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Realization and Characterization of an Al-air Battery

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Abstract
The objective of this study is the realization of an aluminum-air battery. The battery is made of an aluminum alloy sheet as cathode and an electrolyte of KOH of different concentrations to study its performance. In addition, the aluminum sheet after its use was also characterized by optical microscopy, X-ray diffraction, and by atomic force microscope. It has been found that the concentration of the electrolyte has a remarkable effect on the battery discharge process. The best concentration for the best yield has been determined.

Keywords: Al-air battery, graphite, electrolyte, concentration, corrosion, X-ray diffraction

Introduction

A battery is a source of electrical energy or a device to store power via electrochemical reactions in a cell or several cells connected in series [1- 3]. The three main components of the cell are: an anode, a cathode, and an electrolyte [4]. There are several types of battery and among these batteries there are the metal-air batteries which demand more interest, because is both safer and has a greater energy density than other batteries. Its operating principle is based on the exploitation of oxygen from the ambient air as a cathode source, which gives this battery a reduced weight and a lower cost than other types of batteries [5]. Metals that can be used as the anode are sodium lithium, potassium magnesium, calcium, aluminum, Fe, Zn and others. This type of battery has a high energy efficiency which is 5 to 30 times higher than the lithium-ion battery and it is often considered a sustainable alternative [6]. Accoording to Goel et al. [7], the Al-air battery has a unique position among metal-air battery systems. The Al-air battery has a practical energy density of 4.30 kWh/kg, just lower than Li-air battery, but much higher than Zn-air [8, 9]. Figure 1 shows the schematic representation of the Al-air battery and the main chemical reaction in the Al-air battery. The fundamental working principle of a Metal-Air battery is to electrochemically reduce the oxygen in the air and oxidize the metal. For the classic Al-air battery, the electrolyte can be either a solution of KOH or NaCl. The electrons formed in the oxidation reaction at the anode pass through a external environment to perform work on the charge and return to the cathode.

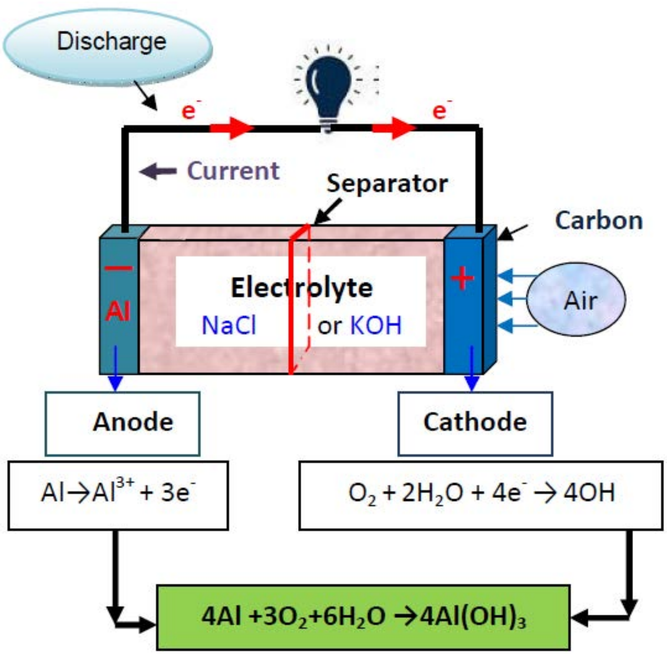

Figure 1: Schematic Representation of Al- Air Battery

In this context, several works have been published on the Al-air battery [10-16]. For example, Gelman et al. [10] investigated the effect of the use of a novel non-aqueous electrolyte (ionic) on the effeciency of Al–air battery. The authors have measured exceptional energy densities of 2300 W h kg−1. However, Cai et al [11]. studied the thermaleffect during the discharge processof aluminum-air battery. They established a theoretical model to explain this phenomenon by combining experimental measurement and mathematical calculation. Yawen et al [12]. invetigatedthe effects of three typical aromatic acids on the corrosion of Al-7075 anode in the KOH water-ethanol electrolyte were investigated. They found that the addition of aromatic acids significantly improves the discharge characteristics of the Al-air battery. In addition, they concluded that these aromatic acids are excellent corrosion inhibitors. Gu et al [13]. conducted a study on the effect of adding Ga3+ to the NaCl electrolyte to improve the discharge voltage of Al-air batteries. They found that the addition of Ga3+ additive in the electrolyte significantly activated the Al anode, which increased the Al-air battery discharge. Bhonge carried out a detailed study to control the parameters that control the evolution of hydrogen with aqueous and non-aqueous solutions having different concentrations of potassium hydroxide in Al-air battery [14]. Among their results, they found that as the concentration of water in the KOH increased, the conductivity improved but the hydrogen evolution deteriorated. In their study, Maria and Tania [15]. had another vision because, they considered the transition from the use of liquid electrolytes to solid electrolytes such as polymers is beneficial for Al-air batteries.

Through these studies selected among other published works, it can be concluded that the studies on al-air batteries are very varied and therefore, the field of research remains very open. For this reason; this research work was carried out and its purpose was the study of the electrolyte concentration effect on the performance and behavior of the Al-air battery.

Materials and Methods

To make an Al-air battery, the basic materials areprepared: Aluminum sheets and Graphite powder and a liquid electrolyte. The chemical composition of the Aluminum sheet is presented in Table 1.

Table 1: Chemical composition of Aluminum.

Element	Al	Si	Cu	Zn	Cr	Pb	Ni
Al 2xxx	Bal	0.598	5.610	0.070	0.023	0.05	0.025

Figure 1 Shows the Graphite Powder Used in Making the Al-Air Battery and Which Has Grains of Average Size of About 0.5 Mm in Diameter.

Figure 1: Graphite Powder.

The electrolyte used for the Al-Air battery is a KOH solution of different concentrations (0.5 mol/l, 1 mol/l, 1.5 mol/l, 2 mol/l). The aluminum plate which is the anode is sized 2 mm x 30 mm x 14 mm.The separator between the graphite and the aluminum is a sheet (very thin paper towel) prepared in the format which is sandwiched between the aluminum plate and the graphite.Note that the outer surface (Graphite and towel) is the cathode. Figure 2 shows the battery prepared in our laboratory.

Figure 2: The prepared Al-Air Battery.

The main instruments used to characterize the batteries produced are a digital voltmeter (DVM) with a digital display. An optical microscope to observe the state of aluminum sheets after their use in the batteries produced.The atomic force microscope (AFM) is used to highlight the surface topography of aluminum sheets.The X-ray diffractometer is used to analyse the surface of the aluminum sheet after its corrosion. The diffractometer used is an Empyreantype, where theanalyzes were carried out under a voltage of 40 KV and an intensity of 20 mA using a copper anticathode (λ = 1.54 Å).

Results and Discussion

The voltage-time curves of the Al-Air battery of different concentrations of KOH electrolyte are shown in Figure 3. It is found that all the voltage-time curves have the same shape; that is to say, a parabolic pace, and which reflect the discharge process of the battery. The curves show a voltage decrease at first, then the voltage remains constant for some time. This behavior during battery discharge was also found by Pino et al [16]. and Panatarani et al [17]. The discharging process is not the same as it depends on the initial electrolyte concentration.The high concentration battery (2 mol/l)has the longest discharge time (400 min), on the other hand the battery which has a low concentration electrolyte (0.5 mol/l) discharges quickly and in a very short time (175 min). It was concluded that when the concentration of the electrolyte increases, the electrolyte inhibits the flow of electrons causing self-discharge with a gradual decrease in voltage [18, 19]. However, it is important to mention that a high concentration of electrolyte can cause strong oxidation of the aluminum plate, i.e., it increases the corrosion process.

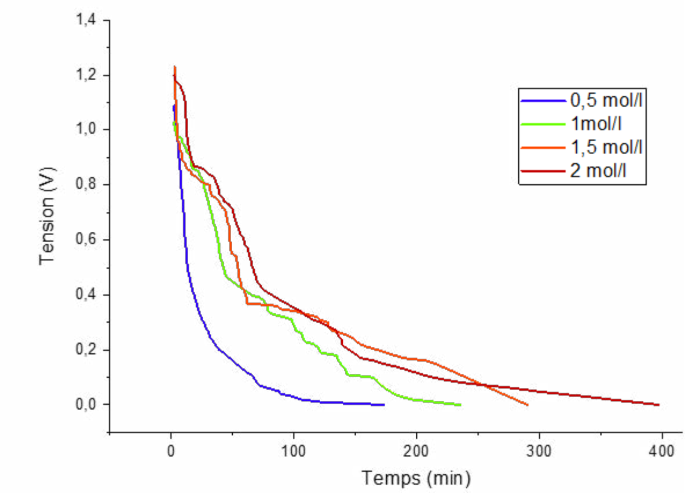

Figure 3: Al-Air Battery Voltage Vs Time with Different Koh Electrolyte Concentrations.

In this analysis part, X-ray diffraction analyzes were carried out on the aluminum plates after their use under the three different concentrations of the electrolyte. Figure 4 presents the three X-ray diffractograms which show the presence of the peaks of aluminum and some peaks belonging to the compounds Al (OH)3 and Al2Cu3 and which are more intense in the aluminum plate of the battery with high electrolyte concentration. These compounds are formed during the reaction between the electrolyte and the surface of the aluminum plate.The compound Al(OH)3 was found by Qing et al [20].

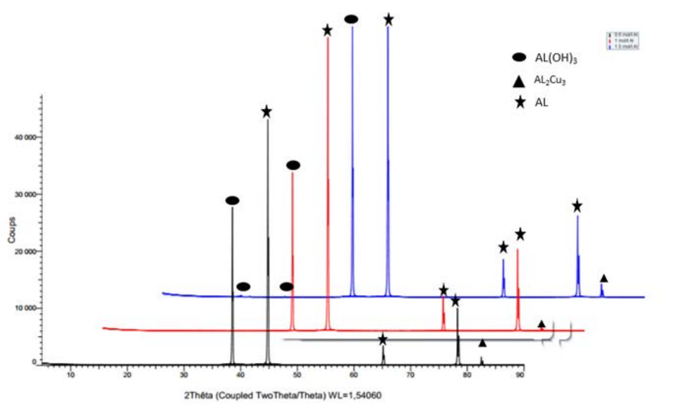

Figure 4: X-Ray Diffractograms of Aluminum Plate Surface After Discharge of Al-Air Battery with Different Concentration (0.5 mol/l, 1 mol/l,1.5 mol/l).

Observation under an optical microscope of the surface condition of the aluminum used in the four different batteries (Fig.5), confirmed the corrosion of this surface and which is more intense and also more visible in the plate belonging to the battery that has the most concentrated electrolyte. The dark areas are the most corroded areas. It is important to note that during the discharge of the metal-air battery, a reduction reaction occurs in the ambient air cathode while the metal anode is oxidized.

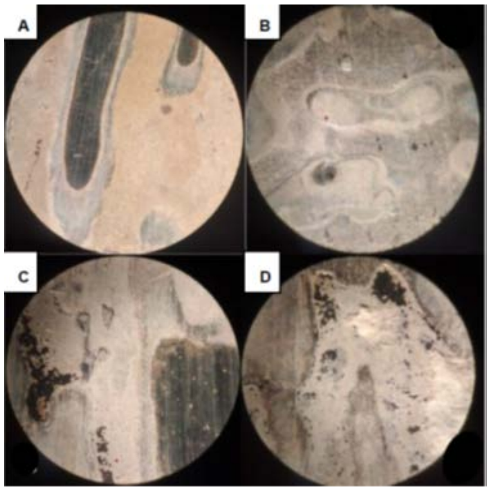

Figure 5: Microscopic Observation of The Surface of the Aluminum Plate After Discharging the Al-Air Battery with Different Concentrations (A- 0.5 mol/l, B- 1 mol/l. and C- 1.5 mol/l. and D- 2 mol/l).

Atomic Force Microscopy (AFM) is a reliable tool to study the surface morphology of material. Figure 5 shows the surface morphology by AFM after oxidation of aluminum for an electrolyte concentration of 0.5 mol/l. The color of the surface, which is dark, is very rough, corresponds to the corrosion areas.

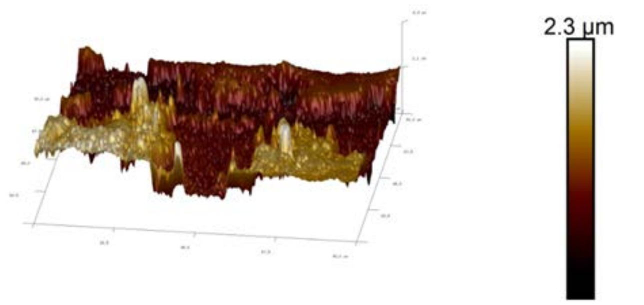

Figure 6: 3D Atomic Force Microscope Image of The Surface of Aluminum at an Electrolyte Concentration of 0.5 mol/l.

Conclusions

From this study of the effect of electrolyte concentration on its discharge process, some conclusions can be deduced:

- Increasing the concentration of the electrolyte increases the duration of its discharge and can reach up to 400 min.
- Increasing the electrolyte concentration will cause severe corrosion of the aluminum plate.
- Two compounds were formed during the corrosion of aluminum which areAl(OH)3 and Al2Cu3
- The aluminium-air battery needs more research as it is considered an attractive candidate as a power source for electric

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