

DESIGN AND CONSTRUCTION OF A MEMBRANELESS ZINC-CHLORINE ELECTRIC CELL

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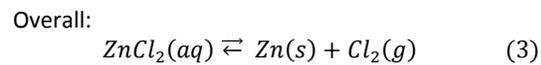
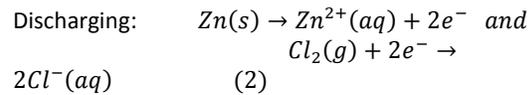
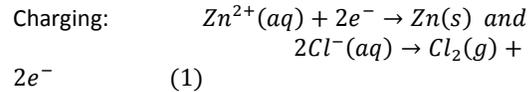
Abstract - Zinc-Chlorine battery received huge attention from researchers in the 1970s and 1980s due to its simplicity and low cost of basic materials. But the additional materials in the existing designs which are meant to enable the battery to operate with a reasonable level of efficiency; have considerably increased the complexity and cost of the battery. This led to a loss of interest by researchers as literature revealed that there has not been researched work in this battery for many years now. We hereby present a new and simple design for Zinc-Chlorine battery that does not use ion exchange membrane, pump, cooler, and heater. The designed electric cell was constructed and tested. It produced an open-circuit voltage of 2.14 V after charging for 2 hours with a dc source voltage of 5.0 V. A maximum current of about 12 mA/cm² was realized from the electric cell.

Keywords: Zinc-Chlorine, Battery, Ion exchange membrane, electric cell

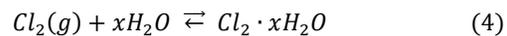
1. INTRODUCTION

The world has come to grips with the fact that there is no alternative to the use of renewable energy if it is to overcome her problem of global warming and achieve sustainable development for all human race. But the problem of the intermittence nature of most of the available renewable energies like solar energy, wind energy, and tidal energy has limited their wide spread adoption all over the World. Although the problem of intermittence of renewable energies as it affects their utilization as reliable power generation sources has to a large extent been solved by the development of batteries and other energy storage systems, the high cost of these batteries and their low life span has made the problem to appear unsolved.

Researchers in different parts of the World are now working to develop low cost and long-lasting energy storage devices. One of the batteries that are believed to fall into this category is the zinc-chlorine battery. The zinc-chlorine battery is an electroplating type of battery which is realized by the use of zinc chloride as an electrolyte in a sealed casing with two passive electrodes like graphite plates. It is a rechargeable battery. The charging and discharging chemical reaction equations of the battery are given in equations 1 to 3.



It operates by the principle of electrolysis during the charging cycle made possible by the current induced oxidation at the cathode (positive battery electrode) and reduction at the anode (negative battery electrode). This brings about the deposition of zinc on the anode and evolution of chlorine at the cathode. During the discharge cycle, reverse reactions occur at the two electrodes: zinc is oxidized at the anode while chlorine is reduced at the cathode. This causes electrons to flow from the anode to the cathode via an external load. The existing zinc-chlorine battery designs are flow cells, as can be seen in the literatures: [1][2][3][4]. They use dense graphite anode and porous graphite cathode. During charging, the ZnCl₂ solution (with concentration of 2 or 3M) is electrolyzed between the two electrodes. Metallic zinc is plated on the dense graphite electrode while chlorine is evolved at the porous graphite electrode. The evolved chlorine is channeled to a reservoir/container where it is mixed with water and cooled to form the solid crystalline solid called chlorine hydrate (Cl₂ · xH₂O). The equation of this chemical reaction between chlorine and water is given in equation 4.



where $x \approx 5.9$

During the discharge cycle, the stored chlorine hydrate is heated to release chlorine. The released chlorine is now mixed with a 0.5M solution of zinc chloride and pumped through the porous electrode where each chlorine atom accepts one electron to become the chloride ion (Cl⁻). At the same time, the metallic zinc at the anode is oxidized, with each atom releasing two electrons to become zinc ion (Zn²⁺). The released electrons flow through an external load to the cathode where they reduce two atoms of chlorine. The EDA design produced a maximum current of 50 mA/cm² at a flow rate of 2 ml · min⁻¹cm⁻² [1].

Mitra constructed and tested an alternative design for zinc-chlorine flow battery which eliminated the use of a pumping device. The cell was instead designed to use the pressure generated in the cell as a result of chlorine gas evolution, to pump the chlorine gas to the container where the hydrate is formed. This design produced a maximum current of 10 mA/cm^2 at a flow rate of about $4 \text{ ml} \cdot \text{min}^{-1} \text{cm}^{-2}$ [3].

One of the problems associated with zinc-chlorine battery is the fear of chlorine leakage as chlorine is a toxic gas. If chlorine gas leaks and a high dose of it is inhaled, it can be fatal [5]. Acute chlorine exposure can cause health problems like violent cough, nausea, vomiting, headache, chest pain, abdominal discomfort, corneal burns, sore throat, and hemoptysis [6].

2. MATERIALS AND METHODS

The materials used for the cell include dense graphite electrodes, zinc chloride, plastic container, and copper connectors. The design has dense graphite cathode and anode plates of dimension $50 \times 100 \times 5 \text{ mm}$ and $50 \times 50 \times 5 \text{ mm}$, respectively. The electrodes were arranged vertically with the cathode above the anode to ensure that the evolved chlorine gas moves straight up to the free space above the electrolyte solution level without first coming in contact with the metallic zinc plated on the anode. The lower end of the cathode and the upper end of the anode were covered with thin plastic caps of dimension $60 \times 15 \text{ mm}$ to prevent zinc dendrite from touching the cathode and shorting the cell. Insulated copper wires were used to connect the electrodes to the cell terminal connectors.

After the preparation of the different parts and the electrolyte solution, the plastic container was filled to the brim with a 0.2 M ZnCl_2 solution. The electrodes which were connected to the terminals (fixed to the plastic container cover) via copper wires were now introduced into the electrolyte bearing container as the container was covered. The container cover was sealed with silicone gum. A tiny opening was made on the lower half of the container to release some quantity of the electrolyte and ensure that the space above the electrolyte solution is free of air. The electrolyte solution was discharged through the created hole until its level falls to the middle of the cathode, to leave half of the cathode in the free space and half in the electrolyte. At this point, the discharge opening was sealed with silicone gum. The volume of the 0.2 M ZnCl_2 electrolyte solution used was 680 ml . The designed cell's parts arrangement and connections is shown in Figure 1 while a picture of the constructed cell is given in Figure 2.

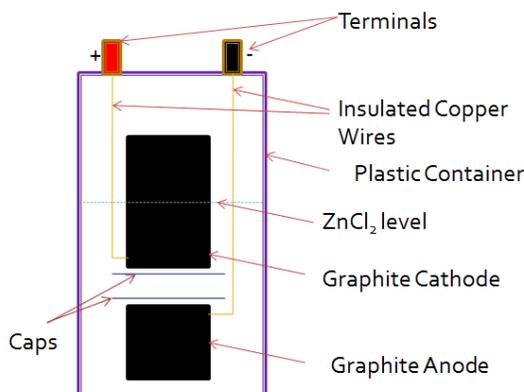


Fig. 1. Schematic diagram of the designed zinc-chlorine cell



Fig. 2. Picture of the constructed zinc-chlorine cell

The constructed electric cell was charged for 2 hours with a dc source voltage of 5 V and discharged through a load resistance of 42Ω . The results were recorded. It was charged again for 2 hours using the same source voltage of 5 V . After charging, the cell's open circuit voltage was measured and recorded. The discharge current test at five different load resistance values of 1Ω , 2Ω , 3Ω , 4Ω and 5Ω was carried out and the results tabulated. The cell was charged for 5 minutes after each test to restore its previous state of charge.

3. RESULTS AND DISCUSSION

The charging, discharging and maximum current test results are presented in the graphs of Figure 3, 4 and 5.

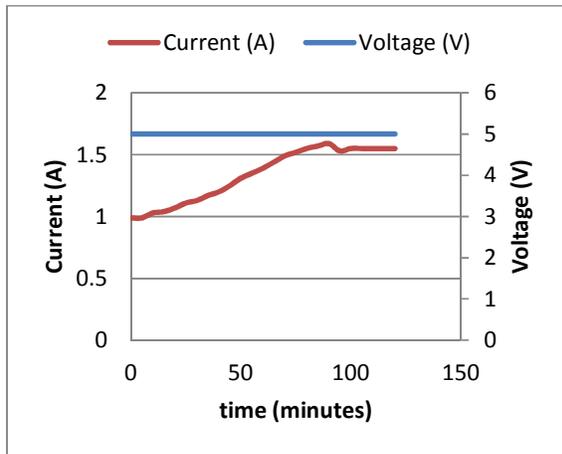


Fig. 3. Graph of charging voltage and current against time for the zinc-chlorine battery

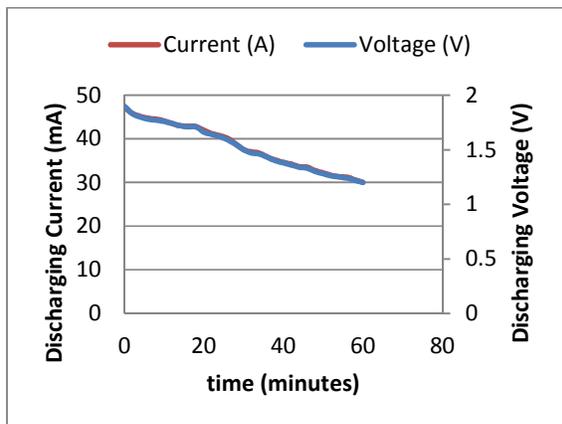


Fig. 4. Graph of discharging voltage and current against time for the zinc-chlorine battery

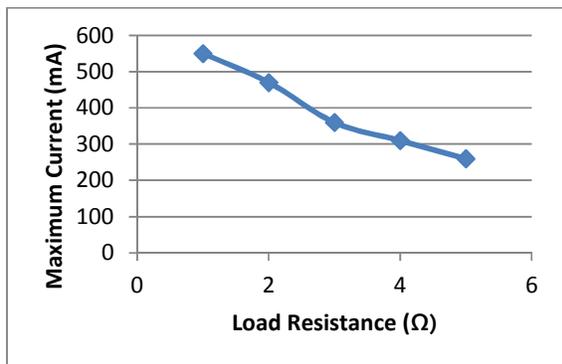


Fig. 5. Graph of Maximum Current against Load Resistance for the zinc-chlorine battery

From the graph of Figure 3, it can be seen that the charging current was increasing with time until full charge. This is suspected to be caused by the electrolyte solution becoming more acidic with time due to the recombination of the evolved chlorine and hydrogen.

From the maximum current test graph of Figure 5, the graph line was extrapolated with the help of excel to obtain the maximum current at zero load resistance, I_{sc} as 612 mA. With this, the maximum current per unit surface area of the electrode was calculated as 12 mA/cm². This compares favorably with literature as the Energy Development Associates (EDA) flow cell design produced a maximum current of 50 mA/cm² [1] and the Mitra flow cell design produced a maximum current of 10 mA/cm² [3]. While these other cells used high electrolyte concentrations of between 2 M and 3 M ZnCl₂ solution, we used only 0.2 M ZnCl₂ solution in this our first design to avoid explosion due to the evolved gas pressure. This makes us believe that when this design is improved upon and between 2 M and 3 M ZnCl₂ solution used, this non-flow zinc-chlorine cell can outperform the flow cell counterpart.

4. CONCLUSION AND RECOMMENDATION

A membraneless Zinc-Chlorine Cell was constructed and tested. An open-circuit voltage of 2.14 V was realized. The constructed electric cell produced a maximum current of about 12 mA/cm² which compared favorably with literature.

It was observed that the cell has a high self-discharge rate as it was found to be discharged to an open circuit voltage of 1.2 V after 12 hours without an external load.

We therefore recommend that new designs of Zinc-Chlorine Cell that will ensure that the evolved hydrogen does not react with chlorine should be made, as we believe that this will help reduce the high self-discharge rate. Other ways of separating the two electrode sections using different designs or materials that cost less than the existing proton exchange membrane should be explored in order to realize a low cost and long-lasting zinc-chlorine battery.

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