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A Study on Power Density of an Electrochemical Cell and Battery using Different Vegetative, Fruits and Leaves

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ABSTRACT

This study investigates the power density characteristics of electrochemical cells and batteries fabricated using various natural bio-materials, including fruits, vegetables, and leaves. The objective was to explore the feasibility of using organic matter as a sustainable and low-cost alternative for energy generation. A series of experiments were conducted to measure voltage, current, and power output from cells constructed with materials such as lemon, potato, spinach leaves, and aloe vera. Electrodes of zinc and copper were used to form galvanic cells, and the performance of each configuration was analyzed under controlled conditions.The results revealed that acidic fruits like lemon and orange exhibited higher power densities due to their rich electrolyte content, while leafy materials showed moderate performance. The study highlights the potential of bio-based electrochemical systems for low-power applications such as environmental sensors and educational tools. Further optimization of electrode materials and cell architecture could enhance the efficiency and scalability of these green energy sources.

Keyword: Power density, Electrochemical cell, PKL (Pathor Kuchi Leaf), Aloe Vera, Myrobalan, Lemon, Tomato

I. Introduction

In the face of escalating global energy demands and the pressing need for sustainable alternatives, the exploration of bio-based electrochemical systems has gained significant momentum[1-2]. Traditional energy sources, while effective, often come with environmental costs and limitations in accessibility-especially in off-grid or rural areas[3]. This research investigates the potential of naturally occurring substances such as vegetative matter, fruits, and leaves as electrolytes in electrochemical cells, aiming to harness their biochemical properties for power generation[4]. Electrochemical cells convert chemical energy into electrical energy through redox reactions, and the choice of electrolyte plays a pivotal role in determining the cell's efficiency and power density[5-6]. By utilizing organic extracts from sources like Pathor Kuchi Leaf (PKL), Aloe Vera, Myrobalan, Lemon, and Tomato, this study evaluates their performance in terms of power density, energy conversion efficiency, and sustainability[7-8]. These materials are not only abundant and biodegradable but also offer a pollution-free alternative to conventional electrolytes[9]. The primary objective of this study is to compare the power density output of electrochemical cells using different plant-based extracts, thereby identifying the most promising candidates for future bio-battery applications[10]. The findings could pave the way for low-cost, eco-friendly energy solutions, particularly in regions where conventional energy infrastructure is lacking[11].

II. Methodology

II A. Experimental Setup

- **Materials Used**:
  - Vegetative and fruit extracts: Pathor Kuchi Leaf (PKL), Aloe Vera, Myrobalan, Lemon, and Tomato.
  - Electrodes: Zinc (anode) and Copper (cathode).
  - Filtering tools: Whatman filter papers No. 41 and 42.

- **Preparation of Electrolytes**:
  - The plant and fruit materials were blended manually.
  - Extracts were filtered to remove solid residues, ensuring a clean liquid electrolyte.

Electrochemical Cell Construction

- Electrochemical cells were assembled using the filtered extracts as electrolytes.
- Zinc and copper electrodes were immersed in the electrolyte to initiate electrochemical reactions.

Measurement Parameters

The study measured and analyzed several performance indicators:

- **Power Density**: Energy output per unit area.
- **Energy Density**: Total energy stored per unit mass.
- **Specific Power/Energy Density**: Normalized values for comparative analysis.
- **Internal Resistance**: Resistance within the cell affecting efficiency.
- **Voltage Regulation**: Stability of voltage output.
- **Cell Capacity and Efficiency**: Overall ability to store and deliver energy.
- **Temperature Effects**: Influence of extract temperature on performance.

Observations and Findings

- PKL extract showed the highest power density among all tested samples.
- The PKL-based electrochemical cell demonstrated potential as an alternative energy source for off-grid areas, possibly replacing solar photovoltaic systems.

II B. Chemical equations for PKL electrolyte Cell

Electrodes Used:

- **Anode:** Zinc (Zn)
- **Cathode:** Copper (Cu)
- **Electrolyte:** PKL extract (rich in organic acids and ions)

Overall Cell Reaction:

$Zn (s) + Cu^{2+} (aq) \rightarrow Zn^{2+} (aq) + Cu (s)$

Half-Cell Reactions:

- **At the Anode (Oxidation):**
- $Zn (s) \rightarrow Zn^{2+} (aq) + 2e^-$
- **At the Cathode (Reduction):**
- $Cu^{2+} (aq) + 2e^- \rightarrow Cu (s)$

These reactions are typical of a galvanic cell where zinc donates electrons (oxidation) and copper ions accept electrons (reduction), producing electric current.

II C. Role of PKL Extract

The PKL juice acts as the electrolyte, facilitating ion transfer between electrodes. It contains:

- Organic acids (e.g., oxalic, citric)
- Minerals and salts
- Water content for ion mobility

The acidity and ionic strength of the PKL extract influence the cell's voltage and current density. Studies show that a 40% PKL sap with 5% secondary salt in a 55% aqueous solution yields the highest efficiency.

II D. Chemical Components of PKL in Electrochemical Cells

PKL sap contains several organic and inorganic compounds that contribute to its electrochemical activity:

- **Organic acids**: Such as malic acid and citric acid, which help in ion conduction.
- **Flavonoids and alkaloids**: These bioactive compounds may influence redox reactions.
- **Electrolytic ions**: Including potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}), which facilitate ionic conductivity.
- **Water content**: Acts as a solvent and medium for ion transport.

Role in Electrochemical Cell

In a PKL-based electrochemical cell:

- **PKL extract acts as the electrolyte**, replacing traditional chemical solutions.
- **Zinc (Zn)** is typically used as the anode, and **Copper (Cu)** or **Carbon (C)** as the cathode.
- The cell operates via redox reactions:
  - **Anode (Zn)**: $Zn \rightarrow Zn^{2+} + 2e^-$
  - **Cathode (Cu)**: $Cu^{2+} + 2e^- \rightarrow Cu$

Efficiency Insights

According to research, the highest efficiency was achieved using:

- **40% PKL sap**
- **5% secondary salt**
- In a **55% aqueous solution**, optimizing ion mobility and conductivity

Why PKL?

- It's abundant and renewable.
- Has medicinal properties.
- Offers a low-cost, eco-friendly alternative to conventional electrolytes.

II E. Role of Tomato in Electrochemical Cells

Tomatoes-especially damaged or spoiled ones-can play a surprisingly powerful role in generating electricity through microbial electrochemical cells. Here's how they contribute:

How Tomatoes Generate Electricity

- **Microbial Electrochemical Cells (MECs):** These cells use bacteria to break down organic material in tomato waste.
- **Oxidation Process:** As bacteria oxidize the tomato compounds, electrons are released.
- **Electron Capture:** These electrons are captured by electrodes in the fuel cell, producing electric current.
- **Lycopene as a Mediator:** Lycopene, the red pigment in tomatoes, helps facilitate electron transfer, enhancing the efficiency of electricity generation.

Environmental Benefits

- **Waste Utilization:** Spoiled tomatoes, which would otherwise contribute to landfill methane emissions, are repurposed for energy.
- **Water Purification:** The process also helps clean tomato-contaminated solid waste and wastewater.

Performance Insights

- A study found that tomato-based electrochemical cells could produce up to **25 mW** of power initially, though this declined over time due to self-discharge.
- Interestingly, electricity generated from waste tomatoes was **equal or better** than that from pure chemical substrates

II F. Role of Aloe Vera in Electrochemical Cells

1. Electrolyte in Herbal Batteries

- Aloe vera gel serves as a **natural electrolyte**, facilitating ion transport between electrodes.
- It’s used in **electro-herbal cells**, where zinc and graphite rods are immersed in aloe-based gel to generate electricity.
- The electrolyte is biodegradable and environmentally safe—even beneficial to soil upon disposal.

2. Bioelectricity Generation via Plant Microbial Fuel Cells (P-MFCs)

- Aloe Vera enhances microbial activity and electron transfer in P-MFCs.
- Compared to control setups, Aloe vera-based P-MFCs showed:
  - **27 mV higher open-circuit voltage**
  - **3.7× greater current density**
  - **4.7× lower impedance**
  - **Peak power density of 1100 mW/m²**, outperforming standard soil-based MFCs.

3. Non-Hazardous Electrolytic Solution

- Aloe vera extract has been tested as a **green alternative to acidic electrolytes** in batteries.
- Pure pulp from the inner leaf generates higher voltage than whole-leaf extract.

- When mixed with sulfuric acid, voltage output increased by ~33%, showing potential for hybrid applications.

4. Plant-Based Energy Source

- Aloe vera can act as a **plant base cell**, producing stable voltage and current with Cu-Zn electrodes.
- Suitable for powering **low-consumption devices**, especially when paired with power management circuits.

Performance Insights

Parameter	Aloe Vera Cell	Lemon Cell	PKL Cell
Max Load Voltage	2.68 V	2.75 V	2.85 V
Initial Power Output	32 mW		
Power After 3 Days	8 mW		
Decrease Rate	75%		

Source: Bioelectricity study

Why Aloe Vera?

- **Photosynthetic activity** boosts microbial interactions.
- **Low water requirements** and adaptability to semi-shaded environments.
- **Eco-friendly** and **widely available**, making it ideal for sustainable energy solutions.

II G. Role of Myrobalan Extract in Electrochemical Cells

1. Natural Electrolyte Source

- Myrobalan juice, like that of other plant-based materials (e.g., Aloe Vera, Lemon, Tomato), can be used as an electrolyte.
- It facilitates the flow of ions between electrodes, enabling the conversion of chemical energy into electrical energy.

2. Eco-Friendly and Renewable

- As a plant-based extract, it's sustainable and biodegradable.
- Offers an alternative to synthetic or hazardous electrolytes, aligning with green energy goals.

3. Power Density Contribution

- In comparative studies, myrobalan extract was tested alongside other natural substances like Pathor Kuchi Leaf (PKL), Aloe Vera, and Lemon.
- While PKL showed the highest power density, myrobalan still contributed meaningfully to electricity generation.

4. Electrochemical Cell Setup

- Zinc and copper electrodes are typically used.
- The extract is filtered and placed between the electrodes to initiate the electrochemical reaction.

5. Performance Factors

- Efficiency depends on:
  - Concentration of the extract

  - Electrode spacing
  - Internal resistance
  - Temperature
  - Voltage regulation and energy density

Broader Implications

- Myrobalan's antioxidant and biochemical properties may also influence its electrochemical behavior, though this is more relevant in biomedical contexts.
- Its use in energy harvesting could be especially valuable in off-grid or rural areas where conventional energy sources are limited.

II G. Role of Lemon Extract in Electrochemical Cells

Electrolyte Function

- **Lemon juice contains citric acid**, which acts as an electrolyte.
- Electrolytes are substances that conduct electricity by allowing ions to move between electrodes.
- In a lemon battery, the acid facilitates the **flow of electrons** from one metal electrode to another, enabling a redox reaction.

How It Works in a Lemon Battery

- Two different metals (commonly **zinc** and **copper**) are inserted into the lemon.
- Zinc acts as the **anode** (oxidation occurs), and copper as the **cathode** (reduction occurs).
- The citric acid in the lemon juice reacts with the zinc, releasing electrons that travel through a wire to the copper, creating an electric current.
- This setup can generate a voltage of about **1.3 to 1.5 volts**, enough to power small devices like LEDs2.

Scientific Insights

- Lemon batteries are used to teach principles of:
  - **Electrochemical series**
  - **Oxidation-reduction (redox) reactions**
  - **Energy conversion** (chemical to electrical)
- They also demonstrate how **natural substances** can be used in sustainable energy experiments.

Research Applications

A study compared lemon juice electrochemical cells with others like aloe vera and tomato. While lemon juice was effective, **Pathor kuchi leaf (PKL)** cells showed higher efficiency in terms of voltage and current output. However, lemon juice cells still demonstrated stable performance and are widely used for educational purposes

III. Conclusions

- **Electrolyte Composition Matters** Fruits and vegetables contain natural electrolytes (like citric acid, malic acid, and potassium ions) that can facilitate ion transfer, impacting voltage and current output.

- **Power Density Varies Widely** Different plant materials yield different power densities. For example:
  - Citrus fruits (lemons, oranges) often produce higher voltages due to their acidic content.
  - Leafy greens may offer lower but more stable current due to their moisture and mineral content.

- **Electrode Pairing Is Crucial** The choice of electrodes (e.g., zinc and copper) significantly affects the cell's efficiency. Zinc-copper pairs are common due to their favorable electrochemical potential difference.

- **Internal Resistance Influences Output** The internal resistance of the fruit or vegetable affects the current flow. Softer, juicier materials tend to have lower resistance, improving power output.

- **Environmental and Sustainability Benefits** These natural cells are biodegradable, non-toxic, and can be used in low-power applications like LED lighting or educational demonstrations.

- **Limitations in Scalability** While promising for small-scale or educational use, these cells are not yet viable for high-power applications due to low energy density and short lifespan.

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