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Performance of Al-Air Battery with Different Electrolytes

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Abstract: Aluminium-air battery is a type of battery that offers high energy density (up to 8.1 kWh/kg) with a theoretical voltage of 2.71 V. Because of the high energy density and versatility, the battery attracts many users. Similar to other batteries, it consists of electrodes and electrolytes. The study aims to investigate the voltage generated by the battery when different electrolytes are employed. Since different electrolytes discharge different amounts of electron charge, the voltage will also differ from one to another. It also holds true when different pH of electrolyte is used. Using NaCl with a pH of 7, NaOH a with pH of 11 and KOH with a pH of 14, the investigation shows that increasing the level of pH results in a higher generated voltage but has the side effect of making Al more easily dissolved into the electrolyte. For the electrolyte which is considered neutral, i.e. NaCL, the lifetime of the battery was the longest as shown by the stability of the generated voltage compared to the other two electrolytes. NaOH and KOH which are categorized as strong bases showed a considerable decrease in generated voltage during the investigation.

Keywords: Voltage generation. Al-air battery, electrolyte, power

1. Introduction

Environmental issues in energy have driven researchers around the world in search of alternative energy in every segment of life. Dependency on fossil fuel especially to generate electricity needs to be complemented with other forms of clean energy sources such as wind energy, solar and hydropower. Those types of energy are cheap, but like any other generated electricity they should be immediately transmitted into the grid or stored in batteries. The need for batteries to store electricity makes the economic potential of green energy questionable when the price tag of those batteries becomes too high. Batteries with a high energy density are required by the transportation sector with the emergence of hybrid or electric cars and also other applications such as mobile telecommunication devices.

In our daily life, the source of energy for electric/electronic devices may come from the electrical grid or from batteries [1-2]. We depend more and more on electricity in our daily lives both inside and outside our house. As one of the common sources of electricity, batteries can be easily found in many electric/electronic devices. Devices such as flashlights, TV remote control, cell phone, and electric cordless drill rely on batteries as their source of energy. All those applications push the improvement of battery for applications in all aspects of modern life.

Many types of batteries are developed to meet the requirement of having high energy density while being cheap to produce and operated. One of them is the Al-air battery [3]. It became one of the main interests in battery research because it offers high energy density (8.71 kWh/kg) with a theoretical voltage of 2.71 V [4-5]. Like other batteries, it consisted of electrodes (anode and cathode) and electrolytes. In the anode, electrons discharge takes place through the oxidation process while in the cathode the reduction process occurs [6-8]. Aluminium acts as an anode while the cathode is made from active carbon [9]. To produce electricity, a strong electrolyte is needed since it conducts electricity better. Strong electrolytes are able to dissolve entirely or almost completely into ions in the solvent and

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generally produce a solution with good conductivity. Strong electrolytes can come in the form of NaCL solution because when it is dissolved in water it generates cations and anions [10-12]. Other strong electrolytes can be produced from strong bases such as NaOH (sodium hydroxide) and KOH (potassium hydroxide) which produce ions when dissolved into water.

Other than strong electrolytes, the battery also needs a good anode that has good conductivity. When it is paired with active carbon powder, an electric circuit is generated. Electrons flow from the cathode that has a higher potential to the anode that has a lower potential. The potential then generates electrical currents when connected to a conductor. The amount of electrons flow is highly dependent on the pH, but on the other hand, aluminium is easily dissolved when the pH is higher. Therefore, it became necessary to investigate the type of electrolytes in relation to voltage and durability of the Al-air battery. A good battery should have a considerably high energy density with reasonable durability. From previous researches, it is known that aqueous electrolyte is required to avoid corrosion at the anode and to prevent hydrogen formation when aluminium is used [13-15]. Also, it concluded that base electrolytes perform better than acid electrolytes and salt or neutral electrolytes. Furthermore, the performance of batteries is enhanced when a corrosion inhibitor is added to the electrolyte. Binbinchen [3] investigated dual membranes-less Al-air batteries with dual electrolytes to achieve a higher cell voltage and power output. Compared to single-cell ones, the dual-electrolyte cell battery generated a higher voltage (600 mV higher) and the energy density peaked at 175 mW/cm2 which is double of single-cell ones.

Egan et al [6] investigated Al-air batteries that have a high energy density (<400 Wh/kg). The performance of the battery was highly influenced by aluminium alloy, oxygen reduction catalyst, and the type of electrolytes used. The problems that are usually present in Al-air battery, i.e. corrosion of aluminium and the occurrence of passive hydroxide in aluminium, were prevented by alloying pure aluminium with Mg, Sn, In, and Ga. Another research [16] of Al-air with the attribute of easy to operate, low cost, and poise lower pollution to the environment was designed with neutral electrolytes of saline (sodium chloride (NaCL), potassium chloride (KCl), or seawater) or alkaline electrolyte (sodium hydroxide (NaOH) or potassium hydroxide (KOH)). This type of Al-air battery was common in low power electronic devices such as emergency light, portable devices, stationary emergency power, and naval application. Compared to an alkaline electrolyte, the saline electrolyte produces lower corrosion and lowering the risk of anode degradation.

The aim of study is to design and test of cheap primary battery, i.e. Al-air battery with acceptable performance compare with other Al-air battery of different electrolyte. Therefore, the essential components in the battery, i.e. aluminum anode, air cathode, separator, and electrolyte, was manufactured from materials available in the market. In designing the Al-air battery, the most common problem is the voltage of the battery is much dependent on the electrolyte. For full reaction of Al-air battery, the theoretical voltage may be as higher as +2.71 V, but it was rarely achieve. The typical voltage of battery was 1.2-1.6 V [4] therefore it was interesting to have a design of Al-air battery with higher voltage.

2. Methods and Materials

The Al-air battery was built from a cylindrical tube of stainless steel as shown in Figure 1. The anode was Al 5052-H19 and the cathode was active carbon powder to draw air from the atmosphere so that battery produce electricity. The carbon powder is the one purchased from BRATACHEM with the size of 230 mesh. The electrolytes were NaOH, NaCl, and KOH that are widely available in the market. Each electrolyte was diluted into water to form a solution with a volume ratio of 1:1 and was tested to confirm its pH (11 for NaOH, 7 for NaCl, and 14 for KOH) with a pH meter. All electrolytes were purchased from CV. NURRA GEMILANG. The research scheme and its measurement are illustrated in Figure 2. The voltage was measured with a digital AVO-meter. A voltage booster was employed because the load, i.e. LED lamp, could not work properly with the low voltage generated by the battery which is beyond operating range. Data were extracted every 5 (five) minutes.

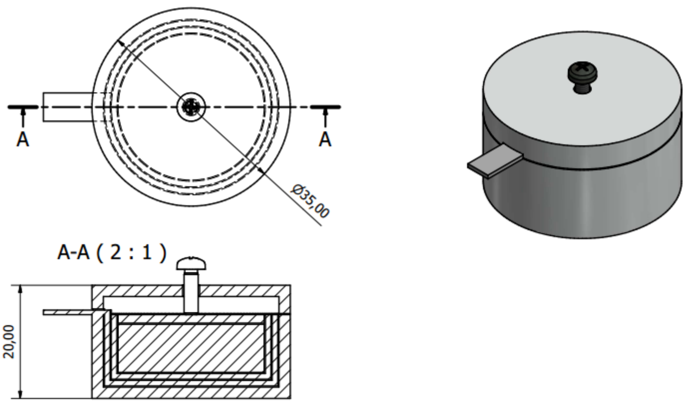

Fig. 1 - Al-air battery, dimensions and shape

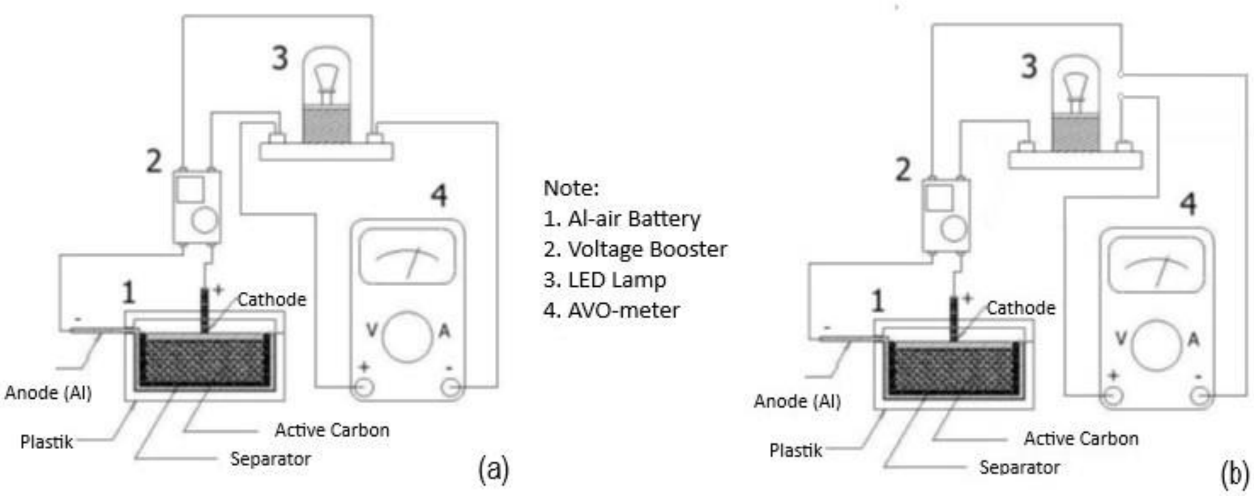

Fig. 2 - Scheme of research and instrumentation (a) voltage measurement; (b) current measurement

In order to produce electricity, the redox reaction in anode and cathode of battery was given in the following.

Anode: $Al\ (s) + 3OH^-\ (aq) \rightarrow Al(OH)_3\ (s) + 3e^-$ +2.31 V

Cathode: $O_2\ (g) + 2H_2O\ (l) + 4e \rightarrow 4OH^-\ (aq)$ +0.40 V

-- +

Full reaction: $4Al(s) + 3O_2\ (g) + 6H_2O\ (l) \rightarrow 4Al(OH)_3\ (s)$ +2.71 V

The aluminum, in foil shape, act as anode and active carbon powder as cathode. The oxygen react with aluminum to form hydrate aluminum oxide and electricity. The battery will no longer produce electricity when aluminum has consumed in the reaction. The parameter of typical Al-air battery from literature was given in Table 1 below as benchmark. Data was extracted every 5 minutes for the measurement of voltage and current of battery. The measurement was conducted for 60 minutes for each round.

Table 1 - Parameters of typical Al-Air Battery

Electrolyte for Al-Air Battery	Volumetric Concentration	pH	Anode	Cathode	Average Voltage (V)	Average Current (mA)	Average Power (mW)	Ref
NaOH	50%	11	Al 5052-H19	Active carbon	1.28	2.95	0.57	[1]
NaCl	50%	7	Al 5052-H19	Active carbon	0.7	7.61	5.37	[17]
KOH	50%	14	Al 5052-H19	Active carbon	1.23	3.26	0.65	[1]

3. Results and Discussion

In this research, the air for the battery was drawn from the environment rather than being enclosed inside the battery. In order for the battery to work properly, air was immersed into the electrolyte through a carbon bar. The carbon bar was selected to avoid reactions with the electrodes hence only allowing air as the source of ion. Active carbon was also added into the electrolyte to function as an electron pump. Electricity is generated when electrons from the anode flow to the cathode and back through the negative ions (OH-) inside the electrolyte. All three electrolytes were employed in the research consecutively to investigate their capacity for electricity generation. The results are shown in Table 1, Table 2, and Table 3 for KOH, NaOH, and NaCL respectively.

In general, compare with other works parameters for average voltage and current as listed in Table 1, the average voltage for the Al-air battery of this work has higher than the benchmark but average current shows much lower value. Table 1, Figure 3, and Figure 4 show that the maximum voltage of Al-air battery with KOH electrolyte was 2.73 V and the current of 0.148 mA. The battery voltage was much closer to the theoretical voltage. The battery tends to deplete as seen by the drop both in voltage and current. Some of the aluminium (anode) dissolved into the electrolyte and also oxides and developed into the surface anode. KOH is a strong base and may cause aluminium to dissolve. The electrolysis process of the solvent (water) also occurred as indicated by the formation of bubbles (hydrogen).

3.1 Performance of Al-air Battery with KOH Electrolytes

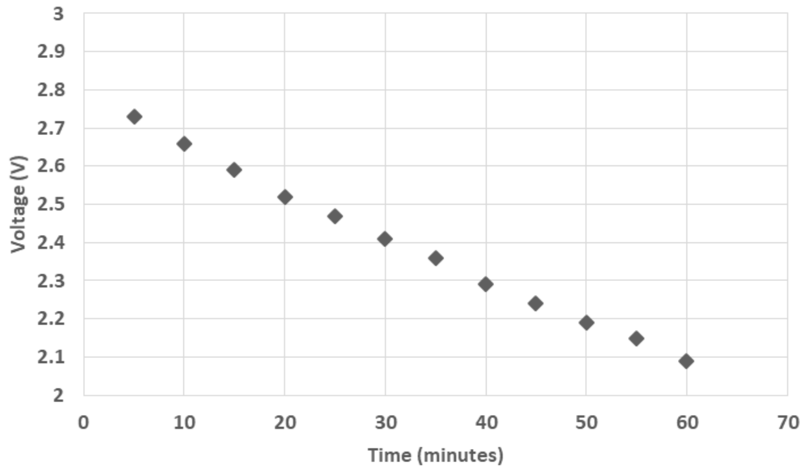

Fig. 3 - Voltage vs time of Al-air battery with KOH electrolyte

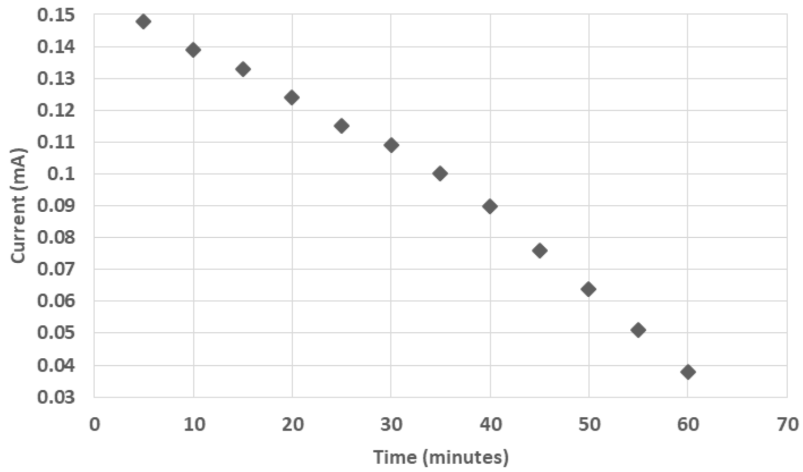

Fig. 4 - Current vs time of Al-air battery with KOH electrolyte

Table 2 - Voltage, Current and Power of Al-air Battery with KOH electrolytes

No.	Time (minutes)	Voltage (V)	Current (mA)	Power (mW)
1	5	2.73	0.148	0.404
2	10	2.66	0.139	0.370
3	15	2.59	0.133	0.344
4	20	2.52	0.124	0.312
5	25	2.47	0.115	0.284
6	30	2.41	0.109	0.263
7	35	2.36	0.100	0.236
8	40	2.29	0.090	0.206
9	45	2.24	0.076	0.170
10	50	2.19	0.064	0.140
11	55	2.15	0.051	0.110
12	60	2.09	0.038	0.079

3.2 Performance of Al-air Battery with NaOH Electrolytes

Even though NaOH is weaker than KOH, the voltage generated is slightly lower than that of KOH electrolyte, i.e. 2.71 V. The current generated was also lower, i.e. 0.146 mA. As with NaOH, the voltage and current of the NaOH electrolyte also dropped over time as shown in Table 2, Figure 5, and Figure 6. The generation of gas (H2) also occurred in this electrolyte. Compared to the NaOH electrolyte, the voltage and current in the experiment were always lower which might be caused by the availability of OH- which is lower than KOH electrolyte.

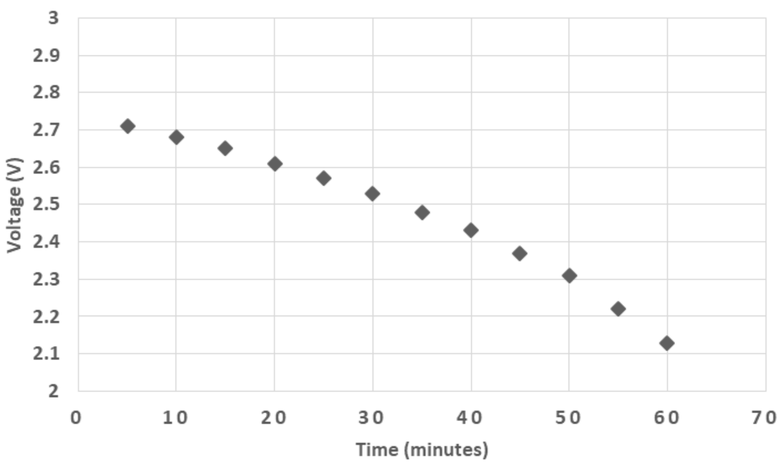

Fig. 5 - Voltage vs time of Al-air battery with NaOH electrolyte

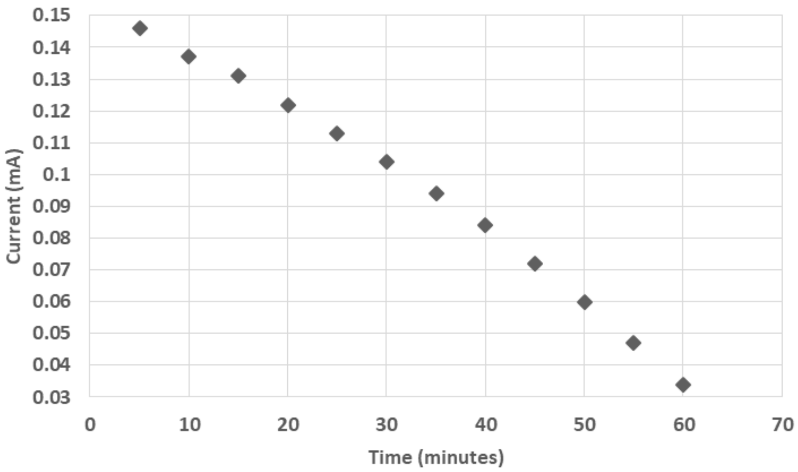

Fig. 6 - Current vs time of Al-air battery with NaOH electrolyte

Table 2 - Voltage, Current and Power of Al-air Battery with NaOH electrolytes

No.	Time (minutes)	Voltage (V)	Current (mA)	Power (mW)
1	5	2.71	0.146	0.396
2	10	2.68	0.137	0.367
3	15	2.65	0.131	0.347
4	20	2.61	0.122	0.318
5	25	2.57	0.113	0.290
6	30	2.53	0.104	0.263
7	35	2.48	0.094	0.233
8	40	2.43	0.084	0.204
9	45	2.37	0.072	0.171
10	50	2.31	0.060	0.139
11	55	2.22	0.047	0.104
12	60	2.13	0.034	0.072

3.3 Performance of Al-air Battery with NaCl Electrolytes

The NaCl electrolyte generated a lower voltage and current of 2.51 V and 0.12 mA respectively as shown in Table 3, Figure 7 and Figure 8. Again, this is due to the lower availability of OH^- in the electrolyte. But the slope of voltage and current drop is lower. Therefore, NaCl gives Al-air battery the capability to generate a more constant voltage and current.

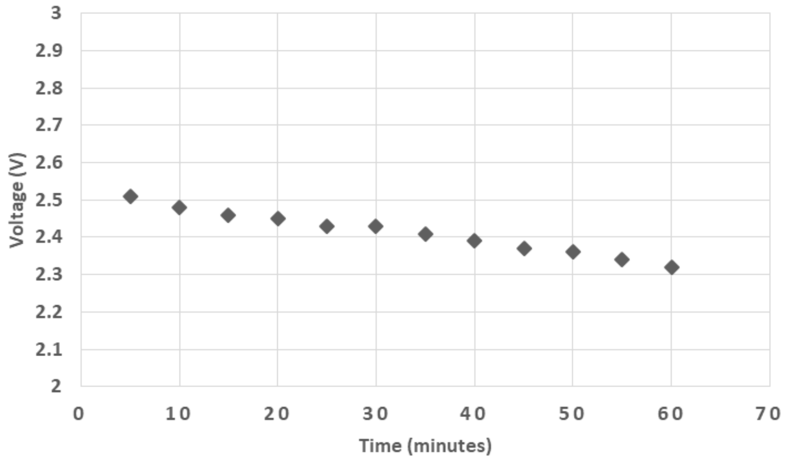

Fig. 7 - Voltage vs time of Al-air battery with NaCl electrolyte

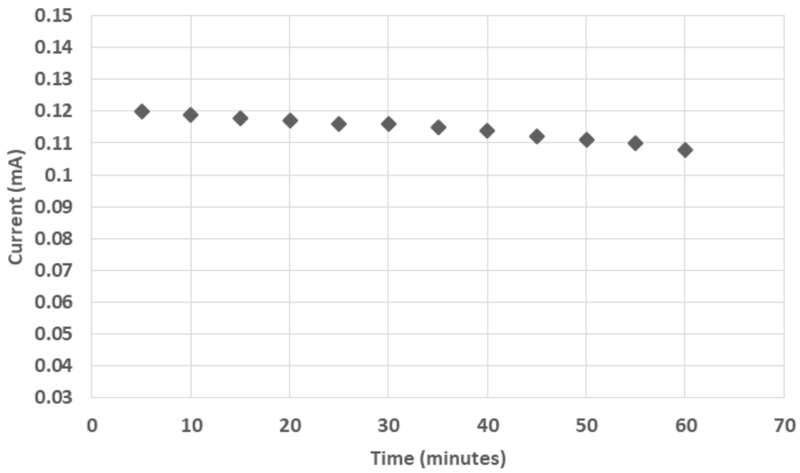

Fig. 8 - Current vs time of Al-air battery with NaCl electrolyte

Table 3 - Voltage, Current and Power of Al-air Battery with NaCl electrolytes

No.	Time (minutes)	Voltage (V)	Current (mA)	Power (mW)
1	5	2.51	0.120	0.301
2	10	2.48	0.119	0.295
3	15	2.46	0.118	0.290
4	20	2.45	0.117	0.287
5	25	2.43	0.116	0.282
6	30	2.43	0.116	0.282
7	35	2.41	0.115	0.277
8	40	2.39	0.114	0.272
9	45	2.37	0.112	0.265
10	50	2.36	0.111	0.265
11	55	2.34	0.110	0.260
12	60	2.32	0.108	0.232

4. Conclusions

From the experiment, all the electrolytes were able to generate electricity for the Al-air battery. Also, all of them have shown a drop both in voltage and current. Other similar phenomena, i.e. aluminum dissolving, formation of oxide in the anode, and gas (H_2) were present during the experiment. KOH and NaOH electrolyte Al-air batteries generated a voltage close to the theoretical voltage but dropped faster than the NaCl electrolyte battery even though the latter generated lower electricity in terms of voltage and current. From the data, it also obvious that the batteries able to produce higher voltage but lower current than the benchmark.

The electricity generation in Al-air is much dependent on the availability of free ions (OH-) in the electrolyte. The supply of the ions may be hampered by the development of oxide in the anode (Aluminium). The more ions (OH-) available in the electrolyte, the more oxide will develop in the anode. Therefore, electrolytes that have more OH- will drop more quickly than ones with less OH-.

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