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A Comparison of the Performance of Saltwater Electrolytic Cell Battery with Zinc-Copper and Aluminum-copper Electrodes

Larry Angelo R. Cañete [a]*

[a] *University of Cebu-Main Campus, Cebu City, Philippines.*

Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

Electrical energy is used to drive a non-spontaneous redox reaction in an electrolytic cell battery, which is composed of an electrochemical cell. The process of breaking down chemical compounds through electrolysis is frequently utilized, and it is derived from the Greek word lysis, which means to disintegrate. The electrolytic cell is composed of an electrolyte, two electrodes (one cathode and one anode), and three other components. Water or other solvents are typically used to make an electrolyte, which is a solution that contains dissolved ions. The purpose of this study is to test, analyze, and construct an electrolytic cell battery using various electrolytic solutions, salt-water concentrations, and the integration of fuel cells and electrodes. The research is designed to be experimental and relies on descriptive analysis to assess it. The design focused on the finding the optimal combination of electrode limited to zinc, copper, and aluminum (soda can), different electrolyte, type of connection of the fuel cells and the different concentration of saline solution used in order to provide optimum energy output. According to the data gathered and analyzed, the Zinc-

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*Corresponding author: E-mail: larryangelocanete9@gmail.com; lcanete@uc.edu.ph

Copper electrode produces an average voltage of 0.705 V per cell. Saltwater electrolyte produces the most effective results based on its cost effectiveness. When saline solution is 30% concentrated, the optimal voltage output is achieved, and fuel cells perform their best when connected in series. Using this parameter, twenty fuel cells are constructed that can produce 14.10 V without any load. The voltage was 7.57 V and the current was 1.1 A when connected to a DC lighting load that has a 12V power supply.

Keywords: Electrodes; electrolytic cell; electrolysis; redox reaction.

1. INTRODUCTION

An electrochemical cell is a device that may produce electrical energy from chemical reactions or use electrical energy to initiate chemical reactions [1]. It uses electrical energy to drive a non-spontaneous reaction called redox reaction. Electrolysis (the Greek word lysis meaning to break up) is a technique that uses them to degrade chemical molecules [2]. Voltaic or galvanic cells generate an electric current, while electrochemical cells that generate chemical reactions, such as electrolysis, are called electrochemical cells [3].

One of the advantages of simple electrolytic cell battery is for its low cost and non-toxic materials [4]. Different type of electrolytic cells such as button cells provide long lasting and fixed current and voltage [5]. Dry cells are easy to carry because its lightweight and Nickel cadmium cells are rechargeable [6]. Electrochemical cell technology is applied to separate pure metals from metallic compounds, to separate other chemical compounds like water and to electroplate metals [7]. Electroplating is the technique of coating an object with a layer of metal by utilizing electrodeposition [8]. Engineers utilize controlled electrolysis to transfer the desired metal coating from an anode to a cathode [9].

An estimated off-grid demand of 209.86 MW was observed in the Philippines. Even the requirement for energy to light the homes of the remote communities is too fundamental, yet many lack access [10]. Efforts to assist off-grid communities involve the use of solar panels, which are among the easiest to install and operate [11]. According to the International Renewable Energy Agency (IRENA), there was a 580 GWe installed solar PV worldwide in 2019 [12]. The availability of sunlight is one of the downsides of solar energy, necessitating energy storage for usage when sunlight is absent [13]. Evening illumination is a necessity for small rural households located in remote locations [14]. These communities primarily utilize kerosene, lamps and candles which are among the most common cause if fires on household [15].

This study focuses on the performance analysis of an electrolytic cell battery. Which will determine the optimum voltage yield of the chosen controlled variables. On which those optimum parameters are then used to construct a fully functional electrolytic cell battery connected to a lighting load.

The researchers conducted this study in order to contribute real and reliable data in the field of constructing an electrolytic cell battery. Moreover, to assist communities in remote areas if this initiative is implemented soon.

1.1 Related Literature

Every cubic meter of freshwater that combines with saltwater generates around 0.65 kilowatt-hours of energy, sufficient to power the average American home for approximately 30 minutes [16]. Globally, the theoretically recoverable energy from coastal wastewater treatment facilities is approximately 18 gigawatts, which is sufficient to power more than 1,700 households for a year [17]. First, sodium and chloride ions are released from the battery electrodes into the solution, allowing current to flow from one electrode to the next [18]. Then, a quick exchange of wastewater effluent with seawater causes the electrode to reintroduce sodium and chloride ions and reverse the flow of current [19]. Energy is recovered during both the freshwater and seawater flushes, with no upfront energy investment and no need for charging [20]. This indicates that the battery is constantly draining and recharging without any external energy input [21]. This study provide proof that salty ocean meets with freshwater could be used as electrolyte solution which could be use on electrolytic battery and is called blue energy.

The electrochemical mechanism of an innovative rechargeable seawater battery system in which seawater serves as the cathode material [22]. Sodium is extracted from saltwater while the battery is being charged, and the extracted sodium is discharged with oxygen dissolved in the seawater to produce power [23]. Both anode (Na metal) and cathode (O_2) materials for the proposed battery are derived from saltwater. On the basis of the discharge voltage (2.9 V) with O_2 involvement and the charge voltage (4.1 V) with Cl_2 evolution during the first cycle, an approximate voltage efficiency of 73% is calculated [24]. After 40 cycles, the cycle performance of a seawater battery made with hard carbon as the anode and a Na super ion conductor as the solid electrolyte is 84 percent [25]. The requirements for energy-storage systems are considerably distinct from those for consumer electronics or electric vehicles (EVs) and vary greatly according on installation size and location, among other variables [26]. This makes it difficult for a single type of battery system to become the dominant solution that meets all needs [27]. Its explore about the electrochemical mechanism of a unique rechargeable seawater battery technology [28].

The present invention describes a new electrolyte (anolyte) for the negative electrode of seawater batteries based on the combination of two ionic liquids (ILs), a sodium salt, and an SEI-forming ingredient [29]. The quaternary anolyte contains N-methyl-N-propylpyrrolidinium bis (fluorosulfonyl) imide (0.6 mol fraction), N-methyl-N-propylpyrrolidinium bis (trifluoro methanesulfonyl) imide (0.3 mol fraction), and sodium bis(fluorosulfonyl)imide (0.1 mol fraction). 5 weight percent ethylene carbonate is added to the ILs and salt combination to enhance SEI formation [30]. Thermal, physicochemical, and electrochemical characterizations of the quaternary electrolyte reveal its usefulness as an anolyte and creation of a highly stable interface with the negative (hard carbon) electrode [31]. At room temperature, lab-scale seawater complete cells employing a hard carbon anode and the ionic liquid-based quaternary anolyte exhibit exceptional capacity, cyclability, and rate capability [32]. In addition, the energy efficiency (voltage efficiency) and cyclability of these cells were superior to those based on a typical organic carbonate anolyte [33]. This article demonstrates the viability of seawater batteries (SWBs) for stationary energy storage on a large scale. This novel battery chemistry employs a newly developed ionic liquid-based electrolyte (anolyte) consisting of two ionic liquids, a sodium ion salt, and an additive to encourage SEI formation [34].

The market for energy storage devices for solar electricity and other renewable energies is no longer limited to a niche [35]. Despite the fact that lithium-ion and lead-acid batteries are mature technology, individuals continue to seek out alternate, dependable options [36]. This presents a fantastic opportunity for saltwater battery technology, which has the potential to positively impact the energy storage sector [37]. This technique employs a non-toxic, water-based electrolyte, making it significantly safer to use and having a negligible impact on the environment [38]. Although saltwater batteries have significant promise for energy storage market applications, this does not mean that they will replace lithium-ion batteries in portable devices anytime soon [39]. These batteries have a lower energy density than lithium-ion batteries and require additional space to provide the same amount of power. Therefore, they have a larger scale focus [40]. As people search for better energy sources that do not require maintenance and are safer in general, saltwater battery technology is growing in popularity [41].

This article describes the energy storage potential of saltwater batteries for various energy sources [42]. With this environmentally friendly setup which provides non-toxic and water-based electrolyte [43]. Large-scale, stationary electrical energy storage (EES) systems with rechargeable, high-energy-density, low-cost batteries are required for the efficient use of electricity derived from renewable sources. It describes a rechargeable saltwater battery whose energy source is NaCl (aq) (catholyte) [44]. The battery is powered by evolution/reduction processes of gases (predominantly O_2, with the possibility of Cl_2) in saltwater at the cathode and reduction/oxidation reactions of Na/Na^+ at the anode [45]. The combination of seawater and the Na-metal-free anode allows for great safety and cheap cost, as well as the regulation of cell voltage and energy density by varying the salt concentration [46]. This study supports that typical saltwater battery as low-cost source and safe rechargeable battery.

All electrolytic cells are comprised of three primary components: two solid electrodes known as the cathode and the anode, and a liquid electrolyte solution [47]. Because the electrolyte solution contains dissolved ions that are free to flow throughout the solution, it conducts electricity [48]. An electrolytic cell's cathode and anode are connected to a source of electrical energy, such as a battery [49]. The cathode is always negatively charged, and the anode is always positively charged in an electrolytic cell [50]. These two electrodes are composed of components that participate in the chemical process, such as copper, silver, and zinc [51]. They are referred to as active electrodes. They can also be composed of chemically inert substances, such as graphite, silicon, and platinum [52]. This article provides the basic components on making a simply electrolytic cell battery.

There are two types of electrochemical cells: a galvanic cell, which generates electricity through a spontaneous reduction and oxidation reaction in the electrolyte solution at the electrode surfaces, and an electrolytic cell, in which the reduction and oxidation reactions are driven by an external electrical power source [53]. Thus, a redox reaction occurs in an electrochemical cell by the transfer of electrons from one substance to another [54]. The oxidizing agent is the electron acceptor, whereas the reducing agent is the electron donor. In the case of a spontaneous redox reaction, electrons flow from the anode to the cathode in the external electron conducting system, and the electrochemical cell represents a galvanic cell that can produce electrical energy [55]. This articles explain the difference between galvanic cells and electrolytic cells, the process in which electron flows in the electrolysis.

1.2 Theoretical Framework

An electrochemical reaction is a process in which electrons travel between a solid electrode and material, such as an electrolyte. This flow causes an electric current across the electrodes, causing the reaction to liberate or absorb heat.

Overall potential of cell.

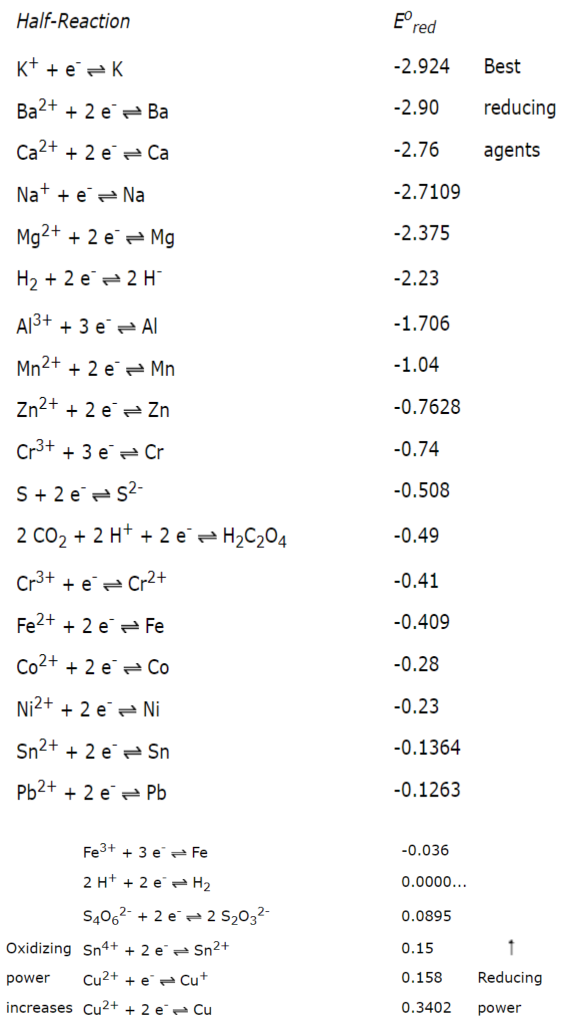
$$E^O = E^O_{red} + E^O_{ox} \qquad [1]$$

Where:

E^O = Overall potential (Volts)
E^O_{red} = Potential of reducing electrode
E^O_{ox} = Potential of oxidizing electrode

The standard-state cell potentials for some common half-reactions are given in the chart below:

Chart 1 : Standard-State Reduction Potentials, E^o_{red}



	Half-Reaction	E^o_{red}	
	$K^+ + e^- \rightleftharpoons K$	-2.924	Best
	$Ba^{2+} + 2e^- \rightleftharpoons Ba$	-2.90	reducing
	$Ca^{2+} + 2e^- \rightleftharpoons Ca$	-2.76	agents
	$Na^+ + e^- \rightleftharpoons Na$	-2.7109	
	$Mg^{2+} + 2e^- \rightleftharpoons Mg$	-2.375	
	$H_2 + 2e^- \rightleftharpoons 2H^-$	-2.23	
	$Al^{3+} + 3e^- \rightleftharpoons Al$	-1.706	
	$Mn^{2+} + 2e^- \rightleftharpoons Mn$	-1.04	
	$Zn^{2+} + 2e^- \rightleftharpoons Zn$	-0.7628	
	$Cr^{3+} + 3e^- \rightleftharpoons Cr$	-0.74	
	$S + 2e^- \rightleftharpoons S^{2-}$	-0.508	
	$2CO_2 + 2H^+ + 2e^- \rightleftharpoons H_2C_2O_4$	-0.49	
	$Cr^{3+} + e^- \rightleftharpoons Cr^{2+}$	-0.41	
	$Fe^{2+} + 2e^- \rightleftharpoons Fe$	-0.409	
	$Co^{2+} + 2e^- \rightleftharpoons Co$	-0.28	
	$Ni^{2+} + 2e^- \rightleftharpoons Ni$	-0.23	
	$Sn^{2+} + 2e^- \rightleftharpoons Sn$	-0.1364	
	$Pb^{2+} + 2e^- \rightleftharpoons Pb$	-0.1263	
	$Fe^{3+} + 3e^- \rightleftharpoons Fe$	-0.036	
	$2H^+ + 2e^- \rightleftharpoons H_2$	0.0000...	
	$S_4O_6^{2-} + 2e^- \rightleftharpoons 2S_2O_3^{2-}$	0.0895	
Oxidizing	$Sn^{4+} + 2e^- \rightleftharpoons Sn^{2+}$	0.15	↑
power	$Cu^{2+} + e^- \rightleftharpoons Cu^+$	0.158	Reducing
increases	$Cu^{2+} + 2e^- \rightleftharpoons Cu$	0.3402	power

The known values of the standard-state reduction potentials for the Cu/Cu2+ and Zn/Zn2+ half-cells to predict the overall potential for the electrolytic cell and to determine which electrode is the anode and which is the cathode.

$$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$$

stronger reducing agent	stronger oxidizing agent	weaker oxidizing agent	weaker reducing agent

Start by writing a balanced chemical equation for the reaction that occurs in this cell. The table of standard-state reduction potentials suggests that zinc is a better reducing agent than copper and that the Cu2+ ion is a better oxidizing agent than the Zn2+ ion. The overall reaction therefore involves the reduction of Cu2+ ions by zinc metal

Divide the reaction into separate oxidation and reduction half-reactions.

Reduction: $Cu^{2+} + 2\ e^- \rightarrow Cu$

Oxidation: $Zn \rightarrow Zn^{2+} + 2\ e^-$

The potential for the reduction of Cu2+ ions to copper metal can be found in the table of standard-state reduction potentials. To find the potential for the oxidation of zinc metal, reverse the sign on the potential for the Zn/Zn2+ couple in this table.

Reduction: $Cu^{2+} + 2\ e^- \rightarrow Cu \quad E^o_{red} = 0.34\ V$

Oxidation: $Zn \rightarrow Zn^{2+} + 2\ e^- \quad E^o_{ox} = -(-0.76\ V) = 0.76\ V$

The overall potential for this cell is the sum of the potentials for the two half-cells.

$$Cu^{2+} + \cancel{2\ e^-} \rightarrow Cu \qquad E^o_{red} = 0.34\ V$$

$$+\ Zn \rightarrow Zn^{2+} + \cancel{2\ e^-} \qquad E^o_{ox} = 0.76\ V$$

$$Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu \quad E^o = E^o_{red} + E^o_{ox} = 1.10\ V$$

Parallel Connection - the current of each cell adds up.

$$I_t = I_1 + I_2 \qquad [2]$$

Series Connection – the voltage of each cell adds up.

$$V_t = V_1 + V_2 \qquad [3]$$

Salt water Solution concentration

$$\text{Weight percent} = W / V \times 100 \qquad [4]$$

Where:

W = mass of the solute in grams (salt)
V = volume of solvent in ml (water)

Mean:

$$\mu = \frac{\Sigma X_i}{N} \qquad [5]$$

Where:

μ = population mean
X_i = each value of population
N = the size of population

Standard Deviation:

$$\sigma = \sqrt{\frac{\Sigma(x_i - \mu)^2}{N}} \qquad [6]$$

Where:

σ = population standard deviation
N = the size of population
x_i= each value of population
μ = population mean

1.3 Conceptual Framework

The following figure shows the input-process-output diagram of the study.

The flow diagram starts with the input wherein the researchers determine the materials and equipment necessary to visualize the research project. Copper, Aluminum, and Zinc are used as electrodes. Vinegar, fresh coconut water, salt-

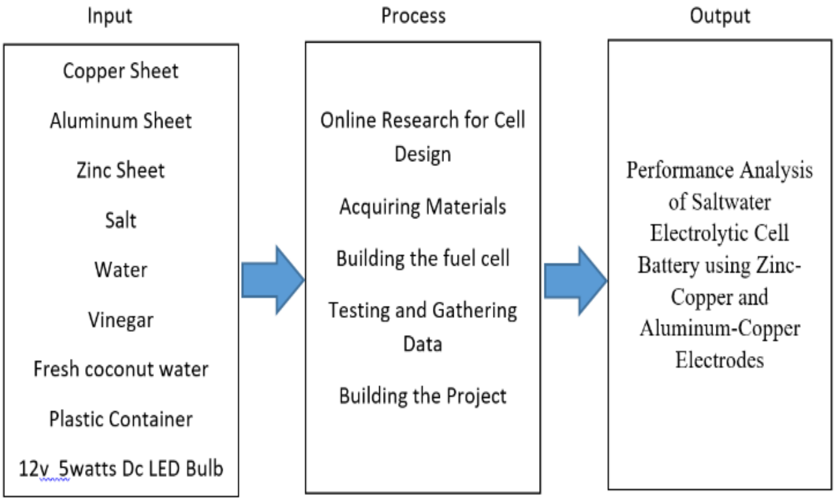


Fig. 1. Input-Process-Output Diagram of the Study

water solution for the electrolytes and plastic container as the housing of the cell. After visualizing, the researchers proceed to the process stage where researching for cell design is done. After a cell design is chosen, acquiring the needed material is followed in preparation for the building the fuel cells. After building the fuel cells, series of testing and experimentation is done in order to gathered the needed data. Those gathered data are carefully examined and analyze in order to determine which of those data yield the optimum result while taking its cost-effectiveness factor into consideration. Those chosen data are then used as the parameters for building the project which is a functional electrolytic cell battery.

1.4 Objectives

The general objectives of this study is to determine the most effective combination of controlled variables which will be used in building the electrolytic cell. The specific objectives of this study is the following:

1. To determine the voltage yield of different combination of electrode limited to:
   1.1 Zinc Copper Electrode;
   1.2 Aluminum Copper Electrode;

2. To determine the voltage decay of electrodes with no load;
   2.1 Zinc Copper Electrodes;
   2.2 Aluminum Copper Electrodes;

3. To determine the voltage yield of different electrolyte;
   3.1 Commercial Vinegar;
   3.2 Local Vinegar;
   3.3 Fresh coconut water;
   3.4 Salt vinegar solution;

4. To determine which saline solution with different concentration yield the optimum voltage;

5. To determine the voltage yield with no load when connected to;
   5.1 Parallel connection;
   5.2 Series connection;
   5.3 Parallel-series connection;
   5.4 Series-parallel connection;

6. To develop a functional saltwater electrolytic cell battery connected to a lighting load.

2. METHODS

2.1 Research Design

The research design applied to our project study is experimental by design and descriptive analysis.

The design of the said project is based on the idea of an experimental study which salt and water mixture (electrolyte), a pair of electrode and the construction of fuel cell to produce enough ampacity and voltage to light a specific lighting apparatus.

A series of test is done by testing different concentration of saline solution and finding which salt solution yield the optimum voltage output. Different electrode limited to zinc, copper and aluminum (soda can) is paired with each other and record which of the combination has its optimum output considering its cost-effective analysis. The voltage decay of the electrode pair with no load. Different electrolytes limited to commercial vinegar, local vinegar, fresh coconut water and salt vinegar solution are tested for its voltage yield. And lastly the type of connection in which the cells are connected are tested to find out which connection (series, parallel, series-parallel and parallel-series) is more suitable. Data gathered from series of tests are recorded and carefully analyze in order to determine which of the following combination and conditions yield the optimum result.

2.2 Project Design

The final project design is constructed base on which setup of controlled variables (type of electrodes, type of connection of fuel cells, types of electrolyte and salinity of electrolyte) gives the optimum result considering its voltage and ampacity which will power the DC lighting apparatus.

Fig. 2 shows a view of the main hardware components in which a twenty electrolytic fuel cell battery connected to its specific DC lighting load controlled by a switch.

- Fuel Cells – is an electrochemical cell that converts the chemical energy of a fuel and an oxidizing agent into electricity through a pair of redox reaction.
- Switch - an electrical component that can disconnect or connect the conducting path in an electrical circuit, interrupting the

electric current or diverting it from one conductor to another
- DC Lighting load – bulb which is powered by direct current.

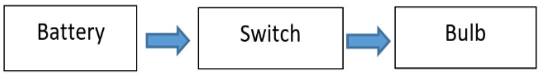


Fig. 2. View of the Main Hardware Components

2.3 Project Development

The project to be developed is to design an alternative source of electricity using saltwater electrolytic cell which will power a specific lighting load base on which combination of controlled variable yield the optimum results.

First step in doing this project study is online research, during which the researchers acquire more knowledge on the internet on different fuel cell design. Finding suitable materials for electrode which are available in the local market. The researcher also considered those recyclable materials that can be used as alternative electrode. after which the researcher acquired the chosen materials ready for building. The third step is building the fuel cell, fuel, the researcher tries to innovate the design which made the fuel cells as compact as possible, leak proof and portable. The fourth step is testing and gathering data, in which the researcher did a series of testing of which of the zinc, copper and aluminum electrode combination yield the highest voltage and ampere. These test also include the different saltwater concentration (5%, 10%, 15%,20%, 25%, 30%,35%,40%, 45%) and the type of connection either parallel or series. These data are carefully analyzing all factors like cost-effective. After in which a certain combination of electrode and conditions is chosen. Building the project is then set in motion as the fifth step of the project development. After the final project is constructed it is evaluated base on its performance,

2.4 Project Implementation

To fulfill all the requirement in order to realize this project, researchers carefully examine the project feasibility through online research. It is also proposed to our adviser for additional ideas and recommendation. Checking the needed materials in our local market and online shop for availability and estimating the cost of materials and other expenditure.

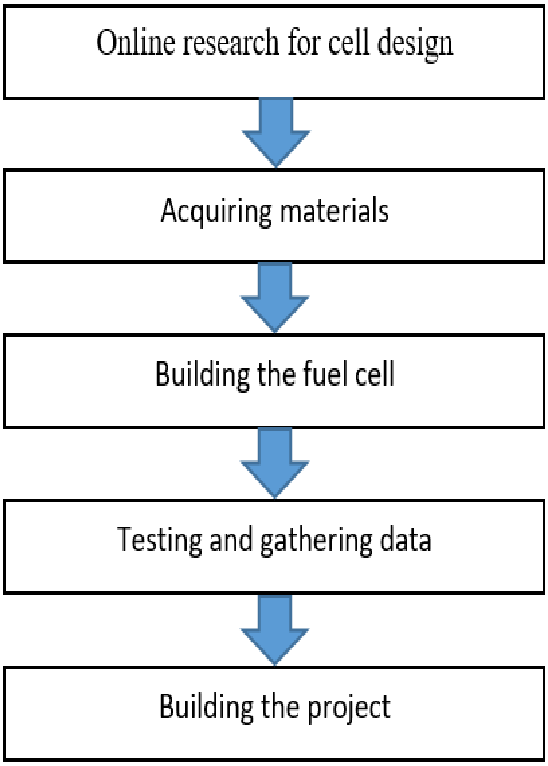


Fig. 3. Project development flow chart of the study

Before implementing the project, the researcher assessed the project plan in order to understand the project deliverables. Which is then followed by executing the plan which starts the experimental and testing phase. During the experimental and testing phase, some changes are made in order to improve and enhance the setups for better results. It is necessary for the reason that some problems came up during the actual testing. Gathering data are then followed. Analyzing the gathered data consistently to measure how the project is progressing. And lastly part of implementation phase is providing the final reports of the project.

2.5 Project Evaluation

The project is evaluated by quantitative means. The series of experimental and testing setup are measure in quantitative voltage and ampere with the use of digital multi tester. Quantitative data are analyzed and examined which will be the based on the outcome of the project.

2.6 Instrument

A digital multi tester is an instrument that measured the voltage and current of a circuit. In this study which deals with a small quantitative data (voltage and current) to be gathered with precision, digital multi tester gives an edge over the analog type.

2.7 Data Collection Procedure

The diagram's general overview and flow gathered quantitative and qualitative data. First, a test trial/reading is chosen to guarantee that the evidence gained will allow the researcher to effectively handle the research problem, where an understanding of the problem will be created and plans for some type of strategy will be made.

Fig. 4. Digital multi-tester

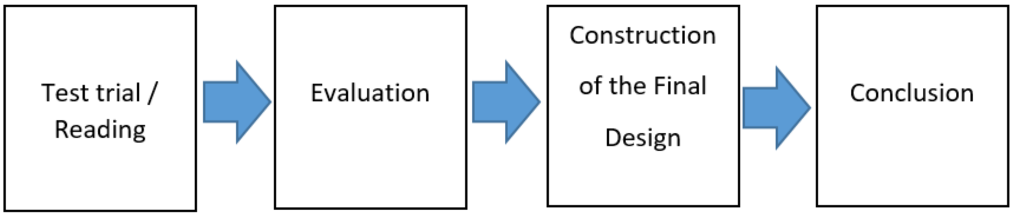


Fig. 5. The flow of Data collection

Table 1. Financial analysis of the study

Item/Size	Materials	Price (₱)
10 pcs ,1x100x100 mm	Copper Sheet	1595.00
10 pcs ,1x100x100 mm	Zinc Sheet	990.00
2 pcs	Aluminum Soda Can	0.00
20 pcs	Alligator Clip	240.00
20 pcs	Plastic Container	200.00
3 kilo	Salt	36.00
1 pc	Digital Multi-tester	349.00
1 pc, 500ml	Beaker	50.00
3 m ,$0.2\ \mathrm{mm}^2$	24 AWG wire	24.00
1	Glass Casing	600.00
TOTAL		4084.00

Next is evaluating the data gathered in test trail phase thoroughly in order to came up with parameters that will be used in the final design which will be the third phase of data collection. And lastly after the final design are made, the researcher carefully analyze and evaluate all data given by the final design.

2.8 Financial Analysis

The financial analysis of the electrolytic cell battery project demonstrates its cost-effectiveness and potential for scalability. The use of zinc-copper electrodes, identified as the most efficient in our tests, offers a balance between performance and expense. Furthermore, the adoption of a 30% saline solution as the electrolyte, coupled with the series connection of fuel cells, provides an optimal voltage output. This setup results in a promising solution for off-grid energy requirements, particularly in remote areas, due to its affordability and efficiency.

3. RESULTS AND DISCUSSION

3.1 Analysis of Voltage Yield of Electrodes

Table 2 shows the voltage yield of Zinc-Copper and Aluminum-Copper electrodes with a dimension of 100mm by 33mm and 1mm thick that are soak in a 30% saline solution. Three test are done with an interval of ten minutes each. Its shows that Zn-Cu electrode yield more voltage than the Al-Cu.

3.2 Analysis of Voltage decay of electrodes with no load

Same setup is prepared using Fig. 6 and Fig. 7 which is then measured its voltage decay. Voltage are measured in each setup every four hours for a duration of 1 week. A total of 42 test are made in each setup.

Fig. 8 shows the voltage decay of a Zinc-Copper electrode with no load. A 0.707 V is measured at the start of the monitoring. During its one-week monitoring, it is observed an average voltage of 0.005 V per day is decayed each day. A 0.672 V is recorded on the last day of monitoring.

Fig. 9 shows the line graph of decay voltage of Aluminum-Copper electrode with no load. Data gathered during its one-week monitoring show an average voltage loss of 0.0046 V each passing day. A 0.502 V is measured on the start of the monitoring and it decays into 0.474 V at the end of a seven-day period.

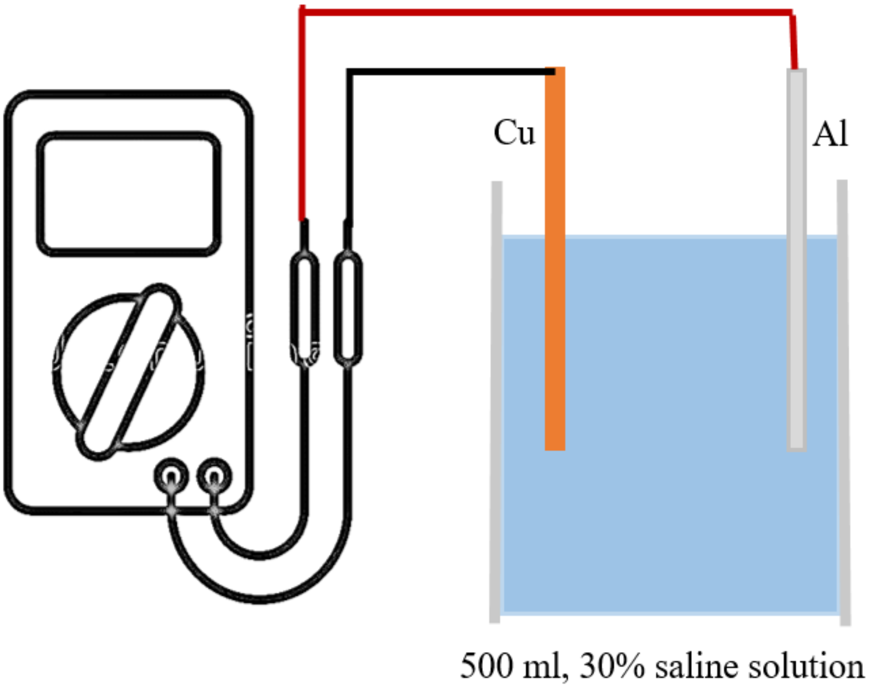


Fig. 6. Setup for measuring its voltage of Zn-Cu electrodes using multi-tester on single fuel cells

Table 2. Voltage yield of electrodes

Electrode Combination	**Voltage**				
	Test 1	**Test 2**	**Test 3**	**μ**	**σ**
Zn-Cu	0.706	0.704	0.707	0.702	0.001
Al-Cu	0.510	0.510	0.509	0.509	0.004

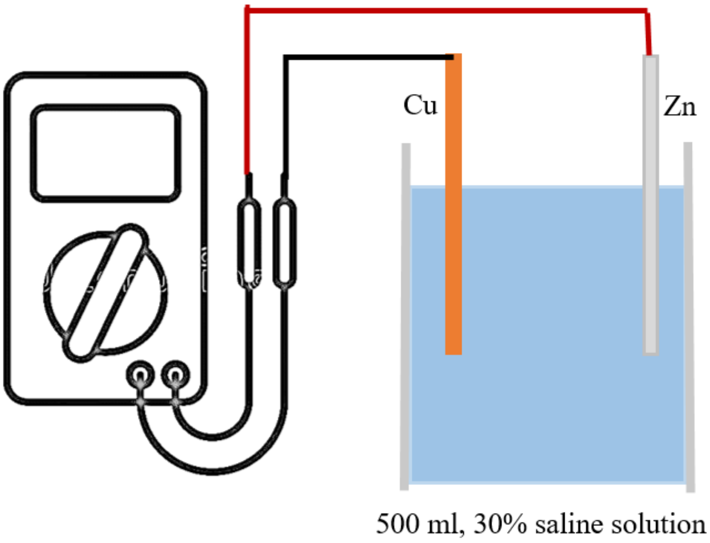


Fig. 7. Setup for measuring its voltage of Al-Cu electrodes using multi-tester on single fuel cells

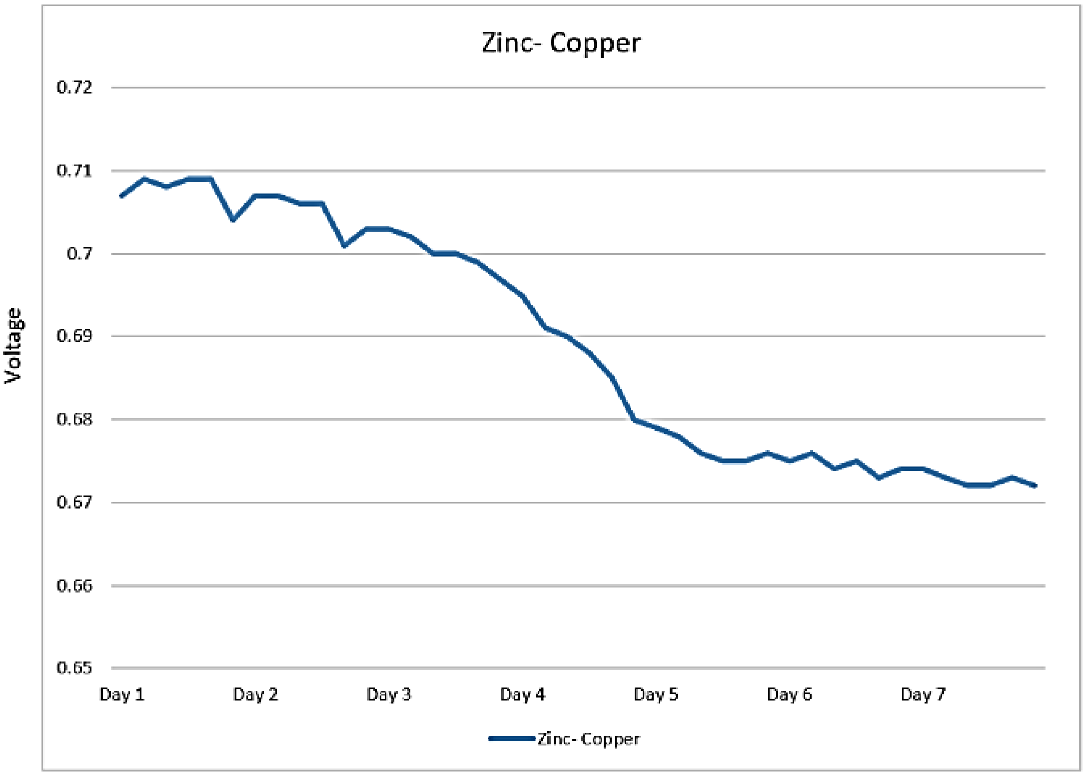


Fig. 8. Decay Voltage of Zinc-Copper

3.3 Analysis of Voltage Yield from different Electrolyte

Zinc Copper electrode and Aluminum electrode are soak in different electrolyte limited to commercial vinegar, local vinegar, fresh coconut water and Salt Vinegar solution. It is then measured its individual voltage yield.

Table 3 shows the voltage yield of Zinc Copper electrode with a dimension of 100mm by 33mm and 1mm thick that is soak in different type of electrolyte in a single fuel cell.

Table 4 shows the voltage yield of Aluminum Copper electrode with a dimension of 100mm by 33mm and 1mm thick that is soak in different type of electrolyte in a single fuel cell.

3.4 Saline Solution Analysis on Voltage

Zinc copper and aluminum copper electrodes with a dimension of 100mm by 33mm and 1mm thick are soak in a single fuel containing different concentration of saline solution. It is then measured its individual voltage yield.

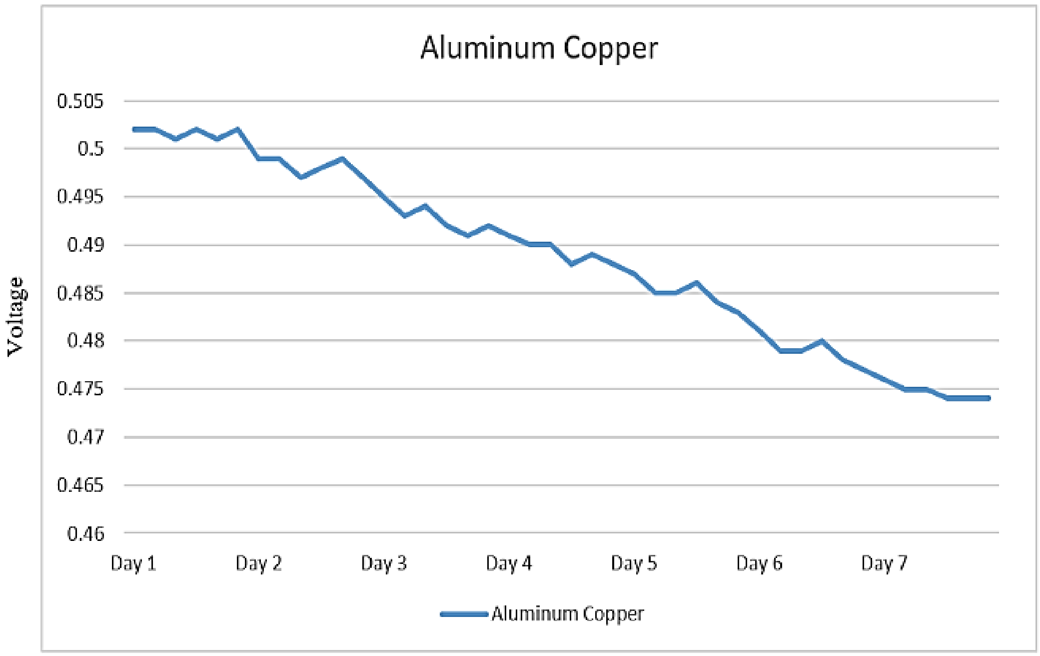


Fig. 9. Decay Voltage of Aluminum-Copper

Table 3. Voltage yield of Zinc Copper

Electrolyte	Voltage						
	Test1	Test 2	Test 3	Test 4	Test 5	**μ**	**σ**
Commercial Vinegar	1.018	1.015	1.012	1.015	1.016	1.015	0.0019
Local Vinegar	0.960	0.963	0.961	0.961	0.960	0.961	0.0011
Fresh Coconut water	0.958	0.955	0.958	0.956	0.957	0.957	0.0012
Salt Vinegar Solution	0.810	0.812	0.815	0.815	0.814	0.813	0.0019

Table 4. Voltage yield of Aluminum Copper

Electrolyte	Voltage						
	Test1	Test 2	Test 3	Test 4	Test 5	**μ**	**σ**
Commercial Vinegar	0.520	0.519	0.519	0.518	0.517	0.5186	0.0010
Local Vinegar	0.475	0.473	0.477	0.477	0.476	0.4756	0.0014
Fresh Coconut water	0.473	0.473	0.470	0.471	0.471	0.4716	0.0012
Salt Vinegar Solution	0.541	0.544	0.544	0.543	0.541	0.5426	0.0013

Table 5 shows the data gathered from a single fuel cell which uses a Copper and Zinc electrode pair. Nine setups are made with each setup having different concentration of salt-water solution starting from 5% up to 45% with a 5% interval. To ensure the precision and accuracy of data gathered, three measurements are made with an interval of ten minutes each using a digital multi tester. And a standard deviation is applied on gathered data to measure the dispersion of dataset relative to its mean.

Fig. 10 shows the line graph of mean voltages yield of each individual salt-water concentrations. As you can see the voltage slowly increases as the concentration of salt increase. But it is observed that the voltages yield after the 30% doesn't significantly increase giving us the indication that it has reaches its optimum voltage output of the said setup.

Table 6 shows the data gathered from the same setup with different electrode which is Aluminum and Copper pair. Same number of setup and same percentage of salinity. Three test are measured with an interval of 10 minutes each to ensure precision and accuracy of data. And lastly getting the standard deviation in each setup to measure how near and close the dataset compare to its mean.

Fig. 10 shows the line graph of mean voltages yield of different concentration of salt-water solution. As you can observe the voltage is increasing slowly proportional to its increasing salinity. But right at the 30% concentration mark, the voltage doesn't significantly increase even with increase of salinity. This indicate that its maximum voltage is reach in this range of salinity.

3.5 Performance of fuel cell per type of connection

Four setups are made in order to determine which type of connection yields a favorable result. Five fuel cells for series and parallel setup are used and connected to each other and measured by a digital multi tester to obtain its total voltage yield. And six fuel cells are used for parallel-series and series-parallel combination. Each cell contains salt-water electrolytic concentration with the same volume and salinity. The researcher chose to use the Zinc and Copper since the previous data gathered resulted into higher voltage yield than the Zinc and Aluminum pair. And we chose the 150g/500g (30%) concentration of salt water solution as its electrolyte.

Table 5. Voltage yield of Zinc Copper on different Saline concentration with no load

Salt/Water Ratio (g/g)	Voltage				
	TEST 1	TEST 2	TEST 3	μ	σ
25g/500g	0.584	0.594	0.581	0.586	0.0055
50g/500g	0.602	0.593	0.591	0.595	0.0047
75g/500g	0.654	0.631	0.621	0.656	0.0138
100g/500g	0.694	0.690	0.684	0.689	0.0041
125g/500g	0.694	0.685	0.698	0.692	0.0054
150g/500g	0.707	0.704	0.704	0.705	0.0014
175g/500g	0.705	0.705	0.704	0.705	0.0004
200/500g	0.705	0.707	0.707	0.706	0.0009
225g/500g	0.707	0.703	0.704	0.705	0.0016

Table 6. Voltage yield of Aluminum Copper on different Saline concentration with no load

Salt/Water Ratio (g/g)	Voltage				
	TEST 1	TEST 2	TEST 3	μ	σ
25g/500g	0.471	0.445	0.453	0.456	0.010
50g/500g	0.480	0.485	0.476	0.480	0.003
75g/500g	0.485	0.488	0.485	0.486	0.001
100g/500g	0.490	0.491	0.488	0.489	0.001
125g/500g	0.503	0.508	0.507	0.506	0.002
150g/500g	0.511	0.510	0.509	0.510	0.0008
175g/500g	0.510	0.504	0.522	0.512	0.007
200/500g	0.512	0.510	0.509	0.510	0.001
225g/500g	0.516	0.511	0.512	0.513	0.002

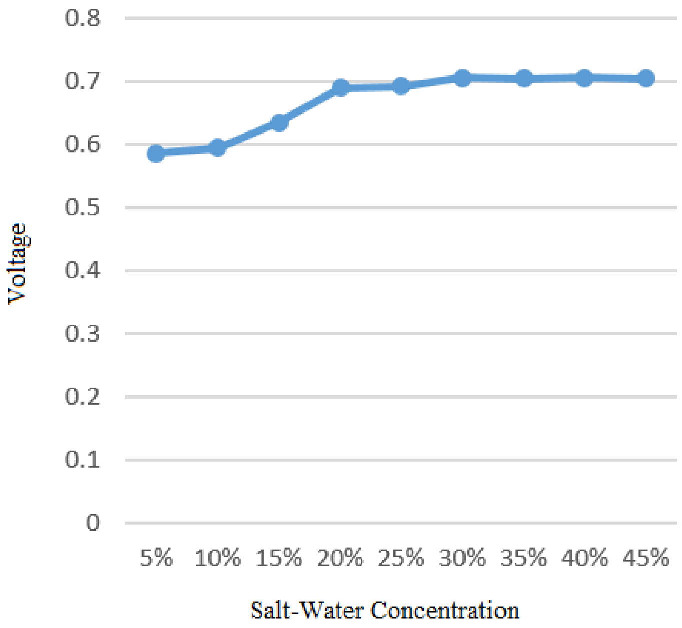


Fig. 10. Graph of voltage yield of Zinc-Copper electrode with different concentration

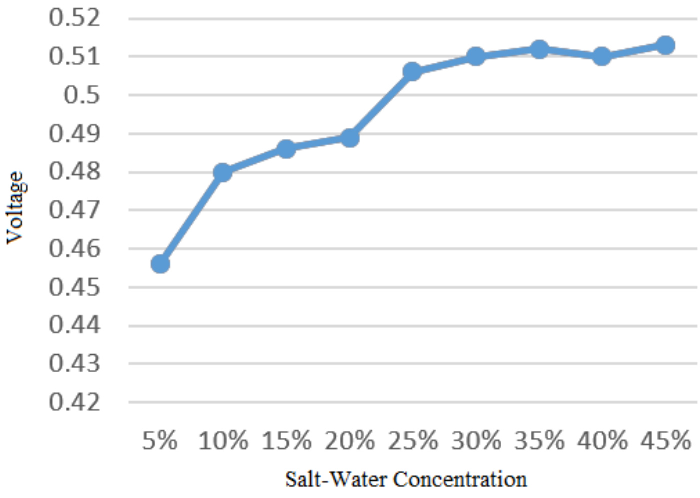


Fig. 11. Graph of voltage yield of Aluminum-Copper electrode on a single fuel cell with no load

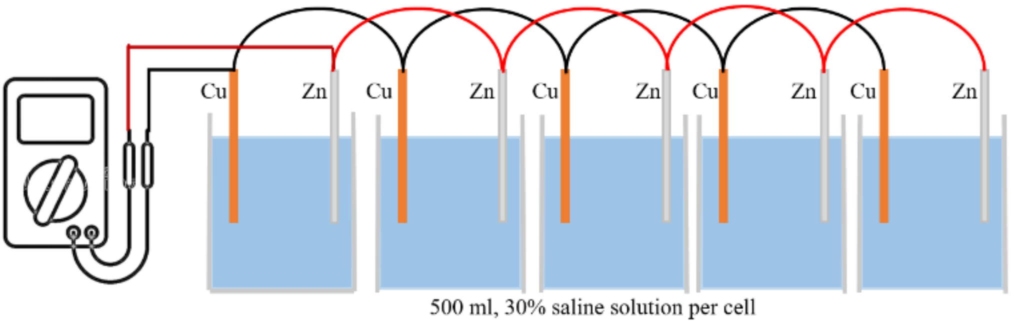


Fig. 12. Schematic diagram of parallel connection

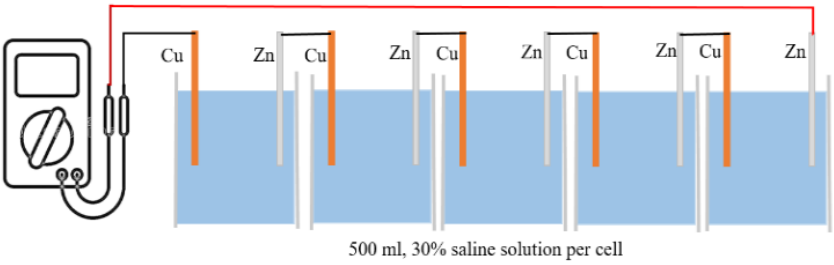


Fig. 13. Schematic diagram of series connection

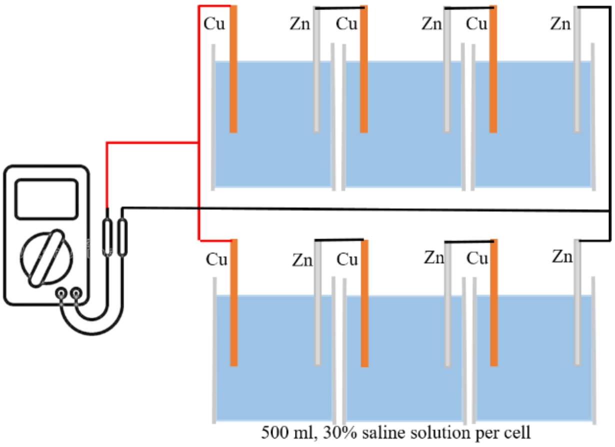


Fig. 14. Schematic diagram of parallel-series connection

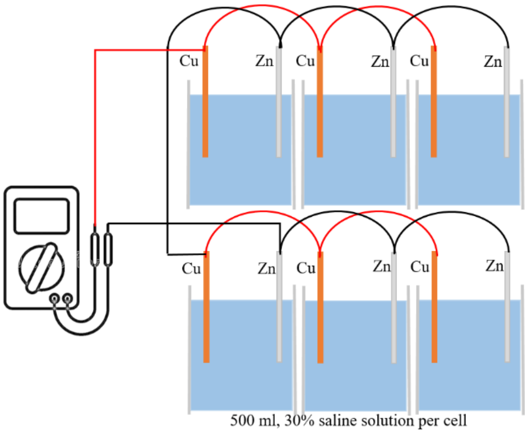


Fig. 15. Schematic diagram of series-parallel connection

To ensure accurate and precise result, the researcher conduct three separate measurement for each setup. Each measurement has an interval of 10 minutes prior to the previous data.

Table 7 shows the voltages of five cells connected in series and parallel. Voltages of six cells connected in parallel-series and series-parallel. Results yield a mean voltage of 3.540V for series and for parallel, yield a mean voltage of 0.706V. Parallel-series and series-parallel yield a mean voltage of 2.125V and 1.419V respectively. This follow the theoretical concept which batteries connected in series will yield a total voltage of the summation voltage of each cell. While batteries connected on parallel will resulted to a total voltage which is the mean the individual battery voltage.

Table 7. Voltage yield on different type of connections

Type of Connection	Voltage			
	Test 1	Test 2	Test 3	μ
Parallel	0.705	0.706	0.706	0.706
Series	3.531	3.529	3.531	3.530
Parallel-Series	2.124	2.131	2.120	2.125
Series-Parallel	1.412	1.421	1.425	1.419

Fig. 16. Actual setup of cells in series connection

Fig. 17. Actual setup of cell in parallel connection

Fig. 18 Actual setup of cell in series-parallel connection

Fig. 19. Actual setup of cell in parallel-series connection

3.6 Functional Electrolytic Fuel Cell

After careful analysis, the researcher decided to choose the Zinc and copper electrode pair for its voltage yield is much higher than the other tested pair. Even though the aluminum electrode is much cheaper than the zinc but due to its voltage yield gap between the two setup, zinc electrode is more favorable for better voltage output. Saline solution is chosen for the reason that it is easy to acquire and others tested electrolyte has its smell issue which is unfavorable. Even though saline has a lower voltage yield compared to the other tested electrolyte, it is picked because of its cost-effectiveness. For the percentage concentration of salt-water solution, we choose to use the 150g/500g of saline. Analysis from the data gathered suggested that voltage yield from 30% concentration to 45% concentration doesn't have a significant increase of voltage. We also found out that even if you increase the concentration of salt to its limit the voltage doesn't increase significantly. For the type of connection which fuel cells are to be connected into, it is more favorable to connect it in a series connection for the reason that a certain voltage is required to light up a specific lighting. Because its output voltage is in a form of direct current, DC lighting load are much suited. Three 12 V DC bulb with different wattage specifically 3W,5W and 7W are tested. Which only the 3 W and 5 W bulb were successful light up. The researcher chose the 5 W to be the load for the final project for it is much brighter than 3 W.

Fig. 20 shows the diagram of the final design that has been chosen by the researcher. This design composes of twenty identical fuel cells that are connected is series which houses the Zinc and copper electrode in each cell with a 30% salinity salt-water electrolyte. The cells are then connected to a single pole single throw switch that powers the 12V, 5 watts DC bulb.

The design resulted to a 14.10 V of total voltage yield with no load. In which each of the twenty identical cell has an average voltage of 0.706 V. The functional electrolytic fuel cell is then tested for its functionality. With its 12 V, 5 watts DC load connected to the electrolytic battery. It is then measured its voltage yield with load every hour until the battery cannot sustain the load anymore. At the start of functionality test an initial of 7.57 V is measured. At which after the first 10 hours, the voltage drop to 7.43 V. The battery lasted for 38 hours until the lighting load starts to dim which end the monitoring phase. Data gathered during the monitoring phase reveals an average voltage loss of 0.58 V per day.

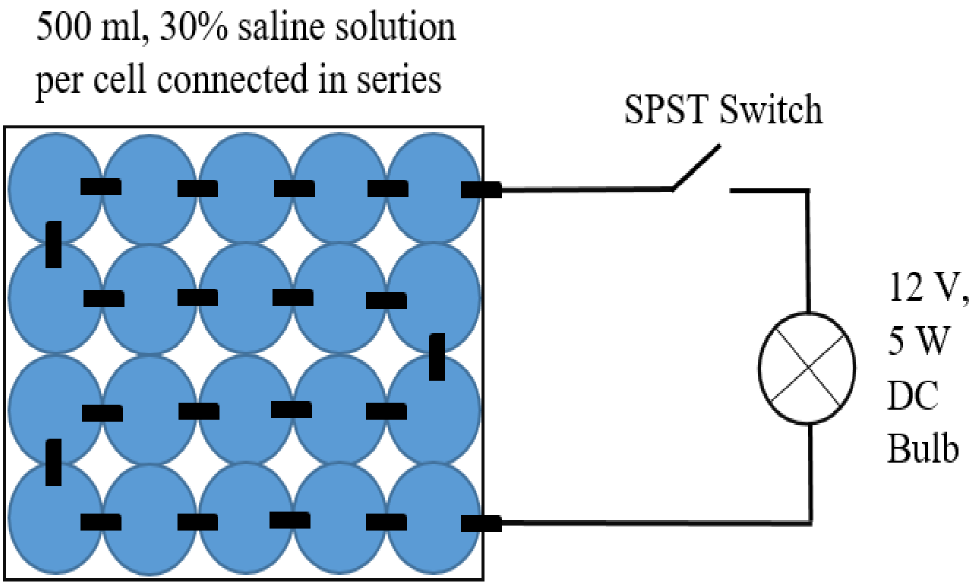


Fig. 20. Schematic diagram of a functional electrolytic cell with load

Fig. 21. Actual setup of a functional electrolytic cell with load

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion

The researcher concluded that zinc and copper electrode are more suitable than the zinc and aluminum pair. One of the reason is zinc anodes tend to dissolve more evenly and completely; while typical aluminum anodes erode unevenly with visible "craters". Zinc is also more chemically active and has a greater electromagnetic potential than aluminum. It is also concluded that the Zinc copper electrode pair has much greater average voltage loss than the aluminum copper electrode when no load is present. Zinc copper has an average voltage loss of 0.005 V per day while the Aluminum copper has an average voltage loss of 0.0046. It is expected that the zinc copper has a higher decay rate than the aluminum copper for a reason of zinc copper is more reactive than the other pair.

Data gathered on different electrolyte resulted to a promising voltage yield. It is concluded that there is a correlation of salinity and acidity on the voltage yield of electrodes. A Commercial Vinegar provides the highest average voltage yield of 1.015 V on Zn-Cu and 0.5186 V on Al-Cu on a single cell. It is also found out that fresh coconut water provides 0.957 V on Zn-Cu and a 0.4716 V on Al-Cu.

For the electrolytic salt-water solution, it is observed that it's much better to have a higher concentration of salt in solution to speed up the electrolysis in the setup. With a high concentration of salt on the solution, it is easy to pull out the electron on the zinc anode which will resulted to favorable voltage. it is also observed that there is a maximum output of the electrode pair which will matter. Even if you increase the concentration of salt there will be no significant increase in voltage because the maximum threshold of voltage output is already reach.

The researcher also found out that it is much favorable that the cells are connected in series. Most lighting load require a high voltage input, for this reason it is highly recommended to connect the cells in series rather than in parallel in order to maximize the voltage output.

During the data gathering on the functional electrolytic cell battery it is found that their is voltage drop when the load is connected on the circuit. It is concluded that the twenty cell design cannot sustain the 12V, 5W DC bulb. Ideally the voltage measured when the load is connected won't drop. It is also concluded that there is a need of change on electrolyte whenever it starts to get murky. Murky electrolyte decreases the conductivity of the electrolyte when will lessen the voltage yield on each fuel cell.

4.2 Recommendation

The researchers recommend the following in order to provide more reliable data result:

1. Fabricate a fix dimensional fuel cell to accurately measure the volume of the electrolyte.
2. Increase the number of fuel cells up to the point where it can fully sustain the 12V 5 W DC bulb.
3. Provide a voltage decay of different electrolytic solution.
4. Provide a correlation between the salinity and acidity with the voltage yield of the electrodes.
5. Integrate an inverter to the system to further increase the voltage yield which will open the possibility to power an AC load.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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