Optimization of parameters and fabrication of Al-air batteries with economically feasible materials

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Abstract. Design and fabrication of Al-air battery were done in this present work with economically viable raw materials. Optimization of anode material, catalyst concentration, current density and electrolyte concentration were carried out. Al 5083 as an anode material results in longer discharge time than Al 7075 and Al 6061 anode used in this study. Catalyst loading of 5% TiCl$_3$, current density of 5 mA cm$^{-2}$ and 10% of NaCl electrolyte were optimized. A single battery cell is fabricated using Al 5083 as an anode, air cathode which consists of graphite, paint as a binder with 5% TiCl$_3$ as a catalyst and 10% NaCl as the electrolyte. The single cell exhibits voltage of about 0.8 V with 20 mA h$^{-1}$ current capacity. The lifecycle of the fabricated battery is tested for four consecutive cycles which demonstrates almost similar shape in the charging and discharging curves representing better stability of the fabricated battery.

1. Introduction

In the current scenario, one of the problem in the society that needs to be addressed is the energy crisis. With the depletion of fossil fuel resources and deteriorating renewable energy sources, the quest for an alternative energy has become the spotlight in research [1]. Since early 1990’s lithium-ion batteries (LIBs) has been the most widely employed portable electronic devices and also used in hybrid electric vehicles owing to their high energy density and low self-discharge [2]. Metal-air batteries have higher capacity and energy density than other devices. In specific, Al-air battery is considered as the novel energy resource compared to the expensive and highly active Li in LIBs. Al-air battery is a type of metal-air battery with an air cathode, Al or Al alloy as the anode and liquid-based electrolyte. The use of air cathode will enhance the energy density. Air cathode assists in carrying oxygen and interact with the catalyst producing energy density that exceeds other commercial rechargeable batteries [1, 3].

The performance of battery depends on the nature of anode, cathode and electrolytes used. Aluminium as an anode is one of promising material owing to its abundance in nature, low cost and ease in processing with high energy capacity. Another abundance material in nature especially in Indonesia is graphite, one form of carbon [4]. Researcher use graphite as cathode material for metal-air battery by integration with catalyst, to enhance the electronic conductivity. The most widely used electrolytes for aluminium battery are NaCl, NaOH and KOH or a combination between them [5]. In this study, NaCl has been selected as an electrolyte based on the abundance of the salt in the sea and hence battery could be used for marine applications. Therefore, the present work employs aluminium as an anode, air cathode (integrated with graphite, paint and TiCl$_3$) and NaCl as an electrolyte for the fabrication of metal-air battery.
The main objective of this present work is to fabricate the Al-air battery with the low-cost materials and to optimize the parameters to obtain an enhanced battery performance. The catalyst used is graphite along with TiCl$_3$, graphite is obtained from the natural resources from Kalimantan region in Indonesia and was used as received. Graphite and graphite-based materials have been used as an electrode material in LIBs, supercapacitor and fuel cells [6]. The presence of graphite is expected to improve the current capacity of the battery owing to its high electrical conductivity. The design, fabrication, and optimization of parameters such as current density, anode material and electrolyte concentration will be discussed and investigated.

2. Experimental Procedure

2.1. Materials

The materials used for the fabrication of Al-air battery are aluminium 5083 (aluminium alloy with Mg and traces of Mn and Cr), air cathode with naturally available graphite as carbon source, black paint (maxwille) as binder, 5% TiCl$_3$ as catalyst, nickel substrate (in the form of a net) with dimension of 300 as current collectors and 10% NaCl as electrolyte concentration, distilled water as solvent for electrolyte and acrylic for battery fabrication. Different aluminium alloys such as Al 6061, Al 7075 which has a varying percent of metals such as Mg, Mn and Cr are tested as anode materials.

2.2. Fabrication of Al-air battery

The methodology involved in the fabrication of Al-air battery involves three stages: Fabrication of battery cell, battery characterization and battery performance analysis. Parameters such as Al alloy anode, current density, catalyst concentration and electrolyte concentration were optimized. With the optimized results the life cycle of the battery was evaluated. The anode is comprised of Al 5083 with a thickness of about 2.5 mm, length 6 cm, and width 5 cm. The steps involved in cathode fabrication are the preparation of cathode active material, manual deposition on Ni substrate and drying. The cathode active material consisting of air cathode (air from the surrounding) and the cathode active material i.e. graphite and paint in the ratio 3:1, it is mixed manually with 5% TiCl$_3$ catalyst. The cathode active material is manually cast on the Ni substrate i.e. Ni mesh 300 and dried at 80°C for 24 h. The electrolyte 10% NaCl solution was added onto the separator (membrane sheet) using a dropper.

Al 5083 anode is placed at both the end of the cell in between that Ni current collector coated with the cathode active material is placed. The separator i.e. sheet of membrane is placed in between the anode and the current collector (Ni mesh). The arrangement of the battery components anode, separator, cathode, net substrate and electrolyte is illustrated in figure 1.

![Figure 1. Fabrication of Al-air battery components.](image)

2.3. Characterization

The constant current discharge was characterized by using Mayuno DC electric load with the current load of 5 mA cm$^{-2}$, 10 mA cm$^{-2}$, 20 mA cm$^{-2}$ and 30 mA cm$^{-2}$. The current capacity of the battery was calculated by using the equation $C = I \times t$, where $C$ is battery capacity (Ah), $I$ is current (A) and $t$ is time (s) [4]. The life cycle of the battery was obtained by releasing battery cell voltage using a current density of 5 mA cm$^{-2}$, then after the zero voltage, then releasing current load until the initial battery
voltage is achieved. The life cycle of the battery was tested using the optimized parameters for four consecutive cycles to analyse the cyclic stability.

3. Results and Discussion

3.1. Effect of anode material

The electrode materials in Al-air battery has a significant role in determining the performance of battery [5, 7]. To study this three different Al alloys were selected as anode materials such as Al 5083, Al 6061, and Al 7075. The potential selected to optimize the anode material is from 0.0 to 0.8 V and 10% NaCl was used as the electrolyte concentration. The discharge behaviour of different anode materials is shown in figure 2, Al 5083 as anode material exhibit a decrease in voltage initially, then the voltage remains constant up to 1500 s of time. In the case of Al 7075, the voltage dropped abruptly and slowly discharged up to 800 s, the decrease in the voltage may be due to the internal resistance of the battery [3]. The performance of Al 6061 was not uniform and the initial potential was low compared to the other anode materials.

![Figure 2](image)

**Figure 2.** Effect of different anode materials on the discharge performance of the Al-air battery.

3.2. Effect of current density

The discharge behaviour of metal-air battery with Al 5083 as an anode with different current densities such as 5, 10, 20 and 30 mA cm\(^{-2}\) was studied. The operating voltage declined in the early stage of discharging and then reached a constant value for 5 and 20 mA cm\(^{-2}\) current density as depicted in figure 3. Whereas current density of 30 mA cm\(^{-2}\) has the shortest discharge time followed by 10 mA cm\(^{-2}\) with a discharge time of 600 s. The current density of 5 mA cm\(^{-2}\) is optimized for further studies since it exhibits the highest voltage with a stabilized discharge rate.

3.3. Effect of catalyst loading

Figure 4 shows the effect of the catalyst on the performance of Al-air battery with discharge current density of 5 mA cm\(^{-2}\). The air cathode consists of graphite with paint as a binder in the ratio 3:1 with TiCl\(_3\) as a catalyst which is stirred magnetically for 30 min followed by manual casting of the material on the Al anode. The battery was fabricated with Al 5083 as an anode, 10% NaCl as electrolyte and air cathode without TiCl\(_3\), with 5% and 10% TiCl\(_3\) respectively. The metal catalyst plays a crucial role by providing the necessary active sites for the reaction, whereas graphite improves the electronic conduction pathways and retains it during battery operation. It can be analysed from the figure 4 that 5% TiCl\(_3\) addition has a prolonged discharge capacity than 10% TiCl\(_3\), without a catalyst, the system exhibits a very low discharge capacity and is unstable.
Figure 3. Effect of different current density and its discharge curve for the Al-air battery.

Figure 4. Effect of catalyst loading for the fabricated Al-air battery single cell.

3.4. Effect of electrolyte concentration
The voltage-time curve for the fabricated Al-air battery with different electrolyte concentration is shown in figure 5. Electrolyte concentration was varied in the range of 5-15%. When the concentration of NaCl is 10%, which is close to the saline water concentration, it can be predicted that the conductivity of the electrolyte is better leading to a higher discharge time. When the electrolyte concentration is increased to 15%, the electrolyte marginally inhibits the flow of electrons leading to self-discharging with a gradual decrease in voltage [8, 9].
3.5. Lifecycle analysis for the fabricated single cell

Lifecycle analysis of battery is vital to demonstrate the stability of the electrode material developed, in the present case the material exhibits a better stability and can be employed for real-time applications. The shape of the charging-discharging curves obtained was uniform and the current capacity was calculated to be 20 mAh\(^{-1}\). Al 5083 was used as an anode with a current density of 5 mA cm\(^{-2}\), 10% NaCl as electrolyte concentration and catalyst loading of about 5% TiCl\(_3\).

This work can be extended by stacking many single cells in series and study its performance analysis. The battery developed with the economic materials can be effectively used in marine applications for power backup.
4. Conclusion
The process parameters such as an electrode, catalyst concentration, electrolyte concentration, current
density influences the performance of Al-air battery. Al 5083 as electrode material exhibits higher
discharge time for a single cell fabricated compared to Al 6061 and Al 7075. Presence of graphite in
the air cathode along with TiCl₃ as catalyst improves the discharge performance of Al-air battery. The
stability of the battery was tested by performing lifecycle analysis for four consecutive cycles with a
discharge time of 7h and current capacity of 20 mAh⁻¹. The increased current capacity is owing to the
presence of highly conducting graphite in the cathode active material. It provides the necessary
conduction pathway for the redox reaction to occur and enhances the current capacity of the fabricated
battery.

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