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# Design and testing of an air battery

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**Abstract.** In this paper, an air battery is studied, discussed, implemented and deployed; the potential applications of air batteries in general are also discussed in detail. An electrochemical battery runs out when all the chemicals inside have finished the current-releasing chemical reactions. In this work, an air battery system is designed and studied using Sodium Chloride (NaCl) and Caustic Potash (KOH) electrolytic solution. The battery life of the designed air battery system is studied in terms of voltage capacity for a period of 4 weeks and 4 days (750 hours) for two air batteries connected in series. As the electrolytic chemicals are being used up when the battery is in operation, it was observed that voltage rating degraded over time even when the battery system is not connected to a load. From the results, an air battery with KOH electrolytic solution produced a higher voltage compared with NaCl electrolytic solution

## 1. Introduction

There are different types of batteries that have developed such as lead-acid batteries, nickel metal hydride batteries, lithium-ion batteries, lithium sulphur batteries, etc. Lithium-ion batteries are usually found in commercial products of portable electronics devices owing to characteristic features such as high energy density, no memory effect and little self-discharge rate [1]. Lithium sulphur batteries, though having been widely studied extensively in literatures and have been ascertained to possess a high energy density, are often limited in commercial use due to high self-discharge rate and bad cycle range [2].

There exist another class of batteries which make use of air as an electrode material (cathode) and a metal such as lithium, sodium, potassium, zinc, magnesium, calcium, aluminium, iron and silicon as anode material. These classes of batteries are termed air batteries. Different types include lithium-air, sodium-air, potassium-air, zinc-air, magnesium-air, calcium-air, aluminium-air, iron-air and silicon-air batteries. Figure 1 shows three metal-air electrodes that make use of aluminium as metal anode. There have been much stimulating research particularly for lithium air systems but silicon-air batteries are under-studied compared to others due to poor cyclic performance [3]

A metal air battery has the supreme advantage over lithium-ion batteries as a result of higher energy density [4] since the energy density of a battery is characterised by the type of electrode materials. The high energy density of air batteries makes them suitable to drive electric vehicles [5]. While having high energy density is a major advantage of air batteries, factors such as anode material and electrolyte issues have somewhat limited their actual implementation and deployment for practical use. One example of a limitation is the occurrence of dendrite growth at the anode after prolonged use [6].



When a battery is connected in a complete circuit, the chemicals inside the battery undergo chemical reactions that release current from one terminal and flow to the other terminal to complete the reaction. Generally, the most important components in an air battery are its air electrode and electrolyte as well as the overall design of the battery. These components are listed in the following sections



**Figure 1.** Three metal-air electrodes that make use of aluminium metal as anode material

## 2. Materials and Methods

The air battery system consists of the electrodes which include the air cathode and metal anode; and electrolytic solution through which a chemical reaction occurs to produce a voltage. These components are explained in the following sections.

### 2.1 Electrolytes:

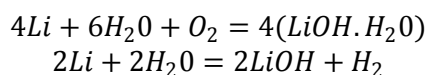
Electrolyte is a critical component in any type of air battery. It plays an indispensable role in the reduction and oxidation reactions that happen at both cathode and anode and in the overall performance of the battery. Just like other electrochemical cells, electrolytes used in air batteries can be classified as aqueous electrolytes and non-aqueous electrolytes.

Two classes of metal air batteries are characterised according to whether the electrolyte is non-aqueous or aqueous. For aqueous air batteries, the redox reaction involves the presence of water molecules at the air cathode while non-aqueous air batteries make use of dimethyl sulfoxide (DMSO), amide or Sulfone-based electrolyte [7]. Aqueous air batteries make use of alkaline solution such as potassium hydroxide as electrolyte [8]. Salt solution can also be used as electrolyte but with the

production of reduced cell voltage compared to when alkaline electrolyte is used. For instance, an Open Circuit Voltage (OCV) of 1.2V is obtainable for Aluminium-air batteries with KOH electrolyte while the OCV reduces to 0.7V with the use of saline electrolyte [9]. For aqueous air batteries, the OCV of the battery is a function of pH value of the electrolyte. In the case of neutral electrolytes, the theoretical OCV is 3.86V. For acidic electrolytes, the OCV can be up to 4.44V while for alkaline electrolytes, the theoretical OCV can be as low as 3.40V [10]. A lithium air battery using a non-aqueous electrolyte consisting of a lithium metal anode, a gel-type polymer electrolyte and a carbon air electrode with a catalyst has been developed [11].

## 2.2 Chemical Reaction:

The reaction involves the reduction of oxygen and the evolution of oxygen in alkaline solutions. The metal (in this case Lithium) used in the air battery will react with water to produce a metal hydroxide and hydrogen gas according to the following reaction:



This release of hydrogen at the metal surface leads to the creation of little cavities which would eventually result in corrosion of the metal. Using aprotic solvents as electrolytes tends to solve the problem of metal corrosion [12]. More so, since the reaction involves the presence of oxygen, the reaction of oxygen with the metal anode results in high self-discharge rate in the presence of KOH.

Yet another fundamental problem with metal air batteries using KOH as electrolyte would be the inclination for the absorption of  $CO_2$  from the atmosphere air [13]. The reaction of  $CO_2$  with KOH electrolyte leads to the formation of insoluble  $K_2CO_3$ , also called carbonation which erodes battery performance. Carbonation problem has been unsolved even till date though the issue has been identified for a long time [14]. One impractical way the carbonation problem can be averted is through rubbing off the absorbed  $CO_2$  from the atmosphere.

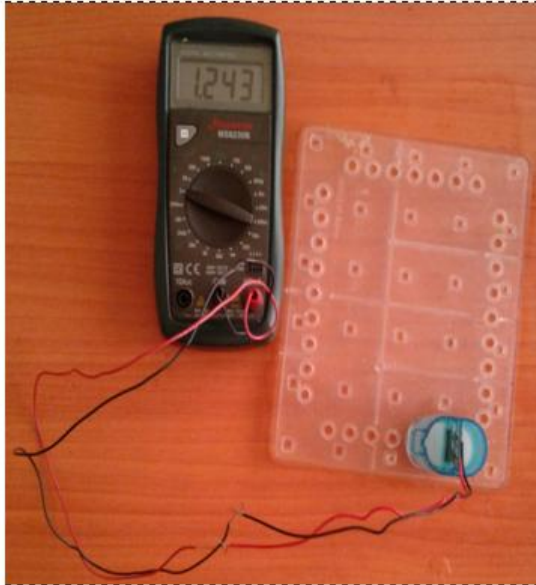
## 2.3 Air Electrodes:

Electrolytes used are saturated aqueous solutions of metal hydroxide or metal chloride. Since the metal anode is unstable in aqueous solution, a watertight separation is required act as the interface between the anode and the aqueous electrolyte [15]. The air electrode which provides an interface between the electrolyte and the open environment must therefore meet the requirement of sufficient porosity so ensure air can penetrate the electrode from the environment, while at the same time be watertight so that the electrolyte will be prevented from leaking through the electrode [16]. This compromise between water tightness and porosity to air is achieved through the addition of a hydrophobic agent such as PTFE [17]. The use of air electrodes offers a major significant change compared to conventional batteries [18] having positive and negative electrode terminals. The potential application of air batteries can be to power segment display lights [19] composed of Light Emitting Diodes (LEDs)

## 3. Results and Discussion

The air battery can generate electricity when salt water is provided as an electrolyte. The metal plate is submerged into the salt electrolyte in the presence of oxygen provided by atmospheric air to produce energy source in form of voltage.

A solution of salt is made by mixing salt crystals with water; the mixture is then stirred to ensure that the salt crystals are dissolved in water. To start operation with NaCl solution, the air metal electrode is submerged into the electrolytic salt solution as shown in Figure 2a.

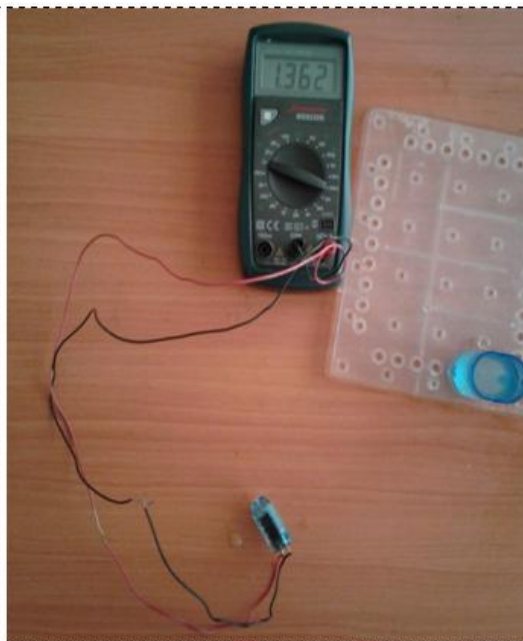


**Figure 2a.** A salt solution (NaCl) is used as electrolyte for air battery and produces a voltage of 1.243V

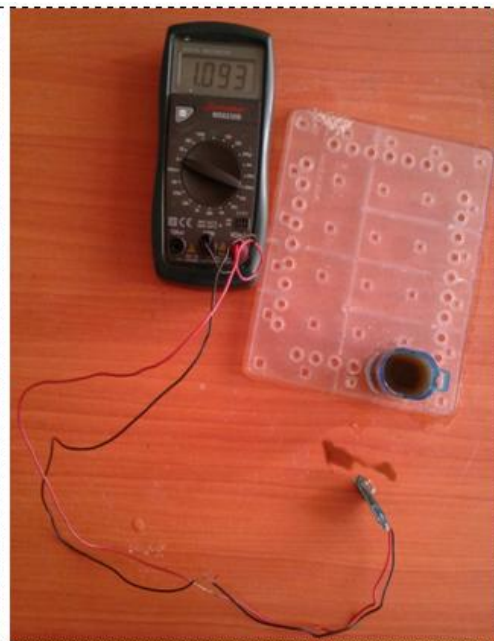


**Figure 2b.** Caustic potash solution (KOH) is used as electrolyte for air battery and produces a voltage of 1.704V

Likewise, a solution of caustic potash is made by mixing KOH crystals with water; the mixture is then shaken to ensure that the KOH crystals are dissolved in water. To start operation with KOH solution, the air metal electrode is submerged into the electrolytic KOH solution as shown in Figure 2b.



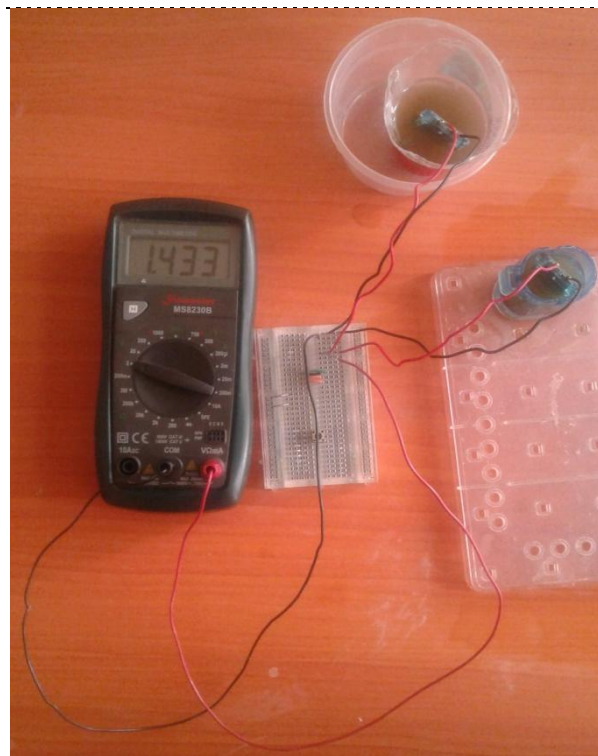
**Figure 3a.** The air battery electrode is removed from the electrolytic salt solution and reads a voltage of 1.362V



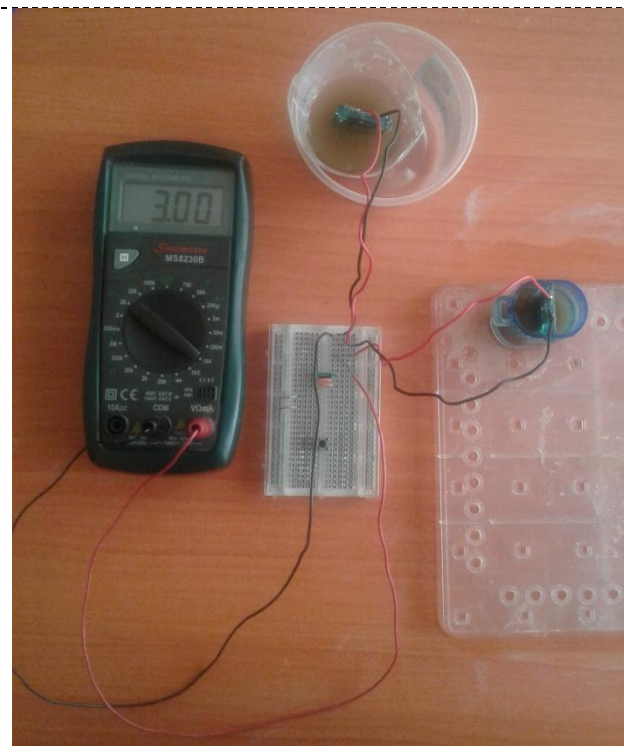
**Figure 3b.** The air battery electrode is removed from the electrolytic KOH solution and reads a voltage of 1.093V owing to the presence of the electrolyte after removal

From Figures 3a and b, it can be observed that the air battery still indicates a voltage reading after the metal electrode has been removed from the electrolyte. This is due to the presence of residue electrolytic solution within the metal anode after removal from the electrolytic solution. After the wet metal electrode dries up, no voltage reading would be detected.

In Figure 4a, two air batteries submerged in KOH solution are connected in parallel to produce a voltage of  $V = \frac{V_1 V_2}{V_1 + V_2} = 1.433V$  while Figure 4b shows two air batteries submerged in KOH solution are connected in series to produce a voltage of  $V = V_1 + V_2 = 3.00V$ .

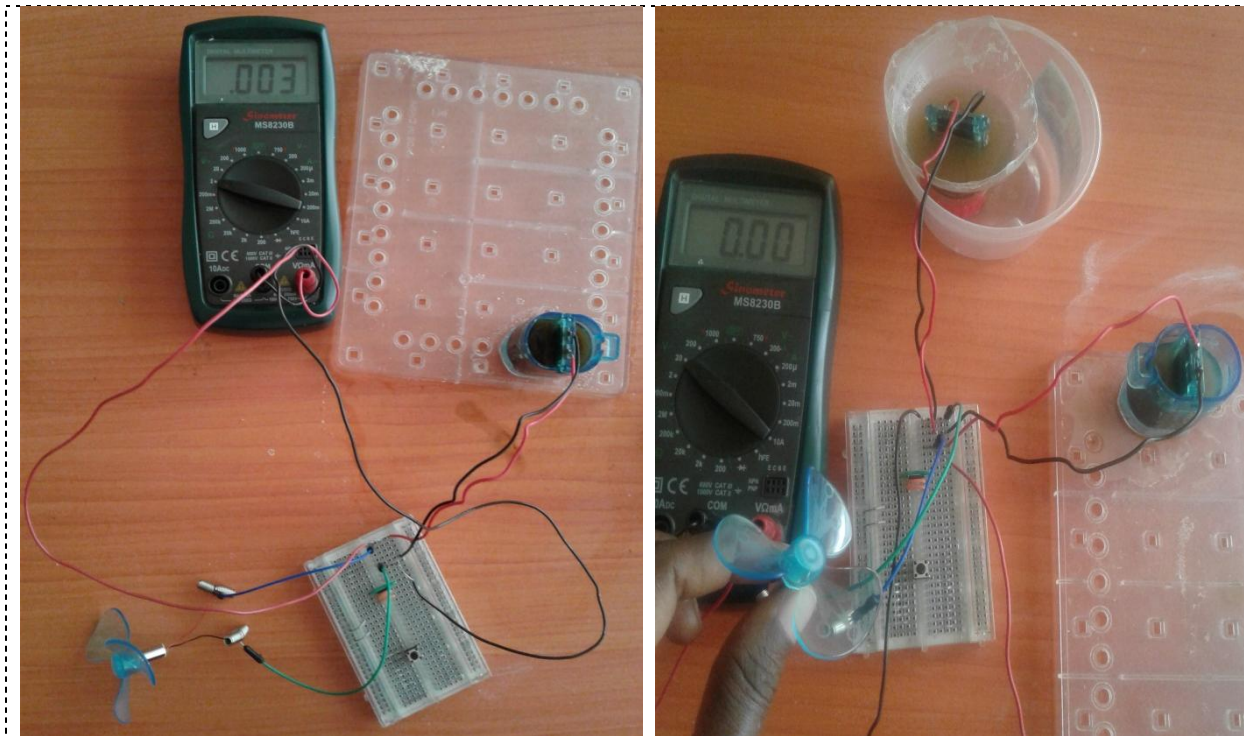


**Figure 4a.** Two air batteries submerged in KOH solution are connected in parallel to produce a voltage of  $V = \frac{V_1 V_2}{V_1 + V_2} = 1.433V$



**Figure 4b.** Two air batteries submerged in KOH solution are connected in series to produce a voltage of  $V = V_1 + V_2 = 3.00V$

A load consisting of a fan driven by a micro DC motor rated at 1.5V is connected across the air battery in Figure 5a, the voltage is seen to drop to 0.03V while the DC motor do not start due to limited current. Likewise, when two air batteries are connected in series and a DC motor load is connected across, the motor still do not start due to limited current as shown in Figure 5b.



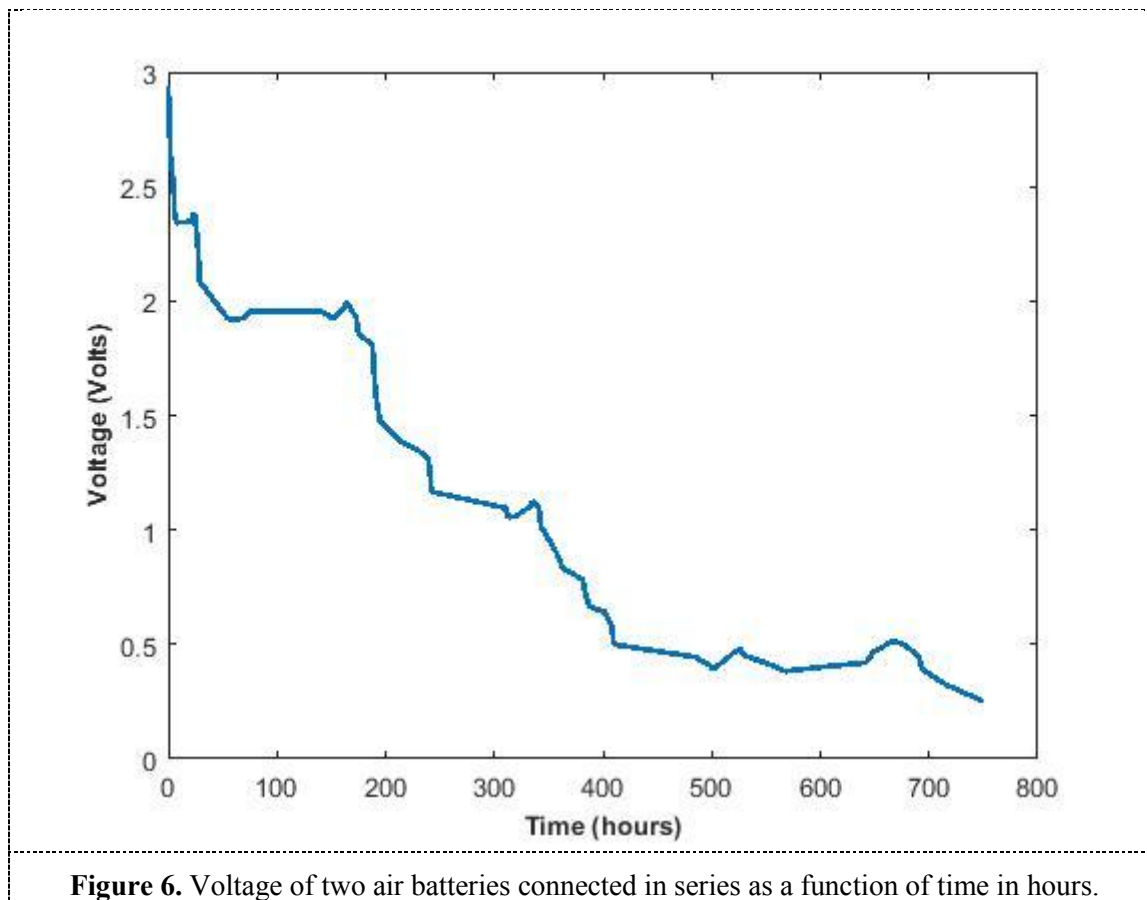
**Figure 5a.** A load consisting of a fan driven by a micro DC motor rated at 1.5V is connected across the air battery, the voltage is seen to drop to 0.03V while the DC motor do not start due to limited current.

**Figure 5b.** A load consisting of a fan driven by a micro DC motor rated at 1.5V is connected across the two air batteries which are connected in series, the voltage is seen to drop to 0.00V while the DC motor do not start due to limited current.

Because air electrode batteries deteriorate after some time as the electrolytic chemicals are used up, the voltage is measured over a period of 4 weeks and 4 days (750 hours) for two air batteries connected in series. A plot of the voltage reading measured at specific times is shown in Figure 6. At time  $t = 151$  hours, the KOH electrolytic solution dried up and was refilled with a new electrolytic solution which resulted in an upward boost in the voltage level from 1.7V to 2.34V.

#### 4. Conclusion

A cell reaction using air battery chemistry has been demonstrated. As the electrolytic chemicals are being used up when the air battery is in operation, it was observed that voltage rating degraded over time even when the battery system is not connected to a load. From the results, an air battery with KOH electrolytic solution produced a higher voltage compared with NaCl electrolytic solution. Air batteries exhibit higher energy density compared with other conventional energy-storage systems but also pose substantial challenges such as the degrade in voltage capacity over time which can be observed from the results. The field of renewable energy, for example, hydro-power, solar or wind energy require efficient energy storage batteries which are indeed possible with air batteries due to higher energy density compared with lithium-ion batteries. Air batteries can be installed in applications extending from small, portable electronics to large electric vehicles such as trains and cars. The air battery is an attractive technology that can be exploited in the field of renewable energy.



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