Preliminary study on aluminum-air battery applying disposable soft drink cans and Arabic gum polymer

S Alva¹, R Sundari¹, H F Wijaya¹, E H Majlan², Sudaryanto³, I G A Arwati¹,² and D Sebayang¹
¹Mechanical Engineering Department, Faculty of Engineering, Mercu Buana University, Meruya Selatan, Kembangan, West Jakarta, 11650, Indonesia.  
²Fuel Cell Institute, The National University of Malaysia, Bangi, Selangor DE, 43600, Malaysia.  
³Center for Sains and Technology Advanced Materials – BATAN Kawasan Puspiptek Serpong, Tangerang Selatan, Banten 15314. 
* sagir.alva@mercubuana.ac.id

Abstract. This study is in relation to preliminary investigation of aluminium-air battery using disposable soft drink cans as aluminium source for anode. The cathode uses commercial porous carbon sheet to trap oxygen from air. This work applies a commercial casing to place carbon cathode, electrolyte, Arabic gum polymer, and aluminium anode in a sandwich-like arrangement to form the aluminium-air battery. The Arabic gum as electrolyte polymer membrane protects anode surface from corrosion due to aluminium oxide formation. The study result shows that the battery discharge test using constant current loading of 0.25 mA yields battery capacity of 0.437 mAh with over 100 minute battery life times at 4M NaOH electrolyte and 20 % Arabic gum polymer as the best performance in this investigation. This study gives significant advantage in association with beneficiation of disposable soft drink cans from municipal solid waste as aluminium source for battery anode.

1. Introduction
Issues on friendly environmental energy have been growing remarkable interest in many disciplines. Serious issues on carbon dioxide since Kyoto Protocol (1997) increasing global temperature due to rapid technology development and vigorous industrial activities have drawn significant attention corresponding with limitations of application of fossil fuel energy from oil and gas resources. Alternative energy sources starting from hydropower, solar, wind, geothermal, electricity until nuclear energy have developed through serial work and thorough investigations expecting to yield low polluted energy [1].

In the context of electricity as energy source, currently, many applications use electric current based on galvanic reaction, for instance, part of automobiles have started to replace petrol energy with electrical battery. Nowadays batteries have been used in large electronic devices including notebooks, tablet computers, pocket calculators, clocks and hand watches, until children toys due to mobility, lightweight, low cost and safety. Having special interest on metal batteries such as lithium – aluminium batteries combined with other components with regard to its electrolyte and cathode material contribute to large industrial applications, however, limitation in their life time have been still a serious obstacle that needs further improvements up to date [2]. Nevertheless, aluminium galvanic based batteries have still attracted many scientists to do more researches and investigations due to aluminium low cost, low weight, and nontoxic material [3].
With regard to aluminium ion batteries, several previous investigations in relation to efforts yielding long lasting and safe battery have been reported [4-10]. The energy of an aluminium ion battery is dependent on several factors like battery cell voltage, capacity and chemical composition. According to Armand & Tarascon [4], an aluminium battery yielded elevated output by increasing chemical potential difference between two electrodes, reducing mass of reactants, and avoiding electrolyte from by-side chemical reactions. By addressing specifically to aluminium-air batteries, an electronic industry produced electricity through chemical reaction of oxygen in atmospheric air and aluminium, however, it is reported that by-product reaction may impede the surface of aluminium anode and as a result, it may result shorter battery survival [4]. Modesto & Yulie reported that simple aluminium-air battery could produce energy of 1.0 V and 100 mA [8]. Earlier investigation as reported by Rao et al. [11], an aluminium-air battery produced a 400 W energy with its replaceable electrolyte. Nevertheless, neglected from its restriction with regard to by-product reaction resisting to further oxidation of aluminium anode, application of aluminium-air batteries have placed the first priority in electronic industries due to economics reason and low weight material [11]. According to Modesto & Yulie [8] and Mohamad [9], the basic concept of electrochemical reaction in aluminium-air batteries was illustrated as follows:

Anode: \[ \text{Al}(s) + 3\text{OH}^{-}(aq) \rightarrow \text{Al(OH)}_3(s) + 3\text{e}^- \quad E^\circ = -2.35 \text{ V} \quad (1) \]

Cathode: \[ \text{O}_2(g) + 2\text{H}_2\text{O}(l) + 4\text{e}^- \rightarrow 4\text{OH}^- (aq) \quad E^\circ = +0.40 \text{ V} \quad (2) \]

Overall: \[ 4\text{Al}(s) + 3\text{O}_2(g) + 6\text{H}_2\text{O}(l) \rightarrow 4\text{Al(OH)}_3(s) \quad E^\circ = 2.75 \text{ V} \quad (3) \]

With regard to the electrochemical reaction, eq. (1) describes the oxidation of aluminium by releasing electrons, while eq. (2) describes the reduction of oxygen from air to form hydroxyl ion (OH-) by capturing electrons, and eq. (3) shows the reduction oxidation reaction of aluminium oxygen in the battery.

Apart from the advantage-disadvantage issues on the application of aluminium-air batteries, this study currently investigates the role of aluminium-air battery using some modification. The application of Arabic gum polymer as hydro gel polymer in this investigation assumes to reduce by-product reaction interfering aluminium anode surface in association with the role of heteroatomic organic compounds (N, O, and S). This study applies porous carbon cathode and sodium base electrolyte. On account of that reason, the main objective of this study is to design aluminium-air battery applying aluminium anode obtained from disposable soft drink cans in municipal solid waste.

2. Material and Experimental

2.1 Materials

Materials used in this paper include aluminium metal obtained from disposable soft drink cans as an anode. Other materials used are air-cathodes and coin cell casing purchased from Magna value Sdn BhD Malaysia. The Arabic gum purchased from Elnasr Ltd., and both electrolytes NaOH and NaCl purchased from Merck.

2.2 Experimental

The fabrication of aluminium-air battery was conducted in the laboratory of production, Mechanical Engineering Department, University of Mercu Buana, Jakarta. For the preparation of aluminium anode, a plate of disposable soft drink cans were cut to adjust the size of proposed diameter and height, respectively, i.e. 16 mm and 2 mm, as shown in Fig. 1a,
followed by cleaning with rubbing paper. The preparation of carbon cathode, porous carbon commercial has cut to fit cashing size with its diameter and height. i.e. 16 mm and 2 mm, respectively, and placed at cashing bottom as shown in Fig. 1b. A sandwich-like arrangement of carbon cathode, Arabic gum with drop wise of NaOH or NaCl, and aluminium anode designed from bottom to surface to form the proposed battery. Different concentrations of Arabic gum in aqueous NaOH solution were prepared to produce optimum result. The Arabic gum stirred mixing with NaOH solution to form homogeneous solution. The homogeneous solution of Arabic gum and electrolyte solution (NaOH or NaCl) placed in a container installed by porous carbon cathode and aluminium anode, and then dried at room temperature for 2 days. After forming gel solution, battery assay was ready for electrical measurements in terms of electrical voltage and current using a battery tester. Prior to assembling the aluminium-air battery, variations of some brands of disposal soft drink cans were characterized by AAS. The aluminium-air battery assay was includes several examinations: (i) electrical voltage and current measurements of variable electrolyte concentrations (NaOH and NaCl); (ii) electrical voltage and current measurements of variable Arabic gum concentrations; (iii) electrical measurements of aluminium-air battery using the highest aluminium content among branded disposable soft drink cans using optimum electrical performance of electrolyte and Arabic gum; and (iv) measurements of aluminium-air battery capacity.

![Figure 1](image.png)

Figure 1 Fabrication of aluminium anode (a) and porous carbon cathode with 20% Arabic gum (b) placed in commercial cashing.

3. Results and Discussions

3.1 AAS Analysis
With regard to aluminium contents of selected four branded disposable soft drink cans (Pocari Sweet, Cap Kaki Tiga, Greensand, and Coca-Cola), this investigation selected Pocari Sweet as the branded disposable soft drink can for aluminium anode in aluminium-air battery assay since this given brand disposable drink can contains the highest aluminium content (Table 1). Having compared to previous investigation as reported by George DS [12], the results of element content shown in Table 1 is generally not much different from previous work. Previous investigation reported 92.5-97.5% Al, 1.0% Mg, 1% Mn, 0.4% Fe, 0.2% Si, and 0.15% Cu obtained from soft drink cans commonly used in Asia [12]. Furthermore, the disposal soft drink cans with pocari sweet branded could be select as an anode material in the assembly of Al-air batteries.

3.2 Battery assay
Variable concentrations of NaCl (3%, 3.60%, 4%, and 2M) and NaOH 4M were prepared to examine the average of electrical voltage (V) and current (mA) based on triplicate measurements. The highest result of electrical measurement of electrolyte solution in terms of voltage and current is taken as the best electrolyte solution to be used for further battery assay and this electrolyte solution will be mixed with Arabic gum until homogeneous solution obtained. The results of electrical measurements using variable concentrations of NaCl and
NaOH shows that 4M NaOH yielded the highest voltage and current (Table 2) and therefore, 4M NaOH electrolyte is selected as the best electrolyte (1.63V and 24.57 mA) for further measurements.

In addition, the reason of using 4M NaOH electrolyte for further study is strengthened by data of electrolyte performance reported in previous investigation. Marliyana et al. [7] reported that 2M NaCl using aluminium (99.8%) anode gave a value of – 0.87 V, while 4M NaOH using pure aluminium (99.999%) anode yielded a value of 1.531 V at room temperature, and seawater using aluminium mixed with minor element (0.1% thalium and 0.1% indium) as anode produced a value of 0.9 V.

Table 1. AAS results of elements for given type of disposable soft drink cans obtained from municipal inorganic waste.

| Element          | Pocari Sweet | Cap Kaki Tiga | Greensands | Coca-Cola |
|------------------|--------------|---------------|------------|-----------|
| Aluminum (Al)    | 96.38        | 89.74         | 90.87      | 93.28     |
| Magnesium (Mg)   | 1.14         | 3.28          | 2.25       | 1.17      |
| Mangan (Mn)      | 0.75         | 1.93          | 1.21       | 1.04      |
| Iron (Fe)        | 0.51         | 1.79          | 1.52       | 1.72      |
| Silicon (Si)     | 0.19         | 0.88          | 1.33       | 0.68      |
| Copper (Cu)      | 0.19         | 2.36          | 1.92       | 1.26      |

Table 2. Results of electrical voltage and current measurements applying variable concentrations of NaCl and NaOH

| Electrolyte Concentration | Measurements | Average Volt (V) | Current (mA) |
|---------------------------|--------------|-----------------|--------------|
| NaCl 3%                   | 0.705        | 0.704           | 0.70         | 7.61       |
| 3.60%                     | 0.716        | 0.714           | 0.71         | 9.36       |
| 4%                        | 0.715        | 0.714           | 0.71         | 10.43      |
| 2 M                       | 0.73         | 0.728           | 0.725        | 10.78      |
| NaOH 4 M                  | 1.64         | 1.63            | 1.62         | 23.9       |

The selection of NaOH over NaCl as electrolyte in this study was also supported by Hofmeister series that the ability of OH- from NaOH to form hydrogen bonding is stronger than that of Cl- causing faster mobility of OH- in electrolyte solution yielding higher electrical voltage and current. [13].

Similar treatment as done for NaOH and NaCl electrolyte solution has applied for Arabic gum solution. Variable concentrations of Arabic gum solution (10%, 20%, and 30%) were prepared and the highest voltage and current of Arabic gum solution has taken as reference after triplicate measurements. The optimum results in terms of electrical voltage and current for a given electrolyte solution (NaOH or NaCl) and Arabic gum solution were mixed together expecting to obtain the optimum condition of aluminium-air battery. In order to examine the corrosion effect of aluminium anode in relation to the existence of Arabic gum in aqueous electrolyte solution of NaOH, this study uses different concentrations of Arabic gum (0%, 20%, and 30%). The results of corrosion effect were shown visually in Fig. 2.
Figure 2 Corrosion effect on Al anode surface with Arabic gum 0% (a); 20% (b); 30% (c). 4M NaOH electrolyte; Carbon cathode; Pocari Sweet disposable cans.

Based on Figure 2 it appears that battery without Arabic gum experienced corrosion, while the other one using Arabic gum looks much cleaner. This is because the Arabic gum membrane has an OH-functional group capable of slowing the movement of ions through hydrogen interactions [14]. Thus, the corrosion process caused by the electrolyte used can be inhibited.

This study used discharge assay applying a battery tester with constant current loading of 0.25 mA to examine the performance of proposed aluminium-air battery. Table 3 shows the discharge data of aluminium-air battery in terms of electrical voltage, current, duration time, and battery capacity for different concentrations of Arabic gum (0%, 20%, and 30%). At first, variable concentrations (0%, 20%, 30%, 40%, and 50%) of Arabic gum were planned to be examined, however, finally only three concentrations (0%, 20%, and 30%) of Arabic gum were examined due to dramatically dropped of battery performance after using 30% Arabic gum (Fig.3 and Table 3). Finally, the results showed that 20% Arabic gum performed the best discharge test with achieved battery capacity of 0.437 mAh.

Higher solution viscosity may hinder ions migration in electrolyte solution resulting lowered battery performance and therefore, the higher Arabic gum concentration (30%) showed lower battery performance rather than that one of Arabic gum 20%.

Figure 3 Discharge test with battery tester applying Arabic gum 0% (a); 20% (b); 30% (c). 0.25 mA current loading. 4M NaOH. Al anode. Porous carbon cathode. Pocari Sweet disposable cans.
Table 3. Battery performance related to electrical voltage, current, and capacity applying Arabic concentrations (0%, 20%, and 30%). 0.25 mA current loading.

| Specification               | Time (h:m:s) | Voltage (mV) | Current (mA) | Duration (min) | Capacity | Total capacity* |
|-----------------------------|--------------|--------------|--------------|----------------|----------|-----------------|
| 0% Arabic gum; 4M NaOH; carbon cathode; pocari sweet cans | 0:00:00      | 1262         | -0.2496      | 4              | -0.01664 |                 |
| 20% Arabic gum; 4M NaOH; carbon cathode; pocari sweet cans (Al anode) | 0:00:00      | 1316         | -0.2496      | 90             | -0.3745  |                 |
| 30% Arabic gum; 4M NaOH; carbon cathode; pocari sweet cans (Al anode) | 0:00:00      | 1348         | -0.2495      | 11             | -0.04574 |                 |

*) round-off data.

The data of battery discharge graphs as presented in Fig. 3 was obviously observed in Table 3. Regarding to battery with 0% Arabic gum (Table 3) only after 9 minutes the capacity dropped to zero, however, battery with 20% Arabic gum (Table 3) was still survived over 100 minutes duration, while battery with 30% Arabic gum survived about 20 minutes. Moreover, with respect to total battery capacity, the 20% Arabic gum battery posed the highest value, i.e. 0.437 mAh, and the reason of this phenomenon has already elucidated above.

4. Conclusions
The preliminary battery discharge test of Al anode and porous carbon cathode shows moderate satisfaction result with regard to achieved battery capacity of 0.437 mAh applying 4M NaOH and 20% Arabic gum polymer. The 20% Arabic gum polymer successfully achieved over 100 minute battery life time. The disposable soft drink cans as Al source for battery anode looks promising for future broader application.

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References
[1] Farahiyah AR, Maniruzzaman A A M, Saidur R, Abu Bakar W A W, Hainin M R, Putrajaya R, and Norhidayah Abdul Hassan N A 2017 Renewable and Sustainable Energy Reviews71 112.
[2] Li Y, Yang J and Song J 2017 Renewable and Sustainable Energy Reviews71 645.
[3] Kazazi M, Abdollahi P and Moghadam M M 2017 Solid State Ionics300 32.
[4] Armand M and Tarascon J M 2008 Nature, 451 652.
[5] Egan DR, Ponce CL, Wood RJK, Jones RL, Stokes K R and Walsh F C 2013 *Journal of Power Sources* **236** 293.

[6] Gelman D, Shvartsev B and EinE Y 2014 *Journal of Materials Chemistry A* **2** 20237.

[7] Marliyana M, Meor ZMT, Edy HM, Siti M, Wan MFWR, Wan RW D and Jaafar S 2015 *Journal of Industrial and Engineering Chemistry* **32** 1.

[8] Modesto T and Julie H Y 2007 *Journal of Chemical Education* **84** 1936A.

[9] Mohamad AA 2008 *Corrosion Science* **50** 3475.

[10] Mori R 2015 *Journal of The Electrochemical Society* **162** A288.

[11] Rao BML, Cook R, Kobasz W and Deuchars G D 1992 *International on Power Sources Symposium, 35th IEEE*, USA.

[12] George D S 1988 From Monopoly to Competition: The Transformation of Alcoa. Cambridge University Press.

[13] Nathaniel V N and Jane M V 2008 *Journal of Molecular Liquids* **143** 160

[14] Abu-Dalo M A and Othman AA 2012 *International Journal of Electrochemical Science* **7** 9303.