Feasibility study of polypropylene-based aluminium-air battery

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Abstract. The global economy depend on the fossil fuel to meet the daily power demands, ranging from electricity supply to transportation. It is estimated that more than 60% of the world power generation is depending on the fossil fuel. Therefore, the search for clean energy to replace fossil fuel has become the current research trend in the world. Metal-air battery featuring high energy density is projected as one of the promising candidate for the next generation energy storage system. There are various type of metal-air batteries available in the literature such as lithium-air battery, magnesium-air battery, silicon-air battery, aluminium-air battery, zinc-air battery, etc. However, aluminium-air batteries with its low cost and high energy density of 4300 Wh/kg show a great potential for future energy storage applications. In this study, the performance of the aluminium-air battery with polypropylene separator is being investigated. The battery is filled with 1M of Potassium Hydroxide electrolyte. Anode of the battery is made of Aluminium foil and carbon fibre cloth is used as cathode of the battery. The experimental results shown that, the maximum capacity of 23 mAh can be achieved using 6.25 mA of constant current discharge. By connecting the batteries in series, it is sufficient to power on a light-emitting diodes and charging a mobile phone.

Keywords: Aluminium-air battery, Energy storage system, Separator, Polypropylene, Electrochemical

1. Introduction

Every country in the world depends on energy to generate electricity, heating, cooling and transportation. Therefore, global energy consumption increases directly proportional towards the growth of the country and it is expected to grow at the rate of 27% from 2017 to 2040 [1]. Most of the countries depend on the traditional energy source - fossil fuel due to cheaper price compared to other resources. However, burning fossil fuel will release harmful emission to the environment. Hence, using renewable energy to replace the fossil fuel is most feasible solution to create greener environment.
Most of the electrical vehicles use lithium-ion batteries as the primary energy source to generate electricity and move the vehicles. Lithium-ion battery has an energy density of 705 Wh/L and power density of 10,000 W/L with rechargeable function [2,3]. However, lithium-ion battery has its own disadvantages such as prone to thermal runaway, narrow operating temperature range and short life span [4]. Hence, an extensive research has been conducted to search for the other type of energy sources to replace Lithium-ion battery. In a recent study, the high energy density and low cost metal-air battery has been identified as a preferable choice to replace lithium-ion battery. The metal-air battery mainly consists of three major components which are anode, cathode and electrolyte. Separator is used to prevent short circuit and allow the crossover of hydroxide ion for electrochemical reaction [5]. This also allows the aluminium-air battery to be fabricated in more compact in size.

Paper-based aluminium-air battery is considered to be the major reformation in metal-air battery due to its properties [6]. Paper possesses lightweight properties, cheap and easy to recycle which make it more environmentally friendly [7]. Besides, paper-based separator able to overcome the self-corrosion of aluminium which allowed use of low purity aluminium anode in battery fabrication and reduce the metal-air cost [8]. However, paper-based gives a negative impact on the power output due to its porosity to prevent the diffusion of OH⁻ and causing lack of OH⁻ supply inside the battery. In this study, the used polypropylene of as an aluminium-air battery separator is investigated to replace the conventional paper-based aluminium-air battery. The performance of polypropylene based aluminium-air battery is characterized with 1M of the Potassium Hydroxide (KOH) electrolyte using 6.25 mA, 12.50 mA and 25.00 mA of discharge current.

2. Research Methodology

2.1. Electrochemical reaction

The main component in aluminium-air battery is aluminium electrode, carbon electrode and electrolyte. Electrolyte acts as hydroxyl ion supply for aluminium electrode to react and producing electrons through Al(OH)₄⁻ and flows through the air cathode which then reacts to generated OH⁻ continuously to produce current. The electrochemical reactions of the aluminium-air battery cell is stated in Eq. 1 to Eq. 3.

Electrochemical reaction at cathode:

\[ 0.5O_2 + H_2O + 2e^- \rightarrow 2OH^- \]  \hspace{1cm} (1)

Electrochemical reaction at anode:

\[ Al \rightarrow Al^{3+} + 3e^- \]
\[ Al^{3+} + 4OH^- \rightarrow Al(OH)_4^- \]  \hspace{1cm} (2)

Overall electrochemical reaction:

\[ 4Al + 3O_2 + 6H_2O \rightarrow 4Al(OH)_3 \]  \hspace{1cm} (3)

2.2. Design of the aluminium-air battery test rig

Fig.1 illustrated the design of the battery test rig. The battery test rig consists of four major parts which are acrylic plate used as the body of the battery, anode of the battery is made of Aluminium foil and cathode of the battery is made of carbon fibre cloth. The length and width of the battery is about 5 cm × 5 cm. Polypropylene absorbent pad is used as the separator of the battery to separate the anode and cathode.
2.3. Experimental analysis

Potassium Hydroxide (KOH) is used as electrolyte in this study with concentration of 1M. The preparation of the KOH solution was prepared using 56.1 g solid potassium hydroxide and diluted in 1 litre of deionized water. Polypropylene absorbent with the porosity 22.4% is soaked in the KOH solution acted as separator to provide an effective transfer medium for the hydroxide ion crossover and prevent short-circuit. The performance of the aluminium-air battery is characterized by discharging the battery under constant current supply using electrochemical workstation (ZIVE SP1). Three different magnitude of discharge currents are used which are 6.25 mA, 12.50 mA and 25.00 mA.

3. Results and Discussion

The performance of the aluminium-air battery can be determined using the constant discharge current. In this study, three different constant current loads were used which is 6.25 mA, 12.50 mA and 25.00 mA. The aluminium-air battery was tested until the voltage of the battery turns 0 V. Fig. 2 shows the discharge performance of the aluminium-air battery with 1M of Potassium Hydroxide. The discharging time of the battery with 6.25 mA is the longest as compared to 12.50 mA and 25.00 mA. This is because the low discharge current load will reduce the corrosion rate of the aluminium electrode compared to high current load.

The initial voltage during 6.25 mA of constant current discharge is about 1.3 V and gradually reduced and stabilized at 1.0 V. On the other hand, the initial voltage during 12.50 mA of constant current discharge is about 1.0 V and gradually reduced and stabilized at 0.8 V. At 25.00 mA of constant current discharge, the initial voltage is 0.8 V and gradually reduced and stabilized at about 0.5 V. The capacity obtained using 6.25 mA, 12.50 mA and 25.00 mA of constant current discharge is about 23 mAh, 11 mAh and 8.5 mAh, respectively. Using small current load will provide larger voltage and longer discharge performance compared to high current loads. This is due to higher reduction rate of the aluminium anode at high current.

![Figure 1. Aluminium-air battery assembly.](image)

![Figure 2. Discharge performance of the aluminium-air battery with 1M of KOH.](image)
4. Conclusion
The feasibility of using polypropylene as a separator for the aluminium-air battery has been investigated with different magnitude of discharge currents. The discharge test showed that the aluminium-air battery with polypropylene based separator able to generate about 1.0 V with 6.25 mA of constant current discharge with maximum capacity of 23 mAh. In the next phase of research work, the effect of different molarity of Potassium Hydroxide will be investigated. In summary, it is proved that polypropylene based aluminium-air battery is a potential candidate for the energy storage system in the electric vehicles and other electronic devices.

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