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Analysing the impact of Potassium Chloride Concentration on the Electrical behaviour of a Rolled Galvanic cell

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Abstract

This study explores how the concentration of the salt bridge electrolyte affects the performance of a rolled Zn–Cu galvanic cell. By using KCl at two concentrations of 0.1 M and 0.5 M, we observed that increased electrolyte concentration resulted with an 8.4% increase in power output. Voltage rose from 0.7669 V to 0.7839 V, current from 2.202 mA to 2.335 mA, and internal resistance decreased from 0.348 Ω to 0.336 Ω. Although the salt bridge does not participate directly in redox reactions, our findings highlight its significant role in charge transport. These results suggest that optimizing electrolyte concentration offers a simple yet effective strategy to improve cell efficiency without altering core components of the cell such as electrode material. This has implications to optimise energy use within rural regions or disaster zones. Further research should explore a broader range of concentrations and electrolyte types, with statistical validation and time-based performance analysis.

Keywords: zinc–copper battery, salt bridge, electrolyte concentration, power output

1. Introduction

A battery is a device that converts chemical energy into electrical energy through a series of redox (reduction and oxidation) reactions. The system which defines the battery is also known as an electrochemical cell[1]. It consists of both an anode and cathode, where oxidation and reduction occur respectively. In a classic galvanic cell, the electrodes are immersed in an electrolyte, which facilitates the migration of ions which is necessary to sustain the redox reactions and maintain charge neutrality[2], otherwise resulting in an imbalance of positive and negative charges. As oxidation at the anode releases electrons, these electrons travel through an external circuit toward the cathode, where they are consumed in the reduction reaction[3]. The resulting flow of electrons constitutes an electric current (DC), which can power an external load. Simultaneously, the internal movement of ions within the electrolyte completes the circuit, ensuring the ongoing operation of the cell. This complementary transport of electrons and ions is fundamental to the function of all battery systems[4].

Recently, there have been many studies which have addressed the simple, copper zinc galvanic cell due to its relatively cheap cost. A study performed by Mohammad Ali Amayreh focused on developing a low-cost, small-scale Zn-Cu galvanic cell using common materials like galvanized nails and copper wires, demonstrating that even with diluted electrolytes, the cell could generate usable voltage[5]. Meanwhile, a separate study explored the potential of rechargeable Zn-Cu batteries by introducing a cation exchange membrane to prevent copper ion crossover, a major limitation in traditional Daniell cells[26]. These innovations highlight a growing interest in sustainable and scalable battery designs using abundant materials like zinc and copper. It was found that salt concentration increasing in diluted electrolytes was found to enhance ion transport within cells7. However, these study's often focus either on large scale applications or on traditional cell geometries[8]. There remain limited experimentations of how experimenting with the ionic conductivity of a salt bridge effects the overall cell, in regard to a low cost, rolled cell[9]. While cell stacking has been examined in relation to the output in flat cells, this study focuses on the rolled configuration due to its simplicity[10]. Batteries are essential in applications ranging from household electronics to transportation and medical devices11. Zinc–copper cells offer a low-cost, non-toxic option for powering small-scale systems such as remote sensors and educational devices. Their ability to deliver efficient DC output makes them ideal for portable, low-power applications[12].

The aim of this experiment is to assess the performance of a "rolled cell" configuration by systematically varying the electrolyte concentration. Through this investigation, we seek to determine whether changes in electrolyte concentration significantly impact the electrical output of the rolled cell, providing insight into the role ionic conductivity can play in energy output.

2. Methods

2.1 Cell Construction

To construct the rolled battery, 8cm by 4cm sheets were cut out of the Copper and Zinc foil, and were compared to ensure identical shape and form. The electrolyte was diluted in the glass measuring cylinder with distilled water to determine the concentration of the electrolyte. Following the dilution of the electrolyte, two sheets of filter paper were cut to the same 8cm by 4cm dimensions of the electrodes and were set aside. Approximately ~10ml of the electrolyte was decanted into the petri dish, and the first strip of filter paper was soaked in the electrolyte until fully saturated. This filter paper soaked in electrolyte acts as both the salt bridge for the battery, ensuring electrical neutrality and a separator which inhibits the anode and cathode from touching and short circuiting. The soaked filter paper was placed in between the copper and zinc strips, and the second strip of filter paper was soaked and laid upon the stack. The total arrangement of layers being copper, separator, zinc, separator. Once constructed, the sheets were rolled into a cylindrical shape, and taped so that they wouldn't unwind, great care was taken to ensure no contact between electrodes, but also no overlap in spacer material, as this could lead to mechanical failure.

Once constructed, the positive lead of the multimeter was attached to the copper sheet, and the negative lead to the zinc sheet (Figure 1).

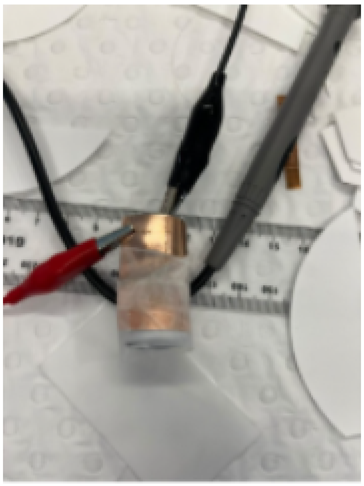

Figure 1: *Rolled cell. Soaked filter paper placed in between the copper and zinc strips, and with a second strip of filter paper was soaked and laid upon the stack. The sheets are rolled into a cylindrical shape, and taped to prevent unwinding. The positive lead of the multimeter is attached to the copper sheet, and the negative lead to the zinc sheet.*

2.2 Equipment and materials

Table 1*: List of equipment and materials used for the construction and testing of the rolled Zn–Cu galvanic cell, including measurement tools and electrolyte components.*

Copper Foil Sheet	Multimeter (UNI-T UT181A)
Zinc Foil Sheet	Alligator Clips and Wires
Filter Paper	LED lights (varied colours)
0.1M Copper (III) Sulfate solution ($CuSO_4$)	Scissors
0.1M Zinc Sulfate solution ($ZnSO_4$)	Tape
0.1M Potassium Chloride solution (KCl)	Ruler
Distilled Water	Glass Measuring Cylinder
Plastic Petri Dishes	Beakers
Metal Tweezers	

2.3 Data collection

Measurements of voltage and current were collected from rolled Zn–Cu galvanic cells constructed as described in Section 2.1. Each cell was tested under two experimental conditions: 0.1 M and 0.5 M KCl as the supporting electrolyte. The cell was allowed to rest for around 30 seconds before testing. For each cell, voltage was tested before the current of the cell, as to not draw current.

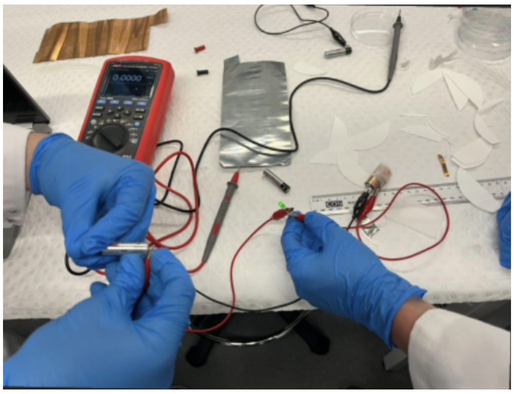

Figure 2: *Rolled Zn–Cu galvanic cell setup using KCl-soaked filter paper as a salt bridge and separator. The cell is connected to a UNI-T UT181A multimeter via alligator clips and wires, with a green LED light used to indicate current flow.*

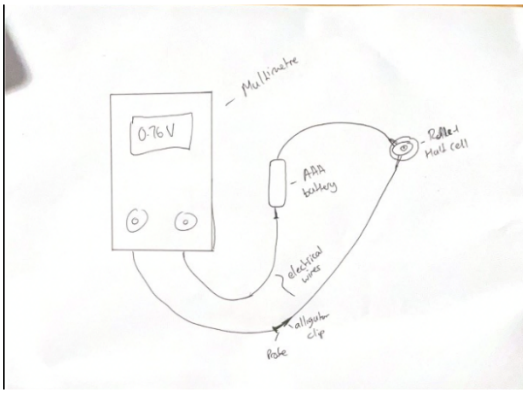

Figure 3: *Diagram of experimental setup including the multimeter, rolled cell, battery and connecting wires.*

3. Results

Results. In this study we examined how changing concentrations of the salt bridge effects the performance of a Zn – Cu rolled cell. The performance of the Zn–Cu rolled galvanic cell was assessed under two different potassium chloride (KCl) concentrations: 0.1 M and 0.5 M. Increasing the concentration of the KCl electrolyte resulted in a modest increase in both voltage and current. At 0.1 M, the average voltage recorded was 766.9 mV and the current was 2.202 mA. At 0.5 M, the voltage rose to 783.9 mV and the current to 2.335 mA, corresponding to approximate increases of 2.2% and 6%, respectively (Table 2).

3.1 Data analysis

The following formulas were used to calculate Power, resistance for calculations.

Power: =

where V and I represent Voltage and current, respectively.

Specific power = P/A(electrode)

where electrode area = 0.03 x 0.06 = 0.0018m

Resistance: =

Data trends were visualised using line plots of KCl concentration versus voltage, current, and power output.

Table 2: *Voltage and current at each KCL concentration. Measured open-circuit voltage and current output of the Zn–Cu rolled galvanic cell at two potassium chloride (KCl) concentrations (0.1 M and 0.5 M).*

CONC of KCL	**Current (mA)**	**Voltage (mV)**
.1M	2.202	0.7669
.5M	2.335	0.7839

These measurements were used to derive additional performance metrics, including power, internal resistance, and specific power. Power output increased from 1.689 mW to 1.830 mW — an 8.4% improvement — while internal resistance decreased from 0.348 Ω to 0.336 Ω. Specific power, defined relative to electrode surface area, also rose from 938.17 to 1016.89 mW/m² (Table 3).

Table 3: *Derived electrical characteristics of the Zn–Cu rolled galvanic cell at two KCl concentrations. Power, resistance, and specific power were calculated based on measured voltage and current values*

CONC of KCL	Power	Efficiency	Resistance	Specific Power:
.1M	1.689	0.697	0.348	938.17
.5M	1.830	0.713	0.336	1016.89

Trends across both current and voltage showed a slight linear increase with higher KCl concentrations (Figure 3), which contributed to the observed increase in power output (Figure 4). These results suggest that enhanced ionic conductivity in the salt bridge, driven by greater electrolyte concentration, plays a meaningful role in improving charge transport within the cell. However, given the limited range and number of data points, further testing would be needed to confirm whether this relationship is consistently linear or follows another pattern.

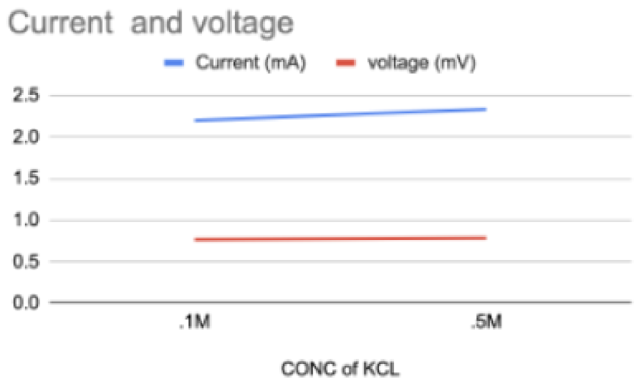

Figure 4: Current (blue, mA) and voltage (red, mV) output of a Zn–Cu rolled galvanic cell at two different KCl concentrations (0.1 M and 0.5 M). A slight increase in both parameters is observed with increased KCl concentration.

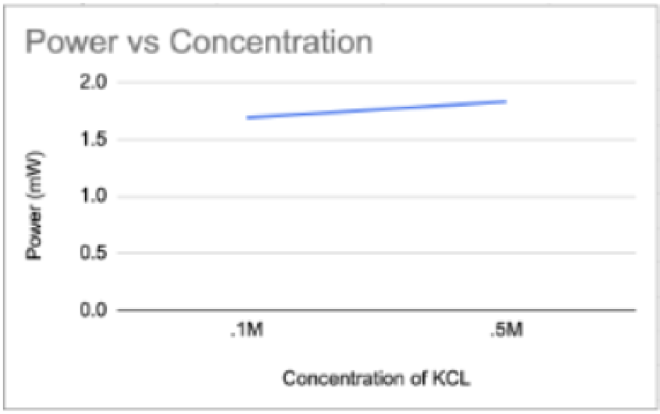

Figure 5: Power output (mW) of a Zn–Cu rolled galvanic cell as a function of potassium chloride (KCl) concentration (0.1M, 0.5M) in the electrolyte-soaked salt bridge

4. Discussion

4.1 interpretation of results and theoretical explanation

Redox half equations:

$$Zn_{(s)} \rightleftharpoons Zn^{2+}_{(aq)} + 2e^{-} \qquad \text{-0.76V (reduction)}$$

$$Cu^{2+}_{(aq)} + 2e^{-} \rightleftharpoons Cu_{(s)} \qquad \text{+0.34V (oxidation)}$$

$$Cu^{2+}_{(aq)} + Zn_{(s)} \rightleftharpoons Cu_{(s)} + Zn^{2+}_{(aq)} \qquad \text{+1.10V}$$

The standard potential of the cell $E°$ in the Nernst Equation) is calculated by subtracting the reduction from the oxidation or the anode from the cathode which as an equation is represented as

$$E^{\circ}_{(cell)} = E^{\circ}_{(cathode)} - E^{\circ}_{(anode)}$$

For this specific redox reaction, the standard potential of the cell or $E^{\circ}_{(cell)}$ is 1.10V.

With limited results no valid and reliable judgments can be made however based on the trends from the limited data increasing the concentration of electrolyte increasing both the current and the voltage produced by the half cell with the voltage and current at a KCl concentration of 0.1M being 0.7669V and 2.202A respectively, constituting slightly lower values then the ones produced by a solution of 0.5M KCl with the voltage produced being 0.7839V and the current being 2.335A. Unfortunately, this does not provide evidence for either a non-linear or linear trends. Based off theoretical results from several published papers, the gathered experimental results do not follow typical Nernstian behaviour with Nernstien's equation proposing that an increase in the electrolyte concentration should decrease the cell potential and thus the voltage[13]. This suggests that the electrolyte does not directly participate in the redox reactions of the half cell and instead only facilitates the flow of ions which is why increasing the concentration increases the voltage[14].

4.2 Comparison to Literature

A review of recent literature suggests that battery performance is not both a function of electrolyte concentration but also strongly affected by the cell’s architecture and electrode design[15]. For instance, studies have shown that modified electrode structures such as those employing 3D porous materials or increased effective surface area can improve ion transport and promote a more uniform deposition of metal ions, thereby reducing the risk of dendrite formation[16]. As noted before, while electrolyte concentration does not universally affect ion mobility in every circumstance[17], it's important to note in the context of our experiment it is the most likely cause. A recent study on flat, paper-based Zn–Cu cells demonstrated that stacking enhances voltage and stability by increasing surface are[18]. Although not focused on rolled cells, the rolled configuration may achieve similar performance gains via increased interfacial area per unit volume.

Given we have attempted to control size, shape and temperature of the electrode, our independent variable was our concentration. As the concentration increased, the observed improvement in performance suggests enhanced ionic conductivity was likely due to improved ion mobility within the salt bridge, which facilitates more efficient charge transport between electrodes[19].

4.3 Real world implications

Although this study was limited in scope due to a limited examination of the effect of concentration of electrolyte had on the performance of a rolled cell, the findings have a broader implication outside of this context. It implies the importance of optimising ionic conductivity to improve the outputs of galvanic cells[20]. This highlights how minor improvements to how a battery is constructed can have noticeable changes in energy delivery. On a larger industrial scale, this could lead to quantifiable gains in energy delivery, increasing the more efficient use of resources[21].

A zinc copper rolled galvanic cell is the definition of simplicity. As such, the results are relevant in scenarios where cost and simplicity are prioritised[22]. Single-use detectors such as environmental monitors often rely on minimalistic battery designs, where opportunities for electrical optimisation such as reducing internal resistance are limited due to size and cost[23]. Low cost and effective adjustments to the salt bridge which can boost performance are often required.

In a boarder scope, it suggests the feasibility of using low toxic systems such as Zn – Cu galvanic cells in portable energy systems[24]. Such an application is often overlooked in conventional battery research, given the increasing need to power to operate, however, to provide this requires materials which are accessible but also operate at cost efficiency. Being able to optimise a low costs system is helpful, especially if used in application such as energy kits for schools, rural communities or in disaster zone. This could include LED lanterns, water quality assessors, and devices which operate under low current loads and doe does not require a complex recharging infrastructure[25].

4.4 Limitations

While the experimental outcomes provided insight into how electrolyte concentration effected the performance of a galvanic cell, many factors restrict the interpretability and generalisation of our results. The study was limited to two, non-repeated concentrations of KCL (0.1M, 0.5M) which restricts the extrapolation of the graph beyond the two given points. It provides no indication of outliers within the dataset due to the absence of either a linear or non-linear trend. This was also due to no repetitions at each concentration, resulting in the inability to perform any statistical measures to mitigate the effects of potential outliers. This absence of repetition also introduces uncertainty surrounding replication of produced results, which is very important if used for research purpose. Variation of Seperator absorption of electrolyte, inconsistencies of material surface and tightness of roll could all effect performance, especially at mV and mA scales, where small alterations can result in significant percentage deviations26. This study was also limited to one type of electrolyte, as we did not explore different electrolyte types.

Furthermore, during experimental preparation, many issues arose due to time constraints and a lack of underlying knowledge before beginning the experiment. This led to a large portion of the allocated time being spent experimenting with getting a working cell battery having many failed attempts due to things such as touching anode and cathode as well as incorrect placement of the voltmeter cables, breaking the circuit. Ultimately, this caused our results to be incomplete, only being able to measure the voltage and current caused by the 0.5M and 0.1M solutions of KCl compared to our intended goal of measuring voltage and current for 0.1, 0.2, 0.3, 0.4 and 0.5 molar concentrations of KCl which would have given us a better range and a deeper understanding of how the electrolyte concentration can affect the voltage and current of a rolled half-cell.

4.5 Future improvements and consideration

To solve this, having both more gradual increments between concentration and more concentrations would be necessary to determine whether the exists an optimal concentration beyond or between 0.5M, and what sort of overall trend we can observe. Future studies should also include replicate trials for each condition to assess the variability between each build of battery.

Future research should focus on expanding the range of electrolytes tested and investigating the performance of the cell over continuous and repeated usages. Additionally, it may be important to investigate varying cell geometries such as stacked and flat cells. This modification will enhance our understanding of how simple modifications can enhance galvanic cell performance for applied contexts.

5. Conclusion

This study addresses how varying concentrations of KCl of a copper zinc rolled cell effects its electrical performance. We noted that an increase in concentration from 0.1M to 0.5M correlated to a noticeable increase in power output (8%), with a marginal decrease in resistance and increase in both voltage and current. Although we had a limited set of data, this indicated that increasing the concentration plays a noticeable role in ion transport, thus affecting current of the cell more than the voltage.

These findings have broader implications. It captures the importance of electrolyte optimisation as a method of improving cell performance; one which is both low cost and low in complexity. It does not require changing of core components of a battery, and thus, such a method for cell optimisation can be applied in contexts where both simplicity and cost are important factors.

However, this study's scope was limited by lack of tested concentrations and lack of testing over time period. This study failed to gauge trends between concentration and its outputs. These limitations suggest that future work should expand the range and granularity of electrolyte concentrations, investigate alternative salts, and include long-term performance assessments to evaluate time-based stability. Repeated trials and statistical analysis will be essential to validate trends and ensure reproducibility.

This work captures the potential for small, but impactful changes to cell design, such as salt bridge optimisation, to allows cells to be more cost effective yet effective in relevant fields.

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