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An Innovative Approach to Assess the Potentiality of Using Activated Carbon and Rice Husk Ash in Aluminum-Air Battery

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ABSTRACT

Aluminum-air (Al-air) cells have the potential to become vital in energy storage applications in the future because of their high energy density, which is even higher than that of commonly used lithium-ion batteries. However, it is not used widely because the cost of air cathode catalysts and metal anode is high. However, suppose the catalysts are replaced with activated carbon or rice husk ash as an alternative and recycled aluminum foil as an anode. In that case, the production cost might be feasible for the vast use of this type of cell. This study's main objective is to utilize some commonly available material in fabricating an Al-air battery suitable for small and day-to-day usage, reducing production costs and limitations. In this paper, a focused analysis was made on the feasibility of using an activated carbon and rice husk mixture as an air cathode catalyst for an Al-air cell, and the observations were interesting. About 11 samples of a mixture of rice husk ash (RHA) and activated carbon (AC) in different ratios have been made to find the best results from 0.68-0.72 V, which increases by 8-20%, measuring each sample after 3 days. In this study, another attempt was made to replace the graphite cathode of a dry cell with a mixture of AC and RHA. Voltage drop is quite negligible for the mixture of 10% RHA. The resulting voltage is similar to the new 100% activated carbon battery as a cathode. If considering the environmental effect, using recycled activated carbon and rice husk ash will decrease pollution and open a new door to apply in primary cells.

Keywords:
Activated carbon (AC), Rice husk ash (RHA), Aluminum-air cell (Al-air), Air cathode catalyst, Graphite cathode

1. Introduction

Production of immense amounts of energy is necessary to meet the growing needs. A large amount of energy is consumed in the form of DC cells. A part of the study is on replacing the graphite cathode of dry cells. Various portable electrical devices use dry cells as an energy source. The dry cell

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is a cell in which the electrolyte exists in the form of a paste, is absorbed in a porous medium, or is otherwise restrained from flowing. It's a type of electric battery commonly used for portable electrical devices. It transforms chemical energy into electrical energy. Zinc is the anode terminal, and graphite rod is the cathode terminal in dry cell [1, 2]. DC cells are used in various portable devices, such as calculators, cameras, clocks, watches, and torches. The global battery market is about $50 billion US, of which roughly $45.5 billion is allocated to non-rechargeable batteries.

Another part of our study is on aluminium-air cells. As an alternative to conventional dry cells, in this study, an aluminium-air battery has been produced using recycled aluminium foil, rice husk ash, waste-activated carbon, etc. These batteries produce electricity from the reaction of oxygen in the air with aluminium. They have one of the most noteworthy energy densities of all dry cells. However, they are not generally utilized because of issues with high anode cost and by-product expulsion when utilizing conventional electrolytes. Waste and recycled products can be used as raw materials to reduce procurement costs.

A metal-air cell consists of many primary and secondary cells. The positive electrode in metal-air batteries is made of carbon and contains a layer of some precious metals that react with oxygen. One of the metals, such as zinc, aluminium, magnesium, or lithium, makes up the other electrode. These batteries are sometimes called fuel cells since air constantly passes through the cell. The aluminium-air battery is very suitable and has the potential to become a source of power for electric vehicles due to its high energy density, which is much higher than that of lithium-ion batteries [3]. Compared with other metal-air batteries, Al-air is very suitable for future large-scale energy applications because of their lowest cost and high specific capacity, which is the second highest only to that of lithium and much higher than those of magnesium and zinc [4, 5]. In the early 1960s, remarkable energy and power densities for aluminium-air batteries were reported. Most current research has been devoted to developing new, advanced catalysts based on metal oxides to enhance the air electrode's catalytic activity. The most effective process is the electrochemical oxidation of aluminium in aqueous alkaline solutions (Al-air battery), considering the energy cycle of aluminium [6]. Recent studies suggest using oil to replace the aqueous electrolyte to prevent corrosion [7]. In another study, polymer electrolytes were suggested for Al-air cells for improved safety [8].

Table 1
Various metal-air battery parameters [9]

Batteries	Theoretical Voltage (V)	Theoretical Specific Capacity (Ah/kg)	Theoretical energy density (kWh/kg)	Practical Operating Voltage (V)
Li – air	3.4	1170	13.0	2.4
Zn – air	1.6	658	1.3	1.0 – 1.2
Mg – air	3.1	920	6.8	1.2 – 1.4
Na – air	2.3	687	1.6	2.3
Al – air	2.7	1030	8.1	1.2 – 1.6

Initially, pure aluminium has been chosen as an anodic material for Al-air batteries in virtue of its excellent electrochemical properties. Thermodynamically, a pure aluminium anode exhibits a potential of -1.66 V (vs. Hg/HgO) in saline and -2.35 V (vs. Hg/HgO) in aqueous solution. However, the practical open-circuit potential of the aluminium electrode is significantly higher, which is attributed to the competition between the considerable electrode processes that occur on the Al surface [10, 11]. A three-electron charge transfer process producing Al^{3+} species and forming corrosion products can be seen on aluminium surface. This side reaction causes corrosion and passivation of the aluminium surface, ultimately leading to the failure of Al-air batteries [12]. Pure aluminium is unstable when used as an anode for Al-air batteries, so the most common method to prolong the battery operation time and decrease the corrosion rate is using Al alloys. The outstanding performance of Al alloys in Al-air batteries can be attributed to the comprehensive effect of each individual alloying component [13]. The most commonly used anode materials in Al-air batteries are Al-Zn, Al-In, Al-Ga and Al-Sn. The electrolyte is a core ingredient of Al-air batteries. NaCl, a saltwater electrolyte, has indeed been studied extensively for use as an Al–air battery electrolyte due to its abundance and safety wherein if used, it could provide a battery potential of ~0.65–1.1 V for pure Al anodes [14]. The air cathode is one of the essential components of an Al-air battery, which is generally composed of a gas diffusion layer, current collector, and catalytic active layer. The gas diffusion layer comprises a carbon material and a hydrophobic binder such as polytetrafluoroethylene (PTFE), making the diffusion layer permeable only to air and preventing the permeation of water [15]. Among the extensive research efforts dedicated to developing advanced ORR electrocatalysts, carbonaceous nanomaterials have been demonstrated as promising metal-free catalysts with satisfactory activity and durability towards ORR [16].

Activated Carbon (AC) can be made from many organic wastes such as soybean oil cake [17], spent tea leaf [18], rubber wood sawdust, and jackfruit waste [19]. The external covering of the rice grain is called the rice husk. Rice Husk Ash (RHA) is used in many sectors. Rice husk is very much available in rice-producing countries, and 30% to 50% of it is organic carbon [20]. RHA is used to improve the microstructure of the cement paste [21], and silica is also extracted from RHA [22]. As it contains a significant amount of carbon, it can be used as an alternative to graphite in cathode. AC and RHA mixtures can generate electricity as cathode catalysts in metal-air cells. This study focuses on waste-to-energy to contribute to waste management and reduce the harmful environmental impact of used dry cells. It is done by using recycled raw materials, removing harmful chemicals, and producing environment-friendly electrochemical energy sources. This approach has adopted two methods to replace conventional dry-cell batteries with activated carbon. A mixture of activated carbon with rice husk ash was used, and recycled aluminum foil was used as the anode.

2. Materials and Methods

2.1 Collection Activated Carbon (AC) and Preparing Rice Husk Ash (RHA)

Activated Carbon (AC) is a very common material. It can be extracted from many abandoned sources. The use of AC can be seen in reducing air pollution, arsenic removal, cleaning vegetables and fruits, water treatment plants, groundwater treatment, in-house purification of drinking water, effluent gas streams purification, mercury vapours removal, NO_x and SO_x removal, phenols and phenolic compounds removal, etc.

At first, the chunk of AC was collected from the old filter. Then, they were crushed using a wooden hammer, as they were in bonded form. After collecting, samples were stored safely in a zip lock bag for further use. Rice Husk Ash (RHA) can be produced by burning rice husk either in an open field or under any special incineration conditions with controlled temperature. The open-burning production of RHA has a high carbon content, which adversely affects concrete properties and causes highly crystalline formation in structures. Figure 1 shows raw activated carbon collected from the source and Rice Husk Ash.

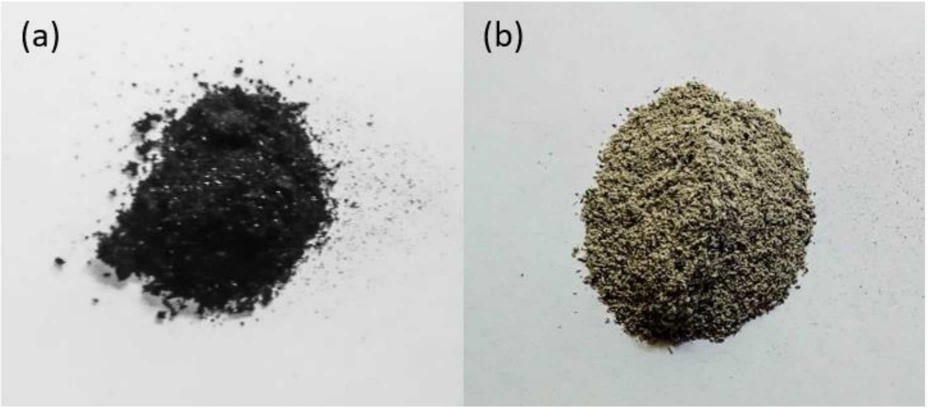

Fig. 1. (a) Activated carbon (AC) and (b) Rice Husk Ash (RHA)

2.2 Preparing Mixtures

After collecting AC and RHA, a precise digital weight machine was used to measure the required amount of mixture. The machine can measure 0.01 g to 500 g and has the function of automatic calibration. The values of the measurements taken are given in Table 2. The total weight of the mixture was 1g.

Table 2
Sample name with different mixture proportion

Sample Name	% of RHA	% of AC	Weight of RHA	Weight of AC
0RHA100AC	0%	100%	0g	1g
5RHA95AC	5%	95%	0.05g	0.95g
10RHA90AC	10%	90%	0.1g	0.9g
20RHA80AC	20%	80%	0.2g	0.8g
30RHA70AC	30%	70%	0.3g	0.7g
40RHA60AC	40%	60%	0.4g	0.6g
50RHA50AC	50%	50%	0.5g	0.5g
60RHA40AC	60%	30%	0.6g	0.4g
70RHA30AC	70%	30%	0.7g	0.3g
80RHA20AC	80%	20%	0.8g	0.2g
90RHA10AC	90%	10%	0.9g	0.1g
100RHA0AC	100%	0%	1g	0g

2.3 Experimental Setup
2.3.1 Al-Air Cell

Used-aluminium foil, tissue paper, wire and salt water were collected as raw materials. Then, the aluminium foil and tissue paper were cut into a 10 cm square block. One aluminium foil, two tissue paper and a single piece of copper wire were used in a single unit cell. Figure 2 shows the raw materials needed in this experiment.

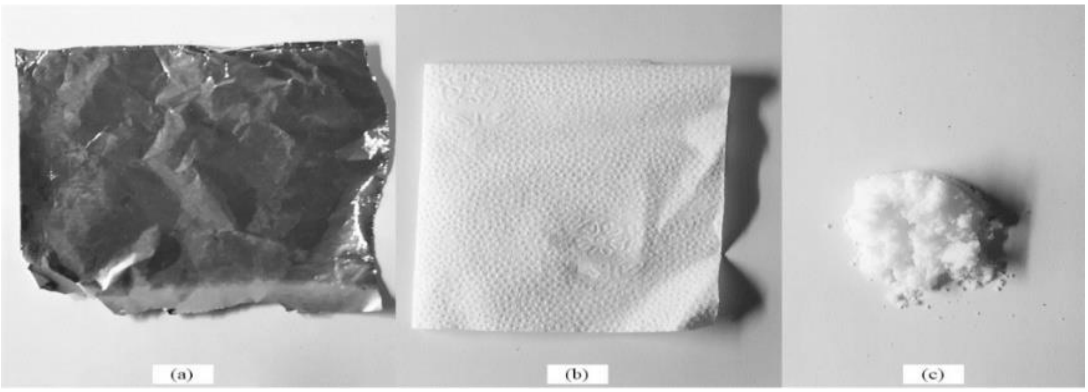

Fig. 2. Raw materials for Al-Air cell prototypes

The saltwater mixture was used as an ion exchanger. This solution was made using 200 ml water and 20 g of common salt (NaCl) using the reaction in Eq. 1.

$$NaCl\ (s) + H_2O(l) \longrightarrow Na^+ + Cl^- + H_2O \tag{1}$$

This type of DC cell relies on reduction and oxidation reactions. Oxidation of aluminium (Al) happens at the anode, and oxygen (O_2) reduction occurs at the cathode, generating electrical energy. The half (Eq. 2 and 3) and overall reaction (Eq. 4) equations are given below:

Anode: $Al(s) + 3OH^-(aq) \rightarrow Al(OH)_3(s) + 3e^-$ (2)

Cathode: $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$ (3)

$$4Al(s) + 3O_2 + 6H_2O(l) \longrightarrow 4Al(OH)_3(s) \tag{4}$$

The experiment started with cleaning every required material, including where the experiment was conducted. A tissue paper was placed over an aluminium foil. Then, 5 ml of salt water was evenly distributed over the tissue paper. The activated carbon and rice husk ash mixture were sprinkled evenly on the wet tissue in different proportions, as shown in Table 1. The copper wire was placed 5 cm from the corner. One end of the wire, which acted as a cathode junction, was revealed outside. Then, another tissue paper was put over it, and a 5 ml salt water mixture was evenly distributed again. Finally, the setup was fixed together, as shown in Figure 3, and made using the same method with different cathode catalyst mixtures.

Fig. 3. Al-air cell prototypes

2.3.2 Graphite Cathode Replacement

The experiment was initialized after the industrial-made battery was arranged from a local shop. Activated carbon was taken from a used water filter; rice husk ash was collected. After collecting the required components, tests were run on them. The voltage reading of the industrial battery (primary cells) was taken with a multimeter at initial condition. Then, the battery was disassembled, and the plastic covering was removed along with the plates on both ends.

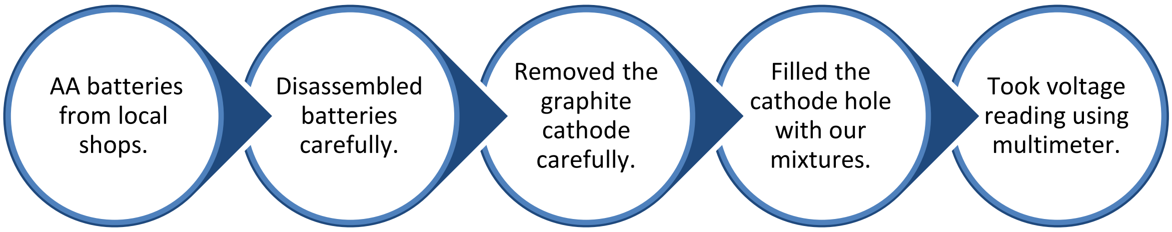

Fig. 4. Steps of graphite cathode replacement

The cathode rod was carefully taken off using a narrow plier so that the apparatus was not damaged. An activated carbon and rice husk ash mixture was used instead of a carbon rod. The mixture was inserted in the place of the rod with the required pressure. Eleven samples were made with different ratios of activated carbon and rice husk ash. Voltage readings were taken carefully for different samples after a specific interval of time using a multimeter. Figure 4 shows a complete flow chart of the whole procedure.

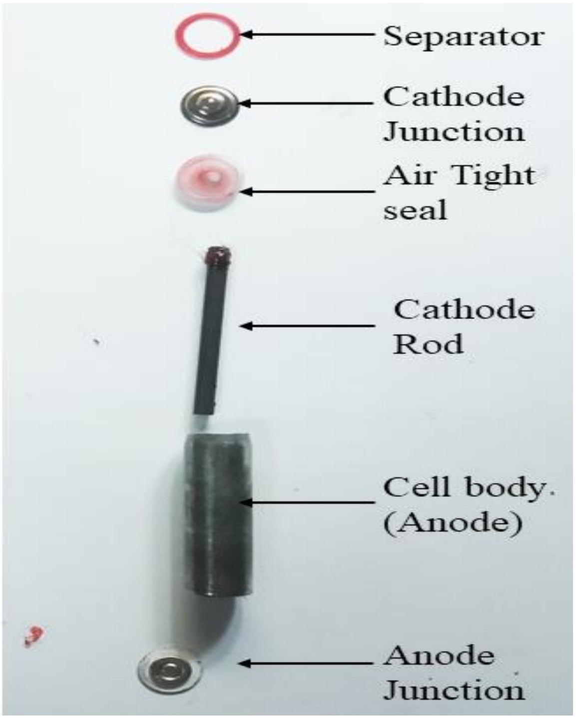

Fig. 5. Disassembled AA cell

Figure 5 is the disassembled photograph of the cell. In a disassembled cell, there were components like a separator, a cathode junction, an air-tight seal to save internal components, a graphite cathode rod, an anode cell body and an anode junction.

Fig. 6. Samples after graphite cathode replacement

The pictures of all prototypes are shown in Figure 6, taken after implementing the same method on eleven different cells for each sample. Separators and seals were not used in the prototypes. The mixture replaced the graphite rod.

3. Results

3.1 Al-air cell

After preparing the samples, voltage readings from each sample were recorded using a multimeter. Reading for the first seven days was collected to analyze the voltage characteristics of the foil cell samples. Table 3 shows the first-day voltage of each sample, along with Rice Husk Ash (RHA) and Activated Carbon (AC) percentages.

Table 3
Voltage reading of Al-air cell at day 1

Sample Name	Percentage (%)		Voltage (V)
	Rice Husk Ash (RHA)	Activated Carbon (AC)	
0RHA100AC	0	100	0.72
10RHA90AC	10	90	0.71
20RHA80AC	20	80	0.64
30RHA70AC	30	70	0.61
40RHA60AC	40	60	0.63
50RHA50AC	50	50	0.63
60RHA40AC	60	40	0.62
70RHA30AC	70	30	0.62
80RHA20AC	80	20	0.6
90RHA10AC	90	10	0.6
100RHA0AC	100	0	0.55

Table 2 also shows that the increasing percentage of rice husk content reduces voltage output. From the sample 30RHA70AC, the voltage reading starts to fluctuate slightly. Hence, the average values were taken. Samples 0RHA100AC and 20RHA70AC (Table 2) were quite stable and ideal for constant voltage supply.

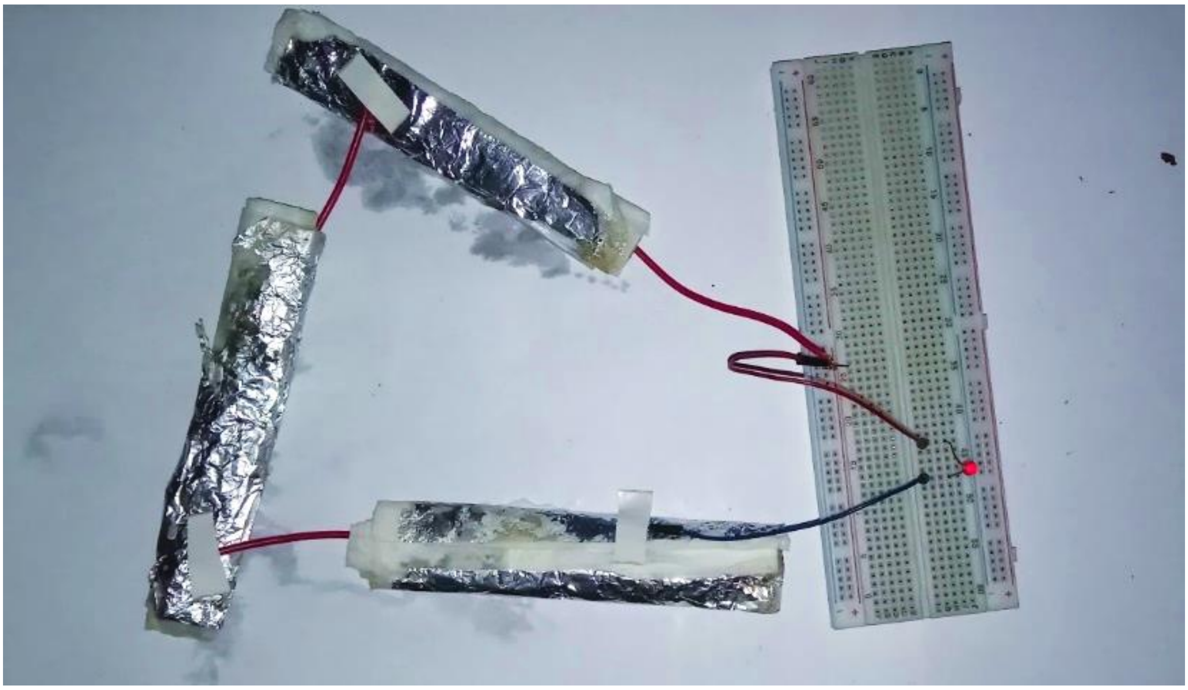

Fig. 7. Series connection of Al-air cells

Three cells were connected to form a battery, which gave us around 2 volts, enough to light a 3mm Red LED (Figure 7). After pressing the cells, more voltage and current were produced. Due to this, the LED was glowing more than before.

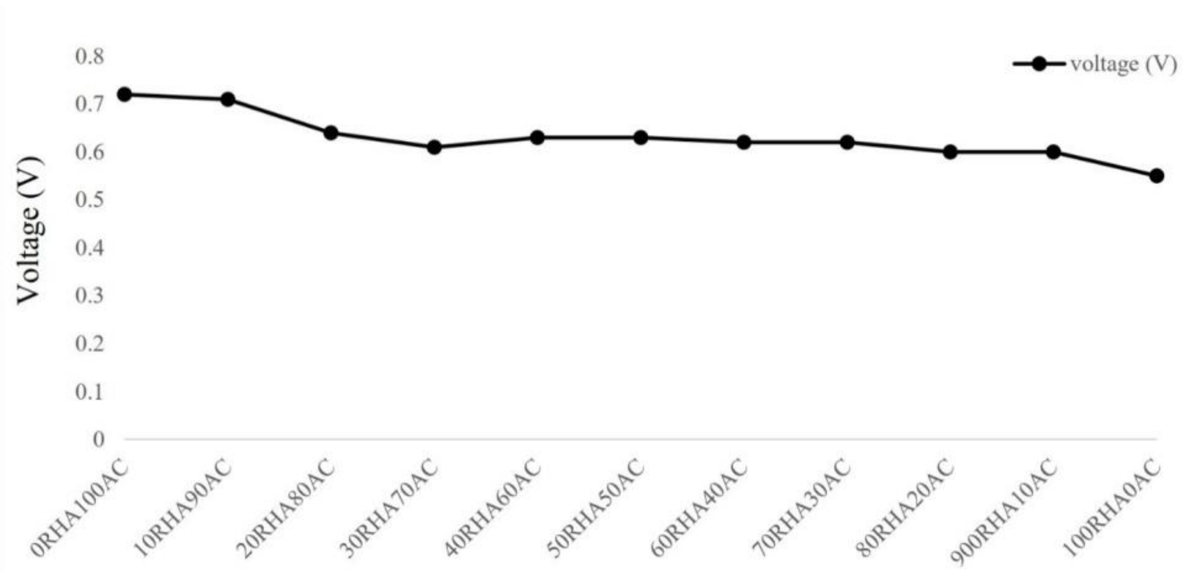

Fig. 8. Measured voltage of each cell on the first day

From Figure 8, it was observed that the voltage range of the samples went from 0.72 V to 0.55 V on the first day of reading. Minimum voltage is obtained from the 100RHA0AC sample.

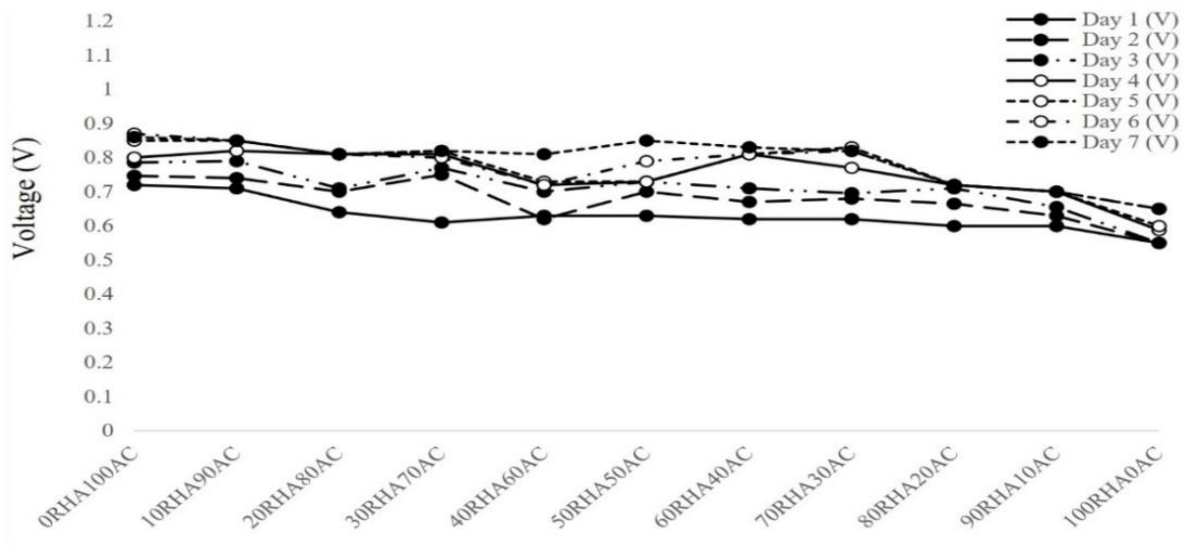

Fig. 9. Change of voltage over seven days

Figure 9 shows the change in voltage of each sample over seven days. This means that the changes in voltage over the days are not constant. Voltage outputs drastically increased on days 3 and 4 as the tissue paper absorbed the electrolyte (NaCl) properly over time, and the increment rate reduced after that. 100RHA0AC sample is an exception as it remains constant for the first three days. The average increment of voltage after day 3 is around 14%. Voltage fluctuation reduces with time, and the dry cell samples become more stable. We have taken a minimum of 0.8 volts as a standard of a usable sample, and from the readings, we suggest that samples from 0RHA100AC to 30RHA70AC are usable after four days of procurement.

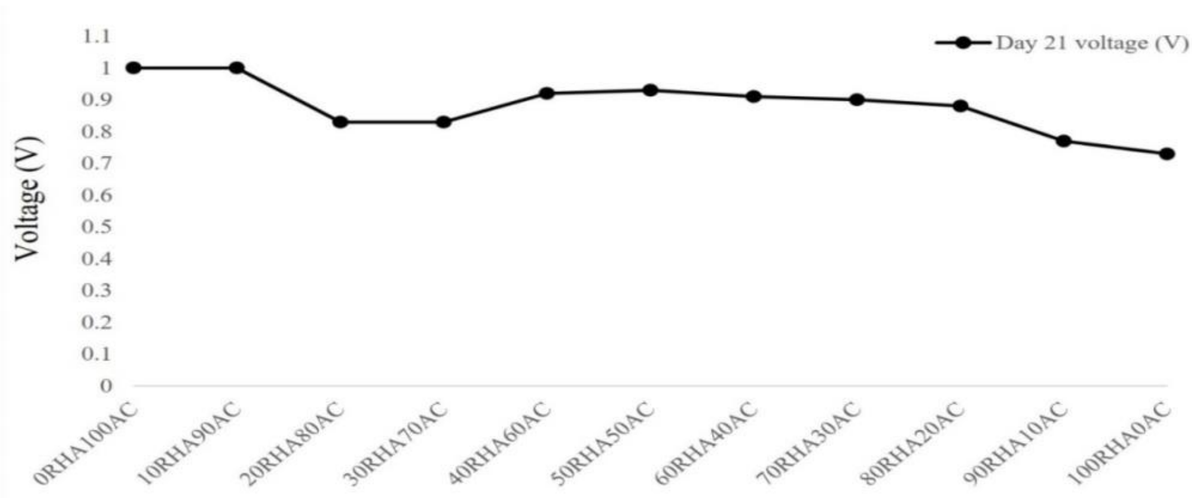

Fig. 10. Voltage of the samples after day 21

The durability of the samples has also been posted. Voltage reading was taken again after 21 days, and found that the samples were functioning. Figure 10 represents the voltage reading from the multimeter after 21 days. Though it shows more voltage, it was dry. This time, the cells were pressed as before. The saltwater used as an ion exchanger was fully evaporated. As a result, the flow of electrons was stopped, and no current was provided by the cells.

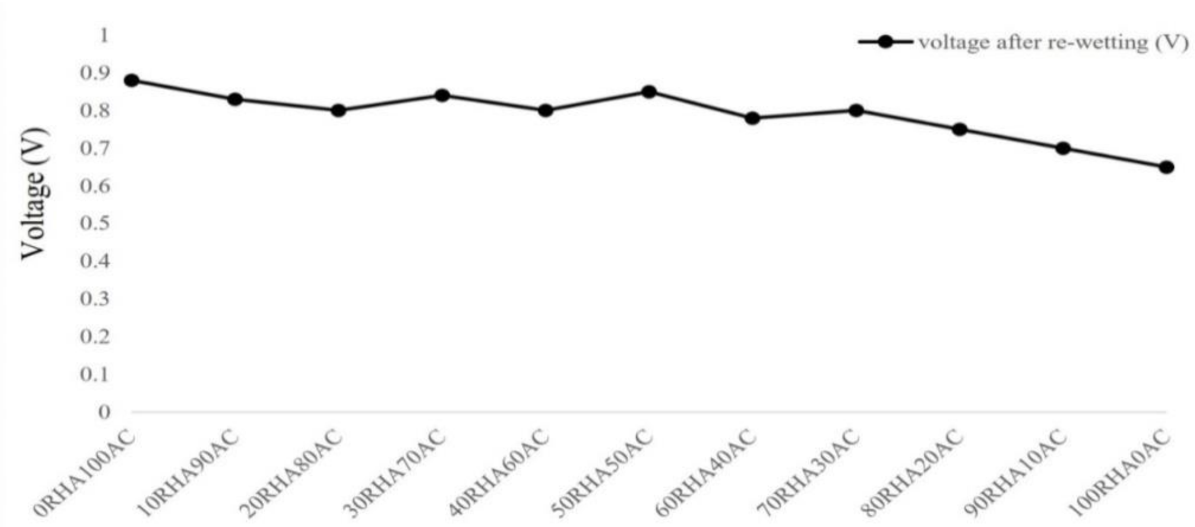

Fig. 11. After re-wetting the cells with water

After that, water was added to the cells and stored in a shadowed area for 24 hours. The following day, the voltage reading was retaken, as shown in Figure 11. Voltage dropped compared to day 21, but it resupplied enough current.

3.2 Graphite Cathode Replacement

After finishing the manufacturing process of the prototypes, voltage reading was taken from each one using a multimeter. Table 4 shows the voltage of each sample along with RHA and AC percentages.

Table 4
Voltage of AA batteries before and after graphite rod replacement

Sample Name	Percentage (%)		Voltage (v)		Voltage Drop (v)
	Rice Husk Ash	Activated Carbon	Before	After	
0RHA100AC	0	100	1.683	1.682	0.001
10RHA90AC	10	90	1.68	1.673	0.007
20RHA80AC	20	80	1.687	1.663	0.024
30RHA70AC	30	70	1.686	1.66	0.026
40RHA60AC	40	60	1.68	1.51	0.17
50RHA50AC	50	50	1.685	1.52	0.165
60RHA40AC	60	40	1.685	1.2	0.485
70RHA30AC	70	30	1.685	1.00	0.685
80RHA20AC	80	20	1.684	0.8	0.884
90RHA10AC	90	10	1.683	0.71	0.973
100RHA0AC	100	0	1.685	0.7	0.985

Figure 12 shows that increased rice husk in samples results in voltage reduction. From sample 30RHA70AC onwards, the voltage starts to fluctuate heavily. In that case, the average voltage was considered. Sample 0RHA100AC to 20RHA70AC (Table 4) was quite stable and ideal for constant voltage supply.

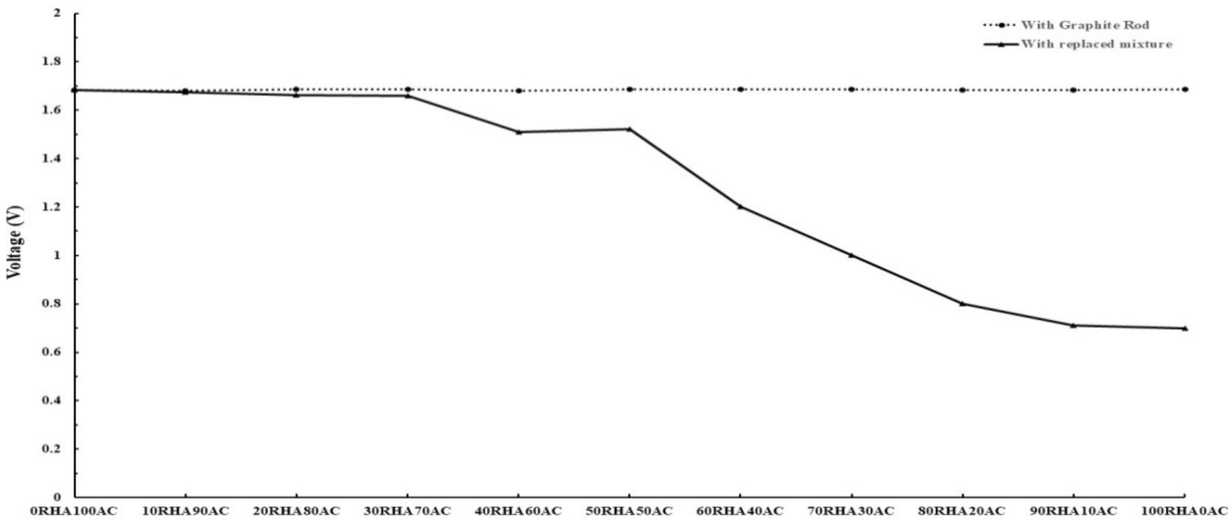

Fig. 12. Voltage comparison of AA batteries before and after graphite rod replacement

4. Conclusions

In this study, as discussed initially, aluminium-air cells have been fabricated with different proportions of the mixture, and a performance analysis has been performed accordingly. A consistent result up to the mixture containing 30 percent rice husk and 70 percent activated carbon has been observed. The best result from the experiment is gained after re-wetting the cells on the 21st day. This study provides insights into the potential of easily procurable, cheap and eco-friendly DC cells from waste. There is much room for development as well. A durability test of all the prototypes should be carried out. Multiple prototypes for each mixture should be prepared and analyzed to understand the characteristics of the setups. Replacing the graphite cathode with recycled activated carbon in primary cells is possible. A mixture of activated carbon and rice husk ash was also functional as a replacement for graphite cathode. Voltage drop is between 0.5-1.5 % to 30 % mixture of RHA. Mixtures containing more than 50 % RHA make the voltage unstable. Using the mixture of AC and RHA in Al-air batteries as a cathode catalyst has also been found functional. Our result is the standard average reading for this type of Al-air cell. Implementation of this mixture will reduce the manufacturing cost.

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