as lithium-air, zinc-air, magnesium-air, and aluminium-air batteries are promising for future generations of EVs because they use oxygen from the air as one of the battery’s main reactants, reducing the weight of the battery and freeing up more space devoted to energy storage

2.2.1.1 Zinc-air fuel cell

Zinc is the mature anode material for many batteries, such as zinc-manganese battery, zinc-silver battery, and zinc-air battery, because of its low equilibrium potential, reversibility, compatibility with aqueous electrolytes, low equivalent weight, high specific energy, high volumetric energy density, abundance, low cost, low toxicity, and ease of handling (McLarnon & Cairns, 2010). The zinc air batteries are the most appropriate for small-current applications such as hearing aids. When a porous zinc anode reacts with alkaline electrolyte, the stability of zinc electrode is a concern due to hydrogen gas evolution, resulting in a later increase in the pressure of the battery cell and water electrolytes (Kim et al., 2010). These side reactions eventually decrease the cycle life of a zinc-air battery. Therefore, zinc electrode will be corroded over time and giving rise to capacity losses and potentially dangerous hydrogen gas build-up (Caramia & Bozzini, 2014)

2.2.1.2 Aluminium-air fuel cell

Aluminium is an attractive anode material for MAFCs because of its negative electrode potential. The aluminium air battery (AAB) is highly suitable for electric vehicles (EVs) as an energy source. However, Aluminium-air batteries are not rechargeable. They will no longer produce electricity once the anode's aluminium is consumed by its reaction with the cathode's oxygen in an aqueous electrolyte to form hydrated aluminium oxide. However, the battery can be mechanically recharged by using new aluminium anodes made from recycled hydrated aluminium oxide (Saurenergy, 2022). Aluminium-air batteries use either alkaline or brine electrolytes. And anode aluminium metal corroded in electrolytes to forms gel like hydrated alumina (Oguzie, 2007), and reduces the cell electricity capacity

2.2.1.3 Magnesium- air fuel cell

Magnesium-air fuel cell is a combination of Mg as the anode and air is reduced at cathode. Reducing electrode is generally based on activated carbon. Sometimes catalysts are also used with a fine layer of aquaphobic polymer material and the metal sheet as the conductive element which is based on the electrode position of electrolyte material. The Mg-air batteries show relatively high energy density and voltage, but low columbic efficiency and high polarization limit their commercialization. For example, the actual value of specific energy is <10 % of the theoretical value, and the working voltage is usually below 1.2 V (Yaqoob et al., 2022). However, the discharge product is sluggish which masks the bottom portion of magnesium anode and difficult to replace after discharge of magnesium anode in alkaline electrolytes The corrosion problem of magnesium electrodes, which reduces the shelf life and operation life of the battery (Rahman et al., 2013). lloying Mg with other metals such as Al, Mn, or Zn, which prevent the hydrogen evolution reaction, has attracted a lot of attention. With the fast development of metallurgical technology, Mg alloys have been widely explored for Mg–seawater batteries (Balasubramanian et al., 1995)

2.3 Electrolyte

In physics and chemistry, an electrolyte is a substance that conducts electrical current as a result of splitting into positively and negatively charged ions, which typically move toward and discharge at the cathode and anode of an electric circuit, respectively. Acids, bases, and salts, which ionise when dissolved in such solvents as water or alcohol, are the most well-known electrolytes. Many salts, such as sodium chloride, behave as electrolytes when melted in the absence of any solvent; and some, such as silver iodide, are electrolytes even in the solid state (“Electrolyte | Definition, Examples, & Facts | Britannica,” 2022). It turns out that when a soluble ionic compound such as sodium chloride undergoes dissolution in water to form an aqueous solution consisting of solvated ions, the rightward arrow used in the chemical equation is justified in that (as long as the solubility limit has not been reached) the solid sodium chloride added to solvent water completely dissociates. In other words, effectively there is 100% conversion of NaCl(s) to Na+(aq) and Cl−(aq). A sodium chloride solution is highly conductive due to the abundance of ions, and the light bulb glows brightly. In such a case, we say that sodium chloride is a strong electrolyte (CHEM 101 - Electrolytes, 2020) Strong electrolytes can dissolve in an aqueous solution, but weak electrolytes do not entirely dissociate into the solvent. The ions and molecules in the electrolyte are both present in the solution. In water, weak electrolytes only partially ionise, whereas strong electrolytes totally ionise. Weak electrolytes include weak bases and weak acids. Strong electrolytes include strong bases, strong acids, and salts. Despite its limited water solubility, salt is regarded as a powerful electrolyte because the water it dissolves in is entirely ionised.

Acetic acid is the acid that is found in vinegar. It is an electrolyte that dissolves in water very easily. However, when it dissolves in water, a large portion of its original molecule does not change into an ion form. Ethanoate is the name of this first state. When acetic acid is dissolved in water, it ionises to form the ions ethanoate and hydronium. Acetic acid is a poor electrolyte as a result (Vedantu, 2021). One of the most crucial steps in creating a battery cell is selecting the electrolyte. The electrolyte nevertheless has a significant impact on the performance of the cell even if it is not involved in the primary electrochemical reactions. its conductivity, among other chemical and electrical characteristics (Gores et al., 2014)

2.4 Saltwater Energy

Due to a growing reliance on imported fuels and dwindling domestic supplies, Malaysia is currently undergoing an energy crisis. Because of population and economic expansion, especially in developing market nations, the world's demand for energy is rising quickly. While accompanied by greater prosperity, rising demand creates new challenges. Energy security concerns can emerge as more consumers require ever more energy resources. And higher consumption of fossil fuels leads to higher greenhouse gas emissions, particularly carbon dioxide (CO_2), which contribute to global warming. At the same time, the number of people without access to electricity remains unacceptably high (Hadia et al., 2022). Most green energy is harvested from natural sources such as wind, thermal, and solar power. Supplying electrical energy directly from these sources is difficult as the energy is still costly and not always available where and when it is needed. Unlike the rest of the world, Malaysia’s energy matrix is becoming more carbon-heavy: in terms of primary energy share, coal has increased from 5% in 1996 to 20% in 2016. In electricity production, coal has replaced natural gas as the main source of energy and now accounts for 46% of electrical energy generation. Meanwhile, modern renewable sources (solar and wind) make up less than 1% (Chai, 2021), but with increased demand for electricity and the likelihood that these natural resources will ultimately run out, more diversity of power supply sources is required and one of the natural resources is salt.

It has been suggested that salt might be used as a lithium substitute for rechargeable batteries and that a solution of fresh and salt water can produce electricity. On electrolytes, numerous investigations have been done. Promising alternative energy sources for power generation have been discovered naturally in saltwater as green energy technology has advanced. Many academics are interested in the design and production of saltwater-powered devices, especially for rural and remote people in Malaysia and around the world. 2018 (Bani et al.). The saltwater battery stores electrical energy based on the electrochemical reactions of the NaCl aqueous solution, which is easily available at low cost. (Park et al., 2016). A battery has three parts: an electrolyte and two electrodes, which are made by different materials, often metals, but some of the first batteries that made by Alessandro Volta around 1880, used saltwater, silver, and zinc to generate electricity.

2.5 Electrodes

Electrodes and electrolyte are the two main fuel cell components that must be changed depending on the kind of fuel cell. Hydrogen is used as fuel at the anode, where oxidation occurs and sends electrons across the external circuit. Ions created in the preceding stage will flow toward the cathode through the electrolyte, where they will combine with oxygen and electrons to create water and electricity as a byproduct (Sarfraz et al., 2020). Electrodes are mostly used to create electrical current and transmit it through non-metal items in order to essentially change those objects in a variety of ways (Admin, 2018).

There are two types of electrodes: active electrodes and inert electrodes. The electrode that actively participates in the electrochemical cell's chemical reaction is known as the active electrode. It takes part in the reactions that take place in the electrolyte to conduct the electricity. Both oxidation and reduction reactions can occur in active electrodes. The active electrode's metal ions will dissolve in the electrolytic solution. Ion exchange is the mode of electrical conductance inactive electrodes. Active electrodes are primarily used in electroplating, which is the process of applying one metal to another metal using an electrochemical cell. Examples of the active electrode are the copper electrode and the magnesium electrode.

The electrode that does not actively participate in the electrochemical cell's chemical reaction is known as the inert electrode. However, rather than exchanging ions with the solution, it is still employed to conduct electricity via transferring electrons. Oxidation and reduction reaction does not occur in inert electrodes, but they add or remove electrons in the process of conducting electricity. Inert electrodes are primarily used in electrolysis, which is a process where the ionic compounds are decomposed by passing electricity through the compound. Examples of inert electrodes are the platinum electrode and graphite electrode (How, 2022). The main properties of anode, cathode and electrolyte materials should be as follow. Anode used in fuel cell is a part of fuel cell that carries out the electrode oxidation reaction, as oxidation take place the electrons move through external circuit. The anode used in fuel cell must be as follows:

• porous and has high catalytic activity for fuel used in it.

• consisting of better electronic and ionic conductivity.

• have compatible thermal expansion coefficient (TEC) with electrolyte.

• have less resistance for polarization.

Oxides based on Ni, Co, Cu, and Zn are some of the most frequently utilised anode materials in fuel cells. The correct electrolytes are then added to these electrode materials to produce a greater anode conductivity. In essence, the anode participates in ionic conductivity and electronic conductivity through the electrolyte (Afzal, 2013). The component of the fuel cell known as the cathode is involved in the reduction of oxygen molecules to generate oxide ions. These oxide ions migrate from the cathode to the electrolyte. Electronic current is also contributed by the cathode. Lithiated-nickel oxide is the typical fuel cell cathode material (LiNiO). LSCF and BSCF are two other typical cathode materials. The following characteristics of the cathode material should also be present:

- better ionic and electronic conductor (Mixed conductor).
- highly porous.
- chemically and physically stable under oxidizing atmosphere.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This section explains the research work plan, experimental setup, and parameter study have been demonstrated clearly. The details of the experimental outcome have been discussed further in the relevant chapters. Figure 3.1 elaborates the research framework to provide a crystal-clear view on the experimental strategy

3.2 Research Work Plan

The developed project was based on an experimental study of the ideal type of fuel cell that can increase the efficiency of the saltwater lamp and the needed output power to light a LED. All the setups had been clearly shown with details of experimental outcomes. In this experiment the voltage and current production with different types of fuel cell was measured using multimeter. Finally, the total duration of the saltwater lamp able to switch on will be determine in term of 30 minutes.

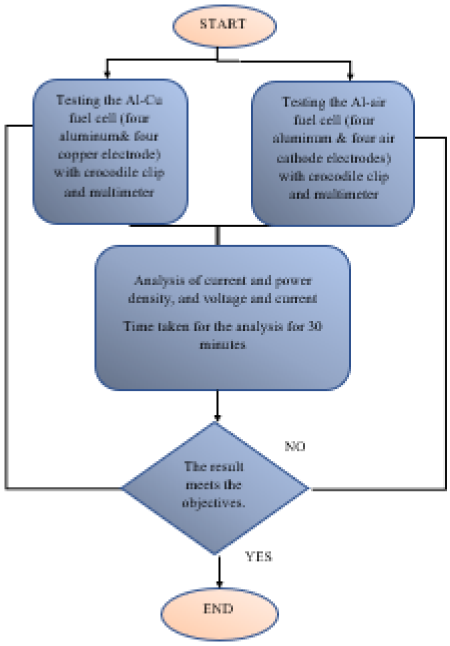

Figure 3.1 Research Work Flow

3.3 Experiment Setup

The saltwater storage tank was built via 3D printing. Together with the manufactured aluminium air fuel cell container, the electrical circuit board was connected with an LED lamp and a switch button. The circuit board then was attached to the water container via the connector that holds the electrodes. The connector was hold four pieces on Aluminium (Al) electrodes. To hold the lantern lamp, the external part of the lantern, which is made of foldable rubber, was fixed with the handle. Finally, the connection between the circuit board and the rest of the setup was checked. The experiment was continued with another type of fuel cell(Al-Cu fuel cell) with different fuel cell container. The Al-Cu fuel cell then was connected with four copper electrodes and four aluminium electrodes. The weight of copper plate was 81 gram while aluminium plate was 28 grams. Both electrodes contain same size (width:0.3cm), (height:6.65 cm) and (length:4.95).

3.4 Parameter Studies

The effect of different type of fuel cell was investigated. To isolate the influence of a given parameter on degrading efficiency some factors must be held constant during the research of these parameters. The factor that held constant was concentration of salt which is 20g weight of salt and 350ml water which is the ideal amount of concentration salt obtained from research journal (Chasteen, N. Dennis Chasteen, & Doherty, 2008). The parameter studies were different fuel cell, Al-Cu fuel cell and Al-air fuel cell. The testing period of current and voltage production was tested for 30 minutes

3.4.1 The Al-Cu fuel cell

The electrode material used for this experiment was four Aluminium (Al) and four Copper (Cu). Aluminium acts as anode and Copper acts as cathode. The combination 2 sets of electrodes were paired in one container with a complete setup of fuel cell and lamp was submerged into salt electrolyte with 20g weight of salt. The saltwater was connected with multimeter for 30 minutes to measure the voltages and currents. The voltage and current obtained from saltwater in the fuel cell will be calculated using the equation 3.1.

$$P = V \times I \qquad 3.1$$

$$P = Power$$

$$V = Voltage$$

$$I = Current$$

The amount of electric current traveling per unit cross-section area of the saltwater lamp was measured using the equation 3.2 and the power (energy density) was calculated using the formula in equation 3.3 where the surface area is 3.93 m^2 and fuel cell volume is 0.00035m^3

$$Current\ density\ \left({}^{A}/{}_{m^2}\right) = \frac{current\ (A)}{Surface\ area\ (m^2)} \qquad 3.2$$

$$Power\ \ density\left({}^{W}/{}_{m^2}\right) = \frac{Power\ Output\ (W)}{Fuel\ Cell\ Volume\ (m^3)} \qquad 3.3$$

3.4.2 Al- air fuel cell

The electrode material used for this Al-air fuel cell four aluminium copper. Aluminium acts as anode and the air acts as cathode connected with a stainless-steel mesh. The combination four aluminium electrode was set in a container with complete setup of fuel cell and lamp will be submerged into salt electrolyte with 20g weight of salt. The saltwater was connected with multimeter for 30 minutes to measure the voltages and currents. The voltage and current obtained from saltwater in the fuel cell will be calculated using the equation 3.1 and the current density was measured using the equation 3.2 and the power (energy density) was calculated using the formula in equation 3.3.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This section explains the result obtained from the experiment with details to ensure that the optimization is develop according to the main objectives.

4.2 Parameter Testing for the fuel cell performances

The experiment for Al-air fuel cell were recorded for 30 minutes for current, voltage and electrical conductivity reading in table 4.1 and table 4.2 for Al-Cu fuel cell.

Table 4.1 Current, Voltage and Electrical Conductivity Data for Al-air Fuel Cell

Data	0 min	5 min	10 min	15 min	20 min	25 min	30 min
Current (A)	0.74	0.79	0.85	0.85	0.85	0.85	0.86
Voltage(V)	3.26	3.26	3.44	3.41	3.42	3.92	3.4
Electrical Conductivity (µs/cm)	45.9	38.1	107.3	183.8	191.8	119.8	195.7

According to the data obtained from table 4.1, Al-air fuel cell recorded higher current and voltage reading compared to Al-Cu fuel cell reading showed in table 4.2. As reported by (Wei et al., 2019), the cell potential different between aluminium and air is +2.71 V which means it have strong oxidising and reducing agent. The higher current and voltage reading of Al-air fuel cell was also due to presence of graphite carbon that acts as catalyst in that fuel cell. The cell potential different showed in equation 4.2

$E^{\circ}_{Al} = -2.31V$

$E^{\circ}_{O_2} = +0.40V$

$$Anode: 4Al + 3O_2 + 6H_2O \rightarrow 4AL(OH)_3 \qquad 4.1$$

$$E^{\circ}_{CELL} = E^{\circ}_{red} - E^{\circ}_{oxid} \qquad 4.2$$

$$0.40V – (-2.31V) = +2.71V$$

An aluminium-air battery combines an anode made from pure lightweight aluminium with an air-electrode that replaces the cathode that operates on oxygen from ambient atmospheric air. During operation, the aluminium depletes and produces a by-product of aluminium hydroxide, $Al(OH)_3$ (Valentine, 2022) as shown in figure 4.1. The aluminium anode starts to corrode and react with salt solution to form aluminium hydroxide and hydrogen gas .Moreover, graphite carbon catalyst plays a crucial role by providing the necessary active sites for the reaction, whereas graphite improves the electronic conduction pathways and retains it during battery operation. . The increased current capacity is owing to the presence of highly conducting graphite in the cathode active material. It provides the necessary conduction pathway for the redox reaction to occur and enhances the current capacity of the saltwater battery

Figure 4.1 $Al(OH)_3$ and Hydrogen Gas Formation in Al − air Fuel Cell

As stated in table 4.2, the voltage and current reading for the Al-Cu fuel cell is lower compared to the Al-air fuel cell but it still managed to light up the saltwater lamp since the cell potential is +1.98V as showed in equation 4.4 which is lower compared to Al-air fuel cell. During the test, the copper reacts with atmospheric oxygen, forming a layer of brown-black copper oxide. Aluminium forces the copper out of the bond, as aluminium is a more active metal than copper in the electrochemical series of metals. Thus, red metallic copper and gaseous hydrogen are released. This reaction takes place very intensively, and with the release of heat (Science, 2017).

$E^{\circ}_{Cu} = +0.32V$

$E^{\circ}_{Al} = -1.66V$

$$2Al + 3Cu^{2+} \rightarrow 2Al^{3+} + 3Cu \quad 4.3$$

$$E^{\circ}_{CELL} = E^{\circ}_{red} - E^{\circ}_{oxid} \quad 4.4$$

$$0.32V - (-1.66)V = 1.98V$$

Table 4.2 Current, Voltage and Electrical Conductivity Data for Al-Cu fuel cell

Data	0 min	5 min	10 min	15 min	20 min	25 min	30 min
Current (A)	0.04	0.05	0.08	0.08	0.07	0.10	0.90
Voltage(V)	2.70	2.40	2.58	3.26	2.58	2.64	2.70
Electrical Conductivity (μs/cm)	191.80	183.80	179.80	183.80	187.80	183.80	187.80

4.3 Current and Power Density

The current and power density data was calculated in table 4.3 and 4.4. Current Density is the flow of current per unit area while power density is a measure of power output per unit volume. Power density allows more power to be processed in a smaller space while enhancing the functionality of a system at reduced, not increased, system costs (Texas Instruments, 2020). Table 4.3 showed the current and power density production for Al-air fuel cell and Al-Cu fuel cell. According to figure 4.2, Al -air fuel cell recorded 1.4732 A/cm^2 current density, which is higher compared to Al-Cu fuel cell,0.3346 A/cm^2. Moreover, in terms of power density in figure 4.3, al -air fuel cell also recorded higher reading, 8139.7 W/m^3 contrasted to simple fuel cell which is 1446.1 W/m^3.

Table 4.3 Current and Power Density for The Both Fuel Cell

Type of fuel cell	Current Density (A/cm^2)	Power Density(W/m^3)
Al-air fuel cell	1.4732	8139.7
Al-Cu fuel cell	0.3346	1446.1

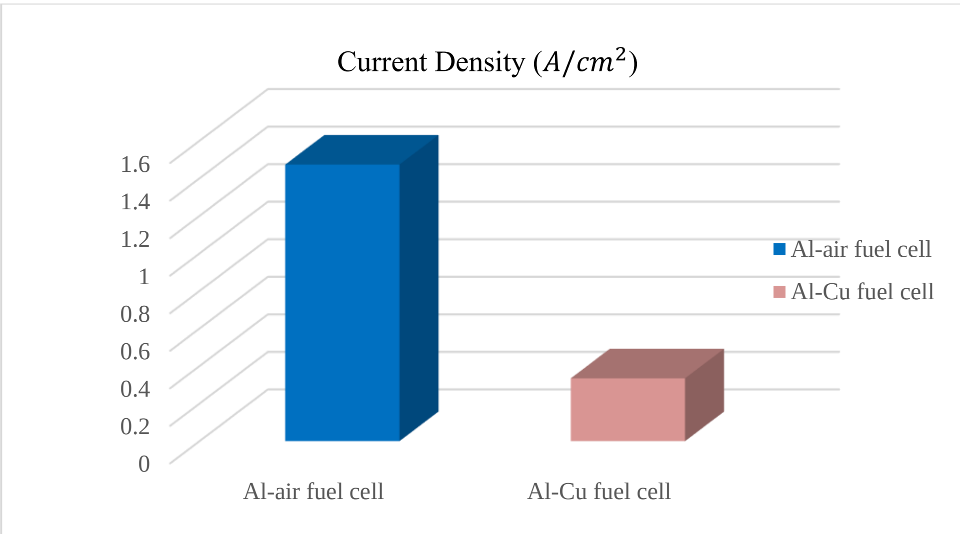

Figure 4.2 Graph Current Density for Al-air and Al-Cu Fuel Cell

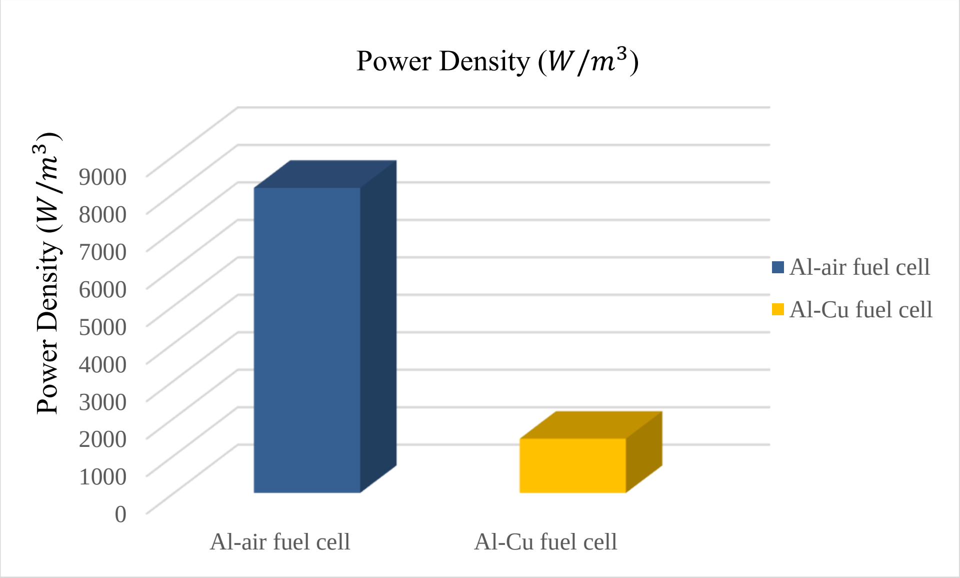

Figure 4.3 Graph Power Density for Al-air and Al-Cu Fuel Cell

CHAPTER 5

CONCLUSION

5.1 Conclusion

In conclusion, the objective to optimize the saltwater lamp performance using a different type of fuel cell is achieved, Al air fuel cell recorded high current and power density compared to the Al-Cu fuel cell. As the cost of air cathode is less and, in many cases, and uses of water or salt solution as an electrolyte that reduces the cost of al air fuel cell manufactured .With the knowledge of operation and improvement of a single fuel cell system in Al -air fuel cell, this study is expecting to assist the local communities that lack of electricity supply or electricity cut off during flood and fisheries and aquaculture sector as well as the coastal communities in terms of providing a better, safer, and cheaper alternative source of electricity. In summary, metal-air battery as a new technology has the advantages of simple structure, fast starting speed, etc. It does not require input of energy and can generate electricity. It is a green technology and worthy of further study.

5.2 Recommendation

Al-Cu fuel cell also can be improved by adding add additives. Referring to a study, by adding a small amount of Copper (II) sulphate solution ($CuSO_4$) into the seawater solution is the best idea as it produces high values of current. In the meantime, it also increases the reading of voltage for the fuel cell itself. The metal anode in the Al-air fuel cell, aluminium, should be explored to achieve a higher specific capacity, more negative electrode potential and lower corrosion resulting from hydrogen evolution. The addition of alloy elements and post-treatment of the alloys are the main approaches to improve the performance of the metal anode. Furthermore, the addition of corrosion inhibitors to electrolytes can ease the self-corrosion of aluminium anodes thus improve the practical efficiency of Al-air batteries. Choosing effective corrosion inhibitors with suitable concentration is a key investigation direction for the future advancement of Al-air technology

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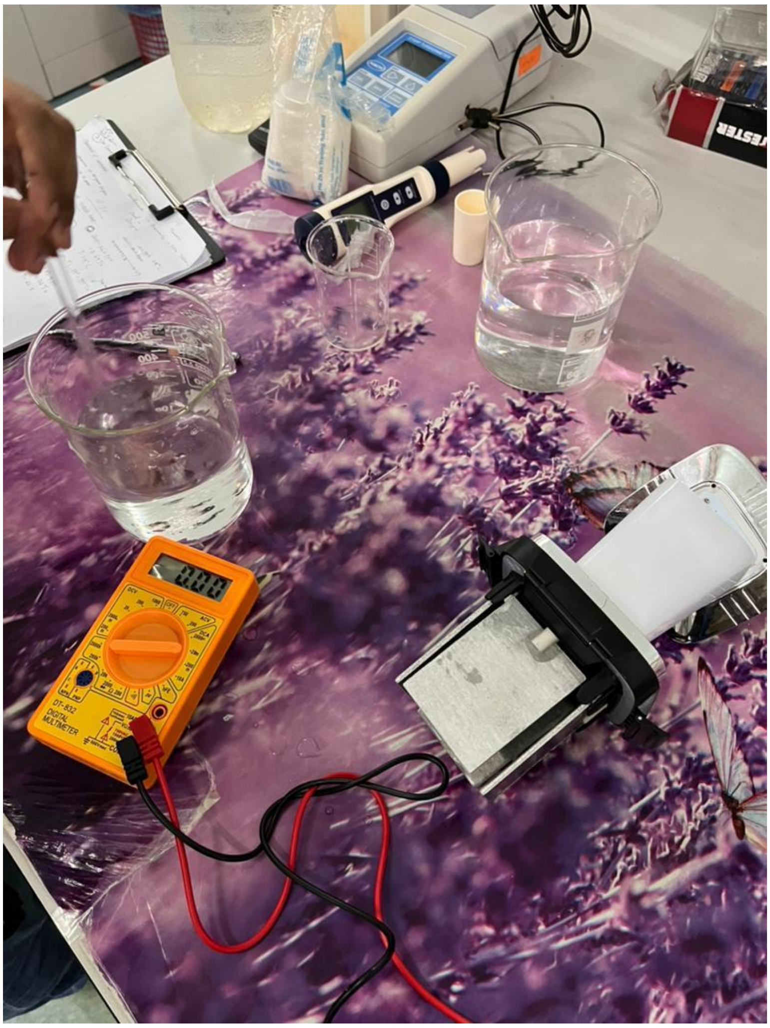
APPENDICES

Appendix A:Sample Preparation



Appendix B: Parameter Testing