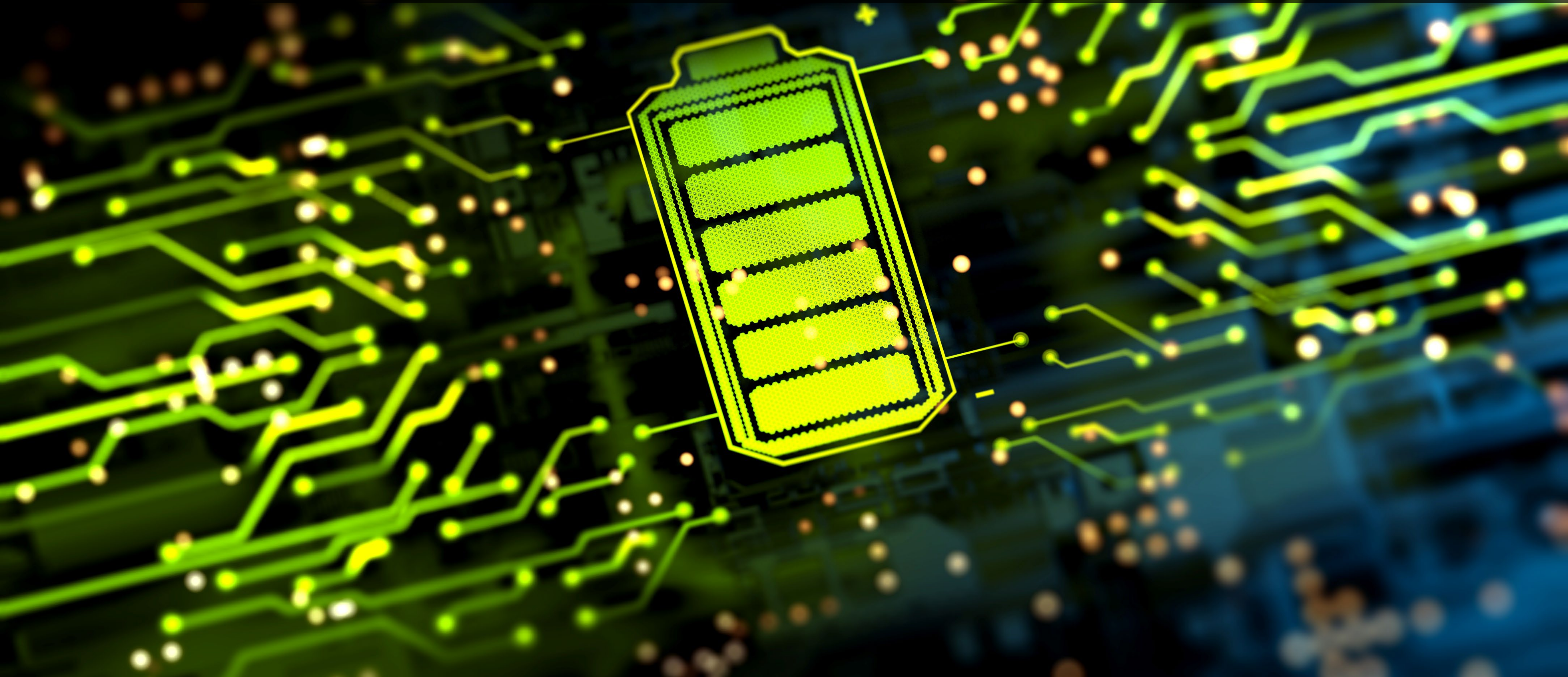
Graphene Sand: Unlocking the potential of Metal Air Batteries



Question ?

How to identify and evaluate new materials for metal air batteries that are cost-effective, environmentally friendly, and more efficient?

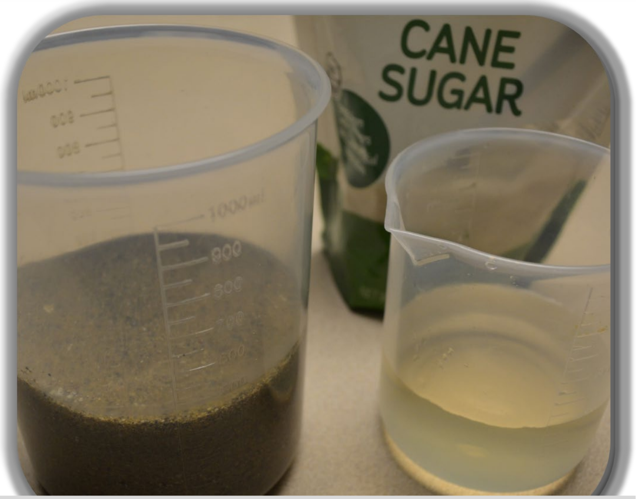
Hypothesis

If graphene sand is used for the cathode component of a metal-air battery, it will generate a higher potential difference compared to using activated charcoal.

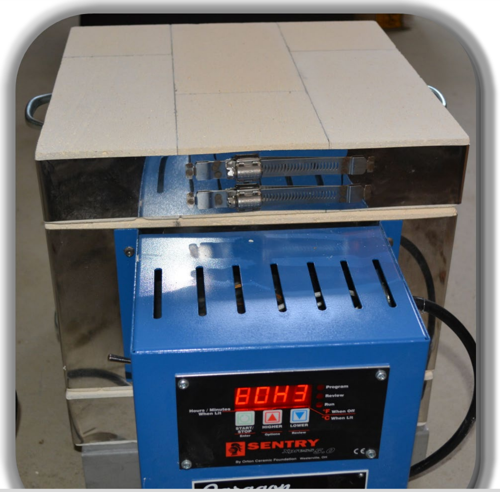
Experiment

Independent variable: Cathode material (graphene sand & activated charcoal).
Dependent variable: Potential difference generated by the battery.
Control group: Graphite only cathode.
Controlled variables: Room temperature, time interval, molar concentration of the electrolyte, amount of material used & measurement devices

Graphene Sand Synthesis

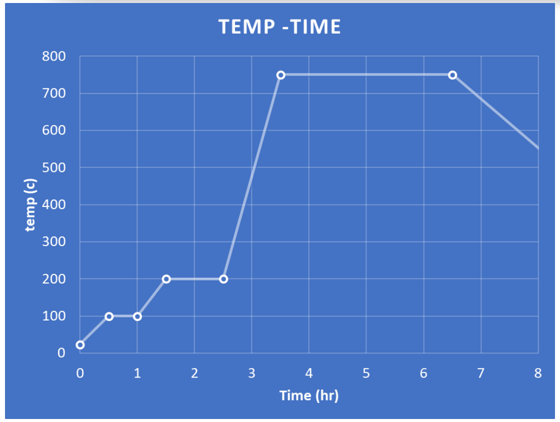


Sand + Sugar + Water

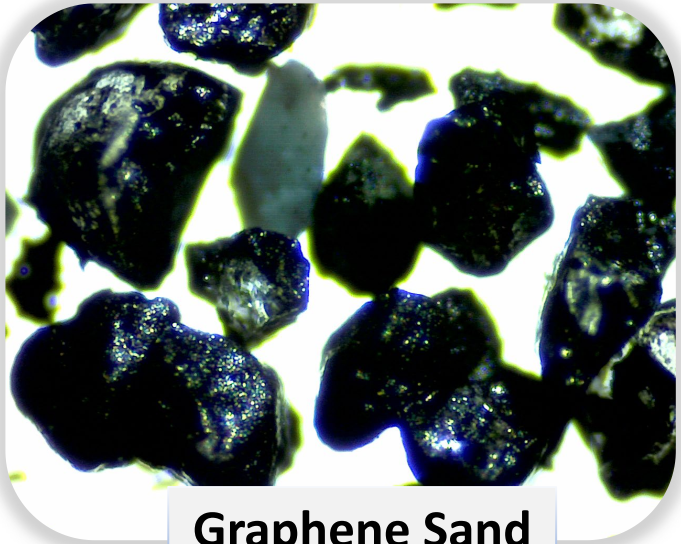


Heated in Kiln at 750 °C

Graphene Sand



Kiln Temperature Cycle
100 °C - Remove moisture
200 °C - Sugar Caramelization
750 °C - Carbon Graphitization



Graphene Sand

Graphene is an allotrope of carbon that is 1 atom thick and is arranged in a hexagonal lattice structure.

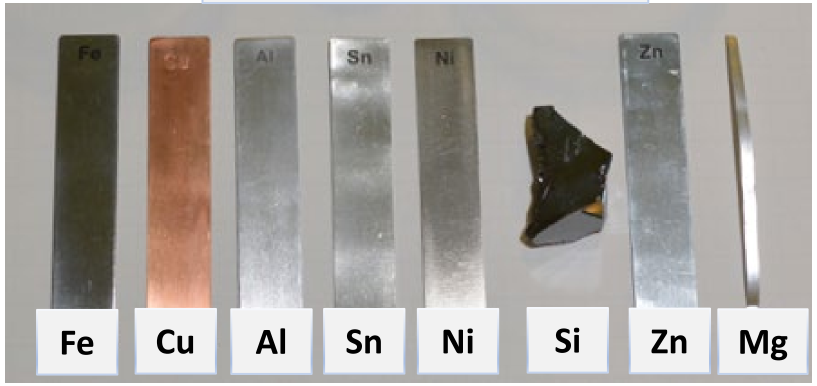
Graphene Sand is sand coated with graphene. Sugar is used as a source of carbon. 5% Sugar - 95% Sand was used in this synthesis.

Experiment – Metal Air Potential Difference study

The objective of this study is to measure the potential difference of metal-air batteries using various metals (Fe, Ni, Mg, Sn, Cu, Zn & Al) and metalloid (Si) as the anode and a graphite-based cathode with Activated Charcoal (AC) with and without MnO_2 catalyst. Two different electrolytes, KOH and NaCl, were evaluated. A multimeter was utilized to measure the potential difference. The primary goal is to identify the optimal anode materials and conditions for metal-air batteries

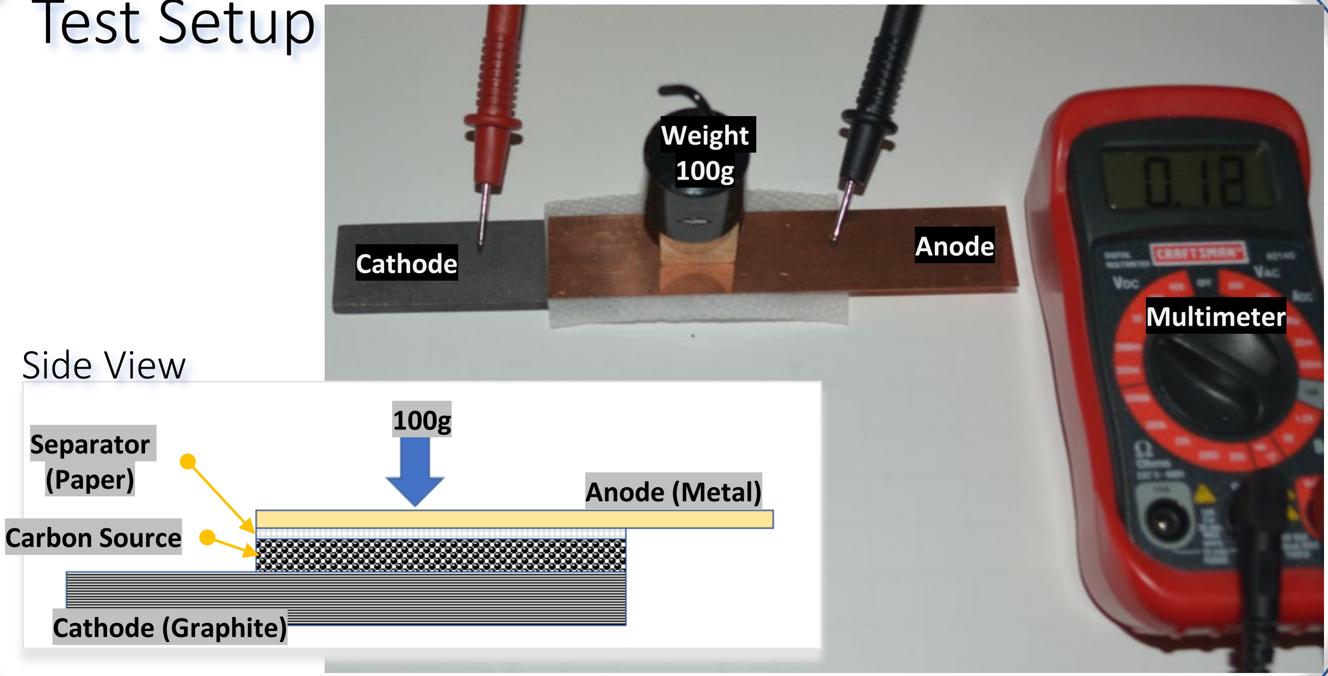
Material used in the Experiment

Metals and Metalloid (Anode)



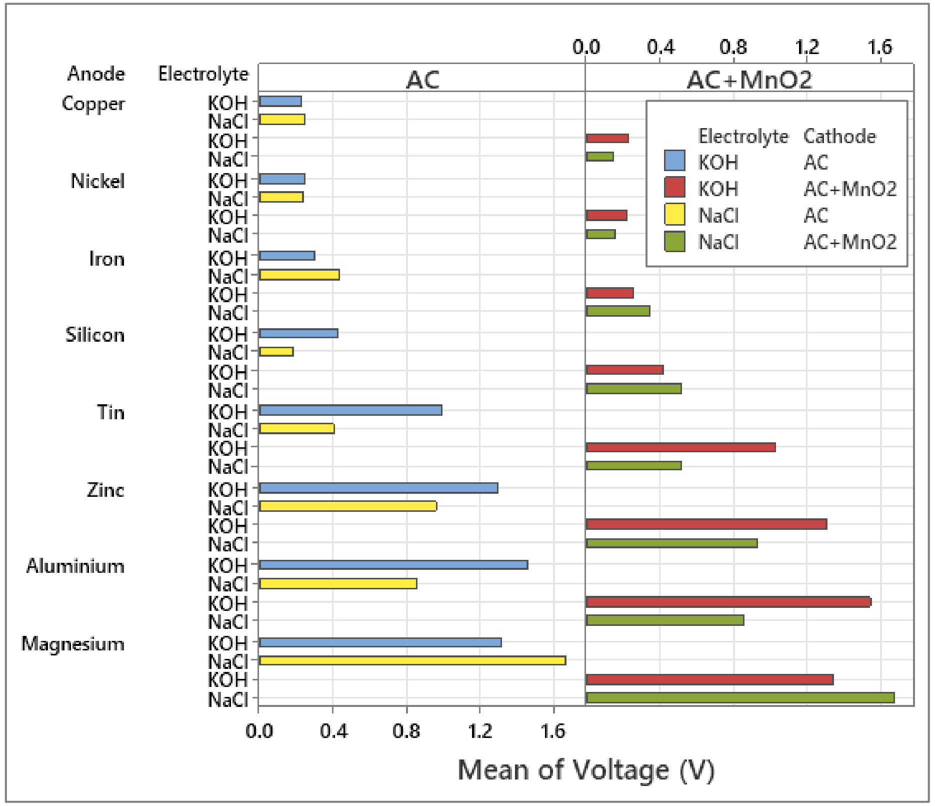
Graphite and Carbon Base(Cathode)

Test Setup



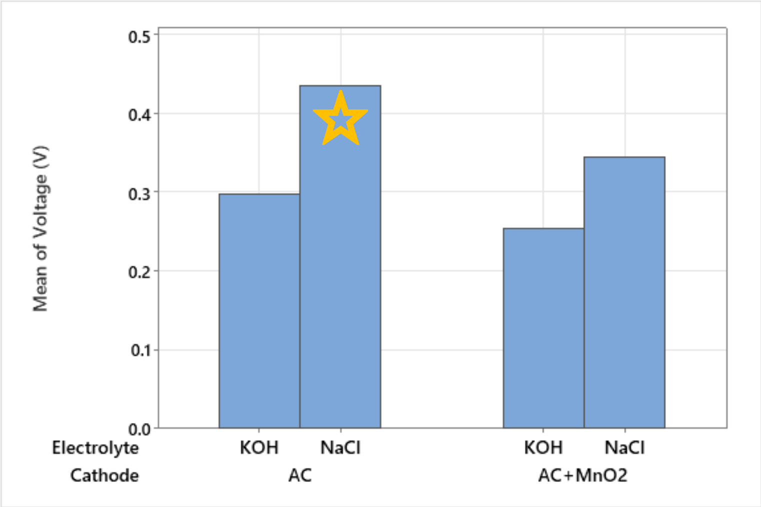
Data Processing – Metal Air Potential Difference study

Potential Difference Measured



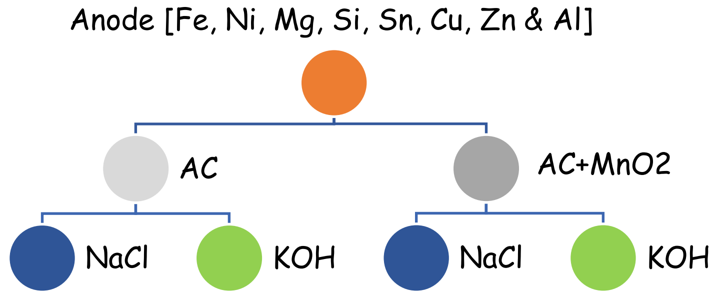
Magnesium, Aluminum, Zinc produced the highest voltage over ~1 V.

Potential Difference for Iron



Despite not producing the highest voltage, Iron generated a mean voltage of approximately 0.45V when used with NaCl electrolyte.

Study Matrix



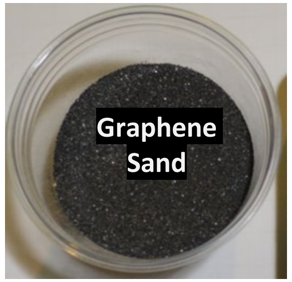
The above hierarchy diagram illustrates the various combinations of independent variables tested in this study. Additionally, four sets of repeat tests were conducted to gather the required data, and the plots show the mean voltage measurements obtained.

Based on this study, Iron was selected for further investigation due to its low cost, reduced toxicity, and ability to be recharged. Addition of MnO_2 catalyst had negative impact for Iron.

Experiment – Evaluation of Active Charcoal Vs Graphene Sand

This study assesses a metal-air battery that uses iron [Fe] as the anode and a cathode composed of Activated Charcoal (AC), Graphene Sand (GS), or a combination of both (AC+GS). Three different electrolytes, namely KOH, NaOH, and NaCl, were analyzed, and the potential difference was measured using a multimeter. The primary objective is to determine the optimal conditions for the Iron Air battery and evaluate the effectiveness of Graphene Sand (GS).

Material Used



Graphite Plate [Control]

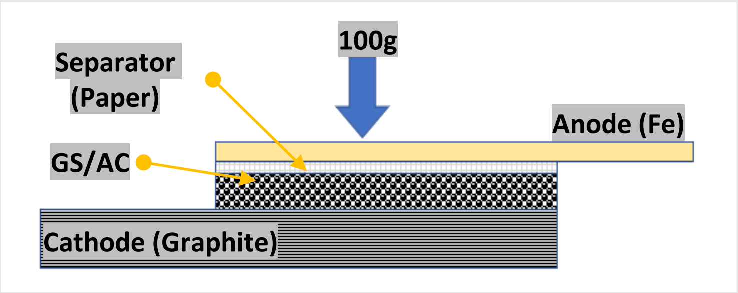
1 mol Electrolyte

KOH

NaCl

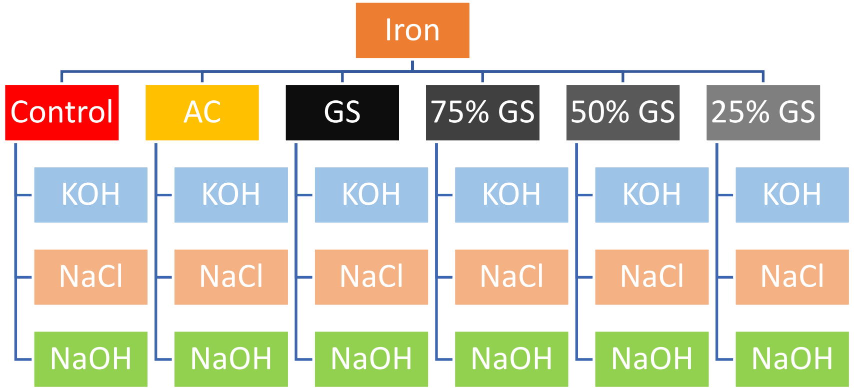
NaOH

Side View of Test Setup



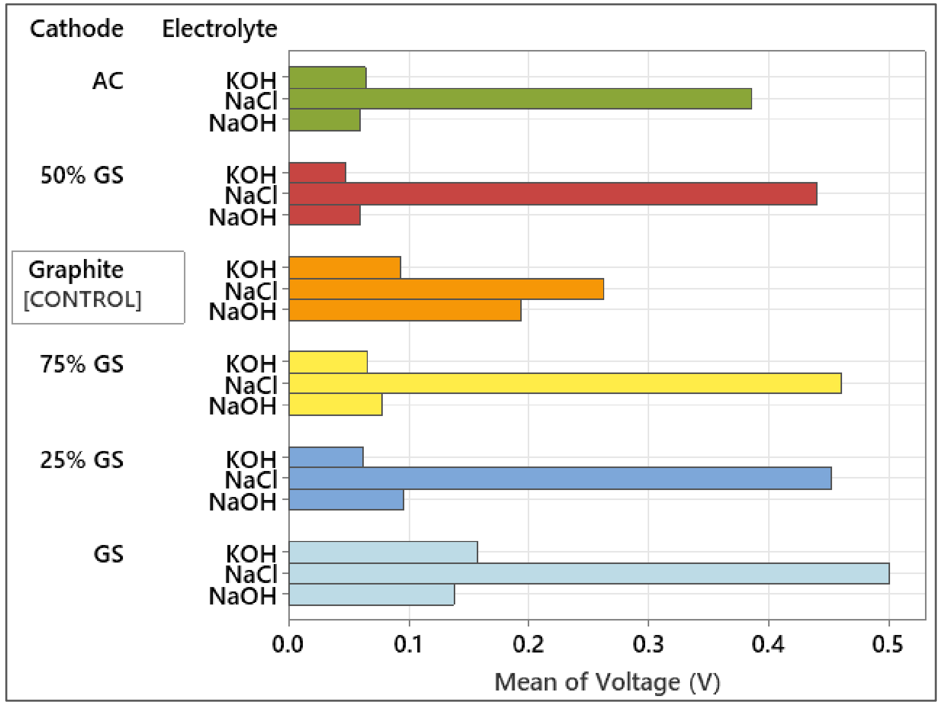
Note that the Control for this experiment was the Graphite Plate without GS or AC.

Test Matrix



Data Processing – Evaluation of Active Charcoal Vs Graphene Sand

Potential Difference Measured

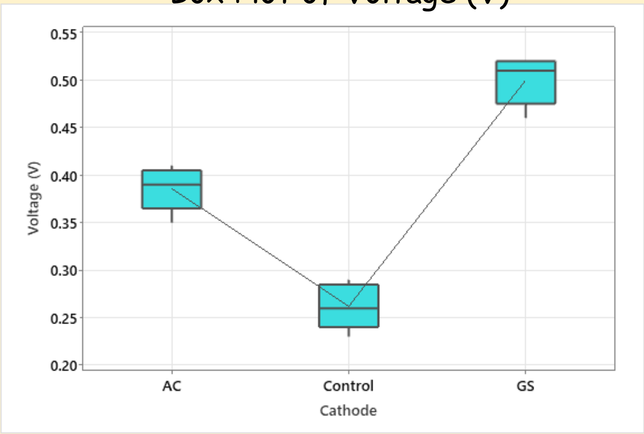


Graphene Sand (GS) produced the highest voltage of 0.5V.

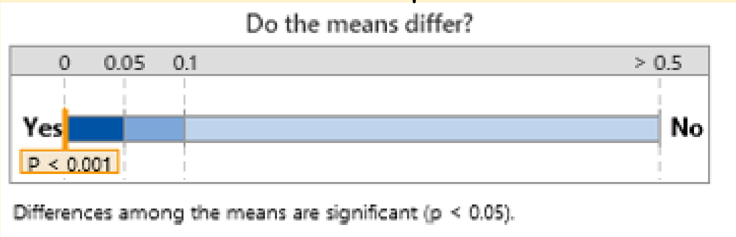
Statistical Data Analysis

A One-Way ANOVA test was performed to evaluate the statistical significance among the three samples (AC, GS, and Control). The results indicated significant differences among the means at a 0.05 (α) level of significance. This suggests that the three samples have distinct characteristics.

Box Plot of Voltage (V)



ANOVA Report



Statistics

Cathode	Sample Size	Mean	Standard Deviation	Individual 95% CI for Mean
AC	5	0.386	0.02302	(0.35741, 0.41459)
Control	5	0.262	0.02387	(0.23236, 0.29164)
GS	5	0.5	0.02550	(0.46834, 0.53166)

According to the study, the combination of Iron and Graphene Sand (GS) with NaCl electrolyte produced the highest voltage of 0.5V. This combination showed a 29.5% improvement compared to Activated Charcoal (AC) and a 91% improvement compared to the Control (Graphite Plate).
This further validates the hypothesis of the study that GS when used for cathode component of a metal-air battery, it will generate a higher potential difference compared to using AC.

Iron-Air Battery Protype Build and Evaluation

Based on the previous studies, using optimal parameters, an Iron-Air battery is built to generate 3V. The prototype battery is tested for charge and discharge cycle using a Battery Capacity Tester.

Protype Build

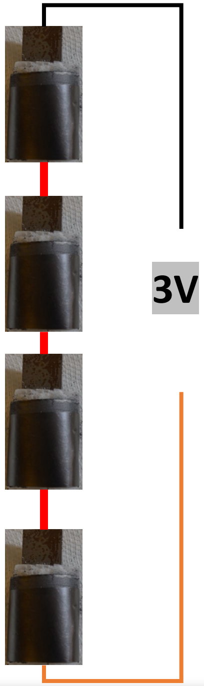
1. Fe plate wrapped with steel wool

2. Flexible graphite sheet (Grafoil) is layered with Graphene Sand and paper separator.

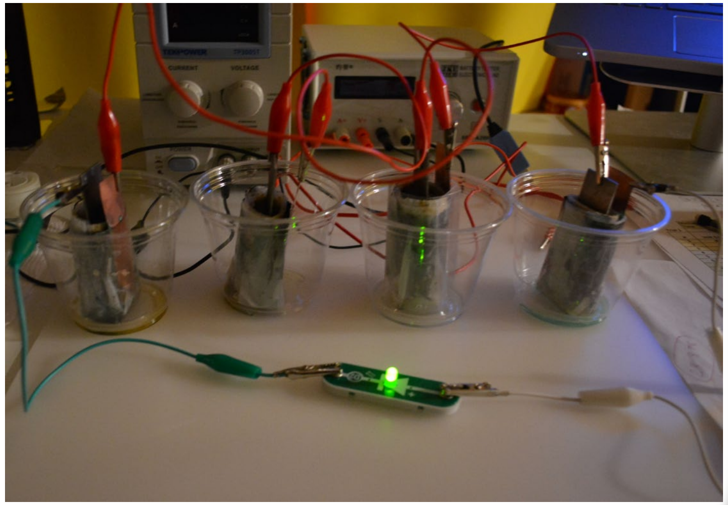
3. The components from step 2 is wrapped and rolled over the material from step 1.

4. Repeat steps 1-3, three times to make 4 such batteries and connect in series for a 3V Battery

Before operating the battery, 1 mol of NaCl electrolyte added to the paper separator.



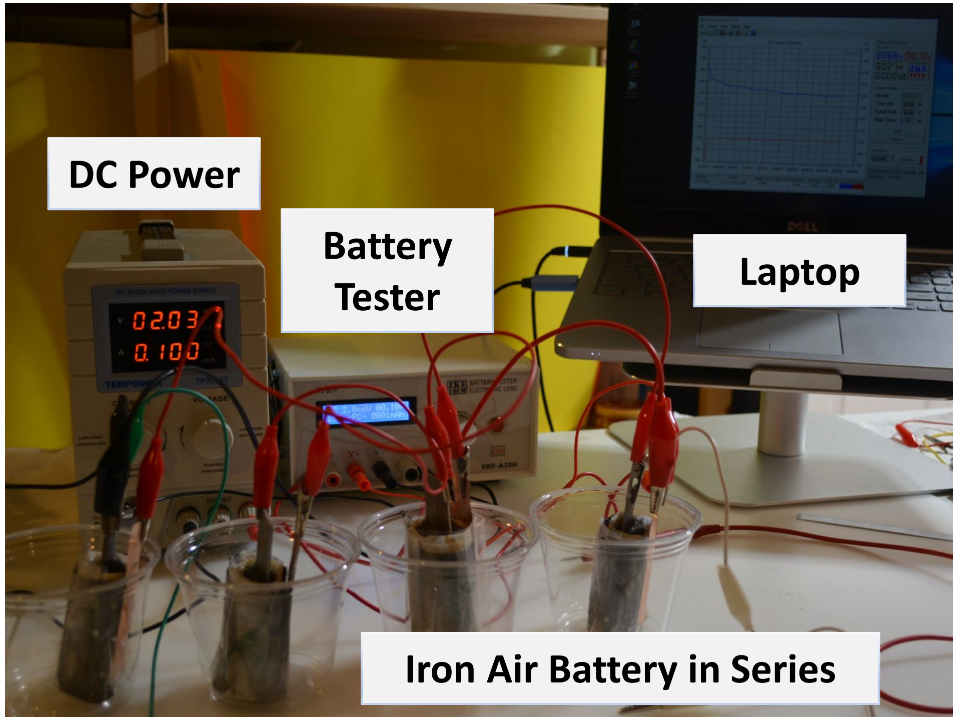
Charged Iron Air Battery protype lighting up an LED



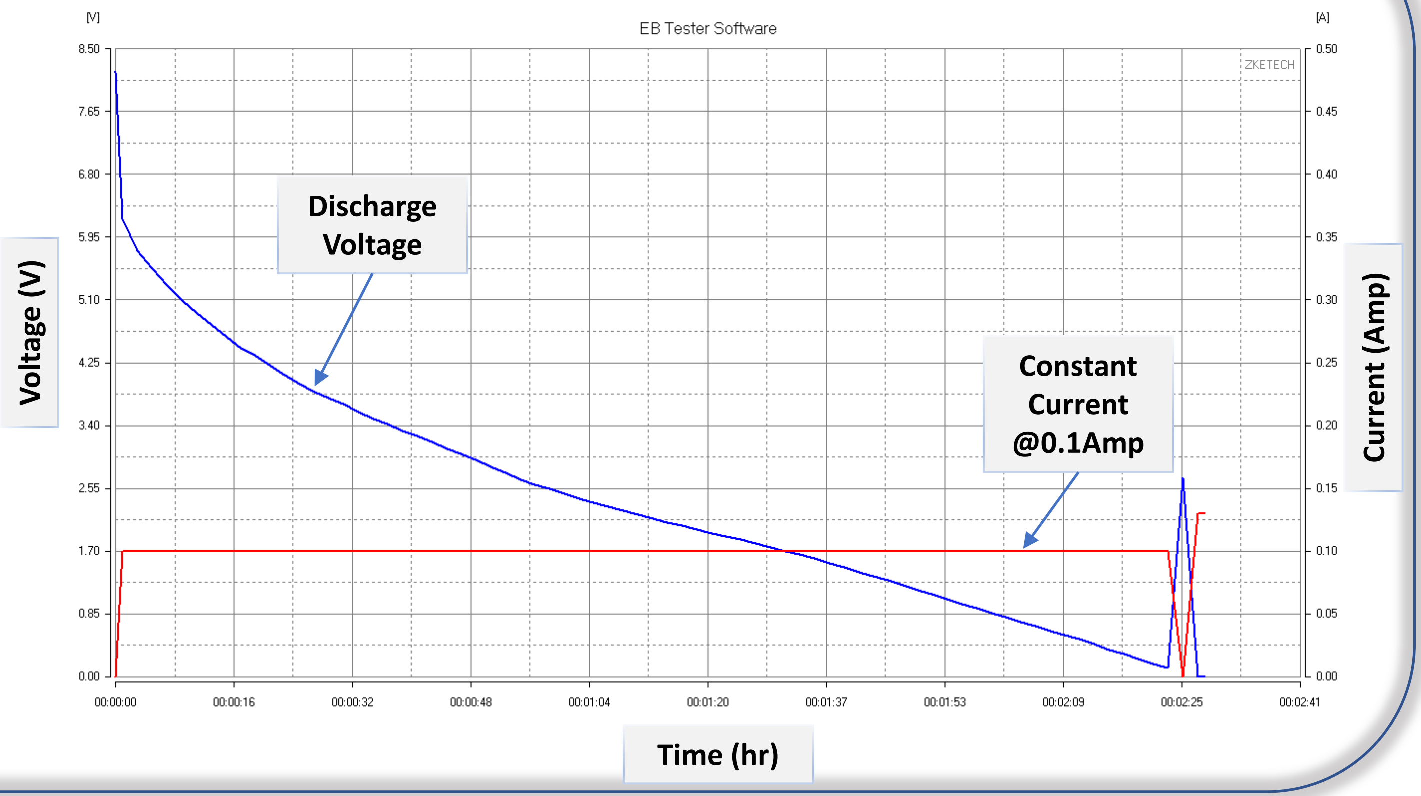
Iron-Air Battery Charge Discharge Testing

To evaluate the battery's performance, battery was charged initially for a specific time and power setting and discharged at a constant current load of 0.1 Amps. The test ended when the voltage reached 0V. Multiple tests were conducted by charging the battery at different time, voltage, and current settings, and the discharge voltage and time to discharge was measured.

Test Setup

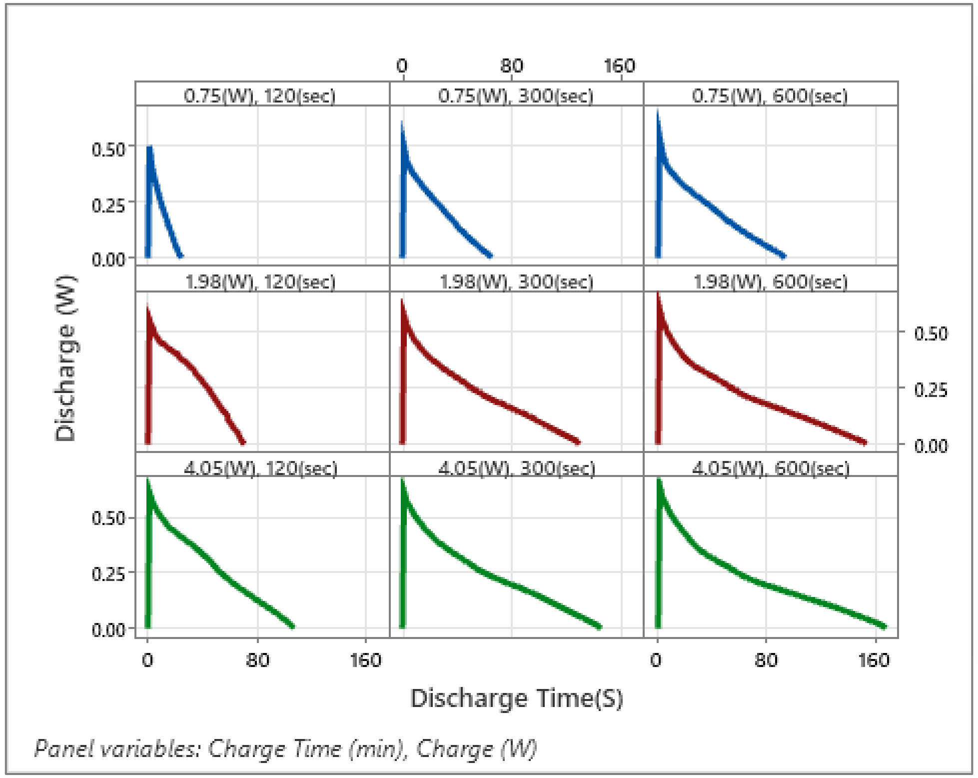


Discharge Voltage and Current Plot

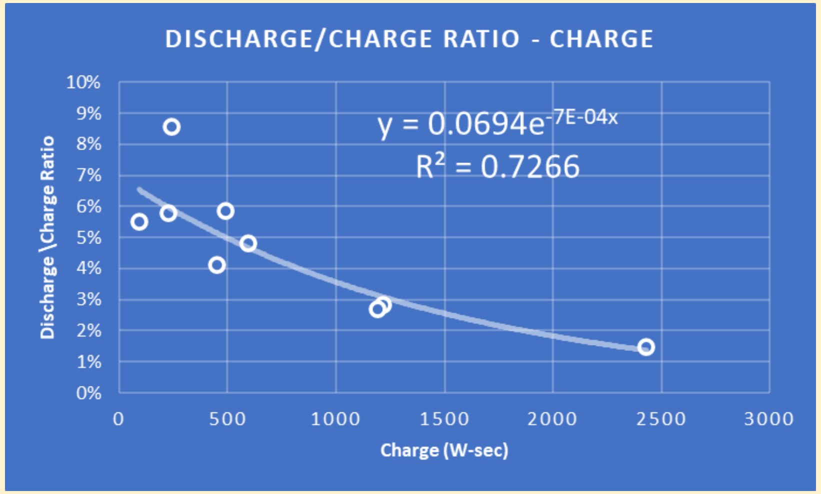


Data Processing – Iron-Air Battery Charge Discharge Testing

[Discharge Power – Time] Plot for different charge parameters of charging time and power



<u>Regression Analysis for Optimal Charging</u>

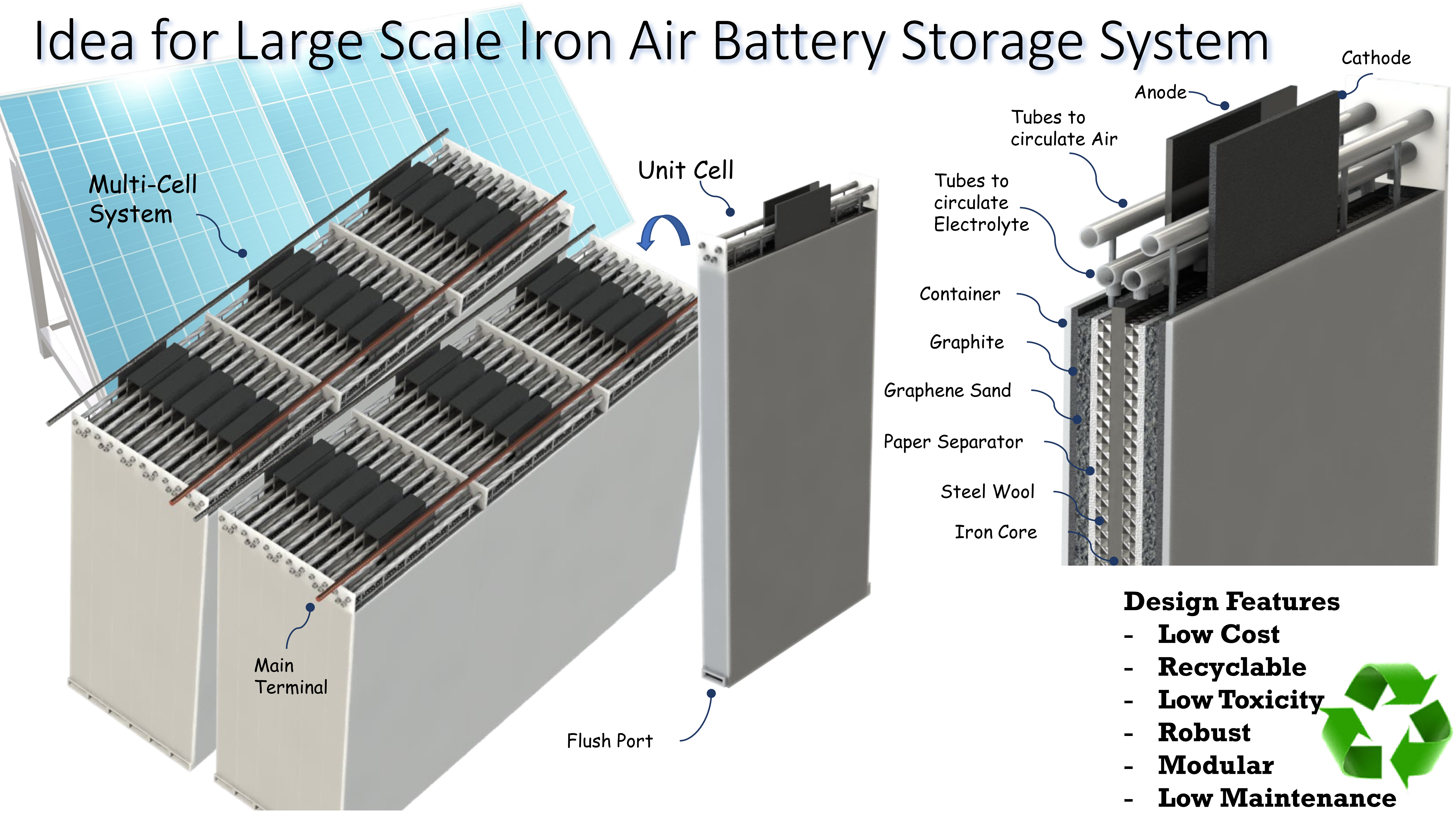


The battery was charged for different charge times of (120-300-600) secs and a charging power of (0.75-1.98-4.05) W.

The regression analysis was performed to maximize the Discharge/Charge Ratio.

The study found that charging at less than 500W-sec (0.00014 kW-hr) provides optimal charging. In other words, it is better to charge the battery for a longer time with low power. This makes the Iron-Air battery more suitable for storing energy from solar power applications.

Idea for Large Scale Iron Air Battery Storage System



Design Features

- **Low Cost**
- **Recyclable**
- **Low Toxicity**
- **Robust**
- **Modular**
- **Low Maintenance**

Summary

1. Iron has the best characteristics for metal-air battery applications in terms of low cost and environmental friendliness.
2. The combination of Iron and Graphene Sand (GS) with NaCl electrolyte produced the optimal parameters for the Iron Air Battery, exhibiting a 29.5% improvement over AC and a 91% improvement over the Graphite Plate (Control).
3. The study confirms the hypothesis that using GS as the cathode component in a metal-air battery generates a higher potential difference compared to using AC.
4. The battery is suitable for slow charging and longer duration applications such as storing energy from solar panels, according to the charge-discharge study.
5. A CAD model of a large-scale modular Iron-Air Battery storage system was created based on the best design parameters from this study.

Conclusion

1. Iron-Air batteries are a cost-effective and less toxic option for large-scale electrical energy storage.
2. While iron's weight makes it unsuitable for mobile applications, it is well-suited for stationary storage systems.
3. The experiment's results confirm the hypothesis that Graphene Sand is well-suited for this application due to its superior electrical conductivity, robustness, uniform grain size, and large surface area that facilitates the electrochemical reaction with air.