De La Salle Santiago Zobel School

Senior High School

STEM Strand

A STUDY OF DIFFERENT SALINITY LEVELS AND CATHODES AFFECTING THE PERFORMANCE OF ALUMINUM-AIR BATTERIES

Submitted to

Fritz M. Ferran

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Submitted by:

JOHN DOMINIC B. AGUILA

RYAN CEDRIC Q. DE VEYRA

ALLEN WAYNE C. ELLETT

BEA KATHRINE G. GUIEB

TOMAS AGUSTIN S. SANTOS

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Abstract

As the Philippine economy situation is rapidly urbanizing, the population growth in most areas is projected to have a substantial increase closely dependent on economic growth which then threatens the supply of resources present in the environment. Therefore, as the world gradually depletes from certain resources which provides a source of energy essential to everyday livelihood, a dire need for renewable resources is at stake. The research is an attempt to pursue a safe and ecologically-favorable to produce sustainable alternative energy in par with the everyday form of producing electrical energy. Various studies have been referenced to provide a good foundation on materials and procedures that were previously used and were effective on the case. A simulation experiment with 36 samples was conducted to determine if distinct salinity levels of the electrolyte solution and the cathode materials used will affect the performance of the aluminum-air battery in terms of cell potential and energy capacity. The analysis of data allowed the study to compare the performance of the aluminum-air battery to each independent variable. Results infer that the variation of the cathode material used and salinity level in a sample is correlational to the overall output along with its factors to consider namely cell potential and energy capacity wherein a distinct variation was able to produce the optimal result in comparison with the others. Thus, the results provide information that could impact the materials of future batteries.

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The Authors

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CHAPTER 1: BACKGROUND OF THE STUDY

I. Introduction

As the world gradually runs out of conventional resources such as petroleum and coal, the use of innovative resources is likely to increase and the development of renewable energy is seen as an urgent issue to solve environmental issues (Brown, 2015). But, due to its dependence on weather condition, the produced energy is not stable (Johansson, 2013). An energy storage system is required which can store the energy generated and provide it stably to the places on demand (Clarke, Dooner, Luo & Wang, 2015).

According to the Department of Energy (2016), electricity consumption grew significantly from 82,413,213 MWh (2015) to 90,797,891 MWh (2016). This growth level increased to 10.2% compared to the 6.7% growth from 2014-2015. Several yellow and red alerts were declared by the system operator due to the decline of electricity generation. Aqeel & Butt (2001) stated that there is a direct relation of the energy consumption of a country to its employment. Similarly they found clues that show a relationship of the GDP of developing countries like Pakistan to its energy consumption.

Lithium-ion battery is currently the most popular electrical energy storage system and it is being applied to most electricity powered systems but it has issues associated with high system cost, safety issues, and low energy density (Energy Storage Association, 2017).

As the third most abundant element in the earth's crust, after oxygen and silicon, aluminum offers an intriguing possibility as a metallic anode for electrochemical systems

(Lide, 2005). Its relatively high density of 2.7g/cm3 coupled with its trivalent ionic state provide it with a theoretical volumetric capacity of 8040mAh/cm3, nearly four times that of lithium (Reed, 2015). Aluminum-air battery has been studied actively since the 1960s but it could not be fully applied due to issues such as the formation of oxide layers on the aluminum surface and the self-corrosion of aluminum (Bhonge, 2017). Bjerrum and Li (2002) stated that using aluminum alloys instead of pure aluminum can lessen the corrosion.

The study focuses on evaluating the performance of aluminum-air batteries taken from recycled soda cans based on different salinity levels and cathodes so that it could be used as an alternative for cheaper and sustainable energy production.

II. Conceptual Framework

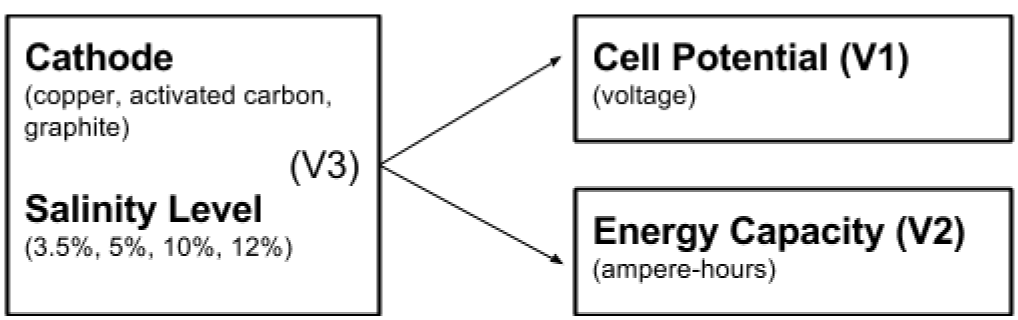

Figure 1.1 Different Variables of the Study

The conceptual framework of this study was based on UNICEF's Sustainable Development Goals that aim to develop policies and programs designed to end poverty, protect the planet, and ensure prosperity for all. It is the 2030 agenda for sustainable development with 169 target countries among them. The agenda consists of 17 goals but the study only focuses on the goal of clean energy (United Nations, 2015).

Figure 1.1 shows the relationship of the variables in the study. The study claimed that the salinity level of the electrolyte solution and the cathode used will affect the performance of the aluminum-air battery in terms of cell potential, energy density and energy capacity. The researchers will compare the performance of the aluminum-air battery to each independent variable.

III. Statement of the Problem

The purpose of this study is to develop a product that gives an alternative for cheaper energy generation that is also clean and sustainable.

Specifically, it aims to answer the following questions:

1. What is the result of changing the salinity level and cathode to cell potential and energy capacity?
2. Is there a significant difference in cell potential at different salinity levels and cathodes?
3. Is there a significant difference in energy capacity at different salinity levels and cathodes?

IV. Significance of the Study

Researches from the International Energy Agency (2016) found that around 1.2 billion people or 16% of the world's population do not have access to electricity. This means that there are many communities who are still stuck in the dark. According to Van Bavel (2013), the reason of this may be because of the fact that the world population is growing at a faster rate than the globalization of electricity.

The study is specifically beneficiary to communities in need of cheaper electricity, engineers, scientists and future researchers for the reason as stated as so:

Communities in need of sustainable and accessible electricity. This study can be applied on these communities to fulfill their physiological needs. Based on their results, these communities can use this product to generate cheap and clean electricity. Improving their environment can create development in their lifestyle and this may open up more jobs in turn.

Engineers. This study applied engineering concepts in developing the product. Engineers can apply this in their field to create an understanding in using alternative sources for sustainable energy production. They can also validate and improve the methods used in the study.

Scientists. This study applied multiple scientific concepts, specifically from the branch of chemistry. Scientists can utilize this in their field to create an understanding in using alternative sources for sustainable energy production. They can also validate and improve the methods used in the study.

Future Researchers. This study can be a foundation in creating other researches about energy production. This research can function as a basis for future work by utilizing other variables. Further researches can utilize variation on the control over the dependent and independent variables. This study serves as a foundation in further studies, theories and researches related to energy production.

V. Scope and Delimitations

The study was limited to developing and measuring the performance of the product, specifically the aluminum-air battery, that gives an alternative for cheaper, clean and sustainable energy generation. The study only utilized three different cathodes (copper, activated charcoal and graphite) and four variation of salinity levels (3.5%, 5%, 10%, 12%). The study was also limited to producing 36 samples from the variables.

V. Definition of Terms

Anode - It is the positive electrode and the terminal where current flows out. It is also where the oxidation occurs. In this study, the anode is aluminum. (Goss & Petrucci, 2007)

Cathode - It is the negative electrode in which a conventional current leaves a polarized electrical device and where the reduction takes place. In this study, the cathodes are copper, activated charcoal and graphite (Goss & Petrucci, 2007)

Electrolyte - Its is a chemical medium that allows the flow of electrical charge between the cathode and anode. In this study, the electrolyte is the salt water. (Goss & Petrucci, 2007)

Energy Production - It is the manipulation of electrical, mechanical, chemical, thermal, or nuclear energy to create electricity and is measured usually in joules or watts. (Sullivan, 2009)

Sustainable Development Goals - It is a set of 17 global goals by the end of 2030 with 169 target countries proposed by the United Nations. Its primary objective is to address the world's primary dilemma for the sake and benefit of the children and youth. (United Nations, 2015)

Water Salinity - refers to the measure of concentrations of salts dissolved within water. Can be classified into 3 depending on the point of origin per body of water; namely natural salinity, dryland salinity and irrigation salinity. It is usually in parts per thousand (ppt). (U.S Geological Survey, 2013)

CHAPTER 2: REVIEW OF RELATED LITERATURE

I. Introduction

The support and backing on energy production procedures have been a point of focus in the literature. According to the different research literature used, a variety of procedures and materials can be utilized. The research literature provides a wide range of studies that tackles an in depth understanding of renewable energy production. However, examination of the literature also presents a limitation in production of energy.

Each section provides concepts that can be implemented to produce electricity while also providing a basic understanding of chemical reactions and elemental properties/relations and how batteries dissipate energy. The first section offers the concept of a hydrogen fuel cell and utilization to produce clean energy. In the second section, a discussion of salt water's way of usage to produce safe and clean energy. Studies such as these are used to research the possible utilization of these methods into a community. Overall, these studies and variables were incorporated in the literature review to create a strong background and support for the study.

II. Body

Clean, Renewable & Sustainable Energy

This type of energy refers to different variations of alternative energy such as hydro, geothermal, s solar and wind that can be considered as an equivalent to the conventional power sources. Utilizing renewable energy can cause an extensive impact in terms of reducing the amount of pollution contributing to the environment. When renewable energy sources are used, it decreases the demand of greenhouse gas emitting fossil fuels that cause harm to the environment (Ahuja & Tatsutani, 2009). Producing renewable energy despite its various benefits, is known to be more expensive in comparison to utilizing the typical fossil fuel form of energy (Brown, 2015). The most common forms of renewable energy has been to found in the most remote areas which makes it hard to find and difficult to obtain. The normal building of power lines connecting to the cities for utilization would therefore cost high. (US Energy Information Administration, 2017)

Hydroelectric Power

Anonymous groups of scientists and engineers recently conceived of a method which allows the researchers to harness the "electrokinetic" properties of liquids from everyday found sources such as ordinary tap water commonly used in most households by people around the world, when being pumped through channels such as pipelines and main waterworks. Kalogirou (2013) states this newly discovered technique offers a potential source of clean, renewable and non-polluting electric power with a variety of possible uses, ranging from powering small electronic devices such as calculators or mobile phones to an entire electrically powered area of residences or settlements.

Hydrogen Fuel Cells

A hydrogen fuel cell is a source of alternative energy that produces electricity through the use of hydrogen gas with only pure water as a byproduct without causing any pollution to the environment (Parent, 2003). Dicks, Larminie & McDonald (2003) stated that another way of looking at the fuel cell is to say that the hydrogen fuel is being 'burnt' or combusted in the simple reaction and the heat energy is converted to electrical energy.

Proton Exchange Membrane (PEM)

Proton exchange membrane (PEM) fuel cells work with a polymer electrolyte in the form of a thin, permeable sheet. The technology uses a water-based acidic polymer membrane as its electrolyte alongside the use of platinum based electrodes (Zohuri, 2016). The Polymer Electrolyte Membrane (PEM) being semi-permeable, strictly allows only positively charged ions to pass through to the cathode while the negatively charged electrons must travel along an external circuit to the cathode, thus creating an electrical current (Corbo, Migliardini & Veneri, 2011). In theory according to Kozak (2014), the estimate efficiency rate for a PEM cell reaches an average ranging from around 40 to 50 percent maximum capacity.

On the cathode side, the metal electrode combines the protons and electrons with oxygen to produce water, which is then expelled as the only waste product; oxygen can be provided in a purified form, or using the various process such as steam reforming process in either large industrial plants or in small scaled portable units (Armaroli & Balzani, 2011). Fossil fuels are nonrenewable resources that have been formed from deposits of the remains of decayed of plants and animal that lived hundreds of million years ago. These deposits of hydrocarbons have been utilized for the purpose of generating electricity upon extracting from the ground . The utilization of fossil fuels have raised multiple environment and health risk concerns. On concern is the use of biofuel contributes as a source of pollution due to being one of the largest source of carbon dioxide emission on to the atmosphere (Demirbas & Gupta, 2010).

Graphite as a Cathode

Graphite, the common material used in most pencils, is made up of countless layers of graphene (Bartolucci, et al., 2011). In the form of a long 1-D nanoscale ribbon, graphene demonstrates unique electrical properties that include either metallic or semiconducting behavior. When short segments of this ribbon are isolated into tiny zero-dimensional (0-D) segments called “nanorectangles,” where the width is measured in atoms, they are classified as either “armchair” or “zigzag” graphene nanoribbons (Nayak and Shemella, 2009).

Because of its excellent conductive properties, graphene could possibly replace copper (Madhuri & Maheshwar, 2015). Carbon nanotubes, which is rolled-up graphene, could replace copper as the primary material used for interconnects but they suffer from setbacks (Ajayan, Endo & Strato, 2007). When single-walled carbon nanotubes are synthesized, approximately one-third of the batch is metallic while the remaining two-thirds are semiconductors (Huang, Lieber & Odom, 2002).

Although graphite has excellent conductive properties, machining graphite electrodes will result in dust particles on shop floors and in the nearby machines. However, the new high-speed mills that are sold today are specially designed to machine graphite. They are totally enclosed and have a vacuum system to remove all of the dust and there are some machines that can even cut square internal corners (Baranek, 2002).

Correlation between salinity and conductivity

Leitz and Weinstein (1976) emphasized a system utilizing sea water to exchange through the usage of an anion and cation membrane. Further studies emphasizes the a variety of material improve the conductivity and charge transfer. Miller and Simon (2008) stated that salt water is an electrochemical capacitor. The salt in the solvent is quickly attracted to both metals rod serving as a connection between them to transfer charges. Supporting the necessity of salt in the water to be conductive.

Cox and McNeil (2000) stated that an increase of salinity level in water will increase conductivity to an extent. The relationship of salinity level to conductivity is not linear, an optimal salinity level produces highest conductivity capability. In their paper, it mentions that the salinity of his experiment in testing the relationship of the salinity of seawater is greatly affected by the temperature due to the sensitivity of the instruments used. Borodin et al. (2015) stated that aqueous solutions are indeed limited to a smaller window compared to other solutions like. Lithium based batteries have a higher yield but pose more risks.

Aluminum-air battery

Based on the study produced by Whittingham (2008), through utilizing the chemical reaction involving materials such as aluminum, water and oxygen to form high concentrations of electrolytes, production of energy in the form of electricity has been formed alongside with unlimited supply of hydrated aluminum as a byproduct for battery usage. When the process reaches optimal state, the aluminum can be recycled and placed back into the battery. This property makes the aluminum air battery self-sustainable. The battery itself has the power storage capabilities of the conventional battery while also having eco-friendly parameters which could be considered as a form of clean renewable energy (McFadden, 2015).

Tamez and Yu (2007) created a variation of the aluminum-air battery, which utilizes the usage of saltwater, charcoal and aluminum foil. The cost effectivity due to the use of lower costing materials adds an added benefit. The low production of electricity from this type of battery. Another battery was created utilizing copper rather than charcoal, producing an equal to greater output compared to the usage of charcoal but with an increased cost.

Knickle and Yang (2002) stated that utilization of this system is proven to work for electronics. Utilization of Aluminum-air battery has high energy production enough to rival electric vehicles. He stated the cost effectiveness in the utilization of aluminum compared to other electric car systems as well its clean energy production, makes it a better choice for future car systems.

Saltwater as an Electrolyte

Seawater in the world's oceans has an average salinity of about 3.5% that can go up to 12% (Feistel, McDougall, Millero & Wright, 2008). In 1949, John Beechlyn was the first to propose the concept of using saltwater as a electrolyte for a wet battery (Brain, Bryant & Pumphrey, 2000). Installing different metal sheets to respectively serve as a positive and negative electrode. Miller and Simon (2008) stated that the salt in the solvent is quickly attracted to both metals rod serving as a connection between them to transfer charges. This makes it an improved electrolyte for charge exchange. The substitution of potassium hydroxide to salt water as the electrolyte drops the theoretical energy yield from 1.2 volts to 0.7 volts per power cell which still makes it cheaper and safer energy production.

Pure Aluminum vs Aluminum Alloys

Aluminum is the pure metal substance found on the Earth’s crust and an alloy is formed by mixing two or more elements together (Sinnott & Towler, 2009). Using pure aluminum generates much corrosion that lead to many studies conducting on the composition of the aluminum anode. The incorporation of small concentrations of metals such as manganese, magnesium, calcium, zinc, gallium, indium, thallium, lead, mercury, phosphorous and tin usually in combinations as ternary or quaternary alloys, has been effective in achieving activation (high current capability) and inhibition of corrosion (Bjerrum & Li, 2002).

Aluminum Soda Cans

Aluminum makes an economical, yet practical, container for soda and other beverages due to its abundance and recycling value and can factories produce about 100 billion aluminum beverage cans a year (Larson, 1993). The aluminum base, for beverage cans consists mostly of aluminum, but it contains small amounts of other metals as well. These are typically 1% magnesium, 1% manganese, 0.4% iron, 0.2% silicon, and 0.15% copper (Duncan & Hosford, 1994).

III. Synthesis

The study was designed to determine a safe and environmentally friendly way to produce energy, and its integration into communities. It was expected that the findings and models can be utilized by communities to create ways to produce energy for their homes with recyclable materials that are easily found. The various literature in this chapter provides a good foundation of using cheap, clean and accessible materials to create the aluminum-air battery though renewable and sustainable energy is still a problem the study has to face. Dolhem & Piozot (2011) stated that the eminent role of electric energy produced from decarbonized sources in a future sustainable economy is particularly highlighted as well as the issues of its needed storage.

The limitation in production time and amount can greatly hamper the effectiveness of utilization. Some literatures showed possible ways to improve the process but entails an increased risk.

CHAPTER 3: METHODOLOGY

This chapter provides a detailed discussion of the methods used to conduct the research study. The research method and design are discussed first followed by the locale and set up. Instrumentation and materials needed for the study is then presented along with the data collection methods, safety procedures, and data analysis method.

I. Research design

The study utilized the Experimental Research design, as the primary objective for the research was to determine how renewable energy could be generated from an alternative source handled from everyday found materials and be sustained for application of public use. In this case the concept of Aluminum-air battery was used wherein chemical reaction involving everyday found materials such as aluminum, water, salt and oxygen were tested for the generation of sustainable electrical charge similar to the capability of the conventional battery.

As stated in Blakstad (2008), the practice of using experimental type of research is commonly used in testing different fields of sciences such as but not limited to chemistry, sociology and medicine. Through manipulating variables systematically different correlation between concepts and predicting phenomenons can be handled by scientific approach. By conducting various experiments, the causation of phenomenons will be tested for analysis of data and formulation of resulting conclusions to explain such conceptions.

In the case of this research, variables namely the different salinity levels situated amongst distinct cathode samples would be varied to test the conductivity of the water to determine the most efficient electron charge transfer that would excel while undergoing a chemical reactions. Data would have to be collected through conducting a series of experiments testing which among the given manipulated variables namely salinity levels and anode samples would be most suitable and efficient for energy production that will be measured through cell voltage, energy capacity and density. Using a variety of salinity levels would vary the result of the dependent variables depending on the condition set such as using an assortment of anodes for the chemical reaction. Through the comparing of such variables, as will be able to find differences; variety of salinity levels and anode materials are closely related to the conductivity and electrical output of the overall end product.

II. Research Locale and Set up

This research was conducted in the school De La Salle Santiago Zobel - Vermosa Campus. This place was selected by the researchers for its readiness of materials in the school’s laboratory. This location was also chosen so that the experiment can be overseen by a teacher for safety purposes. However in the case of lack of resources that would be present within the De La Salle Vermosa campus, the research already into consideration for the use of other facilities within the area that further presents availability of the materials that would be needed.

III. Research Instruments/Materials

Anode

Recycled soda cans were used as the anode in this experiment and were taken from several junk shops. Soda can are usually made out of Aluminum Association (AA) alloys 3004, 3104, or 3204. These alloys contain 98% Aluminum, 1% Manganese and 1% Magnesium.

Cathode

Three cathodes, mainly copper, activated charcoal and graphite, were used in this experiment. Copper was purchased from Ace Hardware, activated charcoal was purchased from Mercury Drug while at the same time also being available at any aquarium supply stores, and graphite was purchased from National Bookstore.

Electrolyte and Electrolyte Additives

The electrolyte is an aqueous NaCl solution. Four set-ups are used and each set-up has a solution with different salinity levels. Specifically, the salinity levels are 3.5 %, 5%, 10% and 12%. According to Chasteen, Chasteen and Doherty (2008), the conductivity of saltwater is at a maximum for a 12% solution by weight. A small amount of sodium hydroxide was added as a catalyst for the chemical reaction.

Instrumentation

A digital multimeter (DMM) was used to measure the dependent variables, mainly for voltage measurements. A power resistor was also added to measure the energy capacity of the battery.

IV. Data Collection Procedure

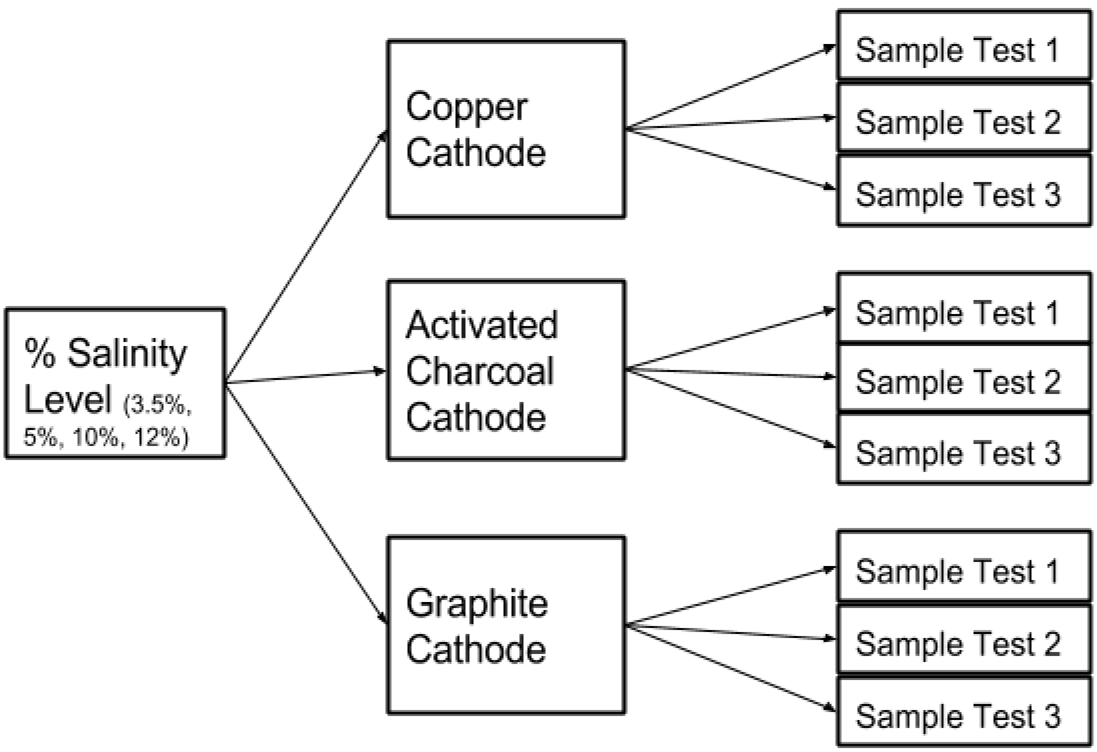

Figure 3.1 Data Collection Design

Figure 3.1 illustrates that for each salinity level there would be sub tests substituting the cathode between the three cathodes with each cathode being tested and recorded three times. Four salinity levels were measured and this produced a total of 36 samples. According to the Central Limit Theorem, the minimum sample size must be 30.

In De La Salle Santiago Zobel-Vermosa, a letter of permission was given to the SHS principal to conduct the study and another letter was given to the overall science coordinator for data collection and use of the laboratory.

Prepare the salt water in the container using 200 mL of water adding 7 g of salt to create 3.5% salinity level, 10g to create 5% salinity level, 20g to create 10% salinity level and 24g to create 12% salinity level plus 2 mL of sodium hydroxide for all solutions. After preparing the salt water prepare 9 g of aluminum (anode) cut from the can and 10cm of copper wire, 1 tablespoon of activated charcoal and 3-5 grams of graphite (cathodes). Place both the aluminum and each cathode into different containers containing the salt water, do not submerge neither the aluminum and cathodes nor let them make contact with each other. Using the digital multimeter, use the voltage mode and connect the black wire to the aluminum and and the red wire to the cathode. Repeat this procedure 3 times and record each test. Repeat this procedure again with the other salinity levels. Further observe what changes to the battery design resulted to a significantly larger energy output in voltage or current.

V. Safety Procedures

The experimental study requires the researchers to work inside a laboratory. Rules and procedures must be followed to ensure safety in the laboratory as the experiments are being conducted. This section provides specific instructions in conducting chemical reactions.

1. Upon working on a setup to which voltage and electric currents is applied in the operation, at least a group of two members must be present in the laboratory for it is highly encouraged to be cautious and comply strictly to the multiple safety rules when executing the experiment alone.
2. Electrically conductive fluids should, to the extent possible, be placed under the electrical installation in order to prevent accidental short circuits in case of leakage.
3. Wires or electrodes of temporarily unused batteries must be secured against accidental short circuits by shielding or clear labeling.
4. When working with batteries especially those that are particularly flammable, a setup must be planned that enables a convenient extinguishing and disposal of the battery.
5. Dilution of acids is known to be dangerous because if water is dissolved to a concentrated, it has the tendency to produce an effect of exploding violently causing injury to the researcher. Therefore never directly pour water into concentrated acid instead just simply add acid to the water first before dissolving.
6. Do not allow any of the chemicals applied to these experiments to come in contact to your hands or skin. Do not breathe any vapors from these chemicals for some of these could be very toxic and harmful to a person's respiratory health. Use proper safety apparatus when handling these chemicals.

7. It is always advised when working with chemicals, chemical safety goggles, gloves, and a lab coat should be the first pieces of equipment to be considered
8. Make sure all chemicals are clearly and currently labeled with the substance name, concentration, date, and name of the individual responsible.
9. Within the setup make sure there are no “live wires” present which can be touched by any other person for it can result to a hazard for electrocution and/or short circuit.

VI. Statistical Treatment and Formulae

Analysis of variance (ANOVA) was used as a statistical treatment to analyze the data. According to Seltman (2012), ANOVA is a method used to test differences between two or more means. It attempts to determine if there is a statistically significant difference among the groups or variables. In this study, aluminum was analyzed under conditions of different cathodes and electrolytes with different salinity levels.

Energy Capacity

The formula is $Energy\ capacity = Power\,(P) \cdot Time\,(t)$ where time is the length of your measurement interval and $Power = Voltage \cdot Current\,(I)$. To measure the energy capacity, measure the voltage and current then multiply the two values. The product would be the power and the power would be multiplied by the time which is generally 1 hour.

CHAPTER 4: DATA ANALYSIS AND INTERPRETATION

In this chapter of the paper, results of the procedure gathered upon experimentation as well as data analysis are to be presented in tabular form at the same time further interpreted for a comprehensive and concise understanding. Upon collection and interpretation, the data analysis was done through utilization of SPSS Application Tool and the statistical treatment One-Way ANOVA was used in response to the given research questions. The One-Way Anova as a statistical treatment is a method determined to find any statistically significant differences between the means or two or more unrelated independent group. The results and analysis obtained from the experiment procedure are as follows.

Research Question 1: What is the result of changing the salinity level and cathode to cell potential and energy capacity?

Table 4.1 *Descriptive Statistics*

Cathode and Salinity Level	Mean Cell Potential	Mean Energy Capacity
Copper at 3.5% salinity level	1.1733	2.3267
Copper at 12% salinity level	1.2167	2.4433
Charcoal at 3.5% salinity level	1.2767	2.5233
Copper at 5% salinity level	1.3467	2.6733
Copper at 10% salinity level	1.3500	2.6800
Charcoal at 5% salinity level	1.3967	2.7633
Charcoal at 12% salinity level	1.4200	2.8300
Charcoal at 10% salinity level	1.4700	2.9333

Graphite at 12% salinity level	1.7033	3.3967
Graphite at 3.5% salinity level	1.7667	3.5000
Graphite at 5% salinity level	1.7733	3.5367
Graphite at 10% salinity level	1.8000	3.5800
	Mean = 1.4744 Minimum = 1.13 Maximum = 1.81 Std. Deviation = .22270	Mean = 2.9272 Minimum = 2.24 Maximum = 3.60 Std. Deviation = .44381

The data in table 4.1 shows that there are varying results of cell potential and energy capacity when the salinity level and cathodes are changed. Graphite at 10% salinity level has highest mean cell potential and energy capacity while copper at 3.5% salinity level has the lowest mean cell potential and energy capacity. For all the cathodes, the table shows that the voltage and ampere hour increases as the salinity level increases however gradually decreases as the salinity level reaches 12% due to the setup being in a case wherein the salinity level is distant from the optimal state where conductivity is at its peak. According to Cox and McNeil (2000), the relationship of salinity level to conductivity is not linear as there is an optimal salinity level that produces the highest conductivity capability. Therefore the measure of conductivity is correlation to the components of the mixture being in a state of equilibrium in effect producing the potential output. Nayak and Shemella (2014) discovered that graphene, a one-atom-thick sheet of graphite, is extremely efficient in conductive properties and can be used in nanoelectronics. Graphene can replace copper as because the copper interconnects get smaller, the copper’s resistance increases and its ability to conduct electricity degrades.

Research Question 2: Is there a significant difference in cell potential at different salinity levels and cathodes?

Table 4.2 *Analysis of Variance (ANOVA) Table of Cell Potential*

		Sum of Squares	df	Mean Square	F	Sig.
CELL POTENTIAL	Between Groups	1.711	11	.156	147.321	.000
	Within Groups	.025	24	.001		
	Total	1.736	35			

Based from the data present in table 4.2, the data ran by one - way ANOVA, $F(11, 24) = 147.321$, $p = 0.000$, at 95% level of confidence, there is a statistically significant difference in cell potential between the independent varying components namely the difference in cathode material used (copper, activated charcoal, graphite) and distinct salinity levels (3.5%, 5%, 10%, 12%) in terms of voltage electrical output upon running tests, considering that the p-value is less than 0.05. This means that the one with the higher mean of the groups has a statistically higher overall electrical energy output performance in terms of the amount of voltage produced which is graphite at 10% salinity level based from table 4.1. Considering that the obtained values from the data collection, specifically the F-values, are large and the p-value has been observed as below 0.05, therefore the results are considered as significant. Graphite and activated charcoal (amorphous) are allotropes of carbon, which is a non-metal by default but graphite is considered a semi-metal while copper on the other hand, is a metal belonging in group 11 (coinage metals) of the periodic table (Chang, 2006). Electric conductivity depends on the density of carriers and their mobility. In the case of graphite, the density of free carriers is approximately four orders of magnitude lower than copper whereas the electric conductivity at ambient temperature is only two orders of magnitude smaller. This results from the higher mobility of free carriers of graphite. In metals, the number of carriers is very high and constant, which makes them good conductors, but their mobility is low (Kurz, Mercier & Zambelli, 2012).

Upon analyzing the obtained values, the results can now be then considered as fairly significant and enough to prove which from the independent group namely cathode material and salinity level upon undergoing test process was able to produce the most significant output. In this case the sample of 10% salinity level alongside with the use of graphite cathode material would now be considered preferable result considering the highest optimal output. Reproduction of this result proves it the most significant in comparison with the others.

Research Question 3: Is there a significant difference in energy capacity at different salinity levels and cathodes?

Table 4.3 *Analysis of Variance (ANOVA) Table of Energy Capacity*

		Sum of Squares	df	Mean Square	F	Sig.
ENERGY CAPACITY	Between Groups	6.796	11	.618	152.347	.000
	Within Groups	.097	24	.004		
	Total	6.894	35			

Based on table 4.3, the data on energy capacity ran by ANOVA $F(11, 24) = 152.347$, $p = 0.000$, at 95% level of confidence, also states the presence of a statistically significant difference to how much energy can be stored in each sample upon running tests giving consideration that the p-value is also less than 0.05. Given this result it can now then be inferred that the variation of the cathode material used and salinity level in a sample is correlational to the overall output along with its factors to consider namely cell potential and energy capacity wherein a distinct variation was able to produce the optimal result in comparison with the others. This means that the one with the higher mean of the groups has a statistically higher overall energy capacity in terms of ampere hour which is graphite at 10% salinity level based from table 4.1. Considering that the obtained values from the data collection, specifically the F-values, are large and the p-value has been observed as below 0.05, therefore the results are considered as significant. Copper, activated charcoal and graphite all have different conductivity and resistivity based on their atomic makeup (Chang, 2006). Activated charcoal is a non-metal, graphite is a semimetal and copper is a metal. In semimetals and semiconductors, the electrical conductivity increases with temperature in certain ranges because the number of carriers is increased (Kurz, Mercier & Zambelli, 2012). Also, the electrical conductivity of semimetals and semiconductors is strongly influenced by the presence of impurities, which increases the number of carriers. In this research, the aluminum anode used was taken from recycled soda cans which is not pure aluminum and graphite pencil was used as the cathode which is not pure graphite.

According to Duncan & Hosford (1994), besides aluminum, soda cans have typically 1% magnesium, 1% manganese, 0.4% iron, 0.2% silicon, and 0.15% copper. According to Bhowmik (2011), graphite, or commonly known as lead pencils, is an intercalated compound, consisting of the mixture of clay (mainly SiO_2 and minor amount of metal oxides) particles in conducting graphite matrix.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

This chapter relates the data and findings gathered from the experimentations to the research questions that ask essential questions that are needed to further understand the topic at hand. The chapter is categorized into two sections: conclusion and recommendation. The conclusion section presents the findings and the implications of the results to available literature on the topic. Using the interpretations of the data gives an aid on how the research questions have been answered and helps create recommendations on what could have been improved on. Understanding what could have been improved in this research may help future researchers with the same topic to have a broader understanding on the topic and this also gives them a definitive list on what could be done in order to accumulate better and more confident results.

Conclusion

This area of the chapter will present the conclusions and the findings of the research paper. The research questions posed in the beginning of the paper will be answered with the data collected from the experiment. The results of the data analysis is used to create an answer to the research questions.

1. The first research question was addressed by testing for the cell potential and energy capacity by varying the salinity level and the cathode used. Testing different cathodes Copper, Charcoal, and Graphite with the varying salinity levels

of 3.5%, 5%, 10%, and 12%, the researchers were able to find that using graphite in a 10% salinity solution yielded the highest cell potential and energy capacity, making it the ideal material for the aluminum air battery while copper in a 3.5% salinity solution yielded the lowest cell potential and energy capacity.

2. The second research question was addressed based on the results of the One-Way Anova and the utilization of an SPSS tool that helped compute for the significant difference in cell potential at varying salinity levels and cathodes. The data gathered from the experiment was interpreted to have a significant difference in cell potential between the different cathode materials and distinct salinity levels in terms of voltage upon running tests. With this, if the difference is statistically significant it shows that the level of salinity and type of cathode directly affects the cell potential of the battery. This means that using the most effective salinity level paired with the most effective cathode, the cell potential will be better than other pairs of salinity levels and cathodes.

3. The third research question was addressed based on the results of the One-Way Anova and the utilization of an SPSS tool that helped compute for the significant difference in energy capacity at varying salinity levels and cathodes. The data gathered was interpreted to be statistically significant in the difference to how much energy can be stored in each sample of salinity level and cathode upon running tests. With this, if the difference is statistically significant it shows that the

level of salinity and type of cathode used will greatly affect the performance of the air battery. Using the right combination of salinity level and type of cathode will give out the most efficient way of creating energy given the different salinity levels and types of cathodes.

Recommendations

1) Further research is needed to broaden the understanding and knowledge of the topic. Expanding the amount of related literature on the topic could have increased the researcher's understanding and knowledge on the topic. This may have introduced new and different concepts that might have been helpful in the completion of this research. Finding out the methodology and the materials used in other related research papers could have been useful with how the methodology of this research paper has been created.
2) Based on the methodological limitations of the study, several recommendations are also provided for future researchers. Increasing diversity in samples would yield various results that can be used to find a stronger support for the most efficient materials used for battery creation. Testing different cathodes and anodes would result in a broader range of data collected that may help in finding the ideal material for the battery. Also, the researchers would further recommend that the studies should also explore other possible factors such as the effects of the battery's environment (temperature and exposure) on battery performance

and capabilities. This is to identify and create a recommended environment for an efficient battery production.

3) Another recommendation would be to test out more specific salinity levels as it may give an insight to whether the salinity level may increase the cell potential and energy capacity of the battery. The result of this research concluded that using graphite in a 10% salinity solution has the highest cell potential and energy capacity. Using more specific salinity levels between 10-12% could still possibly have an increase of cell potential and energy capacity. Testing out different graphite samples could also give a significant difference of cell potential and energy capacity. According to Nayak and Shemella (2014), a one one-atom-thick sheet of graphite, also known as graphene, would yield better results with the battery.

References

Ahuja, D., & Tatsutani, M. (2009). Sustainable energy for developing countries. *SAPI EN. S. Surveys and Perspectives Integrating Environment and Society*, (2).

Ajayan, P. M., Endo, M., & Strano, M. S. (2007). Potential applications of carbon nanotubes. *In Carbon Nanotubes*, 13-62.

Aqeel, A., & Butt, M.S. (2001). The relationship between energy consumption and economic growth in Pakistan. *Asia-Pacific Development Journal, 8*, 101-109.

Armaroli, N., & Balzani, V. (2011). The hydrogen issue. *ChemSusChem, 4*(1), 21-36.

Baranek, S. (2002). Using copper and graphite electrodes: The big picture. Retrieved from https://www.moldmakingtechnology.com/articles/using-copper-and-graphite-electrodes-look-at-the-big-picture

Bartolucci, S. F., Kapoor, D., Koratkar, N., Lee, S., Paras, J., Rafiee, M. A., & Rafiee, J. (2011). Graphene–aluminum nanocomposites. *Materials Science and Engineering: A*, *528*(27), 7933-7937.

Bhonge, K. (2017). *Study of aqueous electrolytes and parameters affecting the performance of aluminum-air batteries*. Northern Illinois University Press: De Kalb, IL.

Blakstad, O. (2008). *Experimental Research.* Retrieved from https://explorable.com/experimental-research

Bjerrum N.J., & Li, Q. (2002). Aluminum as anode for energy storage and conversion: a review. *Journal of Power Source, 4633*, 1-10.

Borodin, O., Fan, X., Gao, T., Ho, J., Luo, C., Olguin, M., Suo, L., Wang, C., & Xu, K. (2015). “Water-in-salt” electrolyte enables high-voltage aqueous lithium-ion chemistries. *Science, 350*(6263), 938-943.

Brain, M., Bryant, C. W., & Pumphrey, C. (2000). *How batteries work. How Stuff Works*, 1.

Brown, L. R. (2015). *The great transition: Shifting from fossil fuels to solar and wind energy*. WW Norton & Company: New York, USA.

Chang, R. (2006). *General chemistry : Essential concepts*. McGraw-Hill Publishing Company: New York, USA

Chasteen, N. D., Chasteen, S. V., & Doherty, P. (2008). The Salty Science of the Aluminum-Air Battery. *The Physics Teacher*, *46*(9), 544-547.

Clarke, J., Dooner, M., Luo, X., & Wang, J. (2015). Overview of current development in electrical energy storage technologies and the application potential in power system operation. *Applied Energy, 137*, 511-536.

Corbo, P., Migliardini, F., & Veneri, O. (2011). *Hydrogen fuel cells for road vehicles*. Springer Science & Business Media: New York, USA.

Cox, M. E., & McNeil, V. H. (2000). Relationship between conductivity and analysed composition in a large set of natural surface-water samples, Queensland, Australia. *Environmental Geology, 39*(12), 1325-1333.

Demirbas, A., & Gupta, R. B. (2010). *Gasoline, diesel, and ethanol biofuels from grasses and plants*. Cambridge University Press: Massachusetts, USA.

Dicks, A., Larminie, J., & McDonald, M. S. (2003). *Fuel cell systems explained (Vol. 2)*. J. Wiley: Chichester, UK.

Dolhem, F., & Poizot, P. (2011). Clean energy new deal for a sustainable world: from non-CO2 generating energy sources to greener electrochemical storage devices. *Energy & Environmental Science, 4*(6), 2003-2019.

Duncan, J.L. & Hosford, W.F. (1994) The aluminum beverage can. *Scientific American*, 48-53.

Energy Storage Association. (2017). *Lithium Ion (LI-ION) Batteries*. Retrieved from http://energystorage.org/energy-storage/technologies/lithium-ion-li-ion-batteries

Feistel, R., McDougall, T. J., Millero, F. J., & Wright, D. G. (2008). The composition of Standard Seawater and the definition of the Reference-Composition Salinity Scale. *Deep Sea Research Part I: Oceanographic Research Papers*, *55*(1), 50-72.

Goss, D. J., & Petrucci, R. H. (2007). *General Chemistry Principles & Modern Applications: Study Guide*. Pearson/Prentice Hall: New Jersey: USA.

Huang, J. L., Lieber, C. M., & Odom, T. W. (2002). Single‐Walled Carbon Nanotubes. *Annals of the New York Academy of Sciences*, *960*(1), 203-215.

International Energy Agency. (2016). *World energy outlook*. International Energy Agency Publications: Paris, France.

Johansson, B. (2013). Security aspects of future renewable energy systems–A short overview. *Energy, 61*, 598-605.

Kalogirou, S. A. (2013). *Solar energy engineering: processes and systems*. Academic Press: Massachusetts, USA.

Knickle, H., & Yang, S. (2002). Design and analysis of aluminum/air battery system for electric vehicles. *Journal of Power Sources, 112*(1), 162-173.

Kozak, R. (2014). *How to turn water into electricity with hydrogen fuel cells*. Retrieved from http://www.romanakozak.com/fuel-cell/

Kurz, W., Mercier, J. P., & Zambelli, G. (2012). *Introduction to materials science*. Elsevier: Amsterdam, Netherlands.

Larson, M. (1993). New ideas come in cans. *Packaging*, 30-31.

Leitz, F. B., & Weinstein, J. N. (1976). Electric power from differences in salinity: the dialytic battery. *Science, 191*(4227), 557-559.

Lide, D.R. (2005). *CRC Handbook of Chemistry and Physics*. CRC Press LLC: Florida, USA.

Madhuri, S., & Maheshwar, S. (2015). *Graphene: An introduction to the fundamentals and industrial applications*. John Wiley & Sons: New Jersey, USA.

McFadden, R. (2015). T*he aluminum air battery and it long term benefits in recreational vehicles.* Retrieved from http://sites.psu.edu/ryanmcfadden/wp-content/uploads/sites/36533/2015/11/aluminum-air-battery.pdf

Miller, J. R., & Simon, P. (2008). Electrochemical capacitors for energy management. *Science Magazine*, *321*(5889), 651-652.

Nayak, S. K., & Shemella, P. (2009). Electronic structure and band-gap modulation of graphene via substrate surface chemistry. *Applied Physics Letters*, *94*(3).

Parent, K. E. (2003). Fuel cells: Energy from gases instead of gasoline. *American Chemical Society*, 1-15.

Reed, L. (2015). *Aluminum ion batteries: Electrolytes and cathodes*. UC Merced Electronic Theses and Dissertations: California, USA.

Seltman, H. J. (2012). Experimental design and analysis. Pittsburgh: Carnegie Mellon University.

Sinnott, R. K., & Towler, G. (2009). *Chemical engineering design: SI Edition*. Elsevier: Amsterdam, Netherlands.

Sullivan, L.E. (2009). Energy. *The SAGE glossary of the social and behavioral sciences*. Sage Publications: Thousand Oaks, CA.

Tamez, M., & Julie, H. Y. (2007). Aluminum—Air Battery. *J. Chem. Educ, 84*(12), 1936A.

United Nations. (2015). *Sustainable development goals*. Retrieved from http://www.un.org/sustainabledevelopment/sustainable-development-goals/

U.S. Energy Information Administration. (2017). *Annual energy outlook 2017 with projections to 2050*. Retrieved from https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf

U.S Geological Survey (2013). *Water basics glossary*. Retrieved from https://water.usgs.gov/water-basics_glossary.html

Whittingham, M. S. (2008). Materials challenges facing electrical energy storage. *Mrs Bulletin*, *33*(4), 411-419.

Zohuri, B. (2016). *Plasma Physics and Controlled Thermonuclear Reactions Driven Fusion Energy*. New York: Springer.

Appendix A

Ms. Agnes Panaligan
Overall Senior High School Head
De La Salle Santiago Zobel - Vermosa

Dear Ms. Panaligan:
Greetings of Peace!

The undersigned are senior high school students under the Science, Technology, Engineering and Mathematics (STEM) strand at the De La Salle Santiago Zobel School – Vermosa. We are currently conducting a research titled, **“A Study of Different Salinity Levels and Cathodes Affecting the Performance of Aluminum-Air Batteries”**.

In line with this, the undersigned would like to request permission and endorsement to conduct the research within the school. The study focuses on evaluating the performance of aluminum-air batteries taken from recycled soda cans so that it could be used as an alternative for cheaper and sustainable energy production. The data that will be gathered from the aforementioned procedures will be very significant to achieve the objectives of this study.

Rest assured that confidentiality of the data gathered will be strictly observed and will be solely used for the above mentioned purpose.

We are truly grateful in anticipation of your favourable response to this request.

Respectfully yours,

Guieb, Bea Kathrine G.
STEM Student

Aguila, John Dominic B.
STEM Student

De Veyra, Ryan Cedric Q.
STEM Student

Ellett, Allen Wayne C.
STEM Student

Santos, Tomas Agustin S.
STEM Student

Noted by:

Sir Fritz M. Ferran
Research Adviser

Sir Jonathan Sarza
Chemistry Teacher

Sir Richard Lasap
Overall Strand Coordinator

Approved:

Ms. Agnes Panaligan
Overall Senior High School Head

Appendix B

Ms. Carmelita Estidola
Science Coordinator
De La Salle Santiago Zobel -Vermosa

Dear Ms. Estidola:
Greetings of Peace!

The undersigned are senior high school students under the Science, Technology, Engineering and Mathematics (STEM) strand at the De La Salle Santiago Zobel School – Vermosa. We are currently conducting a research titled, **"A Study of Different Salinity Levels and Cathodes Affecting the Performance of Aluminum-Air Batteries"**.

In line with this, the undersigned would like to request permission and endorsement to use the chemistry laboratory of the **DLSZ-Vermosa** campus on **November 6-9, 2017**. The study focuses on evaluating the performance of aluminum-air batteries taken from recycled soda cans so that it could be used as an alternative for cheaper and sustainable energy production. The data that will be gathered from the aforementioned procedures will be very significant to achieve the objectives of this study.

Rest assured that confidentiality of the data gathered will be strictly observed and will be solely used for the above mentioned purpose.

We are truly grateful in anticipation of your favourable response to this request.

Respectfully yours,

Guieb, Bea Kathrine G.
STEM Student

Aguila, John Dominic B.
STEM Student

De Veyra, Ryan Cedric Q.
STEM Student

Ellett, Allen Wayne C.
STEM Student

Santos, Tomas Agustin S.
STEM Student

Noted by:

Sir Fritz M. Ferran
Research Adviser

Ms. Agnes Panaligan
Overall Senior High School Head

Sir Jonathan Sarza
Chemistry Teacher

Approved:

Ms. Carmelita Estidola
Science Coordinator