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PERFORMANCE ANALYSIS OF ALOE VERA GEL AS A NATURAL ELECTROLYTE IN SUSTAINABLE BIO-BATTERIES

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ABSTRACT

The escalating global demand for sustainable energy has exposed the severe ecological limitations of conventional chemical batteries, necessitating the development of biodegradable alternatives. This paper presents a comprehensive study on the design, fabrication, and performance analysis of a novel biobattery utilizing Aloe Vera (Aloe barbadensis Miller) gel as a natural electrolyte. The introduction contextualizes the environmental imperative for green energy storage systems. The methodology details the extraction of untreated Aloe Vera gel and the assembly of a non-toxic electrochemical cell. Experimental evaluations, focusing on varying electrode configurations—predominantly Zinc, Copper, and Graphite—and immersion depths, yielded a maximum stable open-circuit voltage of approximately 2.0 V under partial immersion conditions. A rigorous comparative analysis with alternative organic electrolytes (e.g., lemon juice and potato extract) demonstrates that while highly acidic fluids may produce transiently higher voltages, the unique structural integrity and mild acidity of Aloe Vera gel dramatically reduce electrode corrosion, enhancing long-term operational stability. Finally, the conclusion outlines the feasibility of plant-based bio-batteries as a scalable, low-cost paradigm for low-power

electronics and proposes future directions for optimizing internal resistance in off-grid applications.

INDEX TERMS: Bio-battery, Aloe Vera gel, Natural Electrolyte, Green Energy, Sustainable Storage, Electrochemical Cell.

I. INTRODUCTION

ENERGY storage systems are fundamental to modern technological infrastructure; however, the reliance on traditional lead-acid, nickel-cadmium, and lithium-ion batteries presents substantial ecological hazards. The extraction, manufacturing, and improper disposal of these chemical storage units contribute significantly to heavy metal contamination and e-waste accumulation. Consequently, recent electrochemical research has pivoted toward green energy solutions, specifically bio-batteries that leverage natural, biodegradable materials.

Bio-batteries operate on fundamental oxidation-reduction (redox) principles but substitute synthetic electrolytes with organic plant extracts or microbial solutions. Among these, Aloe Vera gel has emerged as a promising candidate. Its composition—comprising roughly 99% water and 1% bioactive compounds (including polysaccharides, amino acids, and mineral ions such as K^+, Na^+, and Ca^{2+})—facilitates moderate ionic conductivity while maintaining a stable pH (4.5–5.5). This mild acidity minimizes the rapid electrode degradation commonly observed with highly acidic fruit juices like lemon or orange extract.

This paper systematically investigates the electrochemical performance of Aloe Vera gel, assessing its voltage output across different electrode pairs, evaluating the impact of immersion depth, and comparing its efficacy against other standard organic electrolytes.

II. MATERIALS AND METHODS

A. Preparation of the Bio-Electrolyte

Fresh Aloe Vera leaves were harvested and cleansed to remove surface impurities. The outer epidermal layer was manually excised to isolate the inner transparent parenchyma tissue (gel). Approximately 500 g of the untreated, natural gel was extracted and transferred into a non-conducting electrochemical cell. No external chemical solvents were introduced, ensuring the electrolyte remained entirely non-toxic and biodegradable.

Fig. 1. Freshly extracted Aloe Vera leaf and gel used as the primary natural electrolyte medium.

B. Electrode Selection and Experimental Setup

Electrodes of high electrical conductivity and varying standard potentials were selected to evaluate performance, primarily Zinc (Zn), Copper (Cu), Aluminum (Al), Iron (Fe), and Graphite. Each electrode measured approximately 3 cm in length and was mechanically polished prior to immersion to eliminate resistive oxide layers.

The electrodes were positioned in the gel without direct contact to prevent short-circuiting. The electrical output (opencircuit voltage) was measured using a highly sensitive digital multimeter. Measurements were recorded at standard room temperature, allowing the system to stabilize before data capture.

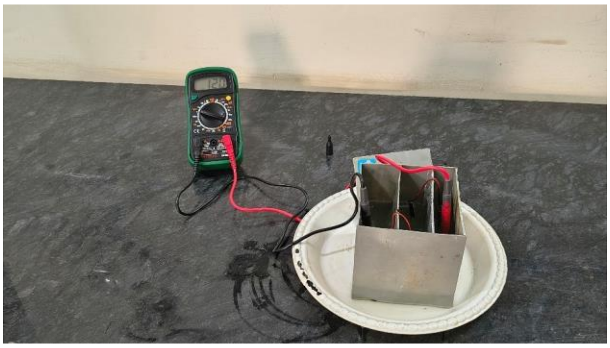

Fig. 2. Complete experimental setup demonstrating the electrodes immersed in the Aloe Vera gel matrix connected to a digital multimeter.

III. RESULTS AND DISCUSSION

A. Voltage and Power Output

The bio-battery demonstrated a consistent open-circuit voltage of roughly 2.0 V under partial immersion conditions, specifically when utilizing a Zn-Graphite or Zn-Cu electrode configuration. The mechanism of action is driven by the anodic oxidation of Zinc ($Zn \rightarrow Zn^{2+} + 2e^{-}$) and the corresponding cathodic reduction facilitated by the gel's ionic content. Because the internal resistance of the gel matrix is higher than that of synthetic liquid electrolytes, the resulting current was limited to the milliampere range (≈ 1–2 mA), restricting the overall power density but proving entirely adequate for micropower applications.

B. Impact of Electrode Material

The potential difference achieved is inherently dependent on the disparity in standard electrode potentials. As illustrated in Fig. 3, the Zn-Cu and Zn-Graphite pairings significantly outperformed combinations utilizing Iron or Aluminum, which suffered from rapid passivation and lower kinetic efficiency.

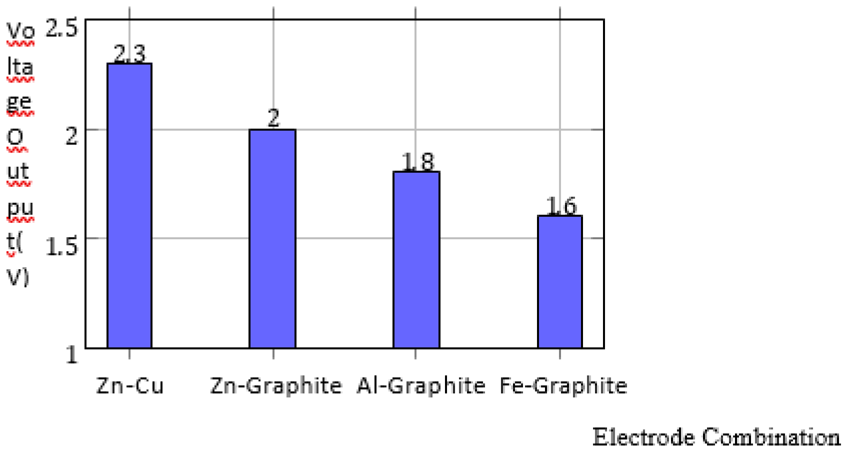

Fig. 3. Variation of output voltage across different electrode combinations.

Furthermore, the effective surface area of the electrodeelectrolyte interface proved critical. Initial readings at 2.0 V were recorded under partial immersion; theoretical scaling indicates that complete immersion and optimized inter-electrode spacing push the potential toward higher expected maxima (up to 3.5 V).

IV. COMPARATIVE ANALYSIS

To benchmark the efficacy of Aloe Vera, its performance was juxtaposed with standard low-cost organic electrolytes. Table I outlines the physical and chemical trade-offs among common plant-based fluids.

Table i: ***Comparative Analysis of Natural Electrolytes.***

Electrolyte	Voltage	Conductivity	Stability	Corrosion Effect	Environment
Lemon Juice	High	Medium	Low	High	Moderate
Orange Juice	Medium	Medium	Medium	Medium	Moderate
Vinegar	Low	Low	Medium	Low	High
Aloe Vera Gel	Medium	Medium	High	Low	Excellent

While lemon juice generated a higher initial peak voltage (≈ 2.8 V) due to its elevated citric acid concentration, it exhibited profound limitations regarding longevity. The high acidity induced rapid anodic corrosion, and its liquid state resulted in high evaporation rates. Conversely, the potato extract yielded a heavily resistive environment, generating only ≈ 1.5 V. As visualized in Fig. 4, Aloe Vera gel (2.0 V) provided an optimal middle ground: its polysaccharide network prevented leakage, drastically reduced evaporation, and buffered the electrodes against rapid oxidation, resulting in superior temporal stability.

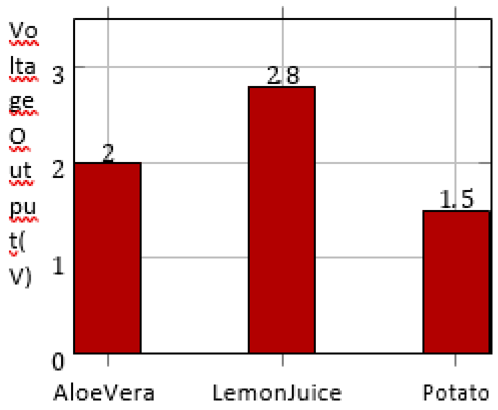

Fig. 4. Comparison of average output voltage: Aloe Vera vs. Lemon Juice and Potato extracts.

V. CONCLUSION AND FUTURE SCOPE

This study validates Aloe Vera gel as a highly viable, eco-friendly natural electrolyte for bio-battery systems. The fabricated cell successfully achieved a stable output of 2.0 V using Zn-Cu and Zn-Graphite electrode setups. Its unique physical structure overcomes the primary limitations of other plant-based electrolytes by preventing leakage and mitigating electrode degradation.

While the low current density confines its immediate applicability to low-power electronics (e.g., biosensors, educational models, and micro-LEDs), the environmental benefits are substantial. Future research should focus on optimizing the internal resistance of the gel matrix—potentially through the integration of biodegradable conductive polymers—and exploring series-parallel stacking of cells to scale up power output for broader off-grid applications.

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